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CALIBRATION AND VALIDATION OF A NEW ASPIRATED PSYCHROMETER FOR TECHNOLOGICAL DEVELOPMENT OF A HUMIDIFIER

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Abstract: The main purpose of this work is to present the manufacturing, calibration and validation of a system for wet and dry bulb temperature measurements obtained on a new psychrometer.

The calibration has lead to the adjustment of the appropriate psychrometer coefficient for the developed psychrometer, as a function of the wet bulb temperature, which fits best with experimental data, obtained on the range from 34% to 87% *RH* and 15°C to 30°C. Another set of experimental points on this range was used for evaluation of the psychrometer uncertainty.

An electronic hygrometer was calibrated simultaneously, and its calibration was also evaluated. The uncertainty of the Relative Humidity obtained in the calibration of the psychrometer was found to be only slightly higher than the uncertainty for the electronic hygrometer. For the wet-bulb temperature determination, the hygrometer presents itself as more precise, while the psychrometer was more accurate. Either could be used for technological development of the humidifier, but the psychrometer delivers a direct measurement of the wet-bulb temperature, independent of the local pressure and dry-bulb temperature, which affects the calculation obtained from the hygrometer data.

Keywords: Psychrometry, Wet-bulb, Hygrometer.

1. INTRODUCTION

The wet-bulb temperature is usually used for calculation of the Relative Humidity (*RH*), which is defined as the ratio of the partial pressure of the water vapor in the actual condition to the partial pressure of the water at saturation.

The efficiency of a humidifier (η) is measured in terms of the capacity to increase the air humidity. The efficiency of an evaporative cooling is also closely related to the air humidity at intake and outlet. The same formula of the efficiency is applied for humidification and evaporative cooling [1], and is a function of dry-bulb temperatures (t_1 at air intake, t_2 at outlet) and wet-bulb (t^*) temperature,

$$\eta = \frac{t_1 - t_2}{t_1 - t^*} . \qquad (1)$$

Although being the wet-bulb temperature a direct measurement, it is function of the moist air properties, mainly its humidity (relative or absolute), and the heat transfer process that occurs on the wick, and psychrometer design. Therefore, the wet-bulb temperature measurement itself is a delicate issue, with many variables influencing its precision.

The calibration of a psychrometer can be made by comparison with a more precise psychrometer, or by comparing the relative humidity calculated from the wet- and dry-bulb measurement of the psychrometer with another humidity measurement system, preferably a primary standard such as a dew-point temperature (t_{DP}) instrument.

The objective of this work is to find the precision of the humidity measurement, and the psychrometric coefficient, for our new psychrometer design.

2. BACKGROUND

The thermodynamic wet bulb temperature (t^*) is defined at an adiabatic process, and the temperature found on the real non-adiabatic process that takes place on a psychrometer (t_w) should be slightly corrected [2] for humidity calculation. The difference (t^* - t_w) is function of the airflow velocity around the wick, and this difference becomes large at velocities under 0.5 m/s [1] (p.208).

The measurement of wet bulb temperature normally is only used for psychrometry, for the determination of the surrounding air humidity. Although there are instruments for direct determination of *RH*, with enough precision for most technology needs, if the wet-bulb temperature is necessary for some other purpose, the direct reading of the psychrometer should be considered. As there is no primary instrument to measure the thermodynamic wet-bulb temperature, the following discussion shall state how to determine the air properties in order to achieve the smallest uncertainty in wet bulb temperature calibration.

2.1 Psychrometric equations

A complete survey of calculation methods of properties for the air-water mixture is found in [3]. Inputting the local pressure, the dry bulb temperature and the wet bulb temperature on a given equation system may result in the moist air Relative Humidity (*RH*). Both the formulation used and the physical details of the wet bulb measurement system have influence on the precision of the calculated *RH*.

Wet and dry bulb temperature usually is correlated through the empirical equation [2,4]:

$$e = e_w - A\,p\,(t - t_w)\,, \tag{2}$$

where A is the psychrometer coefficient in °C^{-1}, p is the atmospheric pressure in Pa, t is the air temperature and t_w is the real wet bulb temperature; e is the actual water vapor pressure of the air at t and e_w is the vapor pressure at t_w. The psychrometer design has a strong influence on A, and controversy exists related to its accurate value. The equation that relates the dependence of A upon t_w, recommended by [5] was developed by Farrel :

$$A = 6.6\times10^{-4}\left(1 + 0.00115\,t_w\right) \tag{3}$$

But this generic equation cannot consider the psychrometer design, and peculiar factors that affects the real heat transfer process that occurs at the wick.

There are two families of psychrometric equations. The ASHRAE equations [2] enable calculation based on the thermodynamic wet-bulb temperature (t^*), which is a unique property, independent of measurement techniques, and can only be approached in a limiting case. While this is a hypothetical concept and cannot be read directly, another family of formulations are based on the real wet-bulb temperatures (t_w). Rosemberg [6] and ASTM [5] present systems of equations based on t_w and A, and were chosen for development of a simulation that compares their difference to the ASHRAE method, as shown on Fig. 1.

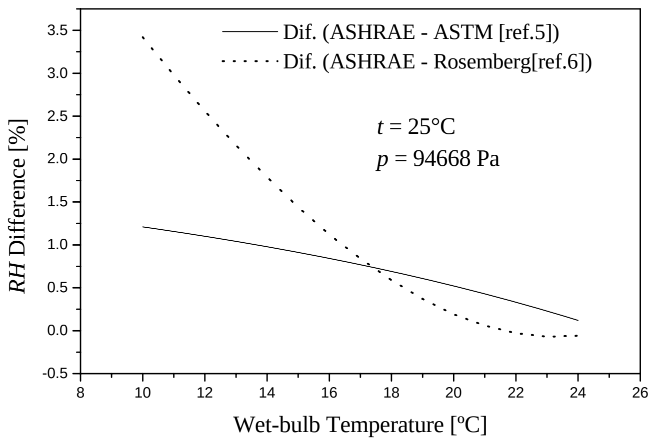

Fig. 1. Comparison of *RH* calculations among three different set of equations.

We have chosen the ASTM method [5] for the calculations through this work because it is an International Standard and has smaller difference when compared to the well-recognized ASRAE method [2].

It is possible to obtain t^* from experimental data (t, RH, p or t, RH, t_{DP}) using the ASRAE method [2], which may be useful as shown in section 5.6.

2.2 Hygrometry

The range of sensing principles used in hygrometers includes dimensional change of materials, gravimetric determination, condensation (detected optically, electrically, or by resonant frequency), rate of evaporative cooling, thermal conductivity, adiabatic expansion, pneumatic bridge, acoustical transmission, electrical impedance, rate of electrolysis of phosphorus pentoxide, spectrometry, transmission of optical fiber, optical refractive index, color change of chemicals, and others [7].

Electrical impedance sensors are the most common type of hygrometer found in industrial applications. They feature a hygroscopic material whose dielectric properties alter as it absorbs water molecules. Changes in humidity are measured as a change in the sensor's electrical capacitance, or resistance, or some combination of the two. Some of their advantages are small size, small cost, and simplicity of use. Some disadvantages are hysteresis, drift, and sensitivity to contamination and (often) to condensation.

3. THE PSYCHROMETER

The design that was built and tested, was focused on the possibility opened by G. J. W. Visscher, [3] (p. 1460) who states that "...a more economical and easier to use instrument can serve as reference, without loss of accuracy."

3.1 Psychrometer Design

The construction material is 200g/m^2 polystyrene sheet 3mm thick, assembled with thermoplastic hot-melt adhesive. Aluminum foil is used on the external surfaces, which protects from about 80% of possible radiation influence on the temperature measurements. Internal surfaces are covered with black opaque vinyl film, to reduce internal reflection.

An axial micro-fan is used to promote the air motion trough the psychrometer. Airspeed in the wick area, close to the throat, was measured with hot-wire sensor. Results shows 4.5 ±0.2 m/s, which is in accordance with [5].

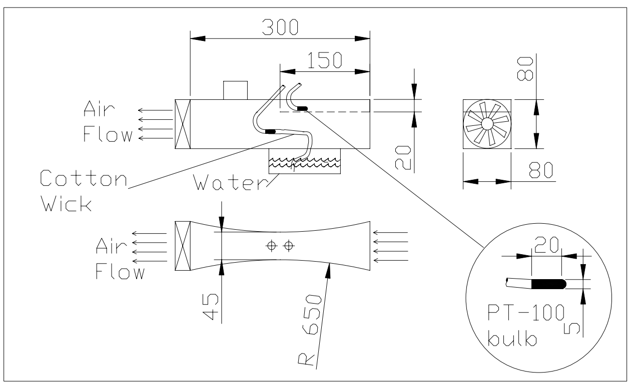

Fig. 2. Simplified drawings of the new psychrometer design.

The airflow is horizontal, and an upper chamber was built to measure dry-bulb temperature, therefore, any humidity from the wet wick would not interfere with the dry-bulb measurement. In the lower chamber, the PT100 bulb is tied to a suspended cotton wick, which thoroughly covers the sensor bulb, and its opposite end is dipped in a water basin. Following recommendations at [5], only distilled water is used, and rubber gloves are used to handle the wick at assembly.

4. EXPERIMENTAL PROCEDURES

4.1 Temperature sensors

The temperature sensors used for dry- and wet-bulb measurements were 3 wire RTD´s connected to a high-resolution acquisition system. The calibration of the RTD´s were performed at constant temperature water bath with agitation, against a mercury in glass thermometer, with decimal reading, recently calibrated by a laboratory accredited by the National Authority (INMETRO), and uncertainty of ±0.06°C.

4.2 Humidity measurements

The calibrations of both humidity sensors (the Psychrometer and the electronic hygrometer) were performed in a Vötsch climatic chamber model VC 4033, using a General Eastern chilled mirror dew-point meter, model Hygro-M3 with sensor 1311DR. This instrument is a primary standard, under valid calibration of the National Authority INMETRO.

In order to achieve complete stabilization of the climatic conditions inside the chamber, after the set point of temperature and humidity, the system was kept steady for at least 30 minutes before acquiring a new data point.

The measurements of wet and dry bulb temperatures were recorded at the calibration, as well as the primary humidity standard results. A collection of 21 points was acquired, on the range from 34% to 87% *RH* and 15°C to 30°C.

The data was numbered from 1 to 21 and split in two groups: the 11 odd numbered points was used for determination of the psychrometer coefficient and 10 the even numbered points was used to evaluation of the psychrometer calibration.

4.3 Hygrometer calibration

The electronic hygrometer is the model LTUR manufactured by Leboc™ with a two-wire 4-20 mA analog output. This electronic device has a sensor placed into an external cylindrical case, which allow the contact with the environmental air. Therefore, the calibration and evaluation of its measurement uncertainty should be important for comparison with the psychrometer performance.

Along with the calibration of the psychrometer, the electronic hygrometer was calibrated simultaneously, in the same climatic chamber. This electronic device had its sensor placed at the intake of the aspirated psychrometer, to measure the same air sample. The instrument’s output was read in a precision amp-meter.

4.4 Wet-bulb temperature

As mentioned above, the wet bulb temperature may be obtained either by direct measurement on a psychrometer or by transforming the Relative Humidity acquired on the electronic hygrometer in t^* following ASHRAE [2] and using a numerical solution based on the Newton-Raphson method.

As the mentioned method does not require the psychrometer coefficient *A*, all experimental data could be used for this section, and it was not necessary to use the methodology exposed in 4.2 for evaluation of *A* and *RH*. Considering that one point was not acquired by the electronic hygrometer, and another was discarded using statistical criteria, 19 data points were used on the analysis of the wet-bulb temperature (section 5.6).

5. RESULTS AND DICUSSION

The procedure allowed the discussion as follows.

5.1. Calibration of the temperature sensors

The calibration of the RTD´s resulted on a uncertainty of ±0.46°C for the wet-bulb thermometer and ±0.46°C for the dry-bulb temperature, obtained with Standard Deviations of 0.225 and 0.228°C, a confidence interval of 95% and degree of freedom of 34.

5.2 Determination of the Psychrometer coefficient A

The selected experimental data was used for determination of the psychrometer coefficient *A*, using the method proposed by ASTM [5] and result is shown as function of t_w in Fig. 3.

The linear regression results

$$A = 6.3760 \times 10^{-4} \left(1 + 0.00504 t_w\right) \quad (4)$$

with standard deviation from the linear fit of approx. 0.6×10^{-4}.

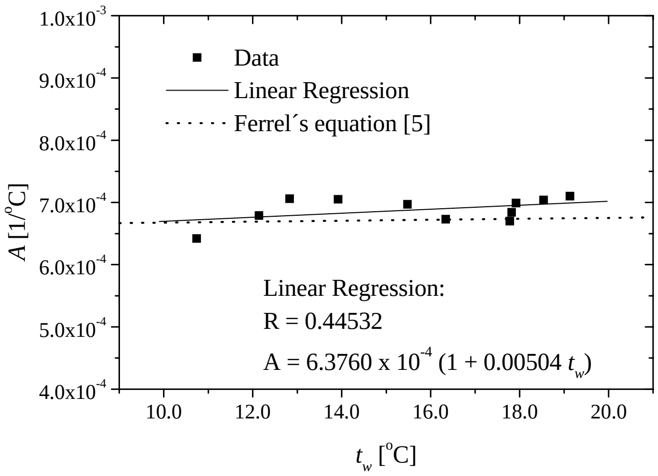

Fig. 3. Psychrometer coefficient *A*, compared to Ferrel´s.

It may be observed from Fig. 3 that the function found has higher temperature dependency than Farrel´s, but the values of *A* found lie within the ones reported by Visscher [3] and Simões-Moreira [8].

5.3 Humidity calculations for the psychrometer

Using the value of $A=f(t_w)$ obtained with the odd numbered data (eq.04), the even numbered experimental points were used to calculate the *RH* with the ASTM formulation. The result is shown in Fig. 4.

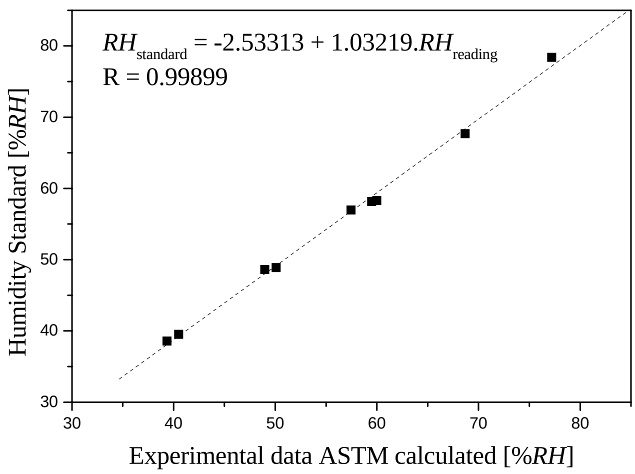

Fig. 4. Relative Humidity calibration results

The linear fitting of the data results in a Standard Deviation of 0.749%. Considering the uncertainty of the standard of ±2% of reading, the degree o freedom as 9, and confidence interval of 95%, the uncertainty in the determination of the *RH* obtained in the calibration of our psychrometer was ±2.62%.

The high uncertainty obtained was mostly due the uncertainty of the calibration system (±2%). Although the uncertainty of the chilled mirror dew-point instrument is only ±1.2%, the non-uniform distribution of *RH* inside the chamber forced the use of the higher uncertainty value.

5.3 Electronic Hygrometer calibration

During the humidity calibration runs, the 4-20 mA output current, *I*, was read in a precision ampere-meter, and 19 points were registered into the range from 30 to 90 % of *RH*, while the atmospheric pressure, *p*, was about 696.6 mmHg, as shown in the Fig. 5. Consequently, the measurement uncertainty was calculated equal to ±2.31% within the confidence interval of 95%.

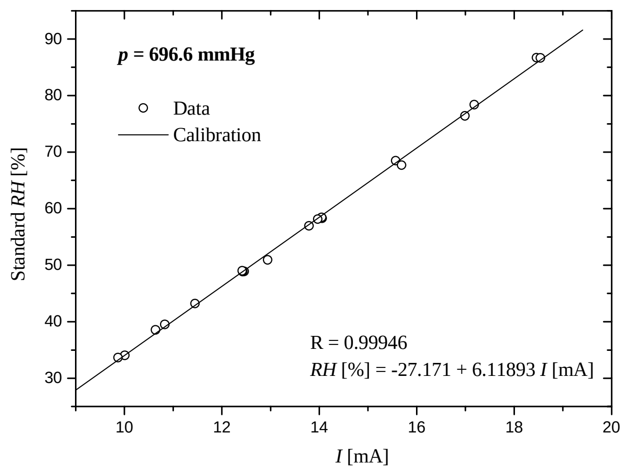

Fig. 5. Calibration curve of the electronic hygrometer

5.6 Wet-bulb temperature analysis

In this analysis, the wet-bulb temperatures were calculated from the dew-point temperatures measured with the chilled mirror meter (t_{DP}), with *t* and *p*, and the electronic hygrometer data was converted to t^* from *RH*, *t* and *p*. Both calculations were made from numerical solution according to ASHRAE [2].

The wet-bulb temperature data from the t_{DP}, *t* and *p* were taken as a parameter in evaluating the electronic hygrometer and the psychrometer performance as a wet-bulb temperature measurement system. Even so, while t_w can be measured directly by using the psychrometer, the hygrometer will always request for a data reduction methodology, since it is equipped with a sensor for *RH*.

From Fig. 5, the *RH* values used to calculate t^* were obtained from the calibration curve, with *I* data measured directly in the precision ampere-meter.

In the following figures, the t^* data calculated from t_{DP}, *t* and *p* were plotted in the vertical axis, while t_w in Fig. 6 and t^* from the hygrometer *RH* data in Fig. 7, they were plotted in the horizontal axis.

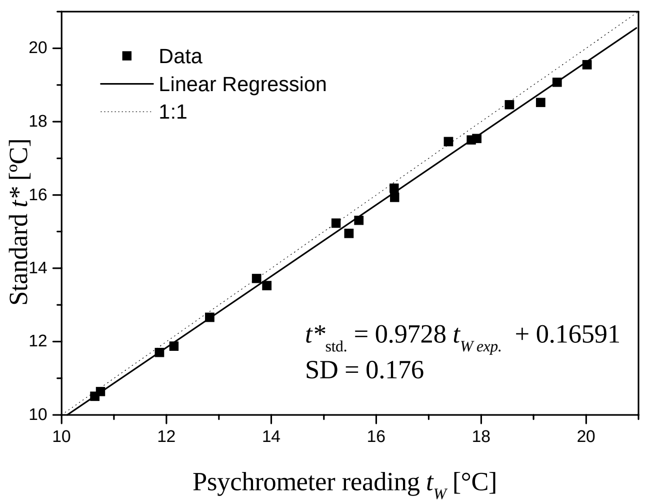

Fig. 6. Wet-bulb temperature calibration, measured with the psychrometer

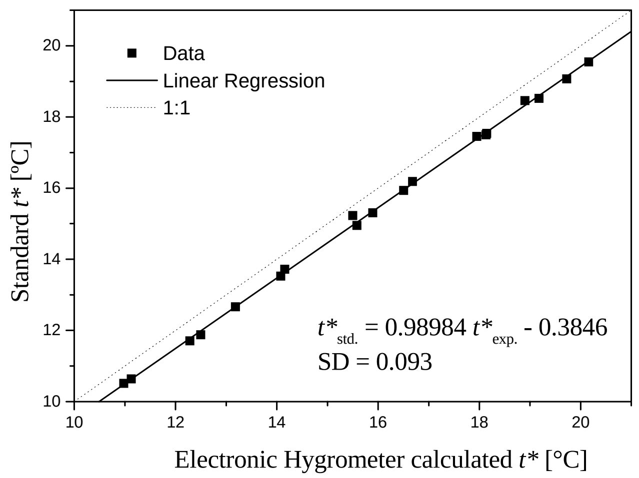

Fig. 7. Wet-bulb temperature calibration, calculated from the electronic hygrometer measurements

One can observe the main differences between both graphs: the regression line of Fig. 6 (psychrometer) has smaller linear coefficient, but some angular deviation from the 1:1 line; the regression line of Fig. 7 (hygrometer) has linear coefficient of –0.3846, which causes higher linear deviation from the 1:1 line. In addition, the hygrometer showed itself as more precise than the psychrometer, since the Standard Deviation (SD) was 0.093ºC, smaller than 0.176ºC.

6. CONCLUSION

The uncertainty in the calibration of the psychrometer on obtaining *RH* (±2.62%) was found to be only slightly higher than the uncertainty for the electronic hygrometer (±2.31%).

Accordingly, the wet-bulb temperature obtained from the electronic hygrometer showed smaller standard deviation than the SD found in the psychrometer. Therefore, the hygrometer presents itself as more precise, while the psychrometer was more accurate.

This means that either could be used for the determination of the Relative Humidity, or for the wet-bulb temperature. But for the latter, such as the case of humidifier efficiency evaluation with equation (1), it should be mentioned that the psychrometer delivers a direct measurement of the desired parameter, independent of the atmospheric pressure and dry-bulb temperature.

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