Air Humidity Measurement Using The Psychrometric Method

Petar Vasilev Sapundjiev

Abstract - **This article deals with measurement of air humidity with electronic devices and some of the problems inherent to it. The aim of the author is to design and examine an electronic aspirated psychrometer, it's properties and the possibility for it's use in air humidity measurement systems. The work describes the mechanical construction of the device, the sensor interfacing and calibration. A saturated-salt solution calibration procedure has been applied in order to verify the device's accuracy .**

Keywords – **air humidity, measurement, aspirated psychrometer, calibration.**

I. INTRODUCTION

The measurement of atmospheric humidity, and often its continuous recording, is an important requirement in most areas of meteorological activity. Nowadays many humidity measuring devices have been developed – there is wide range of analog and digital sensors which can be easily integrated in systems for long term monitoring. A serious drawback of the capacitive and resistive humidity sensors is the poor initial accuracy as an effect of the production technology. Most of them do not satisfy the requirements of meteorological measurements and even of some less responsible applications. When using such type of sensors there is an essential need for some calibration procedure to be applied. It mainly consists in placing the device at certain conditions and comparing its readings to some other, more reliable method of measuring.

This work deals with measurement of humidity using the psychrometric method, its use for observational purposes and working standard.

II. STATEMENT

A psychrometer consists essentially of two thermometers exposed side by side, with the surface of the sensing element of one being covered by a thin film of water or ice and termed the wet or ice bulb, as appropriate. The sensing element of the second thermometer is simply exposed to the air and is termed the dry bulb. This is the most widely used method. Owing to evaporation of water from the wet bulb, the temperature measured by the wet-bulb thermometer is generally lower than that measured by the dry bulb. The difference in the temperatures measured by the pair of thermometers is a measure of the humidity of the air - the lower the ambient humidity, the greater the rate of evaporation and, consequently, the greater the depression of the wet-bulb temperature below the dry-bulb temperature. The size of the wet-bulb depression is related to the ambient humidity by a psychrometer formula. This method can be used for observational purposes and also as working standard. It is more reliable than other electronic hygrometers, because it depends on the calibration of temperature sensors, which are much more reliable than capacitive or resistive RH sensors.

The existing practice in evaluation the relative humidity usually consists in deriving the vapour pressure *e'*, which is the fraction of the ambient pressure that is due to the fraction of water vapor in the air under the conditions of observation. The following semi-empirical psychrometric formula is used:

$$e' = e'_W\,(p, T_W) - Ap(T - T_W) \qquad (1)$$

where e'_W is the saturation vapour pressure with respect to water at temperature T_W and pressure p of the wet bulb; p is the pressure of the air; T the temperature of the dry bulb; and A is the psychrometer coefficient. The coefficient A mostly depends upon the mechanical design of the psychrometer, the rate of air-flow past the wet bulb and the air temperature and its humidity. However, at ventilation rates of no less than $2.2m^{-s}$ and no greater than $10m^{-s}$, the value of A becomes practically independent of the ventilation rate. The value of A does not, then, depend very much on temperature or humidity and its dependence on these variables is usually considered unimportant [5, 6].

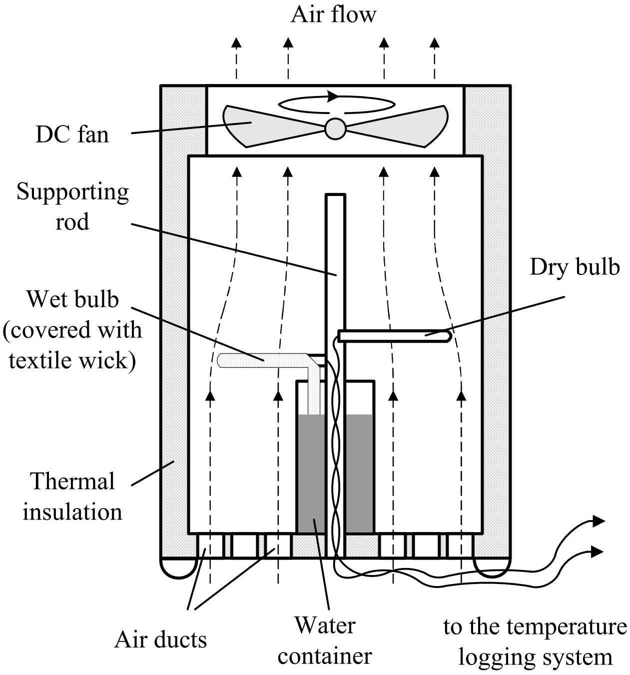

Fig. 1

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The examined aspirated psychrometer (*Fig. 1*) consists of two Pt100 temperature sensors, mounted horizontally on a supporting hollow rod, which is placed in the center of a cylindrical plastic frame with air ducts on the bottom side. On top of the frame there is an electric fan, which forces the air to draw past the thermometers at a desired rate. In order to screen the bulbs from outside radiation, the housing is covered with thermally insulating material, which on its turn is covered with alluminium foil.

The wet bulb has a textile sleeve, fitting closely around the sensing element in order to maintain an even covering of water, which is applied by capillary feed from a reservoir. The water reservoir and wick should be arranged in such a way that the water will reach the bulb with sensibly the wet-bulb temperature, so as not to affect the temperature of the dry bulb. Any visible contamination of the wick should be considered an absolute indication of the necessity for its replacement. Great care should be exercised in handling the wick to prevent contamination from hands. Distilled water should be used for the wet bulb.

The wires connecting the temperature sensors to the microcontroller based data logging system are placed into the supporting rod. In order to reduce errors owing to wire resistance, the Pt100 sensors are connected in bridge circuit using 3-wire connections (*Fig. 2*). On the figure, each wire is represented as a resulting resistance R_W1, R_W2 and R_W3. Given that R_W1 and R_W2 are equal, as well as the currents flowing trough them, the voltage drops across them compensate each other. Each analog channel consists of three op-amp differential instrumentation amplifier, whose properties are described in details in the literature. Both channels are multiplexed to 10bit analog-to-digital converter.

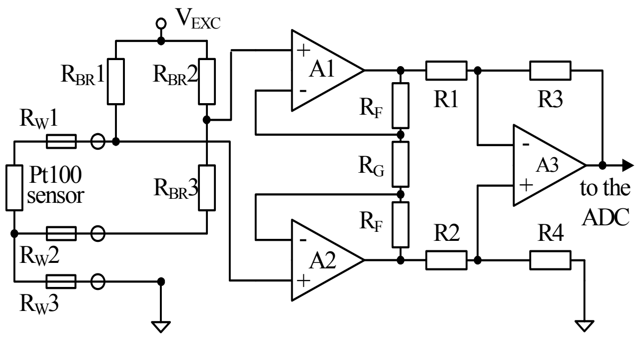

Fig. 2

For the purposes of the current task an accuracy of the temperature measurement of about +/- 0.1°K has to be achieved, in order to reduce the error in derived relative humidity resulting from wet-bulb errors less than 0.5 % RH. Each Pt100 analog channel has been calibrated using appropriate reference resistors set, covering the entire operating range. Subsequently, temperature offset calibration has been applied to the sensors, using the triple point method. A water triple point cell has been used, which provides stable temperature of 0.01°C. Another part of the calibration is the air-flow rate adjustment. Because of the wide range of acceptable air-flow rate, in practice it could be adjusted simply by increasing the fan speed until the psychrometer readings become stable and don't change with further increase of the speed, given that the relative humidity remains constant.

An important part of the psychrometer's design are the formulae which are used for the computation of various measures of humidity. The given equations can be easily integrated in the logging system's software. They were adopted by WMO in 1990 and are convenient for computation and sufficiently accurate for all normal meteorological applications (WMO, 1989*a*):

$$e_W(t) = 6.122 \exp\left[\frac{17.62t}{(243.12+t)}\right] \quad (2)$$

$$e'_W(p,t) = e_W(t) \cdot f(p) \quad (3)$$

$$f(p) = 1.0016 + 3.15 \cdot 10^{-6} p - 0.074 p^{-1} \quad (4)$$

$$e' = e'_W(p,t_W) - 6.53 \cdot 10^{-4} \cdot \left(1 + 9.44 \cdot 10^{-4}\right) \cdot p \cdot (t - t_W) \quad (5)$$

$$U = \frac{e'}{e'_W(p,t)} \cdot 100\% \quad (6)$$

$$t_d = \frac{243.12 \cdot \ln\left[\frac{e'}{6.112 f(p)}\right]}{17.62 - \ln\left[\frac{e'}{6.112 f(p)}\right]} \quad (7)$$

where:

t - air temperature (dry-bulb temperature);

t_W - wet-bulb temperature;

t_d - dewpoint temperature;

p - pressure of moist air;

$e_W(t)$ - saturation vapour pressure in the pure phase with regard to water at the dry-bulb temperature;

$e_W(t_W)$ - saturation vapour pressure in the pure phase with regard to water at the wet-bulb temperature;

$e'_W(t)$ - saturation vapour pressure of moist air with regard to water at the dry-bulb temperature;

$e'_W(t_W)$ - saturation vapour pressure of moist air with regard to water at the wet-bulb temperature;

U - relative humidity.

Once the hardware and software have been set properly, a verification of the psychrometer's readings has to be done. An easy way is to use fixed-point calibration. It is based on chemical systems in equilibrium which allow a known and constant relative humidity value to be maintained in a sealed, reduced-dimension container. These systems use a solution in equilibrium with its own vapor phase in the presence of air at atmospheric pressure. Under these conditions, the moist air in the container is characterized by a relative humidity value dependent on the temperature used for each solution. This value is repeatable and reproducible and can be used to set up a fixed calibration point [1]. Commonly used salts and their saturation relative humidities at 25°C are as follows:

Barium chloride ($BaCl_2$): 90.3 % ;
Sodium chloride (NaCl): 75.3 % ;
Magnesium nitrate ($Mg(NO_3)_2$): 52.9 % ;
Calcium chloride ($CaCl_2$): 29.0 % ;
Lithium chloride (LiCl): 11.1 % .

For the purposes of such kind of calibration, a salt-solution humidity generator has been designed *(Fig. 3)*.

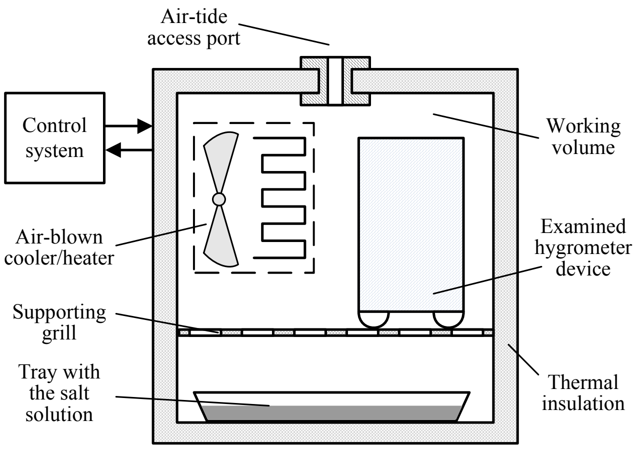

Fig. 3

It mainly consists of thermally insulated chamber with an access hatch (not given at the picture) and air-tide access port for placing the wire connections to the examined devices inside. There is a removable tray for the salt solution at the bottom of the chamber. The examined device can be placed on a supporting grill over the solution. A microcontroller based control system connected to a cooler/heater inside takes care for the temperature management of the generator. To attain uniform heat distribution inside the chamber, the air is stirred by an electric fan. Such a generator may or may not be thermostatic. In a nonthermostatic one, the equilibrium humidity is generated and maintained under conditions of monotonically varying temperature, while in a thermostatic one there is high stability and uniformity in the temperature of the salt solution and the vapor-air mixture.

The process of establishing humidity equilibrium has an exponential character, and therefore any finite value of the establishing time corresponds to a certain deviation of the humidity from the equilibrium value, which is one of the sources of error. However, there are equations describing the processes in the generator, which can be used to determine appropriate period for equilibrium establishment [2]. It is important that the surface area of the solution is large compared to that of the sensor element and the enclosed volume of air so that equilibrium may be achieved quickly.

A great care has to be exercised when preparing the salt solution. The hygrostatic solution is prepared from an analytical-reagent grade salt and pure (distilled or deionized) water. In certain cases, if the purity of the salt is unknown, it should be purified by crystallization from distilled or deionized water prior to its use in the preparation of the hygrostatic solution. The salt has to be dissolved in water in such a proportion that 30 % to 90 % of the weighed sample remains undissolved. Consequently, a weighed sample for the solution shall be heavier (by 30 %) than the one corresponding to the solubility limit at a given temperature. In order to obtain a homogeneous salt solution, the salt crystals have to be added to water of a much higher temperature than that required and then the solution have to be cooled down [4].

For the current experiment a saturated solution of sodium chloride (NaCl) has been prepared. The chosen temperature range is between 25°C and 30°C where equilibrium relative humidity changes from 75.29% to 75.09%, [3]. A change of such magnitude is insignificant for the purposes of the experiment.

III. DISCUSSION

The results represented on *Fig.4* are taken about 24 hours after the chamber has been sealed. The hygrometer gives 75.2 +/-0.25% relative humidity at 27°C. This experiment indicates satisfactory accuracy of the psychrometer in the selected point of the humidity range.

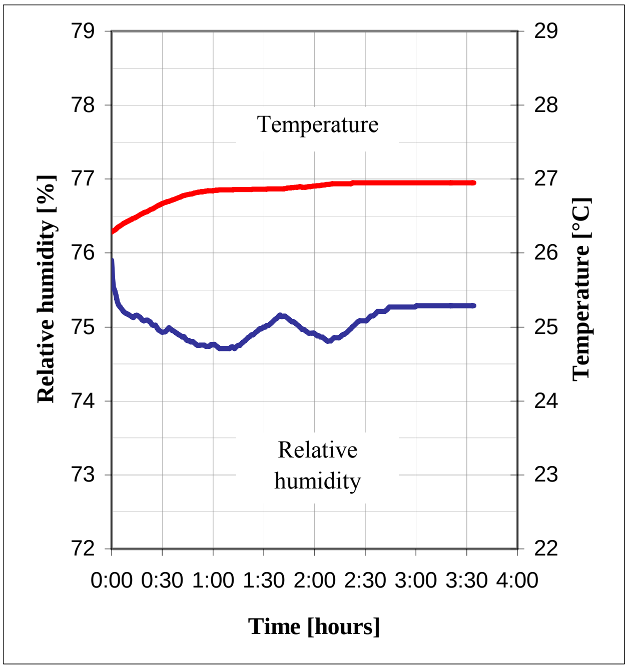

Fig. 4

However, there are some inconveniences when using the aspirated psychrometer as a long term observational hygrometer. The wet bulb with it's covering sleeve should be washed at regular intervals in distilled water to remove soluble impurities. This procedure is more frequently necessary in some regions than others, for example, at or near the sea or in areas subject to air pollution. Another drawback of the psychrometer is the high power consumption owing to the electric fan. The power being consumed by an electric fan, even a small and economic one, is many times greater than the consumption of the entire data-logging system. This is serious problem when the hygrometer has to be part of a battery supplied measurement system. The consumption could be reduced by turning on the fan only when a measurement has to take place.

The experiments show that for the examined device the time for establishing the wet bulb temperature, after the fan has been turned on, is nearly 2 minutes *(Fig. 5)*. It differs depending on the construction, the area of the surface of the wet bulb, the aspiration rate, the current air conditions, etc. The time-constant of the hygrometer is an important parameter and has to comply with the specific requirements of its particular application.

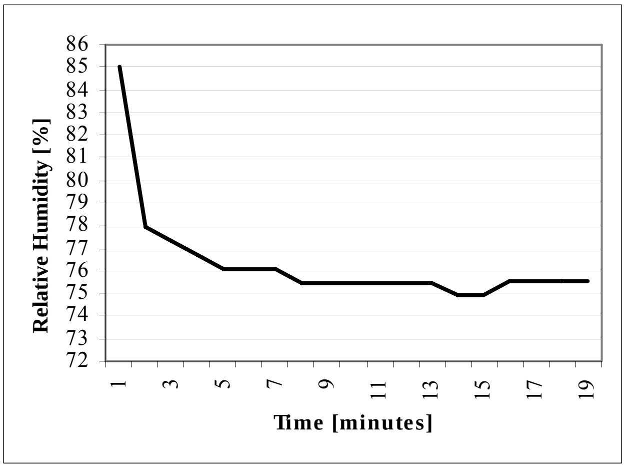

Fig. 5

Special precautions has to be taken when the psychrometer is intended for use at temperatures below 0°C. A wick cannot be used to convey water from a reservoir to the wet-bulb sleeve by capillary action when the wet-bulb temperature is below 0°C. It is an absolute necessity that the thermometers be artificially ventilated; if they are not, the management of the wet bulb will be extremely difficult. More detailed description of the psychrometer working under these conditions could be found in [6].

IV. CONCLUSION

Although the aspirated psychrometer needs more complicated maintenance compared with the capacitive or resistive humidity sensors it is much more reliable because the method in essence consists of temperature measurement. Following few requirements, the device could be reproduced with great success. Serious attention has to be paid at the formulae which are used for the computation of various measures of humidity. An electronic aspirated psychrometer could be used as observational device where there are no constraints of power consumptions and physic dimensions.

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