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CHARACTERIZATION OF METROLOGI LIPI'S PSYCHROMETER

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Abstract– This paper describes characterization of the first psychrometer developed by Puslit Metrologi LIPI. The psychrometer is dedicated to operate at a temperature range of 25 °C to 65 °C and 15 %rh to 90 %rh. The highest temperature range is limited by the local traceability for dew point measurement. The work includes the determination of psychrometer coefficient and its characteristics due to effect of the wind velocity which is adjusted by applying voltage 12 V and 5 V to the fan.

When 12 volt of voltage is applied, the psychrometer coefficient obtained by using Apjohn and Ferrel equations yields 8.3 x 10^{-4} $°C^{-1}$ and 7.2 x 10^{-4} (1+0.0043 t_w)$°C^{-1}$,respectively. The first value produces relative humidity deviation (standard error estimate) from the experimental data less than 2.8 %rh while the second is less than 1.2 %rh. When 5 volt of voltage is applied, both the psychrometer coefficient and the deviation become larger, and on relative humidity of 90%rh the psychrometer coefficient obtained from the experimental data drops considerably which means that wind velocity is insufficient to operate the psychrometer.

Keywords: Psychrometer, wet bulb, hygrometer, humidity, calibration.

1. INTRODUCTION

The need for hygrometer sensors for measuring relative humidity which can operate at above 50 °C is very demanding in Indonesia. From all types of hygrometers, a psychrometer is one candidate who can meet this requirement. Not only it is cheap but also its basic components which are dry and wet bulbs can be made from PRT (Platinum Resistance Thermometer) Pt-100 offering very sufficient accuracy and stability and easy to operate at temperatures up to 100 °C. In addition, uncertainty requirements for calibration of such psychrometers are typically around 1 %rh to 2 %rh, i.e., close to the best calibration and measurement uncertainties (CMCs) claimed by national metrology institutes (NMIs) [1].

Based on this situation, and for knowing better about psychrometer calibration, Metrologi LIPI research center has developed a psychrometer. This is the first psycrometer manufaturer by us. Therefore, characterization is necessary for knowing well the instrument.

2. BACKGROUND

Measuring relative humidity of air can be conducted by using psychrometer. It has two identically temperature sensors called dry-bulb and wet-bulb installed side by side and for industrial purposes, normally, they are made from liquid in glass thermometer with 0.1 °C of resolution.

The dry-bulb thermometer is simple measuring the air temperature while the wet bulb thermometer is covered by a cotton wick and is wetted by pure water. Due to evaporation of the water in the cotton wick, the temperature of the wet-bulb is lower than that of the dry-bulb. The difference in temperature between the dry-bulb and wet bulb depends on the wind velocity of the air contacting the temperature sensing portion of the wet-bulb thermometer, but does not depend on the wind velocity at wind velocities of a certain value or higher. This limit wind velocity is termed the minimum necessary wind velocity. The minimum necessary wind velocity is in order of 0.2 to 5 m/s by reason of the construction of the psychrometer [2].

2.1. Psychrometer equations

Two equations are used and compared each other. They are Apjohn equation [3-4] and Ferrel equation [5-6]. The Apjohn equation considers the psychrometer coefficient as a constant and is written as in (1).

$$\%rh = \frac{e_w - AP(t_d - t_w)}{e_d} \times 100 \qquad (1)$$

Where A is the psychrometer coefficient in $°C^{-1}$, P is the asmospheric pressure in Pa, t_d is the air temperature in °C, t_w is the wet temperature in °C, e_d is the water vapor pressure of the air at dry temperature in Pa and e_w is the water vapor pressure at wet temperature in Pa.

The water vapor pressure e_d and e_w can be determine more accurately by introducing enhancement factor for real gas $f(P,t_d)$ and $f(P,t_w)$ respectively, yielding (2).

$$\%rh = \frac{e_{ws} f(P,t_w) - AP(t_d - t_w)}{e_{ds} f(P,t_d)} \times 100 \qquad (2)$$

Where e_{ds} and e_{ws} are the saturation water vapor at dry and wet temperatures. Both saturation water vapor and the enhancement factor can be calculated by several formulations such as Wexler equation, Sonntag equation, Hardy equation, etc [7]. In this work, we choose Hardy equation.

In the contrary to Apjohn equation, Ferrel equation considers psychrometer coefficient *A* as a function of wet temperature and is written as in (3).

$$\%rh = \frac{e_w - A(1+bt_w)P(t_d - t_w)}{e_d} \times 100 \qquad (3)$$

Where b is a constant.

3. PSYCHROMETER DESIGN

The body is made from aluminum where the front edge is cylindrical shape with diameter of 93 cm. Along the length of the psychrometer the diameter is not constant but follows a venturi shape. At the front, there is a screen for getting more laminar air flow so that the dry thermometer is less affected by the evaporation from the wick of wet thermometer. An electric fan with dimension of 90 cm X 90 cm is attached to the rear panel to flow the air. Two identical Pt-100 are used as the dry and wet bulbs. These PRTs are originally two wires but are modified to be 4 wires. The speed of the electric fan which drives the air velocity can be adjusted by a voltage of 3 to 12 volts. Fig. 1 and Fig.2 shows the psychrometer.

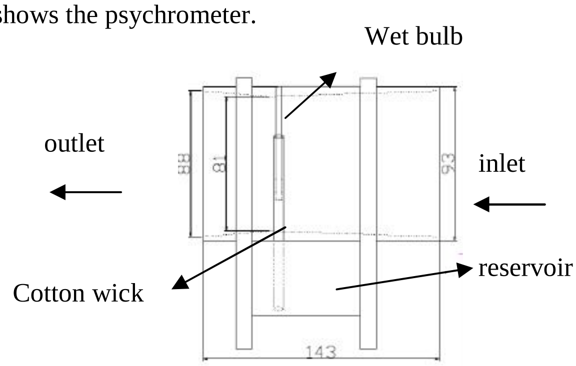

Fig. 1. Drawing of the psychrometer

Fig. 2. The psychrometer

4. EXPERIMENTAL METHOD

4.1 Determining the psychrometer coefficient

To find the coefficent of psychrometer *A*, the psychrometer is put inside the chamber of humidity generator 2500 made by thunder scientific. The outputs from the generator are set to be 50 %rh at 23 °C, 15 %rh at 25 °C, 50 %rh at 25 °C, 90 %rh at 25 °C, 15 %rh at 45 °C, 50 %rh at 45 °C, 90 %rh at 45 °C, 15 %rh at 65 °C, 50 %rh at 65 °C and 90 %rh at 65 °C. The chamber temperature is measured by the integrated RTD of the generator and an additional Pt-100. Both of them have already been calibrated with expandedn uncertainty *U*= 0.03 °C at 95% of convidence level at temperature range of 0 °C to 70 °C. The exact relative humidity inside the chamber is obtained by the chamber temperature and the chamber dew point temperature measured by chilled mirror 373-LHX manufactured by RH Systems. The resistance value of dry and wet PRTs is measured by indicator Chub-E4 made by Hart Scientific. To convert the resistance into degree of Celsius, both of them are calibrated by comparison against our Platinum Resistance Thermometer Pt-25 in a liquid bath resulting expanded uncertainty *U*= 0.03 °C at 95% of convidence level at temperature range of 0 °C to 70 °C. The fan is connected to a voltage of 5 volt and 12 volt from a regulated DC power supply.

4.2 Determining the effect of wind velocity

The experiment is the same as section 4.1 but with different voltage applied to the fan and 5 volt is the value.The goal of applying this voltage is for further development. When there is on-site calibration demanded by customer, it is necessary to have a compact and efficient equipement. In the developing of our psychrometer, automatisation with data logging through computer or laptop is planned where normally, to communicate between hardwares requires a voltage of 5 volt.

5 RESULT AND DISCUSSION

5.1 The psychrometer coefficient

When the experiment was carried out, for 12 volt voltage, at set point of 90 %rh at 65 °C the dew point measured by the chilled mirror was never at stable state. When 5 volt was applied to the fan, the same situation was also happen at set point of 50 %rh at 65 °C and 90 %rh at 65 °C. The reason is that the water vapor produced by evaporation from the wick adds the dew point inside the chamber of the generator and at high temperature and high relative humidity, the effect of this additional water vapor becomes bigger resulting unstability of the dew point temperature. Therefore, The data analysis is conducted by removing the data collected from those set points.

From (2), the constant psychrometer coefficient can be obtained by using linear fitting of the experimental data yielding A=8.3 x 10^{-4} °C^{-1} and A=1.13 x 10^{-3} °C^{-1} for voltage of 12 volt and 5 volt respectively. The graph is showed in Fig. 3.

While using (3), the psychrometer coefficient is obtained to be A=7.2 x $10^{-4}(1+0.0043\ t_w)$ °C^{-1} for 12 volt and A=7.7 x $10^{-4}(1+0.0144\ t_w)$ °C^{-1} for 5 volt.

After finding the psychrometer coefficient *A*, the reative humidity is back calculated to see how much the deviation from the experimental data. When 12 volt is applied, calculating *A* by (2) results deviation less than 2.8 %rh but it is less than 1.2 %rh if (3) is used. Thus (3) will be used for operating the psychormeter. This is also accordance with the method used by [8]. The A values obtained here are slightly higher than the psychrometers calibrated by Spring Singapore [9]. On the other hand, when 5 volt is applied, the deviation is 2 to 3 times deviation produced by 12 volt which is not good as the uncertainty will be higher.

Moreover, the liniearity of the data coming from 12 volt is better than the data coming from 5 volt which means that the data coming from 5 volt is more irregular as the value of R^2 gets far away from 1. The comparison results between 5 volt and 12 volt can be seen in Table 1.

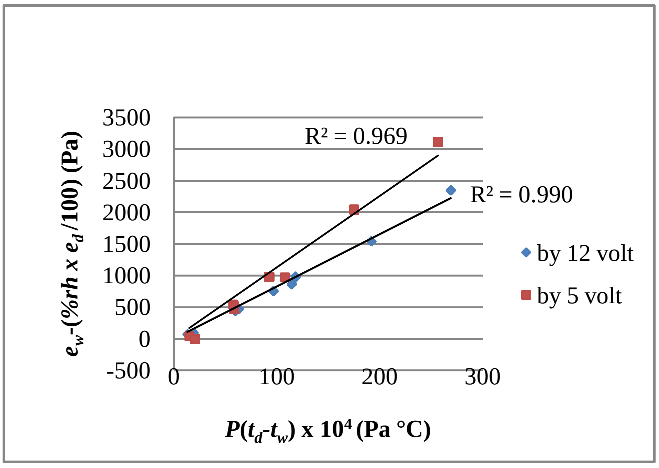

Fig. 3. Linear fitting for finding psychrometer coefficient A based on Apjohn equation

Table1. Comparison results between 5 volt and 12 volt

Applied voltage	Method	Psychrometer coefficient A	Standard Error Estimate
12 volt	Apjohn equation	A=8.3 x 10^{-4} °C^{-1}	2.8 %rh
	Ferrel equation	A=7.2 x 10^{-4} (1+0.0043 t_w) °C^{-1}	1.2 %rh
5 volt	Apjohn equation	A=1.13 x 10^{-3} °C^{-1}	7.7 %rh
	Ferrel equation	A=7.7 x 10^{-4} (1+0.0144 t_w) °C^{-1}	4 %rh

5.2 The effect of wind velocity

To see the effect of wind velocity, the psychrometer coefficient A calculated from each experiment data together with the A obtained by (3) is plotted against relative humidity as it is shown in Fig. 4. When 12 volt is applied to the fan as it is the normal condition for operating the fan, the experiment data are almost stable at around 8 x 10^{-4} °C^{-1} except data at 90 %rh which drop less than 8 x 10^{-4} °C^{-1}. When 5 volt is applied, the experiment data at 15 %rh to 50 %rh result psychrometer coefficient A higher than 8 x 10^{-4} °C^{-1} but at 90 %rh the data become drop deeper than the data produced by 12 volt. Thus, it is showed that applying 5 volt to the fun is insufficient to operate the psychrometer. Therefore, the design of the psychrometer needs to be modificated if a compact system for on-site calibration will still be developed.

In addition, According to Fig.4 the more speed of the wind the more stable pesychrometer coefficient A over the range of relative humidity measurements as it can rise the A value at high relative humidity. Therefore, our psychrometer might be improved by applying a voltage larger than 12 volt.

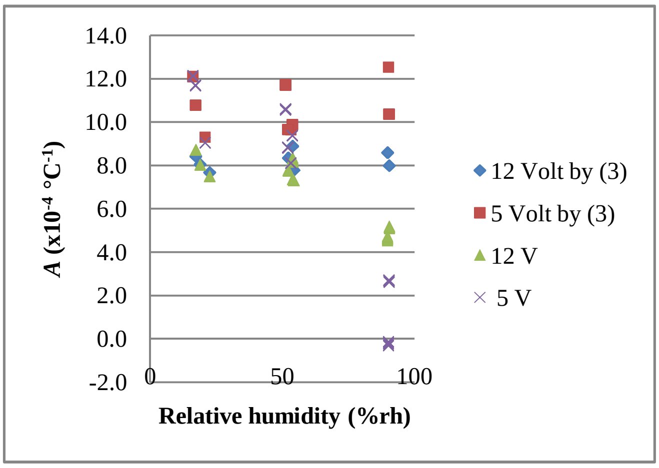

Fig.4. The relation between psychrometer coefficient and relative humidity.

5.3 Temperature Inhomogeneity

Other parameter which usually gives significant impact to relative humidity measurements is temperature inhomogeneity inside the chamber. Thus, Fig. 5. Shows the temperature inhomogeneity at which the experiment was carried out. The value is deduced from the deviation between the maximum value and the minimum value among dry temperatures measured by the integrated RTD, the additional RTD and the dry bulb of the psychrometer.It is concluded that the results obtained in this work are produced at which the temperature inhomogeneity is less than ±0.2 °C.

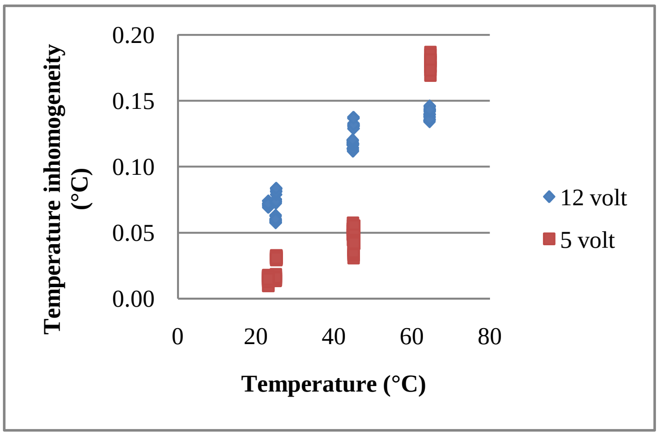

Fig.5. Temperature inhomogeneity

6. CONCLUSIONS

Using two equations, i.e., Apjohn and Ferrel equation and two voltages 5 volt and 12 volt applied to the fan, Metrology LIPI 's psychrometer has been characterized. The psychrometer coefficient A is obtained as A=7.2 x 10-

$^4(1+0.0043\ t_w)$ °C^{-1} which is well defined by Ferrel equation where the fan is powered by 12 volt. This value are slightly higher compare to psychrometers calibrated by Spring Singapore.

The wind velocity gives effect to the psychrometer as faster flowing air can rise up the psychrometer coefficient calculated at high relative humidity resulting good stability over the range of relative humidity measurements.

Improvement in design is necessary to be done if the psychrometer is dedicated to be a compact system powered by 5 volt which the standard voltage for any automatisation systems.

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