STUDY ON HUMIDITY INHOMOGENEITY MEASUREMENT OF A CLIMATIC CHAMBER

KAJIAN TENTANG PENGUKURAN KETIDAKSERAGAMAN KELEMBAPAN PADA SEBUAH CLIMATIC CHAMBER

Arfan Sindhu Tistomo, Aditya Achmadi
Puslit KIM LIPI, Kompleks Puspiptek Serpong, Tangerang
E-mail: arfan@kim.lipi.go.id

ABSTRACT

Study on a method for humidity inhomogeneity measurement based on temperature inhomogeneity has been done. The method combines AS 2853 and DKD 2009 guidelines. A manufacturer specification of a climatic chamber is used for the reference. A Monte Carlo simulation technique is used to generate random data having rectangular distribution. As a result, the introduced method is able to describe the climatic chamber specification. In addition, sensitivity coefficient of relative humidity to temperature varies from 0.02%RH/°C to 7%RH/°C for temperature of 10°C~100°C with relative humidity of 20%RH~98%RH. The worst humidity inhomogeneity for a climatic chamber can be found at lower limit temperature coupled with upper limit relative humidity.

Keywords: *relative humidity, calibration, testing, homogeneity, hygrometer*

ABSTRAK

Sebuah kajian tentang metode pengukuran ketidakseragaman kelembapan berdasarkan ketidakseragaman suhu pada sebuah climatic chamber telah dilakukan. Metode ini memadukan panduan AS 2853 dan DKD 2009. Suatu spesifikasi pabrik sebuah climatic chamber digunakan sebagai acuan. Simulasi dengan teknik Monte Carlo digunakan untuk membangkitkan data acak yang terdistribusi kotak. Sebagai hasilnya, metode yang ditawarkan mampu mendeskripsikan spesifikasi climatic chamber tersebut. Selain itu, koefisien sensitivitas kelembapan relatif terhadap suhu memiliki rentang dari 0.02%RH/°C sampai dengan 7%RH/°C untuk suhu 10°C~100°C dengan kelembapan 20%RH~98%RH. Ketidakseragaman suatu climatic chamber paling besar terdapat pada suhu paling rendah dengan kelembapan relatif paling tinggi.

Kata Kunci: *kelembapan relatif, kalibrasi, pengujian, keseragaman, higrometer*

1. INTRODUCTION

Many calibration laboratories in Indonesia have a secondary standard such as a capacitive hygrometer, a wet-and-dry bulb psychrometer, or a chilled mirror dew point meter as their reference for doing hygrometer calibration in term of relative humidity. These standards require a stable source as a medium and a humidity generator can be used for that purpose.[1] However, in many cases a climatic chamber is enough for the secondary level. Thus, not only the reference and the device under test but also the climatic chamber should be considered in the uncertainty budget. The uncertainty component contributed by a climatic chamber is humidity inhomogeneity which encompasses spatial variation (humidity gradient) and temporal variation (humidity fluctuation).

Ideally, measuring humidity inhomogeneity is similar to measuring temperature inhomogeneity which uses several sensors placed at some points according to geometrical shape of the climatic chamber. However, there are some difficulties in the equipment as well as in the experimental setup when attempting the perfect condition. For example, following the Australia Standard Book 2853[2], a volume of 0.1176 m^3 may need 9 to 11 sensors. This requirement can be achieved easily by type K or T thermocouple but not by capacitive hygrometer. The accuracy of the sensors also plays an important role; unfortunately, it is difficult to have a hygrometer with accuracy better than ± 1.3%RH as it is very expensive. In addition, to locate a hygrometer in a certain position inside a climatic chamber is also more difficult than to locate the one inside a thermocouple. Thus, a valid method is needed to solve these problems.

On the other hand, DKD-R 5-7 Calibration of Climatic Chambers (2004)[3] mentions that the spatial inhomogeneity of the relative humidity can be calculated from the inhomogeneity of the air temperature by assuming that the absolute humidity is homogeneous. Unfortunately, the guidance does not describe the procedure to calculate relative humidity inhomogeneity. Therefore, through this paper, a detail method for measuring humidity inhomogeneity is introduced. The method applies one hygrometer and several temperature sensors. The inhomogeneity of the air temperature is analyzed referring to Australia Standard book 2853 as it is already accepted by KIM LIPI research center and most of calibration laboratories to be the guidance for doing temperature testing of an enclosure although DKD-R 5-7 can also be used for the purpose. The data are taken by simulation since the real experiment cannot be done at this moment. To convince that the method is truly able to describe a characteristic of a climatic chamber, a commercial climatic chamber specification is used as the input parameter and to cross-check the simulation output.

2. THEORETICAL BACKGROUND

2.1 Temperature Testing Based on AS 2853

The guidance asks to measure the basic parameters i.e. the volume of the working space inside an enclosure (V), room temperature (t_{room}) and tested tolerance temperature fluctuation (Δt). Those parameters are used to determine the enclosure grade and the number of required sensors. Depending on the geometric shape of the climatic chamber, the sensors are then located following a fixed sequence, for example, the first sensor is put at the center, second sensor is at the corner and so on. Temperature fluctuation is calculated as half of temporal temperature variation while temperature gradient is half of spatial temperature variation.

2.2 Absolute Humidity, Dew Point, and Relative Humidity

Absolute humidity can be defined as the mass of water vapor in 1 m^3 moist air with unit g/m^3.[4,5] The assumption, in which absolute humidity is homogeneous, means the dew point temperature is constant within everywhere inside the climatic chamber. Dew point temperature is the thermodynamic temperature of a mixture of dry gas and water vapor at total pressure P at which the partial pressure of water vapor is equal to the saturation vapor pressure.[6] The relation between dew point temperature and relative humidity is as follows:

$$RH = \frac{e(t_d, P)}{e(t, P)} \times 100\% \qquad [1]$$

where:

$e(t_d, P)$ is saturation water vapor at dew point temperature (t_d), Pa

$e(t, P)$ is saturation water vapor at tested temperature (t), Pa

This relation can be used not only to calculate RH directly by knowing t_d and t, but also to calculate t_d by numerical iteration method when RH and t are known. Therefore, once dew point temperature of a certain position inside the climatic chamber is known, the temperature data in every point can be altered into relative humidity. Then, calculation for humidity inhomogeneity can be done where humidity fluctuation is half of temporal humidity variation and humidity gradient is half of spatial humidity variation.

To determine saturation water vapor at a given temperature and pressure, several updated Wexler's equations can be used such as Sonntag[7], Hardy[8], and Huang[9]. In this study, calculations are based on Hardy's equation.

2.3 Sampling a Rectangular Distribution

The simulation is carried out by treating all data to have rectangular distribution because the real temperature distribution inside the chamber is hard to predict since it depends on many factors such as geometrical shape, heater position air flow, etc. To sample a set of data from the distribution, the Monte Carlo method is used as follows:[10]

$$\xi = a + (b - a)r \qquad [2]$$

where

a and b are lower and upper limits, respectively, and

r is random number generated from 0 to 1.

3. METHOD

The study takes the specification of a commercial climatic chamber as a data source[11] or the input parameter where workspace dimensions or volume (Width × Deep × High) is 100 × 90 ×100 cm, temperature fluctuation (temp. fluctuation) and temperature gradient (temp. gradient) are ±0.5°C and ±1°C, respectively. The tested temperature is 25°C and the climatic chamber is assumed to produce 98% rh, approximately at upper limit of the climatic chamber, with deviation ±0.04%. This deviation commonly happens due to repeatability of an impedance thermohygrometer probe which is the best type of hygrometers calibrated by KIM-LIPI. The hygrometer is coupled with the first temperature sensor as it is normally placed in the center of workspace. The room temperature is 23°C. The temperature tolerance (Δt) is then calculated as the combined uncertainty of the temperature gradient and the temperature fluctuation, yielding 1.12°C. The number of sensors (N) is also found according to AS2853 procedure, giving 12 sensors for 12 positions.

The first data for each position are generated following an arithmetic series from (tested temperature – Δt) °C to (tested temperature + Δt) °C with interval $2\Delta t/(N-1)$°C to simulate the existing temperature fluctuation and gradient. These first data become reference for other data which are generated by equation (2). At this step, a looping program is used to restrict the generated data not to exceed the temperature fluctuation. Random data is accepted as long as it is lower than (first data + temp.fluctuation) and higher than (first data-temp.fluctuation). A set

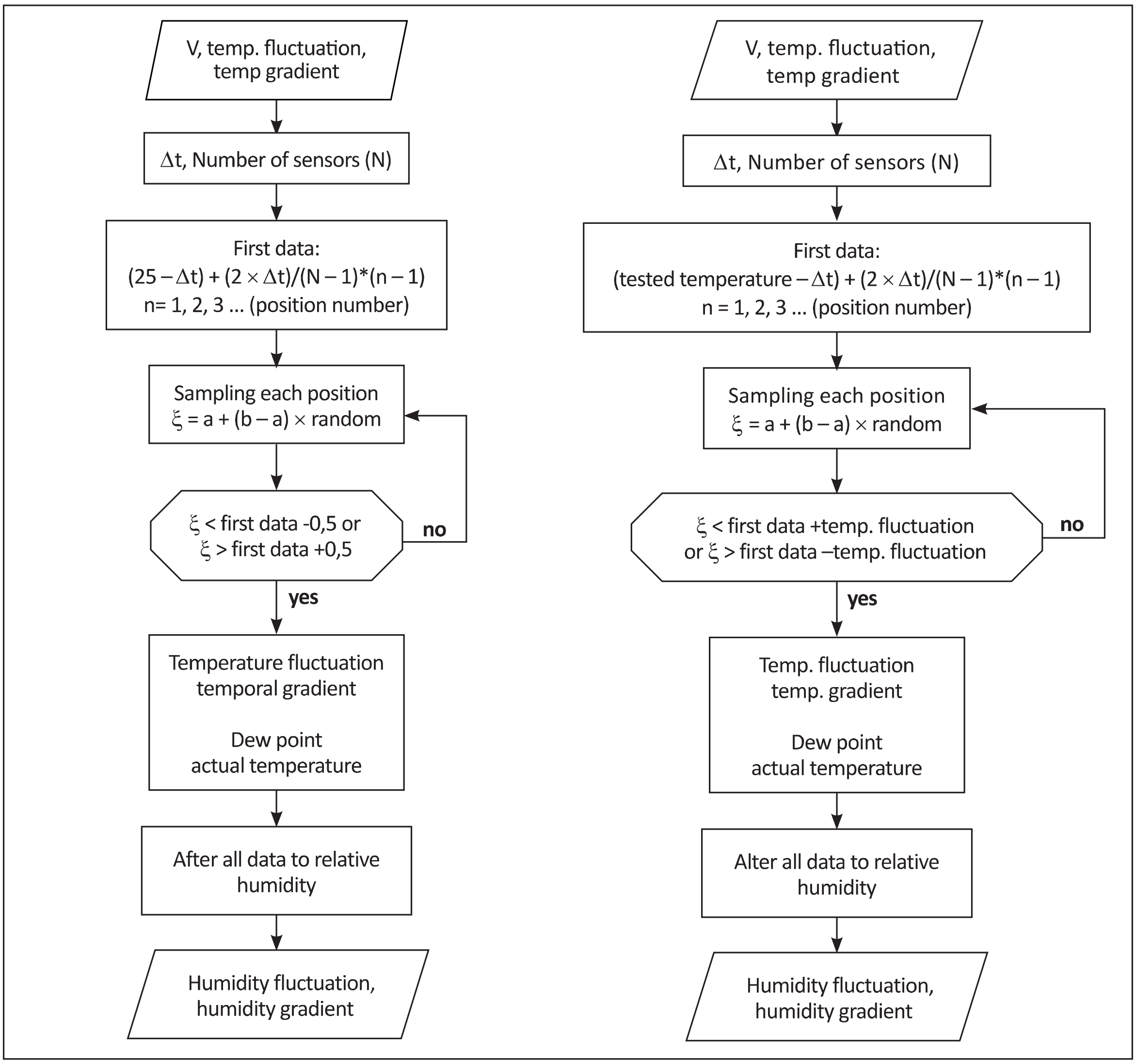

Figure 1. Flowchart of the Simulation.

of data consisted of 10 samples/measurements. After all data have been completely generated, temperature fluctuation (temp. fluctation), temperature gradient (temp. gradient), actual temperature (chamber temperature), and dew point are determined.

Equation (1) is used to find dew point. However, since dew point temperature is the free variable of water vapor function, numerical iteration is needed. Relative humidity (*RH*) and chamber temperature (*t*) are measured by the hygrometer and the first thermocouple at the center is used as the input parameters along with assumption of dew point temperature (t_d). The initial dew point temperature is needed as the start point to track the real dew point temperature. The amount of temperature (*dt*), obtained from the first derivative of saturator water vapor pressure function to dew point temperature (C_i (t_d)), should be continuously added into the initial dew point temperature until the saturator water vapor pressure at dew point temperature resulted from equation (1) and from the numerical iteration differ is less than or equal to 0.01 Pa. Then, the real dew point temperature is the last value of the initial dew point temperature in the iteration process.

By assuming the dew point temperature inside the chamber is constant in every position, all temperature data is altered to humidity data by equation (1). Then, humidity fluctuation, humidity gradient, and actual humidity can be determined. The flowchart of the temperature data simulation and numerical iteration of dewpoint calculation can be seen in Figure 1 and Figure 2, respectively.

4. RESULT AND DISCUSSION

With the workspace dimension of the given specification of the climatic chamber, our calculation suggests that 12 temperature sensors are needed to measure temperature inhomogeneity. Table 1 shows the simulated data. Two-digit decimal is presented here as a common indicator resolution even though KIM LIPI research center's CMC for thermocouple calibration is ±0.3°C and ±1.2% for hygrometer calibration. The analysis for temperature inhomogeneity is then depicted at Table 1 as follows.

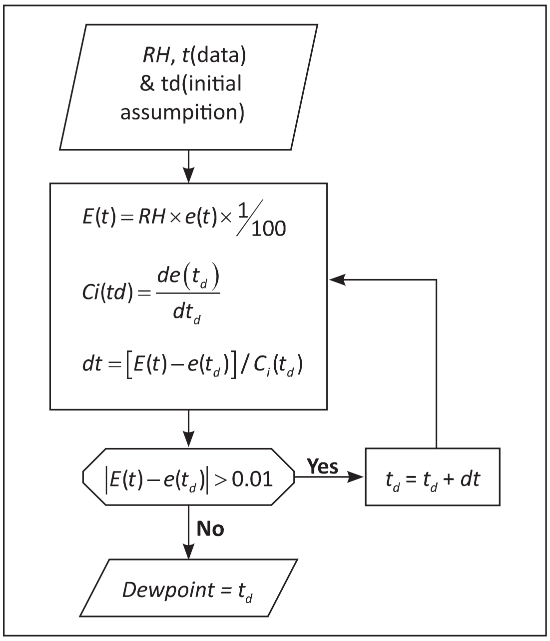

Figure 2. Flowchart of Dewpoint Calculation

Table 2 shows that the calculated temperature fluctuation and gradient are close to the specification. All temperature data in Table 1 are then converted into humidity data in Table 3. The temperature data at point 1 and relative humidity (RH) in Table 2 are used as the initial values for determining dew point of 23.75°C.The value is assumed to be constant in every position inside the climatic chamber. Moreover, Table 4 shows the calculation result of temperature and humidity inhomogeneity which are also close to the specification-indicating the results of the conversion are well representing the condition of the climatic chamber.

Further investigation is carried out based on relative humidity sensitivity coefficient to temperature *d*(*RH*)/*dt* so that altering temperature data to relative humidity data is not necessary. The sensitivity coefficient can be derived from equation (1) as shown in equation (3) and plotted as a graph in Figure 3.

For example, referring to the conditions of temperature, RH, and the dew point of the

$$\frac{d(RH)}{dt} = 100 \times \frac{e(td)}{(e(t))^2} \times \frac{de(t)}{dt} \qquad [3]$$

climatic chamber in Table 2, the value of the sensitivity coefficient is 5.5 %RH/°C (see Figure 3). Multiplying this coefficient with the

Table 1. Simulated data. The unit for each point is °C and % for RH.

Point 1	23.88	23.89	23.89	24.25	23.98	24.03	24.12	24.13	23.89	24.28
RH	98.02	97.96	98.03	98.01	98.02	98.01	98.00	98.01	97.97	98.00
Point 2	24.09	24.58	24.05	24.26	24.36	24.16	24.19	24.23	23.98	24.13
Point 3	24.29	24.78	24.76	23.95	24.39	24.75	24.54	24.17	24.18	24.13
Point 4	24.49	24.94	24.62	24.28	24.15	24.42	24.65	24.16	24.89	24.04
Point 5	24.70	24.74	24.98	24.66	24.34	24.99	24.78	24.95	24.20	25.18
Point 6	24.90	25.20	25.08	25.15	24.62	24.78	25.16	24.49	24.41	24.49
Point 7	25.10	24.99	25.28	25.05	25.55	24.87	25.07	25.48	25.13	24.71
Point 8	25.30	25.78	25.17	25.23	24.92	24.99	25.37	25.06	25.71	25.68
Point 9	25.51	25.95	26.00	25.09	25.05	25.98	25.27	25.98	25.72	25.03
Point 10	25.71	25.57	26.03	25.60	25.61	25.98	25.86	25.23	25.26	25.33
Point 11	25.91	25.85	25.96	25.49	25.72	25.71	25.53	25.89	26.11	26.01
Point 12	26.12	26.02	25.95	26.09	25.82	26.01	25.88	25.77	25.99	26.06

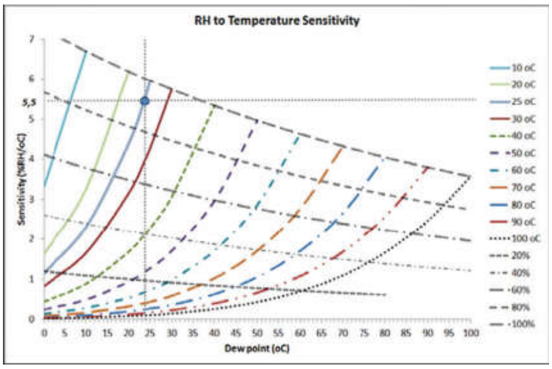

Figure 3. RH to Temperature Sensitivity Coefficient

temperature gradient and fluctuation in Table 2 yields the humidity gradient and fluctuation of 5.1%RH and 2.7%RH, respectively, which are close to the calculation results in Table 4.

The sensitivity coefficients in Figure 3 vary from almost zero (0.02%RH/°C) to around 7%RH/°C depending on the combination of RH and temperature. The sensitivity coefficient is proportional to temperature, but not to humidity. Therefore, one single temperature inhomogeneity can be altered to any humidity inhomogeneity based on the different condition of RH and temperature in the climatic chamber. The temperature gradient 0.93°C in Table 2 can be altered to humidity gradient within the range 0.5%RH to 5%RH using the combination of conditional temperature 25°C to 100°C and humidity 20%RH to 98%RH, shown in Figure 4. Accordingly, choosing the climatic chamber condition in low temperature and high humidity will lead us to the worst result of humidity gradient.

Table 2. Analysis Data for Temperature Inhomogeneity where Dt = Max–Min and Midrange = (Max + Min)/2

Point	Max, °C	Min, °C	Dt, °C	Mid range, °C
1	24.28	23.88	0.40	24.08
2	24.58	23.98	0.60	24.28
3	24.78	23.95	0.83	24.37
4	24.94	24.04	0.90	24.49
5	25.18	24.20	0.98	24.69
6	25.20	24.41	0.79	24.80
7	25.55	24.71	0.84	25.13
8	25.78	24.92	0.86	25.35
9	26.00	25.03	0.97	25.51
10	26.03	25.23	0.80	25.63
11	26.11	25.49	0.62	25.80
12	26.12	25.77	0.35	25.94
RH	98.03	97.96	0.07	98.00
Chamber temperature				25.01 °C
Temperature gradient				**±0.93 °C**
Temperature fluctuation				**±0.49 °C**
Total temperature variation				2.236 °C
RH				98.00 %
Dew				23.75 °C

Table 3. Humidity data. All data are in %.

Point 1	99.18	99.16	99.14	97.04	98.60	98.28	97.80	97.72	99.14	96.83
Point 2	97.98	95.12	98.19	96.95	96.39	97.52	97.37	97.15	98.60	97.71
Point 3	96.79	93.98	94.10	98.77	96.21	94.16	95.37	97.46	97.40	97.70
Point 4	95.62	93.09	94.86	96.86	97.60	96.04	94.75	97.51	93.35	98.26
Point 5	94.46	94.22	92.88	94.69	96.52	92.80	93.99	93.02	97.32	91.80
Point 6	93.33	91.66	92.32	91.94	94.91	94.01	91.88	95.65	96.10	95.66
Point 7	92.20	92.83	91.25	92.48	89.78	93.48	92.35	90.15	92.03	94.38
Point 8	91.09	88.57	91.81	91.52	93.22	92.81	90.72	92.42	88.91	89.07
Point 9	90.00	87.65	87.41	92.24	92.50	87.51	91.29	87.54	88.85	92.61
Point 10	88.92	89.65	87.25	89.50	89.44	87.51	88.16	91.52	91.34	90.95
Point 11	87.85	88.18	87.61	90.08	88.86	88.93	89.88	88.00	86.83	87.37
Point 12	86.80	87.31	87.69	86.94	88.34	87.36	88.01	88.61	87.47	87.09

Table 4. Data Analysis for Temperature Inhomogeneity where DRH=Max-Min and Mid range=(Max+Min)/2

Point	Max, %	Min, %	DRH, %	Mid range, %
1	99.18	96.83	2.36	98.01
2	98.60	95.12	3.49	96.86
3	98.77	93.98	4.79	96.37
4	98.26	93.09	5.17	95.67
5	97.32	91.80	5.52	94.56
6	96.10	91.66	4.44	93.88
7	94.38	89.78	4.60	92.08
8	93.22	88.57	4.65	90.90
9	92.61	87.41	5.20	90.01
10	91.52	87.25	4.26	89.38
11	90.08	86.83	3.25	88.46
12	88.61	86.80	1.81	87.71
Chamber humidity				92.86 %
Humidity gradient				±1 %
Humidity fluctuation				±2.8 %
Total humidity variation				11.686%

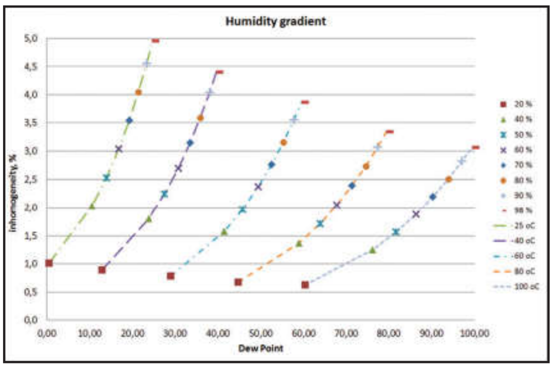

Figure 4. Humidity Gradient by Different Value of Temperature and Humidity and Dew Point

5. CONCLUSION

In conclusion, the method for determining relative humidity inhomogeneity from temperature inhomogeneity has been described. The result matches well with the specification of the real climatic chamber chosen for this study. The coefficient sensitivity which can be used to convert temperature gradient to humidity gradient has been demonstrated. The range of the coefficient sensitivity is from 0.02%RH/°C to 7%RH/°C which is yielded from the combination of lower humidity-higher temperature to higher humidity-lower temperature, respectively.

6. AKNOWLEDGEMENT

Authors thank to Dr. Ghufron Zaid and Mr. Ahmad Sulaeman for the great discussion about the method.

REFERENCES

[1] Lovel-Smith, J. 2009. "The propagation of uncertainty for humidity calculations."*Metrologia* 46, 607–615.

[2] AS 2853. 1986. *Enclosures-Temperature-Controlled-Performance Testing and Grading*. Standards Australia.

[3] DKD. 2009. "Guideline DKD-R 5-7 calibration of climatic chambers." *DKD*. Brauncschweig Germany.

[4] E+E Electronic. 2013. *Principles of humidity – Dalton's law*. Retrieved April 29, 2013 from *www.epluse.su/download/sonst/feuchte_en.pdf*.

[5] Rotronic. 2005. *The Rotronichumidity handbook*. Rotronic Instrument Corp.

[6] Carpentier, V., M. Megharfi, J. Quint, M. Priel, M. Desenfantand, and R. Morice. 2004. "Estimation of hygrometry uncertainties by propagation of distributions". *Metrologia* 41, 432–438.

[7] Sonntag, D. 1998. *Advancements in the field of hygrometr. Meteorogische Zeitschrift*, N. F. 3, 51–66.

[8] Hardy, B. 1998. "ITS-90 formulations for vapor pressure, frostpoint temperature, dewpoint temperature and enhancement factors in the range -100 to +100°C." In *Papers and abstracts from the Third International Symposium on Humidity and Moisture*, NPL, London, 1, 214–222.

[9] Huang, P. 1998. "New equations for vapour pressure in the temperature range -100°C to 100°C for use with the 1997 NIST/ASME steam tables." In *Papers and abstracts from the Third International Symposium on Humidity and Moisture*, NPL, London, 1, 68–76.

[10] JCGM. 2008. *Evaluation of measurement data—Supplement 1 to the "Guide to the expression of uncertainty in measurement" — Propagation of distributions using a Monte Carlo method*. Paris: BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP dan OIML

[11] Espec. 2013. *Temperature and humidity chambers platinous series*. Retrieved April 29, 2013 from *www.r-source.com/DataSheets/Espec/e_catalog_platinous.pdf*