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RESEARCH ARTICLE

AN APPLICATION FOR THE CALIBRATION OF THE TWO-PRESSURE HUMIDITY GENERATOR

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ABSTRACT

Two-pressure humidity generator (2-PHG) has capability to produce environments of known humidity with the "two pressure" method that is proven by NIST. The 2-PHG is supplied with known humidity values, the values can be used for instrument calibration, verification and such as other processes. The set point values can be entered from the device's front panel by an operator. 2-PHG calculates the relative humidity from the pressure and temperature measurements with the formula. The computer controls the ratios on the formula to generate a known humidity value. 2-PHG has to have traceability for using on calibration processes of other devices; 2-PHG must be calibrated. This study represents an application of the 2-PHG calibration by using the guides and articles in the literature about the device. Calibration of the 2-PHG contains examination of the each parameter of the formula that was given for humidity calculation. Four temperature and two pressure probes that are saturation temperature probe, pre-saturation temperature probe, expansion valve temperature probe, chamber temperature probe, low pressure probe, high pressure probe help 2-PHG to calculate the formula. Calibration of the 2-PHG, also, contains the calibration of the temperature probes and the pressure probes. This study expresses an application of the calibration of a 2-PHG which is located in Turkish Standard Institution Gebze Calibration Laboratories and the uncertainty calculation of this application can be seen on this paper. Each uncertainty parameter of the formula and uncertainty parameters of the probes that are affected to the total uncertainty were calculated. For different temperatures and different relative humidities, the measurement uncertainty of this application was given on this paper. This study can be used as a supplementary document in the calibrations of the 2-PGH and in the new studies.

Keywords: Calibration, Humidity, Metrology, Two-pressure humidity generator

1. INTRODUCTION

Two pressure humidity generators are highly accurate for instrument calibrations, evaluations and verifications. The "two pressure" principle has been proven by NIST [1].

The two pressure humidity generator is supplied with continuous humidity values. An operator can input the set point values from the device's front panel. The two pressure humidity generator determines the relative humidity from pressure and temperature measurements by utilizing a formula. Operation of the humidity generator is based on the two-pressure method of producing known atmospheres of relative humidity and assumes that the water vapour pressure remains a fraction of the total pressure, known as Dalton's Law of Partial Pressure [1].

Saturating air with water vapor at a specific pressure and temperature is part of the two-pressure approach.

The saturated gas is isothermally lowered to chamber pressure as it passes through an expansion valve. If the temperature of the gas is held constant during pressure reduction, the humidity, at chamber pressure, may then be approximated as the ratio of two absolute pressures [2]. The following formula [1] can be used to determine relative humidity.

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$$\%RH = (P_{chamber} / P_{saturation}) * 100 \quad (1)$$

In this paper, calibration steps of the two humidity generator are given for an application in the Turkish Standard Institution. The uncertainty formulas were obtained from the publications of the "two pressure humidity generator." The uncertainty estimate for this application may be viewed in this paper. This study expresses an application of the calibration of a two pressure humidity generator that is placed in Turkish Standard Institution Gebze Calibration Laboratories. Each uncertainty parameter of the formula and uncertainty parameters of the probes that are affected to the total uncertainty were calculated. This document provides the measurement uncertainty for this application for various temperatures and relative humidities. Because there are few instances in the literature about the calibration of two-pressure humidity generators and their uncertainty calculations, this work may be helpful for future researches.

Equation 2 is used to compute relative humidities from pressure and temperature values [1]:

$$\% RH = P_c/P_s * e_s/e_c * F_s/F_c * 100 \quad (2)$$

The pressure ratio P_c/P_s is controlled by the computer, and the enhancement factor ratio is used to produce the known humidity, f_s/f_c, and the effective saturation level, e_s/e_c. Produced humidity is directly dependent on the measurement of pressures and temperatures and it does not rely on any other device for the measurement of water vapour content. Precision humidity generation is determined by the accuracy of the pressure measurements and it is dependent on the accuracy and uniformity of temperature inside the chamber [3].

Figure 1 shows the two-pressure humidity generator.

Figure 1. The two-pressure humidity generator

2. PROCEDURES FOR THE CALIBRATION OF THE TWO-PRESSURE HUMIDITY GENERATOR

Two pressure gauges with capacities of 50 psi and 150 psi are included in the device. A reference pressure calibrator with traceability was used to measure low (15 psi), medium (30 psi), and high (50 psi) pressure points for low pressure probes with 50 psi capacities, and low (50 psi), medium (100 psi, and high (150 psi) pressure points for high pressure probes with 150 psi capacities. The pressure values and the actual temperature values were entered to the system through the program and the new coefficients for the device were calculated and recorded to the system. After then the creation of the coefficients on the device, two pressure probes were calibrated by the reference pressure calibrator which has got traceability. Euramet's comprehensive calibration procedure was followed in the pressure calibration and the calibration was made with comparison method [4].

For the two pressure humidity generators to calculate the relative humidity, four temperature probes— saturation temperature probe, pre-saturation temperature probe, expansion valve temperature probe, chamber temperature probe— and two pressure probes— low pressure probe, and high pressure probe— are used. First, the device's four temperature probes were measured at the temperatures on 0 °C (low), 35 °C (middle), and 70 °C (high) in a liquid bath. Next, the temperature coefficients were calculated and saved to the device's software. Following the determination of the temperature coefficients, the temperature probes were calibrated using a liquid bath, a high-accuracy SPRT, and water at its triple point. The same technique was used to calibrate the chamber temperature probe.

Temperature homogeneity and stability tests have been made with reference devices for the cabinet's chamber. A temperature probe was placed in the centre of the cabinet during the stability testing, and after the balance state, temperature measurements were taken at 5-minute intervals, with twenty-one values being recorded for each temperature point. Table 2 shows the temperatures stabilities.

Expanded uncertainty, which in this case is defined as measurement uncertainty multiplied by the expansion coefficient k=2, offers %95 reliability, is given in the tables.

3. RESULTS

The calibration of the chamber temperature probe in the water bath was carried out using the comparison method at various temperatures and the water's triple phase point. Table 1 contains the values and deviations.

Table 1. Reference temperature values, chamber temperature probe's temperature values and deviations

Reference Temperature (ºC)	Reading from the Chamber Temperature Probe (ºC)	Deviation (ºC)
-10,078	-10,02	0,056
-0,010	-0,0074	0,0026
10,234	10,23	-0,004
20,189	20,18	-0,009
30,177	30,17	-0,007
40,173	40,17	-0,003
50,250	50,26	0,010
60,231	60,24	0,009
70,243	70,24	-0,003

The uncertainty analysis of the chamber temperature must take into account a number of factors.

Measurement uncertainty includes the effects of the resolution, self-heating and the reference standard [5].

The standard deviation of the difference between the reference standard and chamber temperature is the uncertainty component of the chamber temperature due to measurement, u(M) [5].

The resolution of the device's temperature indicator is 0,01 ºC. The uncertainty component of temperature resolution is [5]:

$$u(R) = 0{,}01/2\sqrt{3} = 0{,}0029\ °C \tag{3}$$

The temperature probe was calibrated in the water bath, but it uses in air. There is the possibility of some self-heating because of that. The self-heating, with temperature measurements is estimated to be +0,05% of reading [5],

$$u(SH) = 0{,}05\% * T_c \,/\, \sqrt{3} = 0{,}00029 * T_c \tag{4}$$

The uncertainty component of the reference standard was found as $u(T_{ref})$ = 0,004 °C with calculations.

The combined uncertainty of the chamber temperature can be found by the following formula.

$$u_c^2(T_c) = u^2(M) + u^2(R) + u^2(SH) + u^2(T_{ref}) \tag{5}$$

Utilizing a coverage factor k=2, the expanded uncertainty is $U = k * u_c(T_c)$.

Uncertainty components of the chamber temperature are seen in Table 2.

Table 2. Uncertainty components of the chamber temperature inside the cabinet

Component	Temperature (°C)								
	-10	- 0	10	20	30	40	50	60	70
u (M)					0,018				
u (R)					0,0029				
u (SH)	-0,0029	0	0,0029	0,0058	0,0087	0,0116	0,0145	0,0174	0,0203
u (T_{ref})					0,004				
u_c (T_c)	0,0189	0,0187	0,0189	0,0195	0,0206	0,0220	0,0236	0,0255	0,0276
U (T_c)	0,03778	0,03733	0,03778	0,03909	0,04119	0,04395	0,04727	0,05104	0,05515
stability	0,05	0,0004	0,02	0,00	0,02	0,02	0,00	0,00	0,00

Chamber temperature uniformity has a direct effect on relative humidity gradients within the test chamber. The thermometers were then carefully placed at various locations within the test chamber [6].

The maximum measurement deviation is determined by noting the maximum and minimum readings from the set of probes at the same point in time, then taking half the difference of these values.

$$MaxDev = \pm 0.5(MaxReading\text{-}MinReading) \tag{6}$$

Then uniformity can be calculated by the following formula.

$$Uniformity^2 = MaxDev^2 + u^2(T_{ref}) \tag{7}$$

$u(T_{ref})$ is the uncertainty of the reference temperature standard. The maximum deviation and the uniformity of the test chamber temperature are given in Table 3.

Table 3. Temperature maximum deviation and temperature uniformity in the chamber

	0 ºC	35 ºC	70 ºC
Max. deviation	0,400	0,078	0,390
Uniformity	± 0,400	± 0,078	± 0,390

Relative Humidity in a two-pressure humidity generator is determined from the measurements of temperature and pressure and is expressed by the equation below [7].

$$RH = P_c/P_s * e_s/e_c * F_s/F_c * 100 \quad (8)$$

Total uncertainty of the relative humidity is the quantitative combination of the uncertainty component of the pressure ratio, the vapour pressure ratio's uncertainty component, the uncertainty contribution from the enhancement factor and from saturator efficiency [7].

When pressure is greater than 50 psia, the uncertainty contribution from the pressure can be calculated from the formulas that are below [7].

$$u(P_c) = \pm\{\pm \partial P_c/P_s\} * 100 \quad (9)$$

$$u(P_s) = \pm\{(P_c)/(P_s \pm \partial P_s) - (P_c/P_s)\} * 100 \quad (10)$$

For saturation pressures below 50 psia, a different measurement scheme is employed. When pressure is lower than 50 psia, the uncertainty component of the pressure can be calculated as the formula below [7].

$$u(P_c) = \pm\{(P_c + \partial P_c)/(P_s + \partial P_c) - (P_c/P_s)\} * 100 \quad (11)$$

Uncertainty due to pressure hysteresis is given equation below [7].

$$u(H) = \pm\ 0{,}058 * (1 - Pc/Ps) \quad (12)$$

Uncertainty contribution from the pressure measurement resolution can be found by the equations below [7].

$$u(R_{pc}) = \pm\ (resolution/P_s) * 100 \quad (13)$$

$$u(R_{ps}) = \pm\ \{(P_c)/(P_s + resolution/P_s) - (P_c/P_s)\} * 100 \quad (14)$$

Total uncertainty effect from the pressure ratio Pc/Ps can be found by the formula below.

$$u_c^2(P_c/P_s) = u^2(P_c) + u^2(P_s) + u^2(R_{pc}) + u^2(R_{ps}) + u^2(H) \quad (15)$$

Standard uncertainty components of RH due to pressure at various saturation pressures are seen in Table 4.

While the actual measurement accuracy of the two temperature probes is of little concern, the ability of the chamber and saturation temperature probes to indicate the same measured value at the same temperature is important, and is termed the inter-comparison uncertainty [7]. The RH uncertainty due to temperature inter-comparison, $u(T_i)$, is then written as

$$u(T_i) = \pm\ \{(E_{[Ts+\partial Ts]})/(E_{[Tc]}) - 1\} * RH \quad (16)$$

Table 4. Standard Uncertainty Components of RH due to pressure at Various Saturation Pressures

Source	*Term*	*Ps < 50 psi*						*Ps > 50 psi*					
		15,5	*20*	*25*	*35*	*45*	*50*	*50*	*65*	*75*	*100*	*125*	*150*
Measurement	$u(P_c)$	0,003	0,014	0,017	0,017	0,015	0,015	0,021	0,016	0,014	0,010	0,008	0,007
Measurement	$u(P_s)$	0,020	0,015	0,012	0,009	0,007	0,006	0,015	0,009	0,007	0,004	0,002	0,002
Resolution	$u(R_{pc})$	0,004	0,003	0,002	0,002	0,001	0,001	0,001	0,001	0,001	0,001	0,000	0,000
Resolution	$u(R_{ps})$	0,004	0,002	0,001	0,001	0,000	0,000	0,001	0,001	0,000	0,000	0,000	0,000
Hysteresis	$u(H)$	0,045	0,050	0,044	0,023	0,133	0,180	0,060	0,031	0,067	0,026	0,030	0,034
combined	$u_c(P_c/P_s)$	0,050	0,054	0,049	0,030	0,134	0,181	0,065	0,036	0,068	0,028	0,032	0,035

The standard deviation of the difference between the saturation and chamber temperatures over the stated temperature range is ∂T_s.

The uncertainty components of the temperature indicator resolution that is affect to the total uncertainty of the relative humidity are given below.

$$u(R_{Tc}) = \pm \{(E_{Ts}/E_{Tc+0.0029}) - 1\} * RH \quad (17)$$

$$u(R_{Ts}) = \pm \{(E_{Ts+0.0029}/E_{Tc}) - 1\} * RH \quad (18)$$

Standard uncertainty components of RH due to temperature at various temperatures are given in Table 5.

Table 5. Standard Uncertainty Components of RH due to Temperature at Various Temperatures

Source	*Term*	*Temperature (°C)*								
		-10	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*
T_s-T_c Intercomparison	$u(T_i)/RH$	0,00157	0,00204	0,00188	0,00174	0,00161	0,00149	0,00139	0,00130	0,00121
T_s Resolution	$u(R_{Ts})/RH$	0,00016	0,00024	0,00019	0,00018	0,00017	0,00015	0,00014	0,00013	0,00013
T_c Resolution	$u(R_{Tc})/RH$	0,00016	0,00024	0,00019	0,00018	0,00017	0,00015	0,00014	0,00013	0,00013
Self-Heating	$u(SH)/RH$	0,00016	0,00000	0,00019	0,00036	0,00050	0,00062	0,00072	0,00080	0,00087
Combined uncertainty	$u(E_s/E_c)/RH$	0,00159	0,00207	0,00191	0,00179	0,00170	0,00163	0,00158	0,00153	0,00150

Uncertainty of the enhancement factor equation which is affecting to the relative humidity is below and given in Table 6.

$$u(F_s/F_c) = \pm\, 0{,}00088 * (100\text{-}RH) \quad (19)$$

Uncertainty due to saturator efficiency can be calculated as formula below [7].

$$u(SE) = 0{,}143 * RH \quad (20)$$

The combined standard uncertainty, $u_c(RH)$, is obtained by statistical combination of the standard uncertainty components of pressure ratio, vapor pressure ratio, enhancement factor ratio, and saturator efficiency. The combined uncertainty formula is then the sum of the variances

$$u^2(RH) = u^2(P_c/P_s) + u^2(e_s/e_c) + u^2(F_s/F_c) + u^2(SE) \quad (21)$$

Expanded uncertainty of RH with coverage factor k=2 is seen in Table 7.

Table 6. Standard Uncertainty Components of RH due to Enhancement Factor

Source	Term	*Ps < 50 psi*					*Ps > 50 psi*		
		15,5	*20*	*30*	*40*	*50*	*50*	*100*	*150*
		94,84 %RH	73,50 %RH	49,00 %RH	36,75 %RH	29,40 %RH	29,40 %RH	14,70 %RH	9,80 %RH
Combined uncertainty	$u(F_s/F_c)$	0,005	0,023	0,045	0,056	0,062	0,062	0,075	0,079

Table 7. Expanded Uncertainty of RH with coverage factor k=2

Saturation Temperature	*Ps < 50 psi*					*Ps > 50 psi*		
	15,5	*20*	*30*	*40*	*50*	*50*	*100*	*150*
	94,84 %RH	*73,50 %RH*	*49,00 %RH*	*36,75 %RH*	*29,40 %RH*	*29,40 %RH*	*14,70 %RH*	*9,80 %RH*
-10 °C	±0,419	±0,336	±0,242	±0,249	±0,403	±0,219	±0,183	±0,178
0 °C	±0,488	±0,388	±0,274	±0,267	±0,410	±0,233	±0,195	±0,180
10 °C	±0,464	±0,369	±0,263	±0,260	±0,407	±0,228	±0,190	±0,179
20 °C	±0,447	±0,357	±0,255	±0,256	±0,406	±0,225	±0,188	±0,179
30 °C	±0,434	±0,347	±0,249	±0,252	±0,404	±0,222	±0,186	±0,178
40 °C	±0,424	±0,340	±0,244	±0,250	±0,403	±0,220	±0,184	±0,178
50 °C	±0,417	±0,334	±0,241	±0,248	±0,403	±0,219	±0,183	±0,178
60 °C	±0,411	±0,330	±0,238	±0,247	±0,402	±0,218	±0,182	±0,178
70 °C	±0,406	±0,326	±0,236	±0,245	±0,402	±0,217	±0,181	±0,178

4. CONCLUSIONS

Humidity is a computational value. The "two pressure humidity generator" is the one of the most precise way for producing humidity. Utilizing a mathematical equation, the two-pressure humidity generator determines the relative humidity from pressure and temperature measurements. The ratios in the equation are controlled by the computer to produce a known level of humidity.

Two-pressure humidity generators are generally used in metrology institutes, advanced calibration laboratories, meteorological laboratories and military areas that require precise measurements. The relative humidity value obtained by calculation from this device can remain stable for a long time with high accuracy, and fluctuations are less during the measurements. Although the cost is higher than other systems, related devices are preferred for such reasons. These types of devices, which are not usually found in country inventories, provide traceability to secondary level calibration laboratories in countries. The two-pressure humidity generator in the Turkish Standards Institute provides traceability to many different sectors in a wide area in Turkey. Many secondary level calibration laboratories' reference humidity instruments are calibrated by the two-pressure humidity generator in the Turkish Standards Institute. In this sense, the Turkish Standards Institute calibrates its own double-pressure humidity generator with the method described in this publication, in order to reduce dependency on external institutions. During the calibration, thermometers and pressure calibrators with international traceability are used.

This study provided an application for calibrating two-pressure humidity generators. The calibration data for the two-pressure humidity generators, which are located in the calibration laboratory of the Turkish Standard Institution, were provided in this application. Temperature calibration, temperature uniformity analysis, relative humidity calibration of the device was processed by using the literature. Measurement uncertainties were calculated step by step. The components of each parameter which is affecting to the total uncertainty of the relative humidity are examined and calculated.

Calibration results were given for various points in this study by tables. Hygrometers and other humidity measuring devices can now be calibrated using a "two pressure humidity generator."

This compact study is provided to the literature. This study can be a supplementary document for the metrology researchers who are studying on the relative humidity calibration and temperature calibration. Also, this study can be used for the new studies about the calibration of the “two pressure humidity generator” as a document.

NOMENCLATURE

% RH: relative humidity
P_c: Chamber Pressure
P_s: Saturation Pressure
e_s: Saturation Vapor Pressure at Saturation Temperature
e_c: Saturation Vapor Pressure at Chamber Temperature
F_s: Enhancement Factor at Saturation Temperature and Pressure,
F_c: Enhancement Factor at Chamber Temperature and Pressure,
u(M): RH uncertainty due to self-heating of the chamber temperature probe
u(R): RH uncertainty due to self-heating of the chamber temperature probe
u(SH): RH uncertainty due to self-heating of the chamber temperature probe
$u(T_{ref})$: The uncertainty of the reference temperature standard
$uc(T_c)$: Combined uncertainty of the chamber temperature
$u(P_c)$: Uncertainty in chamber pressure measurement
$u(P_s)$: Uncertainty in saturation pressure measurement
u(H): Uncertainty component due to hysteresis
$u(R_{pc})$: Uncertainty due to chamber pressure measurement resolution
$u(R_{ps})$: Uncertainty due to saturation pressure measurement resolution
$u_c(P_c/P_s)$: Uncertainty in the Pressure Ratio Pc/Ps
$u(T_i)$: The RH uncertainty due to temperature intercomparison,
$u(R_{Tc})$: Uncertainty due to chamber temperature resolution,
$u(R_{Ts})$: Uncertainty due to saturation temperature resolution,
$u(F_s/F_c)$: Uncertainty in the Enhancement Factor Ratio
u(SE): Uncertainty due to Saturator Efficiency
u(RH): Total uncertainty in relative humidity

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CONFLICT OF INTEREST

The author stated that there are no conflicts of interest regarding the publication of this article.

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