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Extending dew-point temperature scale up to +50 °C

Doaa Mohamed Abd El-Gelil* and Mohamed Gamal Ahmed

National Institute of Standard, Giza, Egypt

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Abstract. Extension of dew-point temperature scale has been performed using a two-temperature (2-T), constant pressure humidity generator that is developed for the first time by the National Institute of Standard (NIS) in order to extend the calibration capabilities to the high dew-point temperature range at NIS. It relies on the saturation of a stream of gas flowing over a water surface maintained at constant, well-known, temperature. In this paper, primary realization of dew-point temperature scale in a dew-point temperature range up to +50 °C was performed to extend calibration capabilities and to improve the uncertainties of the dew-point temperature scale realization. Several experiments were carried out in order to characterize the generator. Characterization comprises studies of the saturator efficiency, temperature stability and a comparison with a calibrated chilled-mirror hygrometer. The results of the efficiency tests showed good performance of the generator. For uncertainty of measurements, a thorough analysis was also described representing estimations of contributions for all the sources that possibly affect measurements.

Keywords: dew-point / hygrometer / two-temperature generator / uncertainty

1 Introduction

There are several techniques used to generate humidity references by using stream of saturated gas with well-known water vapor content to be used in calibration of chilled-mirror hygrometers such as two-pressure humidity generator, one-temperature dew-point temperature scale, and two-temperature humidity generator [1–3]. NIS primary two-temperature (2-T) humidity generator was previously developed and characterized in the dew-point temperature range from –50 to +10 °C. Characterization of the generator and efficiency tests were carried out through studies on the temperature stability of its liquid bath and the variation of air flow rate at a different temperature in the dew-point range from –50 to +10 °C. The results showed good performance for the generator complying with the concerned range and a measurement expanded uncertainties ranging from ± 0.065 °C to ± 0.074 °C at dew-point temperatures of 0 to –40 °C, respectively [4].

This work describes the realization of the dew-point temperature scale in the range from –10 to +50 °C using (2-T) humidity generator for the first time at NIS to extend the calibration capabilities to the high dew-point range. Dew-point temperature above ambient temperature should be measured with special provisions; the dew-point meter

measuring head and the sample gas line must be heated to avoid any undesired condensation.

2 Experiments

The principle of the two-temperature method in a gas is humidified at a given temperature, defining its dew point. The gas is then fed into a chamber at different temperatures. By varying one or both temperatures, it is possible to obtain any chosen value of dew point temperature.

The main generator parts are air compressor, pure air desiccant dryer, pre-cooler heat exchanger, saturating system (saturator and saturator chamber), two liquid baths, four standard platinum resistance thermometers (SPRTs), two Pt-100's, AC resistance thermometer bridge, multimeter, and MBW chilled-mirror hygrometer (Model DP-30). All these parts are described in detail in reference [4]. A heated hose and steam trap are connected to the dew-point meter; this is shown in Figure 1.

A compressed air, used as a carrier, drawn from the hose pressure line is first dried and filtered by using the air dryer and filter, whose maximum pressure is 1200 kPa to avoid any contamination. A commercial pressure regulator was used to control the pressure in the humidifying system. The flow meter is used to control the flow of the air at a rate up to 60 L/h. Saturation of the air at a given temperature is accomplished in the saturating system (saturator and test chamber).

* Corresponding author: m.dody74@yahoo.com

Fig. 1. Schematic diagram of NIS two-temperature humidity generator.

Fig. 2. The saturator inside the bath.

Fig. 3. The test chamber inside the bath.

Air was led into the pre-cooler heat exchanger that was used to precondition the air before it passes through the saturator inlet tube. The air was then passed through the copper labyrinthine saturator. The saturator was partially filled with distilled water. The saturator is totally immersed in the first liquid thermostatic bath where the temperature is controlled to within 0.01°C at the different set points. The air emerging from the saturator was directed through a stainless steel tube within which SPRT is used as a reference for the saturator temperature and positioned in the saturator exit. After passing this stage, a complete saturation is ensured by directing the air to enter the test chamber. The test chamber is a copper box like a vessel. For temperature stabilization, the gas was directed to pass through a coiled tube heat exchanger before entering the chamber. This chamber is designed to be totally immersed in the second liquid thermostatic bath where the temperature is also controlled to be within

0.01°C . Saturated air is then drawn off from the test chamber through the vertical outlet tube. It is required that the dew-point meter should measure dew-point temperatures above ambient temperature. The meter measuring the head and sample gas line must be heated. The temperature of the unheated connections between the sampling point (inlet of heated hose) and the measuring head (outlet of heated hose) must be above the required dew-point temperature. This is to avoid any undesired condensation. Heated hose and steam trap must be installed and connected to the dew-point meter as shown in Figure 1. The saturating system (saturator and test chamber) is completely immersed into liquid baths (1) and (2) in vertical position, as shown in Figures 2 and 3.

Four calibrated standard platinum resistance thermometers (SPRT) were used as reference thermometers. One of them was used to monitor the saturator temperature, positioned in the saturator exit, and the second was

Fig. 4. Fluctuations of the temperature measured by SPRT at 10 °C for four runs in the saturator.

Fig. 5. Fluctuations of the temperature measured by SPRT at 10 °C for four runs in the test chamber.

Table 1. Results of mean values using SPRTs at +10 °C DP/FP temperature of four runs with different flow rates.

Run No.	Flow rate, L/h	Saturator temperature T_{ds} , °C	Test chamber temperature T_{ds} , °C	Chilled-mirror hygrometer reading T_{dm} , °C
1	25	9.8269	10.0804	10.20
2	35	9.8321	10.0801	10.19
3	45	9.8314	10.0795	10.18
4	55	9.8279	10.0806	10.19

used to monitor the temperature of the bath (1). The third and fourth thermometers were positioned at test chamber exit and bath (2), respectively. A calibrated Pt-100 thermometer was used in another tube near the saturator inlet to measure the saturator temperature gradient.

3 Results and discussion

The obtained results from measurements of the saturator system is given in the temperature range from −10 to +50 °C, increasing by +10 °C (i.e., −10, 0, +10, +20, +30, +40, +50 °C), showing a temperature stability in the dew-point temperature range. Figures 4 and 5 show an example at +10 °C for the measured fluctuations in saturator and test chamber, respectively. The overall temperature stability of the generator ranged from 0.0005 to 0.0007 °C. The fluctuations show that the generator is stable and capable for calibration of chilled-mirror hygrometers. It also shows that the stability time is about 4 h. Hence, it is enough to calibrate these types of meters even with those having long response time. To trust the stability and the repeatability of the results, four runs were carried out at each point. The obtained repeatability measurements range from 0.0002 to 0.0004 °C at dew-point temperatures of 0, +10, +20, +30, +40, +50 to −10 °C, respectively.

Saturating system efficiency was performed at the operating temperature from −10 to +50 °C through the following:

1. Monitoring its output with the chilled-mirror hygrometer while varying the inlet-air flow rates and dew-point temperatures; then, a comparison between the air temperature inside the saturator and the calibrated chilled-mirror hygrometer was done (the flow rate through the hygrometer was kept constant). Table 1 shows an example of the study of the different flow-rates effect.

The variation of the airflow rate has no effect on the saturating system efficiency where there was no significant change in the performance of the generator. Therefore, this test shows good efficiency of the saturating system.

2. The difference between the bath temperature containing the saturating system and the air temperature inside the saturating system.

The efficiency of the saturating system was determined from the temperature difference between the temperature of the baths containing the saturator and the test chamber and the temperature of the saturated air inside the saturator and the test chamber, respectively [5,6]. Table 2 shows the obtained results at four runs. These temperature differences were determined by four SPRTs: first one at the saturator exit tube, the second at bath (1), the third at the test chamber exit tube, and the last one at bath (2).

The uncertainty budget of the generator at dew-point temperature range (−10 to +50 °C) involves the uncertainties of each source and the method of estimation for

Table 2. Difference between the saturating system temperatures and the temperatures of the baths.

Setting temperature, °C	Difference between the saturator temperature and bath (1) temperature, °C	Difference between the test chamber temperature and bath (2) temperature, °C
-10	0.0089	0.0090
0	0.0041	0.0037
+10	0.0050	0.0055
+20	0.0056	0.0064
+30	0.0052	0.0058
+40	0.0058	0.0064
+50	0.0062	0.0069

Table 3. Uncertainty budget of the two-temperature generator at +10°C dew-point temperature.

Source	Symbol	Value	Distribution	Divisor	Sensitivity coefficient	Standard uncertainty	Method of estimation
Repeatability for first SPRT	First SPRT Rep.	0.0013	Normal	1	1	0.0013	Standard deviation of measurements
Repeatability for Second SPRT	Second SPRT Rep.	0.0002	Normal	1	1	0.0002	Standard deviation of measurements
First SPRT calibration	$u(t_{s \text{ sprt cal}})$	0.002	Normal	1	1	0.001	Calibration certificate
First bath stability	$u(t_{s \text{ stab}})$	0.006	Rectangular	$\sqrt{3}$	1	0.0035	Difference between maximum and minimum value of measurements
Second SPRT calibration	$u(t_{s \text{ sprt cal}})$	0.002	Normal	1	1	0.001	Calibration certificate
Second bath stability	$u(t_{s \text{ stab}})$	0.01	Rectangular	$\sqrt{3}$	1	0.00578	Difference between maximum and minimum value of measurements
SPRT resolution (indicator unit)	$u(t_{s \text{ ind res}})$	0.0001	Rectangular	$\sqrt{3}$	1	0.00006	Digital indicator = 0.5 of resolution
Bridge calibration	$u(t_{s \text{ cal}})$	0.0005	Normal	1	1	0.00025	Calibration certificate
Saturator efficiency	$u(t_{s \text{ sat eff}})$	0.0050	Normal	1	1	0.0050	The temperature difference between bath temperature that containing the saturator and the air temperature inside the saturator
Saturator homogeneity	$u(t_{s \text{ sat hom}})$	0.01	Rectangular	$\sqrt{3}$	1	0.00578	The temperature difference between saturator inlet and exit

Table 3. (continued).

Source	Symbol	Value	Distribution	Divisor	Sensitivity coefficient	Standard uncertainty	Method of estimation
Saturator temperature stability	$u(t_{s \text{ sat stab}})$	0.0048	Rectangular	$\sqrt{3}$	1	0.00279	Difference between maximum and minimum value of measurements
Test chamber efficiency	$u(t_{s \text{ cham eff}})$	0.0055	Normal	1	1	0.0055	The temperature difference between bath temperature that contains the test chamber and the air temperature inside the test chamber
Test chamber homogeneity	$u(t_{s \text{ cham hom}})$	0.01	Rectangular	$\sqrt{3}$	1	0.01	The temperature difference between test chamber inlet and exit
Test chamber temperature stability	$u(t_{s \text{ cham stab}})$	0.0005	Rectangular	$\sqrt{3}$	1	0.003	Difference between maximum and minimum value of measurements
Dew-point hygrometer	$u(t_{m \text{ cal}})$	0.06	Normal	1	1	0.03	Calibration certificate
Resolution of hygrometer	$u(t_{m \text{ hygro res}})$	0.005	Rectangular	$\sqrt{3}$	1	0.0057	Digital indicator = 0.5 of resolution
Combined uncertainty						0.33	
Expanded uncertainty ($k = 2$)						± 0.0659	

each source that is contributing to measurements. Table 3 shows explicitly an example of the calculated uncertainty budget at $+10^\circ\text{C}$ dew-point temperature with an expanded uncertainty of 0.0659°C [7–10]. Thus, in the concerned dew-point temperature range, it was found that the measurement uncertainties ranged from 0.0654 to 0.0669°C at dew-point temperatures of 0 to $+50^\circ\text{C}$, respectively, and the measurement uncertainty at -10°C was found to be 0.0697°C .

4 Conclusion

Extending dew-point temperature scale up to $+50^\circ\text{C}$ at NIS –EGYPT has been setup for the first time using a two-temperature (2-T) constant pressure humidity generator. The generator was successfully tested and characterized. Results of the efficiency tests showed that the generator is sufficient for realization of the dew-point temperature. The generator covers the dew-point range from -10 to $+50^\circ\text{C}$ under flow rates between 25 L/h and 55 L/h with measurement-expanded uncertainties ranging from ± 0.0654 to $\pm 0.0669^\circ\text{C}$ at dew-point temperatures of 0 to $+50^\circ\text{C}$, respectively.

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