**SIM.T-K6.2 NIST / CENAM**
**Final Report**

# BILATERAL KEY COMPARISON SIM.T-K6.2 ON HUMIDITY STANDARDS IN THE DEW/FROST-POINT TEMPERATURE RANGE FROM –20 °C TO 20 °C

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## Abstract

A Regional Metrology Organization (RMO) Key Comparison of dew/frost point temperatures was carried out by the National Institute of Standards and Technology (NIST, USA) and the Centro Nacional de Metrologia (CENAM, Mexico) between July, 2008 and December, 2008. The results of this comparison are reported here, along with descriptions of the humidity laboratory standards for NIST and CENAM and the uncertainty budget for these standards. This report also describes the protocol for the comparison and presents the data acquired. The results are analyzed, determining degree of equivalence between the dew/frost-point standards of NIST and CENAM.

Keywords: Comparison, Humidity, Dew Point, Frost Point, Degree of Equivalence.

## 1. Introduction

Key Comparisons determine differences between measurement standards of different National Metrology Institutes (NMIs). They play an important role in ensuring that the standards of all NMIs are in agreement.

At its 20th meeting in April 2000, the Consultative Committee for Thermometry (CCT) called for a Key Comparison on humidity standards to be conducted by all major National Metrology Institutes. It asked CCT Working Group 6 (WG6) on Humidity Measurements (WG6) to draw up a technical protocol for an International Committee on Weights and Measures (CIPM) key comparison named “CCT.K6”. The National Physical Laboratory (UK) and the National Metrology Institute of Japan were chosen to be the pilot laboratory and assistant pilot laboratory, respectively. The National Institute of Standards and Technology (NIST, USA) participated in this key comparison.

The Centro Nacional de Metrologia (CENAM, México) did not participate in CCT.K6. Therefore, to relate the humidity standards of CENAM to those of the CCT.K6 participants, a Regional Metrology Organization (RMO) Key Comparison of dew/frost point temperatures $T_{DP/FP}$ was carried out by NIST and CENAM in between July, 2008 and December, 2008; this comparison was designated as SIM.T-K6.2. Here, it is assumed that $T_{DP/FP}$ is the dew-point temperature $T_{DP}$ for $T_{DP/FP} \geq 0$ and $T_{DP/FP}$ is the frost-point temperature $T_{FP}$ for $T_{DP/FP} < 0$. As an NMI, CENAM meets the Mutual Recognition Arrangement requirements for participation in a key comparison. NIST was the pilot for this bilateral comparison. This bilateral comparison followed the same technical procedures as for the CCT.K6, except that only one transfer standard was used. Also, a range of $-20$ °C $\leq T_{DP/FP} \leq 20$ °C was used instead of $-50$ °C $\leq T_{DP/FP} \leq 20$ °C.

## 2. Participants



| | | |
|---|---|---|
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## 3. Comparison Method

The comparison between dew/frost-point temperatures realized at NIST and CENAM was performed through use of a transfer standard (a chilled-mirror hygrometer). At a given nominal dew/frost point, each participant used its generator to produce moist air having a dew/frost-point temperature determined to be $T^{g}_{DP/FP}$. The transfer standard then measured the dew/frost-point temperature of the generated gas, $T^{m}_{DP/FP}$. The difference between the two values was

$$\Delta T_{DP/FP} = T^{g}_{DP/FP} - T^{m}_{DP/FP}$$

The comparison of NIST and CENAM humidity standards was then performed by comparing the values of $\Delta T_{DP/FP}$ determined using the NIST humidity generator, $\Delta T_{DP/FP}$(NIST) , with those of the CENAM humidity generator, $\Delta T_{DP/FP}$(CENAM).

## 4. Generators

The NIST humidity generator used was the NIST Hybrid Humidity Generator (HHG). Its principle of operation depends on the desired value of $T_{DP/FP}$.

For $T_{DP/FP} \geq -15$ °C, the HHG operates as a conventional two-pressure generator, saturating air with water at a temperature $T_s$ and pressure $P_s$ to produce moist air with a molar fraction $x_g$ given by

$$x_g = \frac{e(T_s)}{P_s} f(T_s, P_s). \tag{1}$$

Here, $e(T_s)$ is the water vapor pressure at $T_s$, calculated using [1-2] and $f(T_s, P_s)$ is the water-vapor enhancement factor, calculated using [3]. The saturator temperature is measured by a standard platinum resistance thermometer (SPRT) immersed in the same temperature-controlled bath as the saturator. The saturator pressure, which can vary from ambient to 500 kPa, is measured by a strain-gauge pressure transducer that is connected by a tube to the saturator at a point near its outlet.

For $T_{DP/FP} \leq -15$ °C, the HHG uses the divided flow method, which involves diluting the saturated gas with dry gas using precisely metered streams of gas. The molar fraction after dilution is

$$x_g = \frac{\dot{n}_s x_s + \dot{n}_p x_p}{\dot{N}} \tag{2}$$

where $\dot{n}_s$ and $\dot{n}_p$ are the molar flows of the saturated gas and pure (dry) gas, respectively, and $\dot{N}$ is the total molar flow. Also, $x_s$ is the molar fraction of water in the saturated gas and $x_p$ is the residual molar fraction of water in the pure gas. For the HHG in divided flow mode, the saturator is operated at a temperature of 1 °C and a pressure of 300 kPa, resulting in $x_s \approx 0.0022$.

The generated dew/frost-point temperature is obtained from $x_g$ by measuring the pressure $P_c$ using a strain-gauge pressure transducer at the inlet of the chilled-mirror hygrometer. $T_{DP/FP}$ is then obtained by iteratively solving the equation

$$x_g = \frac{e(T_{DP/FP})}{P_c} f(T_{DP/FP}, P_c) \tag{3}$$

Here, $e(T_{DP/FP}) = e_w(T_{DP})$ for $T_{DP/FP} \geq 0$, where $e_w$ is the saturated vapor pressure for water, calculated using [1-2]. Also, $e(T_{DP/FP}) = e_i(T_{FP})$ for $T_{DP/FP} < 0$, where $e_i$ is the saturated vapor pressure for ice, calculated using [4-5]. The value of $f(T_{DP/FP}, P_s)$ is calculated using [3]. A more complete description of the NIST HHG may be found in [6].

To ensure the stability of the HHG results, the HHG pressure gauges are calibrated yearly. The HHG SPRT resistance at the triple point of water $R_{TPW}$ is also calibrated yearly. The pressure gauge and SPRT calibrations are performed at NIST. The policy of the HHG laboratory is that if the change in $R_{TPW}$ from that of the original calibration ever corresponds to a temperature drift of more than 10 mK, a full calibration will be performed. Finally, NIST employs check standards during every customer calibration for the purpose of detecting any possible errors or long-term drifts.

The CENAM humidity generator used was a commercially made generator (Thunder Scientific Model 2500 [7-10]. It operates as a two-pressure generator (see Eq. 1) over its entire range. The saturator temperature can be varied from 0 °C to 70 °C and the saturator pressure can be varied from ambient to 1.03 MPa. The generator uses four 10 kΩ thermistors to measure and control the saturator temperature. It uses two piezoresistive pressure transducers to measure and control the saturator pressure, one designed for the range 0-0.34 MPa (0-50 psia) and the other for the range 0-1.03 MPa (0-150 psia); the first is used to measure pressures below 0.34 MPa and the second to measure pressures from 0.34 MPa to 1.03 MPa. Calculations of $T_{DP/FP}$ were made from $T_s$ and $P_s$ using Eq. 1 and Eq. 3, using the formulations for $e_w$, $e_i$, and $f$ given in [1-5]. A more complete description may be found in [9].

The four thermistors of the CENAM generator are calibrated yearly using a CENAM-calibrated SPRT and the generator's pressure transducers are calibrated yearly using CENAM pressure standards. Also, CENAM performs verifications of both thermometers and pressure gauges every 6 months. These actions ensure the stability of the CENAM generator results and the traceability of its pressure and temperature measurements to national standards.

## 5. Transfer standard

| | |
|---|---|
| Instrument type: | Chilled-mirror hygrometer |
| Measurand | dew/frost-point temperature |
| Model: | RH Systems 373H [7] |
| Serial Number: | 02-1002 |
| Size (in Packing case): | 59 cm x 81 cm x 48 cm |
| Weight (in Packing case): | 47 kg |
| Manufacturer: | RH Systems, USA |
| Owner: | CENAM, Mexico |
| Electrical supply: | 220 V / 50 Hz |
| Approximate value for insurance and customs declaration: | US$ 27,600 |

## 6. Measurement process

Sample air with $T_{DP/FP}$ realized by a participant's standard generator was introduced into the inlet of a transfer-standard hygrometer through a stainless steel tube. The tube was attached to the transfer standard using a 6.35 mm Swagelok [7] fitting. A 100 ohm platinum resistance thermometer (PRT) embedded beneath the surface of the transfer standard's mirror measured the dew/frost-point temperature. The current applied through the PRT was nominally 1 mA. At both NIST and CENAM, the resistance of the PRT was measured using respective Agilent 3458A [7] multi-meters. These multimeters had been calibrated against their respective national standards and they were autocalibrated just before the beginning of the comparison measurements. The measured resistance was then converted to a nominal dew/frost-point temperature using the reference function given in IEC 60751 [11].

A total of four dew/frost-point temperatures were used for the comparison: 20 °C, 0 °C, −10 °C and −20 °C. Each participant made four independent measurements for each dew/frost-point temperature, performed on different days, reforming the condensate on the hygrometer's mirror each time. At each measured dew/frost point, the PRT resistance readings were monitored until they drifted less than 0.010 Ω (0.025 °C) over a period of 20 minutes (dew points) or 40 minutes (frost points); at that point they were assumed to be in a steady state. Afterwards, multiple readings of the resistance of the PRT were recorded, and the mean and standard deviation of these readings were recorded.

## 7. Measurement data

Table 1 shows the results of the generator/hygrometer comparisons for both CENAM and NIST. For $T_{\mathrm{DP/FP}} \approx 0$ °C it is assumed that the condensate on the hygrometer mirror is always water (never ice). Based on the difference between the dew point and frost point temperatures at the dew/frost-point values realized at $T_{\mathrm{DP/FP}} \approx 0$ °C, we estimate the standard uncertainty for this assumption to be less than 0.005 °C.

Table 2 shows the difference between generated and measured dew/frost-point temperatures $\Delta T_{\mathrm{DP/FP}}$ for four measurements. For a given nominal value of $\Delta T_{\mathrm{DP/FP}}$, the results of CENAM and NIST are shown on separate rows. The results for each of the four measurements are shown in separate columns. The mean and standard deviation of these measurements are shown in the last two columns. The data shown in Table 2 is plotted in Fig. 1.

## 8. Comparison Uncertainty

For a set of determinations of $\Delta T_{\mathrm{DP/FP}}$ made at a nominal value of $T_{\mathrm{DP/FP}}$, the standard uncertainty of the generator/hygrometer comparison $u_{\mathrm{c}}(\Delta T_{\mathrm{DP/FP}})$ is given by

$$u_{\mathrm{c}}\left(\Delta T_{\mathrm{DP/FP}}\right) = \left[u_{\mathrm{A}}^2\left(\Delta T_{\mathrm{DP/FP}}\right) + u^2\left(T_{\mathrm{DP/FP}}^{\mathrm{g}}\right) + u^2\left(T_{\mathrm{DP/FP}}^{\mathrm{m}}\right)\right]^{1/2} \qquad 4)$$

Descriptions of $u_{\mathrm{A}}(\Delta T_{\mathrm{DP/FP}})$, $u\left(T_{\mathrm{DP/FP}}^{\mathrm{g}}\right)$, and $u\left(T_{\mathrm{DP/FP}}^{\mathrm{m}}\right)$ are given below.

First, $u_{\mathrm{A}}(\Delta T_{\mathrm{DP/FP}})$ is the type A uncertainty for the determination of $\Delta T_{\mathrm{DP/FP}}$. This uncertainty includes the reproducibility of the generator, the chilled-mirror hygrometer, and the multimeter making the resistance measurements. It also includes resolution errors arising from rounding off the values of $\Delta T_{\mathrm{DP/FP}}$ to two digits after the decimal point. For simplicity, it was assumed that $u_{\mathrm{A}}(\Delta T_{\mathrm{DP/FP}})$ is independent of $T_{\mathrm{DP/FP}}$. For each NMI, $u_{\mathrm{A}}(\Delta T_{\mathrm{DP/FP}})$ was determined as the average value of $\sigma(\Delta T_{\mathrm{DP/FP}})$ for the four nominal $T_{\mathrm{DP/FP}}$ values. For CENAM and NIST these average values were 0.009 °C and 0.010 °C, respectively. The individual values of $\sigma(\Delta T_{\mathrm{DP/FP}})$ are given in Table 2.

**Table 1.** Results of generator/hygrometer comparisons.

| Hygrometer RH Systems 373H, S/N 02-1002 | | | | | |
|---|---|---|---|---|---|
| Nominal $T_{DP/FP}$ (°C) | Meas. # | Realized $T_{DP/FP}$ (°C) | Measured PRT Resistance (Ω) | Measured $T_{DP/FP}$ (°C) | $\Delta T_{DP/FP}$ (°C) |
| CENAM | | | | | |
| 20 | 1 | 19.96 | 107.743 | 19.87 | 0.09 |
| 20 | 2 | 19.96 | 107.740 | 19.86 | 0.10 |
| 20 | 3 | 19.90 | 107.709 | 19.78 | 0.12 |
| 20 | 4 | 19.90 | 107.714 | 19.80 | 0.10 |
| NIST | | | | | |
| 20 | 1 | 19.99 | 107.740 | 19.86 | 0.12 |
| 20 | 2 | 19.99 | 107.741 | 19.86 | 0.12 |
| 20 | 3 | 20.15 | 107.797 | 20.01 | 0.14 |
| 20 | 4 | 19.93 | 107.725 | 19.82 | 0.11 |
| CENAM | | | | | |
| 0 | 1 | 0.00 | 99.948 | –0.13 | 0.13 |
| 0 | 2 | 0.01 | 99.945 | –0.14 | 0.15 |
| 0 | 3 | –0.04 | 99.927 | –0.19 | 0.15 |
| 0 | 4 | –0.04 | 99.926 | –0.19 | 0.15 |
| NIST | | | | | |
| 0 | 1 | 0.11 | 99.992 | –0.02 | 0.13 |
| 0 | 2 | 0.04 | 99.971 | –0.08 | 0.12 |
| 0 | 3 | 0.05 | 99.977 | –0.06 | 0.11 |
| 0 | 4 | 0.02 | 99.955 | –0.12 | 0.14 |
| CENAM | | | | | |
| –10 | 1 | –10.00 | 96.033 | –10.14 | 0.14 |
| –10 | 2 | –10.01 | 96.032 | –10.14 | 0.13 |
| –10 | 3 | –10.04 | 96.013 | –10.19 | 0.15 |
| –10 | 4 | –10.04 | 96.012 | –10.19 | 0.15 |
| NIST | | | | | |
| –10 | 1 | –10.06 | 96.018 | –10.18 | 0.12 |
| –10 | 2 | –9.99 | 96.045 | –10.11 | 0.12 |
| –10 | 3 | –10.01 | 96.036 | –10.13 | 0.12 |
| –10 | 4 | –10.07 | 96.012 | –10.19 | 0.12 |
| CENAM | | | | | |
| –20 | 1 | –20.01 | 92.108 | –20.13 | 0.12 |
| –20 | 2 | –20.02 | 92.106 | –20.14 | 0.12 |
| –20 | 3 | –20.03 | 92.096 | –20.16 | 0.13 |
| –20 | 4 | –20.03 | 92.095 | –20.16 | 0.13 |
| NIST | | | | | |
| –20 | 1 | –20.04 | 92.099 | –20.16 | 0.12 |
| –20 | 2 | –20.09 | 92.094 | –20.17 | 0.08 |
| –20 | 3 | –19.95 | 92.140 | –20.05 | 0.10 |
| –20 | 4 | –19.89 | 92.165 | –19.99 | 0.10 |

**Table 2.** Difference between realized and measured dew/frost-point temperatures $\Delta T_{DP/FP}$ for NIST and CENAM

| Nominal $T_{DP/FP}$ (°C) | NMI | Meas. 1 $\Delta T_{DP/FP}$ (°C) | Meas. 2 $\Delta T_{DP/FP}$ (°C) | Meas. 3 $\Delta T_{DP/FP}$ (°C) | Meas. 4 $\Delta T_{DP/FP}$ (°C) | $\overline{\Delta T_{DP/FP}}$ (°C) | $\sigma(\Delta T_{DP/FP})$ (°C) |
|---|---|---|---|---|---|---|---|
| 20 | CENAM | 0.09 | 0.10 | 0.12 | 0.10 | 0.103 | 0.012 |
| 20 | NIST | 0.12 | 0.12 | 0.14 | 0.11 | 0.123 | 0.013 |
| 0 | CENAM | 0.13 | 0.15 | 0.15 | 0.15 | 0.145 | 0.011 |
| 0 | NIST | 0.13 | 0.12 | 0.11 | 0.14 | 0.125 | 0.013 |
| −10 | CENAM | 0.14 | 0.13 | 0.15 | 0.15 | 0.143 | 0.008 |
| −10 | NIST | 0.12 | 0.12 | 0.12 | 0.12 | 0.120 | 0.000 |
| −20 | CENAM | 0.12 | 0.12 | 0.13 | 0.13 | 0.125 | 0.005 |
| −20 | NIST | 0.12 | 0.08 | 0.10 | 0.10 | 0.100 | 0.016 |

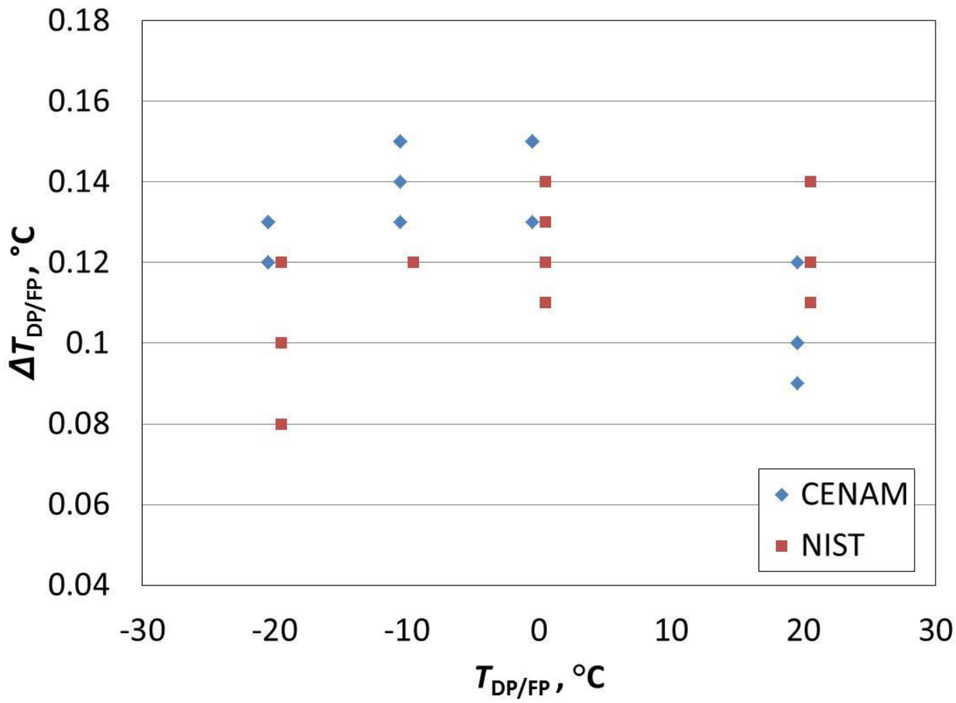


**Figure 1.** Difference between realized and measured dew/frost-point temperatures $\Delta T_{DP/FP}$ for NIST and CENAM. Note: data from the two NMIs are slightly offset horizontally to facilitate viewing.

Secondly, $u\left(T_{\mathrm{DP/FP}}^{\mathrm{g}}\right)$ is the type B uncertainty of the generated value of $T_{\mathrm{DP/FP}}$. The source of the values $u\left(T_{\mathrm{DP/FP}}^{\mathrm{g}}\right)$ for NIST is [6], which contains a complete uncertainty budget for the NIST Hybrid Humidity Generator. The source of the values $u\left(T_{\mathrm{DP/FP}}^{\mathrm{g}}\right)$ for CENAM is [10], which provides an uncertainty analysis for the Thunder Scientific Model 2500. Table 3 shows the uncertainty elements and their standard uncertainty values for the NIST generator, for the four nominal values of $T_{\mathrm{DP/FP}}$. Table 4 shows the contribution of these uncertainty elements to $u\left(T_{\mathrm{DP/FP}}^{\mathrm{g}}\right)$. Similarly, Tables 5 shows the values of these standard uncertainties for the CENAM generator and Table 6 shows their contribution to $u\left(T_{\mathrm{DP/FP}}^{\mathrm{g}}\right)$ for CENAM.

Finally, $u\left(T_{\mathrm{DP/FP}}^{\mathrm{m}}\right)$ is the type B uncertainty of the measured value of $T_{\mathrm{DP/FP}}$. It is given by the type B uncertainty of the resistance measurement of the multimeter measuring the resistance of the PRT in the chilled mirror hygrometer. The values of $u\left(T_{\mathrm{DP/FP}}^{\mathrm{m}}\right)$ were 0.002 °C for both CENAM and NIST.

Table 7 shows the calculated value of $u_{\mathrm{c}}(\Delta T_{\mathrm{DP/FP}})$ and its components for each value of $T_{\mathrm{DP/FP}}$ and each participating NMI. Note that in this table we have adjusted the values of $u(T_{\mathrm{DP/FP}}^{\mathrm{g}})$ at 0 °C to account for the uncertainty of whether dew or frost has condensed on the mirror of the hygrometer. For this, we have added a standard uncertainty of 0.005 °C in quadrature to these values.

## 9. Drift of Transfer Standard

The first generator/hygrometer comparison measurements were made at CENAM in July 2008. Afterwards, the transfer standard was sent to NIST so that it could perform its comparison measurements. The transfer standard was returned to CENAM in December 2008, and the next comparison measurements were made in May 2009.

Drift of the transfer standard during the course of the CENAM-NIST comparison may be estimated by examining the difference between the CENAM generator/hygrometer comparisons performed in July 2008 and May 2009. This difference is shown in Fig. 2. The difference between the average of the July 2008 comparisons and the May 2009 comparisons is approximately 0.01 °C. It is quite possible that this difference is due to random uncertainty from reproducibility rather than to drift. Nevertheless, in our uncertainty budget we have added a type B uncertainty component due to the possibility of transfer standard drift. Based on the results of Fig. 2, we have estimated it to contribute a standard uncertainty of 0.005 °C to the CENAM-NIST comparison.

**Table 3.** Uncertainty elements and their standard uncertainty values for the NIST generator, for the four nominal values of $T_{DP/FP}$.

| **Uncertainty for NIST generator:** | $T_{DP}$ = 20 °C | $T_{DP}$ = 0 °C | $T_{FP}$= -10 °C | $T_{FP}$= -20 °C |
|---|---|---|---|---|
| **Saturator Temperature Measurement** | | | | |
| Calibration uncertainty | 0.001 °C | 0.001 °C | 0.001 °C | 0.001 °C |
| Long-term stability | 0.001 °C | 0.001 °C | 0.001 °C | 0.001 °C |
| **Saturator Pressure Measurement** | | | | |
| Calibration uncertainty | 18 Pa | 47 Pa | 39 Pa | 42 Pa |
| Long-term stability | 7 Pa | 7 Pa | 7 Pa | 7 Pa |
| **Hygrometer Pressure Measurement** | | | | |
| Calibration uncertainty | 18 Pa | 18 Pa | 18 Pa | 18 Pa |
| Long-term stability | 7 Pa | 7 Pa | 7 Pa | 7 Pa |
| **Flow measurement (divided flow method):** | | | | |
| Calibration uncertainty | ---- | ---- | ---- | 0.05 % |
| Long-term stability | ---- | ---- | ---- | 0.02 % |
| **Calculation:** | | | | |
| Saturation vapor pressure formula(e) | 0.15 Pa | 0.10 Pa | 0.06 Pa | 0.04 Pa |
| Water vapor enhancement formula(e) | 0.0002 | 0.0006 | 0.0005 | 0.0006 |

**Table 4.** Contribution of the uncertainty elements in Table 3 to $u\left(T^{g}_{DP/FP}\right)$ for NIST, in °C, for the four nominal values of $T_{DP/FP}$. The combined standard uncertainty is shown in the last row.

| **Uncertainty for NIST generator:** | $T_{DP}$ = 20 °C | $T_{DP}$ = 0 °C | $T_{FP}$= -10 °C | $T_{FP}$= -20 °C |
|---|---|---|---|---|
| **Saturator Temperature Measurement** | | | | |
| Calibration uncertainty | 0.001 | 0.001 | 0.001 | 0.001 |
| Long-term stability | 0.001 | 0.001 | 0.001 | 0.001 |
| **Saturator Pressure Measurement** | | | | |
| Calibration uncertainty | 0.003 | 0.002 | 0.002 | 0.001 |
| Long-term stability | 0.001 | 0.000 | 0.000 | 0.000 |
| **Hygrometer Pressure Measurement** | | | | |
| Calibration uncertainty | 0.003 | 0.002 | 0.002 | 0.002 |
| Long-term stability | 0.001 | 0.001 | 0.001 | 0.001 |
| **Flow measurement (divided flow method):** | | | | |
| Calibration uncertainty | ---- | ---- | ---- | 0.003 |
| Long-term stability | ---- | ---- | ---- | 0.001 |
| **Calculation:** | | | | |
| Saturation vapor pressure formula(e) | 0.002 | 0.001 | 0.002 | 0.003 |
| Water vapor enhancement formula(e) | 0.004 | 0.009 | 0.007 | 0.006 |
| **Combined standard uncertainty:** | **0.006** | **0.010** | **0.008** | **0.008** |

**Table 5.** Uncertainty elements and their standard uncertainty values for the CENAM generator, for the four nominal values of $T_{DP/FP}$.

| **Uncertainty for CENAM generator:** | $T_{DP}$ = **20 °C** | $T_{DP}$ = **0 °C** | $T_{FP}$= **-10 °C** | $T_{FP}$= **-20 °C** |
|---|---|---|---|---|
| **Saturator Temperature Measurement** | | | | |
| Calibration uncertainty | 0.02 °C | 0.02 °C | 0.02 °C | 0.02 °C |
| Long-term stability | 0.001 °C | 0.001 °C | 0.006 °C | 0.01 °C |
| **Saturator Pressure Measurement** | | | | |
| Calibration uncertainty | 49 Pa | 204 Pa | 223 Pa | 575 Pa |
| Long-term stability | 15 Pa | 53 Pa | 47 Pa | 115 Pa |
| **Hygrometer Pressure Measurement** | | | | |
| Calibration uncertainty | 49 Pa | 49 Pa | 49 Pa | 49 Pa |
| Long-term stability | 15 Pa | 15 Pa | 15 Pa | 15 Pa |
| **Flow measurement (divided flow method):** | | | | |
| Calibration uncertainty | ---- | ---- | ---- | ---- |
| Long-term stability | ---- | ---- | ---- | ---- |
| **Calculation:** | | | | |
| Saturation vapor pressure formula(e) | 0.15 Pa | 0.12 Pa | 0.06 Pa | 0.06 Pa |
| Water vapor enhancement formula(e) | 0.0002 | 0.0006 | 0.0005 | 0.0011 |

**Table 6.** Contribution of the uncertainty elements in Table 3 to $u\left(T^{g}_{DP/FP}\right)$ for CENAM, in °C, for the four nominal values of $T_{DP/FP}$. The combined standard uncertainty is shown in the last row.

| **Uncertainty for CENAM generator:** | $T_{DP}$ = **20 °C** | $T_{DP}$ = **0 °C** | $T_{FP}$= **-10 °C** | $T_{FP}$= **-20 °C** |
|---|---|---|---|---|
| **Saturator Temperature Measurement** | | | | |
| Calibration uncertainty | 0.020 | 0.017 | 0.015 | 0.013 |
| Long-term stability | 0.001 | 0.001 | 0.005 | 0.004 |
| **Saturator Pressure Measurement** | | | | |
| Calibration uncertainty | 0.010 | 0.010 | 0.007 | 0.005 |
| Long-term stability | 0.003 | 0.002 | 0.001 | 0.001 |
| **Hygrometer Pressure Measurement** | | | | |
| Calibration uncertainty | 0.010 | 0.008 | 0.007 | 0.006 |
| Long-term stability | 0.003 | 0.003 | 0.002 | 0.002 |
| **Flow measurement (divided flow method):** | | | | |
| Calibration uncertainty | ---- | ---- | ---- | ---- |
| Long-term stability | ---- | ---- | ---- | ---- |
| **Calculation:** | | | | |
| Saturation vapor pressure formula(e) | 0.001 | 0.001 | 0.003 | 0.003 |
| Water vapor enhancement formula(e) | 0.003 | 0.007 | 0.006 | 0.012 |
| **Combined standard uncertainty:** | **0.025** | **0.023** | **0.020** | **0.020** |

**Table 7.** Standard uncertainty of the determinations of $\Delta T_{DP/FP}$ for NIST and CENAM. The column headings are described in the text.

| Nominal $T_{DP/FP}$ (°C) | Participating Institute | $u_A(\Delta T_{DP/FP})$ (°C) | $u(T^{g}_{DP/FP})$ (°C) | $u(T^{m}_{DP/FP})$ (°C) | $u_c(\Delta T_{DP/FP})$ (°C) |
|---|---|---|---|---|---|
| 20 | CENAM | 0.009 | 0.025 | 0.002 | 0.026 |
| 20 | NIST | 0.010 | 0.006 | 0.002 | 0.012 |
| 0 | CENAM | 0.009 | 0.023 | 0.002 | 0.025 |
| 0 | NIST | 0.010 | 0.010 | 0.002 | 0.014 |
| −10 | CENAM | 0.009 | 0.020 | 0.002 | 0.022 |
| −10 | NIST | 0.010 | 0.008 | 0.002 | 0.013 |
| −20 | CENAM | 0.009 | 0.020 | 0.002 | 0.022 |
| −20 | NIST | 0.010 | 0.008 | 0.002 | 0.013 |

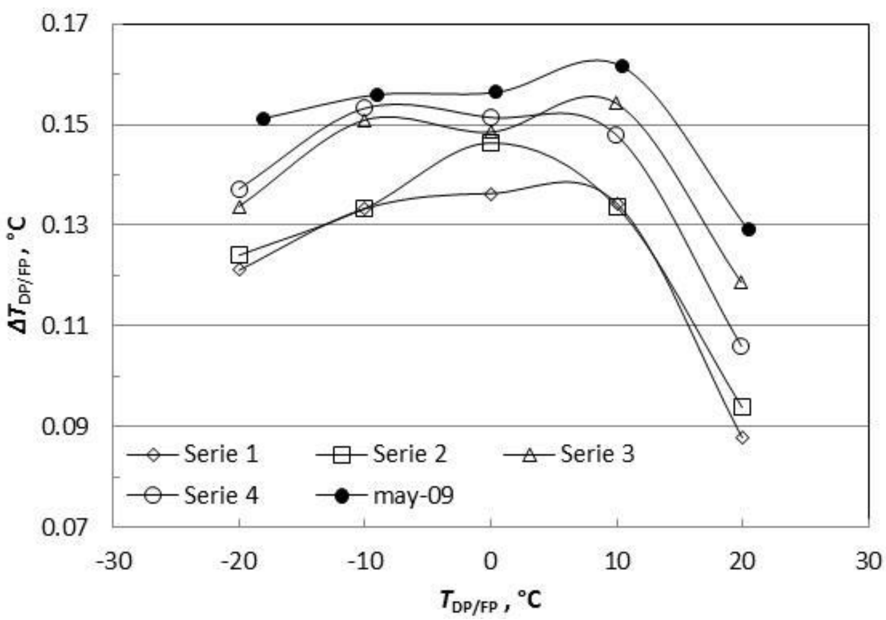


**Figure 2.** Difference between the CENAM generator/hygrometer comparisons performed in July 2008 (Series 1,2,3, and 4) and May 2009.

## 10. Degree of Equivalence

The values $\Delta T_{DP/FP}$ given in Table 1 may be used to determine the degree of equivalence $D_{CENAM}(T_{DP/FP})$ between the values of $T_{DP/FP}$ realized by CENAM and reference values of $T_{DP/FP}$, $[T_{DP/FP}]_{Ref}$ :

$$D_{CENAM}(T_{DP/FP}) = [T_{DP/FP}]_{CENAM} - [T_{DP/FP}]_{Ref} \quad 5)$$

Once Draft B for the report of CCT K6 Key Comparison is approved, $[T_{DP/FP}]_{Ref}$ will be $[T_{DP/FP}]_{KCRV}$, the CCT K6 Key Comparison Reference Value (KCRV) for $T_{DP/FP}$. In the meantime we shall define

$$[T_{DP/FP}]_{Ref} \equiv [T_{DP/FP}]_{NIST} \qquad 6)$$

since NIST is a participant in CCT K6 and will later be able to provide linkage to $[T_{DP/FP}]_{KCRV}$. Therefore, for the purposes of this report,

$$D_{CENAM}(T_{DP/FP}) = [T_{DP/FP}]_{CENAM} - [T_{DP/FP}]_{Ref} = [\Delta T_{DP/FP}]_{CENAM} - [\Delta T_{DP/FP}]_{NIST} \qquad 7)$$

The uncertainty of the degree of equivalence $u(D_{CENAM}(T_{DP/FP})$ is the combination of $u_c(\Delta T_{DP/FP})$ for CENAM, $u_c(\Delta T_{DP/FP})$ for NIST, and the uncertainty $u_{drift}$ due to possible drift of the transfer standard:

$$u[D_{CENAM}(T_{DP/FP})] = \left\{ [u_c^2(\Delta T_{DP/FP})]_{CENAM} + [u_c^2(\Delta T_{DP/FP})]_{NIST} + u_{drift}^2 \right\}^{1/2}. \qquad 8)$$

The expanded ($k$=2, 95% confidence level) uncertainty for the degree of equivalence is

$$U(D_{CENAM}) = 2u(D_{CENAM}), \qquad 9)$$

The results are presented in Table 8 and plotted in Fig. 2. As can be seen in Table 8 and Fig. 3, all values of $D_{CENAM}$ are within their expanded uncertainties.

**Table 8.** Degree of equivalence between CENAM and NIST and its expanded uncertainty ($k$ = 2) in a comparison of four humidity levels

| Nominal $T_{DP/FP}$ (°C) | $D_{CENAM}$ (°C) | $U(D_{CENAM})$ (°C) |
|---|---|---|
| 20 | −0.020 | 0.059 |
| 0 | 0.020 | 0.058 |
| −10 | 0.023 | 0.052 |
| −20 | 0.025 | 0.052 |

## 11. Summary

NIST and CENAM have completed a bilateral comparison of their humidity standards. The dew/frost-point temperatures produced by the generators of the two NMIs were compared using a chilled-mirror hygrometer as a transfer standard. The nominal dew/frost-point temperatures used for the comparison were 20 °C, 0 °C, –10 °C and –20 °C. The comparisons have determined the degree of equivalence between $[T_{DP/FP}]_{CENAM}$ and a reference value for $T_{DP/FP}$, presently defined as $[T_{DP/FP}]_{NIST}$. For all dew/frost-point temperatures over the range studied, the degree of equivalence was within 0.025 °C and well within its expanded uncertainty.

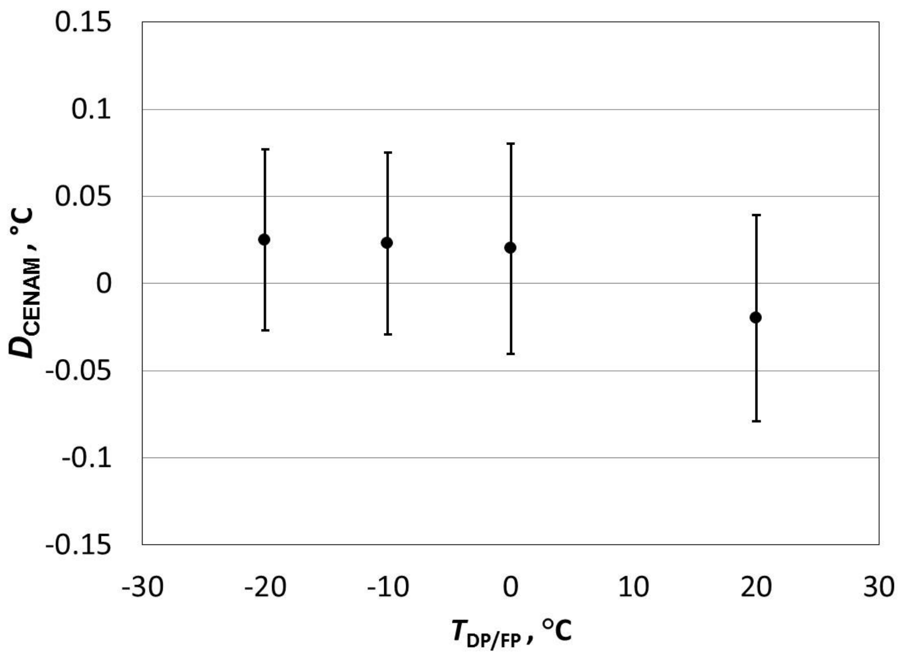


**Figure 3.** The degree of equivalence between the four dew/frost-point temperatures realized by the standard generator of CENAM, $[T_{DP/FP}]_{CENAM}$ and the corresponding reference values $[T_{DP/FP}]_{Ref}$ (represented by $[T_{DP/FP}]_{NIST}$ ), as defined in Eq. 7.

## 12. References

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[6] C.W. Meyer et al, "Calibration of Hygrometers with the Hybrid Humidity Generator", NIST Special Publication 250-83 (2008).

[7] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

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