SIM.T-K6.7 – INMETRO / INTI

BILATERAL KEY COMPARISON OF INMETRO AND INTI HUMIDITY STANDARDS IN THE DEW/FROST-POINT TEMPERATURE RANGE FROM -30 °C TO +60 °C

J. D. Brionizio [1], J. G. Skabar [2]

[1] Instituto Nacional de Metrologia, Qualidade e Tecnologia (INMETRO)
Av. Nossa Senhora das Graças, 50 – Xerém – Duque de Caxias – RJ – Brasil – CEP: 25250-020
[2] Instituto Nacional de Tecnología Industrial (INTI)
Av. General Paz, 5445 – San Martin – Bs. As. – Argentina – B1650WAB

Abstract

The aim of this paper is to describe a bilateral comparison carried out by the hygrometry laboratories of the National Metrological Institutes of Brazil and Argentina, INMETRO and INTI, respectively. The comparison, registered as a bilateral key comparison of the Inter American Metrology System (SIM) as SIM.T-K6.7 – INMETRO/INTI, was performed in the range from -30 ºC to 60 ºC of dew/frost-point temperatures. This paper presents the facilities of the laboratories, the measurement procedures, the uncertainty analysis, the compatibility of the measurement results (by means of the normalised error and by the degree of equivalence) and the degree of equivalence for the dew-point temperatures 1 ºC and 20 ºC between INTI and the CCT-K6 key comparison reference value by means of a previous comparison between INMETRO and the National Institute of Standards and Technology (NIST).

Keywords: Comparison, Humidity, Normalised Error, Degree of Equivalence.

1. INTRODUCTION

At a meeting held in Paris on October 1999, the directors of the National Metrology Institutes (NMIs) of thirty-eight Member States of the Bureau International des Poids et Mesures (BIPM) and representatives of two international organizations signed a Mutual Recognition Arrangement (MRA) for national measurement standards and for calibration and measurement certificates issued by NMIs. A number of other institutes have signed since then. The MRA gives users reliable information on the comparability of national metrology services and provides the technical basis for arrangements negotiated for international trade, commerce and regulatory affairs [1]. Hence, comparison of reference standards between NMIs became very important.

At its 20th meeting on April 2000, the Consultative Committee for Thermometry (CCT) called for a key comparison on humidity standards to be conducted by all major NMIs. It was asked CCT Working Group for Humidity (WG-Hu) to draw up a technical protocol for an International Committee on Weights and Measures (CIPM) key comparison named "CCT-K6". For each nominal comparison point, a key comparison reference value (KCRV) was calculated. In this key comparison, the National Physical Laboratory (NPL, UK) and the National Metrology Institute of Japan (NMIJ) were chosen to be the pilot laboratory and assistant pilot laboratory, respectively, and the National Institute of Standards and Technology (NIST, USA) was one of the participants [2].

The National Institute of Metrology, Quality and Technology (INMETRO, Brazil) did not participate in CCT-K6. Therefore, to relate the humidity standards of INMETRO to those of the CCT-K6 participants, a Regional Metrology Organization (RMO) key comparison of dew/frost-point temperature was carried out by INMETRO and NIST from October 2009 to March 2010. The bilateral comparison, designated as SIM.T-K6.3, was piloted by NIST and followed the same technical procedures as for the CCT-K6, except that only one transfer standard was used and the dew/frost-point temperature range was changed from -50 °C to 20 °C to -30 °C to 20 °C [3].

Besides the bilateral comparison with NIST, INMETRO had one with the National Institute of Metrological Research (INRIM, Italy) in 2006 in the dew/frost-point temperature range from -40 °C to 40 °C [4] and another one with the National Institute of Industrial Technology (INTI, Argentina) from September to November 2010 in the dew/frost-point temperature range from -20 °C to 60 °C [5]. However, in 2017, INMETRO and INTI decided to repeat the comparison, extending the range to -30 °C of frost-point temperature, and to link some of INTI's results to CCT-K6 KCRV by means of the comparison between INMETRO and NIST.

The aim of this work is to describe the bilateral comparison, designated as SIM.T-K6.7, carried out by the hygrometry laboratories of INMETRO and INTI from March to April 2017 in six comparison points in the dew/frost-point temperature range from -30 ºC to 60 ºC. The comparison was piloted by INMETRO, and as transfer standard a chilled-mirror hygrometer (CMH) was used. The technical protocol of this bilateral key comparison is presented in Appendix 1.

The measurements started at INMETRO by comparison of the transfer standard readings with those indicated by a standard CMH. The air samples were generated by a home-made dew-point generator and a working humidity generator equipped with a climatic chamber where the sensor of the transfer standard was positioned. The transfer standard was then hand-carried to INTI, where it was also calibrated inside the climatic chamber of the primary humidity generator. After returning to INMETRO's laboratory, measurements were repeated in order to check the CMH stability and to obtain a larger data sample since the beginning of the calibration.

For both laboratories, this paper presents their facilities, the measurement procedures, the uncertainty analysis, the compatibility of their measurement results (by means of the normalised error and by the degree of equivalence) and the degree of equivalence (DoE) for the for the dew-point temperatures 1 ºC and 20 ºC between INTI and the CCT-K6 key comparison reference value (KCRV) by means of a previous bilateral comparison between INMETRO and the National Institute of Standards and Technology (NIST, USA).

2. PARTICIPANTS

The participants of the bilateral comparison and their contact information are described below:

- *Instituto Nacional de Metrologia, Qualidade e Tecnologia* (INMETRO)
  Address: Av. Nossa Senhora das Graças, 50 – Xerém – Duque de Caxias – RJ – Brasil – CEP: 25250-020
  Contact: Júlio Dutra Brionizio
  Phone: +55 21 2679 9066
  E-mail: jdbrionizio@inmetro.gov.br

- *Instituto Nacional de Tecnología Industrial* (INTI)
  Address: Av. General Paz, 5445 – San Martín – Buenos Aires – Argentina – B1650WAB
  Contact: Javier García Skabar
  Phone: +54 11 4724 6200/300/400
  E-mail: jskabar@inti.gob.ar

3. FACILITIES OF THE LABORATORIES

The humidity laboratory of INMETRO has five standard CMHs of which three have been extensively calibrated in designated institutes and NMIs, such as NPL, CETIAT (Centre Technique des Industries Aérauliques et Thermiques), E+E Elektronik and MBW Calibration, in the dew/frost-point temperature range from -75 ºC to 90 ºC.

For the generation of air samples, the humidity laboratory of INMETRO has four commercial humidity generators: (*i*) a Michell divided-flow generator, model DG-4, which works in the dew/frost-point temperature range from -75 ºC to 20 ºC. In this equipment, dried gas is divided into two streams of which one passes through a water saturator and is mixed with the other stream to produce a certain gas sample. Dew/frost-point temperatures can be selected via a front panel keypad, through factory pre-set values, or by manually mixing the wet and dry gases by means of metering valves mounted on its front panel; (*ii*) a Thunder Scientific two-pressure humidity generator, model 2500ST, which works in the relative humidity range from 10 %rh to 95 %rh and temperature range from -10 °C to 70 °C. This equipment will be soon characterized as one more reference standard of the laboratory, in the dew/frost-point temperature range from -35 °C to 68 °C, by means of temperature and pressure measurements in the saturator and in the chamber of the equipment; (*iii*) and two Weiss Technik climatic chambers, models SB2-300 and WK3-340/40, that have a relative humidity operating range from 10 %rh to 98 %rh in the range from 10 ºC to 95 ºC. The laboratory also has a home-made dew/frost-point generator which has been studied and developed to work as its reference standard.

The humidity standard of INTI is a two pressure primary humidity generator. It is a commercial equipment, Thunder Scientific 2500 LT, serial number 0607577 humidity range is 10 %rh to 95 %rh and temperature range is -10 ºC to 70 ºC. This is approximately -35 ºC to 65 ºC in dew-point temperature. The two pressures principle for generating humidity air samples is a process that involves, first the saturation of an air sample at one pressure and then the decompression of this sample to produce an air sample with less humidity [6, 7].

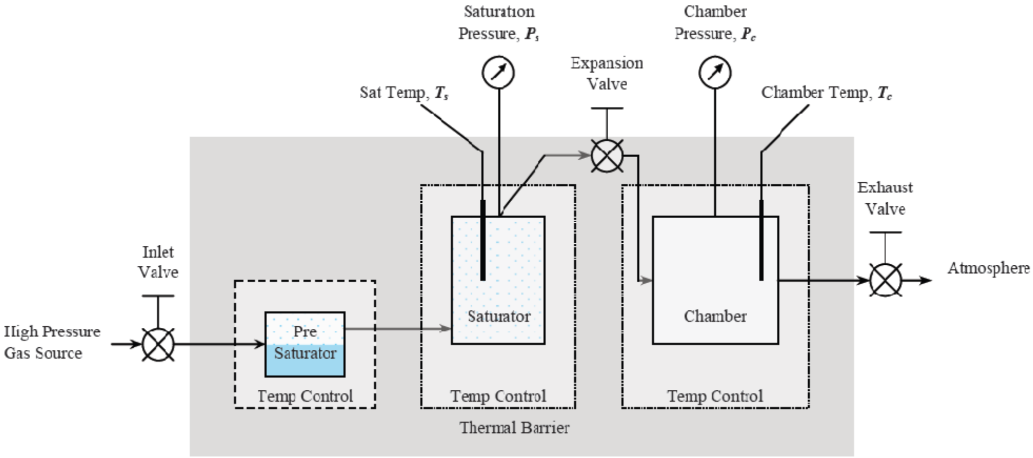

Figure 1 – Principle of INTI's Humidity Standard

The humidity value of the generated air sample is determined by the measurements of saturator pressure, sample chamber pressure, saturator temperature and sample chamber temperature using Equation (1) or (2) [6, 7, 8].

$$rh(\%) = \left(\frac{f(P_s.t_s) \cdot e_w(t_s) \cdot P_c}{f(P_c.t_c) \cdot e_w(t_c) \cdot P_s} \right).100 \qquad (1)$$

$$f(P_c, t_{dew}) \cdot e_w(t_{dew}) = \frac{f(P_s, T_s) \cdot e_w(T_s)}{P_s} \cdot P_c \qquad (2)$$

Where,
$rh(\%)$ – Relative humidity;
t_{dew} – Dew point temperature;
$e_w(t)$ – Vapor pressure;
$f(P, t)$ – Enhancement factor;
P_x – Pressure ($x = s$: saturator, c: chamber);
t_x – Temperature ($x = s$: saturator, c: chamber).

The Thunder Scientific 2500 LT is commanded via a front panel or via RS232 port by software 2500 ControlLog for control and data acquisition. In this generator it is only possible to control the saturator pressure and the saturator temperature. The sample chamber is at atmospheric pressure and at the same temperature as the saturator. The value of the relative humidity or dew-point temperature is showed in the front panel or via software. The pressure and temperature measurements are traceable to SI. Both sensors are calibrated at INTI with traceability at the temperature and pressure national standards.

The INTI humidity lab also has two instruments as secondary standards and a climatic chamber: a Vaisala HM70 with a probe HMP77B capacitive hygrometer, an Almemo FNA846 aspirated psychrometer and a Weiss SB1/300/40 climatic chamber. These are used in the calibration services and tests.

4. TRANSFER STANDARD

As transfer standard, a CMH belonging to INMETRO was used. CMHs are considered as one of the most accurate and reliable methods of measuring dew/frost-point temperatures. This kind of instrument has been widely used as reference standards in calibration laboratories and as transfer standards in comparisons of humidity national standards.

It was used a CMH manufactured by Michell Instruments, model Optidew Vision, serial numbers 118931 (display) and 118849 (sensor), which can operate in the range from -60 ºC to 90 ºC of dew/frost-point temperature. The hygrometer control unit is separated from the dew-point sensor. The latter can thus be mounted in several ways to suit the purpose. A software program allows its control and the data acquisition. In order to prevent any loss of measurement accuracy due to mirror contamination, the hygrometer uses an automatic compensation system based on a self-learning prediction algorithm which adjusts the operating conditions in order to achieve optimal performance at all times.

5. MEASUREMENT PROCEDURES

A total of six humidity points were used for the comparison. Four dew-point temperatures at nominal values of 1 °C, 20 ºC, 40 °C and 60 °C and two frost-point temperatures at nominal values of -30 °C and -20 °C. The nominal value of 1 °C represents the range near 0 °C while being far enough above it to avoid ambiguities that can arise around the freezing point of water.

For the dew/frost-point temperature values of -30 °C, -20 °C and 1 ºC, the gas sample generated by a participant's generator could be introduced into the inlet of the sensor housing of the transfer standard or the sensor could be placed directly in the chamber of the generating system without its housing. For the dew-point temperatures values of 20 °C, 40 ºC and 60 °C, the sensor of the transfer standard should be placed directly in the chamber of the generating system without its housing, and with chamber temperature from 10 ºC to 30 ºC above the dew-point temperature.

At both institutes, for all the six comparison points, four measurement runs were carried out in order to quantify the effect of any irreproducibility of the transfer standard. For each run, the condensate was cleared and re-formed and at least ten measurements were taken over a period of 10 to 20 minutes.

5.1. Measurements at INMETRO

The air samples were generated by the home-made dew/frost-point generator for the frost-point temperature of -30 °C and by one of the climatic chambers (WK3-340/40) for the dew/frost-point temperatures of -20 °C, 1 ºC, 20 °C, 40 °C and 60 °C. For all the points, the reference dew/frost-point temperature values were indicated by a standard CMH (MBW 373LHX identified as PR 004) which is traceable to MBW Calibration (designated institute for humidity in Switzerland). Another standard CMH (MBW 373 identified as PR 002), which is traceable to CETIAT, was also used. The measurements of PR 002 and PR 004 were compared in many opportunities, and the compatibility between them (determined by means of the normalized error) was confirmed in all the cases.

When using the climatic chamber, the sensor of the transfer standard was positioned approximately in the centre of the equipment. Air samples from the chamber were brought to the measurement head of the standard hygrometer PR 004 by means of its internal diaphragm pump, or by an external suction pump, and a heated hose. The hose inlet was placed near the sensor of the transfer standard. The gas flow rate in the standard hygrometer was set from 0.7 l/min to 1 l/min. For the dew/frost-point temperatures of -20 ºC and 1 ºC, the hose, the internal tubing and the measurement head of the standard hygrometer PR 004 were kept at room temperature (21 ºC). For the dew-point temperatures of 20 ºC, 40 ºC and 60 ºC, in order to prevent any condensation, the devices were heated from 10 ºC to 25 ºC above the actual dew-point temperature.

For the frost-point temperature of -30 ºC, the sensor of the transfer standard was housed into a stainless steel sampling device which was thermally insulated. The device was then connected to the home-made dew/frost-point generator by means of stainless steel tubes. Pre-saturated gas was supplied to the home-made dew/frost-point generator by means of a commercial dew-point generator (Michell Intruments, model DG-4). The gas flow rate was set to approximately 1 l/min. The system operated in the open circuit mode. The sampling device with the transfer standard sensor was cooled to approximately 1 ºC by means of a water/ethanol mixture supplied by a circulating thermostatic bath. Before performing the measurements, the acquisition system was purged for about 10 hours.

The calibration systems were considered stable and ready for beginning the data acquisition when, after a long period of time, the dew/frost-point measurements of the standard and transfer CMHs varied constantly within a fixed measuring range, which means that the hygrometers were in the steady state condition. The standard and transfer CMHs varied roughly within the range of 0.05 ºC and 0.30 ºC (for the frost-point temperature of -30 ºC) and 0.20 ºC and 0.30 ºC (for the frost-point temperature of -20 ºC), respectively. For the dew-point temperatures, the standard hygrometer varied within the range of 0.10 ºC and the transfer hygrometer varied within the range of 0.10 ºC (for the values of 0 ºC , 20 ºC and 60 ºC) and 0.30 ºC (for the value of 40 ºC). Nevertheless, in many calibration points (measurement runs), the readings of the hygrometers varied within a smaller range than those described previously. These measurement variations of both hygrometers were simultaneously monitored by means of graphics plotted by their software. In order to assure that the standard and transfer CMHs were in the steady state condition, it was checked in the graphics of the instruments that their readings had been varying constantly within the measuring range for at least 15 minutes before the 20 minutes of the measurement run.

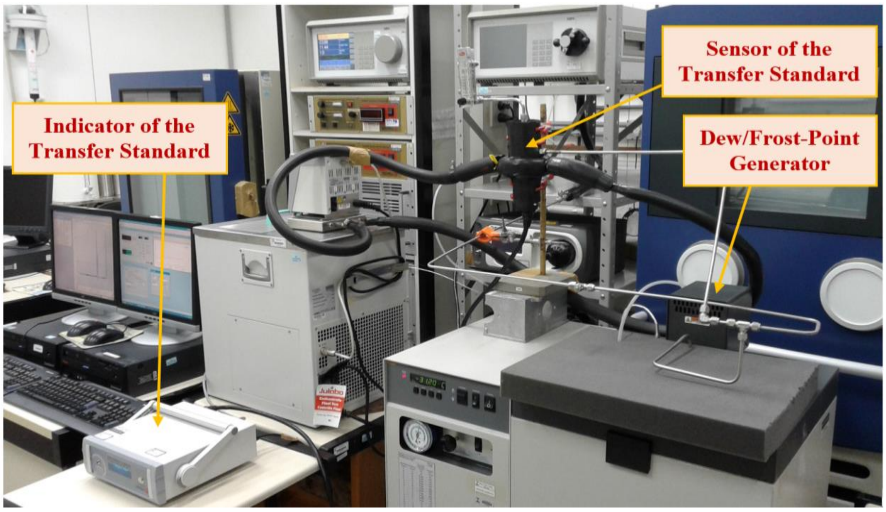

Figure 2 – Transfer Standard Sensor Connected at the Dew/Frost-Point Generator of INMETRO

5.2. Measurements at INTI

The measurements were performed in the chamber of the generator. All points were measured with a sensor transfer placed in the centre of the chamber and a chamber temperature sensor placed beside it. Several positions of the sensor transfer were tested in order to avoid the effects of the high flux of air over the mirror. The air flux of generator was tested at 10 l/min, 15 l/min and 20 l/min, and no differences were found. The air flux wasn't measured at the instrument; these were different operating conditions of the generator.

In all cases the saturator temperature, that is approximately the same as the chamber temperature, was set at 8 ºC or more over the dew-point temperature of the generated sample to avoid any kind of condensation.

The standard generator of INTI was adjusted at each comparison point and its measurements, together with those of the transfer CMH, were continuously acquired over a long period of time. For the frost-point temperatures of -30 ºC and -20 ºC, the generator was around 16 hours in the steady state condition in each point. The transfer CMH was programed to perform a new frost formation at each 3 hours, in order to acquire several repetitions of the same set point. Previous experiences using this instrument show that this period of time is enough to reach the maximum stability. The data were posteriori analysed. In order to compare measurements of the transfer CMH and the standard generator, periods of 20 minutes were generally selected before a new frost formation, where the dispersion of the transfer CMH measurements was minimum. For the dew-point temperatures, the generator was around 7 hours in the steady state condition in each point. For the repetitions, new dew formations on the mirror of the transfer CMH were manually induced after 1 hour of stable measurements, which means time interval in which the indications of the instrument did not change more than 0.2 ºC. The data were posteriori analysed using the same criteria of the frost-point temperatures. The measurement variations of both instruments were simultaneously monitored by means of graphics plotted by their software, in order to verify the steady state condition of them. The standard generator was considered in the steady state condition when its dew/frost-point measurements varied within 0.05 ºC or less.

Only the raw measurements of saturator pressure, chamber pressure and saturator temperature were used. The reference values of dew-point temperature were calculated with a home-made software. This software was validated satisfactorily with Control Log and other commercial software. The uncertainty of the reference dew-point temperature was calculated by classical uncertainty propagation and checked by simulation of distributions [7, 8, 9, 10].

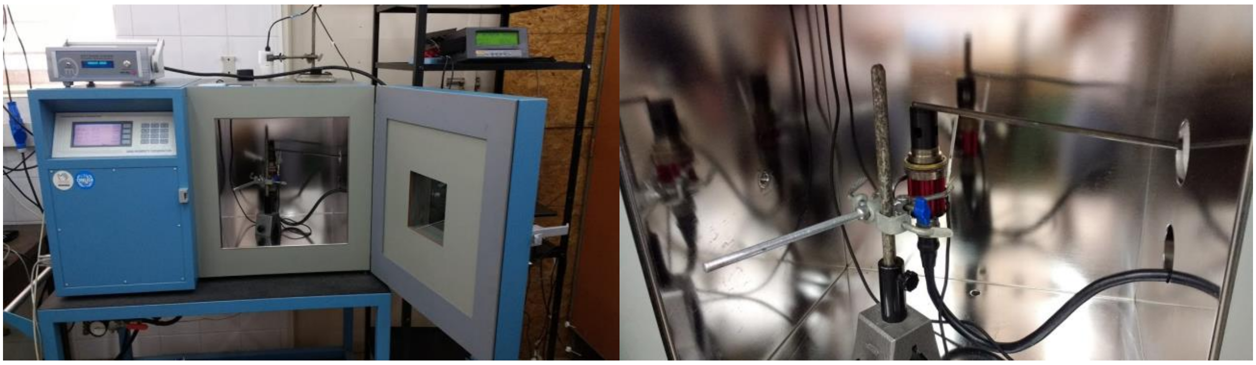

Figure 3 – Transfer Standard Sensor Inside of the Chamber of INTI Primary Generator

6. MEASUREMENT DATA AND UNCERTAINTIES

For each nominal comparison point, four measurement runs were performed resulting in four mean values for the reference standard readings (r_S) and four mean values for the transfer standard readings (t_S). Table 1 presents these values for INMETRO and INTI.

Table 1 – Mean Values of the Measurements for the Four Runs (in °C)

		INMETRO				INTI			
-30	r_S	-30.25	-30.24	-30.24	-30.24	-29.83	-29.86	-29.85	-29.85
	t_S	-29.59	-29.57	-29.52	-29.61	-29.25	-29.31	-29.31	-29.39
-20	r_S	-20.20	-20.17	-20.12	-20.23	-19.94	-19.94	-19.93	-19.92
	t_S	-19.80	-19.75	-19.75	-19.82	-19.51	-19.37	-19.37	-19.51
1	r_S	0.92	0.92	0.98	1.02	1.12	1.11	1.11	1.11
	t_S	1.19	1.19	1.27	1.30	1.50	1.40	1.40	1.40
20	r_S	20.07	20.10	20.11	20.13	20.16	20.17	20.16	20.15
	t_S	20.30	20.31	20.32	20.34	20.40	20.30	20.30	20.30
40	r_S	40.11	40.13	40.14	40.16	40.16	40.17	40.16	40.18
	t_S	40.39	40.37	40.42	40.43	40.40	40.40	40.40	40.40
60	r_S	60.17	60.17	60.22	60.21	59.97	59.95	59.92	59.91
	t_S	60.50	60.50	60.54	60.52	60.20	60.20	60.16	60.16

For each nominal comparison point, it was calculated the average of the four mean values of the reference standard readings (R_S), the average of the four mean values of the transfer standard readings (T_S) and the correction (C), which is the difference between R_s and T_s. These values are presented in Table 2 for both institutes.

Table 2 – Average of the Mean Values and Corrections (in °C)

	INMETRO			INTI		
	R_S	T_S	C	R_S	T_S	C
-30	-30.24	-29.57	-0.67	-29.85	-29.32	-0.53
-20	-20.18	-19.78	-0.40	-19.93	-19.44	-0.49
1	0.96	1.24	-0.28	1.11	1.43	-0.32
20	20.10	20.32	-0.22	20.16	20.33	-0.17
40	40.14	40.40	-0.26	40.17	40.40	-0.23
60	60.19	60.52	-0.33	59.94	60.18	-0.24

Based on the Guide to the Expression of Uncertainty in Measurement [11], the laboratories calculated the measurement uncertainty at each comparison point. The combined standard uncertainty (u_c) was calculated using Equation (3) below:

$$u_c = \sqrt{\sum_{i=1}^{4} u_i^2} \qquad (3)$$

Where,
u_1 – Standard uncertainty associated with the reference standard (based on a normal distribution);
u_2 – Standard uncertainty due to the resolution of the transfer CMH (based on a rectangular distribution);
u_3 – Standard uncertainty associated with the repeatability of the transfer CMH (based on a normal distribution);
u_4 – Standard uncertainty associated with the reproducibility of the transfer CMH (based on a rectangular distribution).

At INMETRO, the standard uncertainty of the reference standard (u_1), calculated using Equation (4), is composed by the following uncertainty sources: calibration of the standard CMH (u_{cal}), resolution (u_{res}), drift between successive calibrations (u_{drift}), repeatability of measurements (u_{rep}) and fitting of the correction curve (uf_{it}). The uncertainty values were divided by a divisor according to the assumed probability distributions.

$$u_1 = \sqrt{u_{cal}^2 + u_{res}^2 + u_{drift}^2 + u_{rep}^2 + u_{fit}^2} \qquad (4)$$

An uncertainty budget for INMETRO standard is presented in Table 3.

Table 3 – Uncertainty Budget for INMETRO standard (in °C)

	u_{cal}	u_{res}	u_{drift}	u_{rep}	u_{fit}	u_1
-30	0.035	0.003	0.016	0.001	0.010	**0.040**
-20	0.025	0.003	0.016	0.017	0.010	**0.036**
1	0.025	0.003	0.016	0.007	0.010	**0.032**
20	0.025	0.003	0.016	0.002	0.010	**0.032**
40	0.025	0.003	0.016	0.001	0.010	**0.031**
60	0.035	0.003	0.016	0.002	0.010	**0.040**

At INTI, the standard uncertainty of the reference standard is derived from the uncertainty of the primary generator. An uncertainty budget for INTI standard is presented in Appendix 1.

In both laboratories, the measurement repeatability and reproducibility were considered as uncertainty sources of the transfer standard. The repeatability reflected the ability of the instrument to replicate measurements during the data acquisition of a measurement run (short-term stability), while the reproducibility demonstrated the dispersion of the mean values of the four measurement runs. For each comparison point, the experimental standard deviation of the mean of each run was calculated, and the highest value was adopted as the standard uncertainty associated with the repeatability (u_3). Four correction values (differences between r_s and t_s) could also be calculated to each comparison point. The half of the difference between the highest and the lowest values was adopted as the standard uncertainty associated with the reproducibility (u_4).

Table 4 shows the standard uncertainty sources and the combined uncertainties for both institutes.

Table 4 – Standard Uncertainty Sources and Combined Uncertainties (in °C)

	INMETRO					**INTI**				
	u_1	u_2	u_3	u_4	u_c	u_1	u_2	u_3	u_4	u_c
-30	0.040	0.029	0.016	0.026	**0.058**	0.058	0.029	0.115	0.035	**0.137**
-20	0.036	0.029	0.025	0.014	**0.054**	0.047	0.029	0.088	0.046	**0.114**
1	0.032	0.029	0.011	0.006	**0.045**	0.039	0.029	0.000	0.026	**0.055**
20	0.032	0.029	0.003	0.006	**0.044**	0.031	0.029	0.000	0.032	**0.053**
40	0.031	0.029	0.004	0.012	**0.044**	0.038	0.029	0.000	0.006	**0.048**
60	0.040	0.029	0.003	0.006	**0.050**	0.052	0.029	0.050	0.006	**0.077**

The measurement expanded uncertainty (U) was calculated by multiplying the combined standard uncertainty (u_c) by a coverage factor (k) equals two, which corresponds to a confidence interval of approximately 95%. Table 5 presents the uncertainties at the comparison points for each participating laboratory.

Table 5 – Measurement Uncertainties (in °C)

T	**INMETRO**		**INTI**	
	u_c	U	u_c	U
-30	0.058	**0.12**	0.137	**0.27**
-20	0.054	**0.11**	0.114	**0.23**
1	0.045	**0.09**	0.055	**0.11**
20	0.044	**0.09**	0.053	**0.11**
40	0.044	**0.09**	0.048	**0.10**
60	0.050	**0.10**	0.077	**0.15**

Figure 4 presents the corrections at INMETRO and INTI. The vertical error bar associated with each measurement point represents the expanded uncertainty listed in Table 5.

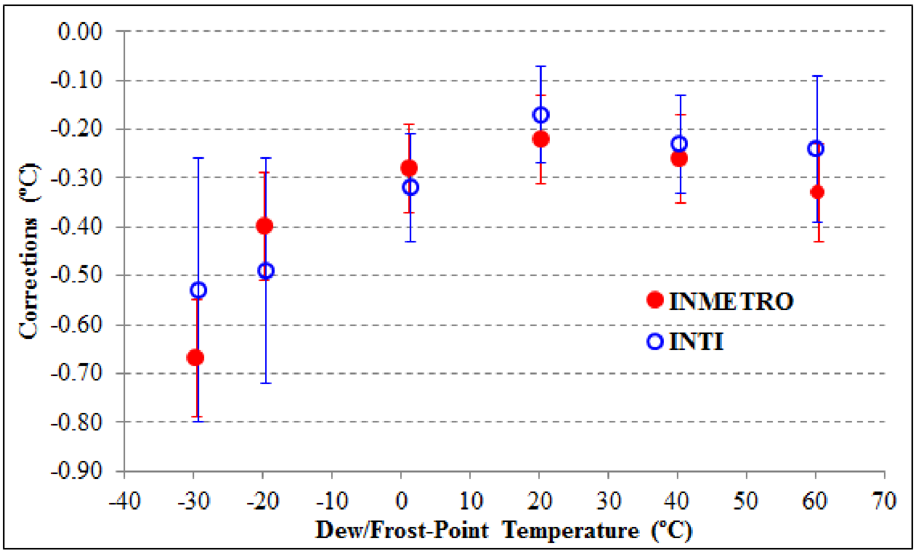

Figure 4 – Corrections and Associated Expanded Uncertainties

7. DRIFT OF THE TRANSFER STANDARD

The first comparison between laboratory humidity standard and transfer standard was made at INMETRO in March 2017. One month later, the transfer standard was hand-carried to INTI for performing the comparison measurements, and afterwards it was hand-carried to INMETRO. By the end of April, four of the six humidity points were repeated at INMETRO using the same procedures of the first comparison.

Drift of the transfer standard during the course of the INMETRO-INTI comparison could be estimated by examining the measurements at the dew/frost-point temperatures performed at INMETRO in March and April 2017. For both measurements, Table 6 presents the average of the four mean values of the reference standard readings (R_S), the average of the four mean values of the transfer standard readings (T_S), the corrections (C) and the drifts of the transfer CMH (d), which was estimated as the difference between the corrections obtained in March and April.

Table 6 – Measurements Performed at INMETRO for Drift Evaluation (in ºC)

	March 2017			April 2017			d
	R_S	T_S	C	R_S	T_S	C	
-20	-20.18	-19.78	-0.40	-20.09	-19.78	-0.31	-0.09
1	0.96	1.24	-0.28	1.12	1.25	-0.13	-0.15
40	40.14	40.40	-0.26	40.16	40.40	-0.24	-0.02
60	60.19	60.52	-0.33	60.18	60.54	-0.36	0.03

The absolute difference between the corrections obtained in March and April varied from 0.02 to 0.15 ºC. It is quite possible that these differences are due to reproducibility uncertainty rather than to drift. However, the laboratories decided to add a type B uncertainty component due to the possibility of transfer standard drift in the uncertainty budget of the bilateral comparison.

8. NORMALISED ERROR

The compatibility of the measurement results of both laboratories was analysed by means of the normalised error (E_n) as a function of the dew/frost-point temperature. A comparison measurement is satisfactory when its E_n is equal or lower than one [12]. E_n numbers were calculated according to the Equation (5) below.

$$E_n = \left| \frac{C_{INMETRO} - C_{INTI}}{\sqrt{(U_{INMETRO})^2 + (U_{INTI})^2 + \left(d/\sqrt{3}\right)^2}} \right| \qquad (5)$$

The dew/frost-point temperatures of -30 ºC and 20 ºC were not repeated when the transfer CMH returned to INMETRO. Thus, for the frost-point temperature of -30 ºC, it was adopted the drift found at the frost-point temperature of -20 ºC and, for the dew-point temperature of 20 ºC, the drift value was interpolated between those found at the dew-point temperatures of 0 ºC and 40 ºC.

Table 7 shows the differences between the corrections of INMETRO and INTI ($C_{INMETRO}$ and C_{INTI}, respectively), the expanded uncertainties of INMETRO and INTI ($U_{INMETRO}$ and U_{INTI}, respectively) with k = 2, the drifts of the transfer CMH (d) and the E_n numbers of all the comparison points.

Table 7 – E_n Numbers

	$C_{INMETRO}$ - C_{INTI}	$U_{INMETRO}$	U_{INTI}	d	E_n
-30	-0.14	0.12	0.27	-0.09	0.5
-20	0.09	0.11	0.23	-0.09	0.3
1	0.04	0.09	0.11	-0.15	0.2
20	-0.05	0.09	0.11	-0.09	0.3
40	-0.03	0.09	0.10	-0.02	0.2
60	-0.09	0.10	0.15	0.03	0.5

9. DEGREE OF EQUIVALENCE

The degree of equivalence (DoE) between participants i and j is determined by the pair of values ($D_{i/j}$, $U(D_{i/j})$) using:

$$D_{i/j} = R_i - R_j \qquad (6)$$

$$U(D_{i/j}) = 2u(D_{i/j}) \qquad (7)$$

Where, $D_{i/j}$ is the difference between the results (R) of both participants and $U(D_{i/j})$ is the uncertainty of $D_{i/j}$ with k = 2, which corresponds to a confidence interval of approximately 95% [13].

In the case of this bilateral comparison, R is the dew/frost-point correction of the transfer CMH and $u(D_{i/j})$ is given by:

$$u^2(D_{i/j}) = u^2(R_i) + u^2(R_j) + u^2(d) \qquad (8)$$

Where, $u(d)$ is the uncertainty in the comparison due to the drift of the transfer standard, as described in Section 6.

The DoE of NIST in the CCT-K6 multilateral key comparison were [2]:

Table 8 – Degrees of Equivalence between NIST and KCRV (in ºC)

	-50 ºC	**-30 ºC**	**-10 ºC**	**1 ºC**	**20 ºC**
$D_{NIST/KCRV}$	-0.128	-0.072	-0.039	-0.011	-0.006
$U_{NIST/KCRV}$	0.030	0.038	0.043	0.060	0.050

For the bilateral comparison carried out between INMETRO and NIST (SIM.T-K6.3), Table 9 presents the DoE for all the comparison points calculated according to Equations (6), (7) and (8) [3].

Table 9 – Degrees of Equivalence between INMETRO and NIST (in ºC)

	-30 ºC	**-10 ºC**	**0 ºC**	**20 ºC**
$D_{INMETRO/NIST}$	-0.040	0.083	0.050	0.018
$U_{INMETRO/NIST}$	0.20	0.20	0.20	0.20

INMETRO could then be linked to CCT-K6 KCRV by means of the bilateral comparison carried out with NIST. The CCT-K6 comparison was performed at the dew/frost-point temperature values of -50 °C, -30 °C, -10 °C, 1 °C and 20 ºC. However, the first two values were not considered since the NIST Hybrid Humidity Generator was not used at those points in CCT-K6. Also, as the CCT-K6 comparison was performed at 1 °C and the comparison between INMETRO and NIST was performed at 0 °C, the participants considered these values acceptably close for linkage and assumed that [14]:

$$D_{NIST/KCRV}(1\,°C) = D_{INMETRO/NIST}(0\,°C) \qquad (9)$$

The difference between INMETRO and KCRV, $D_{INMETRO/KCRV}$, and its expanded uncertainty, $U(D_{INMETRO/KCRV})$, with coverage probability of approximately 95% (k = 2) were respectively determined as:

$$D_{INMETRO/KCRV} = D_{INMETRO/NIST} + D_{NIST/KCRV} \quad (10)$$

$$U^2(D_{INMETRO/KCRV}) = U^2(D_{INMETRO/NIST}) + U^2(D_{NIST/KCRV}) \quad (11)$$

Table 10 shows the calculated DoE between INMETRO and KCRV using the results presented in Tables 8 and 9 and Equations (10) and (11).

Table 10 – Degrees of Equivalence between INMETRO and KCRV (in ºC)

	-10 ºC	**1 ºC**	**20 ºC**
$D_{INMETRO/KCRV}$	0.044	0.039	0.012
$U_{INMETRO/KCRV}$	0.20	0.21	0.21

The compatibility of the measurement results of INTI and INMETRO was also analysed by means of the degree of equivalence. $D_{INTI/INMETRO}$ was calculated according to Equation (6), using the results (corrections) of the transfer standard found in both laboratories (Table 2); and $U(D_{INTI/INMETRO})$ was calculated according to Equations (7) and (8), using the expanded uncertainties of both laboratories and the drift of the transfer standard based on rectangular distribution (Table 7). Table 11 shows the DoE between INTI and INMETRO.

Table 11 – Degrees of Equivalence between INTI and INMETRO (in ºC)

	-30 ºC	**-20 ºC**	**1 ºC**	**20 ºC**	**40 ºC**	**60 ºC**
$D_{INTI/INMETRO}$	0.14	-0.09	-0.04	0.05	0.03	0.09
$U_{INTI/INMETRO}$	0.31	0.28	0.22	0.18	0.14	0.18

As INMETRO is linked to the CCT-K6 KCRV at the dew/frost-point temperatures of -10 ºC, 1 ºC and 20 ºC, INTI can then be linked to CCT-K6 KCRV by means of the this bilateral comparison for the dew-point temperatures of 1 ºC and 20 ºC. The difference between INTI and KCRV, $D_{INTI/KCRV}$, and its expanded uncertainty, $U(D_{INTI/KCRV})$, with coverage probability of approximately 95% (k = 2) were respectively determined as:

$$D_{INTI/KCRV} = D_{INTI/INMETRO} + D_{INMETRO/NIST} + D_{NIST/KCRV} \quad (12)$$

$$U^2(D_{INTI/KCRV}) = U^2(D_{INTI/INMETRO}) + U^2(D_{INMETRO/NIST}) + U^2(D_{NIST/KCRV}) \quad (13)$$

The DoE between INTI and KCRV can be finally determined using Equations (12) and (13) and Tables 8, 9 and 11. These values are presented in Table 12 below.

Table 12 – Degrees of Equivalence between INTI and KCRV (in ºC)

	1 ºC	**20 ºC**
$D_{INTI/KCRV}$	-0.001	0.062
$U_{INTI/KCRV}$	0.31	0.27

10. CONCLUSION

INMETRO and INTI have concluded a bilateral comparison of their humidity standards in six comparisons points in the dew/frost-point temperature range from -30 ºC to 60 ºC. The comparison was piloted by INMETRO and carried out from March to April 2017. A CMH was used as transfer standard and its drift was estimated by comparing measurements performed at INMETRO before and after the measurement period at INTI. The compatibility of their measurement results (by means of E_n and DoE) and the DoE between the institutes and the CCT-K6 KCRV were presented.

By the E_n numbers, Table 7 shows that for all the six comparison points the values were lower than one, which means that the measurement results of INMETRO and INTI have compatibility within their expanded uncertainties with a confidence level of approximately 95%.

By the DoE, Table 11 shows that for all the six comparison points the differences between the measurement results of INMETRO and INTI were well within their expanded uncertainties, which means that their measurements results are compatible with a confidence level of approximately 95%.

The DoE between INMETRO and KCRV (for the dew/frost-point temperatures values of -10 ºC, 1 ºC and 20 ºC) and between INTI and KCRV (for the dew-point temperatures values of 1 ºC and 20 ºC) were also shown. In both cases, the differences between the measurement results of the institutes and the KCRV were within their expanded uncertainties (Tables 10 and 12), which means that their measurements results are compatible with the KCRV with a confidence level of approximately 95%. In case of INMETRO, the linkage with the KCRV was made through a bilateral comparison with NIST (SIM.T-K6.3); and in case of INTI, the linkage with the KCRV was made through this bilateral comparison with INMETRO (SIM.T-K6.7).

REFERENCES

[1] Bureau International des Poids et Mesures (BIPM). *CIPM – Mutual Recognition Arrangement*. Available at http://www.bipm.org/en/cipm-mra/. Accessed on June 1st 2011.

[2] Bell, S.; et al. *Final report to the CCT on key comparison CCT-K6: Comparison of local realisations of dew-point temperature scales in the range -50 °C to +20 °C*. Metrologia, vol. 52, Tech. Suppl., 03005, 2015.

[3] Huang, P.; Meyer, C.; Brionizio, J. D. *Final Report: Bilateral Key Comparison SIM.T-K6.3 on Humidity Standards in the Dew/Frost-Point Temperature Range from -30°C to 20°C*. Metrologia, vol. 52, Tech. Suppl., 03001, 2015.

[4] Brionizio, J. D.; Fernicola, V.; Banfo, M.; Lima, S. G. *Bilateral Comparison of INMETRO and INRIM Humidity Standards*. Proceedings of the 14th Congrés International de Metrologie, Paris, 2009.

[5] Brionizio, J. D.; Skabar, J. G. *Final Report on SIM.T-K6.4: Comparison of INMETRO and INTI Humidity Standards*. Metrologia, vol. 50, Tech. Suppl., 03010, 2013.

[6] Thunder Scientific Corporation. *Operation and Maintenance Manual of Series 2500 Bench top Two-Pressure Humidity Generator*. 1991-2001.

[7] Lovell-Smith, J. *Uncertainty Analysis for Humidity Generators*. IRL Report, n º 988, 2000.

[8] Hardy, R. *ITS90 Formulation for Vapor Pressure, Frostpoint Temperature, Dewpoint Temperature and Enhancement Factor in the Range -100 ºC to +100 ºC*. Papers and Abstracts from the Third International Symposium on Humidity and Moisture, p. 214-222, London, 1998.

[9] Carpentier, V.; Megharfi, M.; Quint, J.; Priel, M.; Desenfant, M.; Morice, R. *Estimation of Hygrometry Uncertainties by Propagation of Distributions*. Metrologia, vol. 41, nº 6, 2004.

[10] Skabar, J. G., *Uncertainty estimations for standard humidity generator of INTI*. Int. J. Thermophysics, vol. 36, nº 8, p. 2172-2184, https://doi.org/10.1007/s10765-015-1905-4, 2015.

[11] Joint Committee for Guides in Metrology (JCGM). *Evaluation of Measurement Data: Guide to the Expression of Uncertainty in Measurement*. 1st Ed., 2008.

[12] ISO/IEC. *17043: Conformity Assessment – General Requirements for Proficiency Testing*. 2010.

[13] Cox, M. G. *The Evaluation of Key Comparison Data*. Metrologia, vol. 39, nº 6, p. 589-595, 2002.

[14] P. H. Huang, C. W. Meyer, J. D. Brionizio. *Appendix to the Report: Bilateral Key Comparison SIM.T-K6.3 on Humidity Standards in the Dew/Frost-point Temperature Range from –30 °C to 20 °C*. 2017.

Appendix 1 – Technical Protocol

The following pages show the technical protocol for SIM.T-K6.7, together with its Appendices 1 and 2. In addition, the protocol included, as Appendix 3 (not shown here), a MS Excel template for reporting comparison results.

SIM.T-K6.7

COMPARISON OF HUMIDITY STANDARDS

Instituto Nacional de Metrologia, Qualidade e Tecnologia (INMETRO), Brazil
Instituto Nacional de Tecnología Industrial (INTI), Argentina

Dew/Frost-Point Temperature –30 °C to +60 °C

TECHNICAL PROTOCOL

April 2017

Contents

1. INTRODUCTION

1.1. Under the Mutual Recognition Arrangement (MRA)[1] the metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs).

1.2. At its 20th meeting in April 2000, the Consultative Committee for Thermometry, CCT, considered a Key Comparison on humidity as imperative for the related laboratories. This document is based on a technical protocol drawn up by the members of Working Group on Humidity Measurements (CCT-WG-Hu).

1.3. It is appropriate to have a comparison of humidity standards between *Instituto Nacional de Metrologia, Qualidade e Tecnologia* (INMETRO), Brazil, and *Instituto Nacional de Tecnología Industrial* (INTI), Argentina.

1.4. The two participants indicated above have prepared this technical protocol.

1.5. The procedures outlined in this document cover the technical procedure to be followed during measurement of a transfer standard. The procedure, which follows the guidelines established by the BIPM[2], is based on current best practice in the use of dew/frost-point hygrometer and takes account of the experience gained from the research and calibration activities of the participants over the years.

1.6. This comparison is aimed at checking the degree of equivalence between realisations of local scales of dew/frost-point temperature of humid air established in a previous comparison among the participating National Metrology Institutes (NMIs)[3], and expand it to a wider range (from -30 °C to +60 °C).

1.7. INTI's results for the dew-point temperatures 1 °C and 20 °C will be linked to CCT-K6 key comparison reference value by means of a previous comparison between INMETRO and the National Institute of Standards and Technology (NIST, USA). Detailed information about it can be found in chapter 7.

2. ORGANIZATION

2.1. Participants

2.1.1. Details of mailing and electronic addresses are given in Appendix 1. The participating institutes are:

- Instituto Nacional de Metrologia, Qualidade e Tecnologia (INMETRO) – Brazil
- Instituto Nacional de Tecnología Industrial (INTI) – Argentina

2.1.2. INMETRO is the Pilot of the comparison, taking main responsibility for running the comparison.

[1] MRA, Mutual Recognition Arrangement, BIPM, 1999.
[2] CIPM MRA-D-05, Version 1.6, March 2016.
[3] J. D. Brionizio and J. G. Skabar. *Final Report on SIM.T-K6.4: Comparison of INMETRO and INTI Humidity Standards*. Metrologia, Vol. 50, Tech. Suppl., 03010 (2013)

2.1.3. By their declared intention to participate in this comparison, the laboratories accept the general instructions and the technical protocol written down in this document and commit themselves to follow strictly the procedures of this protocol as well as the version of the "Guidelines for Key Comparisons" in effect at the time of the initiation of the Comparison.

2.1.4. Once the protocol and list of participants have been approved, no change to the protocol or list of participants may be made without prior agreement of all participants.

2.1.5. All participants must be able to submit an uncertainty budget of their humidity standard system.

2.2. **Method of Comparison**

2.2.1. The comparison will be made by means of the calibration of a travelling transfer standard. The transfer standard will independently measure dew/frost-point temperature of a sample of moist air produced by a participant's standard system using the same measuring process.

2.2.2. Circulation scheme

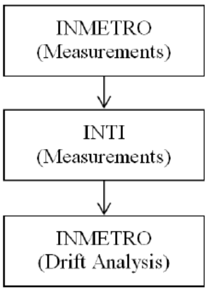

Figure 1 – Circulation scheme of the comparison

2.3. **Handling of Artefact**

2.3.1. The artefact shall be examined before the start of measurements. The participants are expected to follow all instructions in the operator's manual provided by the instrument manufacturer for proper unpacking, subsequent packing and operation. During packing and unpacking, the participants shall check the contents with the packing list including the operator's manual.

2.3.2. The transfer standard must only be handled by authorized persons and stored in such a way as to prevent damage.

2.3.3. During operation of the transfer standard, if there is any unusual occurrence, e.g., loss of heating or cooling control, the Pilot laboratory shall be notified immediately before proceeding.

2.4. **Transport of Artefact**

2.4.1. The transfer standard will be hand-carried from INMETRO to INTI by an INMETRO's technician, which will be at INTI while comparison measurements are conducted at the dew/frost-point temperatures required. After that, the transfer standard will be hand-carried from INTI to INMETRO by the INMETRO's technician. Each participant shall take actions in order to guarantee the exit and entrance of the transfer standard in its country.

2.5. **Shipping Costs**

2.5.1. INTI will be responsible for the travelling costs and daily allowances of an INMETRO's technician who will hand-carry the transfer standard. Each institute will be responsible for the customs charges. INMETRO will be responsible for the insurance of the transfer standard, which shall be sufficient to cover the costs of the item and any damages that may occur.

2.6. **Timetable**

Table 1 – Timetable of the comparison

Activity	Start Month	Provisional Date
Submission of a technical protocol to participants for unanimous approval	May 2016	
Submission of revised technical protocol to SIM/WG3 (thermometry WG) for approval.		December 2016
Completion of measurements at INMETRO		March 2017
Travelling standard hand-carried to INTI		March 2017
Completion of measurements at INTI		April 2017
Measurements at INMETRO to check the transfer standard stability (if necessary)		May 2017
Report A ready		December 2017
Deadline for comments on report A		February 2018
Draft B ready and submitted to SIM/WG3		March 2018
Paper publication		December 2018

3. DESCRIPTION OF THE TRANSFER STANDARD

3.1. **Artefact**

3.1.1. The travelling standard selected for the comparison is a state-of-the-art dew-point hygrometer, chilled-mirror type, commercially available. It has proven to be robust with known performance characteristics such as repeatability and transportability.

3.1.2. Details of travelling standard:

Table 2 – Details of the transfer standard

Manufacturer:	Michell Instruments Ltd., UK
Model:	Optidew Vision
Serial Number:	118931 (display) / 118849 (sensor)
Size:	260 mm (d) x 290 mm (w) x 120 mm (h)
Weight:	2.5 kg
Size in packing case:	300 mm (d) x 460 mm (w) x 200 mm (h)
Owner:	INMETRO, Brazil
Electrical supply:	90-264 V / 47-440 Hz
Approximate value for insurance and customs declaration:	US$ 25,000

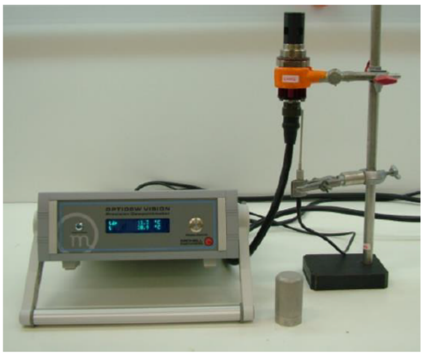

Figure 2 – Travelling standard

4. MEASUREMENT INSTRUCTIONS

4.1. Measurement Process

4.1.1. The participants shall refer to the operating manual for instructions and precautions for using the travelling standard. Participants may perform any initial checks of the operation of the hygrometer that would be performed for a normal calibration. In the case of an unexpected instrument failure at a participant institute, the Pilot shall be informed in order to revise the time schedule, if necessary, as early as possible.

4.1.2. A total of six humidity points are used for the comparison. Four dew-point temperatures at nominal values of 1 °C, 20 °C, 40 °C and 60 °C and two frost-point temperatures at nominal values of –30 °C and –20 °C. The value of 1 °C nominally represents 0 °C, while avoiding any complication due to phase change between water and ice.

4.1.3. For the frost/dew-point temperature values of –30 °C, –20 °C and 1 ºC, the gas sample generated by a participant's standard/working generator can be introduced into the inlet of the sensor housing of the travelling standard hygrometer (through a stainless steel tube, or by means of a Teflon hose, terminating with a 6 mm Swagelok fitting), or the sensor can be placed directly in the chamber of the generating system without its housing. For the dew-point temperatures values of 20 °C, 40 °C and 60 °C, the sensor of the transfer standard shall be placed directly in the chamber of the generating system without its housing.

4.1.4. When the sensor is placed directly inside of the chamber of the generating system, the temperature of the chamber shall be from 10 ºC to 30 ºC above the dew-point temperature.

4.1.5. At –30 °C and –20 °C, participants shall report the applied condition in terms of frost-point temperature. The measured condition at these temperatures will be assumed to be with respect to ice, unless otherwise reported.

4.1.6. It is recommended that measurements are performed in rising order of dew/frost point.

4.1.7. The condensate shall be cleared and re-formed for each value or repetition of dew/frost point.

4.1.8. The values of dew/frost point applied to the travelling standard shall be within ±0.5 °C of the six agreed nominal values for the comparison, and ideally closer than this. Deviations greater than this may increase the uncertainty in the comparison, for a particular result.

4.1.9. The conditions for operation of the travelling standard:

(1) Clean the mirror surface using cotton tips with distilled or de-ionised water. This may be preceded by initial cleaning with alcohol if necessary;
(2) When the sensor is placed in the sampling block, set the indicated flow rate of the gas sample from 0.1 l/min to 2 l/min, according to the hygrometer's specifications. When the sensor is inserted directly inside of the generator's chamber, do not place it near any input or output gas flow. The sensor shall be placed approximately in the middle of the chamber. The maximum gas velocity for direct insertion is 10 m/s, for higher values the sintered guard shall be used;
(3) The dew/frost-point indication of the hygrometer is either read from the hygrometer display or acquired by computer through the instrument's serial port. Each participant must report the measurement way chosen.

4.1.10. Each dew/frost-point temperature shall be separately repeated (reproduced) four times to reduce the effect of any irreproducibility of the travelling standard. For each time, at least 10 readings taken over a period of 10 to 20 minutes shall be acquired.

4.1.11. The transfer standard used in this comparison must not be modified, adjusted or used for any purpose other than described in this document, nor given to any party other than the participants in the comparison.

4.1.12. The Pilot will make an assessment of any drift in the travelling standard during the comparison, based on measurements at the Pilot laboratory at the beginning and in the end of the comparison period.

4.1.13. If unacceptable performance or failure of the travelling standard is detected, the participants will discuss the situation and agree a course of action.

4.2. Data Collection

4.2.1. At each measured value, the mean and standard deviation of multiple readings of the displayed dew/frost-point temperature shall be monitored. Participants may apply their own criteria of stability for acceptance of measurements. When hygrometer is in equilibrium with the gas sample, the standard deviation of a set of the readings, taken over a period of 10 to 20 minutes, is likely to be no more than 0.025 °C approximately.

4.2.2. Values reported for dew/frost-point temperatures produced by a participant's standard system shall be the value applied to the instruments, after any allowances for pressure and temperature differences between the point of realisation (laboratory system) and the point of use (travelling standard).

5. REPORTING OF MEASUREMENT RESULTS

5.1. Participants must report their measurement results of four repeated experiments, within six weeks of completing their measurements.

5.2. The participants must not disclose their measurement results to a third party. The participants will exchange their measurement results after all the measurements are completed.

5.3. The parameter to be compared between the two laboratories in this bilateral comparison is the mean difference found between the laboratory humidity standard system and the travelling standard. Note that the values of dew/frost-point temperature reported for the travelling standard are "arbitrary" values calculated from the readings. The travelling standard is used simply as a comparator.

5.4. Participants shall report results to each other in terms of dew/frost-point temperature. The main measurement results comprise:

- Values of dew/frost-point applied to the travelling standard and associated standard uncertainty;
- Values of difference between applied dew/frost point and measured dew/frost point.

A provisional template for reporting results is shown in Appendix 3, and can be available to participants in electronic form as an Excel spreadsheet.

5.5. From the data measured by each participant, results will be analysed in terms of differences between applied and measured dew/frost-point temperatures.

5.6. Participants shall provide a general description of the operation of their dew/frost points apparatus and humidity generator systems.

5.7. Participants shall also provide an example plot of equilibrium condition at a nominal frost-point temperature of –30 °C, over a suggested period of at least one hour.

6. UNCERTAINTY OF MEASUREMENT

6.1. The uncertainty of the comparison results will be derived from some or all of:

- the quoted uncertainty of the dew/frost-point realisation (applied dew/frost point) including any uncertainties due to pressure drop or other influences acting between the point of realisation and the point of use (travelling standard);
- the estimated uncertainty relating to the short-term stability of the travelling standard at the time of measurement;
- the estimated uncertainty due to any drift of a travelling standard over the period of the comparison (estimated by the Pilot);
- the estimated uncertainty in mean values due to dispersion of repeated results (reflecting the combined reproducibility of generator and travelling standard);
- the estimated uncertainty due to the resolution of the travelling standard (if found to be significant);
- the estimated uncertainty due to non-linearity of the travelling standard in any case where measurements are significantly away from the agreed nominal value;
- the estimated covariance between applied (generator/system) and measured (travelling standard) values of dew/frost-point (if found to be significant); and
- any other components of uncertainty that are thought to be significant.

6.2. Uncertainty analyses shall be according to the approach given in the Guide to the Expression of Uncertainty of Measurement[4]. A list of the all significant components of the uncertainty budget shall be evaluated, and must support the quoted uncertainties. Evaluations shall be given at a level of one standard uncertainty. Type B estimates of uncertainty may be regarded as having infinite degrees of freedom, or an alternative estimate of the number of degrees of freedom may be made following the methods in the Guide.

6.3. The uncertainty budget stated by the participating laboratory shall be referenced to an internal report and/or a published article.

7. DEGREES OF EQUIVALENCE

7.1. The Degree of Equivalence (DoE) of a measurement standard relative to a key comparison reference value, KCRV, is expressed quantitatively by two terms: its deviation from the KCRV and the expanded uncertainty of this deviation computed at a 95% level of confidence[2].

7.2. The DoE between two measurement standards is expressed quantitatively by two terms: the difference between their respective deviations from the KCRV and the expanded uncertainty of this difference computed at a 95% level of confidence[2].

7.3. **NIST/KCRV**

The National Institute of Standards and Technology (NIST, USA) participated in the CCT-K6 multilateral key comparison in dew/frost-point temperature, $T_{DP/FP}$, from -50 °C to +20 °C[5]. For each nominal $T_{DP/FP}$ a key comparison reference value was calculated. The difference for dew/frost-point temperatures (expressed in °C) between NIST and KCRV, $D_{NIST/KCRV}$, is defined as:

$$D_{NIST/KCRV} = (R_{DP/FP})_{NIST} - (R_{DP/FP})_{KCRV} \qquad (1)$$

Where, $(R_{DP/FP})_{NIST}$ and $(R_{DP/FP})_{KCRV}$ are the measured and applied dew/frost-point temperature of NIST and KCRV, respectively.

The combined uncertainty of the difference, $u(D_{NIST/KCRV})$, is defined as:

$$u^2(D_{NIST/KCRV}) = u^2(R_{DP/FP})_{NIST} + u^2(R_{DP/FP})_{KCRV} + u^2{}_{DRIFT} \qquad (2)$$

Where, $u(R_{DP/FP})_{NIST}$ and $u(R_{DP/FP})_{KCRV}$ are the uncertainties of the measured and applied dew/frost-point temperature of NIST and KCRV, respectively, and u_{DRIFT} is the uncertainty in the comparison due to the drift of the hygrometers.

The expanded uncertainty of the difference, $U(D_{NIST/KCRV})$, with coverage factor k = 2, which provides a coverage probability of approximately 95% for sufficiently large effective number of degrees of freedom of $u(D_{NIST/KCRV})$, is defined as:

$$U(D_{NIST/KCRV}) = 2u(D_{NIST/KCRV}) \qquad (3)$$

[4] Joint Committee for Guides in Metrology (JCGM). *Evaluation of measurement data – Guide to the expression of uncertainty in measurement*. 1st ed. (2008)

[5] S. Bell et al. *Final report to the CCT on key comparison CCT-K6 – Comparison of local realisations of dew-point temperature scales in the range –50 °C to +20 °C*. Metrologia, Vo. 52, Tech. Suppl., 03005 (2015)

The DoE between NIST and KCRV is defined as:

$$\left(D_{NIST/KCRV}, U_{NIST/KCRV}\right) = \left[D_{NIST/KCRV}, ku\left(D_{NIST/KCRV}\right)\right] \qquad (4)$$

The DoE of NIST in the CCT-K6 multilateral key comparison are:

Table 3 – Degree of equivalence between NIST and KCRV

	-50 °C	-30 °C	-10 °C	1 °C	20 °C
$D_{NIST/KCRV}$ / °C	-0.128	-0.072	-0.039	-0.011	-0.006
$U_{NIST/KCRV}$ / °C	0.030	0.038	0.043	0.060	0.050

7.4. **INMETRO/NIST**

Identified as SIM.T-K6.3, NIST and INMETRO performed a bilateral key comparison of their humidity standards in the dew/frost-point temperature range from -30 °C to +20 °C[6]. Some results of this bilateral comparison are linked to the KCRV.

The difference for dew/frost-point temperatures (expressed in °C) between INMETRO and NIST, $D_{INMETRO/NIST}$, is defined as:

$$D_{INMETRO/NIST} = \left(R_{DP/FP}\right)_{INMETRO} - \left(R_{DP/FP}\right)_{NIST} \qquad (5)$$

Where, $(R_{DP/FP})_{INMETRO}$ and $(R_{DP/FP})_{NIST}$ are the measured dew/frost-point temperatures of INMETRO and NIST, respectively.

The combined uncertainty of the difference, $u(D_{INMETRO/NIST})$, is defined as:

$$u^2\left(D_{INMETRO/NIST}\right) = u^2\left(R_{DP/FP}\right)_{INMETRO} + u^2\left(R_{DP/FP}\right)_{NIST} + u^2{}_{DRIFT} \qquad (6)$$

Where, $u(R_{DP/FP})_{INMETRO}$ and $u(R_{DP/FP})_{NIST}$ are the uncertainties of the measured dew/frost-point temperatures of INMETRO and NIST, respectively, and u_{DRIFT} is the uncertainty in the comparison due to the drift of the transfer standard.

The expanded uncertainty of the difference, $U(D_{INMETRO/NIST})$, with coverage probability of approximately 95% ($k = 2$) is defined as:

$$U\left(D_{INMETRO/NIST}\right) = 2u\left(D_{INMETRO/NIST}\right) \qquad (7)$$

The DoE of INMETRO in the bilateral key comparison are:

Table 4 – Degree of equivalence between INMETRO and NIST

	-30 °C	-10 °C	0 °C	20 °C
$D_{INMETRO/NIST}$ / °C	-0.040	0.083	0.050	0.018
$U_{INMETRO/NIST}$ / °C	0.20	0.20	0.20	0.20

[6] P. H. Huang, C. W. Meyer, J. D. Brionizio. *Bilateral Key Comparison SIM.T-K6.3 on Humidity Standards in the Dew/Frost-point Temperature Range from –30 °C to 20 °C*. Metrologia, Vol. 52, Tech. Suppl., *03001* (2015)

7.5. **INMETRO/KCRV**

The CCT-K6 comparison was performed at $T_{DP/FP}$ values of 20 °C, 1 °C, −10 °C, −30 °C and −50 °C. The last two values are not considered here since the NIST Hybrid Humidity Generator was not used at those points in CCT-K6. As the CCT-K6 comparison was performed at 1 °C and the comparison between INMETRO and NIST was performed at 0 °C, the participants consider these values acceptably close for linkage and assume that[7]:

$$D_{NIST/KCRV}(1\,°C) = D_{INMETRO/NIST}(0\,°C) \qquad (8)$$

Since INMETRO did not participate in CCT-K6 comparison, Eqs. (1) and (5) may be used to determine $D_{INMETRO/KCRV}$:

$$D_{INMETRO/KCRV} = D_{INMETRO/NIST} + D_{NIST/KCRV} \qquad (9)$$

The expanded uncertainty of the difference, $U(D_{INMETRO/KCRV})$, with coverage probability of approximately 95% ($k = 2$) is defined as:

$$U^2(D_{INMETRO/KCRV}) = U^2(D_{INMETRO/NIST}) + U^2(D_{NIST/KCRV}) \qquad (10)$$

Combining the results of Tables 3 and 4 and using Eqs. (9) and (10), the values to $D_{INMETRO/KCRV}$ and $U(D_{INMETRO/KCRV})$ are:

Table 5 – Degree of equivalence between INMETRO and KCRV

	-10 °C	1 °C	20 °C
$D_{INMETRO/KCRV}$ / °C	0.044	0.039	0.012
$U_{INMETRO/KCRV}$ / °C	0.20	0.21	0.21

The values of $D_{INMETRO/KCRV}$ are all within the $k = 2$ uncertainty values $U(D_{INMETRO/KCRV})$.

7.6. **INTI/KCRV**

Because INMETRO is linked to the CCT-K6 key comparison reference values at $T_{DP/FP}$ of -10 °C, 1 °C and 20 °C by means of SIM.T-K6.3, the results of INTI in this bilateral comparison (SIM.T-K6.7) for the dew-point temperatures 1 °C and 20 °C can be linked to KCRV.

The difference for the dew-point temperatures between INTI and KCRV, $D_{INTI/KCRV}$, is defined as:

$$D_{INTI/KCRV} = D_{INTI/INMETRO} + D_{INMETRO/NIST} + D_{NIST/KCRV} \qquad (11)$$

Where $D_{INTI/INMETRO}$, the difference for the dew/frost-point temperatures (expressed in °C) between INTI and INMETRO, is defined as:

$$D_{INTI/INMETRO} = (R_{DP/FP})_{INTI} - (R_{DP/FP})_{INMETRO} \qquad (12)$$

Where, $(R_{DP/FP})_{INTI}$ and $(R_{DP/FP})_{INMETRO}$ are the measured dew/frost-point temperatures of INTI and INMETRO, respectively.

[7] P. H. Huang, C. W. Meyer, J. D. Brionizio. *Appendix to the Report: Bilateral Key Comparison SIM.T-K6.3 on Humidity Standards in the Dew/Frost-point Temperature Range from −30 °C to 20 °C.* (2017)

The expanded uncertainty of the difference, $U(D_{INTI/KCRV})$, with coverage probability of approximately 95% ($k = 2$) is defined as:

$$U^2(D_{INTI/KCRV}) = U^2(D_{INTI/INMETRO}) + U^2(D_{INMETRO/NIST}) + U^2(D_{NIST/KCRV}) \qquad (13)$$

Where $U(D_{INTI/INMETRO})$, the expanded uncertainty of the difference with coverage probability of approximately 95% ($k = 2$), is defined as:

$$U(D_{INTI/INMETRO}) = 2u(D_{INTI/INMETRO}) \qquad (14)$$

The combined uncertainty of the difference, $u(D_{INTI/INMETRO})$, is defined as:

$$u^2(D_{INTI/INMETRO}) = u^2(R_{DP/FP})_{INTI} + u^2(R_{DP/FP})_{INMETRO} + u^2{}_{DRIFT} \qquad (15)$$

Where, $u(R_{DP/FP})_{INTI}$ and $u(R_{DP/FP})_{INMETRO}$ are the uncertainties of the measured dew/frost-point temperatures of INTI and INMETRO, respectively, and u_{DRIFT} is the uncertainty in the comparison due to the drift of the transfer standard.

APPENDIX 1

DETAILS OF PARTICIPATING INSTITUTES

Instituto Nacional de Metrologia, Qualidade e Tecnologia – INMETRO

Address:	Laboratório de Higrometria (Prédio 04) – Av. Nossa Senhora das Graças, 50 Xerém – Duque de Caxias – RJ – Brasil – CEP: 25250-020
Contact:	Júlio D. Brionizio
Phone:	+55 21 2679 9066
Fax:	+55 21 2679 9027
E-mail:	jdbrionizio@inmetro.gov.br

Instituto Nacional de Tecnología Industrial – INTI

Address:	Física y Metrología – Avenida General Paz, 5445 B1650WAB San Martín – Buenos Aires – Argentina
Contact:	Javier García Skabar
Phone:	+54 11 4724 6200/300/400
Fax:	+54 11 4713 4140
E-mail:	jskabar@inti.gob.ar

APPENDIX 2

PROVISIONAL CHECKLIST FOR REPORTING OF CONDITIONS OF MEASUREMENT

The following is guidance for reporting of the background information to the key comparison measurements. This information is likely to be of secondary importance, but will become relevant if there should be any need to resolve anomalies which might appear in the results.

The report should include the following information:

- A full description of the humidity generator used in the comparison and the traceability of the realisation to the SI, including:
    - The gas used (air);
    - The connection between the hygrometer and the standard - tubing material and dimensions;
    - Description of cleaning the mirror;
    - Value of flow rate set for each hygrometer;
    - Description of any problems with the hygrometers, or with the participant's generator system.

- For each separate repetition of each measurement point:
    - Applied reference value(s) (generated dew/frost-point temperature determined by the generator/system, after any correction for pressure drop to the point of use);
    - Standard deviation of the applied value(s);
    - Standard uncertainty of the applied value(s);
    - Values indicated by the travelling standard hygrometer;
    - Standard deviation of the hygrometer indicated values;
    - Difference between the applied (reference system) value and the measured (hygrometer) values;
    - Combined standard uncertainty of the difference;
    - Date when the measurements were carried out;
    - Hygrometer coolant temperature settings and measure values;
    - Temperature and pressure in saturator of generator;
    - Pressure difference between the hygrometer and the generator, and value of correction(s) applied to compensate for this, if any;
    - Environmental conditions (temperature, humidity, pressure);
    - Number of recorded values;
    - Stabilisation time;
    - Time interval taken to record the values;
    - "Raw data" in units of temperature.

Appendix 2 – Uncertainty Budget for INTI Standard

2.1 – Uncertainty Budget for INTI standard at -30 °C of frost-point temperature

Quantity (Symbol)	Components	estimate	unit	type	distribucion	degrees of freedom (type A)	standar uncertainty	unit	sensitivity coeficient	unit	Uncertainty contribution	unit
Ps	saturator pressure indication	924176	Pa									
Ps+C	saturator pressure	**923487**	Pa									
ucal	calibration uncertainty	-689	Pa	B	N		344,74	Pa	1	Pa	-0,0035	°C
resol	resolution (traducer range / 25000)*0.5/√(3)	0,000		B	R		11,94	Pa	1	Pa	-0,0001	°C
desvest	mean standar uncertainty (10 ≤ n)	0,000		A	N	10	72,83	Pa	1	Pa	-0,0007	°C
uPs	Uncertainty of saturator pressure measurement						**352,55**	Pa	-1,0E-05	°C / Pa		
Pc	chamber pressure indication	101255	Pa									
Pc+C	chamber pressure	**101048**	Pa									
ucal	calibration uncertainty	-207	Pa	B	N		34,47	Pa	1	Pa	0,0033	°C
resol	resolution (traducer range / 25000)*0.5/√(3)			B	R		3,98	Pa	1	Pa	0,0004	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	1,09	Pa	1	Pa	0,0001	°C
uPc	Uncertainty of chamber pressure measurement						**34,72**	Pa	9,48E-05	°C / Pa		
ts	saturator temperature indication	-6,984	°C									
ts+C	saturator temperature	**-6,844**	°C									
ucal	calibration uncertainty	0,140	°C	B	N		0,020	°C	1	°C	0,0166	°C
resol	resolution (0,01)*0.5/√(3)			B	R		0,003	°C	1	°C	0,0024	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	0,004	°C	1	°C	0,0033	°C
sat efficiency	Saturator efficiency, saturator bath uniformity, contamination of supply gas and water						0,050	°C	1	°C	0,0418	°C
uts	Uncertainty of saturator temperature measurement						**0,05**	°C	8,32E-01	°C		
e(ts)	vapor pressure formulae (ts)	342,768	Pa	B	N		0,152	Pa	0,028	°C / Pa	0,0043	°C
f(ts,Ps)	enhancement factor formulae (ts,Ps)	1,036	°C	B	N		0,003	°C	9,296	°C	0,0313	°C
e(tdew/frost)	vapor pressure formulae (tdew/frost)	38,664	Pa	B	N		0,062	Pa	0,249	°C / Pa	0,0153	°C
f(tdew/frost, Pc)	enhancement factor formulae (tdew/frost,Pc)	1,005	°C	B	N		0,001	°C	-9,579	°C	-0,0051	°C
tfrost	Combined standar uncertainty - references humidity generator	**-29,83**	°C								0,0577	°C

2.2 – Uncertainty Budget for INTI standard at -20 °C of frost-point temperature

Quantity (Symbol)	Components	estimate	unit	type	distribucion	degrees of freedom (type A)	standar uncertainty	unit	sensitivity coeficient	unit	Uncertainty contribution	unit
Ps	saturator pressure indication	875546	Pa									
Ps+C	saturator pressure	**874857**	Pa									
ucal	calibration uncertainty	-689	Pa	B	N		344,74	Pa	1	Pa	-0,0040	°C
resol	resolution (traducer range / 25000)*0.5/√(3)	0,000		B	R		11,94	Pa	1	Pa	-0,0001	°C
desvest	mean standar uncertainty (10 ≤ n)	0,000		A	N	10	59,04	Pa	1	Pa	-0,0007	°C
uPs	Uncertainty of saturator pressure measurement						**349,96**	Pa	-1,2E-05	°C / Pa		
Pc	chamber pressure indication	101150	Pa									
Pc+C	chamber pressure	**100943**	Pa									
ucal	calibration uncertainty	-207	Pa	B	N		34,47	Pa	1	Pa	0,0035	°C
resol	resolution (traducer range / 25000)*0.5/√(3)			B	R		3,98	Pa	1	Pa	0,0004	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	1,22	Pa	1	Pa	0,0001	°C
uPc	Uncertainty of chamber pressure measurement						**34,72**	Pa	1,03E-04	°C / Pa		
ts	saturator temperature indication	5,002	°C									
ts+C	saturator temperature	**5,077**	°C									
ucal	calibration uncertainty	0,075	°C	B	N		0,020	°C	1	°C	0,0145	°C
resol	resolution (0,01)*0.5/√(3)			B	R		0,003	°C	1	°C	0,0021	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	0,001	°C	1	°C	0,0008	°C
sat efficiency	Saturator efficiency, saturator bath uniformity, contamination of supply gas and water						0,045	°C	1	°C	0,0328	°C
uts	Uncertainty of saturator temperature measurement						**0,05**	°C	7,24E-01	°C		
e(ts)	vapor pressure formulae (ts)	877,227	Pa	B	N		0,044	Pa	0,012	°C / Pa	0,0005	°C
f(ts,Ps)	enhancement factor formulae (ts,Ps)	1,030	°C	B	N		0,003	°C	10,123	°C	0,0264	°C
e(tdew/frost)	vapor pressure formulae (tdew/frost)	103,811	Pa	B	N		0,114	Pa	0,100	°C / Pa	0,0114	°C
f(tdew/frost, Pc)	enhancement factor formulae (tdew/frost,Pc)	1,004	°C	B	N		0,000	°C	-10,379	°C	-0,0049	°C
tfrost	Combined standar uncertainty - references humidity generator	**-19,94**	°C								0,0466	°C

2.3 – Uncertainty Budget for INTI standard at 1 °C of frost-point temperature

Quantity (Symbol)	Components	estimate	unit	type	distribucion	degrees of freedom (type A)	standar uncertainty	unit	sensitivity coeficient	unit	Uncertainty contribution	unit
Ps	saturator pressure indication	358521	Pa									
Ps+C	saturator pressure	**358521**	Pa									
ucal	calibration uncertainty	0	Pa	B	N		344,74	Pa	1	Pa	-0,0132	°C
resol	resolution (traducer range / 25000)*0.5/√(3)	0,000		B	R		11,94	Pa	1	Pa	-0,0005	°C
desvest	mean standar uncertainty (10 ≤ n)	0,000		A	N	10	13,47	Pa	1	Pa	-0,0005	°C
uPs	Uncertainty of saturator pressure measurement						**345,21**	Pa	-3,8E-05	°C / Pa		
Pc	chamber pressure indication	100607	Pa									
Pc+C	chamber pressure	**100400**	Pa									
ucal	calibration uncertainty	-207	Pa	B	N		34,47	Pa	1	Pa	0,0048	°C
resol	resolution (traducer range / 25000)*0.5/√(3)			B	R		3,98	Pa	1	Pa	0,0005	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	3,22	Pa	1	Pa	0,0004	°C
uPc	Uncertainty of chamber pressure measurement						**34,85**	Pa	1,38E-04	°C / Pa		
ts	saturator temperature indication	20,000	°C									
ts+C	saturator temperature	**20,060**	°C									
ucal	calibration uncertainty	0,060	°C	B	N		0,030	°C	1	°C	0,0258	°C
resol	resolution (0,01)*0.5/√(3)			B	R		0,003	°C	1	°C	0,0025	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	0,001	°C	1	°C	0,0010	°C
sat efficiency	Saturator efficiency, saturator bath uniformity, contamination of supply gas and water						0,026	°C	1	°C	0,0219	°C
uts	Uncertainty of saturator temperature measurement						**0,04**	°C	8,60E-01	°C		
e(ts)	vapor pressure formulae (ts)	2347,931	Pa	B	N		0,117	Pa	0,006	°C / Pa	0,0007	°C
f(ts,Ps)	enhancement factor formulae (ts,Ps)	1,012	°C	B	N		0,001	°C	13,731	°C	0,0111	°C
e(tdew/frost)	vapor pressure formulae (tdew/frost)	662,600	Pa	B	N		0,033	Pa	0,021	°C / Pa	0,0007	°C
f(tdew/frost, Pc)	enhancement factor formulae (tdew/frost,Pc)	1,004	°C	B	N		0,000	°C	-13,837	°C	-0,0047	°C
tdew	Combined standar uncertainty - references humidity generator	**1,12**	°C								0,0387	°C

2.4 – Uncertainty Budget for INTI standard at 20 °C of frost-point temperature

Quantity (Symbol)	Components	estimate	unit	type	distribucion	degrees of freedom (type A)	standar uncertainty	unit	sensitivity coeficient	unit	Uncertainty contribution	unit
Ps	saturator pressure indication	241317	Pa									
Ps+C	saturator pressure	**241110**	Pa									
ucal	calibration uncertainty	-207	Pa	B	N		34,47	Pa	1	Pa	-0,0023	°C
resol	resolution (traducer range / 25000)*0.5/√(3)	0,000		B	R		3,98	Pa	1	Pa	-0,0003	°C
desvest	mean standar uncertainty (10 ≤ n)	0,000		A	N	10	6,30	Pa	1	Pa	-0,0004	°C
uPs	Uncertainty of saturator pressure measurement						**35,27**	Pa	-6,7E-05	°C / Pa		
Pc	chamber pressure indication	100813	Pa									
Pc+C	chamber pressure	**100606**	Pa									
ucal	calibration uncertainty	-207	Pa	B	N		34,47	Pa	1	Pa	0,0055	°C
resol	resolution (traducer range / 25000)*0.5/√(3)			B	R		3,98	Pa	1	Pa	0,0006	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	0,23	Pa	1	Pa	0,0000	°C
uPc	Uncertainty of chamber pressure measurement						**34,70**	Pa	1,60E-04	°C / Pa		
ts	saturator temperature indication	35,001	°C									
ts+C	saturator temperature	**35,031**	°C									
ucal	calibration uncertainty	0,030	°C	B	N		0,020	°C	1	°C	0,0179	°C
resol	resolution (0,01)*0.5/√(3)			B	R		0,003	°C	1	°C	0,0026	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	0,002	°C	1	°C	0,0018	°C
sat efficiency	Saturator efficiency, saturator bath uniformity, contamination of supply gas and water						0,026	°C	1	°C	0,0228	°C
uts	Uncertainty of saturator temperature measurement						**0,03**	°C	8,94E-01	°C		
e(ts)	vapor pressure formulae (ts)	5638,964	Pa	B	N		0,282	Pa	0,003	°C / Pa	0,0008	°C
f(ts,Ps)	enhancement factor formulae (ts,Ps)	1,008	°C	B	N		0,000	°C	16,026	°C	0,0064	°C
e(tdew/frost)	vapor pressure formulae (tdew/frost)	2362,798	Pa	B	N		0,118	Pa	0,007	°C / Pa	0,0008	°C
f(tdew/frost, Pc)	enhancement factor formulae (tdew/frost,Pc)	1,004	°C	B	N		0,000	°C	-16,098	°C	-0,0037	°C
tdew	Combined standar uncertainty - references humidity generator	**20,16**	°C								0,0307	°C

2.5 – Uncertainty Budget for INTI standard at 40 °C of frost-point temperature

Quantity (Symbol)	Components	estimate	unit	type	distribucion	degrees of freedom (type A)	standar uncertainty	unit	sensitivity coeficient	unit	Uncertainty contribution	unit
Ps	saturator pressure indication	213734	Pa									
Ps+C	saturator pressure	**213527**	Pa									
ucal	calibration uncertainty	-207	Pa	B	N		34,47	Pa	1	Pa	-0,0030	°C
resol	resolution (traducer range / 25000)*0.5/√(3)	0,000		B	R		3,98	Pa	1	Pa	-0,0003	°C
desvest	mean standar uncertainty (10 ≤ n)	0,000		A	N	10	25,23	Pa	1	Pa	-0,0022	°C
uPs	Uncertainty of saturator pressure measurement						**42,90**	Pa	-8,7E-05	°C / Pa		
Pc	chamber pressure indication	100724	Pa									
Pc+C	chamber pressure	**100517**	Pa									
ucal	calibration uncertainty	-207	Pa	B	N		34,47	Pa	1	Pa	0,0064	°C
resol	resolution (traducer range / 25000)*0.5/√(3)			B	R		3,98	Pa	1	Pa	0,0007	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	1,36	Pa	1	Pa	0,0003	°C
uPc	Uncertainty of chamber pressure measurement						**34,73**	Pa	1,86E-04	°C / Pa		
ts	saturator temperature indication	55,000	°C									
ts+C	saturator temperature	**55,005**	°C									
ucal	calibration uncertainty	0,005	°C	B	N		0,020	°C	1	°C	0,0180	°C
resol	resolution (0,01)*0.5/√(3)			B	R		0,003	°C	1	°C	0,0026	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	0,000	°C	1	°C	0,0002	°C
sat efficiency	Saturator efficiency, saturator bath uniformity, contamination of supply gas and water						0,035	°C	1	°C	0,0318	°C
uts	Uncertainty of saturator temperature measurement						**0,04**	°C	9,00E-01	°C		
e(ts)	vapor pressure formulae (ts)	15766,78	Pa	B	N		0,788	Pa	0,001	°C / Pa	0,0009	°C
f(ts,Ps)	enhancement factor formulae (ts,Ps)	1,008	°C	B	N		0,000	°C	18,605	°C	0,0044	°C
e(tdew/frost)	vapor pressure formulae (tdew/frost)	7449,51	Pa	B	N		0,372	Pa	0,003	°C / Pa	0,0009	°C
f(tdew/frost, Pc)	enhancement factor formulae (tdew/frost,Pc)	1,005	°C	B	N		0,000	°C	-18,691	°C	-0,0026	°C
tdew	Combined standar uncertainty - references humidity generator	**40,16**	°C								0,0378	°C

2.6 – Uncertainty Budget for INTI standard at 60 °C of frost-point temperature

Quantity (Symbol)	Components	estimate	unit	type	distribucion	degrees of freedom (type A)	standar uncertainty	unit	sensitivity coeficient	unit	Uncertainty contribution	unit
Ps	saturator pressure indication	158586	Pa									
Ps+C	saturator pressure	**158379**	Pa									
ucal	calibration uncertainty	-207	Pa	B	N		34,47	Pa	1	Pa	-0,0047	°C
resol	resolution (traducer range / 25000)*0.5/√(3)	0,000		B	R		3,98	Pa	1	Pa	-0,0005	°C
desvest	mean standar uncertainty (10 ≤ n)	0,000		A	N	10	7,85	Pa	1	Pa	-0,0011	°C
uPs	Uncertainty of saturator pressure measurement						**35,58**	Pa	-1,4E-04	°C / Pa		
Pc	chamber pressure indication	101022	Pa									
Pc+C	chamber pressure	**100815**	Pa									
ucal	calibration uncertainty	-207	Pa	B	N		34,47	Pa	1	Pa	0,0074	°C
resol	resolution (traducer range / 25000)*0.5/√(3)			B	R		3,98	Pa	1	Pa	0,0008	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	4,56	Pa	1	Pa	0,0010	°C
uPc	Uncertainty of chamber pressure measurement						**35,00**	Pa	2,13E-04	°C / Pa		
ts	saturator temperature indication	70,001	°C									
ts+C	saturator temperature	**70,011**	°C									
ucal	calibration uncertainty	0,010	°C	B	N		0,020	°C	1	°C	0,0187	°C
resol	resolution (0,01)*0.5/√(3)			B	R		0,003	°C	1	°C	0,0027	°C
desvest	mean standar uncertainty (10 ≤ n)			A	N	10	0,001	°C	1	°C	0,0009	°C
sat efficiency	Saturator efficiency, saturator bath uniformity, contamination of supply gas and water						0,050	°C	1	°C	0,0470	°C
uts	Uncertainty of saturator temperature measurement						**0,05**	°C	9,34E-01	°C		
e(ts)	vapor pressure formulae (ts)	31216,91	Pa	B	N		1,561	Pa	0,001	°C / Pa	0,0011	°C
f(ts,Ps)	enhancement factor formulae (ts,Ps)	1,008	°C	B	N		0,000	°C	21,411	°C	0,0029	°C
e(tdew/frost)	vapor pressure formulae (tdew/frost)	19915,32	Pa	B	N		0,996	Pa	0,001	°C / Pa	0,0011	°C
f(tdew/frost, Pc)	enhancement factor formulae (tdew/frost,Pc)	1,006	°C	B	N		0,000	°C	-21,480	°C	-0,0018	°C
tdew	Combined standar uncertainty - references humidity generator	**59,97**	°C								0,0515	°C