Condensation Hygrometers as Humidity Transfer Standards

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Introduction

Condensation hygrometers provide direct and fundamental measurement of dew point temperature by regulating the flow of coolant or regulating the electrical current through thermoelectric coolers to control a target surface to a temperature where the formation and evaporation of dew or frost an equilibrium. The temperature of the target is by definition the dew or frost point temperature. Dew point temperature is a measurement of the amount of water vapor in air or other gases. The dew point temperature is solely dependent on the partial pressure of water vapor which by virtue of the ideal gas law relationships with enhancement factors may converted to other humidity measurement parameters such as relative humidity, mass mixing ratio, volumetric mixing ratio, wet bulb temperature, enthalpy, heat index and absolute humidity. Condensation hygrometers are widely used as reference instruments for the calibration of many types of humidity sensors and instruments. The span of measurement in terms of dew point ranges from –80 to +85ºC.

Operation of Condensation Hygrometers

Condensation hygrometers control a target to an equilibrium temperature such that the mass of dew or frost is at a constant. The temperature of the target is measured and is by definition the dew or frost point temperature. Several methods which detect the onset of condensation including optical feedback control based on light scattering, change in mass as measured by a microbalance, change is electrical parameters such as resistance or capacitance or change is acoustic wave propagation may be used to control of the flow or evaporation of coolants, refrigerants or thermoelectric cooling. The ability of these instruments to measure humidity is based on precisely measuring the surface temperature of the target where dew or frost forms. This is typically accomplished with a precision four-wire platinum resistance temperature detector (PRTD) or other types of temperature sensors.

Figure 1. is a schematic of a chilled condensation hygrometer that utilizes optical feedback, thermoelectric cooling and an PRTD to measure the temperature of a

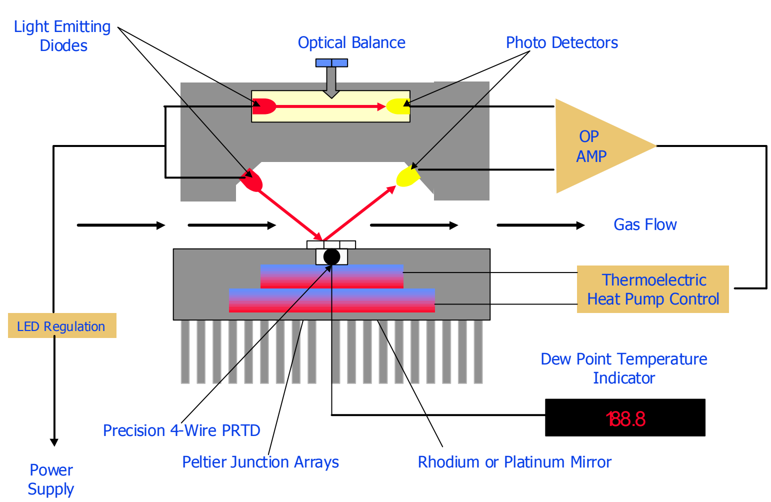

Figure 1

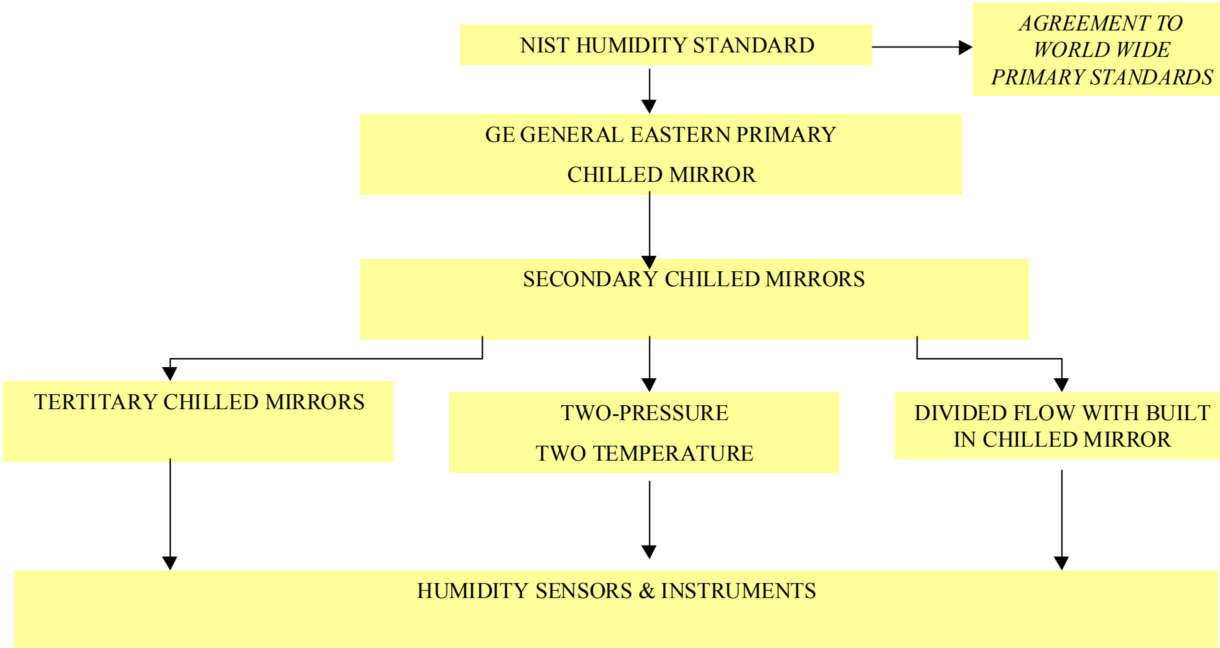

Figure 2.

Table 1.

NIST Two–Pressure Humidity Generator, Mark 2, Range and Uncertainty

Humidity Parameter	Range	Expanded Uncertainty
Mixing ratio, r_w (g water vapor/ kg dry air)	$0.0015 < r_w < 0.005$	1.5 % of value
	$0.005 < r_w < 0.1$	1.0 % of value
	$0.1 < r_w < 0.3$	0.5 % of value
	$0.3 < r_w < 515$	0.3 % of value
Volume ratio, V (X 10^{-6})	$3 < V < 10$	1.5 % of value
	$10 < V < 170$	1.0 % of value
	$170 < V < 500$	0.5 % of value
	$500 < V < 820\,000$	0.3 % of value
Dew point temperature, T_d (°C)	$-70 < T_d < -35$	0.1 °C
	$-35 < T_d < +40$	0.04 °C
Relative humidity, RH (%) at test chamber temperature, T_c (°C) of:	$-55 < T_c < -40$	3–98 1.5 %
	$-40 < T_c < -20$	3–98 0.8 %
	$-20 < T_c < 0$	3–98 0.2 %
	$0 < T_c < +40$	3–98 0.2 %

Table 2.

Target	NIST 2-P Gen	M3/1311-XR	Deviation
20.00	19.81	20.21	0.04
10.00	9.81	9.87	0.06
0.00	-0.08	0.04	0.12
-10.00	-10.00	09.90	0.10
-20.00	-20.06	-20.04	0.02
-30.00	-30.14	-30.15	-0.01
-40.00	-40.05	-40.22	-0.17
-50.00	-50.00	-49.78	0.22
-60.00	-60.01	-59.83	0.18
-70.00	-70.12	-70.23	-0.11

polished metal mirror made of platinum or rhodium plated copper.

Calibration of Primary Hygrometers

Primary condensation hygrometers are typically sent to national standards laboratories such as NIST (National Institute of Standards and Technology) for calibration against primary humidity standards. Figure 2. illustrates the hierarchy of traceability to NIST. The hygrometers are typically tested at several points and the data reported back as a deviation from the standard. A calculation of the uncertainty of the national standard combined with the hygrometer is performed. The hygrometer is returned to the lab and typically used as the "primary standard" for the lab. Other condensation hygrometers now designated as "secondary standard" hygrometers are calibrated against the primary. The secondary hygrometers are used to calibrate tertiary hygrometers which are the "work-horse" standards sold commercially.

Humidity generators such as two-pressure/two temperature generators or divided flow generators may also be calibrated against the secondary condensation hygrometers as "tertiary standards". Along with condensation hygrometers these are are typically used to calibrate various types of humidity instruments that typically use resistive and capacitive humidity sensors.

Table 1 provides listing of NIST's expanded uncertainty for humidity calibration based on the Mark 2 Two-Pressure Humidity Generator. (NIST Calibration Services Guide). The two pressure system saturates air at an elevated pressure then expands the air to a second lower pressure. By precisely measuring the pressure of the saturator and expanded air as well as the temperature of the saturator and expansion chamber generated humidity values can be determined to the certainties listed above. By precisely measuring the pressure and temperature of both the saturator and test conditions the water vapor pressure can be determined based on the following relationship:

$$e_w(t_c) = e_w(t_s) \times \frac{f(P_c, T_c)}{f(P_s, T_s)}$$

$e_w(t_c)$ = water vapor Pressure in the test chamber
$e_w(t_s)$ = water vapor Pressure in the saturator
F(Ps,Ts) = function of the saturation temperature and pressure with enhancement factor to compensate for the non-ideal gas behavior of water vapor

Instruments sent to NIST and other national standards labs are used as transfer standards for other instruments used for calibration. In each calibration transfer from the national standard error is introduced. While the long-term stability of condensation hygrometers is well documented it is important to access the uncertainty of the process particularly when claims of traceability to NIST or other national standards labs are made.

Condensation hygrometers fundamentally measure dew or frost point temperature. Coupled with temperature and pressure measurements as well as knowing the gas composition other humidity parameters can be derived or calculated. For these conversions the uncertainty of the temperature, pressure and gas composition variables must be

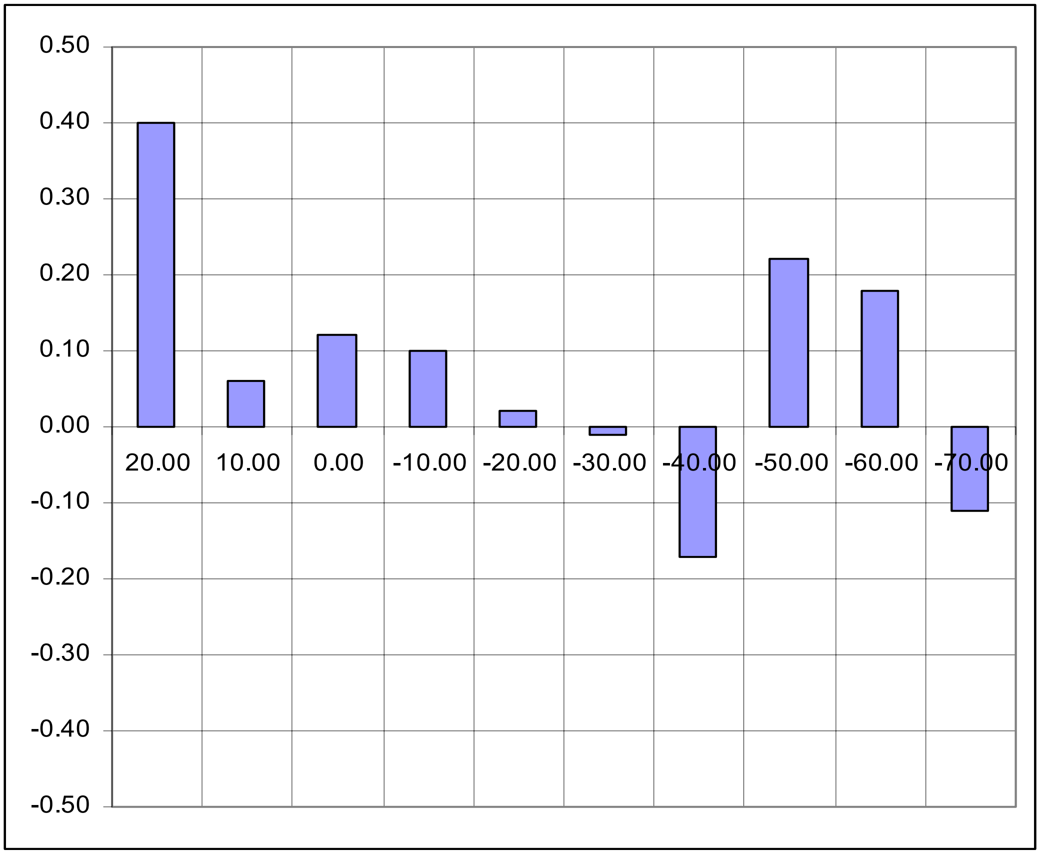

Figure 3

accounted for.

When using condensation hygrometers for calibration, finite stabilization times must be applied to allow control algorithms to achieve stability and accuracy. Finite dwell times, particularly at low humidity levels, must be applied to allow sample tubing to fully outgas water vapor. At levels below –60ºC, frost point dwell times may take several hours. Thermal stability and temperature uniformity also play an important role in humidity calibrations.

A Case Study of a Primary Condensation Hygrometer

The following is a description from NIST which describes of the process of calibrating GE General Eastern's Model M3/1311-XR five stage chilled mirror hygrometer which is was calibrated against the NIST Two-Pressure Humidity Generator Standard.. The reference report 836/H-4736/ TN266896-02 was issued on April 16, 2002.

"Air of known water vapor content, generated by the NIST Two-Pressure Humidity Generator, Mark 2, was introduced into the inlet of the hygrometer through a 1/4-inch (0.635 cm) diameter stainless steel tube. The calibration procedure is described in Section B of NISTIR 4677, entitled "NIST Calibration Services for Humidity Measurement." The uncertainty of a generated dew- or frost-point temperature is expressed as an expanded uncertainty $U=ku_c$, with U determined from a combined standard uncertainty u_c and a coverage factor k=2. The determination of uncertainties is described in "Determining Uncertainties of Relative Humidity, Dew/Frost-Point Temperature and Mixing Ratio

Figure 4

Deviation of M3/1311-XR From NIST Two-Pressure Generator over Four Years

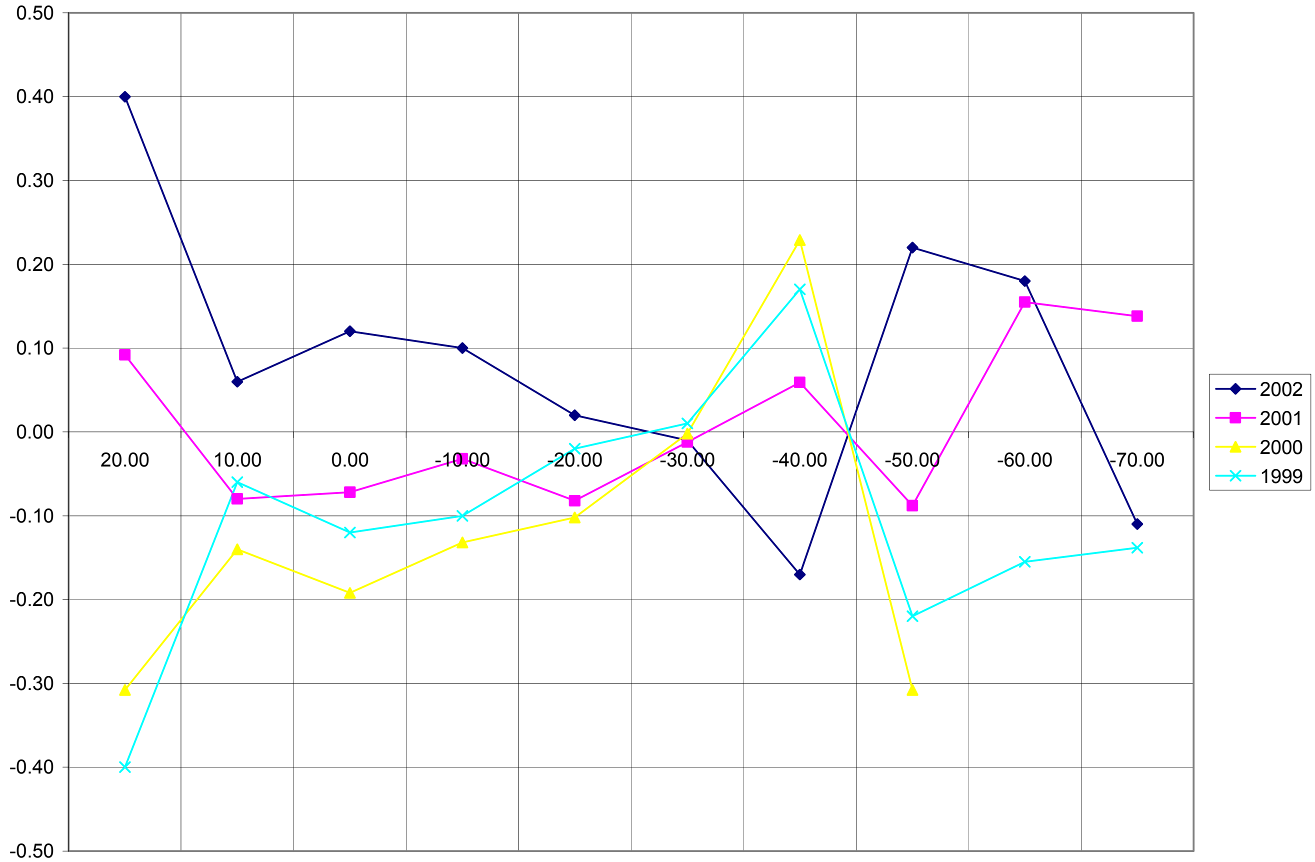

Figure 5

in a Humidity Standard Generator," Proc. The Third International Symposium on Humidity & Moisture, Vol. 1, pp. 149-158 (1998).

The dew-point hygrometer under test uses a thermoelectric heat sink and a compressor for cooling the dew-point mirror. The mirror is maintained at the dew-point temperature by automatically controlling the current through the thermoelectric cooler. A 100-ohm platinum resistance thermometer (PRT) is embedded beneath the surface of the mirror to measure the dew-point temperature. The hygrometer was assumed to be in equilibrium with the air sample when the hygrometer display indicated a constant dew-point value for a time interval of thirty minutes or longer."

The test results are shown on Table 2. Figure 3 shows the deviations from the two-pressure generator (The values are in ºC Dew/Frost Point. The expanded uncertainty for the M/1311-XR at over the range of –35 to +40ºC is calculated to 0.06ºC

Figure 4. is a picture of the M3/1311-XR five-stage chilled mirror hygrometer. The unit is capable of measurements to –80ºC frost point. It is designed with a separate power supply to keep heat away from the chilled mirror cell. The unit is also equipped with a water jacket which utilizes chilled water to assist in cooling.

Establishing Long-Term Drift Data

When using a condensation hygrometer as a reference instrument it is important to establish a "history" of the unit's drift characteristics. A primary hygrometer should have minimal drift. Typically, the hygrometer can be sent back to a standards lab on a periodic basis . In the case of GE General Eastern's unit a yearly calibration is performed. Figure 5 shows the deviation from the NIST Two-Pressure Generator over a 4 year period.

Using a Primary Hygrometer as a Transfer Standard

It is estimated that the dew point measurement uncertainty of M3/1311-XR is 0.06ºC Dew/Frost Point between –35 to +40ºC. The unit is used as a primary standard to calibrate

Table 3

Relative Humidity (%)	68% Confidence	95% Confidence
5	0.09	0.18
10	0.17	0.34
20	0.31	0.62
30	0.45	0.90
40	0.58	1.2
50	0.73	1.5
60	0.84	1.7
70	1.0	2.0
80	1.1	2.2
90	1.1	2.2
95	1.3	2.6

other chilled mirrors. A dew point generator is used which consist of a divided flow metering system and alternately a two pressure generator is used. The primary hygrometer and the secondary device under test are set up in series such that both hygrometers sample the same air stream. All stainless steel tubing is utilized. Each unit is allowed to stabilize and a the readings are compared. Correction factors per the latest deviations from the NIST generator are applied to the secondary instruments. The estimated uncertainty of the secondary instruments is 0.1ºC. The secondary instruments are then used in a similar fashion to calibrate tertiary instruments whose uncertainty is estimated at 0.15ºC.

Chilled mirror condensation hygrometers fundamentally measures dew or frost point temperatures. When converting to other humidity parameters such as relative humidity (% RH), volumetric mixing ratio (PPMv), mass mixing ratio (PPMw, g/Kg etc), or absolute humidity (g/M^3), the uncertainties of the temperature and pressure measurements must be factored in with the uncertainty of the gas composition and the equations used to convert one parameter to the other. The gas composition is usually identical between the reference standard and the device under test is usually identical therefore this factor may be minimal. Temperature gradients between the standard and the device under test is of prime importance. Temperature error, gradients and the inability to achieve stable moisture equilibrium are the greatest source of errors in humidity calibration . Table 3. provides the estimated uncertainty of a relative humidity calibration performed in air, at 25ºC, ±0.15 dry bulb, and 1 atmosphere with a tertiary chilled mirror hygrometer. The calibration chamber has a temperature error gradient of ±0.1C between the reference temperature sensor and the device under test.

References

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