NISTIR 5455

New Expressions of Uncertainties for Humidity Calibrations at the National Institute of Standards and Technology

Peter H. Huang
James R. Whetstone

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards
and Technology
Process Sensing Groups
Process Measurements Division
Chemical Science and Technology Laboratory
Gaithersburg, MD 20899

NIST

NISTIR 5455

New Expressions of Uncertainties for Humidity Calibrations at the National Institute of Standards and Technology

Peter H. Huang
James R. Whetstone

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards
and Technology
Process Sensing Groups
Process Measurements Division
Chemical Science and Technology Laboratory
Gaithersburg, MD 20899

June 1994

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary

TECHNOLOGY ADMINISTRATION
Mary L. Good, Under Secretary for Technology

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Arati Prabhakar, Director

NEW EXPRESSIONS OF UNCERTAINTIES FOR HUMIDITY CALIBRATIONS AT THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

NIST humidity standards are documented in NISTIR 4677, entitled "NIST Calibration Services for Humidity Measurement" [1]. In accordance with a new NIST policy for expressing the uncertainty of measurements [2], previous uncertainties stated in tables 24 and 26 of reference 1 have been revised. Based on the "Guide to the Expression of Uncertainty in Measurement" [3], the systematic error and random error in the pressure and temperature measurements in table 24 of reference 1 were estimated by Type B and Type A evaluations of standard uncertainty, respectively. The Type A and B standard uncertainties are combined into the combined standard uncertainty, u_c, by the method of the "law of propagation of uncertainty" or the "root-sum-of-squares" method [2], i.e., $u_c = (u_A^2 + u_B^2)^{1/2}$. The Type A standard uncertainties associated with temperature and pressure measurements given in table 1 are 1σ values, thereby differing from the previous 3σ-random errors given in table 24 of reference 1.

The previously estimated systematic errors associated with temperature measurements [1] were primarily due to the maximum temperature gradient measured in the final bath of the two-pressure humidity generator which contains the saturator and the test chamber. The uncertainties of enhancement factor listed in table 24 of reference 1 were based on a formalism not consistent with that of reference 2. To satisfy the new NIST requirement, an analysis was performed on Type B uncertainty components to reflect a triangular distribution [2]. Now the relative combined standard uncertainty, u_{cr}, in mixing ratio can be calculated using equation (51) of reference 1 and the subscript r indicates that u_c is a relative combined standard uncertainty,

$$u_{cr} = \left(\frac{u(r_w)}{r_w}\right)_c = \frac{P_s}{P_s - f e_w}\left[\left(\frac{u(e_w)}{e_w}\right)^2 + \left(\frac{u(P_s)}{P_s}\right)^2 + \left(\frac{u(f)}{f}\right)^2\right]^{1/2} \qquad (1)$$

or

$$U_{c,r} = \frac{P_s}{P_s - f e_w}\left[u_r^2(e_w) + u_r^2(P_s) + u_r^2(f)\right] \qquad (2)$$

where

r_w = saturation mixing ratio
P_s = saturator pressure
f = enhancement factor
e_w = saturation water vapor pressure over a plane surface of the pure phase of liquid water or solid ice at the saturator temperature.

The experimental uncertainties are given in equations 3 - 5.

$$u_r(e_w) = \frac{u(e_w)}{e_w} = \textit{saturation vapor pressure relative uncertainty} \quad (3)$$

$$u_r(e_w) = \frac{u(P_s)}{P_s} = \textit{saturtor pressure relative uncertainty} \quad (4)$$

$$u_r(f) = \frac{u(f)}{f} = \textit{enhancement factor relative uncertainty} \quad (5)$$

Additionally, the combined uncertainty in temperature measurement is used to calculate standard uncertainties in saturation water vapor pressure based on the International Temperature scale of 1990 [4,5]. Previous data of temperature and water vapor pressure obtained for table 24 of reference 1 were based on the International Practical Temperature Scale of 1968 [6]. The type A and Type B uncertainties of table 1 were used to calculate the experimental uncertainties listed for $u_r(e_w)$, $u_r(P_s)$, and $u_r(f)$. The last column of relative expanded uncertainties is then computed using equation (1).

Furthermore, NIST policy requires that the value of a measureand should be confidently asserted to lie within an interval about a measurement result. The measure of uncertainty intended to meet this requirement is termed expanded uncertainty, U, and is obtained by multiplying the combined standard uncertainty, u_c, by a coverage factor, k. A coverage factor of 1, 2, and 3 defines an interval for the value of a measureand having approximate level of confidence 68.3, 95.4, and 99.7 percent of a normal distribution, respectively.

Under the new NIST policy, a coverage factor of 2 is generally used to provide the expanded uncertainty values. The calculated relative expanded uncertainties in mixing ratio, volume ratio, dew-point temperature, and relative humidity for the NIST two-pressure humidity generator are listed in tables 1 and 2 of this document, and they supersede tables 24 and 26 of reference 1, respectively. The relative expanded uncertainties associated with humidity parameters are similar in value to those previously listed in reference 1. For a humidity parameter described by a normal distribution, the relative expanded uncertainty listed in table 2 defines an interval having a level of confidence of approximately 95 percent.

Table 1. Experimental Uncertainties

Saturator Temp. (°C)	Saturator Press. (Pa)	Type B Uncertainties Temp. (°C)	Type B Uncertainties Press. (Pa)	Type A Uncertainties Temp. (°C)	Type A Uncertainties Press. (Pa)	$u_r(e_w)$	$u_r(P_s)$	$u_r(f)$	Rel. Expanded Uncertainties with k = 2 $u_{c,r}$ x 100* (%)
-20	2×10^5	0.012	69.0	0.00014	13.80	0.00115	0.00035	0.00035	0.25
-20	1×10^5	0.012	69.0	0.00016	15.90	0.00115	0.00071	0.00018	0.27
-20	1×10^5	0.012	69.0	0.00015	6.20	0.00115	0.00069	0.00018	0.27
-20	5×10^5	0.012	69.0	0.00011	8.27	0.00115	0.00014	0.00086	0.29
0	5×10^5	0.004	69.0	0.00004	11.00	0.00029	0.00014	0.00065	0.14
0	2×10^5	0.004	69.0	0.00003	3.00	0.00029	0.00035	0.00027	0.11
0	1×10^5	0.004	69.0	0.00003	5.50	0.00029	0.00069	0.00014	0.15
25	1×10^5	0.004	69.0	0.00011	7.60	0.00024	0.00069	0.00006	0.15
25	5×10^5	0.004	69.0	0.00004	8.27	0.00024	0.00014	0.00036	0.09
25	2×10^5	0.004	69.0	0.00006	2.77	0.00024	0.00035	0.00016	0.09
25	2×10^5	0.004	69.0	0.00014	6.20	0.00024	0.00035	0.00016	0.09

* computed from equation(1)

Table 2. NIST Two-Pressure Humidity Generator, Mark 2, Range and Uncertainty

Humidity parameter	Range	Expanded Uncertainty, k = 2
Mixing ratio, r_w (g water vapor/kg dry air)	$0.0015 \leq r_w < 0.005$	1.5% of value
	$0.005 \leq r_w < 0.1$	1.0% of value
	$0.1 \leq r_w < 0.3$	0.5% of value
	$0.3 \leq r_w < 515$	0.3% of value
Volume ratio, V (ppm)		
	$3 \leq V < 10$	1.5% of value
	$10 \leq V < 170$	1.0% of value
	$170 \leq V < 500$	0.5% of value
	$500 \leq V < 820{,}000$	0.3% of value
Dew-point temperature, T_d (°C)		
	$-70 \leq T_d < -35$	0.1
	$-35 \leq T_d < +40$	0.04
Relative humidity, RH (%) at test chamber temperature T_c (°C) of:		
$-55 \leq T_c < -40$	3-98	1.5
$-40 \leq T_c < -20$	3-98	0.8
$-20 \leq T_c < 0$	3-98	0.4
$0 \leq T_c < +40$	3-98	0.2

REFERENCES

[1] Huang, P.H., "NIST Calibration Services for Humidity Measurement", NISTIR 4677 (October 1991).

[2] Taylor, B.N. and Kuyatt, C.E., "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results", NIST Technical Note 1297 (1993).

[3] ISO, "Guide to the Expression of Uncertainty in Measurement", ISO Technical Advisory Group 4 (TAG 4) and Working Group 3 (WG 3) (1993)

[4] Preston-Thomas, H., "The International Temperature Scale of 1990 (ITS-90)", Metrologia **27**, 3-10 (1990); ibid., 107 (1990).

[5] Huang, P.H., "Thermodynamic Properties of Moist Air Containing 1000 to 5000 ppm_v of Water Vapor", NISTIR 5741, 43-51 (April 1993).

[6] "The International Practical Temperature Scale of 1968, Amended Edition of 1975", Metrologia **12**, 7 (1976).