Test Chamber Temperature Uniformity Analysis
of the
Thunder Scientific Model 9500 Two-Pressure Humidity Generator

By Michael Hamilton

1 Introduction

The Test Chamber Temperature Uniformity for a Model 9500 Humidity Generator is described in this analysis. The 9500 operates by generating the %RH setpoint based on pressure and temperatures, which include the test chamber temperature probe. This means the system automatically compensates for any temperature difference in the test chamber based on the actual chamber temperature probe reading. In scenarios where the device under test is not bundled with the chamber temperature probe or when there are multiple devices under test in the test chamber, temperature variations within the test chamber can contribute to the overall %RH uncertainty of the generator.

2 Test Chamber

The Model 9500 Humidity Generator incorporates a 12" x 12" x 12" test chamber (Figure 1) that is completely immersed in a water bath on all six sides. The bath provides temperature conditioning and thermal stability to the test space and associated humidity-generating components. Lowering the bath allows chamber cover removal for full access to the test space. Access is also available through circular ports in the chamber cover or circular port cover adapters. The air inlet is located on the lower right side of the chamber, and the air outlet is on the upper left side. The chamber pressure measurement port is located near the front corner on the upper left side. The chamber temperature probe can be positioned wherever needed within the chamber.

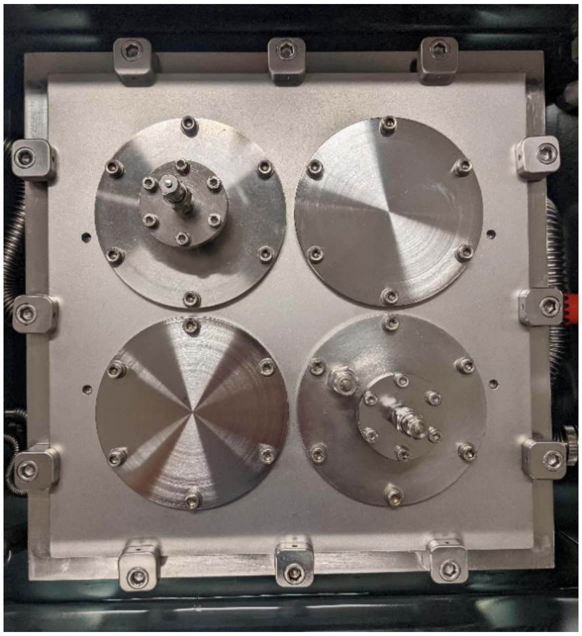

Figure 1

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2.1 Test Setup

Testing was completed using Model 9500 serial number 22030154. Two Fluke 1504s (EN0169 & EN0171) with 9" 5644 probes were used as temperature references. The probes were positioned in the center of the access ports on a four-port chamber lid. The probes extended roughly 5" into the chamber (Figures 1 & 2). To help eliminate systematic errors and uncertainty of the two references used, their positions are swapped at each temperature point. This swapping allows each 1504 to measure each position. The final temperature for a position is then defined as the average reading between the two 1504s, effectively canceling any error or uncertainty caused by the reference.

During the test, distilled water was used as the bath fluid. Approximately one thousand 20mm diameter Hollow Bath Balls from LW Scientific[1] were used in the bath as a thermal insulator or "Water Bath Blanket" to help evaporation at higher temperatures (Figure 2). A chilled mirror hygrometer was connected using a heated hose to record the dew point within the chamber. The heated hose ran in Delta 60 °C mode, where the hose temperature is maintained at 60 °C warmer than the measured dew point. The hose was positioned next to position 4 or position 2 after lid rotation (Figure 3).

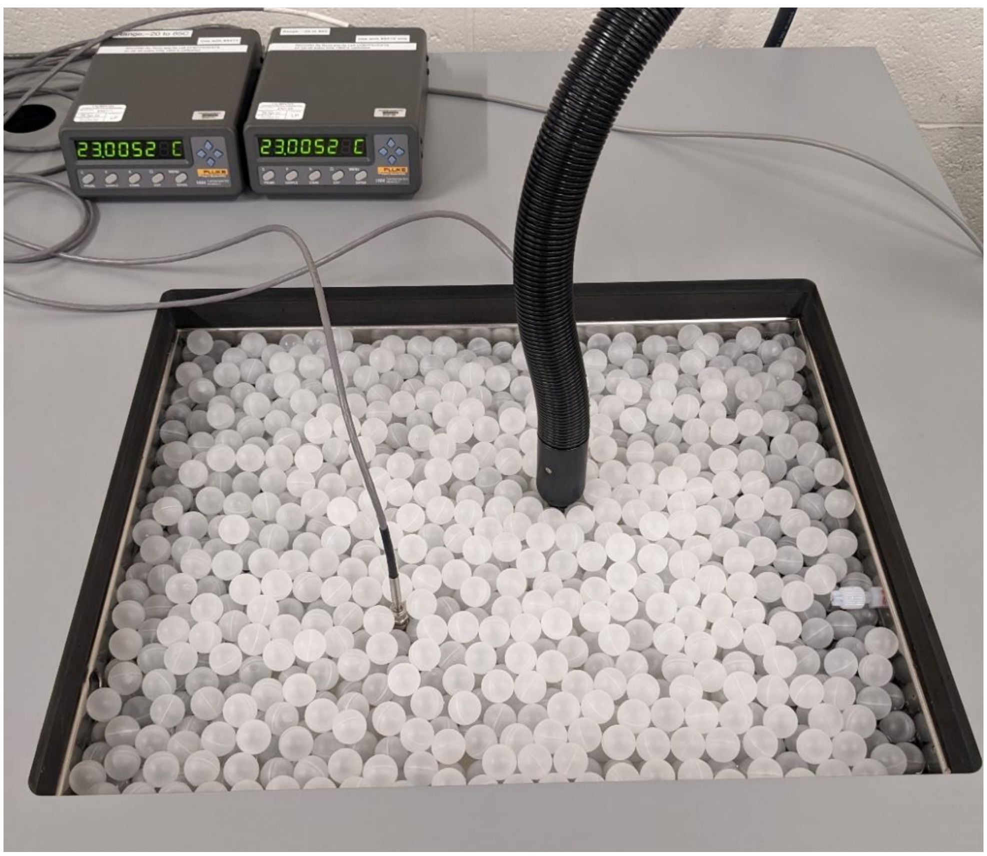

Figure 2

[1] https://www.lwscientific.com/products/hollow-bath-ball-blanket. (2022). Retrieved from https://www.lwscientific.com/.

Arbitrary dew and frost point temperatures were generated during testing to simulate typical calibration conditions. The test chamber pressure was controlled at 12.5 psiA to provide a slight positive pressure, so the chilled mirror's pump was not required.

The average ambient lab temperature during testing was 23.8 ± 0.5 °C. The temperature was measured using a Fluke 1504 (EN0002) about 6" back from the chamber opening and roughly 16" above the countertop surface.

Tables 1 & 2 list the test chamber conditions for each test point along with the 1504's positions within the test chamber (Figure 3).

Test Point #	Bath Fluid Setpoint (°C)	Dew/Frost (°C)	Chamber Pressure (psiA)	Mass Flow Rate (L/min)	Position	
					EN0171	EN0169
1	72	50	12.5	50	1	4
2	72	50	12.5	50	4	1
3	72	50	12.5	100	4	1
4	72	50	12.5	100	1	4
5	50	30	12.5	50	1	4
6	50	30	12.5	50	4	1
7	50	30	12.5	100	4	1
8	50	30	12.5	100	1	4
9	35	20	12.5	50	1	4
10	35	20	12.5	50	4	1
11	35	20	12.5	100	4	1
12	35	20	12.5	100	1	4
13	25	0	12.5	50	1	4
14	25	0	12.5	50	4	1
15	25	0	12.5	100	4	1
16	25	0	12.5	100	1	4
17	15	-10	12.5	50	1	4
18	15	-10	12.5	50	4	1
19	15	-10	12.5	100	4	1
20	15	-10	12.5	100	1	4
21	5	-20	12.5	50	1	4
22	5	-20	12.5	50	4	1
23	5	-20	12.5	100	4	1
24	5	-20	12.5	100	1	4

Table 1

Test Point #	Bath Fluid Setpoint (°C)	Dew/Frost (°C)	Chamber Pressure (psiA)	Mass Flow Rate (L/min)	Position	
					EN0171	EN0169
25	72	50	12.5	50	3	2
26	72	50	12.5	50	2	3
27	72	50	12.5	100	2	3
28	72	50	12.5	100	3	2
29	50	30	12.5	50	3	2
30	50	30	12.5	50	2	3
31	50	30	12.5	100	2	3
32	50	30	12.5	100	3	2
33	35	20	12.5	50	3	2
34	35	20	12.5	50	2	3
35	35	20	12.5	100	2	3
36	35	20	12.5	100	3	2
37	25	0	12.5	50	3	2
38	25	0	12.5	50	2	3
39	25	0	12.5	100	2	3
40	25	0	12.5	100	3	2
41	15	-10	12.5	50	3	2
42	15	-10	12.5	50	2	3
43	15	-10	12.5	100	2	3
44	15	-10	12.5	100	3	2
45	5	-20	12.5	50	3	2
46	5	-20	12.5	50	2	3
47	5	-20	12.5	100	2	3
48	5	-20	12.5	100	3	2

Table 2

Testing was performed at the default mass flow rate of 50 L/min and the maximum mass flow rate of 100 L/min. Questions regularly arise regarding which mass flow rate through the chamber is best. Increased mass flow rate usually helps the device(s) under test as it exchanges the humidity within the chamber faster. This increased exchange rate helps bring the device(s) to point faster, but control stability becomes a concern at higher flow rates. Any pressure drop caused by control instability within the chamber can significantly affect temperature uniformity. The ideal gas law defines that a pressure change causes a temperature change when the volume is held constant. This temperature effect can regularly be observed whenever the chamber pressurizes or depressurizes to the setpoint. The default 50 L/min mass flow rate has generally been determined to be the best compromise, but this analysis explores the impact of the maximum mass flow rate on the test chamber's temperature uniformity.

3 Test Chamber Temperature Uniformity

The chamber temperature uniformity is broken into two parts for this analysis: temperature variation and temperature fluctuations.

3.1 Temperature Variation

Chamber temperature variation is calculated using four positions within the chamber (Figure 3). At each point, 10 minutes of data is recorded in either positions 1 and 4 or 2 and 3. The lid is rotated 90 ° to change from positions 1 and 4 to 2 and 3. At the end of the ten minutes, the probes are swapped between positions 1 and 4 or 2 and 3. The probes are given time to equilibrate, and 10 minutes of data is recorded for each reference at the new position.

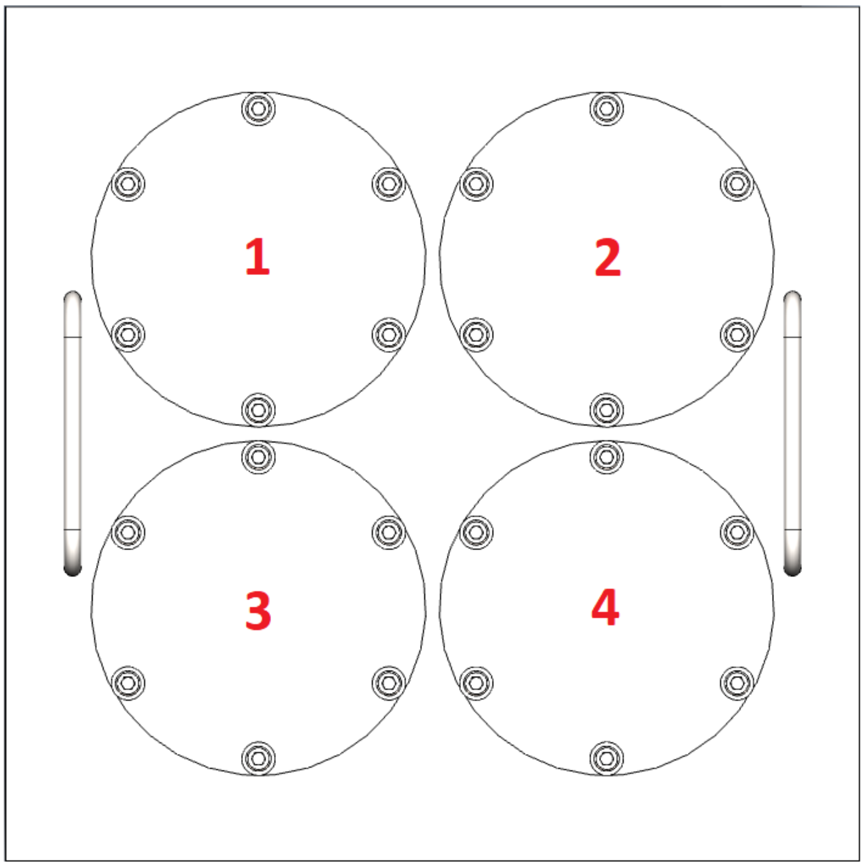

Figure 3

The average for each position is then calculated using the 10 minutes of data from each 1504. The variation at each temperature is determined as the highest average position reading of the two 1504s minus the lowest average position reading of the two 1504s (Equation 1).

$$\text{Temperature Variation} = 0.5 * (\text{Max Reading} - \text{Min Reading}) \quad [1]$$

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The temperature variation is calculated for each temperature point at the default 50 L/min mass flow rate (Table 3).

Average Chamber Temperature Variation (U_v)						
	50 L/min					
°C	Position 1	Position 2	Position 3	Position 4	Variation	Average
72	71.9765	71.9772	71.9784	71.9769	0.0009	0.0011
50	49.9872	49.9906	49.9902	49.9874	0.0017	
35	34.9967	34.9964	34.9963	34.9969	0.0003	
25	25.0041	25.0005	25.0004	25.0040	0.0018	
15	15.0105	15.0079	15.0077	15.0105	0.0014	
5	5.0136	5.0138	5.0134	5.0140	0.0003	

Max Reading	Min Reading

Table 3

The temperature variation is calculated for each temperature point at the maximum 100 L/min mass flow rate (Table 4).

Average Chamber Temperature Variation (U_v)						
	100 L/min					
°C	Position 1	Position 2	Position 3	Position 4	Variation	Average
72	71.9758	71.9783	71.9790	71.9760	0.0016	0.0011
50	49.9885	49.9896	49.9896	49.9887	0.0006	
35	34.9987	34.9982	34.9980	34.9989	0.0005	
25	25.0041	25.0026	25.0023	25.0042	0.0009	
15	15.0107	15.0083	15.0067	15.0104	0.0020	
5	5.0142	5.0132	5.0128	5.0144	0.0008	

Max Reading	Min Reading

Table 4

A combined temperature variation is calculated for each temperature point at either mass flow rate. This combined temperature variation shows the worst possible position-to-position comparison independent of the mass flow rate. The largest or maximum temperature position variation is then used to determine the overall test chamber temperature variation U_v (Table 5).

Average Chamber Temperature Variation (U_v)										
	50 L/min				100 L/min					
°C	Position 1	Position 2	Position 3	Position 4	Position 1	Position 2	Position 3	Position 4	Position Variation	Maximum
72	71.9765	71.9772	71.9784	71.9769	71.9758	71.9783	71.9790	71.9760	0.0016	0.0020
50	49.9872	49.9906	49.9902	49.9874	49.9885	49.9896	49.9896	49.9887	0.0017	
35	34.9967	34.9964	34.9963	34.9969	34.9987	34.9982	34.9980	34.9989	0.0013	
25	25.0041	25.0005	25.0004	25.0040	25.0041	25.0026	25.0023	25.0042	0.0019	
15	15.0105	15.0079	15.0077	15.0105	15.0107	15.0083	15.0067	15.0104	0.0020	
5	5.0136	5.0138	5.0134	5.0140	5.0142	5.0132	5.0128	5.0144	0.0008	

Max Reading	Min Reading

Table 5

3.2 Temperature Fluctuations

Test chamber temperature fluctuation U_f is the largest or maximum standard deviation calculated for each 1504 position at each temperature point over 10 minutes (Tables 6 & 7). Test chamber temperature fluctuations U_f are determined individually for both mass flow rates.

Chamber Temperature Fluctuations (U_f)									
	Mass Flow Rate = 50 L/min								
	EN0169				EN0171				Maximum
°C	Position 1	Position 2	Position 3	Position 4	Position 1	Position 2	Position 3	Position 4	
72	0.0021	0.0015	0.0016	0.0011	0.0010	0.0015	0.0009	0.0013	0.0024
50	0.0006	0.0012	0.0023	0.0006	0.0004	0.0024	0.0016	0.0004	
35	0.0003	0.0005	0.0007	0.0004	0.0003	0.0007	0.0003	0.0001	
25	0.0004	0.0007	0.0008	0.0003	0.0004	0.0005	0.0008	0.0003	
15	0.0006	0.0007	0.0007	0.0008	0.0005	0.0007	0.0008	0.0003	
5	0.0003	0.0003	0.0003	0.0007	0.0006	0.0003	0.0006	0.0002	

Average 0.0008

Table 6

Chamber Temperature Fluctuations (U_f)									
°C	Mass Flow Rate = 100 L/min								Maximum
	EN0169				EN0171				
	Position 1	Position 2	Position 3	Position 4	Position 1	Position 2	Position 3	Position 4	
72	0.0012	0.0016	0.0016	0.0016	0.0009	0.0009	0.0010	0.0010	0.0025
50	0.0011	0.0008	0.0025	0.0005	0.0004	0.0022	0.0007	0.0007	
35	0.0006	0.0007	0.0007	0.0004	0.0004	0.0006	0.0005	0.0003	
25	0.0005	0.0005	0.0006	0.0009	0.0009	0.0004	0.0004	0.0004	
15	0.0006	0.0015	0.0009	0.0005	0.0002	0.0004	0.0006	0.0006	
5	0.0006	0.0004	0.0007	0.0005	0.0004	0.0006	0.0003	0.0005	
							Average 0.0008		

Table 7

3.3 Combined Temperature Uniformity

The combined standard uncertainty is obtained by the statistical combination of the individual standard uncertainty components of Temperature Variation (U_v) (Table 5) and Temperature Fluctuations (U_f) (Tables 6 & 7), as summarized in Table 8.

9500 Test Chamber Temperature Uniformity Components of Uncertainty					
Description	Uncertainty (±)	k=	Distribution	Degrees of Freedom	Evaluation
Average Chamber Temperature Variation (U_v)	0.002	1	Normal	1919.0	Type A
Chamber Temperature Fluctuations (U_f) - 50 L/min	0.0024	1	Normal	959.0	Type A
Chamber Temperature Fluctuations (U_f) - 100 L/min	0.0025	1	Normal	959.0	Type A
Combined Standard Uncertainty (±):					0.004
Effective Degrees of Freedom:					3063.602
Confidence:					95.45%
k:					2.00
Expanded Combined Uncertainty (±):					0.008

Table 8

The final Test Chamber Temperature Uniformity Specification for the Model 9500 Two-Pressure Humidity Generator can then be defined as:

uniformity specification = 0.008 °C [2]

3.4 Summary

Both mass flow rates had the same average temperature variation of 0.0011 °C across the temperature range (Tables 3 & 4). The higher 100 L/min mass flow rate had 5 out of 6 of the Max Readings, and the default 50 L/min mass flow rate had only 1 Max Reading. Both mass flow rates had an equal number of Min Readings with 3 out of 6 (Table 5).

The variations across the temperature ranges were similar. Position 3 appeared as a consistent cold spot, and position 4 appeared as a consistent hot spot at both mass flow rates (Tables 3 & 4). This hot spot might be a combination of being near the chamber inlet and next to the heated hose.

Temperature fluctuations were very similar between the two mass flow rates, with the same average of 0.0008 °C, and the maximums only differed by 0.0001 °C (Tables 6 & 7).

Temperature fluctuations were overall more prominent in the higher temperature ranges. These larger fluctuations are likely caused by the additional bath maintenance cycles required to maintain the correct bath level as bath fluid is lost to evaporation. Each bath maintenance cycle adds or removes water from the holding tank. Since the holding tank is at ambient or cabinet temperature, any addition of water causes a slight bath temperature change. This shows the importance of using some type of thermal insulator over the bath, such as the hallow bath balls used in this test, when operating above ambient temperatures.

[2] Chamber Temperature Uniformity is defined as the maximum temperature difference between any two locations over the temperature range of 0 °C to 72 °C when using a thermal insulator over the bath, such as hallow bath balls. Locations are defined at the center of the chamber lid access ports, approximately 5" into the chamber. It is recommended to use this specification as a rectangular distribution.

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