Uncertainty Analysis
of the
Thunder Scientific Model 1220 Two-Pressure Humidity Generator

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1.0 Introduction

Described here is the generated humidity uncertainty analysis, following the Guidelines of NIST and NCSL International [1, 6, 7], for a Model 1220 Humidity Generator that utilizes the NIST developed and proven two-pressure humidity generation principle [2, 3]. Generation of humidity in a system of this type does not require direct measurements of the water vapor content of the gas. Rather, the generated humidity is derived from the measurements of saturation and chamber pressures, and saturation and chamber temperatures.

The measurement instrumentation used in both our in-house working standards and our manufactured devices are obtained from companies which have demonstrated either NIST traceability or traceability to other acceptable standards. In most cases, we use the specifications supplied by these manufacturers as the starting point for our uncertainty statements. Over time, comparison calibrations against a NIST traceable pressure gauge and NIST traceable standard resistance thermometer, as well as the results of an on-going intercomparison program of both the individual components and of the outputs of generators as a system, have allowed the determination of the ranges of disagreement among the various temperatures and pressures that go into the final determination of the output uncertainties. The average values of these disagreements represent the uncertainties from our in-house processes and things like instrument drift over time; and these are coupled with the uncertainties given by the various instrument manufacturers to give overall uncertainty statements.

This document lists the various uncertainty sources, their magnitudes, and their origins over the operating range of the Model 1220 generator (refer to the specifications section in the Model 1220 system manual for exact operating range).

2.0 Defining Equations

NIST Technical Note 1297[1] states that the uncertainty in a dependent variable, which depends only on uncorrelated input variables, is

$$u^2(y) = \sum_i u^2(x_i)\left(\frac{\partial y}{\partial x_i}\right)^2 \qquad (1)$$

Relative Humidity is defined as the amount of water vapor in a sample compared to the maximum amount possible at the given sample's temperature and pressure.

This can be expressed by the following formula:

$$\%RH = \frac{e(T_D)\cdot f(T_D, P_C)}{e(T_C)\cdot f(T_C, P_C)}\cdot \eta_S \qquad (2)$$

Where the *f* functions are enhancement factors, *e* is the saturation vapor pressure, η_S is the % efficiency of saturation, T_C is the chamber temperature, T_D is Dew/Frost point temperature, and Pc is the chamber pressure.

The Dew/Frost point temperatures can be expressed by the following formulas:

$$e_W(T_D)\cdot f(T_D, P_C) = f(T_S, P_S)\cdot e(T_S)\cdot \frac{P_C}{P_S} \qquad (3)$$

Document: Model_1220_Uncertainty_Analysis
Author: Michael Hamilton
Date: August 2024

$$e_I(T_F)\cdot f(T_F,P_C) = f(T_S,P_S)\cdot e(T_S)\cdot\frac{P_C}{P_S} \tag{4}$$

Where the *f* functions are enhancement factors, e_w is the saturation vapor pressure over water, e_I is the saturation vapor pressure over ice, T_D, T_F, T_S are the Dew point, Frost point and saturation temperatures, and Pc and Ps are the chamber and saturation pressures. Note that the actual Dew/Frost point temperature is defined implicitly and must be obtained through iterative solving.

Combining equation 2 with equations 3 and 4 we can express Relative Humidity in the terms of saturation and chamber temperatures and saturation and chamber pressure only by the following formula:

$$\%RH = \frac{e(T_S)\cdot f(T_S,P_S)}{e(T_C)\cdot f(T_C,P_C)}\cdot\frac{P_C}{P_S}\cdot\eta_S \tag{5}$$

By incorporating the relationship in equation 1 into an uncertainty equation of the form of equation 5, it can be shown that the total uncertainty in relative humidity is given by the expression:

$$u^2(RH) = u^2(T_C)\left(\frac{\partial RH}{\partial T_C}\right)^2 + u^2(T_S)\left(\frac{\partial RH}{\partial T_S}\right)^2 + u^2(P_C)\left(\frac{\partial RH}{\partial P_C}\right)^2 + u^2(P_S)\left(\frac{\partial RH}{\partial P_S}\right)^2 + u^2(\eta_S)\left(\frac{\partial RH}{\partial \eta_S}\right)^2 \tag{6}$$

Similarly incorporating the relationship in equation 1 into an uncertainty equation of the form of equation 3 and 4, the uncertainties in dew point and frost point measurement are given by the expression:

$$u^2(T_D) = u^2(T_S)\left(\frac{\partial T_D}{\partial T_S}\right)^2 + u^2(P_C)\left(\frac{\partial T_D}{\partial P_C}\right)^2 + u^2(P_S)\left(\frac{\partial T_D}{\partial P_S}\right)^2 + u^2(\eta_S)\left(\frac{\partial T_D}{\partial \eta_S}\right)^2 \tag{7}$$

and

$$u^2(T_F) = u^2(T_S)\left(\frac{\partial T_F}{\partial T_S}\right)^2 + u^2(P_C)\left(\frac{\partial T_F}{\partial P_C}\right)^2 + u^2(P_S)\left(\frac{\partial T_F}{\partial P_S}\right)^2 + u^2(\eta_S)\left(\frac{\partial T_F}{\partial \eta_S}\right)^2 \tag{8}$$

3 Uncertainty Components

In the mathematical analysis of equations 6, 7 and 8, we will analyze the uncertainties due to each component separately and then combine the uncertainties to obtain the total expanded uncertainty. We are concerned with four basic categories of uncertainty: pressure, temperature, the saturation vapor pressure/enhancement factor equations and percent efficiency of the saturator. Each of these categories may also have associated uncertainty components. In determining components of uncertainty, there are several things to consider, such as measurement accuracy or uncertainty, measurement resolution, uniformity, etc.

Listed below are the identified major uncertainty contributors and their components for the Model 1220 humidity generator.

- Uncertainty contribution from pressure (P_s and P_c) which includes
  - Measurement accuracy
    - Reference standard
    - Linearity
    - Drift (P_c includes long-term drift)
    - Hysteresis
    - Temperature effects over the calibrated range
    - Repeatability
  - Measurement resolution

- Uncertainty contribution from temperature (T_s and T_c), which includes
  - Measurement accuracy
    - Reference standard
    - Measurement resolution
    - Module error
    - Hysteresis
    - Self-Heating
    - Stability (Repeatability)
  - Temperature control stability (Applies to Saturation Temperature (T_s) only)
  - Chamber Uniformity (Applies to Chamber Temperature (T_c) only)

- Uncertainty contribution from Equations, which includes
  - Saturation Vapor Pressure Equation (e(T))
  - Enhancement Factor Equation (f(T,P))

- Uncertainty contribution from percent efficiency of the saturator (η_S)

3.1 Pressure Uncertainty Contribution

The pressure terms, P_c or P_s, in a two-pressure humidity generator are major determining factors. The Model 1220 humidity generator uses one pressure transducer to measure the saturation pressure and another pressure transducer to measure the chamber pressure. In this design, each pressure transducer contributes its own uncertainty to the overall system and will be addressed independent of one another.

The pressure uncertainty contribution in terms of relative humidity can be determined by the partial numeric differential of the RH equation with respect to pressure, multiplied by the uncertainty of the pressure component. The equation for this becomes.

$$uRH_{[component]} = \frac{\partial}{\partial P}\left[\frac{e_S(T_S)\cdot f(T_S,P_S)}{e_S(T_C)\cdot f(T_C,P_C)}\cdot\frac{P_C}{P_S}\cdot\eta_S\right]\cdot uP_{[component]} \quad (9)$$

$uRH_{[component]}$ = Pressure component uncertainty in terms of percent relative humidity.

$uP_{[component]}$ = Pressure component uncertainty in terms of pressure.

The pressure uncertainty contribution in terms of dew or frost point temperature can be determined by the partial numeric differential of the iterative dew or frost point equation with respect to pressure, multiplied by the uncertainty of the pressure component. The equation for this becomes

$$uT_{D[component]} = \frac{\partial}{\partial P}\left[e_W(T_D)\cdot f(T_D,P) = f(T_S,P_S)\cdot e(T_S)\cdot\frac{P_C}{P_S}\right]\cdot uP_{[component]} \quad (10)$$

$$uT_{F[component]} = \frac{\partial}{\partial P}\left[e_I(T_F)\cdot f(T_F,P) = f(T_S,P_S)\cdot e(T_S)\cdot\frac{P_C}{P_S}\right]\cdot uP_{[component]} \quad (11)$$

$uT_{D[component]}$ = Pressure component uncertainty in terms of dew point temperature.

$uT_{F[component]}$ = Pressure component uncertainty in terms of frost point temperature.

$uP_{[component]}$ = Pressure component uncertainty in terms of pressure.

3.1.1 Pressure Accuracy Uncertainty Component

Pressure measurement accuracy of Model 1220 humidity generator's saturation pressure transducer is specified by the manufacturer as 0.02% of the full scale. This total manufacturer uncertainty (k=2) includes reference standard, linearity, drift, hysteresis, temperature effects over the calibrated range and repeatability. Taking a conservative approach that is based on a rectangular distribution, the uncertainty component of the saturation pressure accuracy is then

$uP_{s[accuracy]}$ = (160 psia (full scale) * 0.02%) / √3
= (0.032 psia) / √3 (DOF=infinite)

Pressure measurement accuracy of Model 1220 humidity generator's chamber pressure transducer is specified by the manufacturer as 0.02% of reading. This total manufacturer uncertainty (k=2) includes reference standard, linearity, drift, hysteresis, temperature effects over the calibrated range and repeatability. While the Model 1220's pressure transducers show excellent stability over 180 days, some slight drift can be observed in the chamber pressure transducer over a year interval. To account for this drift, a long-term drift component will be combined with the manufacturer specification to define the accuracy of the chamber pressure transducer, as shown in Table 1.

Model 1220 Chamber Pressure (Pc) Components of Uncertainty					
Description	Uncertainty (±)	k=	Distribution	Degrees of Freedom	Evaluation
Manufacturer Specification	0.00294	1	Rectangular	Infinity	Type B
Long-Term Drift	0.00306	1	Normal	Infinity	Type B
				Combined Standard Uncertainty (±):	0.00350
				Effective Degrees of Freedom:	Infinity
				Confidence:	95.45%
				k:	2
				Expanded Combined Uncertainty (±):	0.00700

Table 1

Using the expanded result from Table 1, the uncertainty component of chamber pressure accuracy is then

$uP_{c[accuracy]}$ = 0.007 psia
(using a coverage factor, k=2, at an approximate level of confidence of 95%)

Note: This analysis will use standard pressure as the chamber pressure reading for all calculations

3.1.2 Pressure Resolution Uncertainty Component

The Model 1220 humidity generator digitally communicates with both the saturation and chamber pressure transducers. Based on a rectangular distribution of the half-interval of resolution, the uncertainty component of pressure resolution is then

$uP_{s\,[resolution]}$ = 0.001 psia / √12 (DOF=infinite)

$uP_{c\,[resolution]}$ = 0.001 psia / √12 (DOF=infinite)

3.1.3 Pressure Uncertainty Contribution Summary

The standard %RH uncertainties (*uRH*) components calculated using equation 9 from the associated individual pressure components are summarized in Table 2 and Figure 1.

Standard Pressure Uncertainty Components of %RH											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
		98.0%RH	**73.6%RH**	**49.2%RH**	**37.0%RH**	**29.6%RH**	**19.9%RH**	**15.0%RH**	**10.1%RH**		
5 °C	Ps Accuracy	0.120298	0.067667	0.030074	0.016916	0.010826	0.004811	0.002706	0.001202	Infinity	Type B
	Ps Resolution	0.001880	0.001057	0.000470	0.000264	0.000169	0.000075	0.000042	0.000019	Infinity	Type B
	Pc Accuracy	0.023256	0.017462	0.011668	0.008771	0.007033	0.004716	0.003557	0.002399	Infinity	Type B
	Pc Resolution	0.000019	0.000014	0.000010	0.000007	0.000006	0.000004	0.000003	0.000002	Infinity	Type B
	Combined	*0.122540*	*0.069892*	*0.032262*	*0.019057*	*0.012911*	*0.006737*	*0.004470*	*0.002683*	*Infinity*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.1%RH**		
30 °C	Ps Accuracy	0.120366	0.067708	0.030093	0.016927	0.010834	0.004815	0.002708	0.001203	Infinity	Type B
	Ps Resolution	0.001881	0.001058	0.000470	0.000264	0.000169	0.000075	0.000042	0.000019	Infinity	Type B
	Pc Accuracy	0.023269	0.017468	0.011668	0.008767	0.007027	0.004706	0.003546	0.002386	Infinity	Type B
	Pc Resolution	0.000019	0.000014	0.000010	0.000007	0.000006	0.000004	0.000003	0.000002	Infinity	Type B
	Combined	*0.122609*	*0.069933*	*0.032279*	*0.019065*	*0.012914*	*0.006733*	*0.004462*	*0.002673*	*Infinity*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.0%RH**		
60 °C	Ps Accuracy	0.120326	0.067715	0.030110	0.016941	0.010843	0.004820	0.002711	0.001205	Infinity	Type B
	Ps Resolution	0.001880	0.001058	0.000470	0.000265	0.000169	0.000075	0.000042	0.000019	Infinity	Type B
	Pc Accuracy	0.023261	0.017463	0.011662	0.008761	0.007020	0.004698	0.003537	0.002376	Infinity	Type B
	Pc Resolution	0.000019	0.000014	0.000010	0.000007	0.000006	0.000004	0.000003	0.000002	Infinity	Type B
	Combined	*0.122568*	*0.069939*	*0.032293*	*0.019074*	*0.012918*	*0.006731*	*0.004457*	*0.002664*	*Infinity*	

Table 2

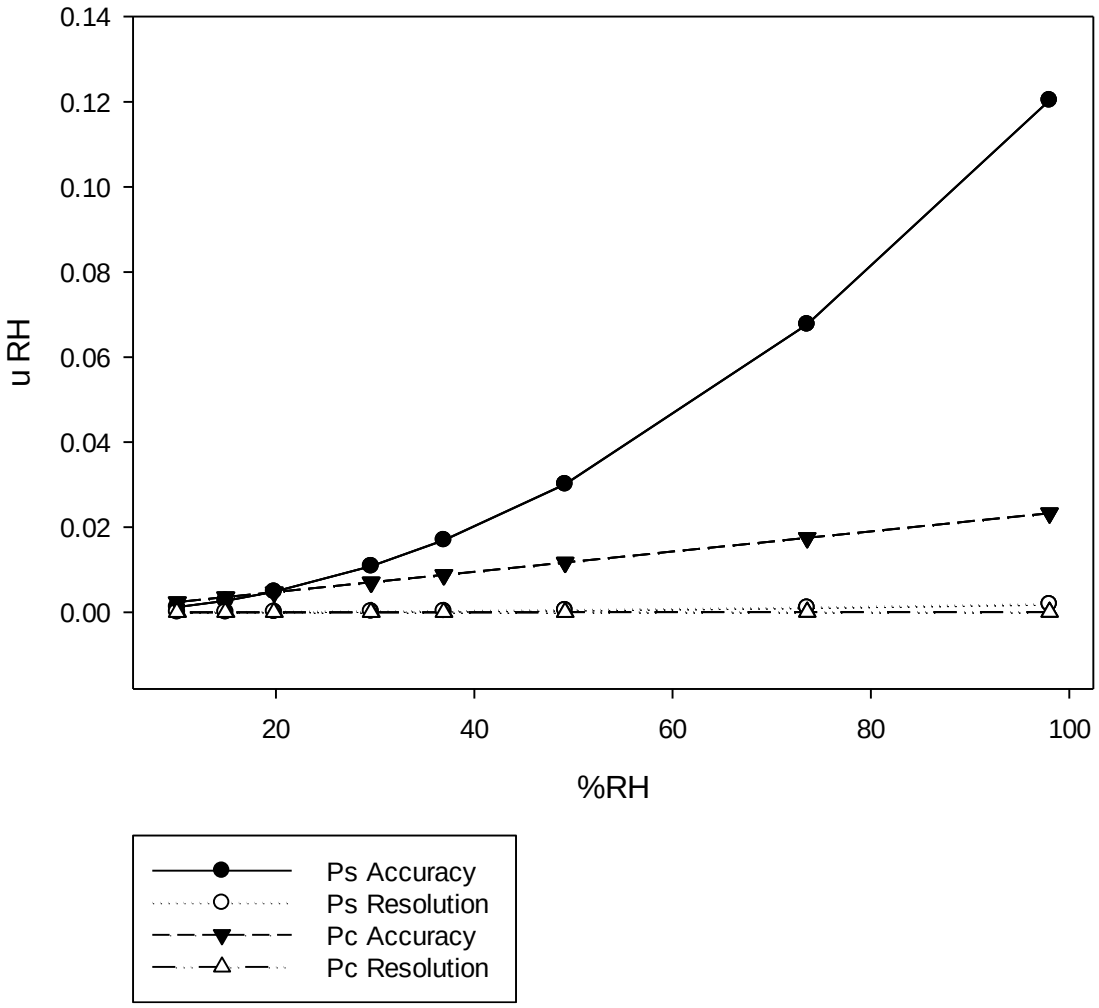

Figure 1

The standard Dew Point Temperature uncertainties (uT_D) components calculated using equation 10 from the associated individual pressure components are summarized in Table 3 and Figure 2.

Standard Pressure Uncertainty Components of Dew Point Temperature (°C)											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
		4.7 °C	**0.7 °C**	**-4.8 °C**	**-8.5 °C**	**-11.3 °C**	**-16.2 °C**	**-19.5 °C**	**-24.0 °C**		
5 °C	Ps Accuracy	0.017556	0.012727	0.008092	0.005869	0.004575	0.002907	0.002106	0.001333	Infinity	Type B
	Ps Resolution	0.000274	0.000199	0.000126	0.000092	0.000071	0.000045	0.000033	0.000021	Infinity	Type B
	Pc Accuracy	0.003394	0.003284	0.003139	0.003042	0.002970	0.002847	0.002765	0.002657	Infinity	Type B
	Pc Resolution	0.000003	0.000003	0.000003	0.000003	0.000002	0.000002	0.000002	0.000002	Infinity	Type B
	Combined	*0.017883*	*0.013145*	*0.008680*	*0.006611*	*0.005455*	*0.004069*	*0.003476*	*0.002973*	*Infinity*	
		29.6 °C	**24.8 °C**	**18.2 °C**	**13.7 °C**	**10.4 °C**	**4.5 °C**	**0.5 °C**	**-4.8 °C**		
30 °C	Ps Accuracy	0.021325	0.015401	0.009744	0.007044	0.005478	0.003468	0.002506	0.001583	Infinity	Type B
	Ps Resolution	0.000333	0.000241	0.000152	0.000110	0.000086	0.000054	0.000039	0.000025	Infinity	Type B
	Pc Accuracy	0.004122	0.003973	0.003777	0.003647	0.003551	0.003388	0.003280	0.003137	Infinity	Type B
	Pc Resolution	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	Infinity	Type B
	Combined	*0.021722*	*0.015907*	*0.010451*	*0.007933*	*0.006529*	*0.004848*	*0.004128*	*0.003514*	*Infinity*	
		59.6 °C	**53.5 °C**	**45.4 °C**	**40.0 °C**	**35.9 °C**	**28.8 °C**	**24.0 °C**	**17.5 °C**		
60 °C	Ps Accuracy	0.026423	0.018991	0.011941	0.008598	0.006666	0.004200	0.003026	0.001905	Infinity	Type B
	Ps Resolution	0.000413	0.000297	0.000187	0.000134	0.000104	0.000066	0.000047	0.000030	Infinity	Type B
	Pc Accuracy	0.005108	0.004899	0.004627	0.004448	0.004317	0.004095	0.003949	0.003757	Infinity	Type B
	Pc Resolution	0.000004	0.000004	0.000004	0.000004	0.000004	0.000003	0.000003	0.000003	Infinity	Type B
	Combined	*0.026915*	*0.019615*	*0.012807*	*0.009681*	*0.007943*	*0.005866*	*0.004975*	*0.004213*	*Infinity*	

Table 3

Standard Pressure Uncertainty Components of Dew Point Temperature (°C)

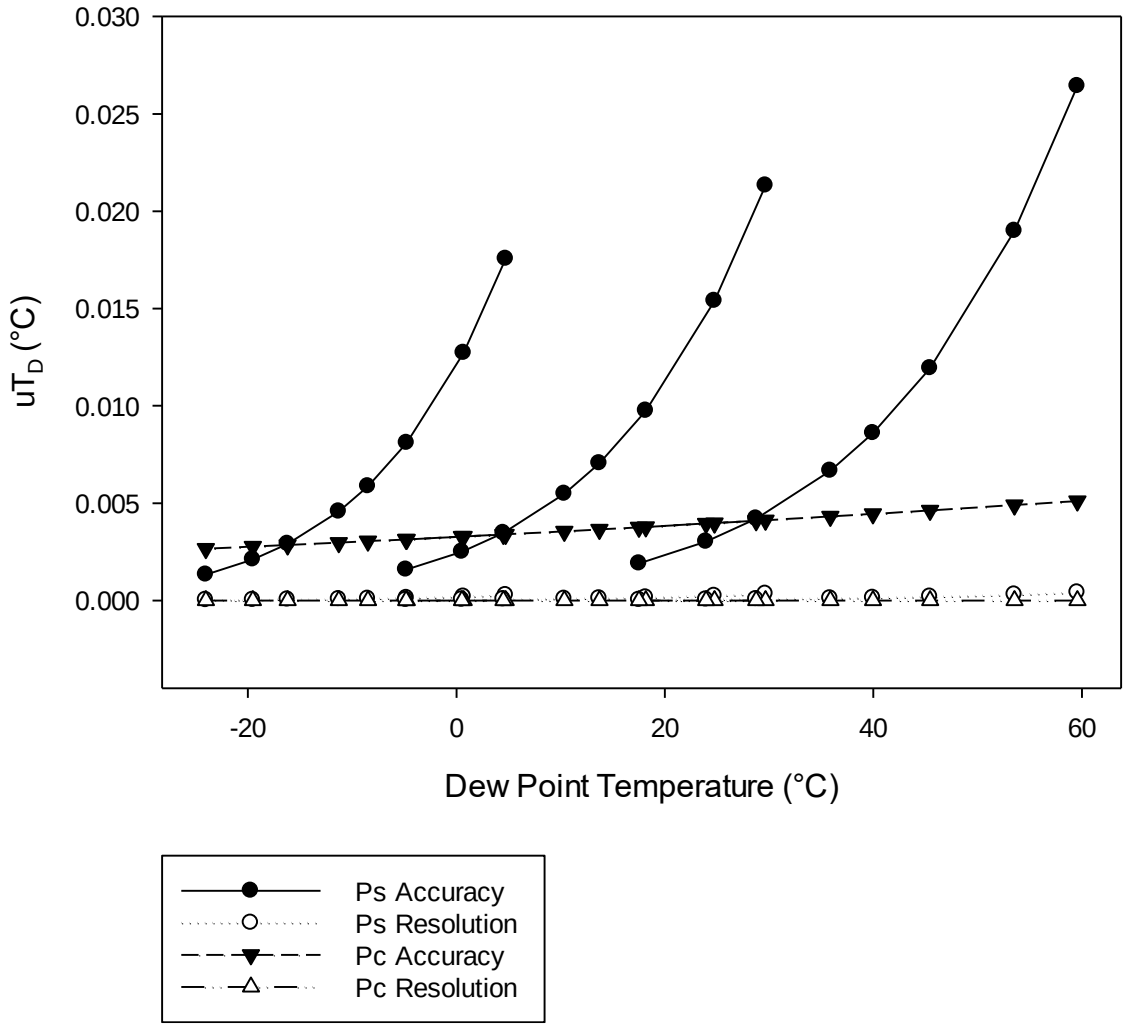

Figure 2

The standard Frost Point Temperature uncertainties **(uT_F)** components calculated using equation 11 from the associated individual pressure components are summarized in Table 4 and Figure 3.

Note: Any frost point value that is not possible is grayed out of the following table.

Standard Pressure Uncertainty Components of Frost Point Temperature (°C)											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
				-4.2 °C	**-7.5 °C**	**-10.1 °C**	**-14.5 °C**	**-17.5 °C**	**-21.6 °C**		
5 °C	Ps Accuracy			0.007197	0.005252	0.004113	0.002635	0.001919	0.001223	Infinity	Type B
	Ps Resolution			0.000112	0.000082	0.000064	0.000041	0.000030	0.000019	Infinity	Type B
	Pc Accuracy			0.002791	0.002722	0.002670	0.002580	0.002520	0.002439	Infinity	Type B
	Pc Resolution			0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	Infinity	Type B
	Combined			*0.007720*	*0.005916*	*0.004904*	*0.003688*	*0.003167*	*0.002728*	*Infinity*	
									-4.3 °C		
30 °C	Ps Accuracy								0.001408	Infinity	Type B
	Ps Resolution								0.000022	Infinity	Type B
	Pc Accuracy								0.002790	Infinity	Type B
	Pc Resolution								0.000002	Infinity	Type B
	Combined								*0.003125*	*Infinity*	
60 °C	Ps Accuracy									Infinity	Type B
	Ps Resolution									Infinity	Type B
	Pc Accuracy									Infinity	Type B
	Pc Resolution									Infinity	Type B
	Combined									*Infinity*	

Table 4

Standard Pressure Uncertainty Components of Frost Point Temperature (°C)

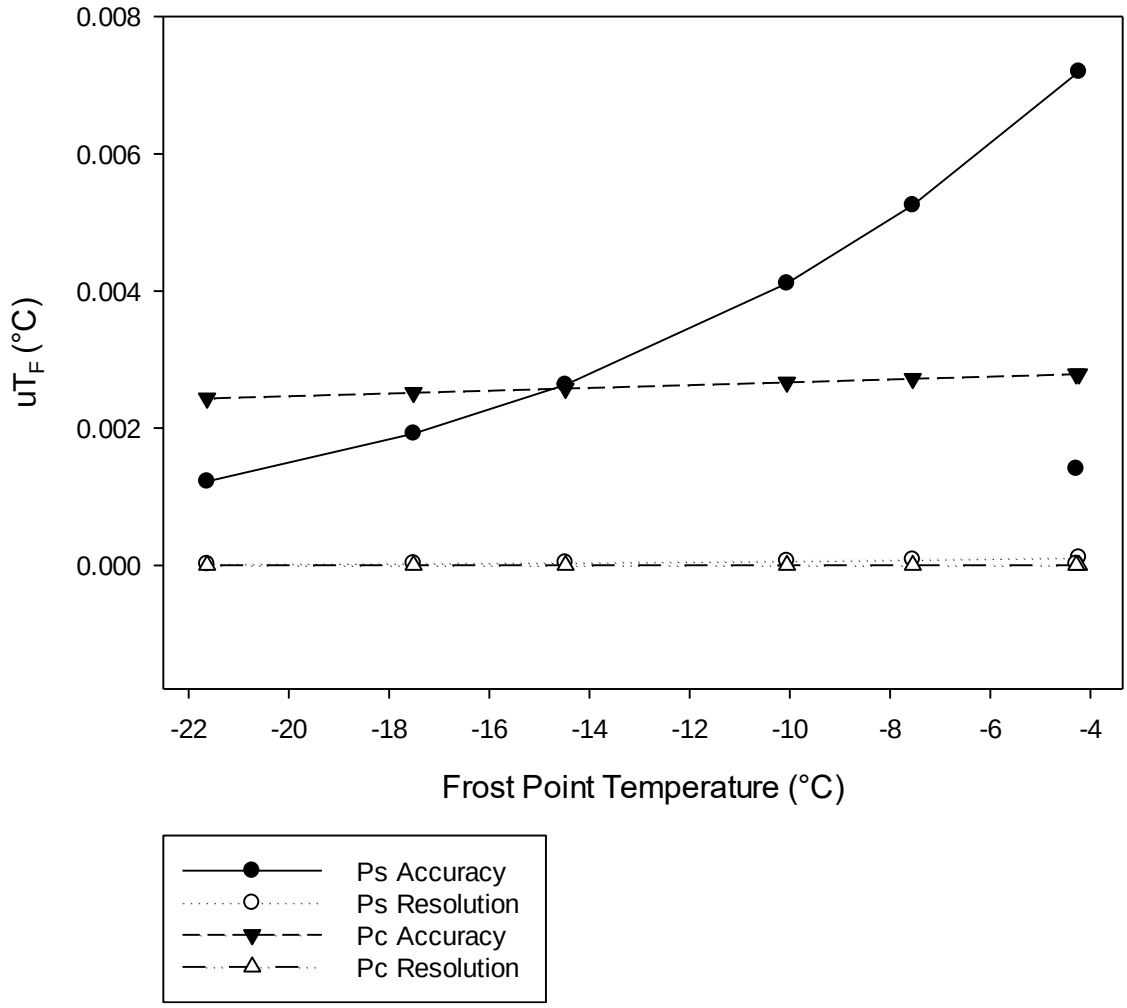

Figure 3

3.2 Temperature Uncertainty Contribution

The temperature terms, T_c or T_s, in a two-pressure humidity generator are another major contributor of uncertainty and are used mathematically to calculate saturation vapor pressures. The Model 1220 humidity generator uses one temperature probe to measure the saturation temperature and another temperature probe to measure the chamber temperature. In this design, each temperature probe contributes its own uncertainty to the overall system and will be addressed independent of one another.

3.2.1 Saturation Temperature Uncertainty Contribution

The saturation temperature uncertainty contribution in terms of relative humidity can be determined by the partial numeric differential of the RH equation with respect to saturation temperature, multiplied by the uncertainty of the saturation temperature component. The equation for this becomes

$$\mathrm{uRH}_{[\mathrm{component}]} = \frac{\partial}{\partial T_S}\left[\frac{e_S(T_S)\cdot f(T_S,P_S))}{e_S(T_C)\cdot f(T_C,P_C)}\cdot\frac{P_C}{P_S}\cdot\eta_S\right]\cdot \mathrm{u}T_{S[\mathrm{component}]} \quad (15)$$

$\mathrm{uRH}_{[\mathrm{component}]}$ = Saturation Temperature component uncertainty in terms of percent relative humidity.

$\mathrm{uT}_{S[\mathrm{component}]}$ = Saturation Temperature component uncertainty in terms of temperature.

The saturation temperature uncertainty contribution in terms of dew or frost point temperature can be determined by the partial numeric differential of the iterative dew or frost point equation with respect to saturation temperature, multiplied by the uncertainty of the saturation temperature component. The equations for these become

$$\mathrm{uT}_{\mathrm{D}[\mathrm{component}]} = \frac{\partial}{\partial T_S}\left[e_W(T_D)\cdot f(T_D,P_C) = f(T_S,P_S)\cdot e(T_S)\cdot\frac{P_C}{P_S}\right]\cdot \mathrm{uT}_{\mathrm{S}\,[\mathrm{component}]} \quad (16)$$

$$\mathrm{uT}_{\mathrm{F}[\mathrm{component}]} = \frac{\partial}{\partial T_S}\left[e_I(T_F)\cdot f(T_F,P_C) = f(T_S,P_S)\cdot e(T_S)\cdot\frac{P_C}{P_S}\right]\cdot \mathrm{uT}_{\mathrm{S}\,[\mathrm{component}]} \quad (17)$$

$\mathrm{uT}_{\mathrm{D}[\mathrm{component}]}$ = Saturation Temperature component uncertainty in terms of dew point temperature.

$\mathrm{uT}_{\mathrm{F}[\mathrm{component}]}$ = Saturation Temperature component uncertainty in terms of frost point temperature

$\mathrm{uT}_{\mathrm{S}[\mathrm{component}]}$ = Saturation Temperature component uncertainty in terms of temperature.

3.2.1.1 Saturation Temperature Measurement Uncertainty Component

Temperature measurement accuracy of Model 1220 humidity generator's saturation temperature probe encompasses 7 separate components that are listed and combined in Table 5.

Model 1220 Temperature Components of Uncertainty					
Description	Uncertainty (±)	k=	Distribution	Degrees of Freedom	Evaluation
Standard - 1560 Black Stack	0.02	2	Normal	Infinity	Type B
NI-9216 Resolution	0.0000625849	1	Resolution	Infinity	Type B
NI-9216 Offset Error	0.00237	1	Rectangular	Infinity	Type B
NI-9216 Gain Error	0.00002765	1	Rectangular	Infinity	Type B
5606 Hysteresis	0.015	1	Rectangular	Infinity	Type B
5606 Self Heating	0.003	1	Rectangular	Infinity	Type B
Fluid Control Stability	0.002	1	Normal	Infinity	Type A
				Combined Standard Uncertainty (±):	0.01356
				Effective Degrees of Freedom:	Infinity
				Confidence:	95.45%
				k:	2
				Expanded Combined Uncertainty (±):	0.02712

Table 5

Using the expanded result from Table 5 and taking a conservative approach that is based on a rectangular distribution, the uncertainty component of saturation temperature accuracy is then

$$uT_{s[accuracy]} = 0.027\ °C / \sqrt{3}\ (DOF=infinite)$$

resulting in

$$uT_{s[accuracy]} = 0.031\ °C$$

(using a coverage factor, k=2, at an approximate level of confidence of 95%)

3.2.1.2 Saturation Temperature Control Stability

The Model 1220 humidity generating system encompasses a computer-controlled fluid temperature circuit that uses distilled water as the heat transfer medium. This medium is responsible for conditioning the temperature of the test chamber and humidity generating components to provide stable temperature and humidity levels.

The fluid temperature stability inherently impacts the saturation temperature stability. To quantify the uncertainty contributed by the system's overall temperature control stability, the average standard deviation of the saturation temperature probe (RTD1) was determined from the 10-minute sample period of each temperature during chamber uniformity testing [9].

$uT_{s\,[stability]}$ = 0.005 °C (DOF= infinite)

3.2.2 Chamber Temperature Uncertainty Contribution

The chamber temperature uncertainty contribution in terms of relative humidity can be determined by the partial numeric differential of the RH equation with respect to chamber temperature, multiplied by the uncertainty of the chamber temperature component. The equation for this becomes

$$uRH_{[component]} = \frac{\partial}{\partial T_C}\left[\frac{e_S(T_S)\cdot f(T_S,P_S)}{e_S(T_C)\cdot f(T_C,P_C)}\cdot\frac{P_C}{P_S}\cdot\eta_S\right]\cdot uT_{C[component]} \quad (18)$$

$uRH_{[component]}$ = Chamber Temperature component uncertainty in terms of percent relative humidity.

$uT_{C[component]}$ = Chamber Temperature component uncertainty in terms of temperature.

Examining equations 3 and 4, dew and frost point equations, we see that the chamber temperature has no component and, therefore, no uncertainty contribution to the generated dew or frost point temperatures.

3.2.2.1 Chamber Temperature Measurement Uncertainty Component

Temperature measurement accuracy of Model 1220 humidity generator's chamber temperature probe encompasses 7 separate components that are the same as those listed in Table 4. Using the expanded result from table 4 and taking a conservative approach that is based on a rectangular distribution, the uncertainty component of chamber temperature accuracy is then

$uT_{c[accuracy]}$ = 0.027 °C / √3 (DOF=infinite)

resulting in

$uT_{c[accuracy]}$ = 0.031 °C
(using a coverage factor, k=2, at an approximate level of confidence of 95%)

3.2.2.2 Chamber Temperature Uniformity Uncertainty Component

The 1220 operates by generating the %RH setpoint based on pressure and temperatures which include the chamber temperature probe. This means any temperature difference in the chamber is automatically compensated by the system 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 chamber then temperature gradients within the chamber can contribute to the overall %RH uncertainty of the generator. Using the expanded result from the "Model 1220 Chamber Temperature Uniformity Analysis" [9] that is based on a rectangular distribution, the uncertainty component of chamber temperature uniformity is then

$$uT_{c[uniformity]} = 0.05\ °C / \sqrt{3}\ (DOF=infinite)$$

3.2.3 Temperature Uncertainty Contribution Summary

The standard uncertainties (*uRH*) components calculated using equations 15 and 18 from the associated individual temperature components previously shown are summarized in Table 6 and Figure 4.

Standard Temperature Uncertainty Components of %RH											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
		98.0%RH	**73.6%RH**	**49.2%RH**	**37.0%RH**	**29.6%RH**	**19.9%RH**	**15.0%RH**	**10.1%RH**		
5 °C	Ts Accuracy	0.106568	0.080006	0.053444	0.040163	0.032195	0.021571	0.016259	0.010948	Infinity	Type B
	Ts Stability	0.034182	0.025662	0.017142	0.012882	0.010327	0.006919	0.005215	0.003512	Infinity	Type B
	Tc Accuracy	0.106569	0.080019	0.053468	0.040193	0.032228	0.021609	0.016300	0.010992	Infinity	Type B
	Tc Uniformity	0.197350	0.148183	0.099015	0.074432	0.059682	0.040016	0.030185	0.020355	Infinity	Type B
	Combined	*0.250658*	*0.188204*	*0.125750*	*0.094523*	*0.075787*	*0.050808*	*0.038319*	*0.025833*	*Infinity*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.1%RH**		
30 °C	Ts Accuracy	0.087757	0.065874	0.043989	0.033046	0.026480	0.017725	0.013348	0.008971	Infinity	Type B
	Ts Stability	0.028148	0.021129	0.014110	0.010600	0.008493	0.005685	0.004281	0.002877	Infinity	Type B
	Tc Accuracy	0.087758	0.065881	0.044003	0.033064	0.026501	0.017750	0.013375	0.009000	Infinity	Type B
	Tc Uniformity	0.162514	0.122001	0.081487	0.061230	0.049076	0.032870	0.024768	0.016667	Infinity	Type B
	Combined	*0.206412*	*0.154953*	*0.103492*	*0.077761*	*0.062322*	*0.041738*	*0.031446*	*0.021155*	*Infinity*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.0%RH**		
60 °C	Ts Accuracy	0.070776	0.053150	0.035501	0.026669	0.021367	0.014294	0.010757	0.007218	Infinity	Type B
	Ts Stability	0.022701	0.017048	0.011387	0.008554	0.006853	0.004585	0.003450	0.002315	Infinity	Type B
	Tc Accuracy	0.070774	0.053133	0.035484	0.026656	0.021359	0.014294	0.010761	0.007229	Infinity	Type B
	Tc Uniformity	0.131063	0.098395	0.065711	0.049363	0.039553	0.026470	0.019929	0.013387	Infinity	Type B
	Combined	*0.166466*	*0.124980*	*0.083469*	*0.062703*	*0.050241*	*0.033621*	*0.025309*	*0.016998*	*Infinity*	

Table 6

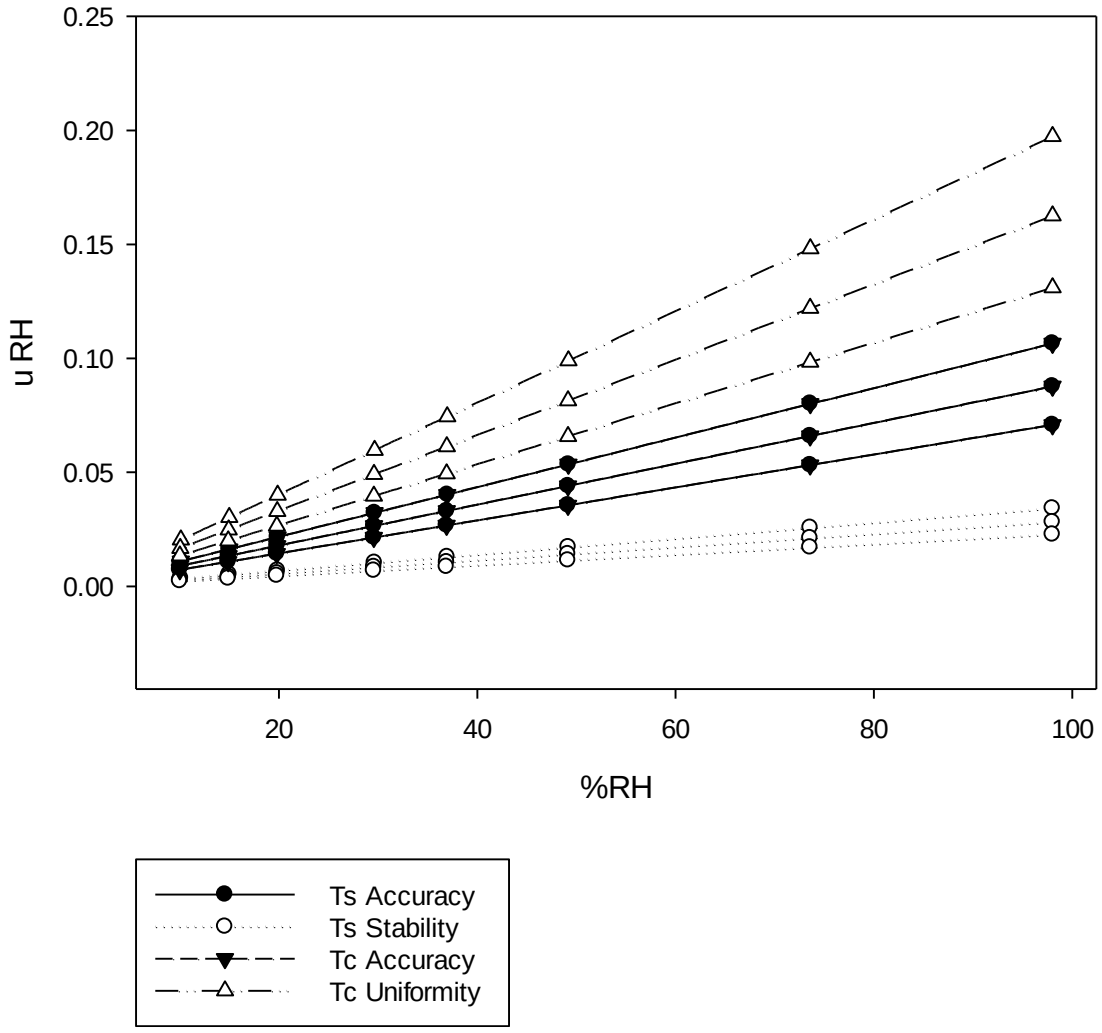

Figure 4

The standard uncertainties (uT_D) components calculated using equation 16 from the associated individual temperature components previously shown are summarized in Table 7 and Figure 5.

Standard Temperature Uncertainty Components of Dew Point Temperature (°C)											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
		4.7 °C	**0.7 °C**	**-4.8 °C**	**-8.5 °C**	**-11.3 °C**	**-16.2 °C**	**-19.5 °C**	**-24.0 °C**		
5 °C	Ts Accuracy	0.015552	0.015048	0.014380	0.013935	0.013604	0.013033	0.012651	0.012139	Infinity	Type B
	Ts Stability	0.004988	0.004827	0.004613	0.004470	0.004363	0.004180	0.004058	0.003894	Infinity	Type B
	Tc Accuracy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Infinity	Type B
	Tc Uniformity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Infinity	Type B
	Combined	*0.016332*	*0.015803*	*0.015102*	*0.014634*	*0.014287*	*0.013687*	*0.013286*	*0.012749*	*Infinity*	
		29.6 °C	**24.8 °C**	**18.2 °C**	**13.7 °C**	**10.4 °C**	**4.5 °C**	**0.5 °C**	**-4.8 °C**		
30 °C	Ts Accuracy	0.015548	0.014984	0.014243	0.013752	0.013389	0.012767	0.012352	0.011803	Infinity	Type B
	Ts Stability	0.004987	0.004806	0.004568	0.004411	0.004294	0.004095	0.003962	0.003786	Infinity	Type B
	Tc Accuracy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Infinity	Type B
	Tc Uniformity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Infinity	Type B
	Combined	*0.016328*	*0.015736*	*0.014958*	*0.014442*	*0.014060*	*0.013407*	*0.012972*	*0.012395*	*Infinity*	
		59.6 °C	**53.5 °C**	**45.4 °C**	**40.0 °C**	**35.9 °C**	**28.8 °C**	**24.0 °C**	**17.5 °C**		
60 °C	Ts Accuracy	0.015542	0.014906	0.014079	0.013535	0.013136	0.012456	0.012006	0.011413	Infinity	Type B
	Ts Stability	0.004985	0.004781	0.004516	0.004341	0.004213	0.003995	0.003851	0.003661	Infinity	Type B
	Tc Accuracy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Infinity	Type B
	Tc Uniformity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Infinity	Type B
	Combined	*0.016322*	*0.015654*	*0.014785*	*0.014214*	*0.013795*	*0.013081*	*0.012608*	*0.011986*	*Infinity*	

Table 7

Standard Temperature Uncertainty Components of Dew Point Temperature (°C)

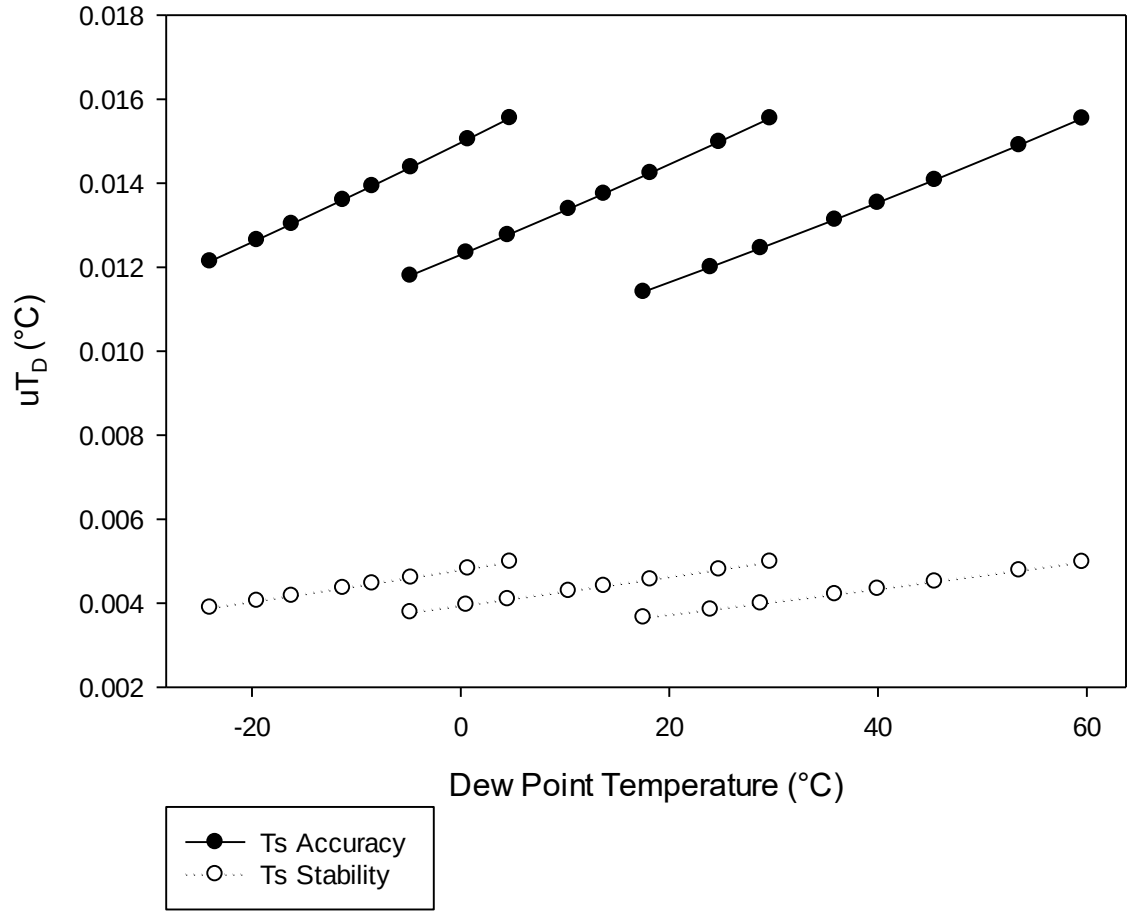

Figure 5

The standard uncertainties **(uT_F)** components calculated using equation 17 from the associated individual temperature components previously shown are summarized in Table 8 and Figure 6.

Note: Any frost point value that is not possible is grayed out of the following table.

Standard Temperature Uncertainty Components of Frost Point Temperature (°C)											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
				-4.2 °C	**-7.5 °C**	**-10.1 °C**	**-14.5 °C**	**-17.5 °C**	**-21.6 °C**		
5 °C	Ts Accuracy			0.012789	0.012470	0.012231	0.011812	0.011527	0.011141	Infinity	Type B
	Ts Stability			0.004102	0.004000	0.003923	0.003789	0.003697	0.003574	Infinity	Type B
	Tc Accuracy			0.0	0.0	0.0	0.0	0.0	0.0	Infinity	Type B
	Tc Uniformity			0.0	0.0	0.0	0.0	0.0	0.0	Infinity	Type B
	Combined			*0.013431*	*0.013096*	*0.012844*	*0.012405*	*0.012106*	*0.011700*	*Infinity*	
									-4.3 °C		
30 °C	Ts Accuracy								0.010498	Infinity	Type B
	Ts Stability								0.003367	Infinity	Type B
	Tc Accuracy								0.0	Infinity	Type B
	Tc Uniformity								0.0	Infinity	Type B
	Combined								*0.011025*	*Infinity*	
60 °C	Ts Accuracy									Infinity	Type B
	Ts Stability									Infinity	Type B
	Tc Accuracy									Infinity	Type B
	Tc Uniformity									Infinity	Type B
	Combined									*Infinity*	

Table 8

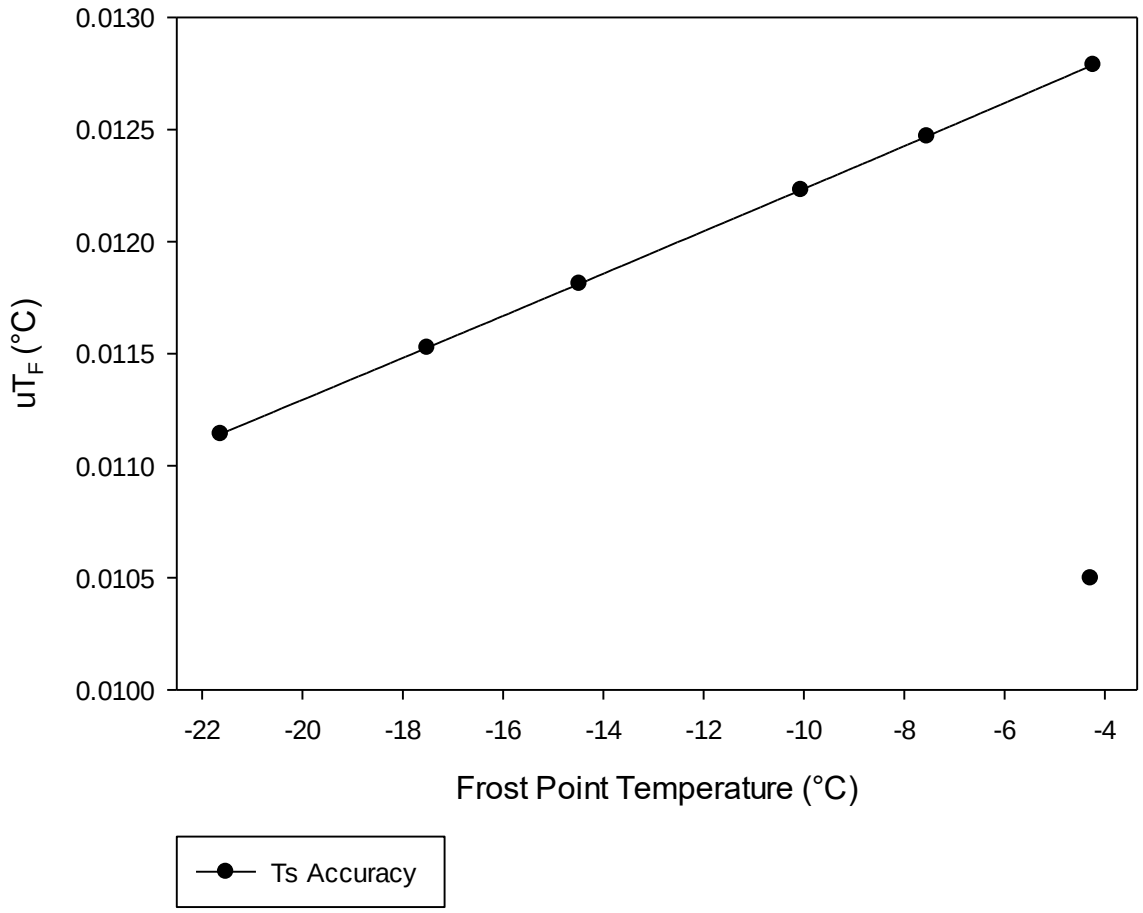

Figure 6

3.3 Equation Uncertainty Contribution

The equations used to calculate the saturation vapor pressure at a given temperature and its enhancement factor at the same temperature and given pressure have published uncertainties as determined by the author or authors of the equations. These equations are used throughout the Relative Humidity, Dew point and Frost point equations and therefore contribute their own uncertainty to the overall system.

3.3.1 Saturation Vapor Pressure Equation Uncertainty Component

The saturation vapor pressure is the partial pressure of the water vapor at a given temperature with respect to ice or water. The saturation vapor pressure is dependent on temperature only and is computed with the Wexler's [4] saturation vapor pressure equation. Wexler [4] also list a table of uncertainties at various temperatures for his saturation vapor pressure equation. These uncertainty values are interpolated to determine the saturation vapor pressure equation uncertainty component for a given temperature.

3.3.2 Enhancement Factor Equation Uncertainty Component

Enhancement factors are slight correction factors used to account for the non-ideal behavior of water vapor when admixed with other gases. The enhancement factor is dependent on both temperature and pressure and is computed with Greenspan's [5] enhancement factor equation. Wexler and R.W. Hyland [8] list a table of uncertainties for various temperatures and pressures for the enhancement factor equation. These uncertainty values are interpolated to determine the enhancement factors equation uncertainty component for a given temperature and pressure.

3.3.3 Equation Uncertainty Contribution Summary

The standard uncertainties (*uRH*) components calculated using the associated equation uncertainty tables mentioned above are summarized in Table 9 and Figure 7.

Standard Equation Uncertainty Components of %RH											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
		98.0%RH	**73.6%RH**	**49.2%RH**	**37.0%RH**	**29.6%RH**	**19.9%RH**	**15.0%RH**	**10.1%RH**		
5 °C	SVP@Ts	0.003825	0.002869	0.001912	0.001434	0.001147	0.000765	0.000574	0.000382	Infinity	Type B
	F@Ts,Ps	0.010115	0.009973	0.009843	0.009788	0.009764	0.009728	0.009535	0.009426	Infinity	Type B
	SVP@Tt	0.003825	0.002872	0.001919	0.001443	0.001157	0.000776	0.000585	0.000395	Infinity	Type B
	F@Tt,Pt	0.009925	0.007452	0.004980	0.003743	0.003001	0.002012	0.001518	0.001024	Infinity	Type B
	Combined	*0.015168*	*0.013095*	*0.011358*	*0.010675*	*0.010344*	*0.009994*	*0.009689*	*0.009498*	*Infinity*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.1%RH**		
30 °C	SVP@Ts	0.010554	0.007916	0.005277	0.003958	0.003166	0.002111	0.001583	0.001055	Infinity	Type B
	F@Ts,Ps	0.005152	0.005770	0.006395	0.006715	0.006912	0.007175	0.007209	0.007268	Infinity	Type B
	SVP@Tt	0.010555	0.007924	0.005292	0.003977	0.003187	0.002135	0.001609	0.001082	Infinity	Type B
	F@Tt,Pt	0.005000	0.003753	0.002507	0.001884	0.001510	0.001011	0.000762	0.000513	Infinity	Type B
	Combined	*0.016563*	*0.013146*	*0.010151*	*0.008951*	*0.008381*	*0.007844*	*0.007592*	*0.007441*	*Infinity*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.0%RH**		
60 °C	SVP@Ts	0.002345	0.001759	0.001173	0.000880	0.000704	0.000470	0.000352	0.000235	Infinity	Type B
	F@Ts,Ps	0.005194	0.006119	0.007051	0.007523	0.007813	0.008189	0.008220	0.008274	Infinity	Type B
	SVP@Tt	0.002345	0.001760	0.001176	0.000883	0.000708	0.000474	0.000357	0.000239	Infinity	Type B
	F@Tt,Pt	0.005016	0.003766	0.002515	0.001889	0.001514	0.001013	0.000763	0.000512	Infinity	Type B
	Combined	*0.007946*	*0.007603*	*0.007668*	*0.007857*	*0.008020*	*0.008278*	*0.008270*	*0.008296*	*Infinity*	

Table 9

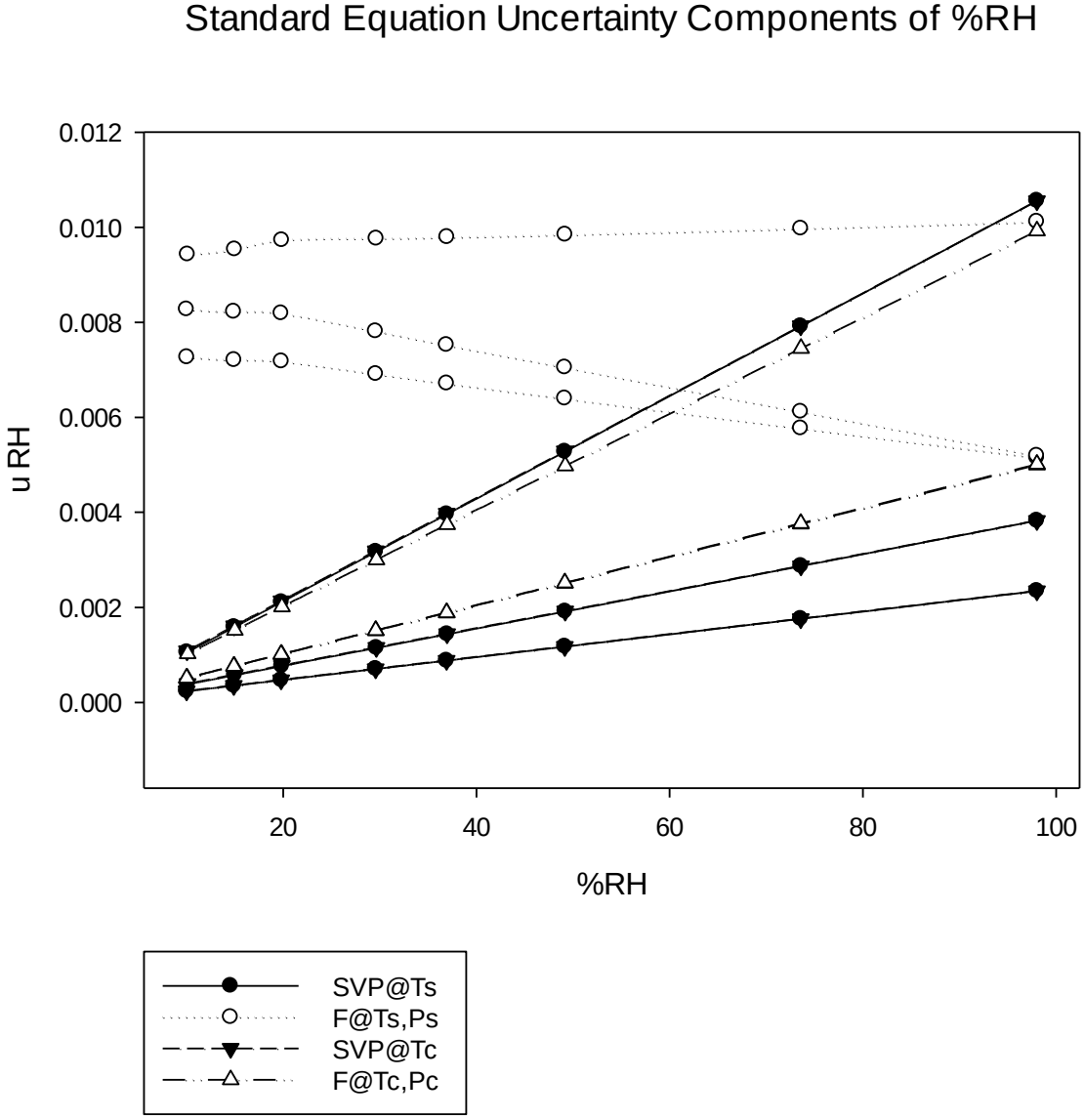

Figure 7

The standard uncertainties **(uT_D)** components calculated using the associated equation uncertainty tables mentioned above are summarized in Table 10 and Figure 8.

Standard Equation Uncertainty Components of Dew Point Temperature (°C)											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
		4.7 °C	**0.7 °C**	**-4.8 °C**	**-8.5 °C**	**-11.3 °C**	**-16.2 °C**	**-19.5 °C**	**-24.0 °C**		
5 °C	SVP@Ts	0.000558	0.000540	0.000515	0.000498	0.000485	0.000462	0.000446	0.000424	Infinity	Type B
	F@Ts,Ps	0.001476	0.001876	0.002648	0.003396	0.004126	0.005878	0.007419	0.010452	Infinity	Type B
	SVP@Td	0.000539	0.000264	0.000211	0.000204	0.000200	0.000191	0.000186	0.000179	Infinity	Type B
	F@Td,Pt	0.001448	0.001403	0.001664	0.001857	0.001992	0.002206	0.002339	0.002276	Infinity	Type B
	Combined	*0.002209*	*0.002418*	*0.003177*	*0.003908*	*0.004611*	*0.006298*	*0.007794*	*0.010707*	*Infinity*	
		29.6 °C	**24.8 °C**	**18.2 °C**	**13.7 °C**	**10.4 °C**	**4.5 °C**	**0.5 °C**	**-4.8 °C**		
30 °C	SVP@Ts	0.001870	0.001801	0.001709	0.001647	0.001601	0.001520	0.001465	0.001388	Infinity	Type B
	F@Ts,Ps	0.000913	0.001312	0.002071	0.002794	0.003495	0.005168	0.006671	0.009562	Infinity	Type B
	SVP@Td	0.001899	0.002184	0.001591	0.001219	0.000955	0.000524	0.000253	0.000211	Infinity	Type B
	F@Td,Pt	0.000916	0.001292	0.001608	0.001554	0.001514	0.001446	0.001401	0.001668	Infinity	Type B
	Combined	*0.002962*	*0.003377*	*0.003511*	*0.003797*	*0.004240*	*0.005602*	*0.006977*	*0.009808*	*Infinity*	
		59.6 °C	**53.5 °C**	**45.4 °C**	**40.0 °C**	**35.9 °C**	**28.8 °C**	**24.0 °C**	**17.5 °C**		
60 °C	SVP@Ts	0.000515	0.000493	0.000465	0.000447	0.000433	0.000409	0.000393	0.000371	Infinity	Type B
	F@Ts,Ps	0.001141	0.001716	0.002796	0.003818	0.004803	0.007135	0.009174	0.013082	Infinity	Type B
	SVP@Td	0.000534	0.000774	0.001008	0.001124	0.001447	0.001960	0.002109	0.001533	Infinity	Type B
	F@Td,Pt	0.001102	0.001056	0.001443	0.001892	0.001463	0.000987	0.001351	0.001599	Infinity	Type B
	Combined	*0.001751*	*0.002214*	*0.003336*	*0.004430*	*0.005243*	*0.007476*	*0.009518*	*0.013273*	*Infinity*	

Table 10

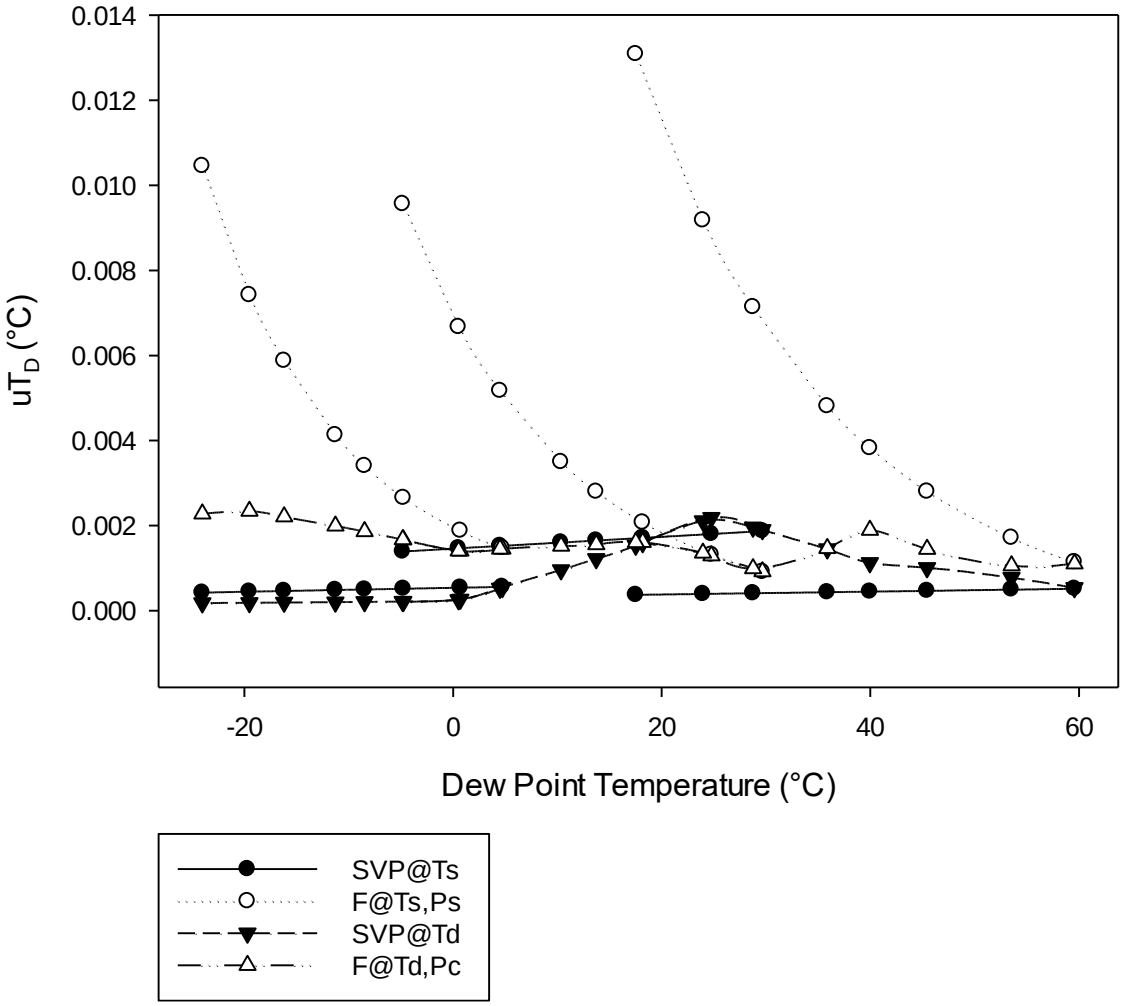

Figure 8

The standard uncertainties **(uT_F)** components calculated using the associated equation uncertainty tables mentioned above are summarized in Table 11 and Figure 9.

Note: Any frost point value that is not possible is grayed out of the following table.

Standard Equation Uncertainty Components of Frost Point Temperature (°C)											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
				-4.2 °C	**-7.5 °C**	**-10.1 °C**	**-14.5 °C**	**-17.5 °C**	**-21.6 °C**		
5 °C	SVP@Ts			0.000458	0.000445	0.000436	0.000419	0.000407	0.000389	Infinity	Type B
	F@Ts,Ps			0.002355	0.003039	0.003709	0.005327	0.006760	0.009593	Infinity	Type B
	SVP@Td			0.002880	0.004868	0.006298	0.008278	0.009550	0.011067	Infinity	Type B
	F@Td,Pt			0.001447	0.001606	0.001721	0.001905	0.002023	0.002088	Infinity	Type B
	Combined			*0.004018*	*0.005976*	*0.007522*	*0.010035*	*0.011881*	*0.014799*	*Infinity*	
									-4.3 °C		
30 °C	SVP@Ts								0.001235	Infinity	Type B
	F@Ts,Ps								0.008505	Infinity	Type B
	SVP@Td								0.002914	Infinity	Type B
	F@Td,Pt								0.001450	Infinity	Type B
	Combined								*0.009190*	*Infinity*	
60 °C	SVP@Ts									Infinity	Type B
	F@Ts,Ps									Infinity	Type B
	SVP@Td									Infinity	Type B
	F@Td,Pt									Infinity	Type B
	Combined									*Infinity*	

Table 11

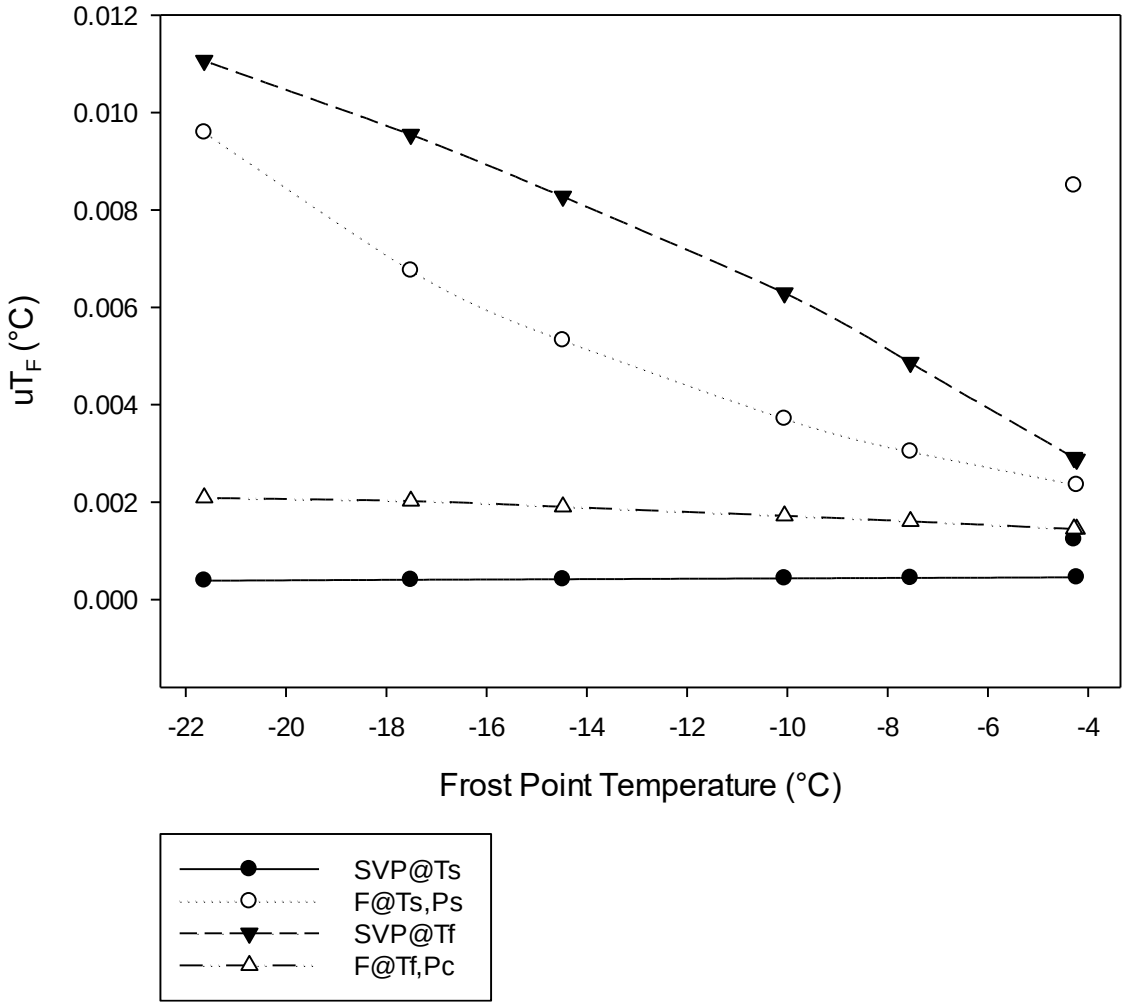

Figure 9

3.4 Saturator Efficiency Uncertainty Contribution

All two-pressure humidity generators rely on the saturator's ability to fully saturate the gas with water vapor as it passes from the inlet to the outlet. The Model 1220 humidity generator incorporates a pre-saturator device along with the saturator to ensure the complete saturation of the gas with water vapor. Although this design helps ensure 100% saturation of the gas, there may still be small amounts of uncertainty.

Based on engineering research and development work on the Model 1220, the uncertainty component of % efficiency of saturation is determined to be

$$\eta_S = 99.91\%$$

The standard uncertainties (*uRH*) components calculated using the above associated % efficiency component are summarized in Table 12 and Figure 10.

Standard Saturator Efficiency Uncertainty Components of %RH											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
		98.0%RH	**73.6%RH**	**49.2%RH**	**37.0%RH**	**29.6%RH**	**19.9%RH**	**15.0%RH**	**10.1%RH**		
5 °C	η_S	0.088206	0.066230	0.044255	0.033267	0.026675	0.017885	0.013491	0.009098	Infinity	Type B
	Combined	*0.088206*	*0.066230*	*0.044255*	*0.033267*	*0.026675*	*0.017885*	*0.013491*	*0.009098*	*Infinity*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.1%RH**		
30 °C	η_S	0.088205	0.066217	0.044228	0.033233	0.026636	0.017840	0.013443	0.009046	Infinity	Type B
	Combined	*0.088205*	*0.066217*	*0.044228*	*0.033233*	*0.026636*	*0.017840*	*0.013443*	*0.009046*	*Infinity*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.0%RH**		
60 °C	η_S	0.088206	0.066220	0.044223	0.033221	0.026619	0.017815	0.013412	0.009009	Infinity	Type B
	Combined	*0.088206*	*0.066220*	*0.044223*	*0.033221*	*0.026619*	*0.017815*	*0.013412*	*0.009009*	*Infinity*	

Table 12

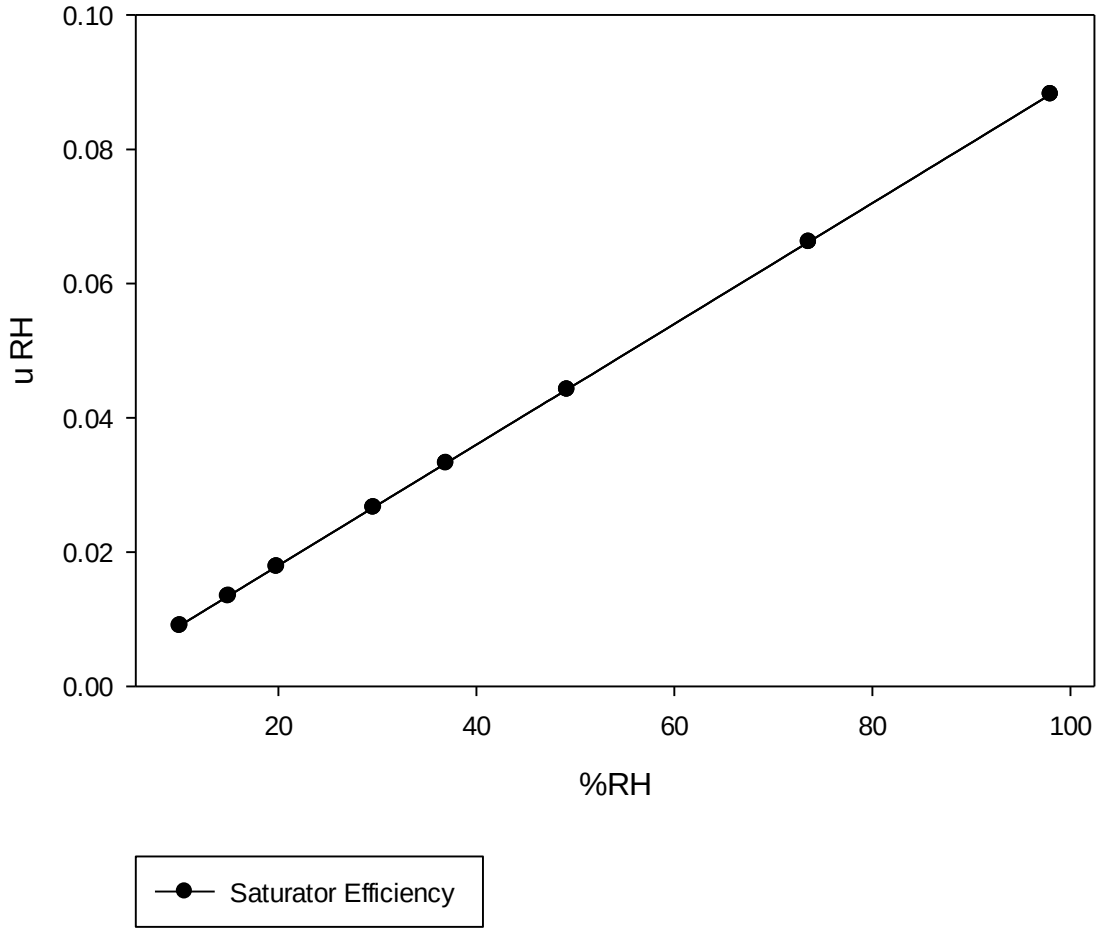

Figure 10

The standard uncertainties (uT_D) components calculated using the above associated % efficiency component are summarized in Table 13 and Figure 11.

Standard Saturator Efficiency Uncertainty Components of Dew Point Temperature (°C)											
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
		4.7 °C	**0.7 °C**	**-4.8 °C**	**-8.5 °C**	**-11.3 °C**	**-16.2 °C**	**-19.5 °C**	**-24.0 °C**		
5 °C	η_S	0.012872	0.012457	0.011908	0.011542	0.011272	0.010807	0.010497	0.010088	Infinity	Type B
	Combined	*0.012872*	*0.012457*	*0.011908*	*0.011542*	*0.011272*	*0.010807*	*0.010497*	*0.010088*	*Infinity*	
		29.6 °C	**24.8 °C**	**18.2 °C**	**13.7 °C**	**10.4 °C**	**4.5 °C**	**0.5 °C**	**-4.8 °C**		
30 °C	η_S	0.015627	0.015062	0.014320	0.013829	0.013468	0.012850	0.012440	0.011902	Infinity	Type B
	Combined	*0.015627*	*0.015062*	*0.014320*	*0.013829*	*0.013468*	*0.012850*	*0.012440*	*0.011902*	*Infinity*	
		59.6 °C	**53.5 °C**	**45.4 °C**	**40.0 °C**	**35.9 °C**	**28.8 °C**	**24.0 °C**	**17.5 °C**		
60 °C	η_S	0.019370	0.018572	0.017538	0.016861	0.016365	0.015523	0.014970	0.014245	Infinity	Type B
	Combined	*0.019370*	*0.018572*	*0.017538*	*0.016861*	*0.016365*	*0.015523*	*0.014970*	*0.014245*	*Infinity*	

Table 13

Standard Saturator Efficiency Uncertainty Components of Dew Point Temperature (°C)

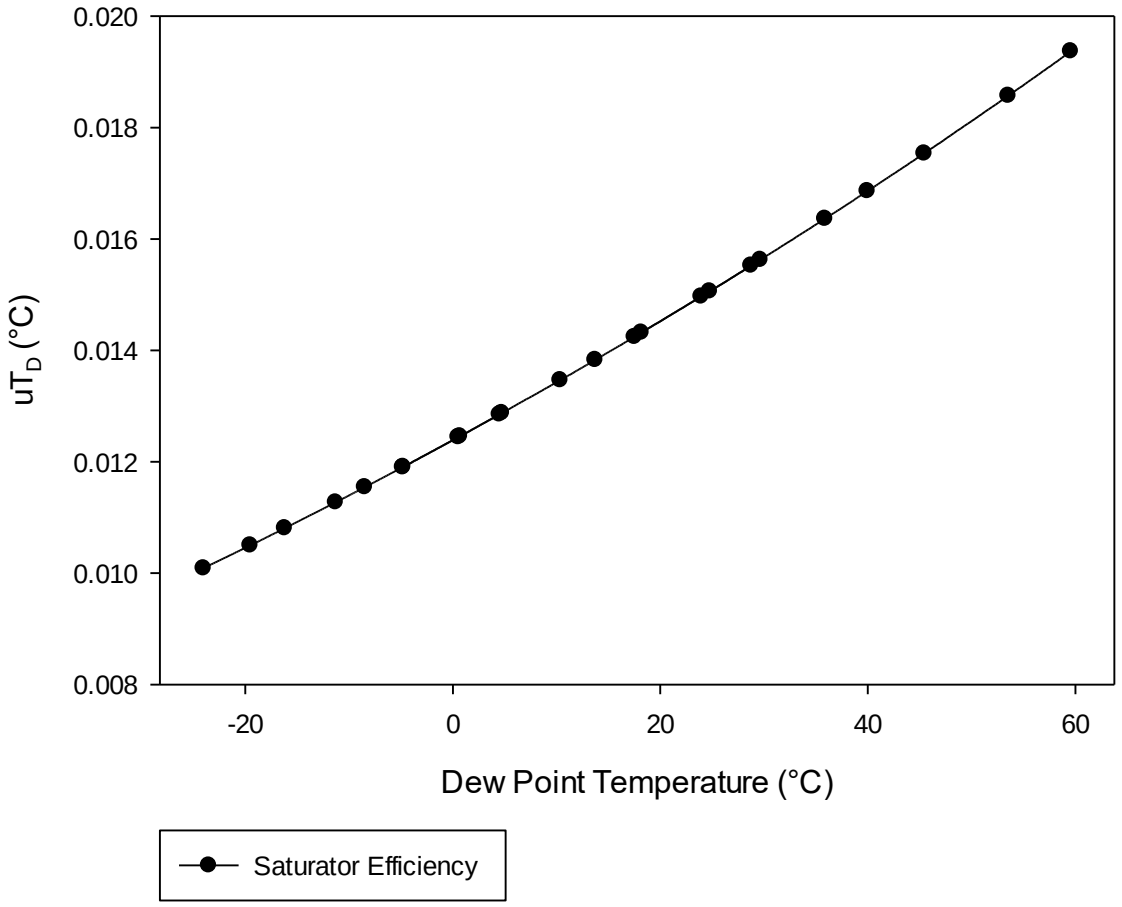

Figure 11

The standard uncertainties **(uT_F)** components calculated using the above associated % efficiency component are summarized in Table 14 and Figure 12.

Note: Any frost point value that is not possible is grayed out of the following table.

Standard Saturator Efficiency Uncertainty Components of Frost Point Temperature (°C)												
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**	**Evaluation**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**		
				-4.2 °C	**-7.5 °C**	**-10.1 °C**	**-14.5 °C**	**-17.5 °C**	**-21.6 °C**		
5 °C	η_S			0.010590	0.010329	0.010134	0.009794	0.009565	0.009258	Infinity	Type B
	Combined			*0.010590*	*0.010329*	*0.010134*	*0.009794*	*0.009565*	*0.009258*	*Infinity*	
									-4.3 °C		
30 °C	η_S								0.010586	Infinity	Type B
	Combined								*0.010586*	*Infinity*	
60 °C	η_S									Infinity	Type B
	Combined									*Infinity*	

Table 14

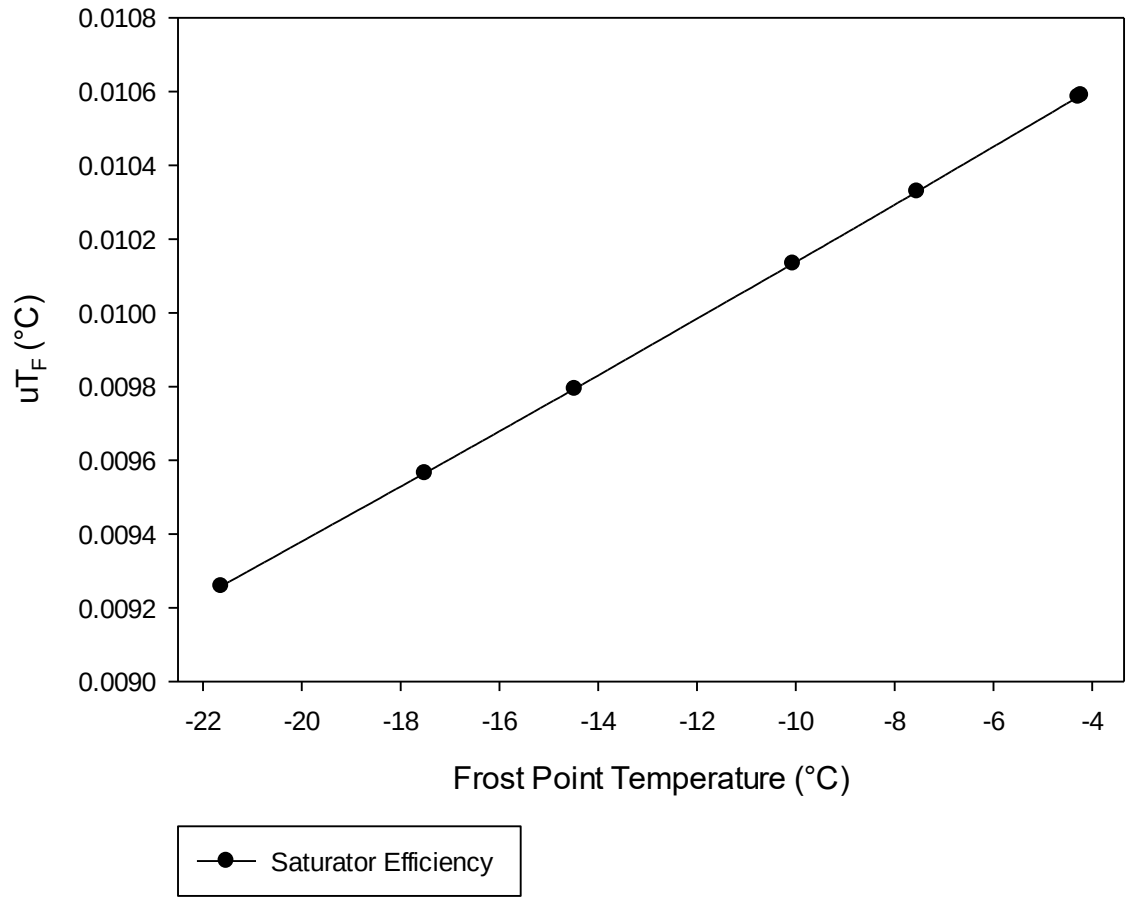

Figure 12

4.0 Combined Standard and Expanded Uncertainty

The combined standard uncertainty is obtained by the statistical combination of the individual standard uncertainty components of pressure, temperature, and equation in terms of relative humidity, dew point or frost point. Utilizing a confidence level of 95.45% and a coverage factor k=2, the expanded uncertainty, U, is expressed by multiplying the combined standard uncertainty by the coverage factor as show in the following formula

$$U = k * u_c \quad (19)$$

Using equations 6 and 19, the combined individual standard uncertainty components for pressure, temperature, equation and saturator efficiency, the total combined standard uncertainty (u) and the total combined expanded uncertainty (U) in terms of relative humidity %RH are summarized in Table 15 and Figure 13.

Uncertainty Components of %RH										
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**	
		98.0%RH	**73.6%RH**	**49.2%RH**	**37.0%RH**	**29.6%RH**	**19.9%RH**	**15.0%RH**	**10.1%RH**	
5 °C	Pressure	0.122540	0.069892	0.032262	0.019057	0.012911	0.006737	0.004470	0.002683	Infinity
	Temperature	0.250658	0.188204	0.125750	0.094523	0.075787	0.050808	0.038319	0.025833	Infinity
	Equation	0.015168	0.013095	0.011358	0.010675	0.010344	0.009994	0.009689	0.009498	Infinity
	Saturator Efficiency	0.088206	0.066230	0.044255	0.033267	0.026675	0.017885	0.013491	0.009098	Infinity
	Combined	*0.293012*	*0.211810*	*0.137627*	*0.102559*	*0.082030*	*0.055196*	*0.042002*	*0.029112*	*Infinity*
	Expanded (k=2)	*0.586023*	*0.423620*	*0.275255*	*0.205119*	*0.164061*	*0.110392*	*0.084005*	*0.058223*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.1%RH**	
30 °C	Pressure	0.122609	0.069933	0.032279	0.019065	0.012914	0.006733	0.004462	0.002673	Infinity
	Temperature	0.206412	0.154953	0.103492	0.077761	0.062322	0.041738	0.031446	0.021155	Infinity
	Equation	0.016563	0.013146	0.010151	0.008951	0.008381	0.007844	0.007592	0.007441	Infinity
	Saturator Efficiency	0.088205	0.066217	0.044228	0.033233	0.026636	0.017840	0.013443	0.009046	Infinity
	Combined	*0.256307*	*0.182917*	*0.117523*	*0.087148*	*0.069502*	*0.046553*	*0.035314*	*0.024328*	*Infinity*
	Expanded (k=2)	*0.512614*	*0.365834*	*0.235046*	*0.174296*	*0.139004*	*0.093106*	*0.070628*	*0.048657*	
		98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.0%RH**	
60 °C	Pressure	0.122568	0.069939	0.032293	0.019074	0.012918	0.006731	0.004457	0.002664	Infinity
	Temperature	0.166466	0.124980	0.083469	0.062703	0.050241	0.033621	0.025309	0.016998	Infinity
	Equation	0.007946	0.007603	0.007668	0.007857	0.008020	0.008278	0.008270	0.008296	Infinity
	Saturator Efficiency	0.088206	0.066220	0.044223	0.033221	0.026619	0.017815	0.013412	0.009009	Infinity
	Combined	*0.224894*	*0.157970*	*0.100122*	*0.073898*	*0.058855*	*0.039516*	*0.030145*	*0.021119*	*Infinity*
	Expanded (k=2)	*0.449788*	*0.315939*	*0.200243*	*0.147795*	*0.117710*	*0.079033*	*0.060290*	*0.042238*	

Table 15

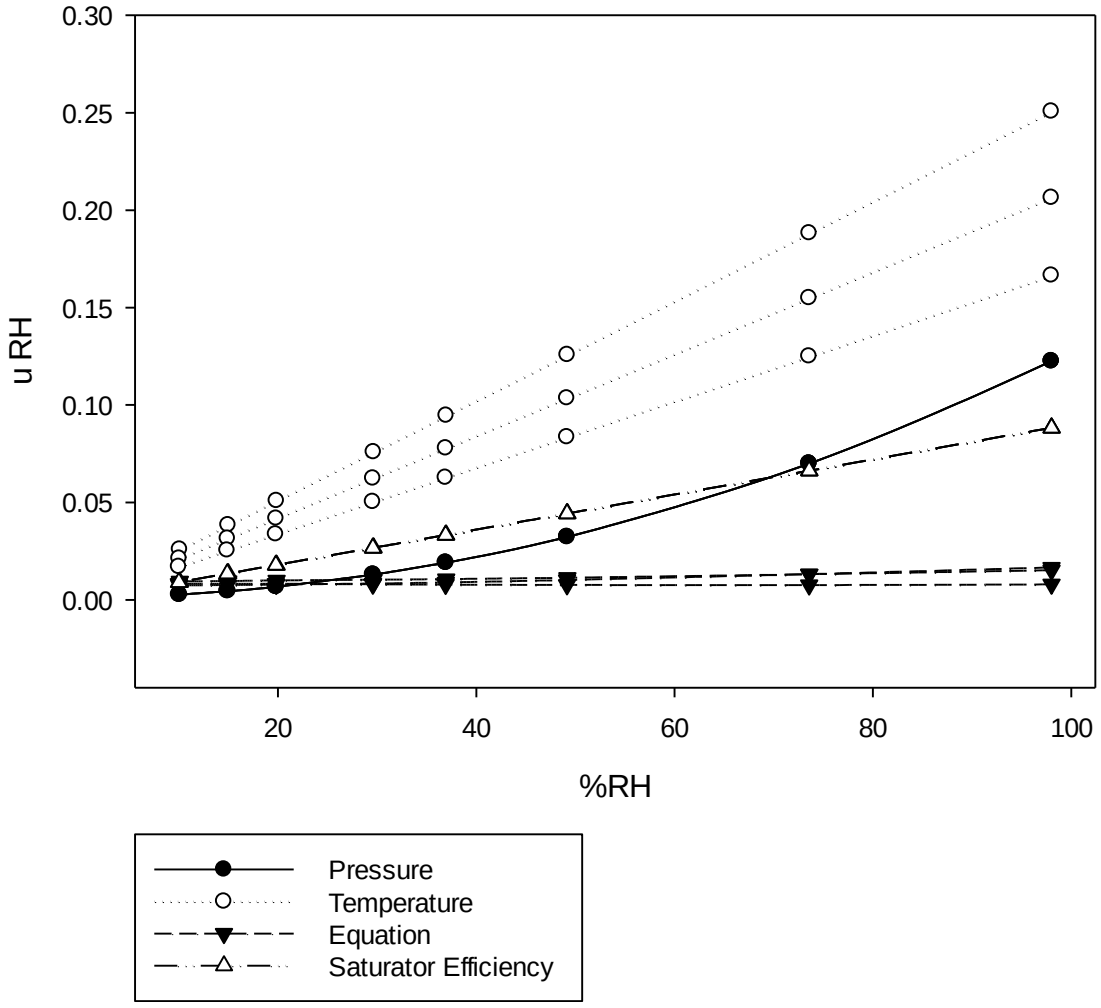

Figure 13

Using equations 7 and 19, the combined individual standard uncertainty components for pressure, temperature, equation and saturator efficiency, the total combined standard uncertainty (u) and the total combined expanded uncertainty (U) in terms of dew point temperature T_D (°C) are summarized in Table 16 and Figure 14.

Uncertainty Components of Dew Point Temperature (°C)										
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**	
		4.7 °C	**0.7 °C**	**-4.8 °C**	**-8.5 °C**	**-11.3 °C**	**-16.2 °C**	**-19.5 °C**	**-24.0 °C**	
5 °C	Pressure	0.017883	0.013145	0.008680	0.006611	0.005455	0.004069	0.003476	0.002973	Infinity
	Temperature	0.016332	0.015803	0.015102	0.014634	0.014287	0.013687	0.013286	0.012749	Infinity
	Equation	0.002209	0.002418	0.003177	0.003908	0.004611	0.006298	0.007794	0.010707	Infinity
	Saturator Efficiency	0.012872	0.012457	0.011908	0.011542	0.011272	0.010807	0.010497	0.010088	Infinity
	Combined	*0.027516*	*0.024157*	*0.021338*	*0.020158*	*0.019549*	*0.018983*	*0.018961*	*0.019692*	*Infinity*
	Expanded (k=2)	*0.055032*	*0.048314*	*0.042676*	*0.040317*	*0.039099*	*0.037966*	*0.037922*	*0.039384*	
		29.6 °C	**24.8 °C**	**18.2 °C**	**13.7 °C**	**10.4 °C**	**4.5 °C**	**0.5 °C**	**-4.8 °C**	
30 °C	Pressure	0.021722	0.015907	0.010451	0.007933	0.006529	0.004848	0.004128	0.003514	Infinity
	Temperature	0.016328	0.015736	0.014958	0.014442	0.014060	0.013407	0.012972	0.012395	Infinity
	Equation	0.002962	0.003377	0.003511	0.003797	0.004240	0.005602	0.006977	0.009808	Infinity
	Saturator Efficiency	0.015627	0.015062	0.014320	0.013829	0.013468	0.012850	0.012440	0.011902	Infinity
	Combined	*0.031487*	*0.027183*	*0.023459*	*0.021844*	*0.020968*	*0.019994*	*0.019717*	*0.020095*	*Infinity*
	Expanded (k=2)	*0.062974*	*0.054366*	*0.046919*	*0.043688*	*0.041937*	*0.039988*	*0.039434*	*0.040191*	
		59.6 °C	**53.5 °C**	**45.4 °C**	**40.0 °C**	**35.9 °C**	**28.8 °C**	**24.0 °C**	**17.5 °C**	
60 °C	Pressure	0.026915	0.019615	0.012807	0.009681	0.007943	0.005866	0.004975	0.004213	Infinity
	Temperature	0.016322	0.015654	0.014785	0.014214	0.013795	0.013081	0.012608	0.011986	Infinity
	Equation	0.001751	0.002214	0.003336	0.004430	0.005243	0.007476	0.009518	0.013273	Infinity
	Saturator Efficiency	0.019370	0.018572	0.017538	0.016861	0.016365	0.015523	0.014970	0.014245	Infinity
	Combined	*0.037001*	*0.031299*	*0.026483*	*0.024488*	*0.023424*	*0.022414*	*0.022325*	*0.023249*	*Infinity*
	Expanded (k=2)	*0.074003*	*0.062598*	*0.052965*	*0.048977*	*0.046848*	*0.044828*	*0.044650*	*0.046497*	

Table 16

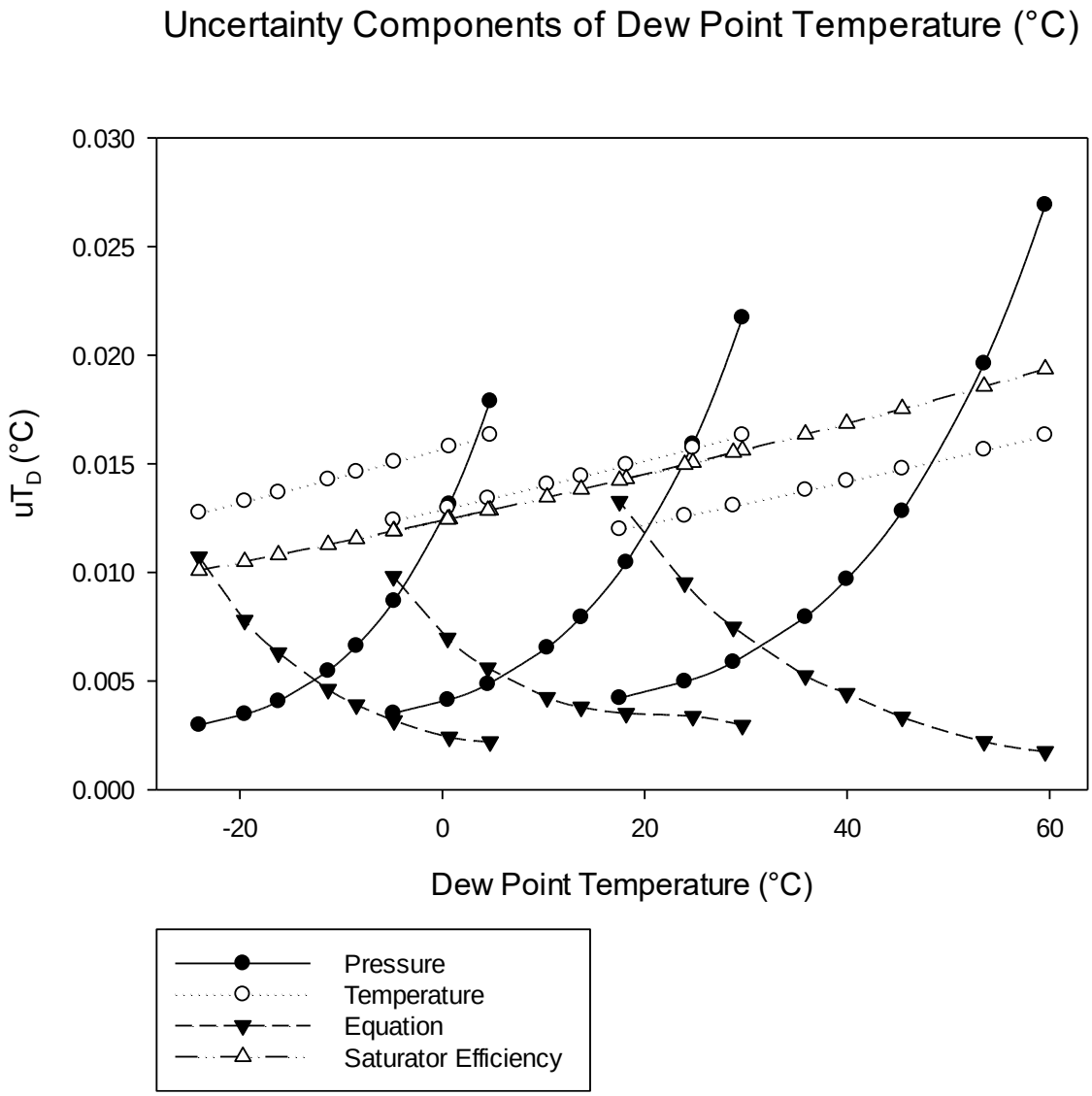

Figure 14

Using equations 8 and 19, the combined individual standard uncertainty components for pressure, temperature, equation and saturator efficiency, the total combined standard uncertainty (u) and the total combined expanded uncertainty (U) in terms of frost point temperature T_F (°C) are summarized in Table 17 and Figure 15.

Note: Any frost point value that is not possible is grayed out of the following tables.

Uncertainty Components of Frost Point Temperature (°C)										
Saturation Temperature	**Description**	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								**Degrees of Freedom**
		15	**20**	**30**	**40**	**50**	**75**	**100**	**150**	
				-4.2 °C	**-7.5 °C**	**-10.1 °C**	**-14.5 °C**	**-17.5 °C**	**-21.6 °C**	
5 °C	Pressure			0.007720	0.005916	0.004904	0.003688	0.003167	0.002728	Infinity
	Temperature			0.013431	0.013096	0.012844	0.012405	0.012106	0.011700	Infinity
	Equation			0.004018	0.005976	0.007522	0.010035	0.011881	0.014799	Infinity
	Saturator Efficiency			0.010590	0.010329	0.010134	0.009794	0.009565	0.009258	Infinity
	Combined			*0.019191*	*0.018679*	*0.018663*	*0.019082*	*0.019729*	*0.021191*	*Infinity*
	Expanded (k=2)			*0.038381*	*0.037358*	*0.037325*	*0.038164*	*0.039457*	*0.042382*	
									-4.3 °C	
30 °C	Pressure								0.003125	Infinity
	Temperature								0.011025	Infinity
	Equation								0.009190	Infinity
	Saturator Efficiency								0.010586	Infinity
	Combined								*0.018106*	*Infinity*
	Expanded (k=2)								*0.036212*	
60 °C	Pressure									Infinity
	Temperature									Infinity
	Equation									Infinity
	Saturator Efficiency									Infinity
	Combined									*Infinity*
	Expanded (k=2)									

Table 17

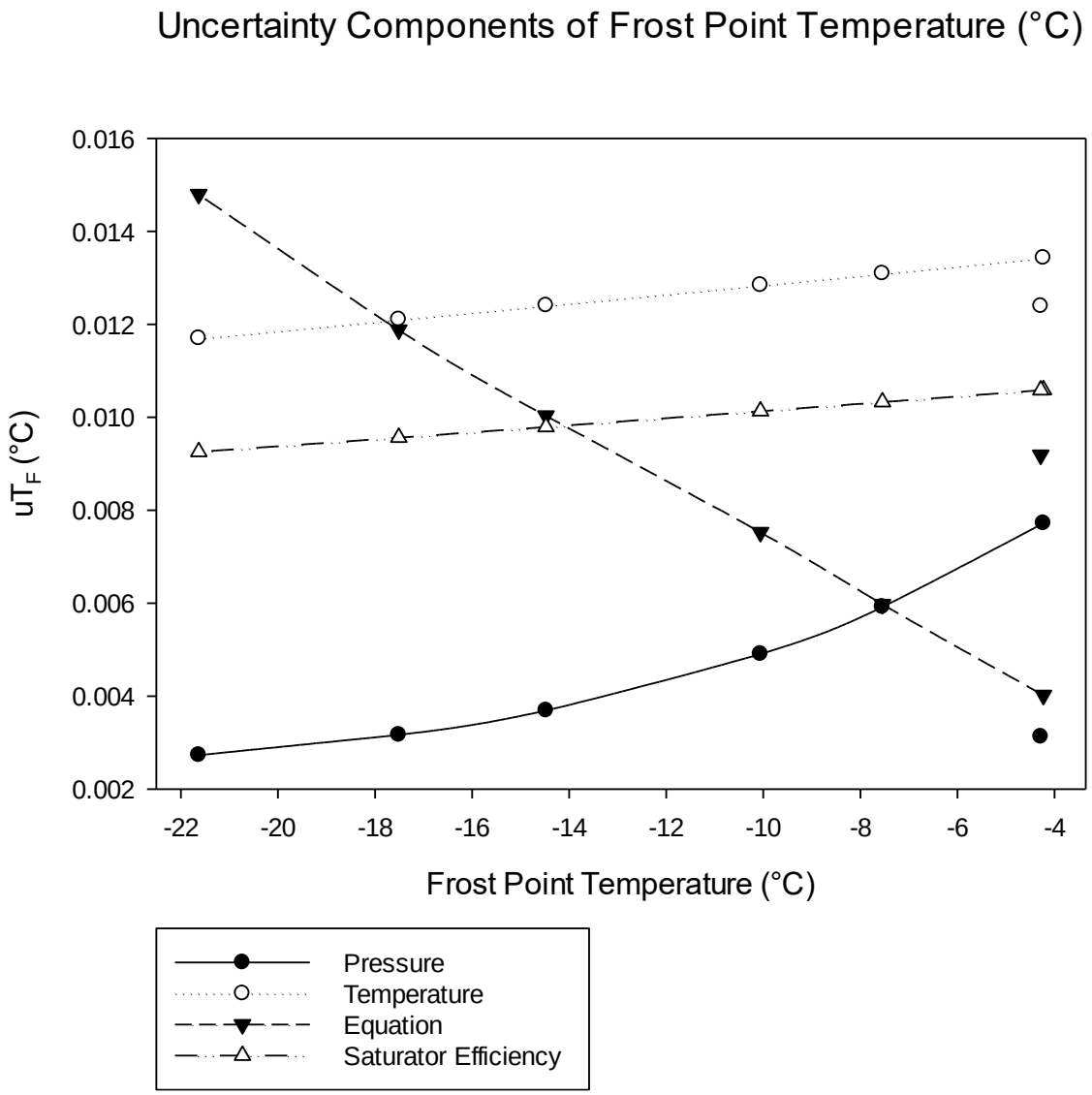

Figure 15

5.0 Summary

To simplify the %RH uncertainty results, the following uncertainty specification statement is used to describe the %RH uncertainty for the Model 1220:

0.6% of reading RH

(using a coverage factor, k=2, at an approximate level of confidence of 95%)

A summary of the combined expanded uncertainty (U_{RH}) and uncertainty specification for %RH are shown in Table 18 and Figure 16.

Expanded Uncertainty of %RH								
Saturation Temperature	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**							
	15	**20**	**30**	**40**	**50**	**75**	**100**	**150**
	98.0%RH	**73.6%RH**	**49.1%RH**	**36.9%RH**	**29.6%RH**	**19.8%RH**	**14.9%RH**	**10.0%RH**
5 °C	0.586	0.424	0.275	0.205	0.164	0.110	0.084	0.058
30 °C	0.513	0.366	0.235	0.174	0.139	0.093	0.071	0.049
60 °C	0.450	0.316	0.200	0.148	0.118	0.079	0.060	0.042
0.6% Specification	0.588	0.442	0.295	0.221	0.178	0.119	0.089	0.060

Table 18

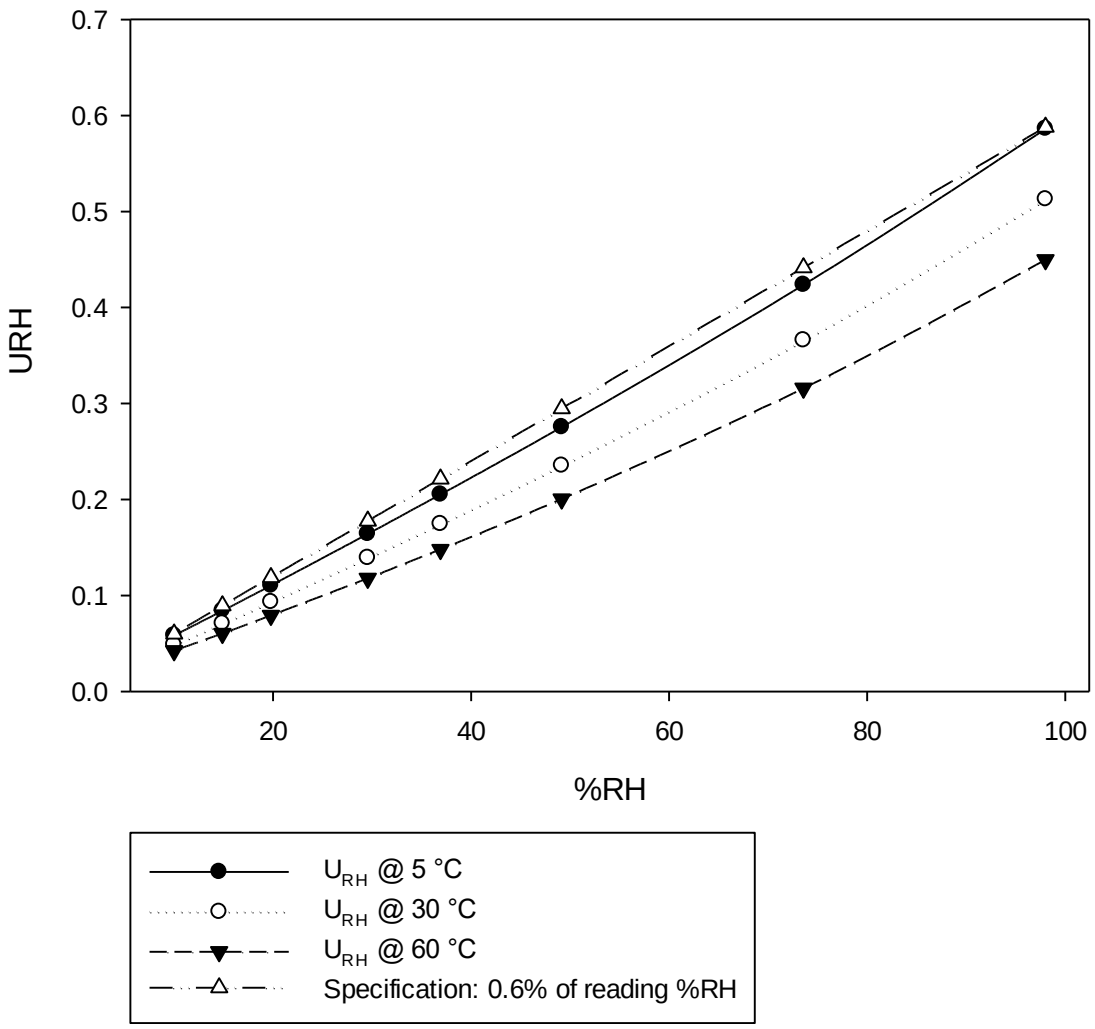

Figure 16

To simplify the Dew Point Temperature uncertainty results, the following uncertainty specification statement is used to describe the Dew Point (°C) uncertainty (U_{TD}) for the Model 1220 over the range of 5 °C to 60 °C:

0.08 °C

(using a coverage factor, k=2, at an approximate level of confidence of 95%)

A summary of the combined expanded uncertainty and uncertainty specification for Dew Point Temperature (°C) over the range of 5 to 60 °C are shown in Table 19 and Figure 17.

Expanded Uncertainty of Dew Point Temperature (°C)								
Saturation Temperature	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**							
	15	**20**	**30**	**40**	**50**	**75**	**100**	**150**
	4.7 °C	**0.7 °C**						
5 °C	0.055	0.048						
	29.6 °C	**24.8 °C**	**18.2 °C**	**13.7 °C**	**10.4 °C**	**4.5 °C**	**0.5 °C**	
30 °C	0.063	0.054	0.047	0.044	0.042	0.040	0.039	
	59.6 °C	**53.5 °C**	**45.4 °C**	**40.0 °C**	**35.9 °C**	**28.8 °C**	**24.0 °C**	**17.5 °C**
60 °C	0.074	0.063	0.053	0.049	0.047	0.045	0.045	0.046
0.08 Specification	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

Table 19

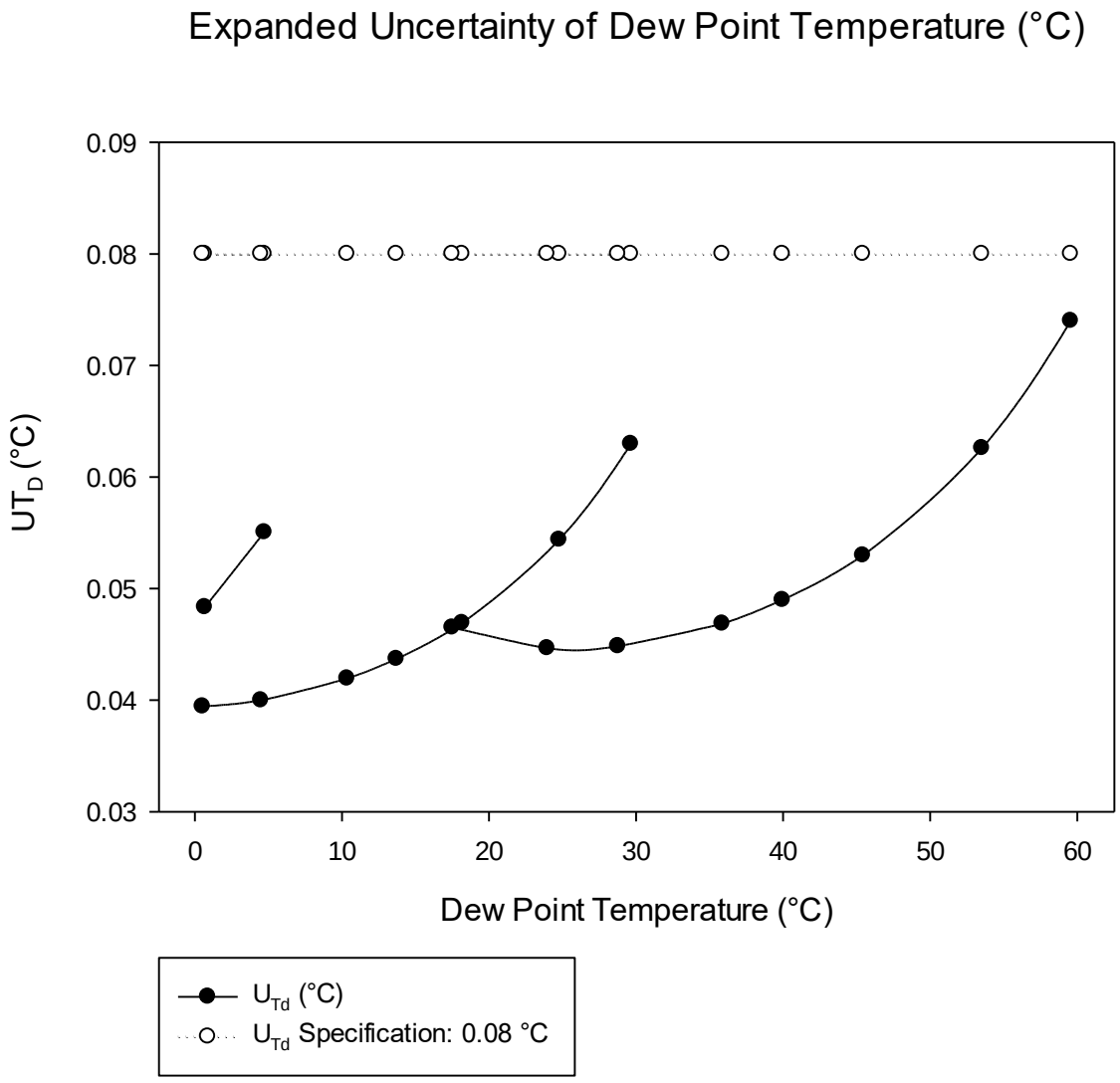

Figure 17

To simplify the Dew/Frost Point Temperature uncertainty results, the following uncertainty specification statement is used to describe the Dew/Frost Point (°C) uncertainty (U_{TF}) for the Model 1220 for Dew/Frost Point Temperatures below 0 °C:

0.05 °C

(using a coverage factor, k=2, at an approximate level of confidence of 95%)

A summary of the combined expanded uncertainty and uncertainty specification for Dew/Frost Point Temperature (°C) below 0 °C are shown in Table 20 and Figure 18.

Expanded Uncertainty of Dew/Frost Point Temperature (°C)									
Saturation Temperature	**Saturation Pressure Range (psia), Chamber pressure = 14.7 psia**								
	15	**20**	**30**	**40**	**50**	**75**	**100**	**150**	
			-4.8 °C	**-8.5 °C**	**-11.3 °C**	**-16.2 °C**	**-19.5 °C**	**-24.0 °C**	**T_D**
5 °C			0.043	0.040	0.039	0.038	0.038	0.039	
			-4.2 °C	**-7.5 °C**	**-10.1 °C**	**-14.5 °C**	**-17.5 °C**	**-21.6 °C**	**T_F**
5 °C			0.038	0.037	0.037	0.038	0.039	0.042	
								-4.8 °C	**T_D**
30 °C								0.040	
								-4.3 °C	**T_F**
30 °C								0.036	
0.05 Specification	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	

Table 20

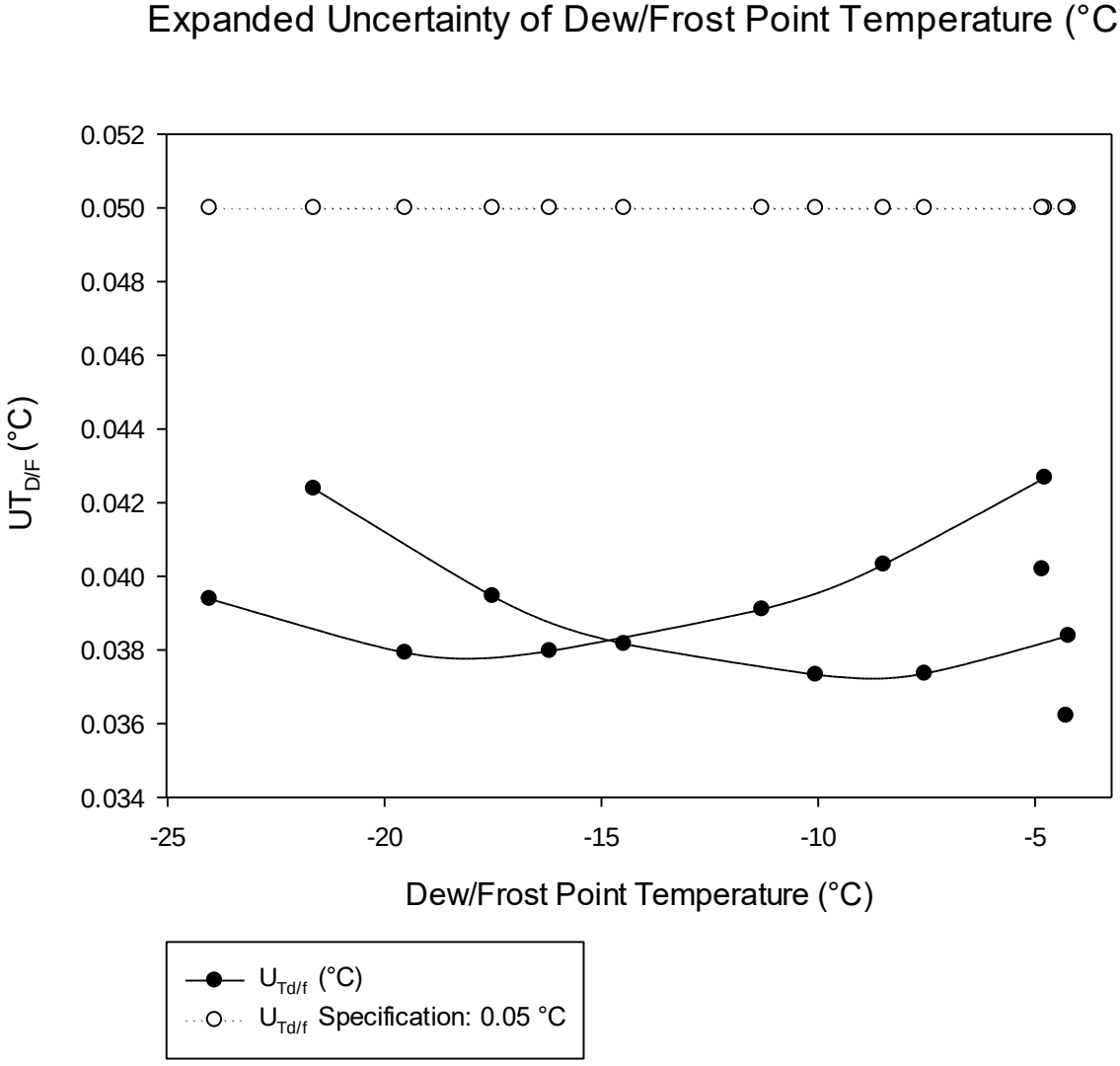

Figure 18

6.0 References

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9. Michael Hamilton, "Model 1220 Chamber Temperature Uniformity Analysis", Thunder Scientific Corporation, August 2024