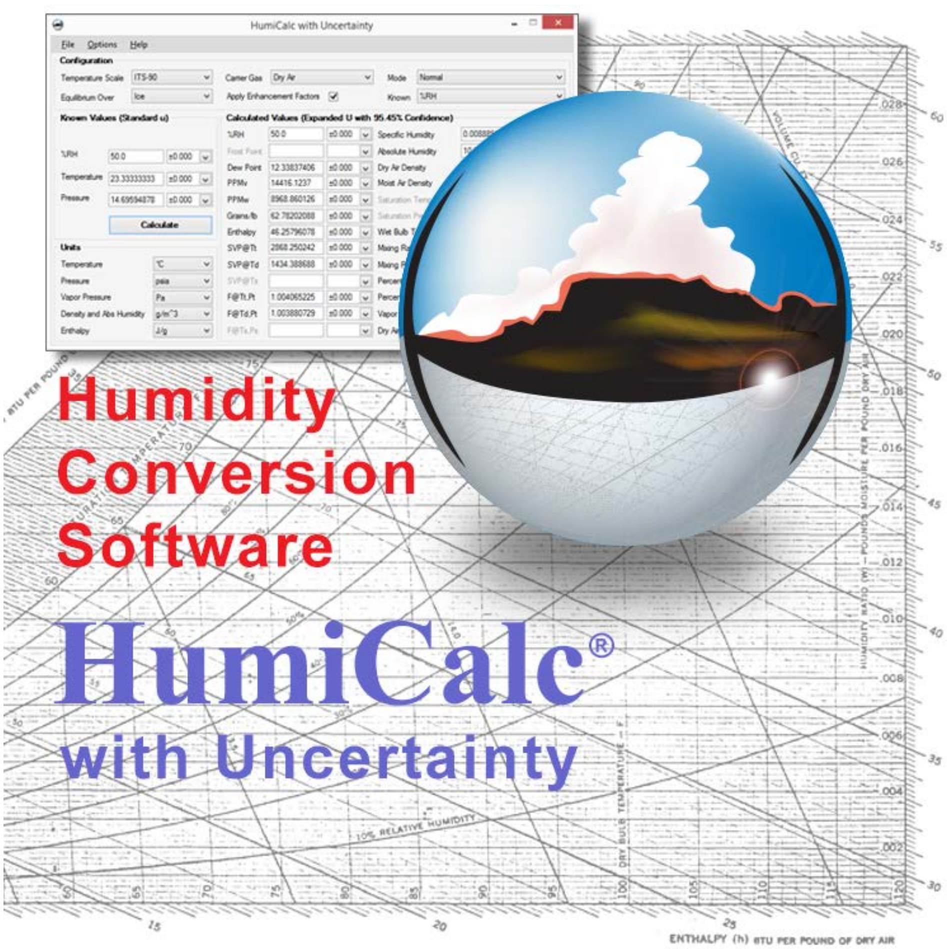
HUMICALC® WITH UNCERTAINTY REFERENCE MANUAL



VERSION

3.0.1.1 Rev B July 2019

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WARRANTY

HumiCalc is warranted by Thunder Scientific Corporation to be free from defects in material and workmanship for a period of twelve (12) months from date of original purchase.

During the warranty period, we will at no charge, repair or replace, at our option, any product that proves to be defective, provided you return the product to Thunder Scientific Corporation, shipping prepaid. This warranty does not apply to any product that has been damaged by accident or misuse, or that has been repaired, serviced, altered, or modified by anyone other than an authorized representative of Thunder Scientific Corporation.

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INTRODUCTION

Welcome to HumiCalc with Uncertainty! Whether you are new to humidity calculations or have years of experience, you will find HumiCalc to be a valuable tool, unmatched in the humidity world. Using HumiCalc you can easily and accurately solve complex humidity conversion and uncertainty problems, which until now, could only be estimated using spreadsheets and calculators. Our exclusive HumiCalc program combines powerful, iterative, numerical capabilities with simple, user-friendly operation.

Using HumiCalc with Uncertainty you can:

- Solve complex humidity conversion just like the original HumiCalc.
- Calculate complex humidity uncertainty based on known uncertainty components.
- Calculate complex humidity “As Found” error based on calibration data.

WHAT'S IN THIS MANUAL

This manual is your guide to the operation of HumiCalc, and is intended to provide you with a working knowledge of its capabilities and use.

The **Getting Started** section contains information on system requirements and covers program installation.

The **Operation** section provides you with an overview of the HumiCalc displays, menus and configuration options.

The **Examples** section has several "word problem" style samples to follow and learn from. This section is far from being an all-inclusive list of possibilities and is merely a small sample of some of the more common types of humidity problems you may encounter.

Appendix A contains a list of humidity related terms and gives an explanation of each.

Appendix B contains reference information about some of the humidity formulas and their sources, used in HumiCalc.

This manual shows you how to perform complex humidity calculations, uncertainties and conversions, but it doesn't teach basic humidity relationships or uncertainty. We assume that you're already somewhat familiar with the definitions and relationships of interest to you.

However, you don't need to understand all humidity parameters if you don't intend to use them. Even though you may occasionally be instructed to perform a conversion by first calculating an intermediary variable, this does not necessarily mean that you need to understand this intermediary variable or its relationship to your particular application.

1

GETTING STARTED

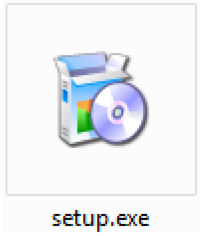
This section is intended to provide you with enough information to install HumiCalc and start the application.

HUMICALC MINIMUM SYSTEM REQUIREMENTS

- 1GHz Intel® Pentium® or equivalent processor
- 256MB of RAM (512MB recommended for complex uncertainty scenarios)
- Minimum 800 x 600 screen resolution
- Microsoft® Windows® Vista (x86 or x64); Windows XP Professional, or Home Edition with Service Pack 2; Microsoft Windows 2000 with Service Pack 4
- Microsoft .NET Framework version 2.0
- Adobe® Acrobat® Reader
- Microsoft Internet Explorer 6.0 or 7.0

INSTALLING HUMICALC

- Insert the HumiCalc CD or locate the downloaded HumiCalc installation package.
- Click the setup.exe file to begin the installer.

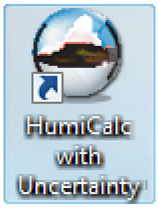


Note: You must have administrative rights to install the application.

- Follow the on screen installer directions.

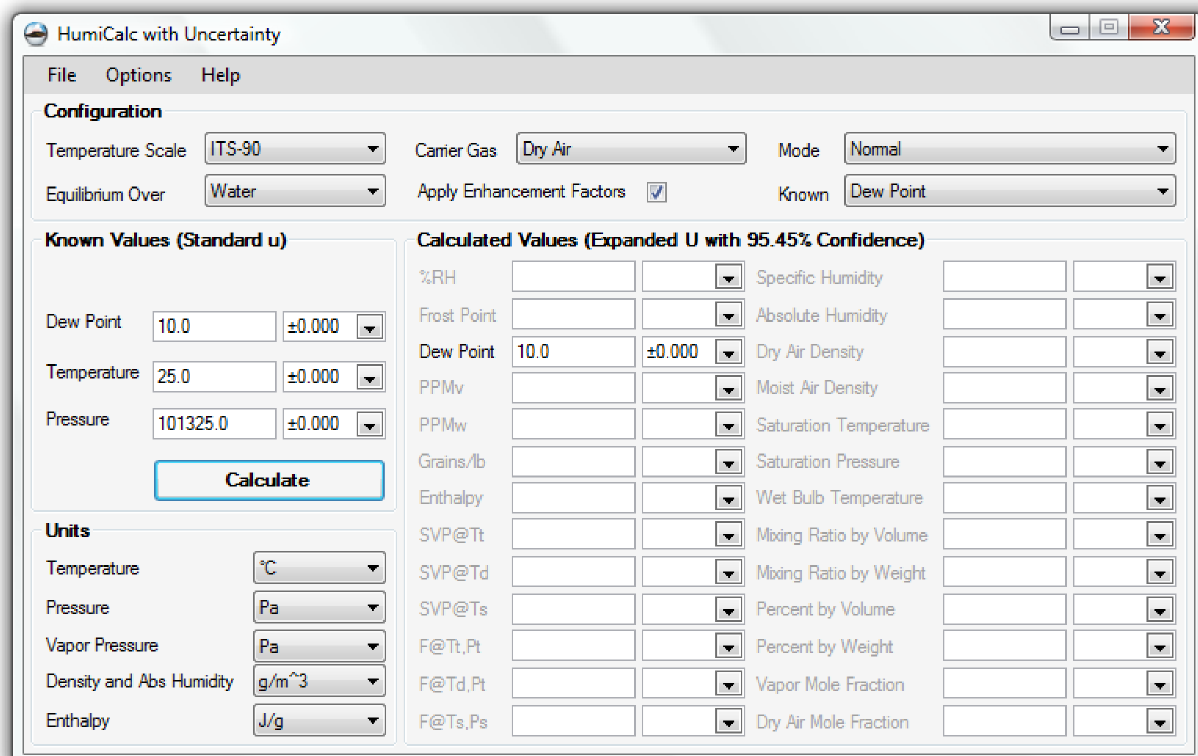
STARTING HUMICALC

- Locate and double-click the HumiCalc icon.

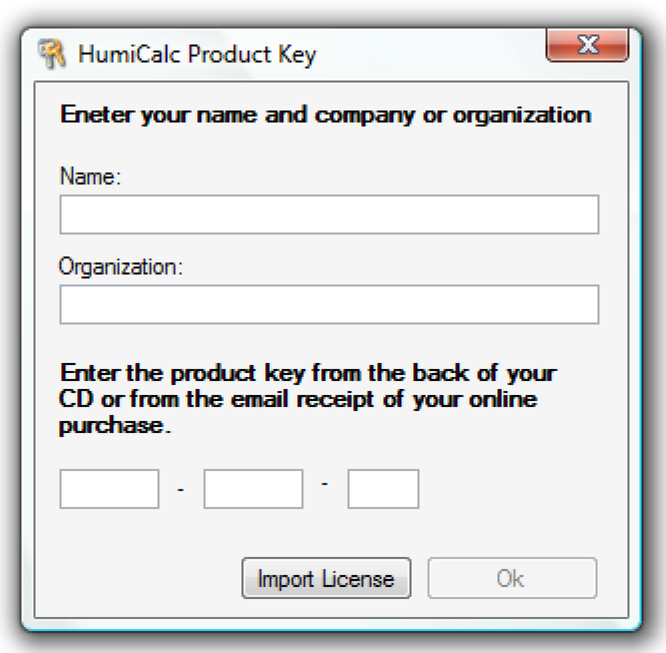


- The splash screen will appear once the program is initialized. Note: It may take some time for the banner screen to be displayed after installing the application.

- The splash screen will display a loading status near the bottom, once loading is complete the splash screen will close and the main window will be displayed.



- A HumiCalc Product Key Dialog will appear the first time HumiCalc starts if no valid license is present.



- Enter your "Name", "Organization" and the "Product Key" from the back of the HumiCalc CD case or as received in the email receipt when purchasing HumiCalc online.

- Click Ok to save the license information.

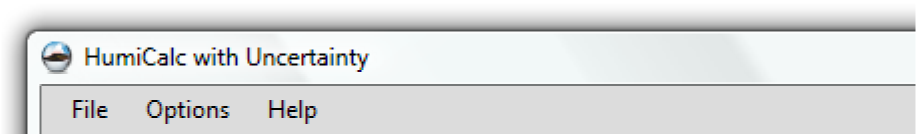
2

OPERATION

This section provides you with detailed information relating to the layout, configuration and use of HumiCalc. By following along, you will become familiar with the features and configurations for HumiCalc.

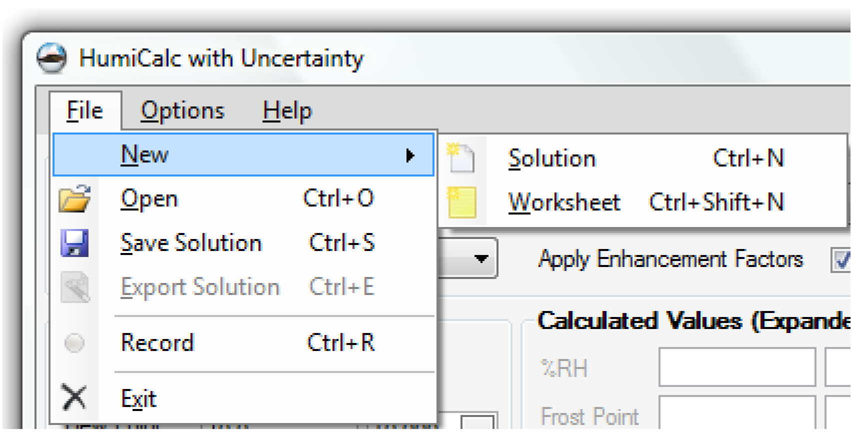
MENU BAR

The **Menu Bar** consists of three submenu drop downs: **File**, **Options** and **Help**.



FILE MENU

The **File** Menu consists of six selections: New, Open, Save Solution, Export Solution, Record and Exit.



New

The New selection consists of two choices: Solution and Worksheet. Selecting New Solution will load an empty solution with default configuration and data values. Selecting New Worksheet will open a new empty worksheet. HumiCalc Solution and Worksheet files are used to store user data entries so that they can be saved and loaded at a later date.

> *Warning: Selecting New Solution will result in all solution entries being cleared. It is important to save any entries prior to using the New Solution option if you desire to retain the data entered.*

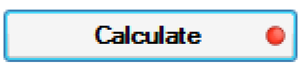
Open
Selection will open a file dialog box to allow navigation to a HumiCalc Solution or Worksheet file for loading of previously saved work.

Save Solution
Selection will open a file dialog box to allow navigation and naming of the HumiCalc Solution file that will be saved. All current configuration and data entries will be saved in the HumiCalc Solution file to allow the user to load at any time in the future.

Export Solution
The Export Solution option allows the user to export the current HumiCalc Solution into an Adobe PDF (*.pdf), Enhanced Metafile (*.emf), Excel Workbook (*.xls), Excel 2007 Workbook (*.xlsx), Rich Text Format (*.rtf) or a Word 2007 Document (*.docx). Selection will open a file dialog box to allow navigation and naming of the exported file.

> *Note: It is required to have a Green or Yellow check mark calculation status before exporting.*

Record
Selection will begin recording all calculations. Active recording is indicated by a red light on the "Calculate" button. During recording each presses of the "Calculate" button will record all configuration, known, unit and result data to a capture file in a tab delaminated format.

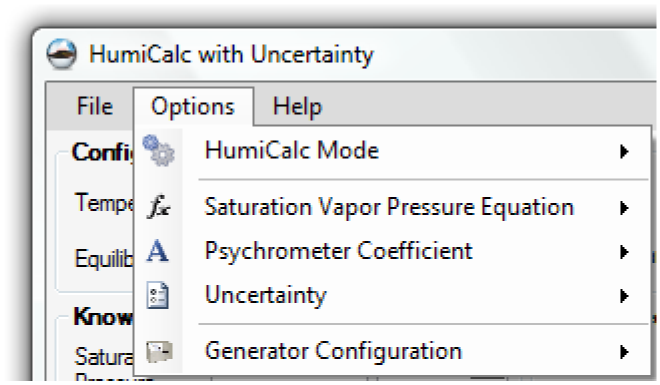


Selection of the Record menu item while recording will stop the calculation recording and will open a file dialog box to allow navigation and naming of the capture file containing the recorded data to be saved.

Exit
Selection will close the application.

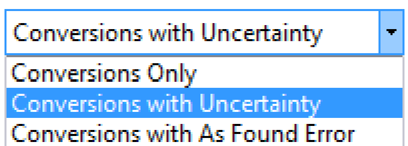
OPTIONS MENU

The **Options** Menu consists of five selections: HumiCalc Mode, Saturation Vapor Pressure Equation, Psychrometer Coefficient, Uncertainty and Generator Configuration.



HumiCalc Mode

Selection of the HumiCalc Mode will present the user with three different modes that HumiCalc can operate in.



Conversion Only

Conversion Only mode will remove any uncertainty or error fields on the main display and will operate only as a humidity conversion tool. This is basically the same as the original HumiCalc.

Note: Conversions can be performed in any mode by simply entering only known values and leaving either the uncertainty or error fields blank.

Conversion with Uncertainty

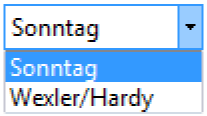
Conversion with Uncertainty mode will display special uncertainty fields on the main display next to each entry. This mode will allow the user to calculate different humidity uncertainties based on the entered known values and their uncertainty components. This mode is extremely helpful when calculating uncertainty budgets or uncertainty for calibration reports.

Conversion with As Found Error

Conversion with As Found Error mode will display special error fields on the main display next to each entry. This mode will allow the user to calculate "As Found Error" based on the entered known values and their error from an entered standard or reference. This mode is useful in identifying the effects that "As Found Error" has on different humidity parameters.

Saturation Vapor Pressure Equation

Selection of the Saturation Vapor Pressure Equation will present the user with two different equations that can be used to calculate Saturation Vapor Pressure.



Sonntag

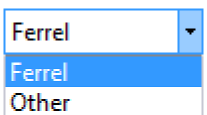
Configures HumiCalc to use Sonntag's(6) vapor pressure formulas and uncertainties.

Wexler/Hardy

Configures HumiCalc to use Wexler's and Hardy's(9) vapor pressure formulas and uncertainties.

Psychrometer Coefficient

Selection of the Psychrometer Coefficient will present the user with two different coefficients that can be used to calculate Wet Bulb Temperature.



Ferrel

Configures HumiCalc to use Ferrel's Psychrometer coefficient for all Wet Bulb Temperature calculations.

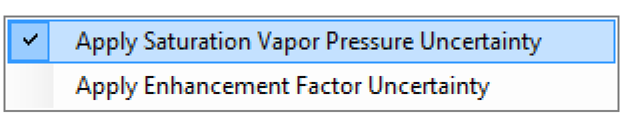
Other

Displays a dialog box to allow the user to enter a specific Psychrometer coefficient.

Uncertainty

Selection of Uncertainty will present the user with the ability to apply or to not apply the two types of equation uncertainty. The user can select to apply Saturation Vapor Pressure equation uncertainty published by either Sonntag(6) or Wexler/Hardy(1)(2)(9) (depending on which Saturation Vapor Pressure Equation is selected) to all uncertainty calculations. The user can also choose to apply or to not apply Enhancement Factor equation uncertainty published by Hyland(11) to all uncertainty calculations that have Enhancement Factors applied.

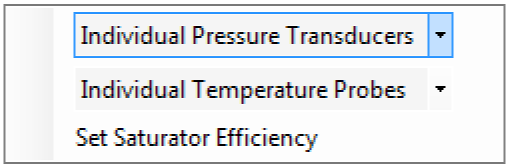
Note: This option is only available in "Conversion with Uncertainty" mode.



Generator Configuration

Selection of Generator Configuration will present the user with the ability to configure HumiCalc based on different aspects of a two-pressure or two-temperature generator.

> *Note: This option is only available in "Conversion with Uncertainty" mode and when configured in "Two Pressure" or "Two Temperature" mode.*



Individual or Single Pressure Transducer or Temperature Probes

Some generators operate with a single pressure transducer or temperature probe that is shared between the saturator and chamber. This option allows HumiCalc the ability to share a single uncertainty component or to use individual uncertainty components between the chamber and saturator.

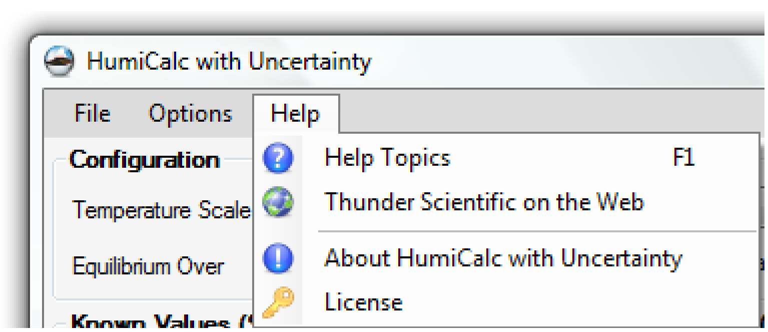
Set Saturator Efficiency

Selection displays a dialog box to allow the user to enter a percent efficiency of saturation for a two-pressure or two-temperature generator.

> *Note: Saturator Efficiency is only applied when the Known is set to either Saturation Pressure or Saturation Temperature*

HELP MENU

The **Help** Menu consists of four selections: Help Topics, Thunder Scientific on the Web, About HumiCalc with Uncertainty and License.



Help Topics

Selection of Help Topics will open this reference manual.

Thunder Scientific on the Web

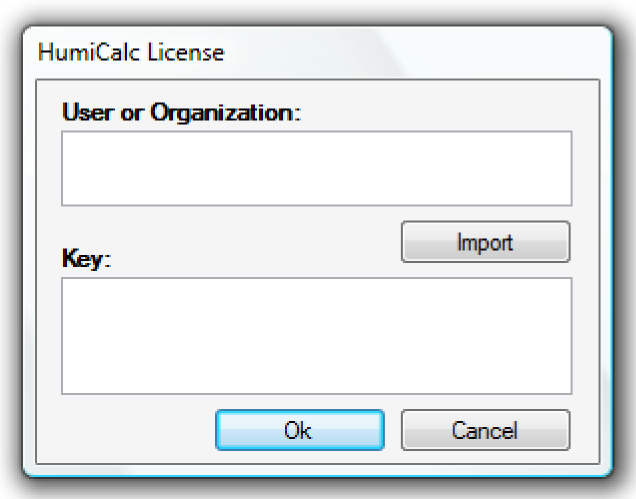
Selection of Thunder Scientific on the Web will open Thunder Scientifics web page, which contains the latest news, products and information from Thunder Scientific Corporation.

About HumiCalc with Uncertainty

Selection of About HumiCalc with Uncertainty will open an About Dialog containing important information about the application.

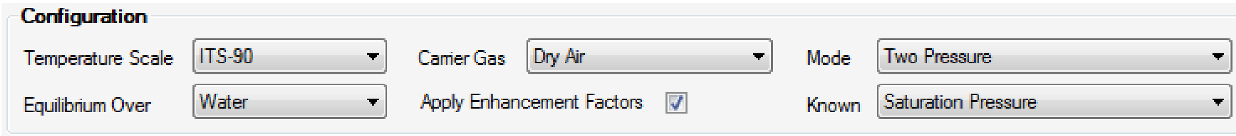
License

Selection of License will open a Dialog containing the user's current software license. The user can also import a purchased license file by selecting the Import button.



CONFIGURATION

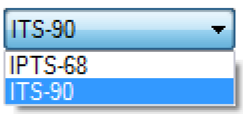
The **Configuration** frame consists of Temperature Scale, Equilibrium Over, Carrier Gas, Enhancement Factor, Mode and Known.



TEMPERATURE SCALE

The **Temperature Scale** Drop-down is used to select either the ITS-90 or IPTS-68 temperature scale.

> *Note: No temperature conversion is performed when switching from one temperature scale to another, but different equations and or coefficients are used based on which temperature scale is selected.*

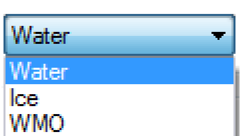


EQUILIBRIUM OVER

The **Equilibrium Over** Drop-down is used to select whether the Saturation Vapor Pressures are calculated with respect to Water, Ice or World Meteorological Organization [WMO]. For temperatures above freezing, Saturation Vapor Pressure is always computed with respect to water vapor at equilibrium over a water surface. At temperatures below freezing, equilibrium can be over either an ice surface or a water surface. For most calculations, equilibrium over a Water surface for test temperatures above freezing and over an Ice surface for test temperatures below freezing should be used.

The WMO dictates that for all test temperatures, even those below freezing, computation is to be evaluated at equilibrium over a water surface. This method should be used when working in the field of meteorology to conform to the accepted reporting practices.

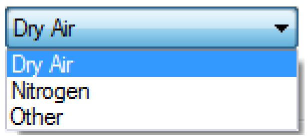
> *Note: WMO is only available in Two Pressure or Two Temperature Mode. In Normal mode simply use Water.*



CARRIER GAS

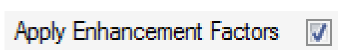
The **Carrier Gas** Drop-down is used to select the carrier gas used. The choices are Dry Air, Nitrogen, and Other. If Other is selected, then the user is asked for a molecular weight for the carrier gas.

> *Warning: The use of Enhancement Factors may not be applicable when using a carrier gas other than Dry Air or Nitrogen.*



APPLY ENHANCEMENT FACTORS

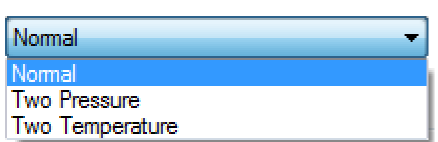
The **Apply Enhancement Factors** Check Box is used to toggle the use of Enhancement Factors on or off during calculations. A check mark means that enhancement factors will be applied to all calculations. The Enhancement Factors correct for the non-ideal behavior of a gas admixed with water vapor. The enhancement factor is a function of two independent variables, pressure and temperature.



> *Note: HumiCalc will warn the user if a calculation is requested and the Apply Enhancement Factors is not selected. This is done to make sure the user does not want to apply Enhancement Factors since it is common practice to use them for all calculations dealing with dry air or nitrogen. On the other hand, if the user has selected 'Other' as the carrier gas, HumiCalc will warn the user if apply Enhancement Factors is selected. This is because the enhancement factor equations and coefficients used by the application may not be applicable for the user entered carrier gas.*

MODE

The **Mode** Drop-down is used to select one of three HumiCalc modes. While similar in many respects, each mode differs slightly from the others in a few aspects.



Normal

The Normal mode is the default mode of HumiCalc and will be used to solve a majority of your humidity conversion problems. Normal mode is based on any one humidity parameter at a single test temperature and test pressure.

Two Pressure

The Two Pressure mode is used primarily in conjunction with humidity generators employing the fundamental principles of "Two Pressure" humidity generation. A Two Pressure humidity generator is one in which a gas is saturated to the dew or frost point at a high, but variable, Saturation Pressure. The gas is then expanded to Test Pressure for use. Generally, the humidity content of the gas is adjusted by varying the Saturation Pressure while the Test Pressure, Test Temperature, and Saturation Temperature remain fixed. The Two Pressure mode is useful in determining all humidity parameters at a given Test Temperature and Test Pressure when the Saturation Temperature and Saturation Pressure are known. Conversely, it will calculate the Saturation Pressure required (at a given Saturation Temperature) providing a known humidity value at the Test Temperature and Test Pressure.

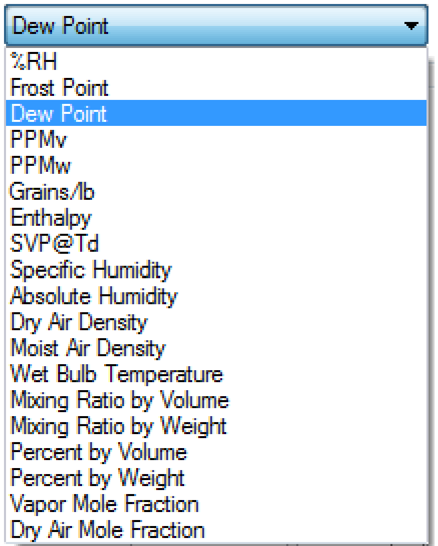
Two Temperature

The Two Temperature mode is primarily used in conjunction with humidity generators employing the fundamental principles of "Two Temperature" humidity generation. A two temperature humidity generator is one in which gas is saturated to the dew or frost point at a cold, but variable, Saturation Temperature. The gas is then warmed to Test Temperature for use. Generally, the humidity content of the gas is adjusted by varying the Saturation Temperature while the Test Temperature, Test Pressure, and Saturation Pressure remain fixed. The Two Temperature Mode is useful in determining all humidity parameters at a given Test Temperature and Test Pressure when the Saturation Temperature and Saturation Pressure are known. Conversely, it will calculate the Saturation Temperature required (at a given Saturation Pressure) providing a known humidity value at the Test Temperature and Test Pressure.

> *Note: Although the Two Temperature and Two Pressure modes appear identical, the Two Temperature mode may be used to calculate Saturation Temperature at a known Saturation Pressure, while Two Pressure mode may be used to calculate Saturation Pressure at a known Saturation Temperature. Therefore, Two Temperature mode always requires Saturation Pressure as one of its known inputs, and Two Pressure mode always requires Saturation Temperature, as one of its known inputs. With this exception, Two Temperature and Two Pressure modes are identical.*

KNOWN

The **Known** Drop-down is used to select the known humidity parameter. HumiCalc requires you to know at least one humidity related parameter in order for it to calculate the others. The parameter chosen then appears as the top item in the Known Values frame.

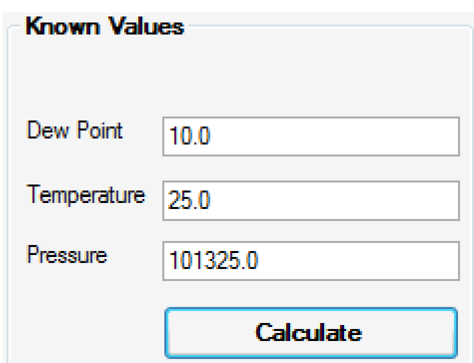


KNOWN VALUES

The **Known Values** frame consists of user enterable known items. Depending on the HumiCalc Mode, the Known Values frame may also display uncertainty or error values for each known.

KNOWN VALUES ONLY

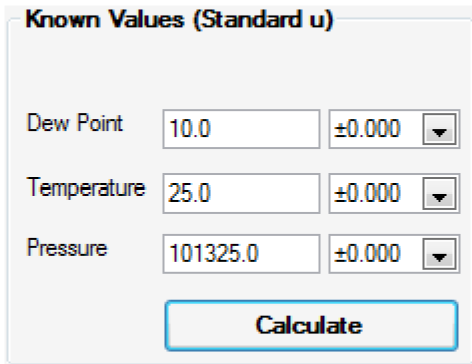
In the **Conversion Only** mode the known value fields are displayed without any uncertainty or error field.



KNOWN VALUES WITH UNCERTAINTY

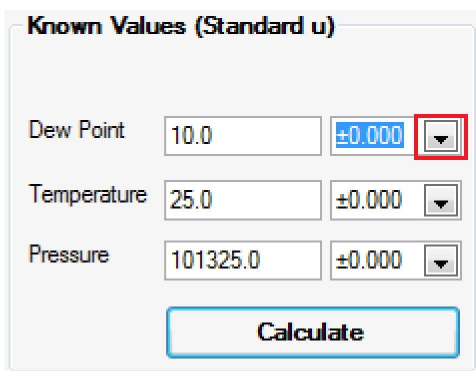
In the **Conversion with Uncertainty** mode an uncertainty field follows each known value field. As stated in the title, the uncertainty displayed is the standard combined uncertainty (u_c) entered by the user for the specific known.

> *Note: Refer to NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" for further information on standard combined uncertainty.*



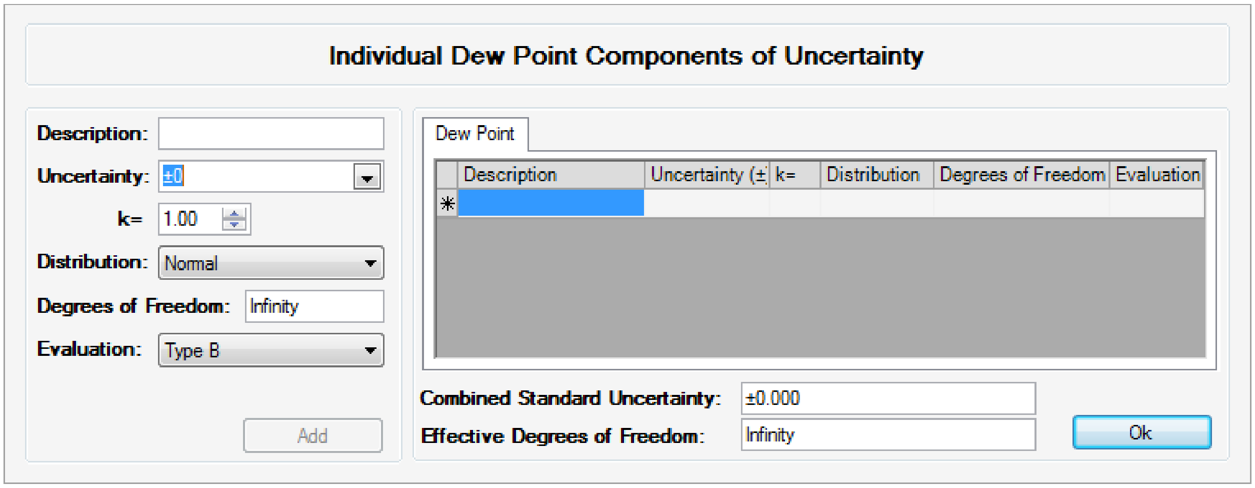
Individual Components of Uncertainty

Each uncertainty field can be expanded using the drop down arrow at the right end of the field.



Once clicked, a drop down form appears that allows the user to enter individual components of uncertainty for the given known value.

> *Note: See the example section of this document for detailed examples of entering individual components of uncertainty.*



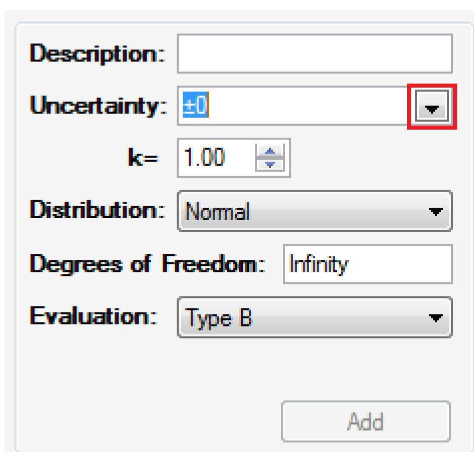
Description

The Description field allows the user to enter a unique description of uncertainty component.

> *Recommendation: Try to enter descriptions that include the given known values name. Like Dew Point or Test Temperature. This will help later when viewing the different calculated humidity parameter's uncertainties.*

Uncertainty

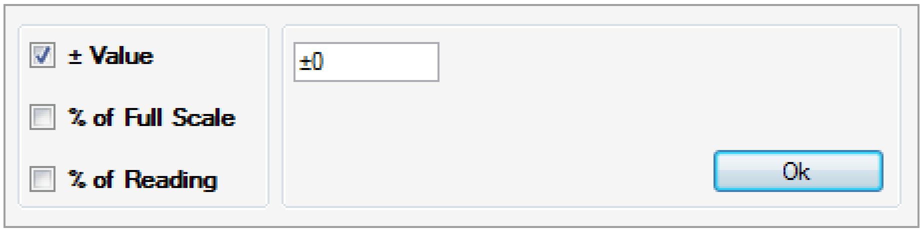
The Uncertainty field allows the user to directly enter the component's uncertainty value. The Uncertainty field can also be expanded using the drop down arrow at the right end of the field.



Once clicked, a drop down form appears that allows the user to select from three different types of uncertainty for the given known value.

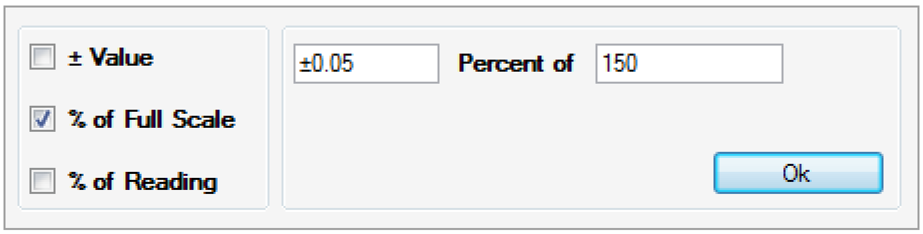
±Value

This is a standard uncertainty value for the component. This is the same as directly entering a value in the uncertainty field on the previous drop down.



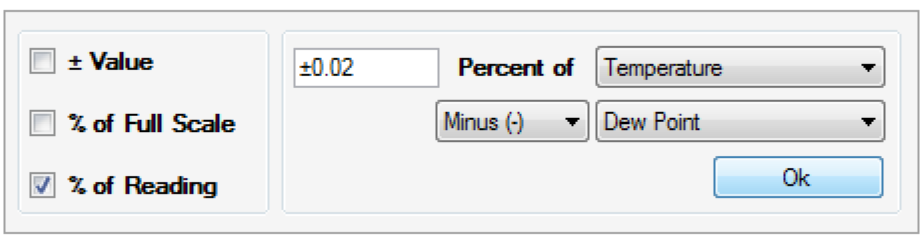
Percent of Full Scale

This is a standard uncertainty value based as a percent of the given full scale value. For example, let say you have a pressure transducer that publishes an uncertainty of ±0.05% of full scale with a full range of 150 psia. You would enter these numbers into HumiCalc with Uncertainty as follows:



Percent of Reading

This is a standard uncertainty value based as a percent of the selected reading. The user can select from any of the current known values and can also perform simple addition or subtraction of any two known values. For example, let say you have a dew point uncertainty component that you have determined to be ±0.02% of the temperature difference between the Test Temperature and the Dew point Temperature. You would enter this into HumiCalc with Uncertainty as follows:



> *Note: HumiCalc with Uncertainty will automatically recalculate percent of reading uncertainty components anytime the selected known changes.*

k=

The k= field allows the user to enter the "k" factor or coverage factor for the entered component's uncertainty value.

Distribution

The Distribution field allows the user to select the type of distribution for the entered component's uncertainty value.

Degrees of Freedom

The Degrees of Freedom field allows the user to enter the degrees of freedom, which depends on the size of the sample for the entered component's uncertainty value.

Evaluation

The Evaluation field allows the user to select either a Type A or Type B for the entered component's uncertainty value.

> *Note: The evaluation type has no effect on the calculation of uncertainty and is supplied solely to assist the user. This is especially helpful when following published guidelines such as the NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results".*

Combined Standard Uncertainty

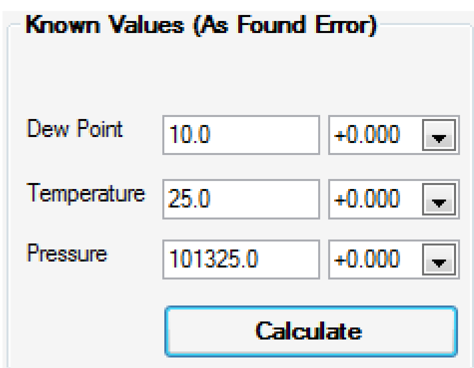
The Combined Standard Uncertainty field displays the combined standard uncertainty (u_c) for the entered uncertainty components. This is the same value as displayed on the main form but with higher resolution.

Effective Degrees of Freedom

The Effective Degrees of Freedom field displays the calculated "Effective Degrees of Freedom" for the combined standard uncertainty using the Welch-Satterthwaite formula.

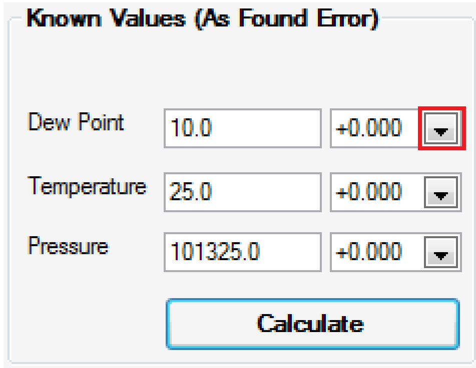
KNOWN VALUES WITH AS FOUND ERROR

In the **Conversion with As Found Error** mode an error field follows each known value field.



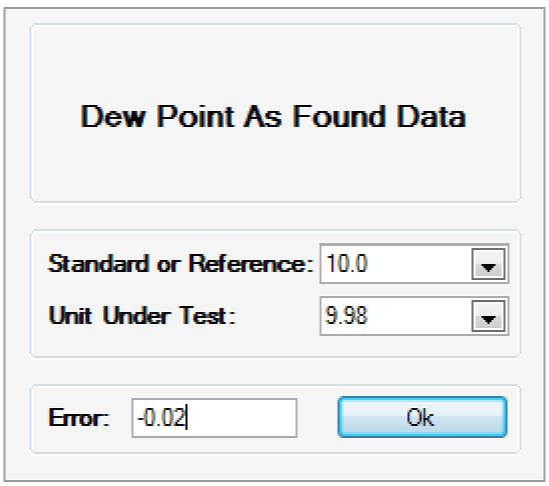
As Found Error

Each error field can be expanded using the drop down arrow at the right end of the field.



Once clicked, a drop down form appears that allows the user to calculate the As Found Error based on a given standard or reference and the unit under test's (UUT) reading.

Note: See the example section of this document for detailed examples of calculating as found error.



Standard or Reference

The Standard or Reference field allows the user to enter the standard or reference reading.

Unit under Test

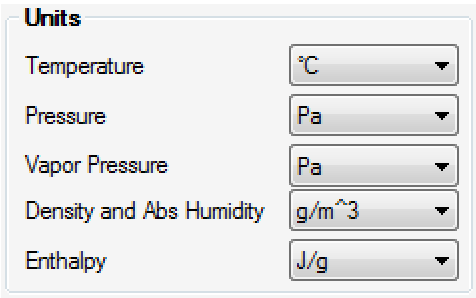
The Unit under Test or UUT field allows the user to enter the units reading when at the standard or reference.

Error

The Error field displays the difference between the standard or reference and the unit under test. This is the calculated "As Found Error".

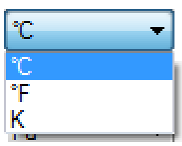
U N I T S

The **Units** frame consists of user selectable units. All values in HumiCalc will be expressed in the selected units. Any time units are changed all affected values are updated.



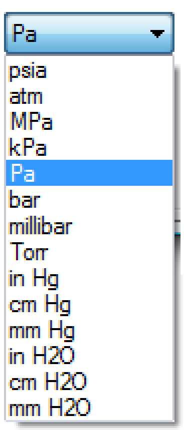
T E M P E R A T U R E

The **Temperature** drop-down list box allows the user to select the desired temperature unit. All temperature values, such as Test Temperature, Frost Point, Dew Point, etc. will update to the new selected unit.



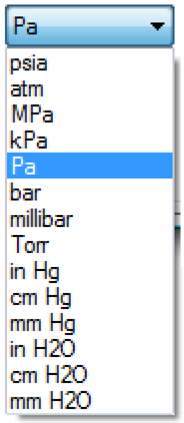
P R E S S U R E

The **Pressure** drop-down list box allows the user to select the desired pressure unit. All pressure values, such as Test Pressure and Saturation Pressure, will update to the new selected units.



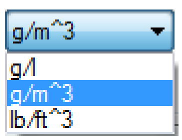
VAPOR PRESSURE

The **Vapor Pressure** drop-down list box allows the user to select the desired vapor pressure unit. All vapor pressure values, such as SVP@Tt, SVP@Td, and SVP@Ts, will update to the new selected unit.



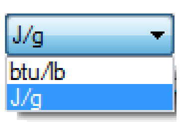
DENSITY AND ABSOLUTE HUMIDITY

The **Density and Absolute Humidity** drop-down list box allows the user to select the desired density and absolute humidity unit. The density and absolute humidity values will update to the new selected unit.



ENTHALPY

The **Enthalpy** drop-down list box allows the user to select the desired enthalpy unit. The enthalpy values will update to the new selected unit.



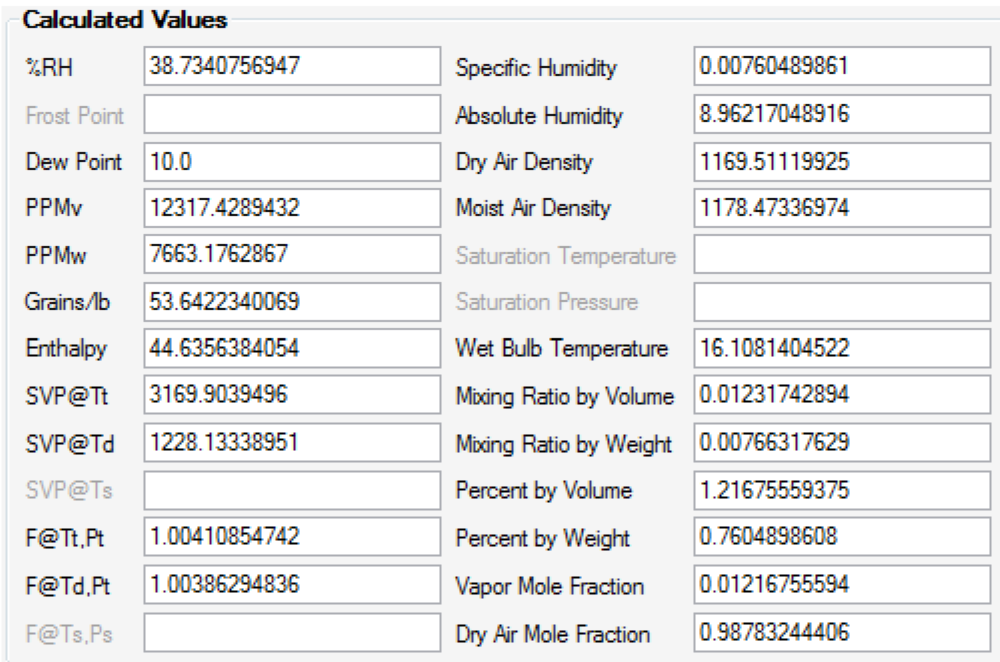
Note: The unit J/g is based on the SI calculation for Enthalpy which is based on a reference state point for the dry-air component of 0 °C. The unit BTU/lb is based on the I-P calculation for Enthalpy which is based on a reference state point for the dry-air component of 0 °F. When switching units HumiCalc will NOT automatically perform a unit conversion because of this difference between reference temperatures. The user will be required to perform a calculation to obtain the Enthalpy in the newly selected unit.

CALCULATED VALUES

The **Calculated Values** frame consists of the calculated humidity parameters based on the given known values and depending on how HumiCalc is configured, can also display expanded uncertainty or error.

CALCULATED VALUES ONLY

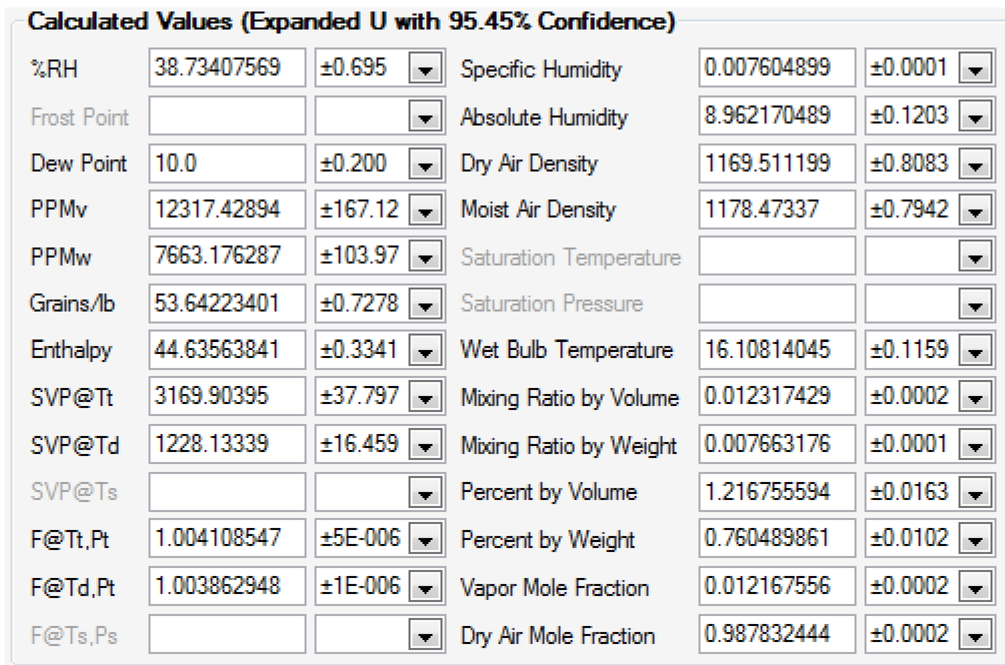
In **Conversion Only** mode, only calculated humidity parameter fields are displayed.



CALCULATED VALUES WITH UNCERTAINTY

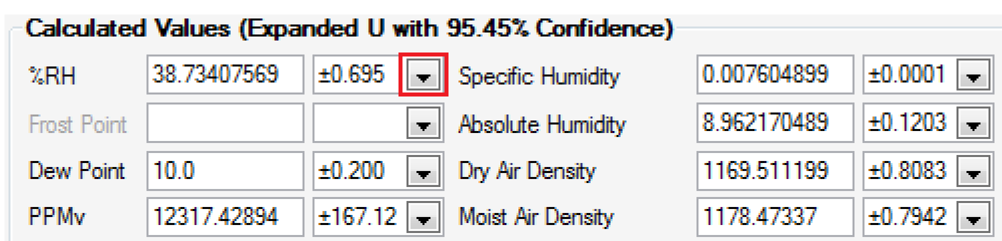
In **Conversion with Uncertainty** mode, an uncertainty field follows each calculated humidity parameter field. As stated in the title, the uncertainty displayed is the expanded uncertainty (U) at the displayed confidence level.

> *Note: Refer to NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" for further information on expanded uncertainty.*

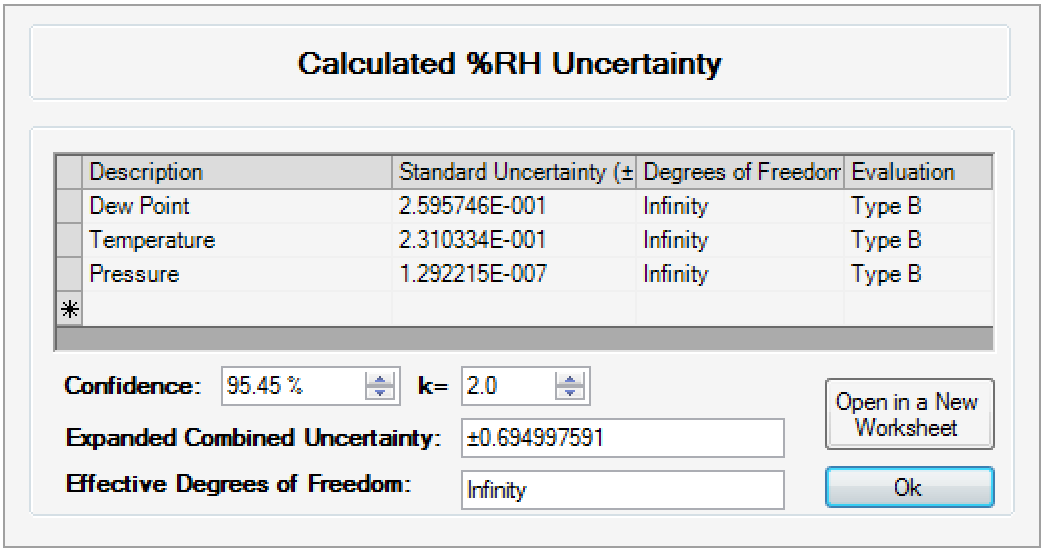


Expanded Uncertainty

Each uncertainty field can be expanded using the drop down arrow at the right end of the field.



Once clicked, a drop down form appears that displays all the components of uncertainty that make up the expanded uncertainty for the given calculated humidity parameter.



Confidence

The Confidence field allows the user to enter the desired level of confidence. Changing the confidence will automatically change the "k" coverage factor based on the effective degrees of freedom. This then updates the expanded combined uncertainty value to reflect the new coverage factor and confidence level.

Note: Refer to NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" for further information on confidence levels.

k=

The "k" coverage factor field allows the user to enter the desired coverage factor. Changing the coverage factor will automatically change the confidence level based on the effective degrees of freedom. This then updates the expanded combined uncertainty value to reflect the new coverage factor and confidence level.

Note: Refer to NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" for further information on coverage factor.

Expanded Combined Uncertainty

The Expanded Combined Uncertainty field displays the expanded uncertainty (U) for the given calculated humidity parameter. This is the same value as displayed on the main form but with higher resolution.

Effective Degrees of Freedom

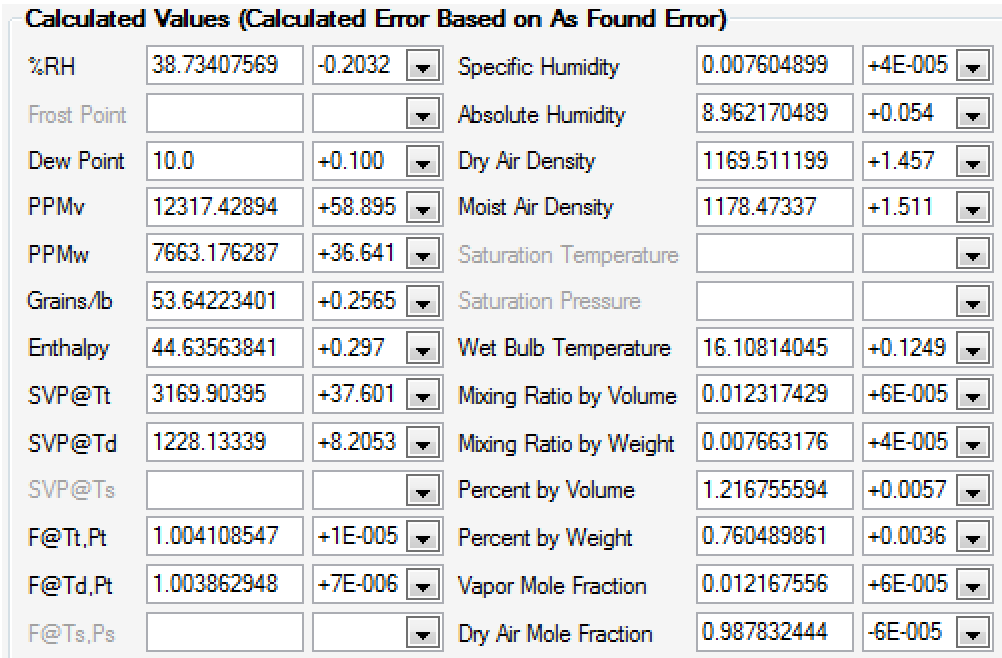
The Effective Degrees of Freedom field displays the calculated "effective degrees of freedom" for the expanded uncertainty using the Welch-Satterthwaite formula.

Open in a New Worksheet

Selection results in the opening of a new worksheet that contains the uncertainty data defined in this drop down. Refer to Section 3 for more information on Worksheets.

CALCULATED VALUES WITH AS FOUND ERROR

In **Conversion with As Found Error** mode, an error field follows each calculated humidity parameter field.

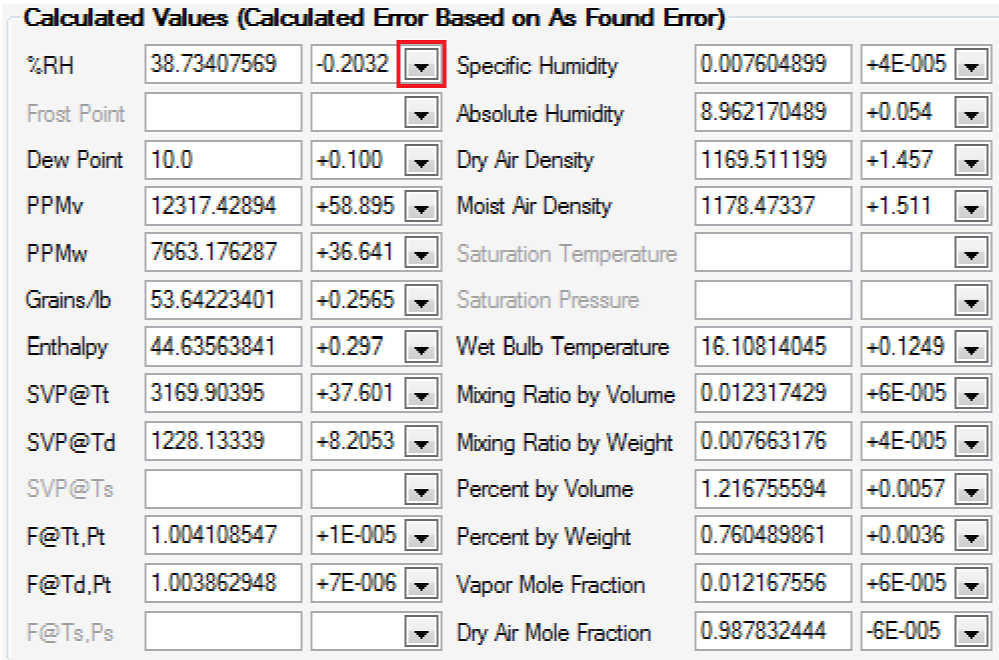


Calculated Values (Calculated Error Based on As Found Error)

%RH	38.73407569	-0.2032	Specific Humidity	0.007604899	+4E-005
Frost Point			Absolute Humidity	8.962170489	+0.054
Dew Point	10.0	+0.100	Dry Air Density	1169.511199	+1.457
PPMv	12317.42894	+58.895	Moist Air Density	1178.47337	+1.511
PPMw	7663.176287	+36.641	Saturation Temperature		
Grains/lb	53.64223401	+0.2565	Saturation Pressure		
Enthalpy	44.63563841	+0.297	Wet Bulb Temperature	16.10814045	+0.1249
SVP@Tt	3169.90395	+37.601	Mixing Ratio by Volume	0.012317429	+6E-005
SVP@Td	1228.13339	+8.2053	Mixing Ratio by Weight	0.007663176	+4E-005
SVP@Ts			Percent by Volume	1.216755594	+0.0057
F@Tt,Pt	1.004108547	+1E-005	Percent by Weight	0.760489861	+0.0036
F@Td,Pt	1.003862948	+7E-006	Vapor Mole Fraction	0.012167556	+6E-005
F@Ts,Ps			Dry Air Mole Fraction	0.987832444	-6E-005

As Found Error

Each error field can be expanded using the drop down arrow at the right end of the field.

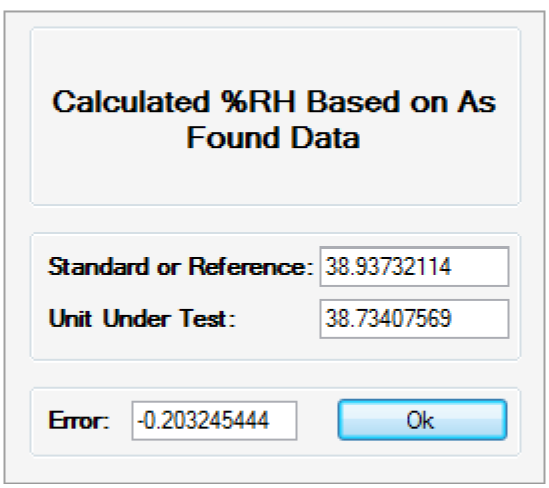


Calculated Values (Calculated Error Based on As Found Error)

%RH	38.73407569	-0.2032	Specific Humidity	0.007604899	+4E-005
Frost Point			Absolute Humidity	8.962170489	+0.054
Dew Point	10.0	+0.100	Dry Air Density	1169.511199	+1.457
PPMv	12317.42894	+58.895	Moist Air Density	1178.47337	+1.511
PPMw	7663.176287	+36.641	Saturation Temperature		
Grains/lb	53.64223401	+0.2565	Saturation Pressure		
Enthalpy	44.63563841	+0.297	Wet Bulb Temperature	16.10814045	+0.1249
SVP@Tt	3169.90395	+37.601	Mixing Ratio by Volume	0.012317429	+6E-005
SVP@Td	1228.13339	+8.2053	Mixing Ratio by Weight	0.007663176	+4E-005
SVP@Ts			Percent by Volume	1.216755594	+0.0057
F@Tt,Pt	1.004108547	+1E-005	Percent by Weight	0.760489861	+0.0036
F@Td,Pt	1.003862948	+7E-006	Vapor Mole Fraction	0.012167556	+6E-005
F@Ts,Ps			Dry Air Mole Fraction	0.987832444	-6E-005

Once clicked, a drop down form appears that displays the "Error" based on the calculated humidity parameter's value at the standard or reference and the calculated humidity parameter's value based on the unit under test's (UUT) readings.

Note: See the example section of this document for a detailed example of calculating as found error.



Standard or Reference

The Standard or Reference field displays the calculated humidity parameter's value based on the standard or reference readings.

Unit under Test

The Unit under Test or UUT field displays the calculated humidity parameter's value based on the units reading when at the standard or reference.

Error

The Error field displays the difference between the calculated humidity parameter's value at the standard or reference and the calculated humidity parameter's value based on the unit under test's (UUT) readings.

SPECIAL CONDITIONS

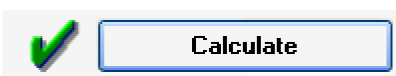
Special Conditions can occur if the known values entered result in a value that is beyond the designed limits or if extrapolation outside published limits were required during calculation.

CALCULATION STATUS

After the user clicks the Calculate button a status image is displayed just to the left of the Calculate button. This image represents one of three different conditions.

Green Check Mark

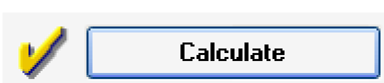
A green check mark indicates that the calculations have been performed and that no special condition has occurred during the calculations.



Yellow Check Mark

A yellow check mark indicates that the calculations have been performed but that some or all calculations required extrapolation beyond the published limits.

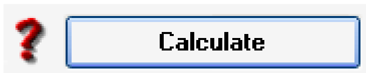
Note: Clicking on the yellow check mark will display a message about the special condition.



Red Question Mark

A red question mark indicates that the calculations have been performed but some or all calculations have gone beyond the designed limits and are either not valid or simply not possible. This special condition will always be preceded by a user message stating which known value is likely causing the condition.

Note: Clicking on the red question mark will display a message about the special condition.



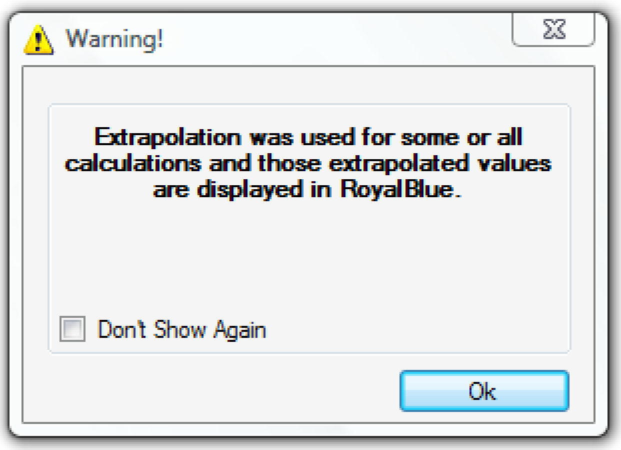
WARNINGS

The user may encounter different types of warning messages during configuration and calculations. These warnings are designed to alert the user to certain conflicting configurations and special conditions.

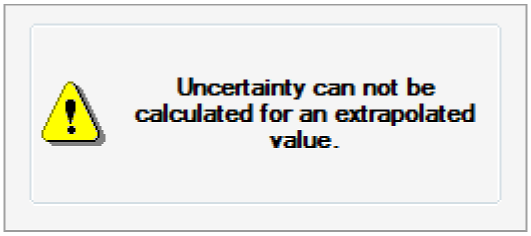
Extrapolation

An "Extrapolation was used" warning tells the user that extrapolation was used for some or all calculations and that those extrapolated values are displayed in Royal Blue to help the user identify which humidity parameters were extrapolated.

Note: Selecting the "Don't Show Again" check box will suppress this dialog from being displayed again until either the application is restarted or the "Reset to Factory Defaults" is selected.



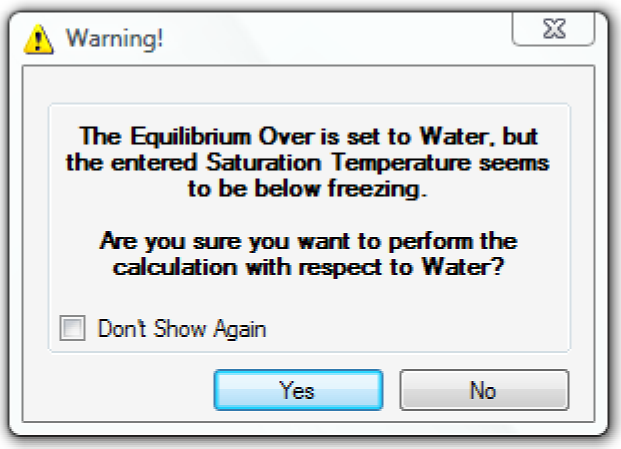
**Special Note on uncertainty and extrapolation: HumiCalc will not calculate any uncertainty if extrapolation was used in any part of the uncertainty calculation. This is simply because the uncertainty is unknown once outside the published limits of the humidity equations. Expanding the drop down uncertainty will result in the following drop down form message.*



Equilibrium Over is set to Water

An "Equilibrium Over is Set to Water" warning tells the user that the equilibrium over is set to water but the entered saturation temperature is below freezing. This warning is designed to draw the user's attention to the selected equilibrium and is not an indication of an error.

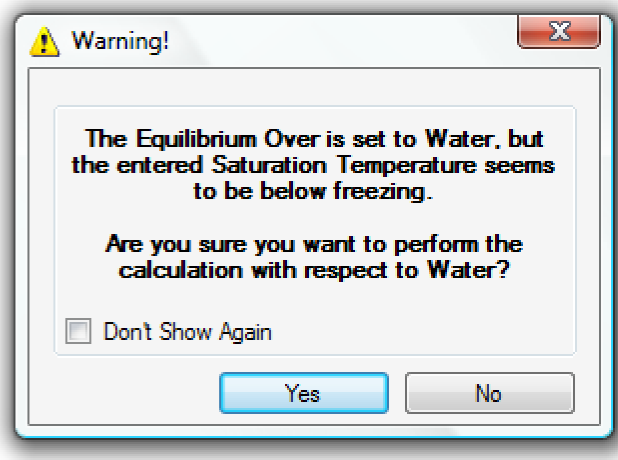
Note: Selecting the "Don't Show Again" check box will suppress this dialog from being displayed again until either the application is restarted or the "Reset to Factory Defaults" is selected.



Apply Enhancement Factors is not checked

An "Apply Enhancement Factors is not checked" warning tells the user that the calculation is about to be performed without enhancement factors. This warning is designed to draw the user's attention to the apply enhancement factor check box and is not an indication of an error.

> *Note: Selecting the "Don't Show Again" check box will suppress this dialog from being displayed again until either the application is restarted or the "Reset to Factory Defaults" is selected.*



Enhancement Factor not applicable

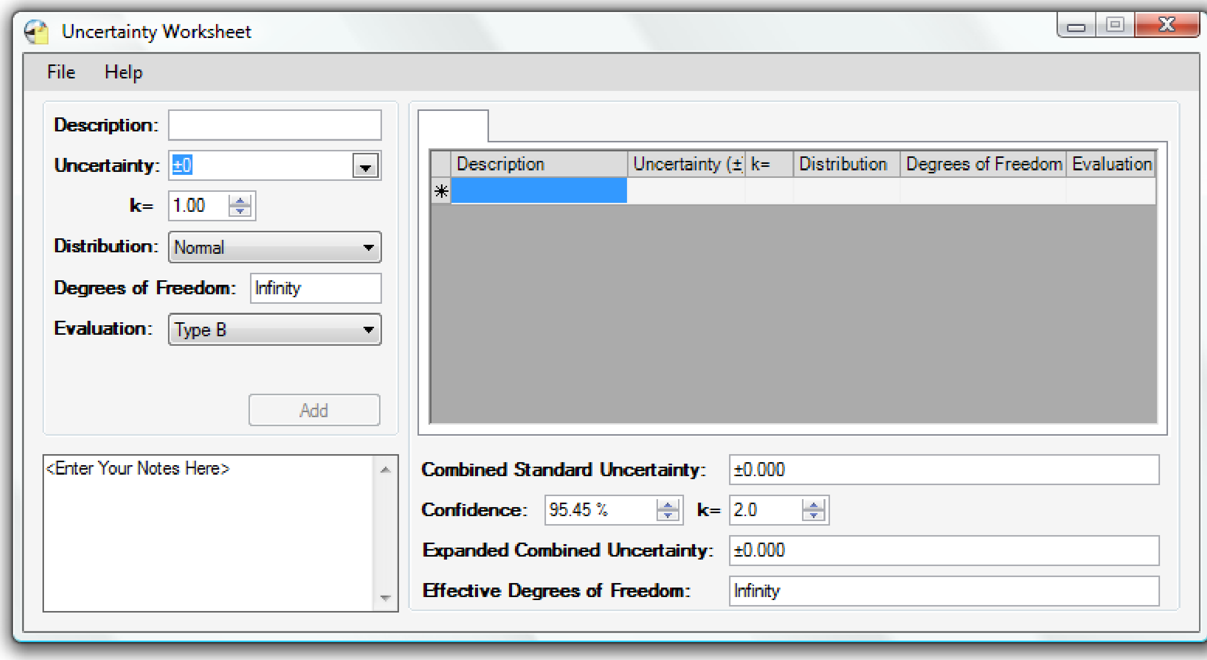
An "Enhancement Factor may not be applicable for this type of Carrier Gas" warning tells the user that the calculation is about to be performed with enhancement factors on, but with a carrier gas selected that is not air or nitrogen. This warning is designed to draw the user's attention to the apply enhancement factor check box and is not an indication of an error.

> *Note: Selecting the "Don't Show Again" check box will suppress this dialog from being displayed again until either the application is restarted or the "Reset to Factory Defaults" is selected.*

3

WORKSHEETS

This section provides you with detailed information relating to the layout, configuration and use of HumiCalc Worksheets. Worksheets work in the same fashion as the individual components of uncertainty drop down dialogs. Worksheets are great for any uncertainty calculation that needs to perform basic "law of propagation of uncertainty" type calculations. That means they can be used for any same unit uncertainty problem even non humidity related uncertainty problems.

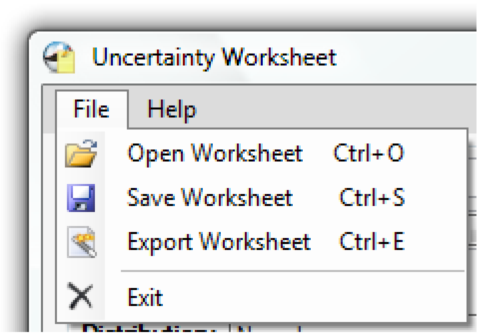


MENU BAR

The **Menu Bar** consists of two submenu drop downs: **File** and **Help**.

FILE MENU

The **File** Menu consists of four selections: Open Worksheet, Save Worksheet, Export Worksheet and Exit.



Open Worksheet

Selection will open a file dialog box to allow navigation to a HumiCalc Worksheet file for loading of previously saved work.

Save Worksheet

Selection will open a file dialog box to allow navigation and naming of the HumiCalc Worksheet file that will be saved. All current data entries in the Worksheet will be saved in the HumiCalc Worksheet file to allow the user to load at a future time.

Export

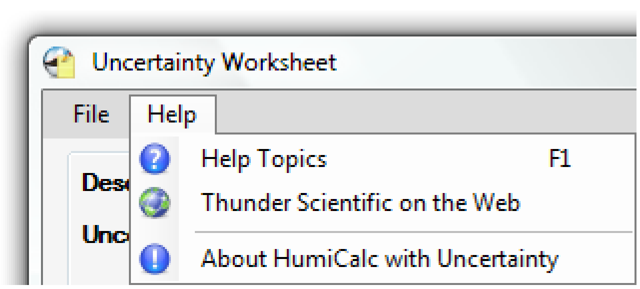
The Export option allows the user to export the current HumiCalc Worksheet into an Adobe PDF (*.pdf), Enhanced Metafile (*.emf), Excel Workbook (*.xls), Excel 2007 Workbook (*.xlsx), Rich Text Format (*.rtf) or a Word 2007 Document (*.docx). Selection will open a file dialog box to allow navigation and naming of the exported file.

Exit

Selection will close the Worksheet.

HELP MENU

The **Help** Menu consists of three selections: Help Topics, Thunder Scientific on the Web and About HumiCalc with Uncertainty.



Help Topics

Selection of Help Topics will open this reference manual.

Thunder Scientific on the Web

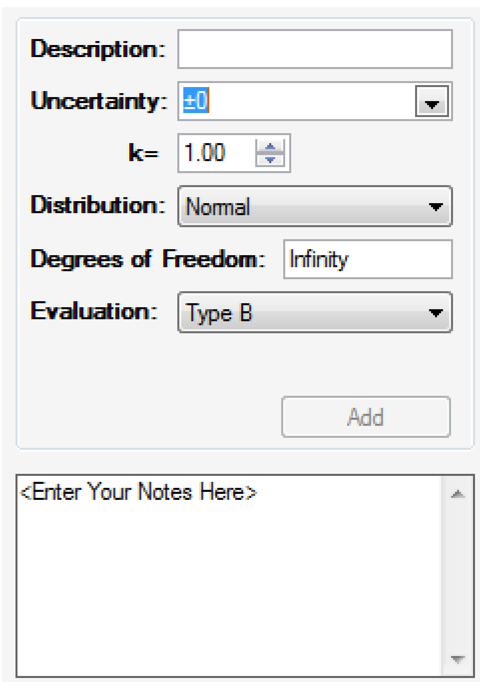
Selection of Thunder Scientific on the Web will open Thunder Scientifics web page, which contains the latest news, products and information from Thunder Scientific Corporation.

About HumiCalc with Uncertainty

Selection of About HumiCalc with Uncertainty will open an About Dialog containing important information about the application.

LEFT SIDE

The **Left** Side is used to enter new components of uncertainty into the worksheet and allows the user to add notes for the entire worksheet. Each component of uncertainty entry consists of a Description, Uncertainty, k=, Distribution, Degrees of Freedom and Evaluation.



DESCRIPTION

The Description field allows the user to enter a unique description of uncertainty component.

> *Recommendation: Try to enter descriptions that include the given known values name. Like Dew Point or Test Temperature. This will help later when viewing the different calculated humidity parameter's uncertainties.*

UNCERTAINTY

The Uncertainty field allows the user to directly enter the component's uncertainty value.

K =

The k= field allows the user to enter the "k" factor or coverage factor for the entered component's uncertainty value.

DISTRIBUTION

The Distribution field allows the user to select the type of distribution for the entered component's uncertainty value.

DEGREES OF FREEDOM

The Degrees of Freedom field allows the user to enter the degrees of freedom, which depends on the size of the sample for the entered component's uncertainty value.

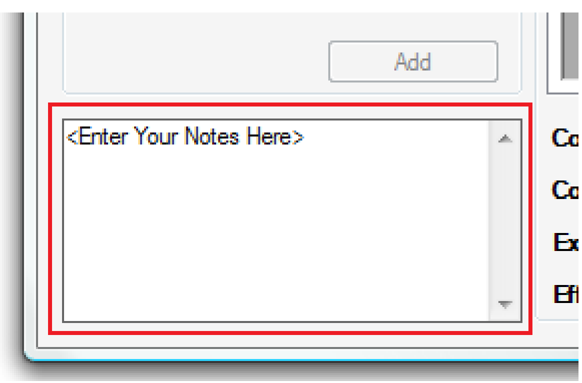
EVALUATION

The Evaluation field allows the user to select either a Type A or Type B for the entered component's uncertainty value.

> *Note: The evaluation type has no effect on the calculation of uncertainty and is supplied solely to assist the user. This is especially helpful when following published guidelines such as the NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results".*

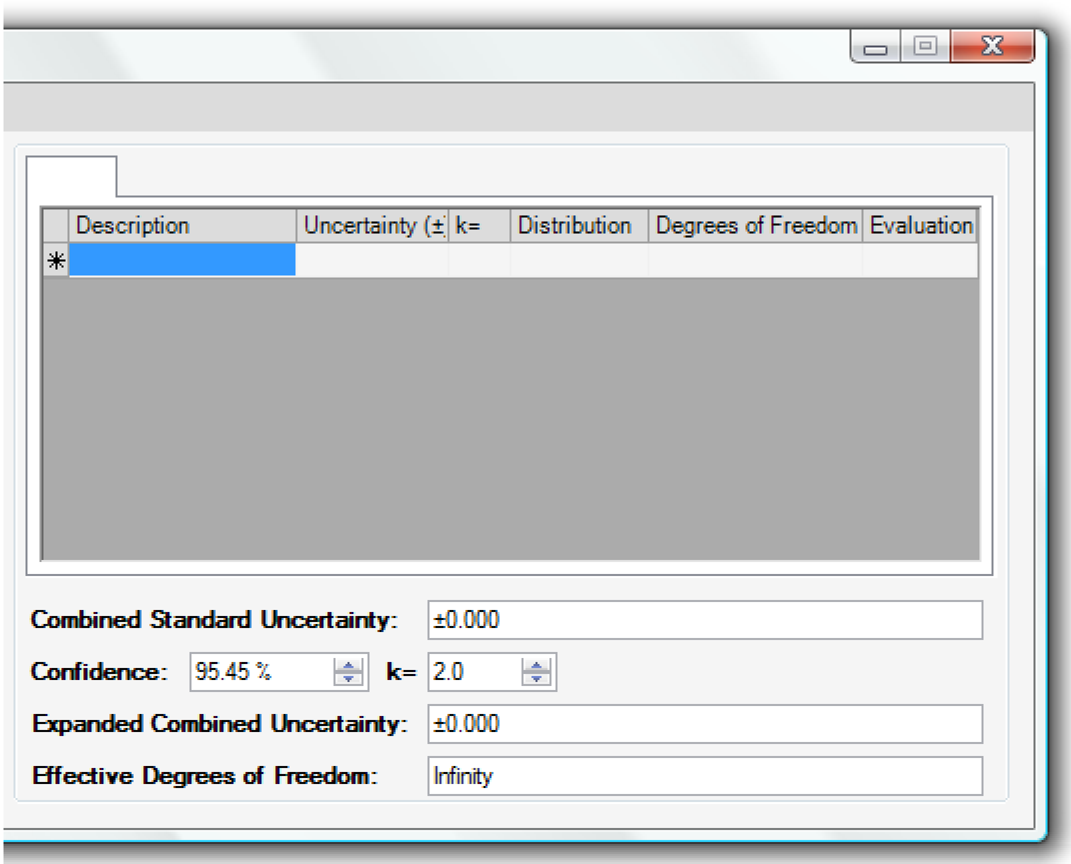
NOTES

The Notes field allows the user to enter textual notes about the overall uncertainty calculation for this worksheet.



RIGHT SIDE

The **Right** Side shows each individual uncertainty components entered in a grid like format. Below the grid are the resulting combined uncertainties of all the entered components. The combined uncertainties consists of Combined Standard Uncertainty, Confidence, k=, Expanded Combined Uncertainty and Effective Degrees of Freedom.



COMBINED STANDARD UNCERTAINTY

The Combined Standard Uncertainty field displays the combined standard uncertainty (u_c) for the entered uncertainty components.

CONFIDENCE

The Confidence field allows the user to enter the desired level of confidence. Changing the confidence will automatically change the "k" coverage factor based on the effective degrees of freedom. This then updates the expanded combined uncertainty value to reflect the new coverage factor and confidence level.

> *Note: Refer to NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" for further information on confidence levels.*

K =

The "k" coverage factor field allows the user to enter the desired coverage factor. Changing the coverage factor will automatically change the confidence level based on the effective degrees of freedom. This then updates the expanded combined uncertainty value to reflect the new coverage factor and confidence level.

> *Note: Refer to NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" for further information on coverage factor.*

EXPANDED COMBINED UNCERTAINTY

The Expanded Combined Uncertainty field displays the expanded uncertainty (U) for the entered uncertainty components.

EFFECTIVE DEGREES OF FREEDOM

The Effective Degrees of Freedom field displays the calculated "effective degrees of freedom" for the expanded uncertainty using the Welch-Satterthwaite formula.

4

EXAMPLES

This section provides you with a few examples relating to the different features and configurations of HumiCalc. By following along, you will become familiar with how to use these features and configurations. The examples shown here do not constitute a comprehensive list of humidity computations, but may be used as guidelines in solving similar or related humidity problems.

CONVERSION EXAMPLES

These are examples dealing with HumiCalc's ability to perform calculations and conversions. These can be performed in any HumiCalc Mode but they do not address any Uncertainty or Error calculations.

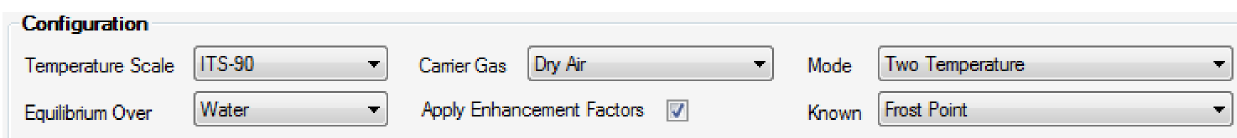
FROST POINT CONTROL WITH A TWO TEMPERATURE GENERATOR

Using a Two Temperature Frost Point generator, determine the Saturation Temperature setpoint needed to generate a Frost Point of -15.0°C at a Saturation Pressure of 25.0 psia in the cell of a hygrometer at 14.7 psia.

> *Note: The Test Temperature has no affect on this calculation due to the relation between the Frost Point and Saturation Temperature, but in this example we will use 21.5°C.*

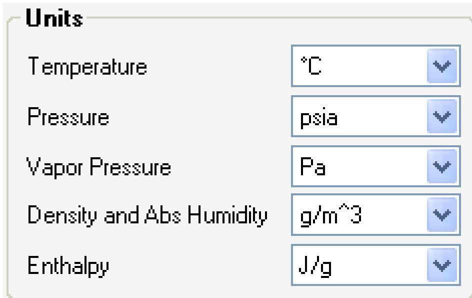
Configuration

Set the Configuration.



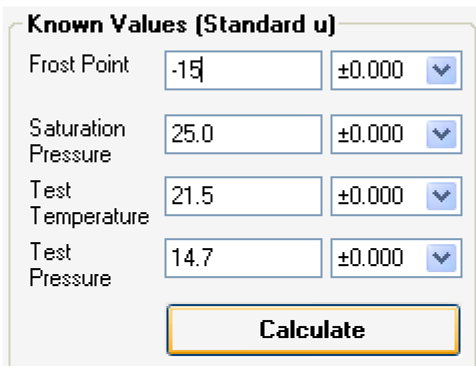
Units

Set the Units.



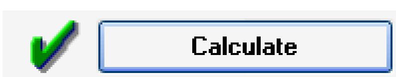
Known Values

Enter the Known Values.



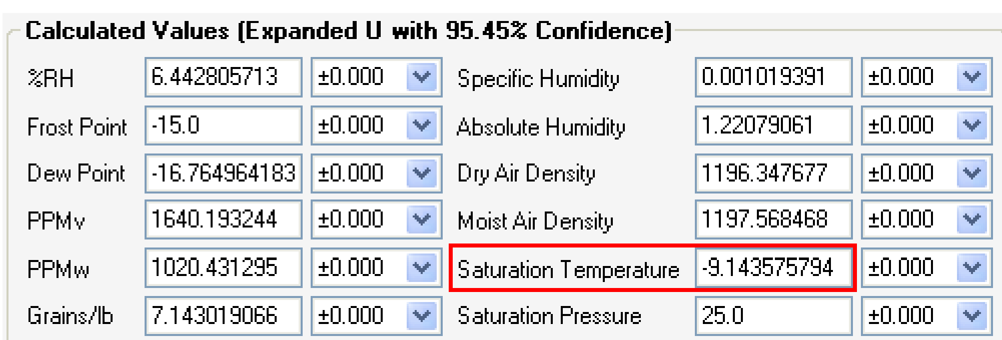
Perform the Calculations

Click the Calculate button.



Results

Look at the calculated values for the Saturation Temperature. This is the Saturator Temperature setpoint needed to generate a -15 °C Frost Point in the unit under test.

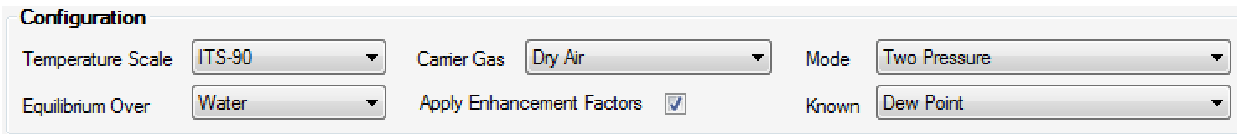


DEWPOINT CONTROL IN A TWO PRESSURE GENERATOR

Determine the Saturation Pressure needed in order to generate air with a Dew Point of 5.0°C in the chamber of a Two Pressure Humidity Generator. Also determine the corresponding %RH. For this example we will use a Saturation Temperature of 21.15°C, a Test Pressure of 15.0 psia and a Test Temperature of 21.11°C.

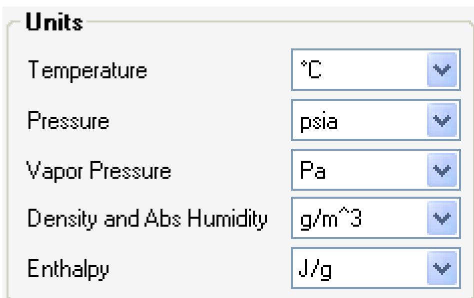
Configuration

Set the Configuration.



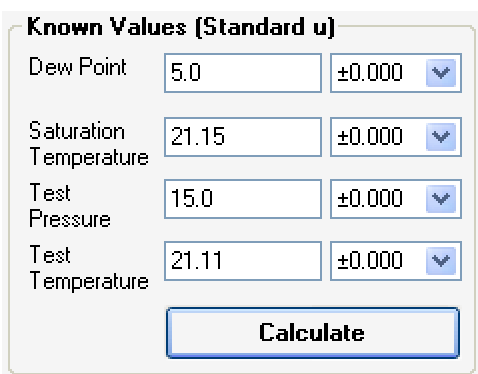
Units

Set the Units.



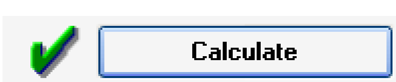
Known Values

Enter the Known Values.



Perform the Calculations

Click the Calculate button.



Results

Look at the calculated values for the Saturation Pressure and %RH. These are the %RH or Saturator Pressure setpoints needed to generate a 5.0°C Dew Point.

Calculated Values (Expanded U with 95.45% Confidence)

%RH	34.8260216	±0.000	Specific Humidity	0.005286326	±0.000
Frost Point			Absolute Humidity	6.451788537	±0.000
Dew Point	5.0	±0.000	Dry Air Density	1214.015524	±0.000
PPMv	8542.148822	±0.000	Moist Air Density	1220.467313	±0.000
PPMw	5314.420127	±0.000	Saturation Temperature	21.5	±0.000
Grains/lb	37.20094089	±0.000	Saturation Pressure	44.37404409	±0.000
Enthalpy	34.70888157	±0.000	Wet Bulb Temperature	12.60138847	±0.000

CONVERTING %RH TO A NEW PRESSURE AND TEMPERATURE

Convert 50.0 %RH measured at 25.0°C and 97020.0 Pa, to the resulting Relative Humidity at 50.0°C and 101325.0 Pa. This type of operation requires a two-step process. First, you will convert %RH at one pressure and temperature to PPMv. You'll then convert this PPMv to a %RH at a new pressure and temperature. PPMv is used as the intermediary variable to effectively hold the mixing ratio of the gas, since once determined; it will not vary with changes in pressure and/or temperature. RH-to-RH conversions of this type should always be done through PPMv or another temperature and pressure insensitive variable.

Configuration

Set the Configuration.

Configuration

Temperature Scale	ITS-90	Carrier Gas	Dry Air	Mode	Normal
Equilibrium Over	Water	Apply Enhancement Factors	☑	Known	%RH

Units

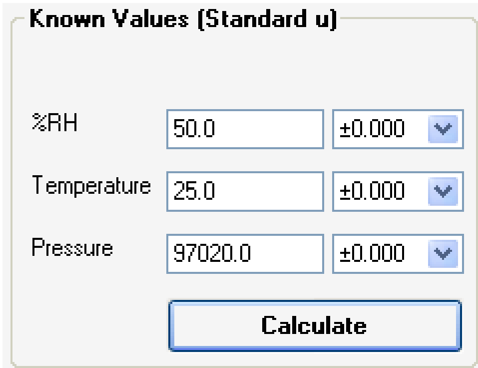
Set the Units.

Units

Temperature	°C
Pressure	Pa
Vapor Pressure	Pa
Density and Abs Humidity	g/m^3
Enthalpy	J/g

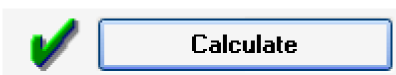
Known Values at the Initial Pressure and Temperature

Enter the Known Values.



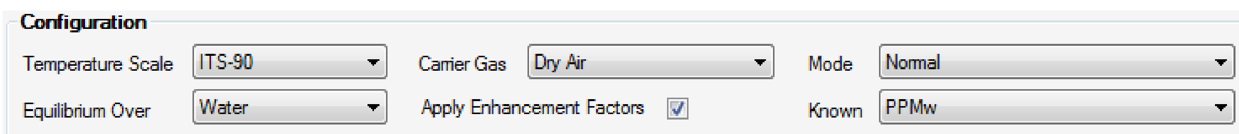
Perform the Calculations

Click the Calculate button.



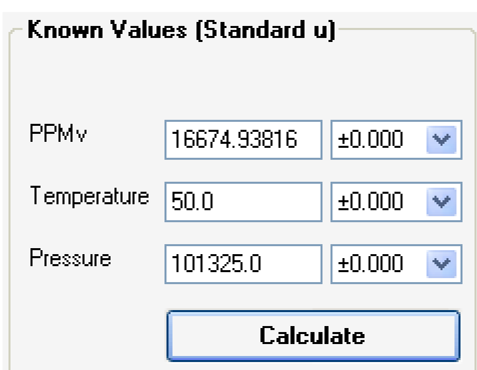
Change Configuration

Change the Configuration to have the known set to PPMv.



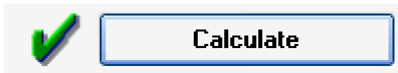
Known Values at the new Pressure and Temperature

Enter the new Temperature and Pressure values but leave the PPMv unchanged.



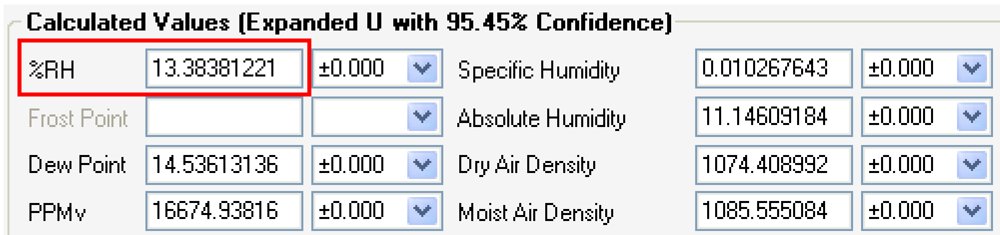
Perform the Calculations

Click the Calculate button.



Results

Look at the calculated value for new %RH.

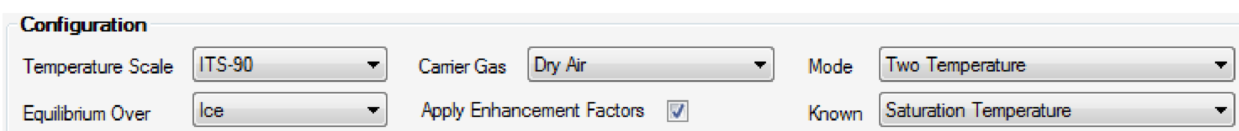


CONVERTING FROST POINT TO A NEW PRESSURE

If the Frost Point is -50.0°C at a pressure of 14.7 psia, what will the Frost Point be at a new pressure of 200.0 psia? What will the Frost Point Vapor Pressure in Pa and Density in grams/liter be at the new pressure? Although this conversion has the same appearance as, and could be performed in a manner similar to, the previous example ("Converting %RH to a New Pressure and Temperature"), this particular conversion may also be done in only one main operation eliminating the need to re-configure midstream. The simplicity of this conversion relies on the synonymous relationship between Frost Point at a known pressure, and Saturation Temperature at a known Saturation Pressure of a Two Temperature (or Two Pressure) Generator. By substituting Saturation Temperature with Frost Point and Saturation Pressure with the pressure of the Frost Point, either the Two Temperature or Two Pressure mode can be used for this conversion.

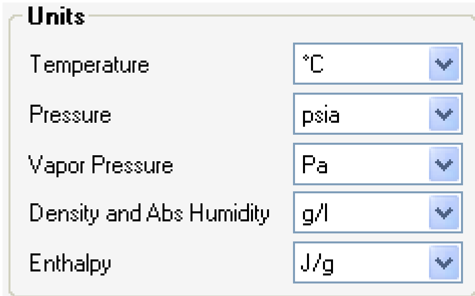
Configuration

Set the Configuration.



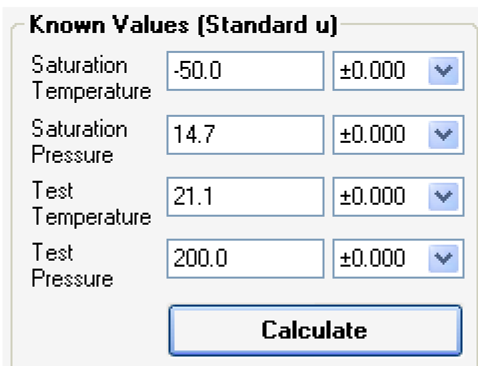
Units

Set the Units.



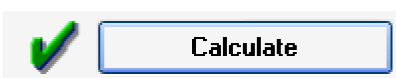
Known Values

Enter the Known Values.



Perform the Calculations

Click the Calculate button.



Results

Look at the calculated values for calculated Frost Point, SVP@Td and Density.

Calculated Values (Expanded U with 95.45% Confidence)

%RH	2.064111559	±0.000	Specific Humidity	0.000024292	±0.000
Frost Point	-27.224774601	±0.000	Absolute Humidity	0.000396578	±0.000
Dew Point	-30.103051003	±0.000	Dry Air Density	16.3250617	±0.000
PPMv	39.04675665	±0.000	Moist Air Density	16.32545828	±0.000
PPMw	24.29258419	±0.000	Saturation Temperature	-50.0	±0.000
Grains/lb	0.170048089	±0.000	Saturation Pressure	14.7	±0.000
Enthalpy	21.26717852	±0.000	Wet Bulb Temperature	18.73348553	±0.000
SVP@Tt	2503.49261	±0.000	Mixing Ratio by Volume	0.000039047	±0.000
SVP@Td	50.55746055	±0.000	Mixing Ratio by Weight	0.000024293	±0.000

DETERMINING %RH IN A TWO PRESSURE GENERATOR

Using a Two Pressure generator, you are calibrating a unit that displaces enough heat to raise the chamber temperature by 1.4°C above the fluid bath and saturator temperatures. What is the %RH in the chamber at this elevated chamber temperature? Also, assuming that you know the internal temperature of the unit, which is generating this heat load, what is the relative humidity within the unit under test at its temperature? First we'll find the %RH at the chamber temperature. Then, since HumiCalc will already be configured correctly, we can recalculate the %RH at the temperature of the heat-loading unit under test. For this example we will use a Saturation Pressure of 64.75 psia, a Saturation Temperature of 21.1°C, a Test Pressure of 15.0 psia and a Test Temperature of 22.5°C.

Configuration

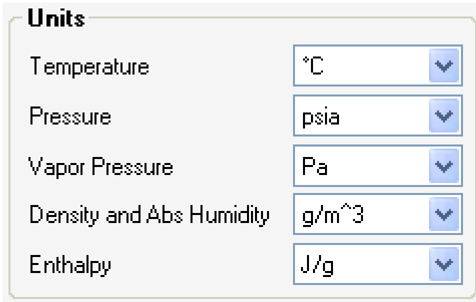
Set the Configuration.

Configuration

Temperature Scale	ITS-90	Carrier Gas	Dry Air	Mode	Two Pressure
Equilibrium Over	Water	Apply Enhancement Factors	☑	Known	Saturation Pressure

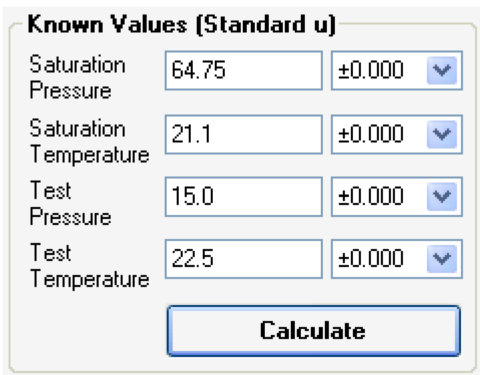
Units

Set the Units.



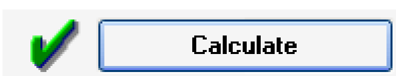
Known Values at Chamber Temperature

Enter the Known Values at Chamber Temperature.



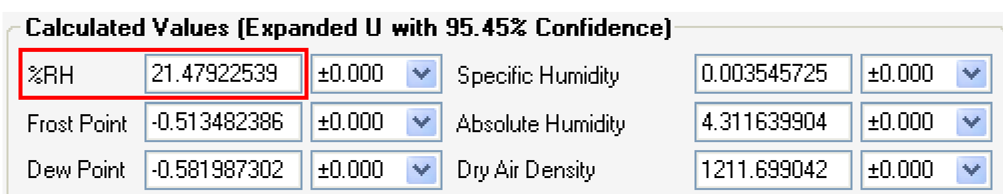
Perform the Calculations

Click the Calculate button.



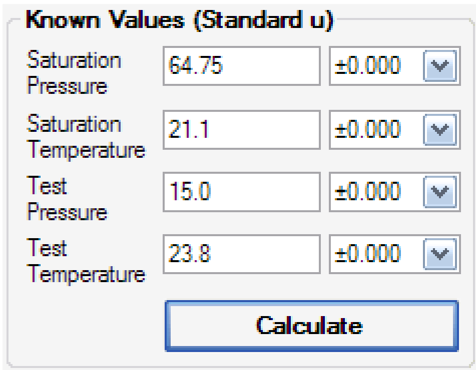
Results

Look at the calculated value for %RH at the chamber temperature.



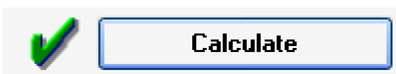
Known Values inside the Unit under Test

Change the Test Temperature Known Value to the temperature inside the unit under test (22.5°C + 1.4°C = 23.8°C).



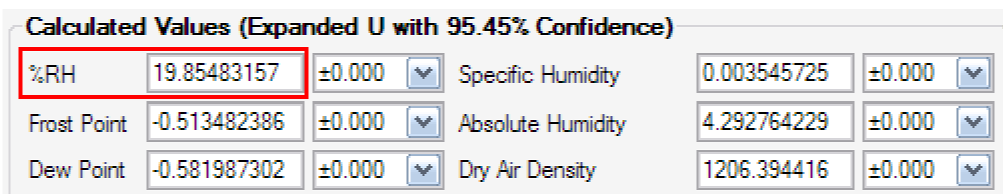
Perform the Calculations

Click the Calculate button.



Results

Look at the calculated value for %RH at the temperature measured inside the unit under test.

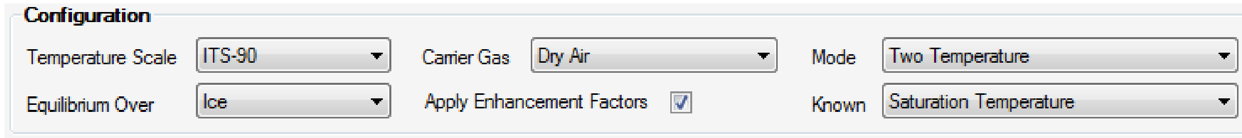


DETERMINING FROST POINT AND PPMW OF A DEHYDRATOR

A Dehydrator operates at a pressure of 3015 psia. A sample of gas is tapped off of the dehydrator outlet and flows through a chilled mirror, which indicates a Frost Point of -60 °F at 14.7 psia. The dehydrator is at 68 °F. What is the PPMw and Frost Point at the pressure of the dehydrator? With some minor differences in appearance, this example is very similar to a previous one ("Converting Frost Point to a New Pressure"), and relies on the principles of synonymous substitution. Here, the indicated Frost Point of the chilled mirror will be referred to as Saturation Temp, and the pressure of the chilled mirror will become the Saturation Pressure. The dehydrator pressure becomes the Test Pressure since that is the pressure to which the calculated humidity values are to be referred.

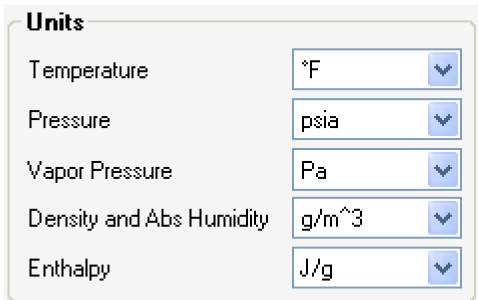
Configuration

Set the Configuration.



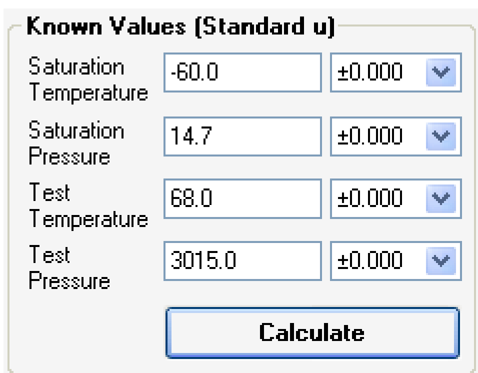
Units

Set the Units.



Known Values

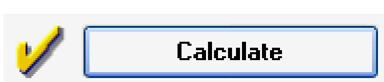
Enter the Known Values.



Perform the Calculations

Click the Calculate button.

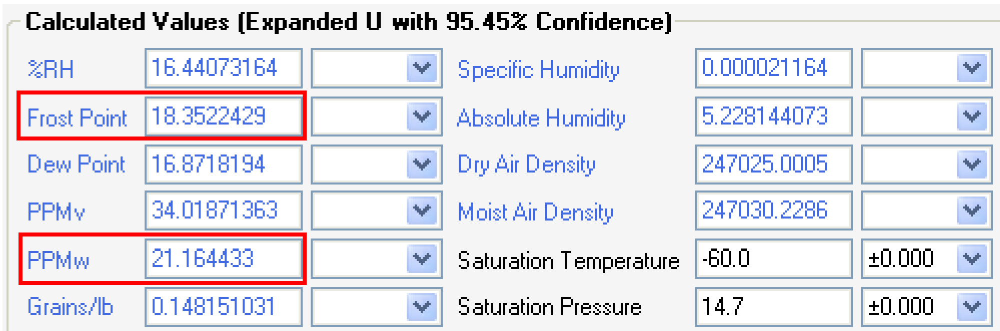
Note: The yellow check mark indicates that there is a special condition with the calculations. In this case it is because the test pressure value is beyond the published limits of the enhancement factor equation and some of the results will be extrapolated.



Results

Look at the calculated value for the PPMw and Frost Point in the dehydrator at a pressure of 3015 psia.

> *Note: Values displayed in blue are extrapolated beyond the published limits of the enhancement equation.*

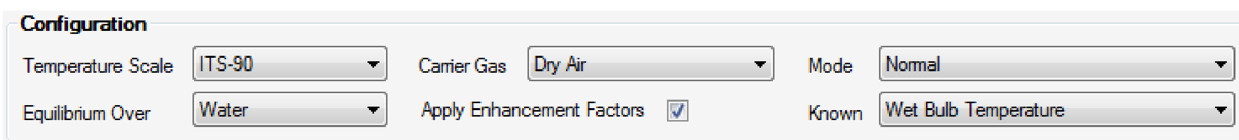


WET BULB/DRY BULB PSYCHROMETER

Using a sling or aspirated Psychrometer, determine the %RH, Dew Point, and grains per pound of the environment. For this example we will use a Wet Bulb Temperature of 38.95°F, a Dry Bulb Temperature of 51.5°F and a Pressure of 758.5 torr.

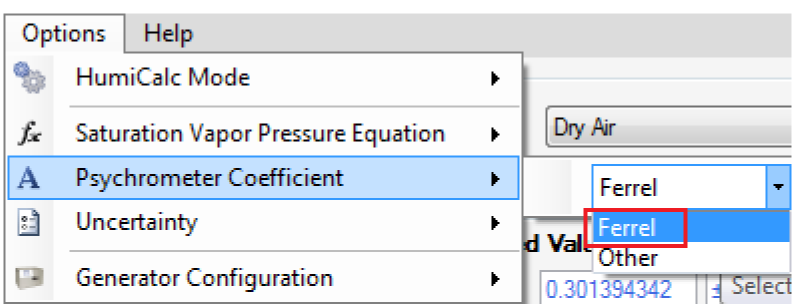
Configuration

Set the Configuration.



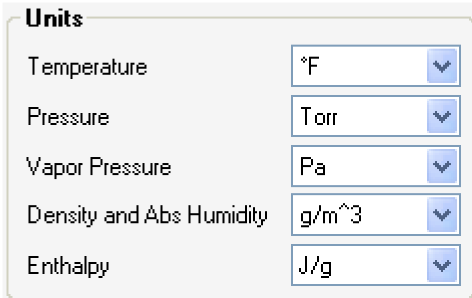
Configuration

Set the Psychrometer Coefficient to use Ferrel's equation.



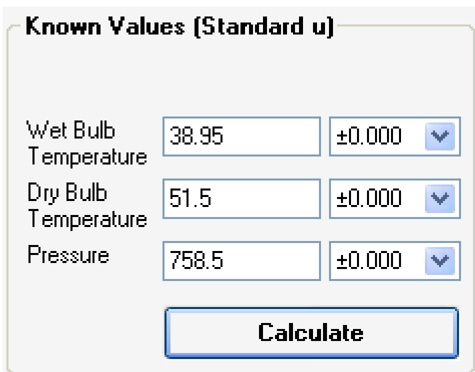
Units

Set the Units.



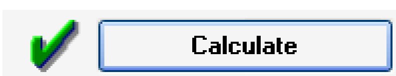
Known Values

Enter the Known Values.



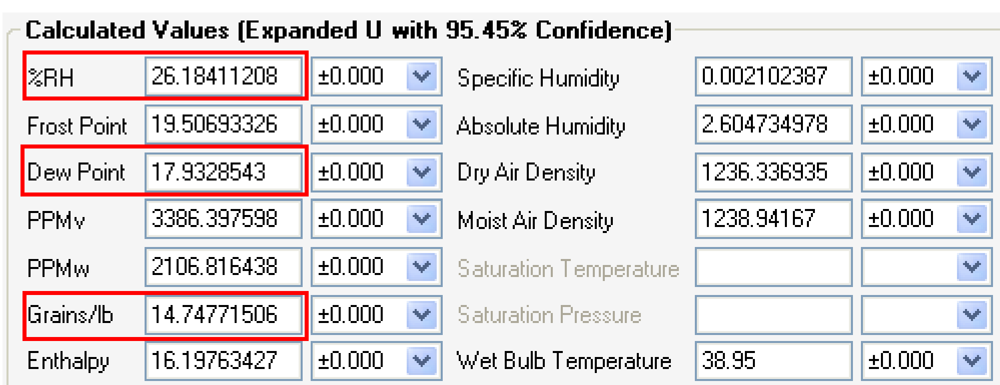
Perform the Calculations

Click the Calculate button.



Results

Look at the calculated value for the %RH, Dew Point, and Grains/lb of the environment.

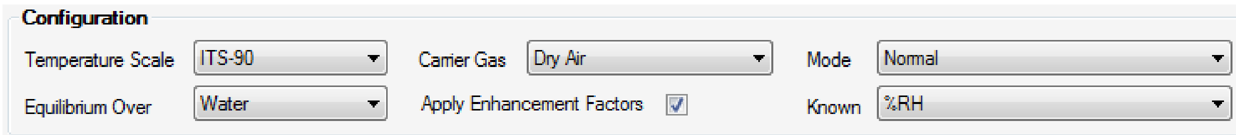


WET BULB CONTROLLED RH GENERATOR

You have an RH chamber that uses a wet bulb control scheme to generate various values of Relative Humidity. With a 24.8°C chamber temperature at a 14.62 psia chamber pressure, what is the wet bulb setpoint needed to generate 50.0 %RH?

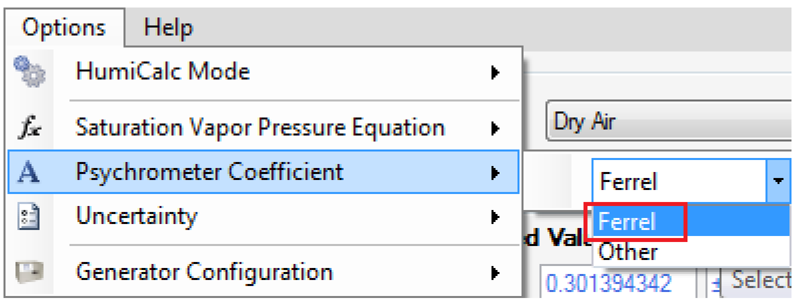
Configuration

Set the Configuration.



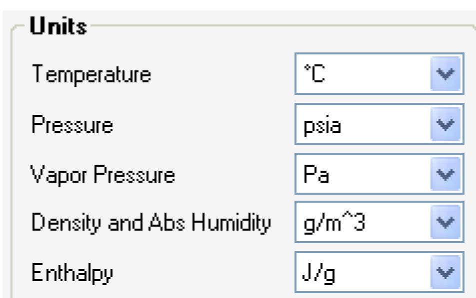
Configuration

Set the Psychrometer Coefficient to use Ferrel's equation.

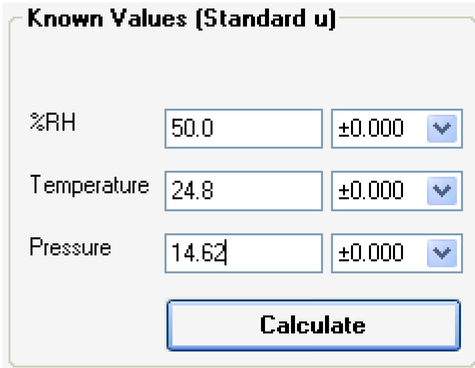


Units

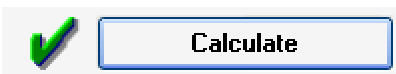
Set the Units.



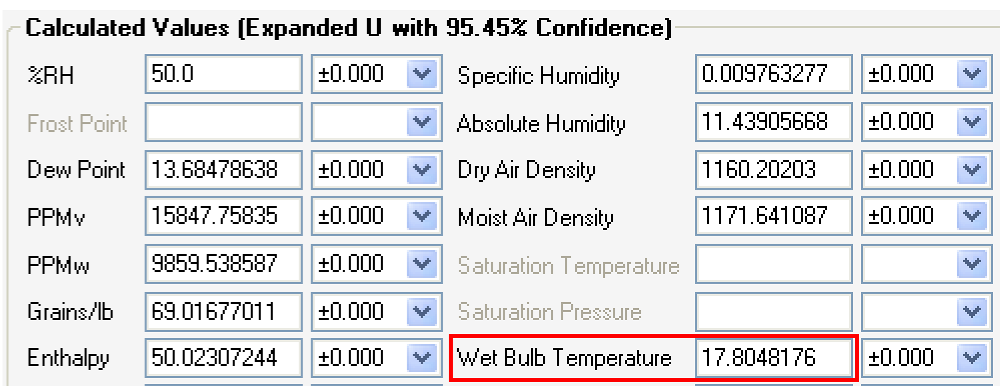
Known Values
Enter the Known Values.



Perform the Calculations
Click the Calculate button.

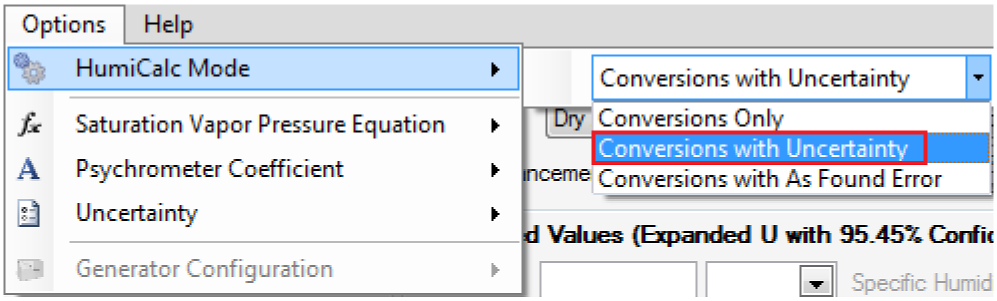


Results
Look at the calculated value for the wet bulb temperature to find the required wet bulb controller setpoint to generate 50 %RH.



UNCERTAINTY EXAMPLES

These examples deal with HumiCalc's ability to perform uncertainty calculations. These can only be performed in the "Conversion with Uncertainty" HumiCalc Mode. These examples are structured slightly different than the conversion examples before, mainly with the focus to demonstrate how to enter and calculate uncertainty. The values entered throughout these examples are simply for demonstration purposes.

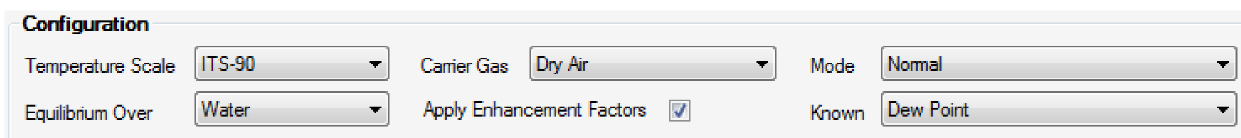


SIMPLE CHILLED MIRROR %RH UNCERTAINTY

This example will perform a simple uncertainty calculation for a Chilled Mirror Hygrometer capable of displaying %RH. We will calculate the %RH uncertainty for this Hygrometer based on an example Dew Point, Pressure and Temperature standard uncertainties.

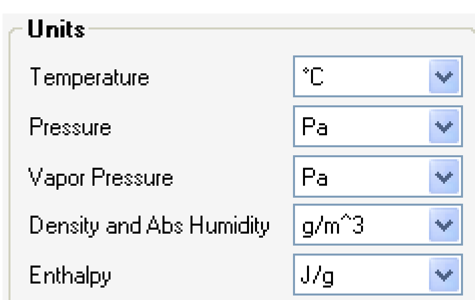
Configuration

Set the Configuration.



Units

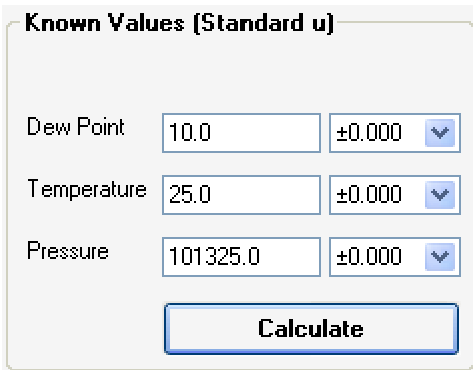
Set the Units.



Known Values

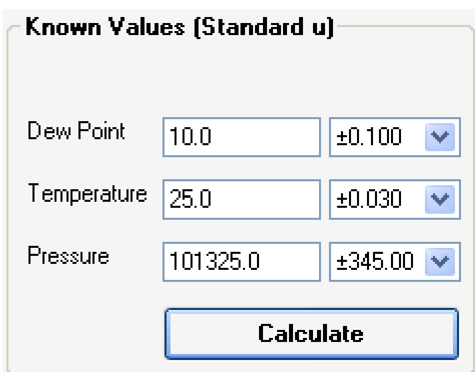
Enter the Known Values.

> *Note: The uncertainty can vary greatly at different points within the working range of a unit. It is always recommended to report the range to which the uncertainty applies or report the maximum uncertainty possible within the unit's working range.*



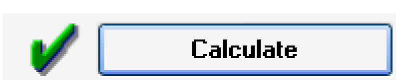
Known Uncertainty Values

Directly Enter the Known Standard Uncertainty (u_c) Values for the Dew Point, Temperature and Pressure.



Perform the Calculations

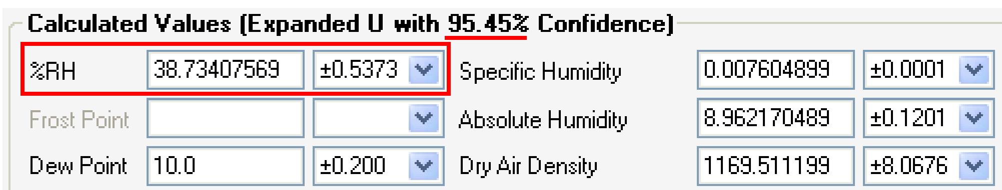
Click the Calculate button.



Results

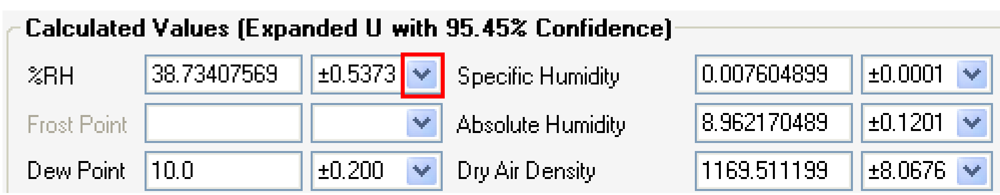
Look at the calculated values for the Expanded %RH Uncertainty (U).

> *Note: In this example we did not enter any degrees of freedom (DOF) and the 95.45% confidence displayed in the title correlates to a k=2 coverage factor. If specific degrees of freedom (DOF) are entered, it is required to view the detailed uncertainty to see the exact "k" coverage factor that correlates to the displayed confidence level. The Confidence level is always the same for all displayed expanded uncertainties, but depending on the degrees of freedom (DOF) the "k" coverage factor may differ from humidity parameter to humidity parameter.*
>
> *Refer to NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" Appendix B for further information on coverage factors.*



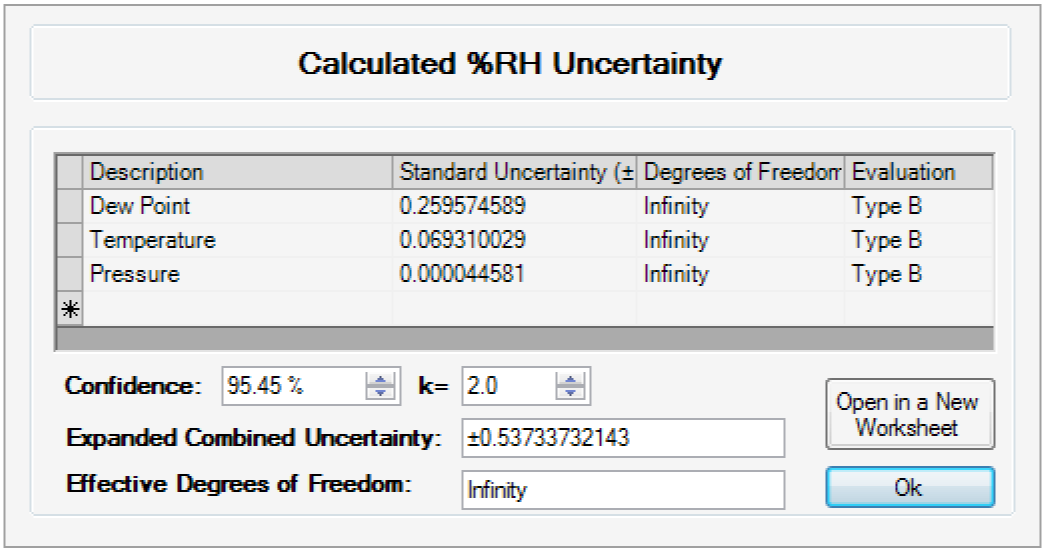
Detailed Uncertainty Results

To view more detailed %RH uncertainty data, click the drop down arrow at the right of the uncertainty field.



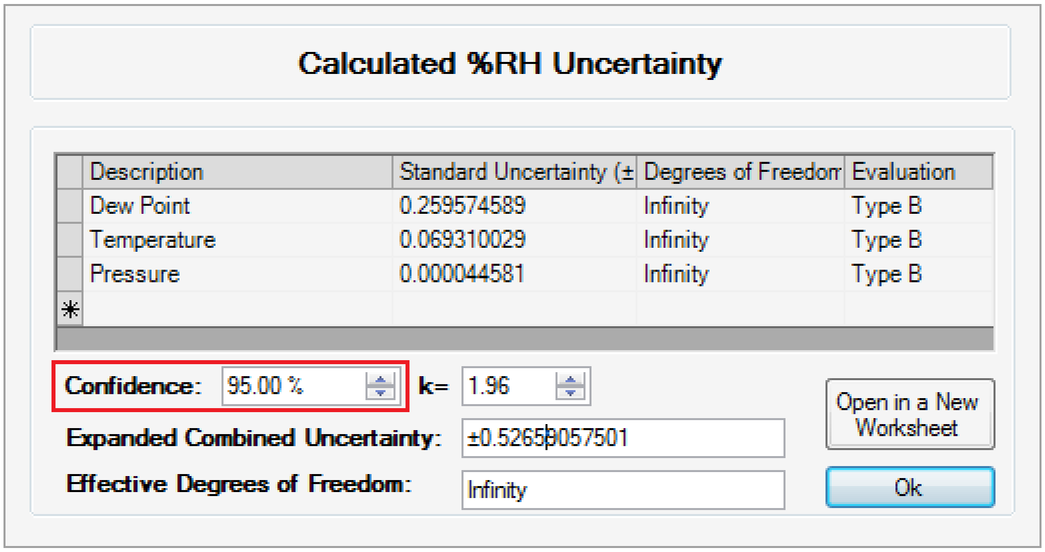
A drop down form will appear displaying the components that made up the Expanded %RH Uncertainty (U). From this we can see each components contribution to the total uncertainty. This is extremely helpful in identifying which inputs are the major contributes.

Note: As shown in the grid title the individual components are displayed as standard uncertainties, meaning no coverage factor is applied.

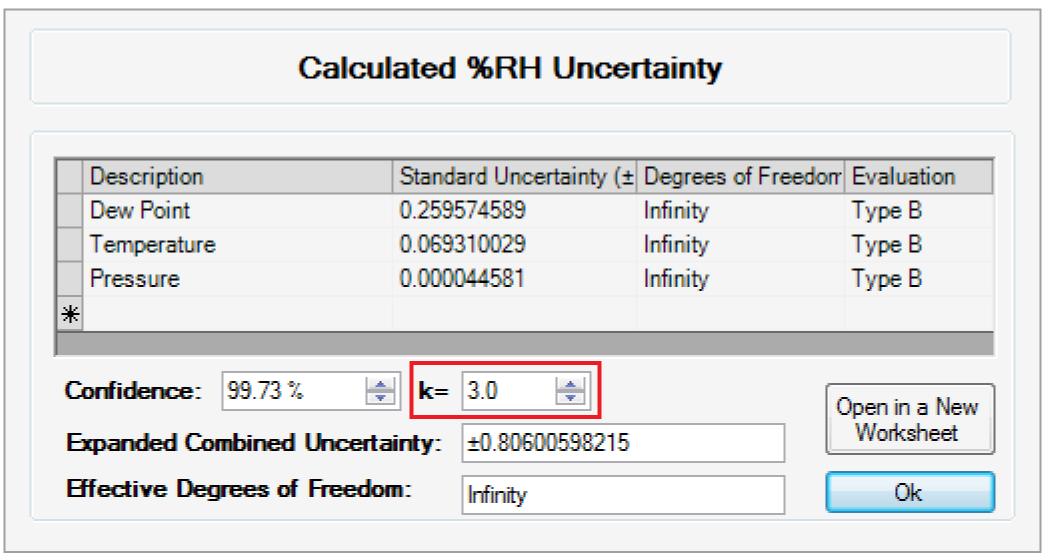


The user can directly change the “k” coverage factor or confidence level and the expanded uncertainty value will be automatically updated based on the new values. Changing the “k” coverage factor will automatically change the confidence level to its corresponding value and vice versa.

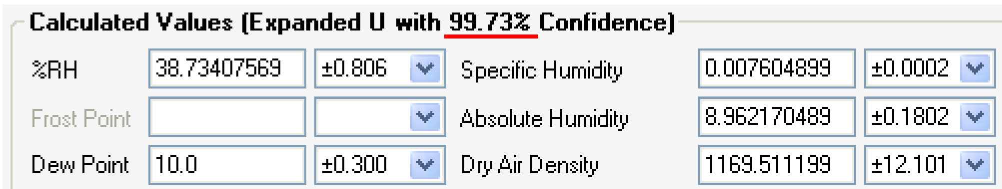
Here we changed the confidence level to 95% and we can see the "k" coverage factor is automatically changed to its corresponding value and the expanded uncertainty is updated to reflect the new coverage factor.



Here we changed the "k" coverage factor to 3 and the confidence level is automatically changed to its corresponding value and the expanded uncertainty is updated to reflect the new coverage factor.



Clicking the Ok button will close the drop down form. We can see the title now displays the Confidence level that we set in the drop down form. All the expanded uncertainties for all the humidity parameters have been updated to reflect the new Confidence level.

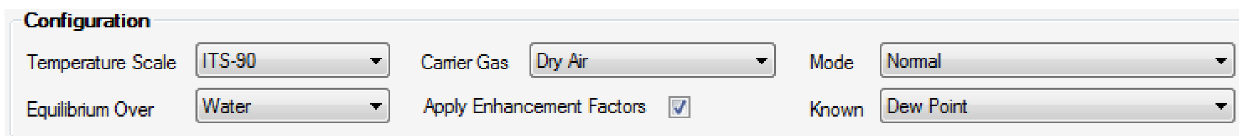


COMPLEX CHILLED MIRROR %RH UNCERTAINTY

This example will perform the same type of uncertainty calculation for a Chilled Mirror Hygrometer as the previous example, but with individual uncertainty components for the Dew Point.

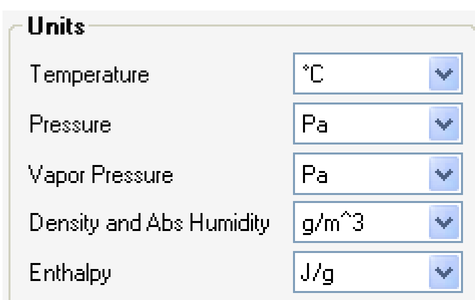
Configuration

Set the Configuration.



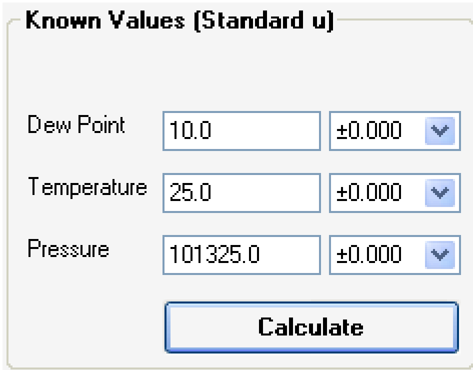
Units

Set the Units.



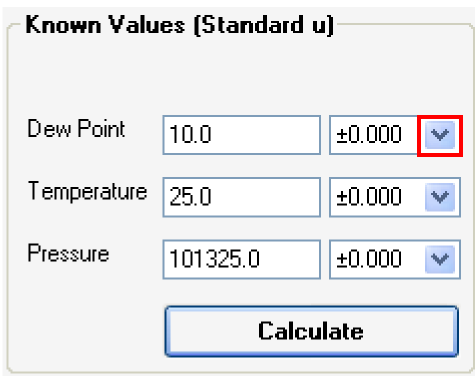
Known Values

Enter the Known Values.

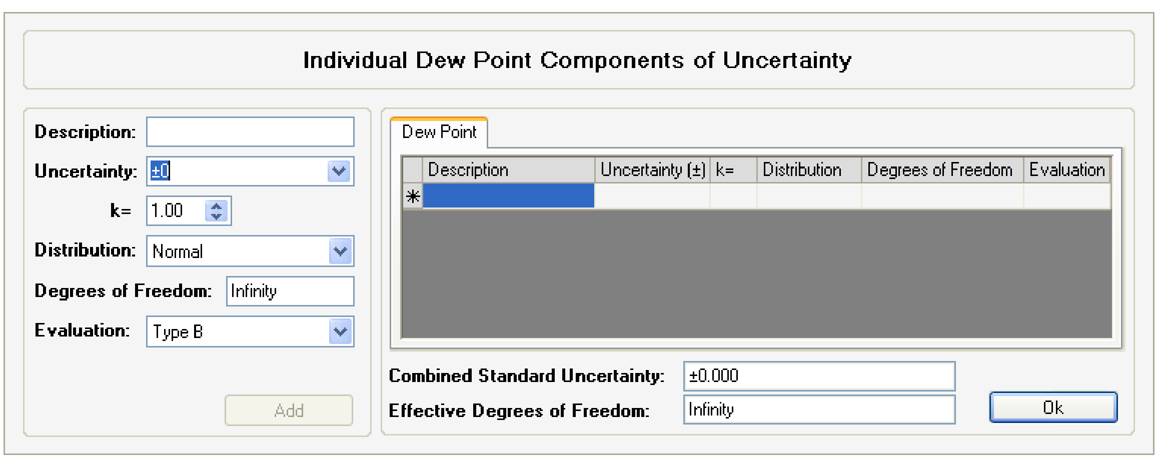


Individual Components of Uncertainty

Click the drop down arrow at the right of the uncertainty field to open a drop down that allows entry of individual components of uncertainty for the given known value.

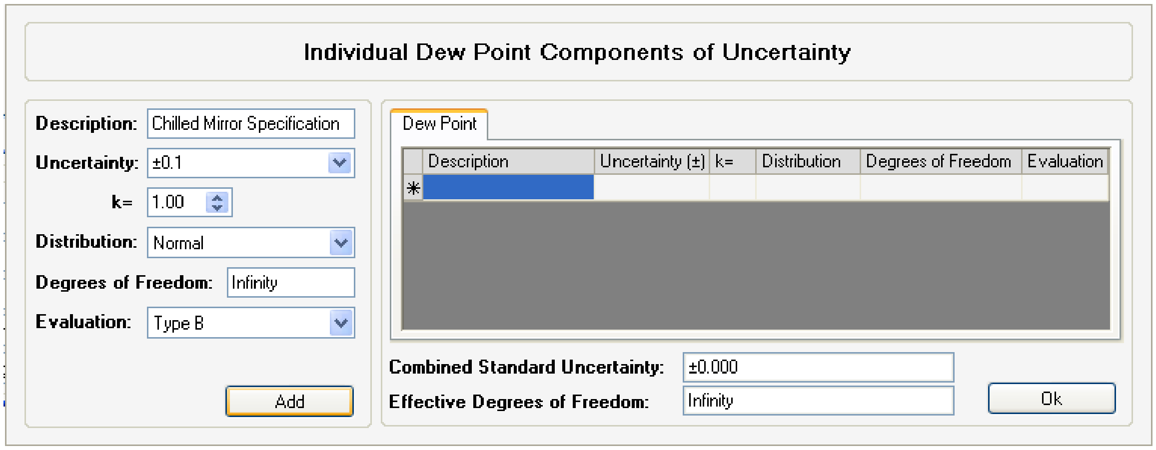


This form allows entry of individual uncertainty components and more detailed uncertainty values.

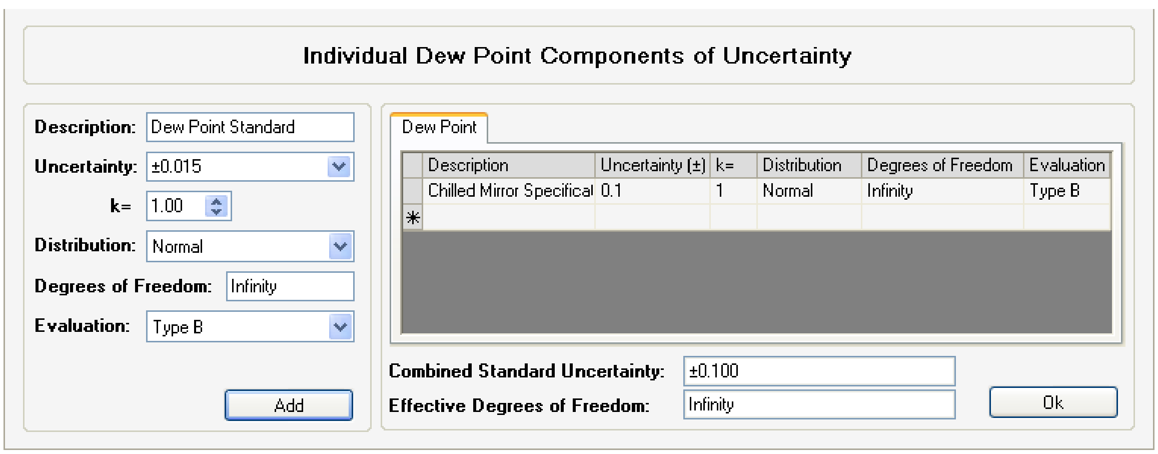


To enter an individual uncertainty component, start by entering the relative information about the uncertainty component in the left frame.

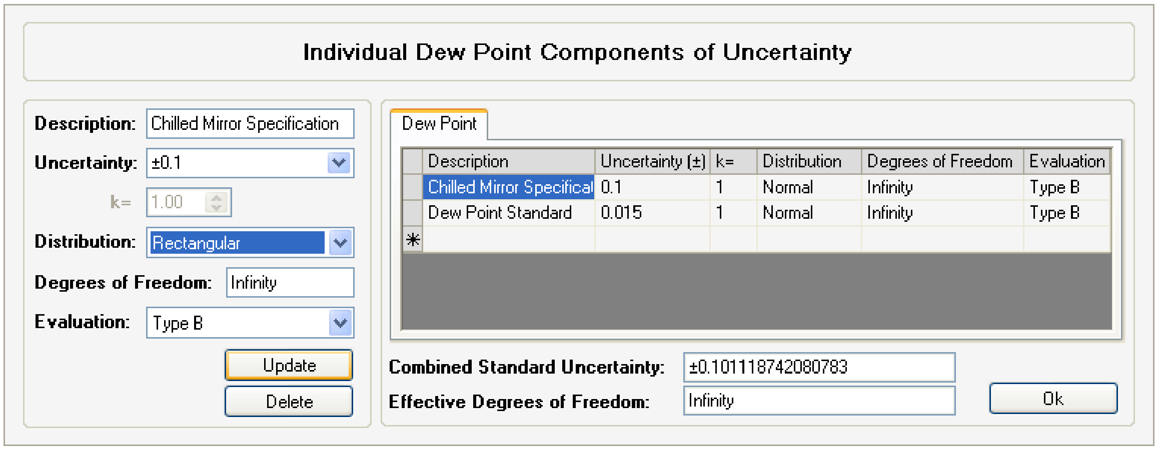
> *Note: HumiCalc will not allow the entry to be added until it has a valid uncertainty value (anything but zero). While it is always recommended to enter a detailed description, HumiCalc does not require it, but it will apply its own generic description if the user leaves the field blank.*



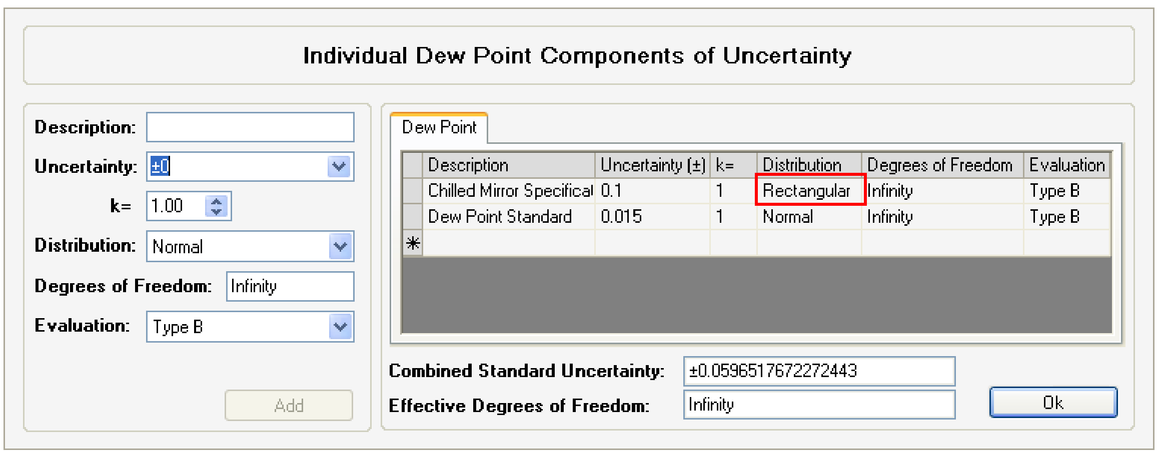
Enter a second component.



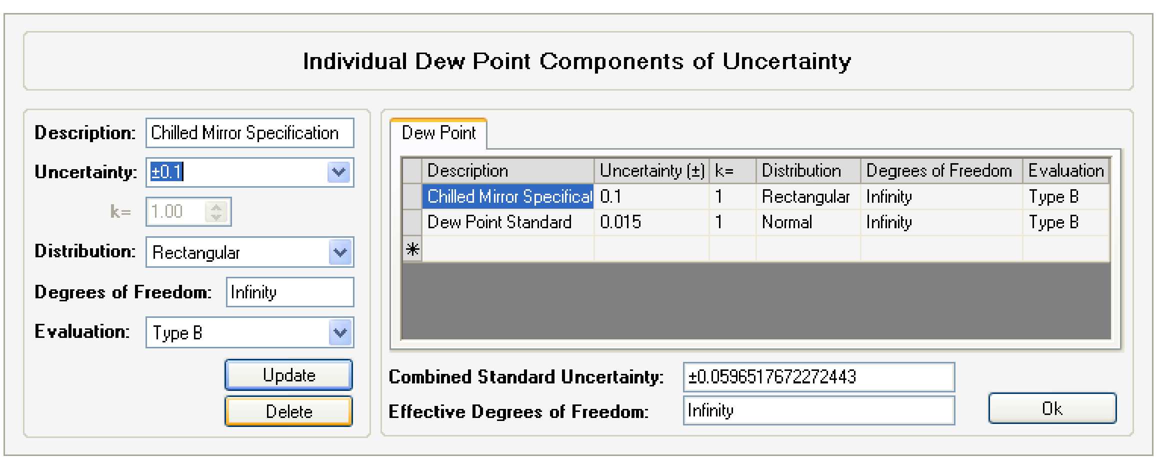
To edit any entered component, simply click the item in the grid and edit any value in the left frame.

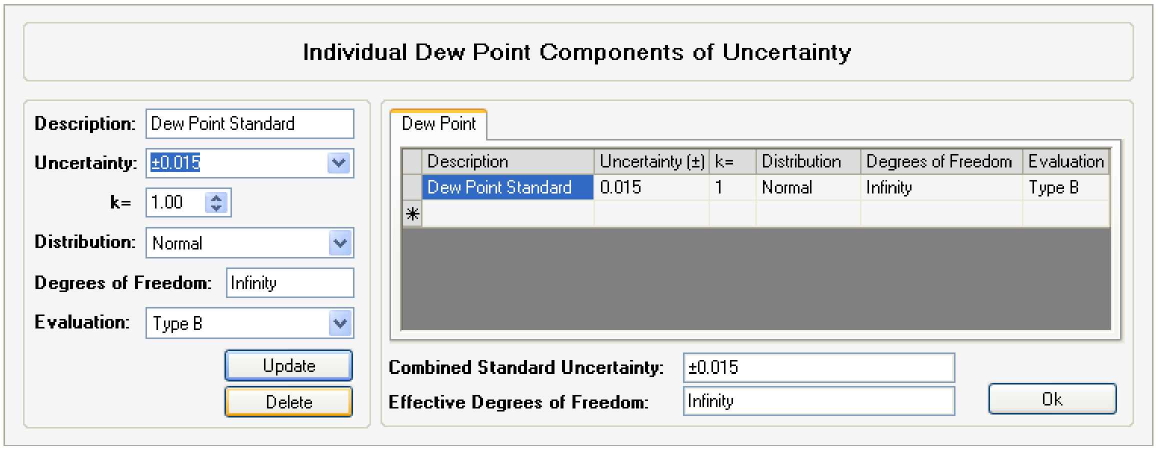


Once completed with the changes, select the "Update" button to confirm the changes.

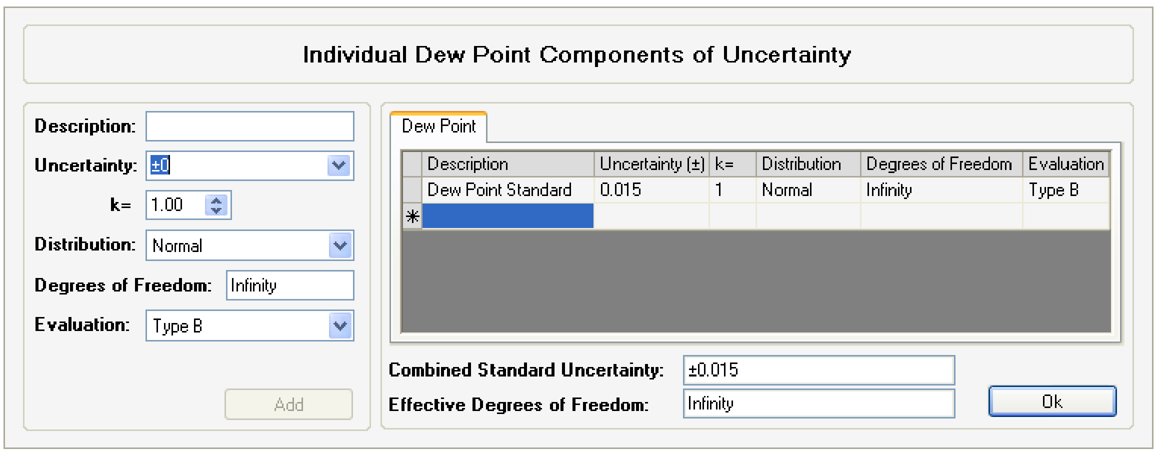


To delete any entered component, simply click the item in the grid and then select the Delete button.

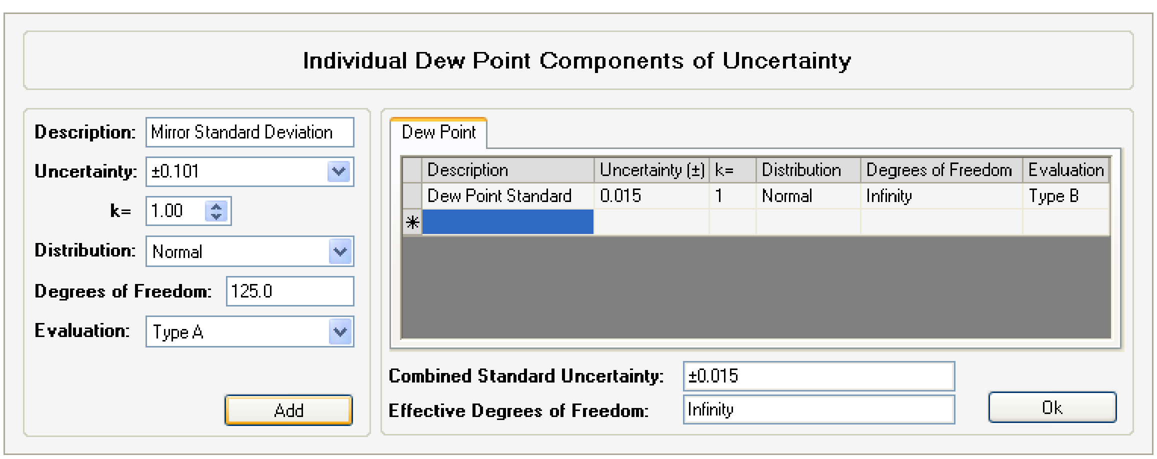




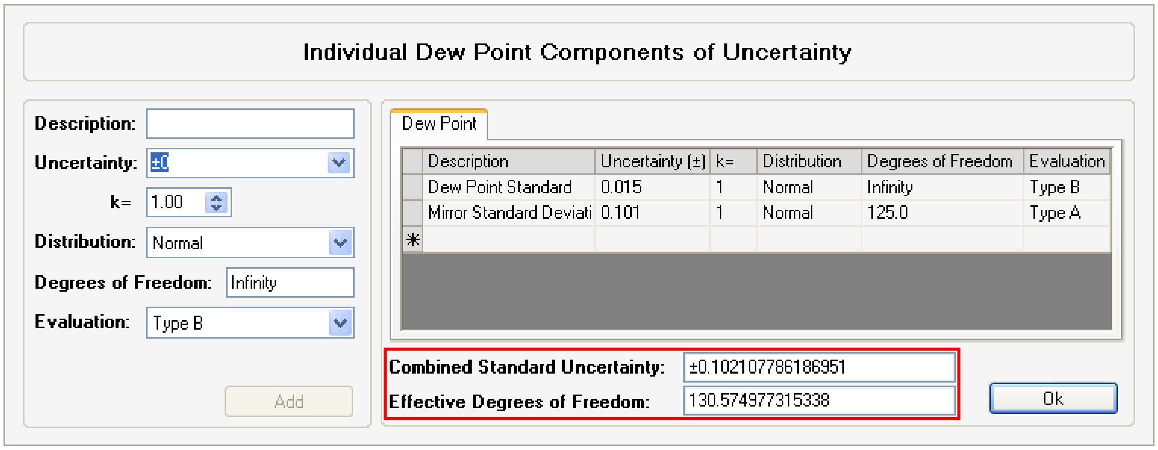
To enter a new component, click the grid row marked by the "*".



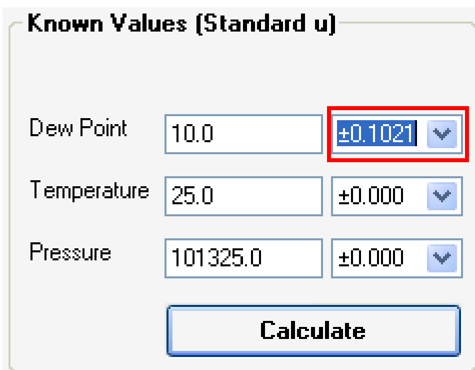
For this new component we will enter an uncertainty estimate based on a statistical method that has a degrees of freedom (DOF) value. Later in the example we will see the effects the DOF value has on the "k" coverage factor at a specific confidence level.



HumiCalc will automatically combine all the individual components of uncertainty and degrees of freedom and will display the combined results at the bottom of the right frame under the grid.

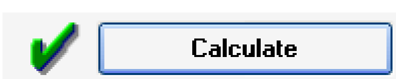


Click the Ok button to close the drop down form. We now see the updated combined standard uncertainty in the known values uncertainty field for Dew Point.



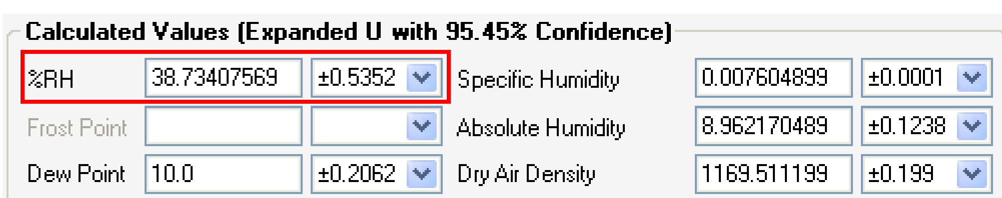
Perform the Calculations

Click the Calculate button.



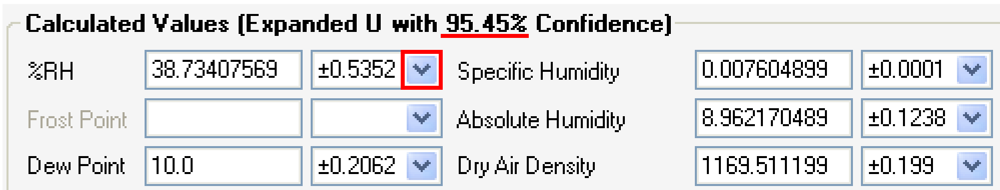
Results

Look at the calculated values for the Expanded %RH Uncertainty (U).

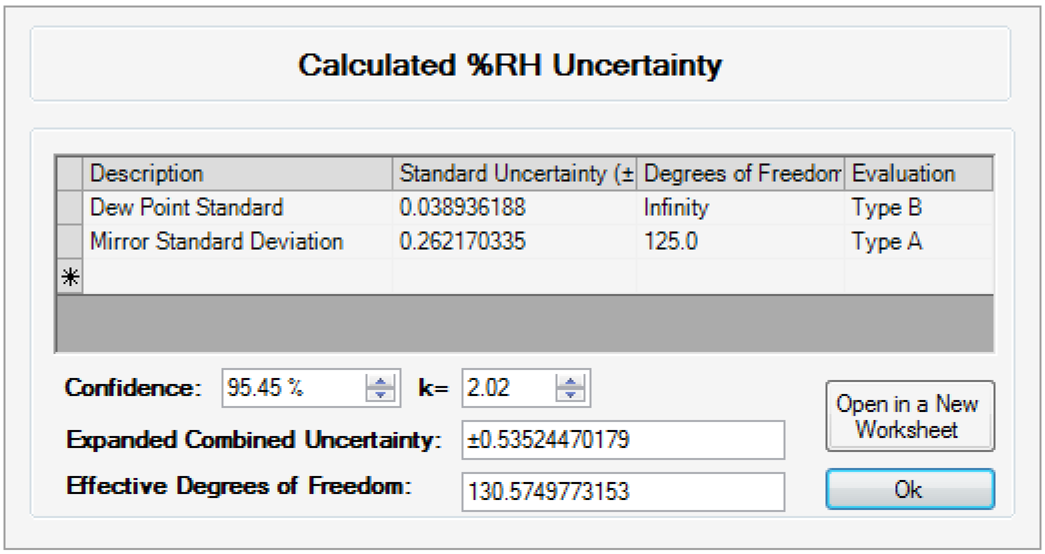


Detailed Uncertainty Results

To view more detailed %RH uncertainty data, click the drop down arrow at the right of the uncertainty field.



A drop down form will appear displaying the components that made up the Expanded %RH Uncertainty (U). Again, from this we can see each components contribution to the total uncertainty.



Also note the "k" coverage factor is 2.02 for a 95.45% confidence. This is because the effective degrees of freedom value is such that a different coverage factor is required to meet the confidence level specified. HumiCalc automatically calculates these values using a t-distribution table.

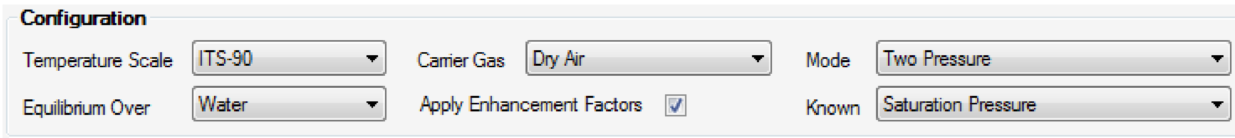
Note: Refer to NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" Table B.1 for an example of a t-distribution table.

TWO-PRESSURE GENERATOR %RH UNCERTAINTY

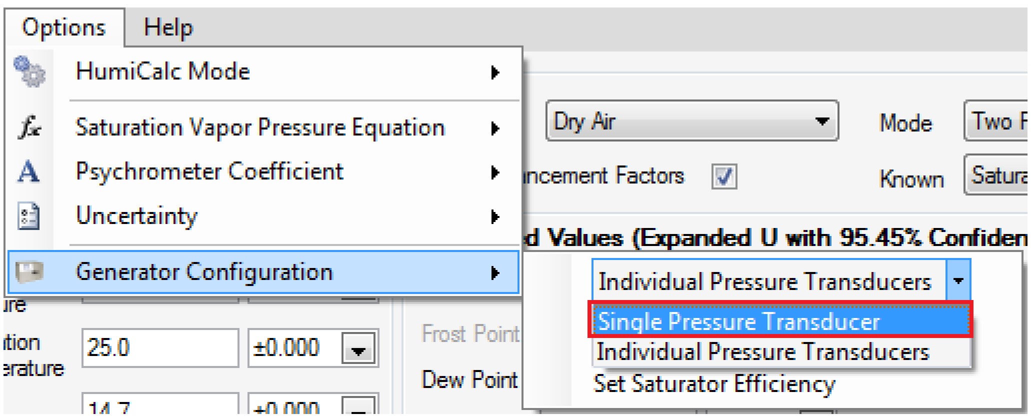
This example will perform %RH uncertainty calculation for a Single Pressure Transducer Two Pressure Generator. This type of generator shares a single pressure transducer between the saturator and chamber.

Configuration

Set the Configuration.

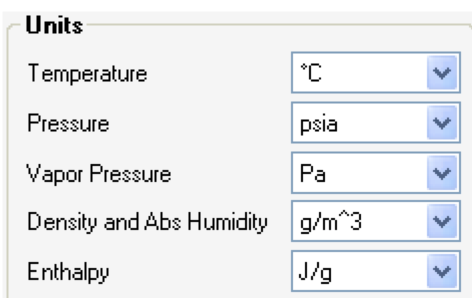


Set the Generator Configuration to use a single pressure transducer. This will tell HumiCalc that a component of the pressure uncertainty is shared between the Saturator and Chamber.



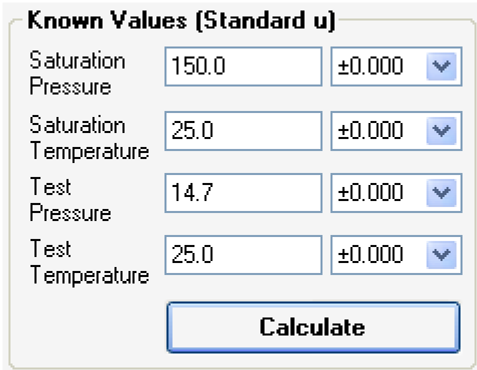
Units

Set the Units.



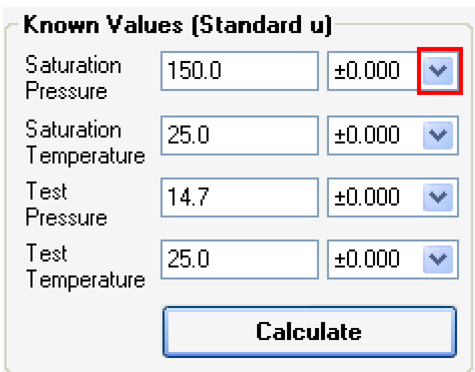
Known Values

Enter the Known Values.



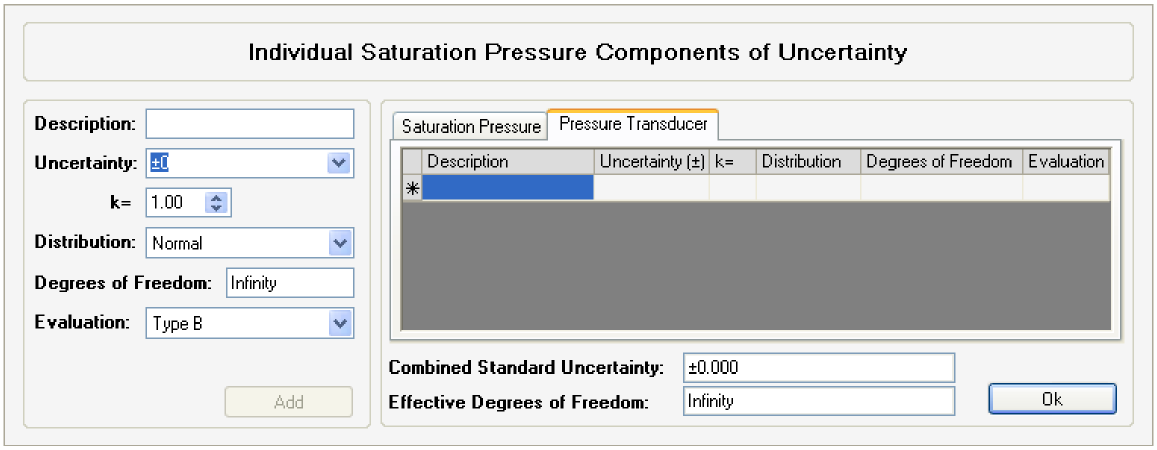
Individual Components of Uncertainty

Click the drop down arrow at the right of the Saturation Pressure uncertainty field to open the individual components of uncertainty drop down.



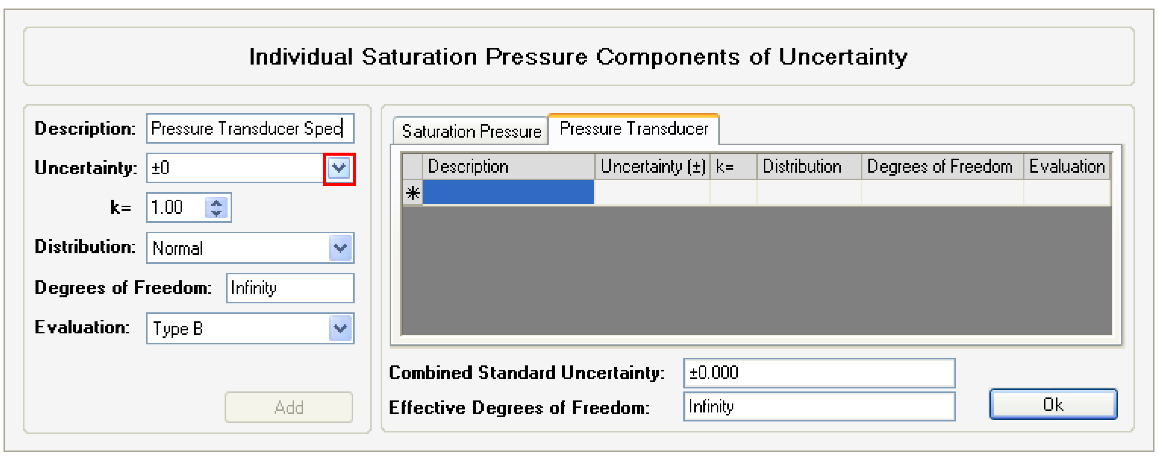
We notice that the drop down form is slightly different from what we had seen in the previous example. There are now selectable tabs above the grid. These tabs allow the user to select uncertainty that will be applied only to this item (Saturator Pressure) or uncertainty that will be applied collectively with the chamber pressure (Pressure Transducer).

> *Note: It is important to understand this concept. All uncertainty components entered for a common component such as the Pressure Transducer or Temperature Probe will be applied as a single entity during the calculation process. Therefore it is not the same as entering the identical uncertainty values for both the Saturator Pressure and Chamber Pressure or Saturator Temperature and Chamber Temperature, because these items will be treated as separate entities during the calculation process.*

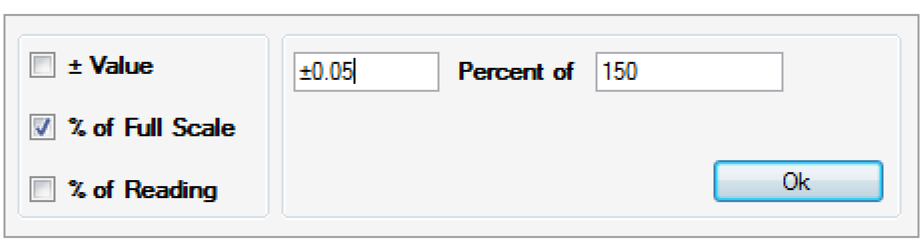


Under this tab the user would enter all relative uncertainty information about the pressure transducer. For example, the specifications supplied by the manufacture of the pressure transducer. Most pressure transducer manufactures list full scale accuracy or uncertainty and in this example we will show how to enter a percent of full scale uncertainty.

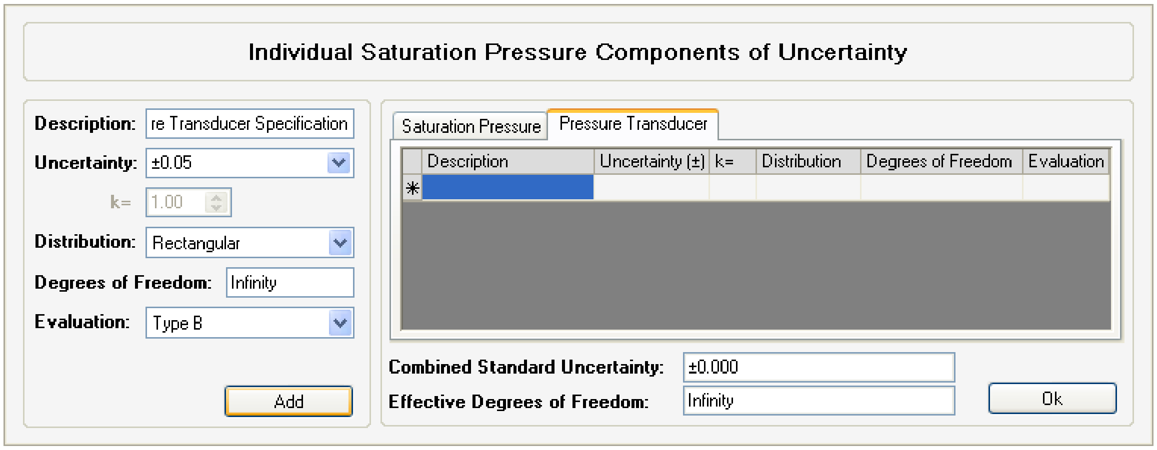
To enter a full scale uncertainty, click the drop down arrow on the uncertainty field.



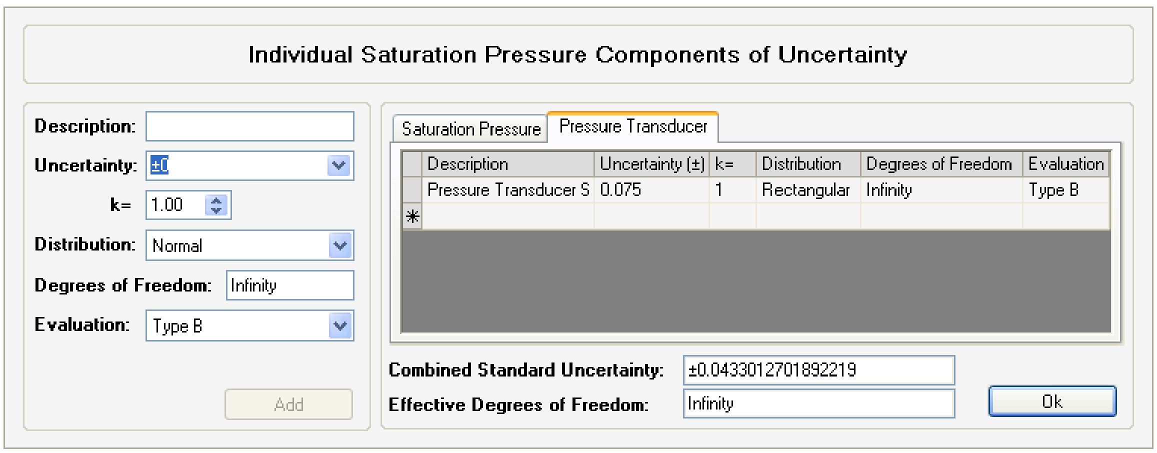
Enter a percent of full scale value. Then select "% Full Scale" and enter the full scale value.



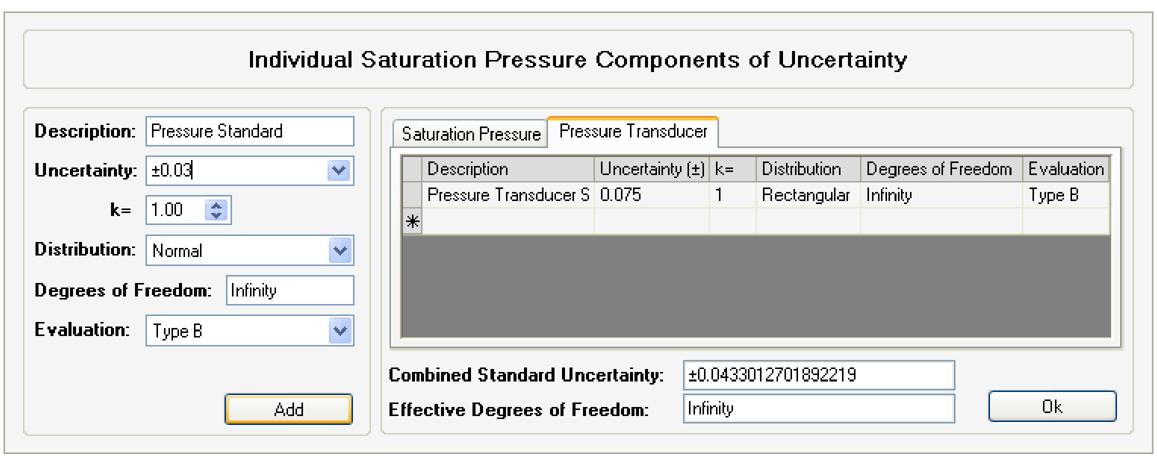
Click the Ok button



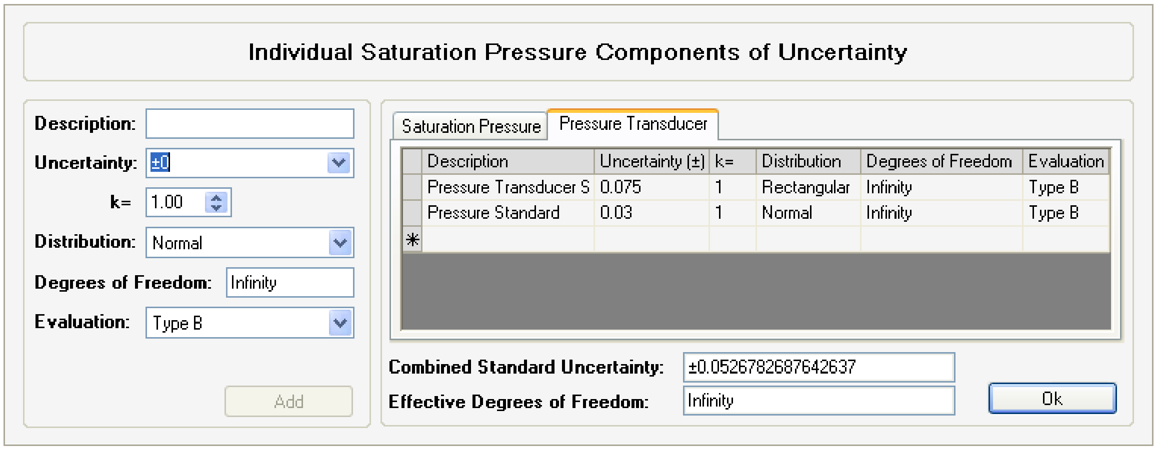
Add the component. Notice that HumiCalc automatically calculated the standard uncertainty for the % full scale value we just entered.



Now we will enter another component. This time we will add the standard or reference used when calibrating the pressure transducer.

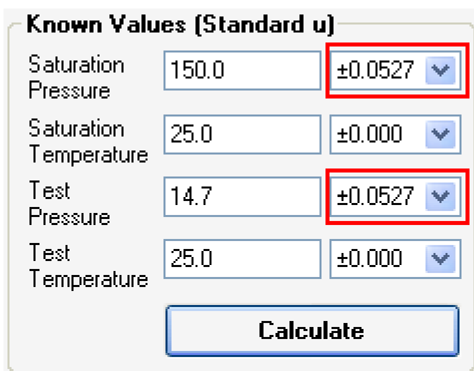


Add the component.

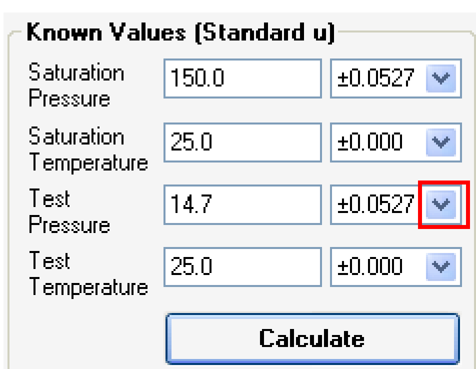


Click the Ok button

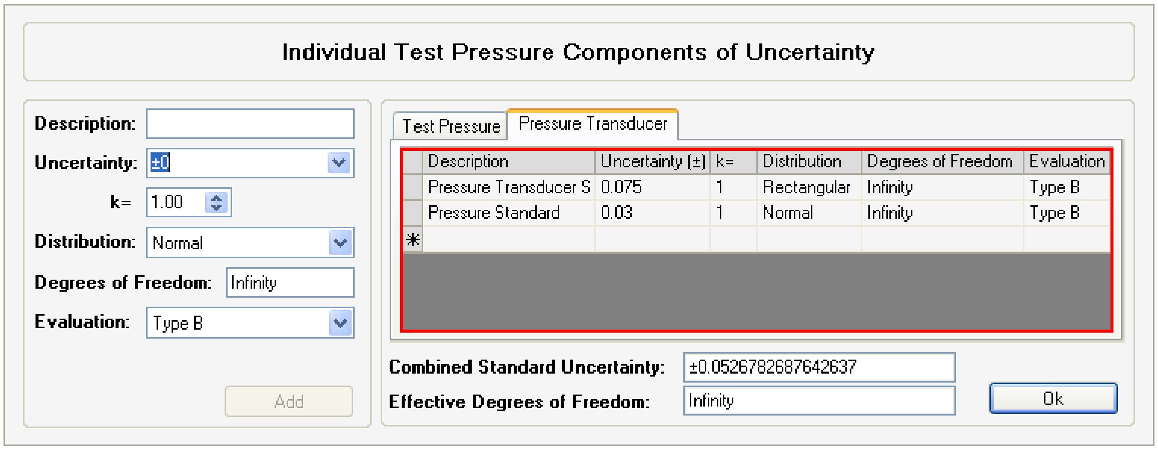
We now see the updated Saturation Pressure Standard Uncertainty and we also see that HumiCalc has automatically updated the Test Pressure Standard Uncertainty as well. This is because we entered uncertainty components for the shared pressure transducer.



Open the individual components of uncertainty drop down for the Test Pressure.

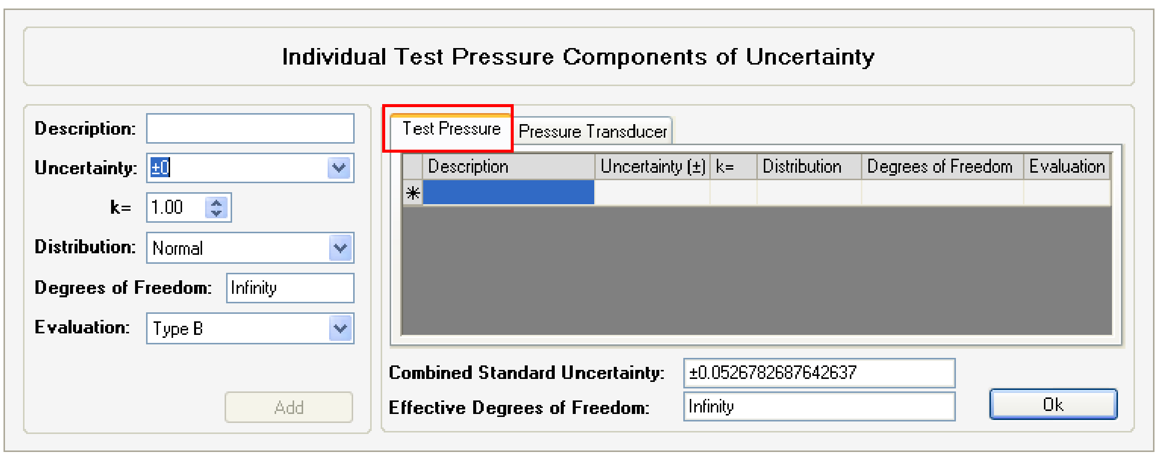


Again we see the Pressure Transducer Uncertainty that we entered through the individual Saturation components of uncertainty drop down in the previous steps.

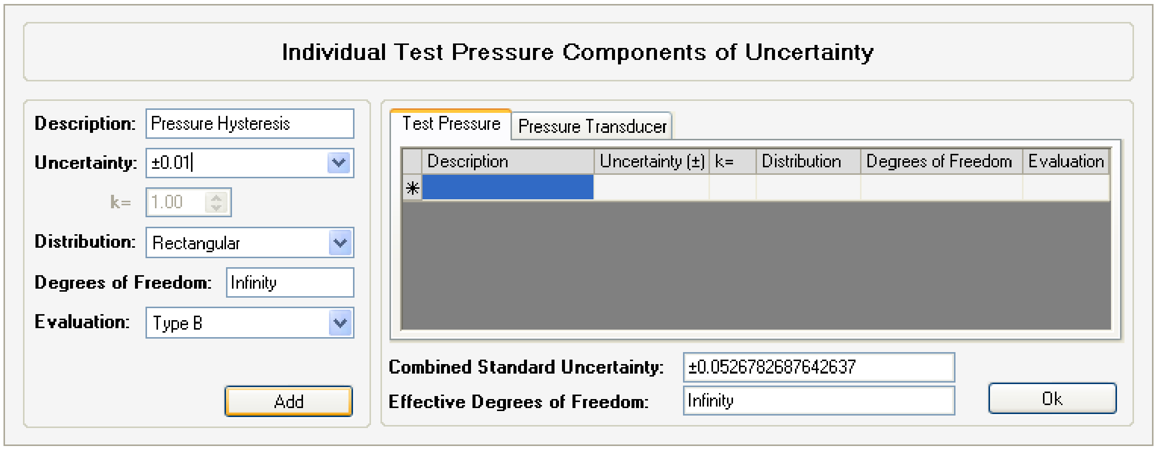


Now we are going to enter a pressure hysteresis, again this is normally listed in the specification of the pressure transducer. For this example we are only going to apply the hysteresis to the Test Pressure. We are doing this to demonstrate how HumiCalc will allow the user to enter shared uncertainty components yet still allow the user to enter specific uncertainty that is only applicable to either the saturator or chamber.

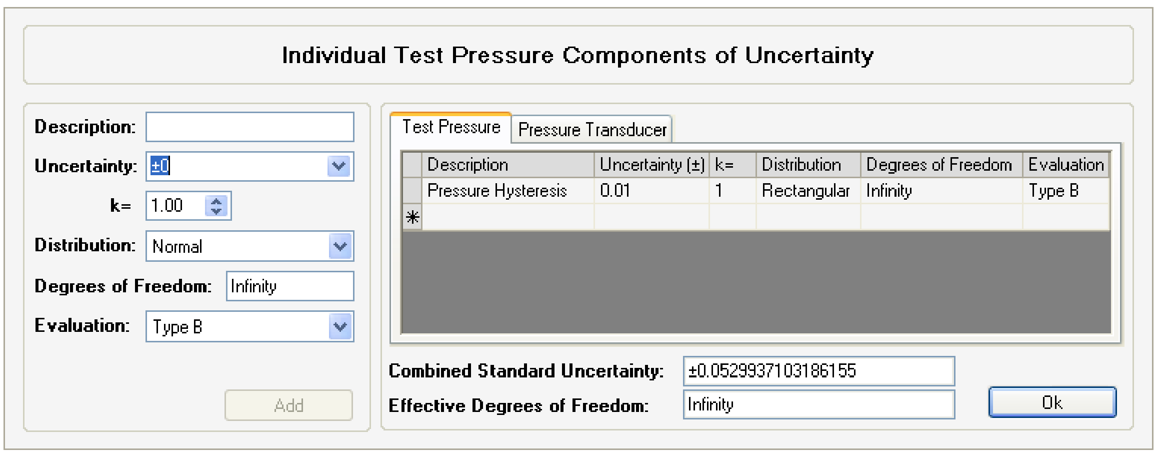
Select the Test Pressure Tab above the grid.



Enter the pressure hysteresis information.

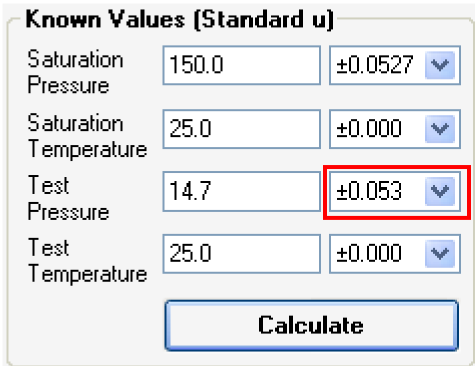


Add the component. Notice that HumiCalc has updated the combined standard uncertainty to include all components from both the Test Pressure tab and the shared Pressure Transducer tab.



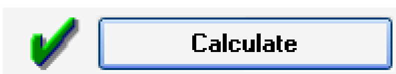
Click the Ok button

We now see the updated Test Pressure Standard Uncertainty. Notice that it now differs from the Saturation Pressure Uncertainty. This is because the Test Pressure Standard Uncertainty now contains an additional hysteresis component that we entered for the Test Pressure.



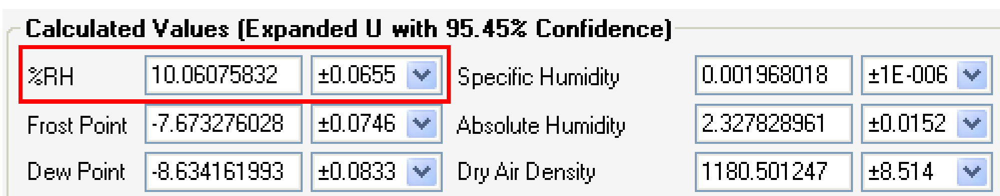
Perform the Calculations

Click the Calculate button.



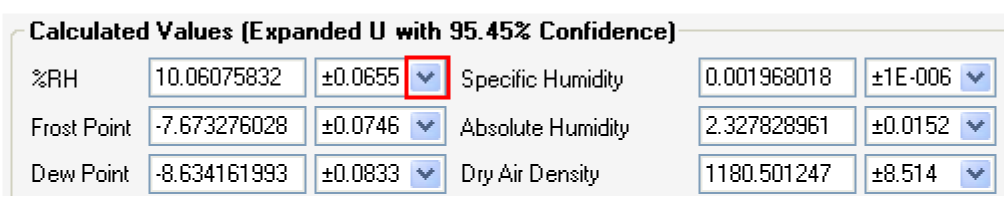
Results

Look at the calculated values for the Expanded %RH Uncertainty (U).

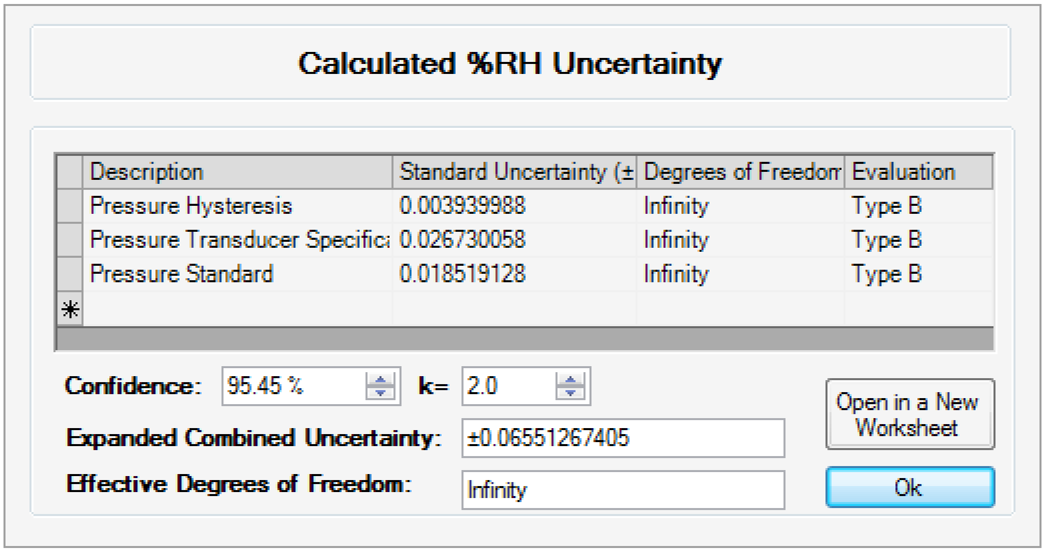


Detailed Uncertainty Results

View the detailed %RH uncertainty data by clicking the drop down arrow at the right of the uncertainty field.

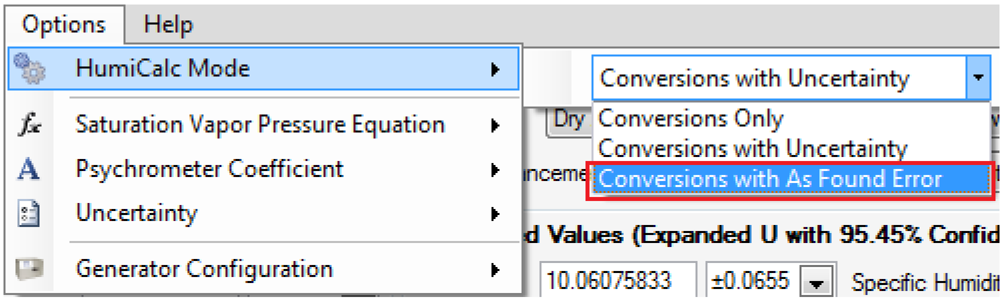


Notice that all three of the entered components are displayed along with their individual contribution to the total uncertainty.



AS FOUND ERROR EXAMPLES

These examples deal with HumiCalc's ability to perform "As Found Error" calculations. These can only be performed in the "Conversion with As Found Error" HumiCalc Mode. These examples are again structured with the focus to demonstrate how to enter and calculate as found error. The values entered throughout these examples are simply for demonstration purposes.

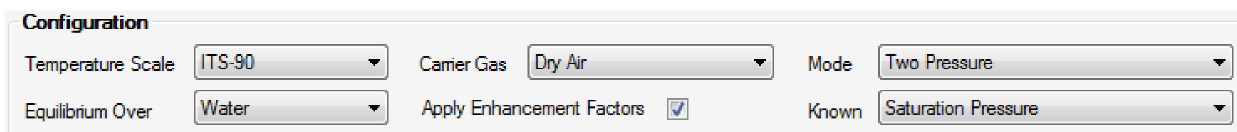


TWO PRESSURE GENERATOR AS FOUND ERROR

This example will perform an "As Found" calculation for a Two-Pressure type generator to see what the effect the pressure and temperature error have on the generated humidity. This is a common question after a calibration of a Two-Pressure type generator, since it is not obvious what influence the different pressure and temperature errors have on the generated humidity.

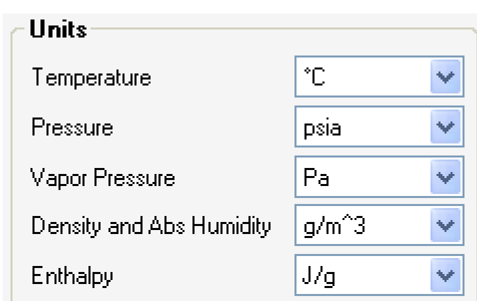
Configuration

Set the Configuration.



Units

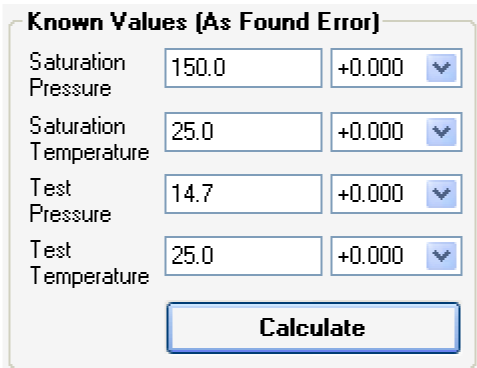
Set the Units.



Known Values

Enter the Known Values.

> *Note: The entered known value will always be treated as the Unit under Test (UUT) value.*

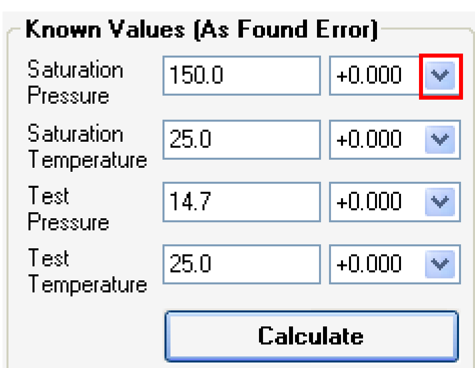


As Found Error

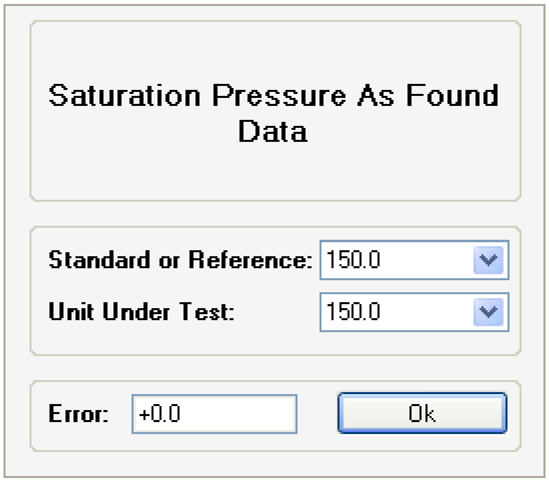
The "as found error" can be either directly entered into the error field for each known item or through the use of the drop down form. Here we will demonstrate the use of the drop down form to enter the as found results from a calibration.

> *Note: The user can directly enter the error on the main form, but cannot on the drop down form. The drop down form is designed to calculate the error based on an entered standard or reference value and the entered unit under test value. HumiCalc will calculate the error as the amount the unit under test is from the standard or reference (Error = UUT - Standard).*

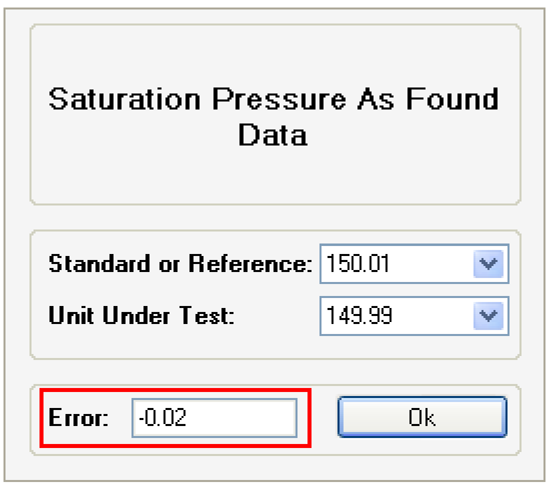
Click the drop down arrow for the Saturation Pressure



This opens the as found drop down form for this item. We can see that the error is zero because the standard and unit under test have the same value.

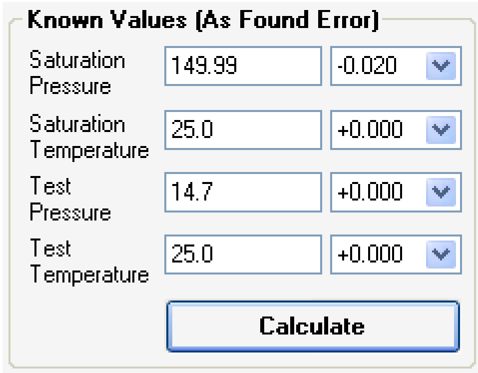


Now we will enter the standard or reference value from the calibration as well as the Unit under Test value. Notice the Error value is automatically calculated.

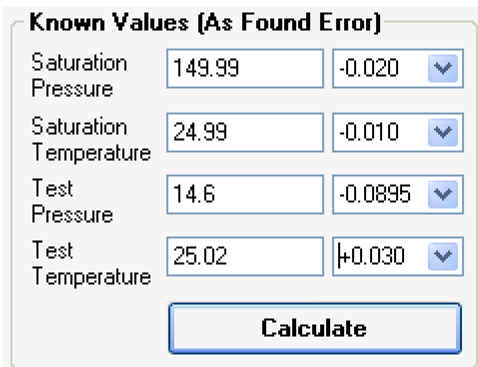


Click the Ok button

We now see the Saturation Pressure error that we just calculated.

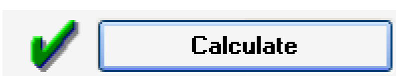


Enter the rest of the values directly.



Perform the Calculations

Click the Calculate button.



Results

Look at the calculated values for the as found error for each humidity parameter. You can see the effect the "As Found" temperature and pressure errors have in terms %RH, Dew Point or any of the other humidity parameters. This is very helpful to the user in determining the effects of an out of tolerance temperature probe or pressure transducer.

Calculated Values (Calculated Error Based on As Found Error)

%RH	9.975316441	-0.0836	Specific Humidity	0.001966975	-9E-007
Frost Point	-7.757290727	-0.0751	Absolute Humidity	2.310613974	-0.0155
Dew Point	-8.728016977	-0.0839	Dry Air Density	1172.39395	-7.3039
PPMv	3167.853406	-1.4781	Moist Air Density	1174.704564	-7.3194
PPMw	1970.851159	-0.9196	Saturation Temperature	24.99	-0.010
Grains/lb	13.79595811	-0.0064	Saturation Pressure	149.99	-0.020
Enthalpy	30.16300747	+0.0279	Wet Bulb Temperature	10.62820799	-0.0392
SVP@Tt	3173.68564	+5.6711	Mixing Ratio by Volume	0.003167853	-1E-006
SVP@Td	316.6200412	-2.082	Mixing Ratio by Weight	0.001970851	-9E-007
SVP@Ts	3168.014579	-1.8894	Percent by Volume	0.31578498	-0.0001
F@Tt,Pt	1.004090138	-2E-005	Percent by Weight	0.196697454	-9E-005
F@Td,Pt	1.003979601	-2E-005	Vapor Mole Fraction	0.00315785	-1E-006
F@Ts,Ps	1.030826483	-2E-006	Dry Air Mole Fraction	0.99684215	+1E-006

WORKSHEET EXAMPLE

This example deals with HumiCalc's ability to perform simple "law of propagation of uncertainty" type calculations. These calculations can be performed using HumiCalc worksheets. Worksheets are great for any uncertainty calculation that is of the same unit even non humidity related uncertainty problems.

SIMPLE UNCERTAINTY CALCULATION

Using a HumiCalc worksheet, determine the expanded combined uncertainty at a 99.73% confidence given the following three uncertainty components:

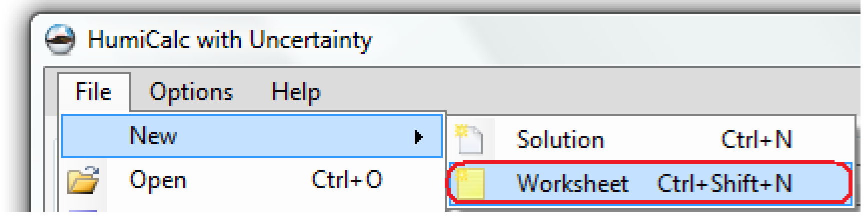
1. Temperature measurement uncertainty statically determined from 57 points to be 0.005.

2. Temperature measurement hysteresis specified by the manufacture to be 0.001 with a rectangular type distribution.

3. Temperature measurement resolution of 0.01.

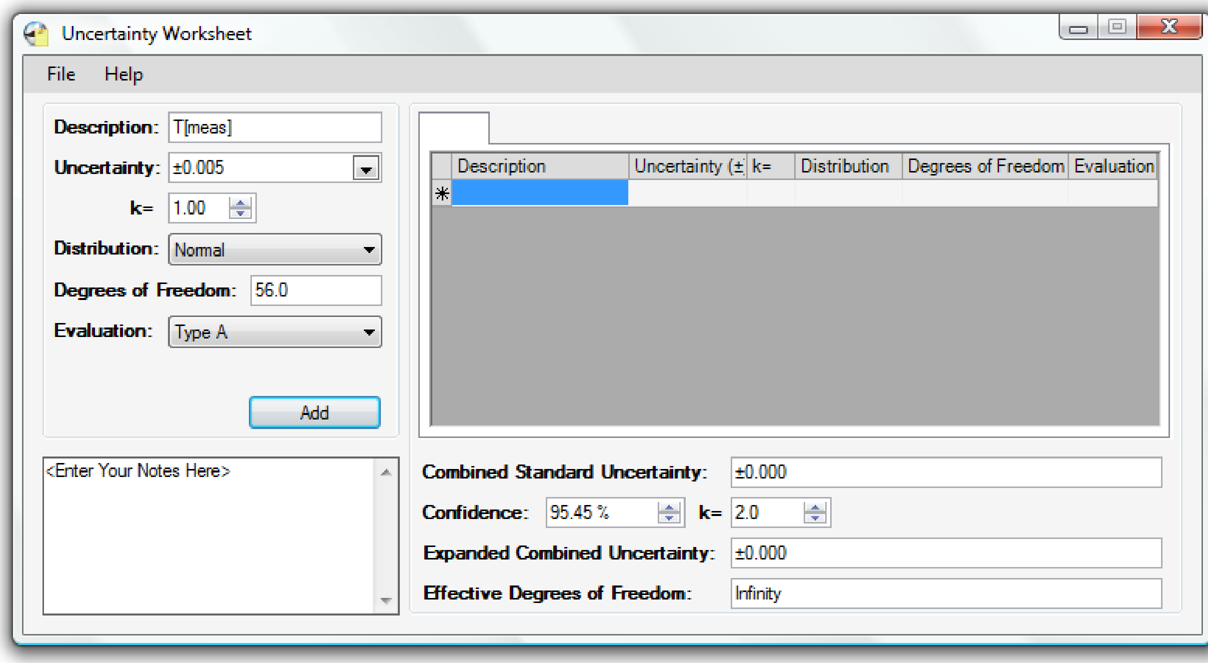
Create a new Worksheet

Open a new worksheet by selecting New Worksheet under the File menu.

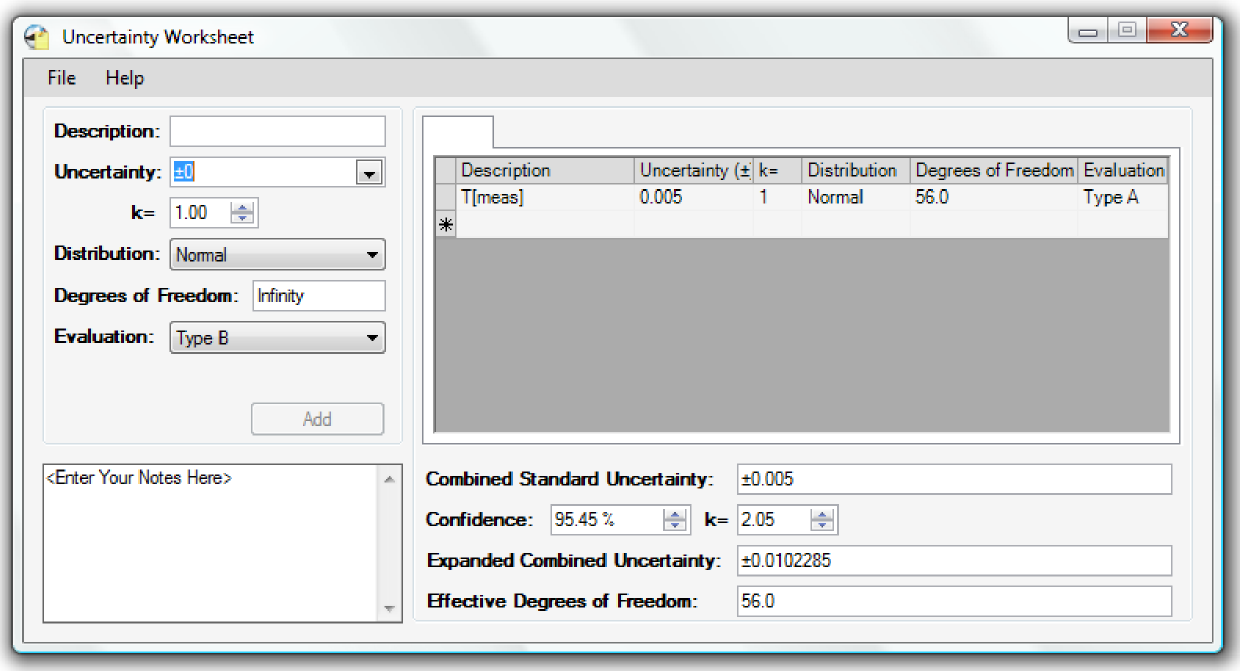


Enter Individual Uncertainty Components

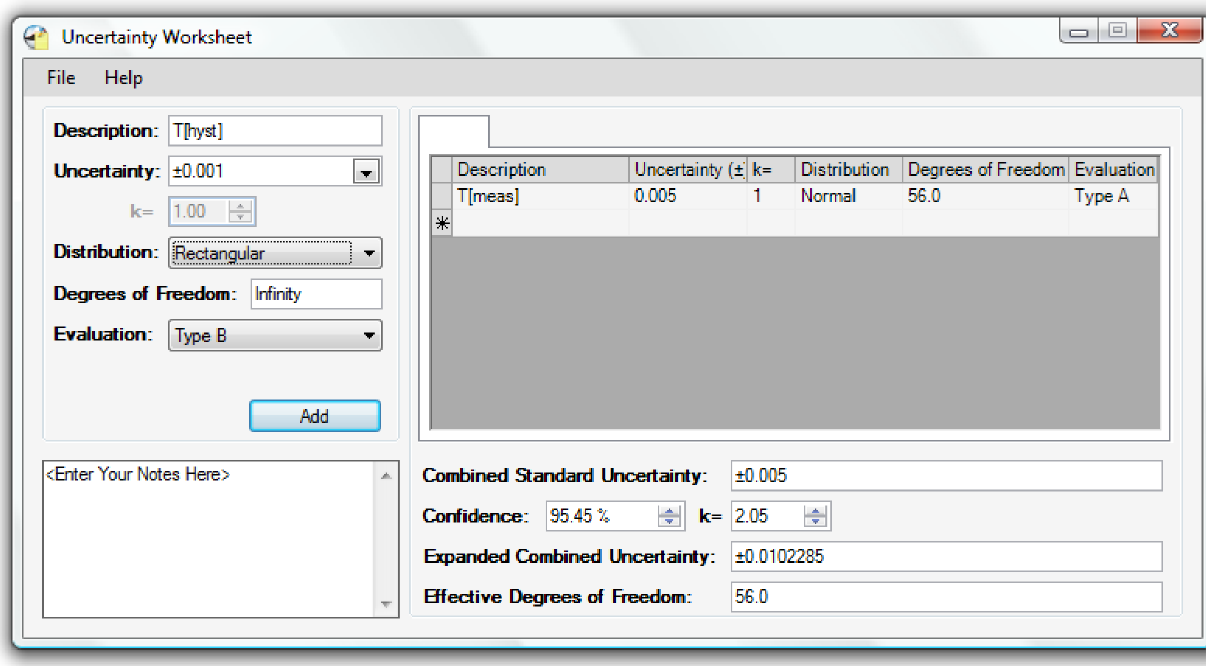
Start by entering the first individual uncertainty component. The first component will have a k=1 since the problem did not specify a k value. We will assume a normal distribution because this is a statically determined value and we will set the degrees of freedom to the number of sample points minus one (57-1=56). Since this was a statically determined value we will set it to be a Type A evaluation.



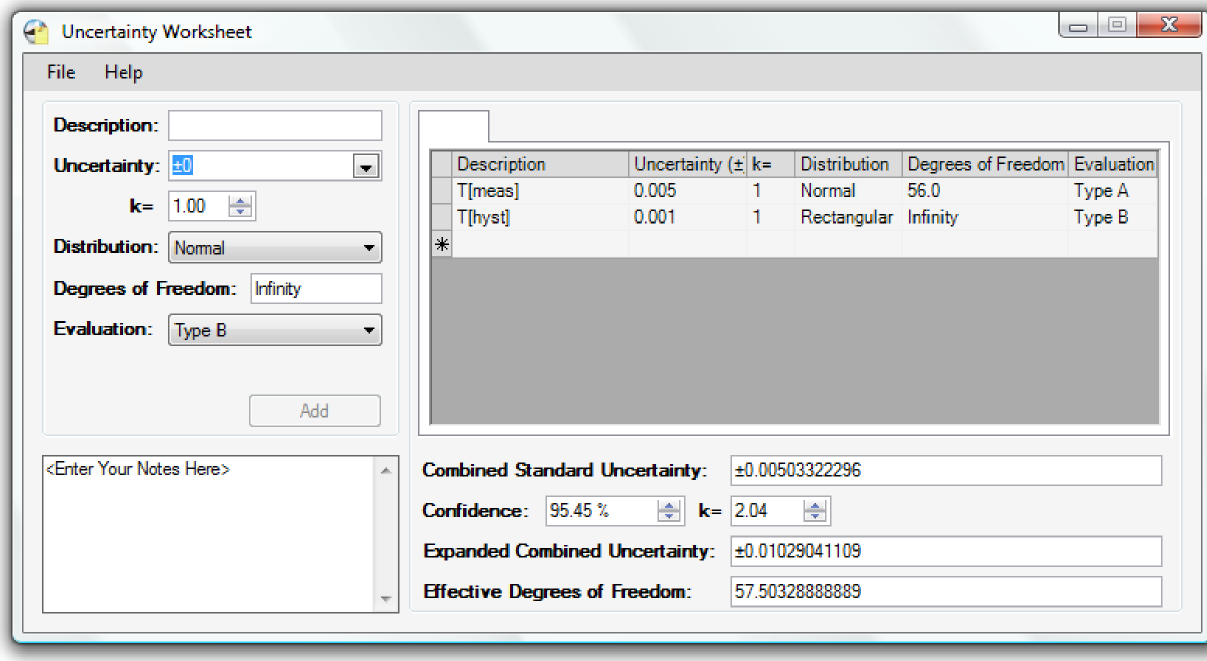
Once the information for the component has been entered, press the Add button to add the component to the worksheet.



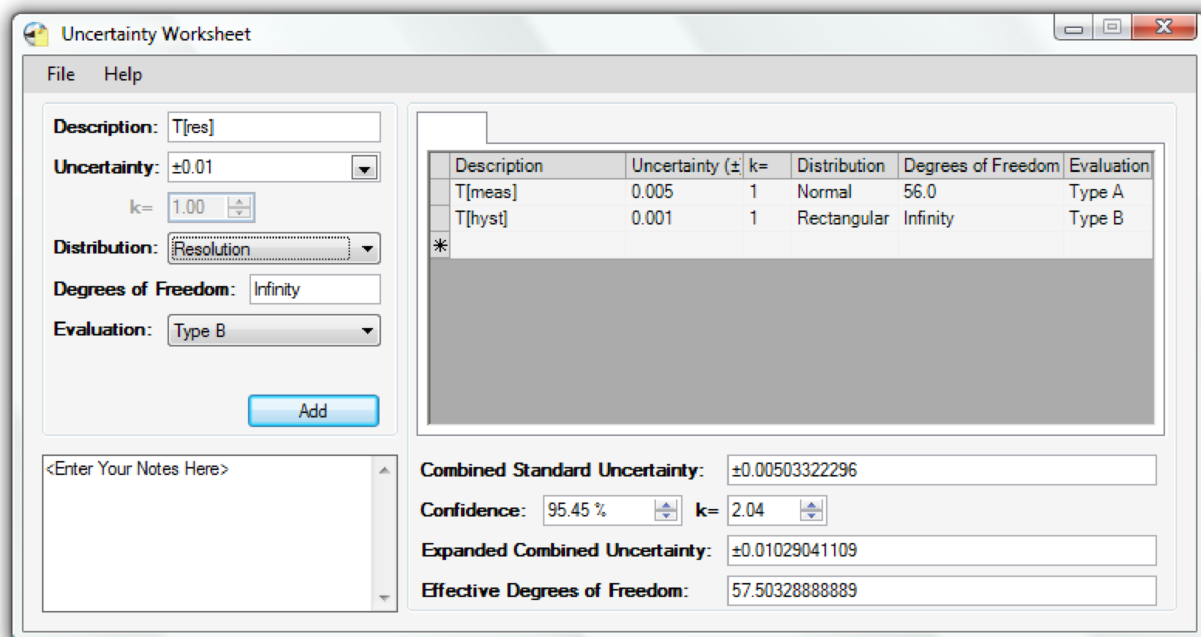
Next add the information for the second individual uncertainty component. The second component has a rectangular distribution and is a Type B evaluation since it is based on a manufacturer's specification.



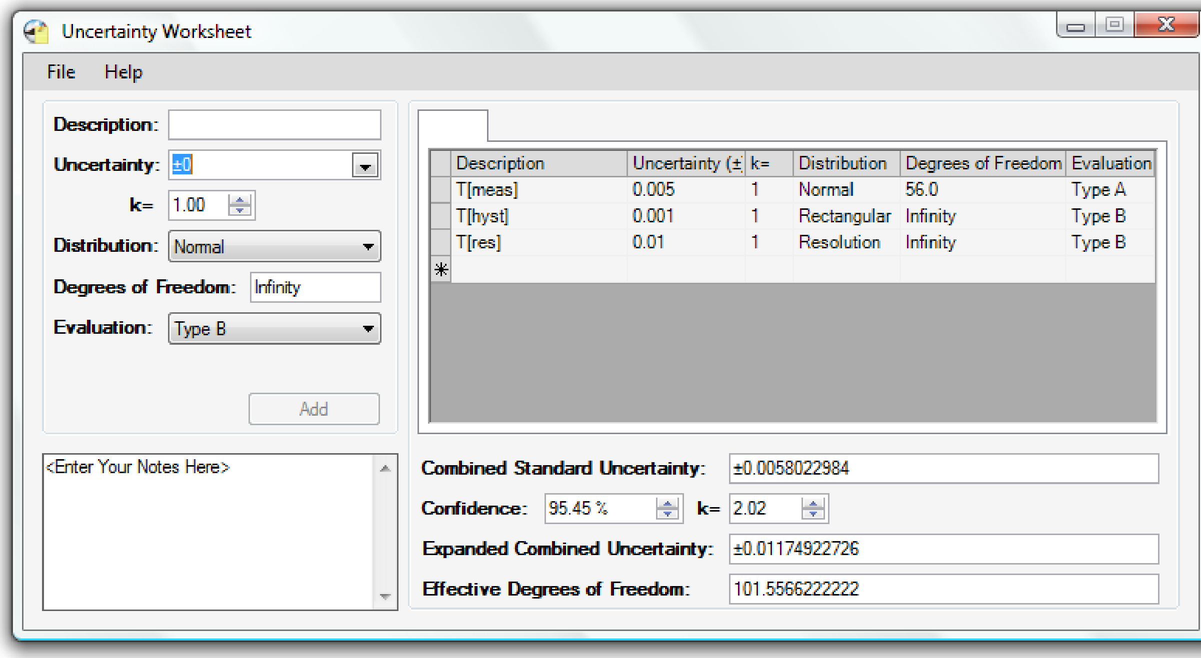
Add the component. Notice that HumiCalc automatically updates the Combined Standard and Expanded Uncertainty as each component is added.



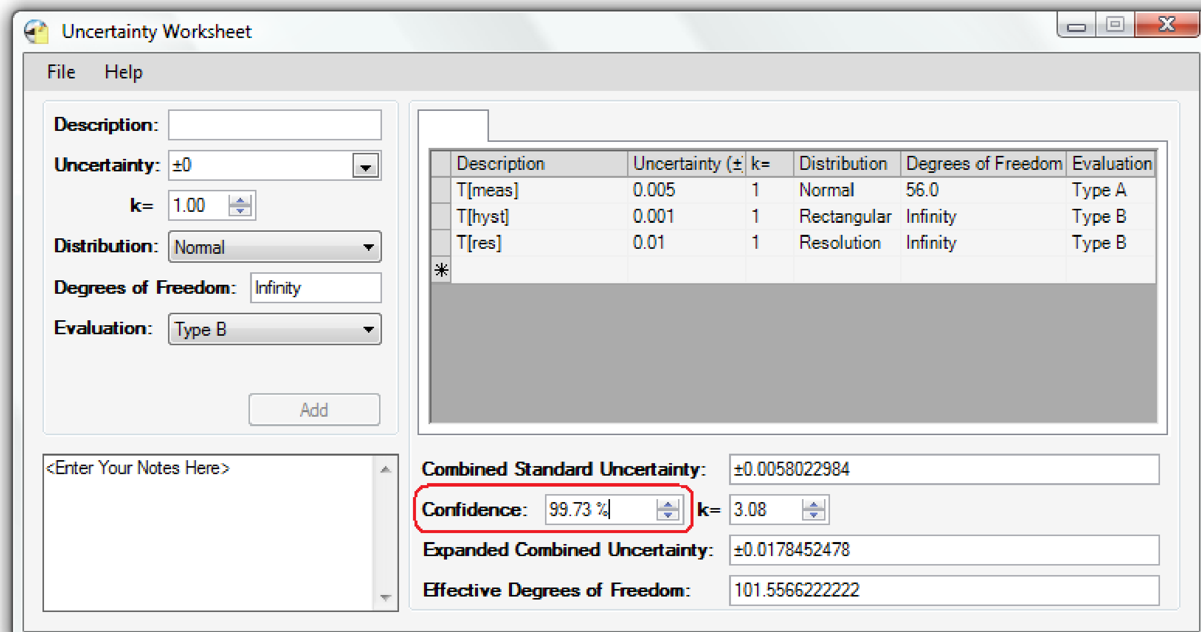
Last, enter the final individual uncertainty component values. The last component has a resolution type distribution and is again a Type B evaluation.



Add the component.

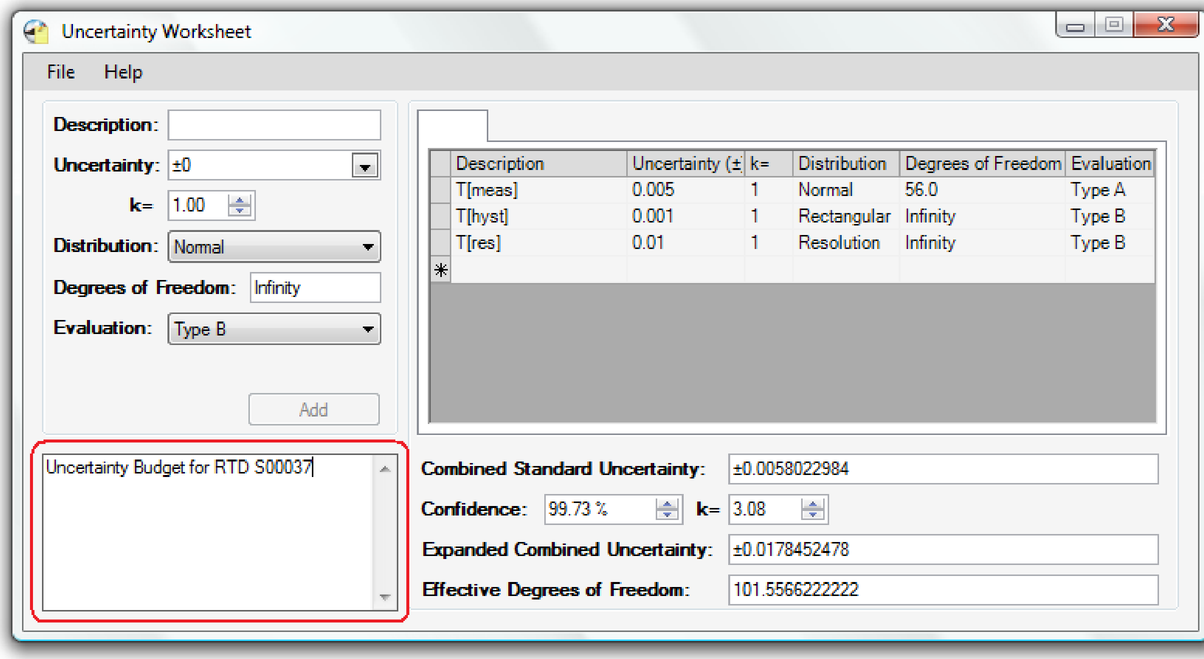


Now select the desired confidence level of 99.73%. Notice how HumiCalc automatically recalculates the correct k factor for the given confidence and effective degrees of freedom.



Add Notes

Worksheets also allow the user to record notes on the worksheet that are stored along with the entries when the worksheet is saved.



A

APPENDIX A

HUMIDITY TERMS AND DEFINITIONS

T_S

Saturation Temperature is the temperature at which air is fully saturated with water vapor to the 100 %RH condition.

T_C

Test Temperature is the temperature at which all conversions are performed. Test temperature is synonymous with chamber temperature. In a majority of applications, test temperature will be the ambient room temperature.

T_D

Dew Point Temperature is the temperature to which a gas must be cooled in order to just begin condensing water vapor in the form of dew. Generally, dew point exists at temperatures above freezing. However, dew point may actually exist below freezing, but it is important to note that dew point is not the same as frost point.

T_F

Frost Point Temperature is the temperature to which a gas must be cooled in order to just begin condensing water vapor in the form of frost. Frost point only exists at temperatures below freezing.

T_W

Wet Bulb temperature is used in wet bulb / dry bulb aspirated Psychrometry, and is the temperature measured by a temperature probe whose tip is coated with water (typically by being covered with a wet sock). When aspirated at a constant air velocity, the wet bulb will cool due to evaporation of the water from the probe. The cool temperature, to which it equilibrates, is used in the calculation of humidity parameters.

A

Psychrometer Coefficient.

P_S

Saturation Pressure is the absolute pressure at which air is fully saturated with water vapor to the 100 %RH condition.

P_C

Test Pressure is the absolute pressure at which all conversions are performed. Test pressure is synonymous with chamber pressure. In a majority of applications, test pressure will be the absolute ambient pressure.

$e(T)$

Saturation Vapor Pressure is a function of temperature. The function can best be described by a lab setup. Imagine a chamber whose temperature T can be controlled. The chamber is partially filled with water. Initially, the remaining space is a vacuum. The pressure P of the space over the water can be measured. At a fixed temperature, water molecules will leave the water and enter the space above at a fixed rate. As water molecules accumulate over the liquid water, the pressure there will increase, and molecules will re-enter the liquid at an increasing rate. Finally, water molecules will be entering and leaving the liquid at the same rate, giving equilibrium and a constant pressure P over the water. The equilibrium pressure P is the Saturation Vapor Pressure at temperature T.

$e_i(T_S)$

Saturation Vapor Pressure computed at the Saturation Temperature with respect to ice.

$e_w(T_S)$

Saturation Vapor Pressure computed at the Saturation Temperature with respect to water.

$e_i(T_C)$

Saturation Vapor Pressure computed at the Test/Chamber Temperature with respect to ice.

$e_w(T_C)$

Saturation Vapor Pressure computed at the Test/Chamber Temperature with respect to water.

$e_i(T_D)$
Saturation Vapor Pressure computed at the Dew/Frost Temperature with respect to ice. For Dew Point Temperatures below freezing, this vapor pressure is computed at the Frost Point Temperature.

$e_w(T_D)$
Saturation Vapor Pressure computed at the Dew Temperature with respect to water.

$e_i(T_W)$
Saturation Vapor Pressure computed at the Wet Bulb Temperature with respect to ice.

$e_w(T_W)$
Saturation Vapor Pressure computed at the Wet Bulb Temperature with respect to water.

$f_i(T_S, P_S)$
Enhancement Factor for Ice at Saturation Temperature and Pressure. The enhancement factor corrects for the non-ideal behavior of a gas admixed with water vapor. The enhancement factor is a function of two independent variables, pressure and temperature.

$f_w(T_S, P_S)$
Enhancement Factor for Water at Saturation Temperature and Pressure. The enhancement factor corrects for the non-ideal behavior of a gas admixed with water vapor. The enhancement factor is a function of two independent variables, pressure and temperature.

$f_i(T_C, P_C)$
Enhancement Factor for Ice at Chamber/Test Temperature and Pressure. The enhancement factor corrects for the non-ideal behavior of a gas admixed with water vapor. The enhancement factor is a function of two independent variables, pressure and temperature.

$f_w(T_C, P_C)$
Enhancement Factor for Water at Chamber/Test Temperature and Pressure. The enhancement factor corrects for the non-ideal behavior of a gas admixed with water vapor. The enhancement factor is a function of two independent variables, pressure and temperature.

$f_i(T_D, P_C)$
Enhancement Factor for Ice at Dew/Frost Temperature and Chamber/Test Pressure. For Dew Point Temperatures below freezing, this vapor pressure is computed using the Frost Point Temperature. The enhancement factor corrects for the non-ideal behavior of a gas admixed with water vapor. The enhancement factor is a function of two independent variables, pressure and temperature.

$f_w(T_D, P_C)$
Enhancement Factor for Water at Dew Temperature and Chamber/Test Pressure. The enhancement factor corrects for the non-ideal behavior of a gas admixed with water vapor. The enhancement factor is a function of two independent variables, pressure and temperature.

M_{v}
Molecular Weight of Water Vapor (18.02 g/mol)

M_a
Molecular Weight of Air (28.9645 g/mol)

R
Universal Gas Constant (8.31432) as defined by The US Standard Atmosphere, 1976 (USSA1976).

$\%RH$
Percent Relative Humidity is the ratio of the amount of water vapor in a sample to the maximum amount possible at the same temperature and pressure.

PPM_V
Parts per Million by Volume is a ratio of the number of molecules of water vapor to the number of molecules of the other constituents in the gas. Once established, PPMv is pressure and temperature insensitive.

PPM_W
Parts per Million by Weight is a ratio of the weight of the water vapor in a sample to the weight of the remaining constituents in the gas. Once established, PPMw is pressure and temperature insensitive.

$Grains / lb$
Grains per Pound is a ratio of the weight, in grains, of water vapor to the weight, in pounds, of the other constituents in the gas. (7000 grains = 1 pound)

W_{VOL}

Mixing Ratio by Volume is a ratio of the partial pressure of the water vapor to the partial pressure of the remaining constituents in the sample.

W_{WT}

Mixing Ratio by Weight is a ratio of the weight of the water vapor to the weight of the remaining constituents in the sample.

$h_{Enthalpy}$

Enthalpy is a measure of the amount of energy required to change a gas from one temperature/humidity value to another. In application, enthalpy is not used as an absolute value, but rather it is the difference in enthalpy between two distinct points which are of interest. The datum point which results in zero enthalpy was therefore arbitrarily chosen at a test temperature of 0 °C and 0 %RH. Applying enthalpy is a matter of computing the difference in enthalpy between two or more distinct calculations.

ϕ_{SH}

Specific Humidity is a ratio of the weight of the water vapor to the total weight of the humidified gas.

ϕ_{AH}

Absolute humidity is the weight of water vapor per unit volume of humidified gas.

ρ_{Dry}

Partial Dry Air Density is the weight per unit volume of only the dry air portion of a moist air sample. In other words, if the water vapor were removed from a fixed volume of air, the remaining dry air would exhibit this density.

ρ_{Moist}

Moist Air Density is the total weight per unit volume of a moist air sample. This density includes both the weight of the air and the weight of the water vapor.

X_v

Vapor Mole Fraction is the mole fraction of water vapor in a sample. It is the ratio of the amount of moles of water vapor to the total moles of the moist air sample. Using Dalton's law of partial pressure this can be represented by the partial pressure of the water vapor divided by the total pressure of the moist air sample. Vapor Mole Fraction and Dry Air Mole Fraction are related by the fact that Dry Air Mole Fraction plus Vapor Mole Fraction always equals one.

X_a

Dry Air Mole Fraction is the mole fraction of the dry air portion of a sample. The dry air portion is considered to be all constituents in a gas exclusive of the water vapor. Dry Air Mole Fraction and Vapor Mole Fraction are related by the fact that Dry Air Mole Fraction plus Vapor Mole Fraction always equals one.

$\%_v$

Percent by Volume is a ratio (expressed as a percentage) of the partial pressure of the water vapor to the total pressure of the sample.

$\%_w$

Percent by Weight is a ratio (expressed as a percentage) of the weight of the water vapor to the total weight of the sample.

u_i

Individual Standard Uncertainty.

u_c

Combined Standard Uncertainty is the combined individual standard uncertainties using the law of propagation of uncertainty.

U

Expanded Uncertainty is a measure of uncertainty that defines an interval about the measurement result within which the value of the measurand is confidently believed to lie.

k

The value of the coverage factor k is chosen on the basis of the desired level of confidence to be associated with the interval defined by $U = k*u_c$.

WEXLER'S SATURATION VAPOR PRESSURE FOR WATER

Wexler's(1) formula for the saturation vapor pressure over water in the pure phase with Hardy's(9) adjusted coefficients for the ITS-90 temperature scale is as follows:

$$\ln e_w = \sum_{i=0}^{6} g_i T^{i-2} + g_7 \ln T$$

Where e_w is the vapor pressure(Pa), over water and T is the temperaure (Kelvin)

ITS-90 adjusted coefficients:

$g_0 = \text{-}2.83657440E + 03$

$g_1 = \text{-}6.02807656E + 03$

$g_2 = 1.95426361E + 01$

$g_3 = \text{-}2.73783019E\text{-}02$

$g_4 = 1.62616980E\text{-}05$

$g_5 = 7.02290560E - 10$

$g_6 = -1.86800090E - 13$

$g_7 = 2.71503050E + 00$

WEXLER'S SATURATION VAPOR PRESSURE FOR ICE

Hyland's & Wexler's(2) formula for the saturation vapor pressure over ice in the pure phase with Hardy's(9) adjusted coefficients for the ITS-90 temperature scale is as follows:

$$\ln e_i = \sum_{i=0}^{4} k_i T^{i-1} + k_5 \ln T$$

Where e_i is the vapor pressure(Pa), over ice and T is the temperaure (Kelvin)

ITS-90 adjusted coefficients:

$k_0 = -5.86664260E+03$

$k_1 = 2.2328702E+01$

$k_2 = 1.39387003E-02$

$k_3 = \text{-}3.42624020E\text{-}05$

$k_4 = 2.70409550E\text{-}08$

$k_5 = 6.70635220E\text{-}01$

SONNTAG'S SATURATION VAPOR PRESSURE FOR WATER

Sonntag's(6) reference formula for the saturation vapor pressure in the pure phase with respect to water is as follows:

$$\ln e_w = \sum_{i=0}^{3} g_i T^{i-1} + g_4 \cdot \ln T$$

Where e_w is the vapor pressure(Pa), over water and T is the temperaure (Kelvin)

ITS-90 coefficients:

$g_0 = -6096.9385$

$g_1 = 21.2409642$

$g_2 = \text{-}2.711193E-2$

$g_3 = 1.673952E-5$

$g_4 = 2.433502$

SONNTAG'S SATURATION VAPOR PRESSURE FOR ICE

Sonntag's(6) reference formula for the saturation vapor pressure in the pure phase with respect to ice is as follows:

$$\ln e_i = \sum_{i=0}^{3} k_i T^{i-1} + k_4 \cdot \ln T$$

Where e_i is the vapor pressure(Pa), over ice and T is the temperaure (Kelvin)

ITS-90 coefficients:

$$k_0 = -6024.5282$$

$$k_1 = 29.32707$$

$$k_2 = 1.0613868E-2$$

$$k_3 = -1.3198825E-5$$

$$k_4 = -0.49382577$$

ENHANCEMENT FACTOR

Greenspan's(3) functional equation for the enhancement factor when air is used as the carrier gas at a given pressure and temperature is as follows:

$$f(T,P) = \exp\left[a\left(1-\frac{e(T)}{P}\right)+b\left(\frac{P}{e(T)}-1\right)\right]$$

Where :

$P =$ The absolute pressure (Pa)

$e(T) =$ The saturation pressure (Pa) over water or ice at temperature T (Kelvin)

$$a = \sum_{i=0}^{3}(A_i \cdot T^i)$$

$$\ln b = \sum_{i=0}^{3}(B_i \cdot T^i)$$

ITS-90 coefficients for water 223.15 to 273.15 (Kelvin):

$$A_0 = -5.5898101 \times 10^{-2}$$

$$A_1 = +6.7140389 \times 10^{-4}$$

$$A_2 = -2.7492721 \times 10^{-6}$$

$$A_3 = +3.8268958 \times 10^{-9}$$

$$B_0 = -8.1985393 \times 10^{1}$$

$$B_1 = +5.8230823 \times 10^{-1}$$

$$B_2 = -1.6340527 \times 10^{-3}$$

$$B_3 = +1.6725084 \times 10^{-6}$$

ITS-90 coefficients for water 273.15 to 373.15 (Kelvin):

$$A_0 = -1.6302041 \times 10^{-1}$$

$$A_1 = +1.8071570 \times 10^{-3}$$

$$A_2 = -6.7703064 \times 10^{-6}$$

$$A_3 = +8.5813609 \times 10^{-9}$$

$$B_0 = -5.9890467 \times 10^{1}$$

$$B_1 = +3.4378043 \times 10^{-1}$$

$$B_2 = -7.7326396 \times 10^{-4}$$

$$B_3 = +6.3405286 \times 10^{-7}$$

ITS-90 coefficients for ice 173.15 to 223.15 (Kelvin):

$$A_0 = -7.4712663 \times 10^{-2}$$
$$A_1 = +9.5972907 \times 10^{-4}$$
$$A_2 = -4.1935419 \times 10^{-6}$$
$$A_3 = +6.2038841 \times 10^{-9}$$
$$B_0 = -1.0385289 \times 10^{2}$$
$$B_1 = +8.5783626 \times 10^{-1}$$
$$B_2 = -2.8578612 \times 10^{-3}$$
$$B_3 = +3.5499292 \times 10^{-6}$$

ITS-90 coefficients for ice 223.15 to 273.15 (Kelvin):

$$A_0 = -7.1044201 \times 10^{-2}$$
$$A_1 = +8.6786223 \times 10^{-4}$$
$$A_2 = -3.5912529 \times 10^{-6}$$
$$A_3 = +5.0194210 \times 10^{-9}$$
$$B_0 = -8.2308868 \times 10^{1}$$
$$B_1 = +5.6519110 \times 10^{-1}$$
$$B_2 = -1.5304505 \times 10^{-3}$$
$$B_3 = +1.5395086 \times 10^{-6}$$

RELATIVE HUMIDITY

Relative Humidity formula based on the effective saturation vapor pressure for a given pressure and temperature is as follows:

$$\%RH = \frac{P_C}{P_S} \cdot \frac{f(T_S, P_S)}{f(T_C, P_C)} \cdot \frac{e(T_S)}{e(T_C)} \cdot 100$$

FROST POINT

Frost point temperature and vapor pressure are obtained by iteratively solving the following equation (not applicable with temperatures above freezing):

$$\ln e_i(T_F) + \ln\ f_i(T_F, P_C) = \ln RH + \ln e(T_C) + \ln\ f(T_C, P_C)$$

DEW POINT

Dew point temperature and vapor pressure are obtained by iteratively solving the following equation:

$$\ln e_w(T_D) + \ln\ f_w(T_D, P_C) = \ln RH + \ln e(T_C) + \ln\ f(T_C, P_C)$$

PARTS PER MILLION BY VOLUME

$$PPM_V = \frac{f(T_D, P_C)e(T_D)}{P_C - f(T_D, P_C)e(T_D)} \cdot 10^6$$

PARTS PER MILLION BY WEIGHT

$$PPM_W = \frac{M_v}{M_a} \cdot \frac{f(T_D, P_C)e(T_D)}{P_C - f(T_D, P_C)e(T_D)} \cdot 10^6$$

GRAINS PER POUND

$$Grains / lb = \frac{M_v}{M_a} \cdot \frac{f(T_D, P_C)e(T_D)}{P_C - f(T_D, P_C)e(T_D)} \cdot 7000$$

MIXING RATIO BY VOLUME

$$W_{VOL} = \frac{f(T_D, P_C)e(T_D)}{P_C - f(T_D, P_C)e(T_D)}$$

MIXING RATIO BY WEIGHT

$$W_{WT} = \frac{M_v}{M_a} \cdot \frac{f(T_D, P_C)e(T_D)}{P_C - f(T_D, P_C)e(T_D)}$$

ENTHALPY (SI)

Enthalpy in J/g with Tc in °C and based on a reference state point for the dry-air component of 0 °C.

$$h_{Enthalpy} = 1.005 \cdot T_C + W_{WT}(2500.9 + 1.805 \cdot T_C)$$

ENTHALPY (I-P)

Enthalpy in BTU/lb with Tc in °F and based on a reference state point for the dry-air component of 0 °F.

$$h_{Enthalpy} = 0.240 \cdot T_C + W_{WT}(1061 + 0.444 \cdot T_C)$$

SPECIFIC HUMIDITY

$$\phi_{SH} = \frac{M_v(e(T_D)f(T_D, P_C))}{M_a(P_C - e(T_D)f(T_D, P_C)) + M_v(e(T_D)f(T_D, P_C))}$$

ABSOLUTE HUMIDITY

$$\phi_{AH} = \frac{M_v(e(T_D)f(T_D, P_C))}{R \cdot T_C}$$

DRY AIR DENSITY

$$\rho_{Dry} = \frac{M_a(P_C - e(T_D)f(T_D, P_C))}{R \cdot T_C}$$

MOIST AIR DENSITY

$$\rho_{Moist} = \frac{M_a(P_C - e(T_D)f(T_D, P_C)) + M_v(e(T_D)f(T_D, P_C))}{R \cdot T_C}$$

VAPOR MOLE FRACTION

$$X_v = \frac{f(T_D, P_C)e(T_D)}{P_C}$$

DRY AIR MOLE FRACTION

$$X_a = \frac{P_C - f(T_D, P_C)e(T_D)}{P_C}$$

PERCENT BY VOLUME

$$\%_v = \frac{f(T_D, P_C)e(T_D)}{P_C} \cdot 100.0$$

PERCENT BY WEIGHT

$$\%_w = \frac{M_v(e(T_D)f(T_D, P_C))}{M_a(P_C - e(T_D)f(T_D, P_C)) + M_v(e(T_D)f(T_D, P_C))} \cdot 100.0$$

WET BULB TEMPERATURE

Wet bulb temperature (T_W) is obtained by iteratively solving the following equation.

Where:
Temperatures are in Kelvin.
A = Psychrometer Coefficient

$$e(T_D) f(T_D, P_C) = e(T_W) f(T_W, P_C) - A \cdot P_C \cdot (T_C - T_W)$$

Ferrel's Psychrometer Coefficient Formula.

$$A = 6.6 \times 10^{-4} \cdot (1 + 0.00115 \cdot (T_W - 273.15))$$

WELCH-SATTERTHWAITE

Used to Estimate the effective degrees of freedom.

$$\nu_{\text{eff}} = \frac{u_c^4(y)}{\sum_{i=1}^{N} \frac{c_i^4 u^4(x_i)}{\nu_i}}$$

LAW OF PROPAGATION OF UNCERTAINTY

"RSS" root-sum-of-squares or square root of the sum-of-the squares method of combining uncertainty components.

$$u_c = \sqrt{\sum_{i=1}^{n} (u_i)^2}$$

B

APPENDIX B

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