

@GAS USER'S MANUAL

VERSION 3.2

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TABLE OF CONTENTS

1	INTRODUCTION.....	1
1.1	Overview	1
1.2	What's New	2
2	USING THE @GAS PROPERTY FUNCTIONS	3
2.1	General Information.....	3
2.2	Description of @Gas Functions.....	3
2.2.1	Valid Operating Range	4
2.2.2	Basic Unit Sets	5
2.2.3	Gas Composition.....	5
2.2.4	Wet or Dry Basis	6
2.2.5	Reference Conditions.....	6
2.3	Using @Gas from Excel	7
2.4	Using @Gas from 1-2-3	8
2.5	Using @Gas from Mathcad	9
2.6	Using @Gas from Visual BASIC	10
2.7	Using @Gas from C/C++ Windows Programming Languages.....	10
2.8	Version and Serial Number	11
3	USING DESKTOP GAS CALCULATOR.....	12
3.1	Overview	12
3.2	Basic Operation.....	12
3.3	Entering Data	13
3.4	Unit Selection	14
3.5	Calculating State Points	15
3.6	Formatting Property Values.....	15
3.7	Labeling and Storing State Points	16
3.8	Printing	16
3.9	Saving And Opening Data Files	17

3.10	Advanced Features	17
3.10.1	Expansion/Compression Tool	17
3.10.2	Heating/Cooling Tool	18
3.10.3	Exchanging Data with Other Programs.....	19
3.11	Getting Help	19
3.12	Error Messages.....	20
3.13	Exiting DeskTop Gas.....	20
4	THEORETICAL BASIS OF @GAS FUNCTIONS	21
4.1	Gas Property Database	24
4.2	Computational Model	26
4.3	Transport Properties.....	26
4.3.1	Viscosity	26
4.3.2	Thermal Conductivity	28
5	SPEED AND ACCURACY	31
5.1	Speed of Calculations	31
5.2	Accuracy of Calculations	31
6	REFERENCES.....	48
	APPENDIX I DETAILED FUNCTION LISTING.....	49
	APPENDIX II @GAS ERROR CODES.....	73

1 INTRODUCTION

@Gas is a software product that provides thermodynamic and transport properties for mixtures of moist gases through functions contained in a Windows Dynamic Link Library (DLL). The **@Gas** package includes **DeskTop Gas**, an interactive gas property calculator and various add-ins which allow the functions to be used as if they were built in to 1-2-3 for Windows, Microsoft Excel and Mathcad. Programmers can call the functions in the DLL directly from many Windows programming languages such as Microsoft's Visual Basic, Visual C++ and Access.

1.1 OVERVIEW

The current library includes the following gases: nitrogen (N₂), oxygen (O₂), argon (Ar), carbon dioxide (CO₂), and water vapor (H₂O). The thermodynamic property functions are calculated for mixtures of all five gases using an accurate third order virial equation of state. See the theory and accuracy section of the HTML version of the User's Manual for an explanation of how Techware developed the equation of state.

These five gases account for 99.997% of the volumetric composition of standard air and also account for better than 99.9% of most combustion gases.

The functions are valid over a temperature range from 180 °K, (-136 °F) to 2000 °K, (3140 °F) and at pressures up to 50 bar (725 psia).

@Gas can be used to calculate the thermodynamic and transport properties of moist air by calling the functions using the composition of standard air. In some cases, when dealing with psychrometric properties of air such as relative humidity, wet bulb temperature or degree of saturation, it may be necessary to use Techware's **@Air** add-in which includes functions to handle these parameters. The two packages use similar equations except that the **@Air** program mixes two gases (dry air plus moisture) while the **@Gas** product mixes five discrete gases. Nonetheless, the values returned by the **@Gas** functions when using a mixture composition corresponding to standard dry air agree quite well with those returned by the **@Air** functions. For this reason, the functions from the two programs can be used together as long as you select consistent unit sets.

Included also in **@Gas** are functions that calculate the saturated vapor pressure of water and the enthalpy and entropy of compressed water. These functions are useful in calculations involving the removal of moisture from gas streams. The saturated vapor functions and the enthalpy and entropy property values for compressed liquid water are based on the IAPWS IF97 formulations used to develop the ASME steam tables. For a complete set of thermodynamic properties for water and steam use Techware's **WinSteam** add-in.

The **@Gas** package supports 32-bit applications running under Windows 95, 98, NT, XP and Windows 2000. The Setup program will try to detect which applications are installed on your system and offer appropriate options for installation.

The Setup program and the installation instructions contained in the **@Gas** package guide you through installing the files you'll need for the applications you expect to use. Example files to help you get started are also provided.

1.2 WHAT'S NEW

@Gas 3.2 does not install the help shortcut on the toolbar when using Excel 2007 or later in order to operate more reliably.

@Gas 3.0 has added many new features over the previous version, **@Gas 2.0**. These include the following:

Extends the temperature range upwards from 1300 °K, (1880 °F) to 2000 °K, (3140 °F) and downward from 273.15 °K (32 °F) to 180 °K (-135.67 °F).

Adds transport property functions:

GasPTXM, which calculates dynamic viscosity given pressure, temperature and gas composition.

GasPTXK, which calculates thermal conductivity given pressure, temperature gas composition.

The gas property calculator, now called DeskTop Gas, has been enhanced to include many new features to make it even more powerful.

Adds five new unit sets: "EngG" which uses psig for pressure instead of psia; "SIF", which uses the formal SI units, MPa for pressure instead of bar and °K for temperature, instead of °C; "SIK" which uses kPa instead of bar for pressure; "MET" which uses the calorie instead of the joule for energy; and "METF" which uses kg/cm² for pressure.

2 USING THE @GAS PROPERTY FUNCTIONS

2.1 GENERAL INFORMATION

All applications using the gas property functions use the same set of functions. In most applications, the functions are called by name. In **DeskTop Gas**, the appropriate functions are called automatically according to your on-screen selections.

Each user of spreadsheets or programs you write using the gas property functions, must have his own copy of **@Gas**. Any program calling the functions must access the dynamic link library at run time. Since this file will be called by many applications, it must be installed on the computer in either the Windows directory or preferably, in the Windows System directory. Normally, the installation program will set this up for you automatically.

In Excel, 1-2-3, Mathcad, Visual BASIC and your own Windows programs, the functions provided by **@Gas** can be used within equations just like each application's built-in math functions. The functions can even be nested. Each function returns a single, floating point result. The functions require several inputs to identify the state point, the gas composition and the unit set. Subsequent sections of this chapter describe the calling syntax and other considerations in using the functions within supported applications.

2.2 DESCRIPTION OF @GAS FUNCTIONS

All of the **@Gas** functions, which are accessible to the user, are summarized in the table below.

Function	Input(s)	Output
Equations of State		
GasPTXV()	Pressure, Temperature, Composition	Specific Volume
GasPVXT()	Pressure, Volume, Composition	Dry Bulb Temperature
GasTVXP()	Temperature, Volume, Composition	Pressure
Thermodynamic Property Functions		
GasPTXW()	Pressure, Temperature, Composition	Saturated Humidity Ratio
GasPXD()	Pressure, Composition	Dew Point Temperature
GasXMW()	Composition	Molecular weight
GasPTXH()	Pressure, Temperature, Composition	Specific Enthalpy
GasPTXHS()	Pressure, Temperature, Composition	Saturated Enthalpy
GasPHXT()	Pressure, Enthalpy, Composition	Dry Bulb Temperature
GasPTXS()	Pressure, Temperature, Composition	Specific Entropy
GasPTXSS()	Pressure, Temperature, Composition	Saturated Entropy
GasPSXT()	Pressure, Entropy, Composition	Dry Bulb Temperature
GasPTXL()	Pressure, Temperature, Composition	Mass fraction of water condensed

Transport Property Functions		
GasPTXC()	Pressure, Temperature, Composition	Specific Heat
GasPTXM()	Pressure, Temperature, Composition	Viscosity
GasPTXK()	Pressure, Temperature, Composition	Thermal Conductivity
Vapor and Liquid Water Property Function		
GasVapTP()	Water Vapor Temperature	Saturated Pressure
GasVapPT()	Water Vapor Press	Saturated Temperature
GasCondPTH()	Pressure, Water Temperature	Specific Enthalpy
GasCondPTS()	Pressure, Water Temperature	Specific Entropy
Miscellaneous Functions		
GasXW()	Composition	Humidity Ratio
GasWX()	Humidity Ratio	Mole fraction of water vapor
GasVer()	None	Version/serial no.

Theoretically, a state point can be uniquely identified by specifying any two thermodynamic properties and the gas composition. In most practical applications, pressure is one of the known variables. Most of the functions contained in **@Gas** assume that pressure is one of the known variables. If this is not the case, one of the equation of state functions may be used to obtain the pressure.

You may be familiar with gas property tables in which pressure is not one of the variables. Typically, the gases are treated as perfect gases in which properties such as enthalpy, entropy and specific heat are not dependent upon pressure. Treating the gas mixture as a perfect gas produces only rough approximations of the actual properties. The perfect gas approximations are reasonable at low pressures but increase in error as the pressure is increased. The formulations used in **@Gas** are based on real gas properties and include the effects of pressure and the mixing of the gases.

A function, GasPTXW, is provided to obtain the saturated humidity ratio for a known pressure and temperature. The Dry Bulb Temperature at saturation is synonymous with the Dew Point Temperature. Therefore, this function can be used with a pressure and the Dew Point Temperature to obtain the moisture content. The inverse of this function is GasPXD, which returns the Dew Point or Dry Bulb Temperature at which the gas becomes saturated based on the amount of water vapor in the gas composition.

The function GasPTXHs calculates the enthalpy of the gas mixture saturated with water at a given pressure and temperature. It is equivalent to calling the GasPTXW function to get the saturated humidity ratio and then calling the GasPTXH function with the calculated humidity ratio. A similar function, GasPTXSs is provided for entropy.

2.2.1 Valid Operating Range

The **@Gas** functions are generally valid over a temperature range from 180 °K, (-136 °F) to 2000 °K, (3140 °F) and at pressures up to 5.0 MPa, (725 psia). The functions detect requests for calculations outside that range and return an error value.

The valid ranges of some functions depend on the amount of water vapor in the gas composition. Those functions may, therefore, return out-of-range errors even though pressure

and temperature are within the ranges cited above. When an out-of-range or invalid set of inputs is used, the add-in functions (i.e., Excel or 1-2-3 add-ins) simply return error values (#VALUE or #NUM). But, DeskTop Gas produces informative error messages. DeskTop Gas can be used in conjunction with the add-ins to develop an understanding of what causes error values in your spreadsheet calculations.

2.2.2 Basic Unit Sets

Input to all the functions and all results can be in any of the available unit sets. @Gas lets the user select the desired unit set with each function call through the use of an extra function argument, the unit set parameter. The unit set parameter selects basic units, Eng, SI, etc. and optional unit set modifiers. The gas property functions within the function library contain the required conversion factors.

When calling gas property functions from Visual Basic or any other Windows programming language, the unit set parameter is required and must be an integer value.

Additional flexibility in entering the unit set parameter is available when using the gas property add-in functions from Excel or 1-2-3. The spreadsheet add-ins allow the unit set parameter to be entered either as a character string or an integer value. Acceptable character strings are listed in the row labeled "Unit Set Name" in the table below. Modifiers can also be appended to these strings as described later in this section. For most users, the character string method is preferable because the characters representing the unit sets and their options are mnemonic. For Mathcad, the unit set can only be entered as a number, however, you can achieve the same effect by defining mnemonics for the base unit sets and the options right on your Mathcad worksheet

The table below summarizes the units used for each unit set.

Unit Set	English	SI Customary	English Gauge	SI Formal	SI kPa	Metric	Metric Formal
Unit Set Number	0	1	2	3	4	5	6
Unit Set Name	"ENG"	"SI"	"ENGG"	"SIF"	"SIK"	"MET"	"METF"
Temperature	°F	°C	°F	°K	°C	°C	°C
Pressure	Psia	Bar	Psig	MPa	kPa	Bar	kg/cm ²
Entropy	Btu/lbm/ °F	kJ/kg/°C	Btu/lbm/°F	kJ/kg/ °C	kJ/kg/°C	kcal/kg/°C	kcal/kg/°C
Enthalpy	Btu/lbm	kJ/kg	Btu/lbm	kJ/kg	kJ/kg	kcal/kg	kcal/kg
Specific Volume	ft ³ /lbm	m ³ /kg	ft ³ /lbm	m ³ /kg	m ³ /kg	m ³ /kg	m ³ /kg
Specific Heat	Btu/lbm/°F	kJ/kg/°C	Btu/lbm/°F	kJ/kg/ °K	kJ/kg/°C	kcal/kg/°C	kcal/kg/°C
Viscosity	Lbm/ft-hr	Centipoise	lbm/ft-hr	Pa-sec	Centipoise	Centipoise	Centipoise
Conductivity	Btu/hr/ft/°F	Watt/m/°C	Btu/hr/ft/°F	Watt/m/°K	Watt/m/°C	Watt/m/°C	Watt/m/°K
Humidity Ratio	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim
Mole Fraction	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim
Molecular Weight	Mass per mole	Mass per mole	Mass per mole	Mass per mole	Mass per mole	Mass per mole	Mass per mole

2.2.3 Gas Composition

The term "Comp" used in the table at the beginning of section 2.2 refers to the gas composition, which is entered as five sequential variables in the function parameter list. Five

values must be entered even if some of the values are zero and they must be in the order N₂, O₂, Ar, CO₂ and H₂O. By default, the value for each gas constituent is entered as a mole fraction or percent volume on a dry basis. The H₂O component is entered as a humidity ratio (mass of moisture per mass of dry gas). This is the same convention used by ASHRAE to handle air properties. This convention is useful in some applications where the process includes heating, cooling, humidification or drying. The gas composition does not change except perhaps for the quantity of moisture, making it more convenient to express the gas composition on a dry basis with a humidity ratio. By default, all of the mass-dependent properties (volume, enthalpy, entropy, specific heat and viscosity) are expressed on a basis of dry gas. This is also the basis of Techware's **@Air** functions, allowing the two add-ins to be used together.

In other cases where the process may involve combustion, the composition of all the gas components will change and it is probably more convenient to express the composition on a wet basis. In this case, all of the gas components, including H₂O, are expressed as mole fractions. This option is enabled by appending "C" to the to the unit set name. For example, if you are working in English units, you would enter the unit set as "EngC".

If you prefer to express the gas composition in terms of mass fractions instead of mole fractions, you may do so by appending "M" to the unit set name. For example the unit set "EngM" would require the gas composition for N₂, O₂, Ar and CO₂ to be entered as mole fractions and H₂O as a humidity ratio. The unit set "EngCM" would require all five gas components to be entered as mass fractions.

If you are using the numerical designation for unit sets, you can select the "C" option by adding 32 to the unit set number or the "M" option by adding 64 to the unit set number.

2.2.4 Wet or Dry Basis

All mass-dependent properties (specific volume, enthalpy, entropy, specific heat and viscosity) can be expressed on either a dry or wet basis. The default for all basic unit sets expresses the properties per mass of dry gas. This is consistent with ASHRAE conventions and is quite useful when dealing with processes that involve evaporation or condensation of water vapor.

If you have chosen to express the gas composition on a wet basis (selected the "C" unit set modifier), you probably want to express the property value on a wet basis as well. You can accomplish this by adding the letter "W" to the unit set name or adding 16 to the unit set number. In this case, the properties will be expressed per total mass of the wet gas including the water vapor. Some of the functions (the "inverse" functions) take per-mass properties as inputs. Remember that the choice of wet or dry basis affects the property whether it is used as an input or output parameter.

2.2.5 Reference Conditions

Enthalpy and entropy values are always expressed relative to particular reference conditions. Many people forget that the values of enthalpy and entropy that are found in published tables are not absolute values but instead, are relative to particular reference conditions. Engineering calculations always deal with enthalpy or entropy differences, typically between in-flowing and out-flowing streams. For this reason, it does not matter what you select as the reference conditions, as long as you use them consistently. **@Gas** allows you to select reference

conditions consistent with ASHRAE or an alternate set of conditions based on absolute zero temperature.

In SI units, ASHRAE uses a reference condition of 0 °C and one atmosphere of pressure for dry air. For water vapor, ASHRAE uses a reference condition of liquid water at the triple point temperature of 0.01 °C. In English units, however, ASHRAE uses a reference condition of 0 °F at one atmosphere of pressure for dry air properties while maintaining the convention of using the triple point as a reference temperature for water properties. For dry gas, the **@Gas** functions use a reference temperature of 0 °F if an English unit set is selected or 0 °C if an SI or Metric unit set is selected. **DeskTop Gas** provides more flexibility as described in section 3. **@Gas** always references water vapor to the triple point of liquid water.

If you try to convert enthalpy (or entropy) values produced by the functions from English to SI units simply using standard conversion factors, you will find a difference equal to the difference in dry gas enthalpy (or entropy) between 0 °F and 32.018 °F. You can avoid this problem by converting the input parameters (e.g. pressure and temperature) to either English or SI units before calling the desired **@Gas** function.

As an alternative, you can set the reference temperature for the dry gas portion to absolute zero, (0 °K) by adding an "A" to the unit set name or adding 8 to the unit set number. In this case the 0 °K reference temperature will be used for any of the English or SI unit sets.

Please note that in all cases, the enthalpy and entropy of the water portion are set to zero for liquid water at the triple point. Some publications, which are based on perfect gas assumptions, assign the zero point for enthalpy and entropy to water in the vapor state at the triple point or some other specified temperature. We believe that setting the zero point for enthalpy and entropy to water in the liquid state rather than in the vapor state has two major advantages. First, the values are numerically equivalent to standard international steam tables (and Techware's WinSteam product). This facilitates the handling of processes that include both moist gas and liquid water streams without worrying about reference temperatures. Second, It greatly simplifies analysis of processes in which water is either condensed from or evaporated to the gas stream.

All of **@Gas**' reference conditions use the International Temperature Scale of 1990 (ITS-90) as the basis of temperature.

2.3 USING @GAS FROM EXCEL

You must load the XLGAS32.XLL add-in to access the gas property functions from Excel. Loading this add-in brings the functions into memory and links them to Excel. You can load the **@Gas** property functions into Excel using Excel's Add-in Manager as described below.

The **@Gas** add-in works with all 32-bit versions of Excel, including Office 2000 and XP. Use the Tools / Add-Ins... menu selection to start Excel's Add-In Manager. If installed using the default values, the file XLGAS32.XLL should be in either the \EXCEL\LIBRARY or the \OFFICE\LIBRARY directory and the Add-In Manager will show that "**@Gas for Excel**" is available. Click the check box next to "**@Gas for Excel**" and press OK. A message will display the Techware copyright notice each time the add-in is loaded.

Each time you start Excel, the **@Gas** functions will be loaded automatically. If you wish to remove the functions, use the Add-In Manager and uncheck the check box next to "**@Gas** for Excel" to remove the add-in. **@Gas** will not load the next time you start Excel until you add it again using the Add-In Manager as described above.

Once the add-in is loaded, the gas property functions are available in the same ways as Excel's built-in functions. That is, they can be typed into cell formulas or they can be inserted using Excel's Insert Function feature. When using this feature, the gas property functions will be alphabetically sorted in a function category called "Engineering". If you need help, use the Excel Help menu and select the '**@Gas** Help' item. This will launch an interactive help window, which provides information regarding the functions and their usage.

Generally, you can use any of the functions listed in section 2.2 in any cell formula. Be sure to prefix the function name with an "=" character if it is the first or only item in a formula. The line below presents an example of a call to a gas property function from Excel:

```
=GasPTXH(a1,b1,c1,d1,e1,f1,g1,"SI")
```

The argument "a1" is for the gas pressure and can be a cell reference or an actual pressure value. In a similar manner, "b1" is for temperature and "c1" through "g1" are for the gas composition. The last argument selects the units set and any options.

The **@Gas** package includes a sample Excel spreadsheet file named EXAMPLE.XLW which illustrates use of the gas property functions. You can find this file in a "Samples" folder in the **@Gas** program folder.

Since the **@Gas** property functions make many floating-point calculations, they can add to a spreadsheet's recalculation time. You may find it desirable to set the spreadsheet to manual recalculation rather than automatic.

2.4 USING @GAS FROM 1-2-3

@Gas works with 32-bit versions of 1-2-3 including 1-2-3 97 and 1-2-3 Millennium. You must load the add-in file named 123GAS.12A to access the gas property functions from 1-2-3. When the add-in is loaded into memory it establishes links between 1-2-3 and the **@Gas** dynamic link library.

Use the File / Add-Ins / Manage Add-ins menu selections to start the Add-In Manager. Before you can use the **@Gas** add-in for the first time, you must register the add-in by pressing the Add-In Manager's Register push-button. If installed using the default values, the file 123GAS.12A should be in the \LOTUS\123\ADDINS directory and will be shown in the Register Add-Ins window. If you installed the file elsewhere, you will have to use the 'Look in' window to search for the file. When you have located the 123GAS.12A file, select it and press the 'Open' push-button. The add-in is now registered.

To load the add-in after it is registered, click on the path name that has the 123GAS.12A file. A check mark will appear to the left of the path name indicating that the add-in is selected. Press the Done push-button to complete the task.

Thereafter, each time you start 1-2-3, the functions will be loaded automatically. If you wish to unload the functions, use the Add-In manager to deselect the add-in. From there forward, the 123GAS.12A add-in will not load until you select it again using the Add-In Manager as described above but it should be unnecessary to go through the registration process again.

Once the add-in is loaded, the gas property functions can be used in any cell formula by typing the function name in the same ways as 1-2-3's built-in functions. If you need help, use the 1-2-3 Help menu and select the '@Gas Help' item. This will launch an interactive help window, which provides information regarding the functions and their usage.

When the add-in is loaded, the gas property functions are available in the same ways as 1-2-3's built-in functions. That is, they can be typed directly into cell formulas. Generally, you can use any of the functions listed in section 2.2 in any cell formula simply by prefixing the function name with an "@" character. The @Gas package contains a sample 1-2-3 spreadsheet file named EXAMPLE.123 which makes several typical calls to the gas property functions.

The line below presents an example of a call to a gas property function from 1-2-3:

```
@GasPTXH(a1,b1,c1,d1,e1,f1,g1,"SI")
```

The argument "a1" is for the gas pressure and can be a cell reference or an actual pressure value. In a similar manner, "b1" is for temperature and "c1" through "g1" are for the gas composition. The last argument selects the units set and any options.

This syntax actually calls an add-in function in the 123GAS.12A add-in. These add-in functions perform error checking and return an appropriate 1-2-3 error value (e.g., ERR) when necessary - typically when input arguments are out of range or when too many arguments are supplied to the function. 1-2-3 will not accept a cell formula that contains a function reference with too few input arguments. The 123GAS add-in functions themselves call functions in TGAS32.DLL to actually perform the calculations.

2.5 USING @GAS FROM MATHCAD

The @Gas add-in for Mathcad is a self-registering DLL. All that is required for Mathcad to access the functions is that the add-in file, MDCGAS32.DLL, be located in the MATHCAD\USEREFI directory. Whenever an @Gas function is used, Mathcad will automatically load and register the function.

The @Gas add-in for Mathcad allows the use of any of the unit sets. Mathcad, however, allows only pure numbers (without units) to be passed to and from user defined functions. The last argument in each function call is the unit set designator and can have a value from 0 to 127 depending upon the selection of base unit set and the unit set options. The other arguments to the function must be numbers without units whose values are consistent with the selected unit set.

The @Gas package contains a sample Mathcad file named EXAMPLE.MCD, which makes typical calls to the gas property functions and illustrates the use of the unit set designator.

Although on-line help for @Gas is not directly available from within Mathcad, the Choose function feature does recognize the @Gas functions and assists user with the functions. Use

the **Math / Choose Function** menu selections to open the Choose Function window. Scroll down the 'Function name is' box to find all of the gas functions listed in alphabetical order. The 'Returns' box will describe the input arguments and the return value for the function that is selected. Pressing the 'Insert' push-button will copy the function to your worksheet with placeholders for each function argument.

2.6 USING @GAS FROM VISUAL BASIC

The gas property functions can be used directly in your Visual Basic programs just like the built-in functions. Before the functions can be used, however, they must be declared as functions and Visual BASIC must be told where to find them. This can all be accomplished by including a DECLARE statement for each of the gas property functions in either the Form code or in the Global code. The DECLARE statement must include the name of the function, the dynamic link library where it can be found (TGAS32.DLL) and the list of arguments (which must all be passed by value, 'ByVal'). A sample DECLARE statement follows:

```
Declare Function GasPTXH Lib "TGAS32.DLL" (ByVal P As Double, ByVal T As Double, ByVal N2 As Double, ByVal O2 As Double, ByVal Ar As Double, ByVal CO2 As Double, ByVal H2O As Double, ByVal Unitset As Integer) As Double
```

A text file, TGASVBDEC.TXT, which lists declarations for all of the **@Gas** functions is copied to a "Programming" folder in the **@Gas** program folder if the "Programming" option was selected during installation.

If you are using the **@Gas** functions in an Excel Visual Basic module to create additional functions, you should use a different name to declare the functions or they will conflict with the functions in the Xlgas32.xll add-in. In this case, you must use the ALIAS keyword in the declaration to identify the true name in the DLL. For example,

```
Declare Function MyGasPTXH Lib "TGAS32.DLL" ALIAS "GasPTXH" (ByVal P As Double, ByVal T As Double, ByVal N2 As Double, ByVal O2 As Double, ByVal AR As Double, ByVal CO2 As Double, ByVal H2O As Double, ByVal Unitset As Integer) As Double
```

A text file, TGASVBADEC.TXT, which lists declarations for all of the **@Gas** functions is copied to a "Programming" folder in the **@Gas** program folder if the "Programming" option was selected during installation.

With each TGAS32 function call, your code should check to ensure that the values returned are greater than -1000. Return values of less than -1000 indicate error conditions. See the Appendix for a listing of error codes and their meanings.

2.7 USING @GAS FROM C/C++ WINDOWS PROGRAMMING LANGUAGES

The gas property functions in TGAS32.DLL can also be called from within C/C++ programs compiled to run under Windows. Prototypes for all functions are provided in the file named 'GASPROTO.H'. All files needed to support your programming applications can be found in the "Programming" folder if you choose to install programming support during installation. You may also find it convenient to include the file named 'GASERR.H'. It defines mnemonic

constants for the various error values returned by the gas functions. The compiled code should also be linked with the import library named 'TGAS32.LIB'.

With each gas property function call, your code should check to ensure that the values returned are greater than -1000. Return values of -1000 or smaller indicate error conditions. See the Appendix for a listing of error codes and their meanings.

2.8 VERSION AND SERIAL NUMBER

There may be new releases of @Gas to add features or to support new applications. Each new release of @Gas will have a version number. Every copy of @Gas sold also has a unique serial number. You can identify the version of the DLL and serial number of your copy by using the GasVer function, which takes no arguments. In Excel, an empty pair of parentheses is needed. In 1-2-3 no parentheses are needed. The GasVer function returns a floating-point number containing the information (e.g., 3.012345). The first two digits indicate the DLL version number. The next five digits make up your copy's serial number.

The serial number also can be found by selecting 'About' on the Help menu of **DeskTop Gas**.

3 USING DESKTOP GAS CALCULATOR

3.1 OVERVIEW

DeskTop Gas is a Windows application, which calculates the thermodynamic and transport properties of a mixture of moist gases. It can be used as an interactive replacement for gas property tables but does much more than that. It automatically calculates all unknown properties when a state point is defined by known properties. The program is flexible, and designed to minimize keystrokes for common calculations. *DeskTop Gas* allows you to enter any number of state points, label them and store the collection of points for later reference. You can print a table of stored points or copy them to the clipboard and paste them into your favorite spreadsheet or word processor.

Major features of this program include:

- validity over **@Gas's** full range of pressures and temperatures
- flexible interactive design
- large choice of units for each property
- tools for heating, cooling, expansion and compression processes
- instant response time
- extensive help screens

If installed properly, *DeskTop Gas* is started by simply double clicking on its name/icon in the **@Gas** subgroup of the *TechwareEng* Group appearing on the Windows Start Menu.

3.2 BASIC OPERATION

The *DeskTop Gas* display is arranged in a tabular format that remains constant although the program window can be re-sized. You may sometimes find it convenient to make the program window smaller. Each of the rows in the top section is dedicated to one of the gas properties (pressure, temperature, specific volume, enthalpy, entropy, specific heat, dynamic viscosity, thermal conductivity and dew point temperature. Each of the rows in the “Gas Composition” section shows the fraction of one of the individual gasses as well as the humidity ratio and molecular weight of the mixture. There is a column that displays the property values for the active point and a column that displays data for one of the stored points.

The key properties that can be used to define the gas state point are: pressure, temperature, specific volume, enthalpy, entropy, and the gas composition. Theoretically, a state point can be uniquely identified by specifying the gas composition and any two of the other five properties. In most practical applications, pressure is usually one of the known variables. Most of the calculations require that the pressure be known. In the rare case when pressure is not known, it can be calculated from the equation of state if the dry bulb temperature and specific volume are known.

Each of the key properties has a check box associated with it. When checked, it signifies that this property is to be used in calculating the state point. In general, two thermodynamic properties and the gas composition must be selected before *DeskTop Gas* will allow a computation. If pressure and temperature are selected, *DeskTop Gas* can compute the gas properties in the state that is saturated with water vapor. In these cases, you will notice that the 'Compute Saturated' button is enabled. Once you select one property, *DeskTop Gas* will disable all the other check boxes whose properties are not allowed in combination with the first selected property. You may change your selections by un-checking one or all of the check boxes and selecting a new combination.

To compute a gas property state point, begin by entering the gas composition in the lower half of the calculator. If you wish to use the composition for standard dry air, press the button labeled "Set to Standard Dry Air". Note the label in the units column next to each gas component. It indicates the basis of the gas composition. Initially, the label should indicate "Vol frac Dry", which means that the gas composition is entered as a volume or mole fraction on a dry basis. Note that the value for water vapor is zero and the box is read only. This ensures that you can only enter water vapor as a humidity ratio. If you want to enter the composition on a wet basis, press the button labeled "Change to Wet Composition". Now you will find that the humidity ratio is read only and water vapor box is enabled. If you want to enter the composition as mass fractions instead of mole fractions, press the button labeled "Change to Mass Fraction". The other button in the gas composition section resets the gas composition to all zeros.

If you want the mass-dependent properties to be expressed on a wet basis instead of a dry basis, press the button labeled "Change to per Wet Mass".

Next, select the input properties by selecting the corresponding check boxes as described above. Enter values for those properties in the boxes to the right of the property names. (The next section describes various methods for entering data.) When you enter a value for any of the key properties, a red "X" appears next to the property value to indicate that a new value has been entered. This is a warning that the value being displayed is not consistent with the current state point. After a compute command is completed successfully, all property values are recalculated and the red "X's" are cleared.

Be sure to enter the values in units consistent with the unit displayed to the right of the value box. If you wish to change units, select the desired units before entering the value. If you change units after the value is entered, the value entered will be converted to the new units.

Next, click the 'Compute' button to find all the unknown properties. If the 'Compute' button is grayed, you have not checked enough properties to define the state point. Fields without check boxes are output only. These include specific heat, viscosity and thermal conductivity and dew point. After recalculation, all fields contain property values for the gas mixture at a particular state point.

3.3 ENTERING DATA

Numeric data is entered in a specially designed edit box called an IO Box, which behaves like a standard Windows edit box but includes some additional features. To enter new data, double click the IO Box and all the data will be highlighted. As you enter new data, the old data will be replaced. To edit data, hold the left mouse button down and drag the mouse over

the characters that you wish to replace, thereby highlighting them. Release the mouse button and type new characters to replace the highlighted ones.

The IO Box has two modes of operation, input and output. When new data is entered, the IO Box is placed in the input mode and a red X appears to the left of the box. After a new state point is computed, all IO Boxes are placed in the output mode and the red X's are removed.

The IO Box accepts either numerical values or arithmetic expressions that can be evaluated to a numeric value. A number can be entered in either decimal or scientific notation. The expression can be any valid arithmetic expression using the following operators:

+	add
-	subtract
*	multiply
/	divide
^	exponent
()	parentheses

Arithmetic calculations can be nested to any level using parentheses. An example of a valid expression is:

$$((1004^2 + 997^2) / 2)^.5$$

which evaluates to 1000.506.

Expressions are evaluated whenever you tab to or click on another control or press the 'Enter' button. Only the resulting value is shown in the box. If you enter an incorrect expression, your computer will beep and the edit cursor will highlight the offending character. You must fix the error before *DeskTop Gas* will allow you to continue.

If the expression you are entering is too long to fit in the box, the box will temporarily increase in length so that you may view more of the expression. When you are finished editing, the box returns to its original length.

To recall the last expression used in an input box, use the 'Recall Expression' command on the 'Edit' menu. You'll then have the opportunity to edit the expression and let the IO Box re-evaluate it. Note that the box retains the last number or expression entered even after a compute command is issued. As a result, the value in the box will not reflect the value of the recalled expression if a compute command has altered the value.

You may use the 'Cut', 'Copy' and 'Paste' commands on the 'Edit' menu or the toolbar to exchange numeric data between *DeskTop Gas*' IO Boxes and any other application that supports the clipboard. If you start entering data in an IO Box and wish to go back to the original data you may use the 'Undo' command on the 'Edit' menu. However, once the IO Box loses the focus, the 'Undo' command is no longer available.

3.4 UNIT SELECTION

DeskTop Gas allows you to use any combination of units for input and output properties. The units for each property can be set independently by using its associated combo box. To change a unit, select its combo box and scroll through the list of available units using either the

keyboard cursor arrows or the mouse. Whenever a new unit is selected, the program converts the values displayed for that property to the new units. Therefore, when entering data you should first select the units and then key in the input values. Otherwise, the values will be converted to the new units and you will have to re-enter them.

The first time the program is started, the properties will be displayed in SI units. You can change all of the units to either standard English or SI units by issuing the 'English Units' or 'SI Units' command from the 'Format' menu or pressing the 'Eng' or 'SI' toolbar button. When you change to English units in this manner, the reference temperature for the dry gas is changed to 0 °F. Similarly, when changing to SI units, the reference temperature is changed to 0 °C.

If you change the units one at a time, the reference temperature will not change, even if you change all of the units from English to SI units. You can force a change in the reference temperature by pressing the 'Ref' button on the toolbar or by selecting 'Options' from the 'Tools' menu and then choosing the 'Reference Point' tab. From either of the dialog boxes, you will be able to select the desired reference temperature.

You may choose any combination of available units for your personal default unit set. Simply select the units you desire for each property and issue the 'Make Current Settings Default' command from the 'Format' menu. The next time you start *DeskTop Gas*, your default unit set will be used.

If you change units and then save a file, those selected units will be restored whenever the file is opened. If you wish to change the units back to your default unit set, issue the command 'Restore Default Settings' from the 'Format' menu.


Unit system changes in *DeskTop Gas* do not affect use of **@Gas** from any other applications (e.g., Excel, 1-2-3, etc.).

3.5 CALCULATING STATE POINTS

When you have finished entering values for the selected input variables, click the on-screen button labeled 'Compute' to calculate all of the state point properties. If the 'Compute' button is grayed, you have not checked enough properties to define the state point.

You may also compute the state point by pressing the 'Enter' key on your keyboard. Note that the 'Enter' key serves two purposes in *DeskTop Gas*. Pressing the 'Enter' key just after entering data in an IO Box, tells *DeskTop Gas* to evaluate the expression in the IO Box. Pressing the 'Enter' key a second time tells *DeskTop Gas* to compute the state point. If you move the focus to any other control after entering data in an IO Box, the expression is evaluated automatically and you only have to press the 'Enter' key only once to compute the state point. The 'Enter' key will not compute a state point if the 'Compute' button is grayed.

3.6 FORMATTING PROPERTY VALUES

DeskTop Gas normally displays all property values in fixed decimal notation. You may increase or decrease the number of decimal places in a selected property IO Box by selecting 'Add Decimal Places' or 'Decrease Decimal Places' from the 'Format' menu or by clicking either of the  toolbar buttons, respectively.

If you wish to change the selected property to scientific notation, select the 'Scientific Notation' command from the 'Format' menu or press the 'EE' toolbar button. The 'Format' menu may be used to change the number format to 'Fixed Decimal' or 'Percent' as well. Corresponding toolbar buttons are 'Fix' and '%' respectively. Of course, the percent format only makes sense for the non-dimensional properties.

The formatting commands are only enabled when the focus is on an IO Box.

3.7 LABELING AND STORING STATE POINTS

DeskTop Gas gives you the option of labeling and storing any number of state points for future reference. After computing the state point, *DeskTop Gas* will automatically suggest a unique name for the new state point such as "Point 1" or "Point 2", but you will probably want to enter something more descriptive. Just enter a new name in the Point Label box.

To store this point, press the 'Store Point' button. (The Store button will not be enabled if the displayed data is not a correctly calculated state point.) *DeskTop Gas* requires all stored points to have a unique label. If you try to store two points with the same label, *DeskTop Gas* will query whether you wish to replace the stored point, which has the same label, with the current point. If not, you should rename the point and try to store it again.

After storing the point, the state point values for the active point will be copied into a storage array and given the name you selected. The point will be displayed in the stored points column in same units as the active point. After a state point is stored, its name is added to the point name combo box in the upper right hand corner of the main window. You can view a stored point by pressing the arrow on the point name combo box and selecting a point from the drop down list.

If you wish to use a stored point with any of the special tools or as the basis for calculating a new point, you must recall the stored point to the active point. Begin by selecting the point from the point name combo box's dropdown list. Next, press the 'Recall Point' button to copy the stored point to the active point. You may now use the active point for new calculations. If you change any input data and press 'Compute', the active point will be changed but the stored point from which you copied the values will remain intact.

You can delete a stored point by first selecting it from the Point Name combo box and then select 'Delete Point' from the 'Edit' menu.

This collection of state points can be saved as a *DeskTop Gas* file. In addition, you can copy state points to the clipboard, where they can be transferred to another application such as a spreadsheet program or word processor.

3.8 PRINTING

You can print a table consisting of all of the stored points by selecting the Print command from either the file menu or the toolbar. The tables will include a column for each of the stored points with each of its properties listed in a row. A label for each row includes the property name and the current units selected. The printing utility will attempt to fit as many points on a page as possible, based on the paper size and orientation that you specify using the 'Print

Setup' command. You can preview the output by selecting the 'Print Preview' command from the 'File' menu.

3.9 SAVING AND OPENING DATA FILES

When you start *DeskTop Gas* or open a new file, it will be untitled. You may save a collection of stored state points along with your selections of units and formats to a *DeskTop Gas* file. Select 'Save' from the 'File' menu or click the disk icon on the toolbar, which will open the "Save As" dialog box. You should enter a name for the file; the file extension ".gas" will be added automatically. You may choose a folder in which to save the file or accept the default folder.

If you have saved the file at least one time during the session, you can save the work under a different filename by choosing the 'Save As' command from the 'File' menu.

To open a saved file, select 'Open' from the 'File' menu or click the open file icon on the toolbar. This will open a dialog box that lists all of your *DeskTop Gas* data files in the current folder. You may select a different folder to view other files. Select the file you want to open and press the 'Open' button to load the file.

To start a new file, select the 'New' button from the Toolbar. If you have stored any points and have not saved the file, you will be prompted to do so.

3.10 ADVANCED FEATURES

DeskTop Gas includes special tools that facilitate the calculation of some common gas processes. These tools include an Expansion/Compression tool and a Heating/Cooling tool.

3.10.1 Expansion/Compression Tool

The Expansion/Compression tool is used to evaluate performance of a gas turbine or an air compressor. If you are predicting the performance and know the efficiency of the turbine or compressor, the tool can be used to calculate the state point conditions at the expansion or compression end point. If you are analyzing the performance of a turbine or compressor and know the conditions at the end point, the tool can be used to calculate the efficiency. The tool also computes the energy converted to shaft work generated by the turbine or used by the compressor.

To use the tool, first select the active state point representing the start of the expansion or compression path. Next, select 'Expand/Compress' from the 'Tools' menu or click the turbine icon on the toolbar, which will open the Expansion/Compression tool dialog box.

In the tool dialog box, select the conditions you will use to compute the end point from the combo box near the top of the screen. Select "Pressure & Efficiency" if you know the pressure and efficiency. If you are checking an actual machine you will need to know the exiting gas temperature or enthalpy. Check either the "Pressure, Enthalpy" or "Pressure, Temperature" buttons as required. The two variables you have chosen will have their value fields enabled; all others will be grayed. Enter the appropriate values and click the 'Compute' button.

The “Gas Flow In” column displays the state point properties entering the equipment, which were copied from the active point. The “Total Flow Out” box has three columns that display the state point properties at the end of the expansion. The first column identifies the thermodynamic properties for the moist gas mixture and liquid water (if any) exiting the equipment. The second column displays the thermodynamic properties for the moist gas exiting and the third column shows the properties for the liquid water if any condensation occurs. The units displayed are those currently in use on *DeskTop Gas*’ main window. If you wish to use different units, you should select those units on the main window before opening the expansion tool.

Below the state point properties, you will find the shaft power based on the entering gas flow rate that you entered. The units for these results will be consistent with your input units.

You may change any of the data and repeat the calculation as required. When you are satisfied with the result, you may copy that state point back to the active point on *DeskTop Gas*’ main window by pressing the 'Close and Copy to Current Point' button. Note that the values of moist gas in the second column will be copied back to the active point. If no condensation has occurred, these values will be the same as in the first column labeled mixture. If condensation has occurred, then the values in the second column will be at saturated conditions.

If you do not wish to replace the current point on the main window with the expansion end point calculated, just press the 'Cancel' button.

3.10.2 Heating/Cooling Tool

The Heating/Cooling tool is used to analyze a gas stream in which heat is either added or removed. If you know the quantity of heat that is being added to or removed from the air stream, you can use the tool to calculate the resulting state point temperature and other conditions. If you know the temperature or enthalpy of the gas leaving the heating or cooling device, you can use the tool to calculate the quantity of heat exchanged.

To use the tool, first make sure that the active state point represents the conditions of the air entering the heating or cooling device. Next, select 'Heat/Cool' from the 'Tools' menu or click the flame icon on the toolbar, which will open the Heating/Cooling tool dialog box.

In the tool dialog box, select the conditions you will use to compute the end point from the combo box near the top of the screen. Select “Pressure, Heat Flow” if you know the pressure and heat added or removed. If you are measuring performance on an existing device you will need to know the exiting gas temperature or enthalpy. Check either of the “Pressure, Enthalpy” or “Pressure, Temperature” buttons as required. The two variables you have chosen will have their value fields enabled; all others will be grayed. Enter the appropriate values and click the 'Compute' button.

The “Gas Flow In” column displays the state point properties entering the equipment, which were copied from the Active Point in the main screen window. The “Total Flow Out” box has three columns that display the state point properties at the end of the expansion. The first column identifies the thermodynamic properties for the mixture of moist gas and liquid water exiting the equipment. The second column displays the thermodynamic properties for the moist gas exiting and the third column shows the properties for the liquid water if any condensation occurs. The units displayed are those currently in use on *DeskTop Gas*’s main

window. If you wish to use different units, you should select those units on the main window before opening the Heating/Cooling tool.

Below the state point properties, you will find the heat added based on the entering gas flow rate that you entered. The units for these results will be consistent with your input units.

You may change any of the data and repeat the calculation as required. When you are satisfied with the result, you may copy that state point back to the Active Point on *DeskTop Gas*' main window by pressing the 'Close and Copy to Current Point' button. Note that the values for moist gas in the second column will be copied back to the active point. If no condensation has occurred, these values will be the same as in the first column labeled mixture. If condensation has occurred, then the values in the second column will be at saturated conditions.

If you do not wish to replace the Active Point on the main window with the heating/cooling state point calculated, just press the 'Cancel' button.

3.10.3 Exchanging Data with Other Programs

DeskTop Gas includes two ways to share data with other applications running on your PC such as Excel. Both methods use the Windows clipboard.

In the first data sharing method, *DeskTop Gas*' 'Edit / Copy' command copies whatever text is highlighted in an IO Box (e.g., a number or part of a number) to the Windows clipboard. From there, that text can be pasted into other applications running on your PC. This is typically done using those applications' 'Edit / Paste' command).

The second data sharing method also places text on the clipboard but uses an extended format that is especially useful for calculations involving gas properties. This method is accessed using the 'Copy Point' command on the 'Edit' menu. Regardless of whether any text is selected, this command copies a *table* of text values to the clipboard using either the Active Point or all of the stored points. The table includes one column for each point. You can optionally direct *DeskTop Gas* to also include property and unit labels in which case they appear as the first column in the table. The table includes one row for each property in the same order as they are displayed on *DeskTop Gas*' main window. All values are copied to the clipboard using the same format displayed on the screen. So, if you need more accuracy in your Excel calculations, set the *DeskTop Gas* display accuracy accordingly, before issuing the 'Copy Point' command.

3.11 GETTING HELP

The Help menu offers extensive on-line help for *DeskTop Gas*. The 'About' item in the Help menu presents the version and serial numbers of your copy of **@Gas**. If the program is running in its Demo mode, the number of days remaining on the Demo are displayed instead of a serial number.

3.12 ERROR MESSAGES

When input values are out of range or any other errors occur, a message box is displayed describing the error. The calculated fields will not be updated until the error condition is resolved.

3.13 EXITING DESKTOP GAS

You may exit *DeskTop Gas* by using any of the standard methods for closing Windows applications. These include the following:

- Click the upper left corner of its program window and select close from the menu.
- Select Exit from the File menu.
- Press Alt + F4 keys.
- Click the “X” button in the upper right corner of the program window.

4 THEORETICAL BASIS OF @GAS FUNCTIONS

It is commonly accepted that virial equations of state work well for gases. In @Gas, the P-V-T behavior of a gas mixture is described by a third order virial equation of state:

$$\frac{pv}{RT} = 1 + \frac{B_m}{v} + \frac{C_m}{v^2} + \dots$$

where,

p = Total pressure

T = Absolute Thermodynamic Temperature

v = Total volume of gas

R = Universal Gas Constant

B_m = second order virial coefficient of the mixture

C_m = third order virial coefficient of the mixture

For the ranges of pressure and temperature used in these functions, coefficients higher than third order can be ignored. It is important to note that B_m and C_m are functions only of temperature.

Over the range of temperatures and pressures covered by these functions, all of the gases except water exist only in the gaseous state. (Actually, CO₂ can exist in a liquid state at the high end of the pressure range and the low end of the temperature range but this state is not considered because it would only occur in a mixture that is almost pure CO₂.) At temperatures where the saturation pressure of pure water is greater than the total gas pressure, the mole fraction of water vapor can range from 0 to 1. That is, there is no limit to the percentage of water vapor in the gas mixture in that situation. Elsewhere, the mole fraction of water vapor can range from 0 to a limiting, saturated, value x_{eq} , which is reached when the condensed phase of water is in thermodynamic equilibrium with the gas solution. This equilibrium fraction is equivalent to the solubility of the condensed water in the solvent gas mixture. In order to facilitate calculation of x_{eq} it is convenient to group the virial coefficients of the non-water gases so that the mixture can be treated as a binary mixture between the non-water gases and water vapor.

The virial coefficients of the gas mixture can be expressed as:

$$B_m = x_g^2 B_{gg} + 2x_g x_w B_{gw} + x_w^2 B_{ww}$$

and

$$C_m = x_g^3 C_{ggg} + 3x_g^2 x_w C_{ggw} + 3x_g x_w^2 C_{gww} + x_w^3 C_{www}$$

where,

x_g = mole fraction of the non-water gases in mixture

x_w = mole fraction of water vapor in the mixture

B_{gg}, C_{ggg} = virial coefficients of the non-water gases

B_{ww}, C_{www} = virial coefficients of water vapor

B_{gw}, C_{ggw}, C_{gww} = cross virial coefficients

Since the sum of the mole fractions of the mixture must equal 1, the value x_g is equal to $1 - x_w$. The second virial coefficient of the non-water gases can be expressed as:

$$B_{gg} = \left[\begin{array}{l} B_{NN}x_N^2 + B_{OO}x_O^2 + B_{AA}x_A^2 + B_{CC}x_C^2 + \\ 2 \left(B_{NO}x_Nx_O + B_{NA}x_Nx_A + B_{NC}x_Nx_C + \right) \\ \left(B_{OA}x_Ox_A + B_{OC}x_Ox_C + B_{AC}x_Ax_C \right) \end{array} \right] / (1 - x_w)^2$$

and the second cross virial coefficient of the mixture can be expressed as:

$$B_{gw} = \left[B_{NW}x_N + B_{OW}x_O + B_{AW}x_A + B_{CW}x_C \right] / (1 - x_w)$$

Similarly, the third virial coefficients can be expressed as:

$$C_{ggg} = \left[\begin{array}{l} C_{NNN}x_N^3 + C_{OOO}x_O^3 + C_{AAA}x_A^3 + C_{CCC}x_C^3 + \\ \left(C_{NNO}x_O + C_{NNA}x_A + C_{NNC}x_C \right) x_N^2 + \\ \left(C_{OON}x_N + C_{OOA}x_A + C_{OOC}x_C \right) x_O^2 + \\ \left(C_{CCN}x_N + C_{CCO}x_O + C_{CCA}x_C \right) x_C^2 + \\ \left(C_{AAN}x_N + C_{AAO}x_O + C_{AAC}x_C \right) x_A^2 \\ 2 \left(C_{NOA}x_Nx_Ox_A + C_{NOC}x_Nx_Ox_C + \right) \\ \left(C_{NAC}x_Nx_Ax_C + C_{OAC}x_Ox_Ax_C \right) \end{array} \right] / (1 - x_w)^3$$

and

$$C_{ggw} = \left[\begin{array}{l} C_{NNW}x_N^2 + C_{OOW}x_O^2 + C_{AAW}x_A^2 + C_{CCW}x_C^2 + \\ 2 \left(C_{NOW}x_Nx_O + C_{NAW}x_Nx_A + C_{NCW}x_Nx_C + \right) \\ \left(C_{OAW}x_Ox_A + C_{OCW}x_Ox_C + C_{ACW}x_Ax_C \right) \end{array} \right] / (1 - x_w)^2$$

and

$$C_{gww} = \left[C_{NWW}x_N + C_{OWW}x_O + C_{AWW}x_A + C_{CWW}x_C \right] / (1 - x_w)$$

where the subscripts N, O, A and C refer to N₂, O₂, Ar and CO₂ respectively.

Assuming that the condensed phase is pure water, the value of x_{eq} can be found by equating the chemical potential of pure condensed water with the chemical potential of its vapor in the

gas solution. Since the equations describing chemical potentials are non-linear and difficult to analyze, phase equilibrium is often described in terms of a thermodynamic function called fugacity. The equality of chemical potentials can be replaced by equating the logarithms of the fugacity of pure condensed water with that of its vapor in the gas mixture solution. The equation of solubility based on this concept is derived by Rabinovich [3] and can be expressed as follows:

$$\ln \frac{x_{eq} P}{p_{ws}} = \ln \frac{z(p, T, x_{eq})}{z_w(p_{ws}, T)} + \frac{1}{RT} \int_{p_{ws}}^p v_{wcond} dp + \frac{2B_{ww}}{v_w''} + \frac{3C_{www}}{2(v_w'')^2} - \frac{2}{v} \left(B_{gw} + (B_{ww} - B_{gw}) x_{eq}^2 \right) - \frac{3}{2v^2} \left(C_{ggw} + 2(C_{gww} - C_{ggw}) x_{eq} + (C_{ggw} - 2C_{gww} + C_{www}) x_{eq}^2 \right)$$

where,

$$z = 1 + \frac{B}{v} + \frac{C}{v^2}, \text{ the compressibility of the gas mixture or the water vapor as required.}$$

p_{ws} = saturation pressure of water vapor at temperature T.

v_{wcond} = the volume of the condensed water.

The solubility equation can be solved for x_{eq} by iteration. For an ideal solution, $x_{eqideal}$ is equal to the ratio of the vapor pressure of the pure water, to the total pressure of the mixture. The ratio of $x_{eq} / x_{eqideal}$ is called the enhancement factor or excess solubility and has a value greater than 1. The value of x_{eq} is used to find the dew point temperature of a gas mixture, to determine the amount of condensation that occurs in a cooling process and to verify that the value of x input by the user does not exceed x_{eq} .

The thermodynamic properties (enthalpy, entropy and specific heat at constant pressure) can be determined from knowledge of the properties in the ideal gas state and the virial coefficients.

The molar enthalpy of a moist gas mixture, h_m , can be described by the equation:

$$h_m = x_N (h_N^o + h_N') + x_O (h_O^o + h_O') + x_A (h_A^o + h_A') + x_C (h_C^o + h_C') + x_W (h_W^o + h_W') + \frac{RT}{v} \left[\left(B_m - T \frac{\partial B_m}{\partial T} \right) + \left(C_m - \frac{1}{2} T \frac{\partial C_m}{\partial T} \right) \frac{1}{v} \right]$$

where,

h_i^o = ideal gas molar enthalpy for gas i

h_i' = constant to adjust reference state for gas i

The molar entropy of the moist gas mixture s_m can be described by the equation:

$$s_m = x_N(s_N^o + s'_N) + x_O(s_O^o + s'_O) + x_A(s_A^o + s'_A) + x_C(s_C^o + s'_C)x_W + (s_W^o + s'_W) - R \ln p + x_N R \ln \left(\frac{pv}{x_N RT} \right) + x_O R \ln \left(\frac{pv}{x_O RT} \right) + x_C R \ln \left(\frac{pv}{x_C RT} \right) + x_W R \ln \left(\frac{P\bar{v}}{x_W RT} \right) - \frac{R}{v} \left(B_m - T \frac{\partial B_m}{\partial T} \right) - \frac{R}{2v^2} \left(C_m - T \frac{\partial C_m}{\partial T} \right)$$

where,

s_i^o = ideal gas molar entropy for gas i

s'_i = constant to adjust reference state for gas i

The molar specific heat at constant pressure of a moist gas mixture, c_m , can be described by the equation:

$$c_m = c_N^o x_N + c_O^o x_O + c_A^o x_A + c_C^o x_C + c_W^o x_W - R - \frac{RT}{v} \left(2 \frac{\partial B_m}{\partial T} + T \frac{\partial^2 B_m}{\partial T^2} \right) - \frac{RT}{2v^2} \left(2 \frac{\partial C_m}{\partial T} + T \frac{\partial^2 C_m}{\partial T^2} \right) + \frac{R \left(1 + \frac{B_m}{v} + \frac{C_m}{v^2} + \frac{T}{v} \frac{\partial B_m}{\partial T} + \frac{T}{v} \frac{\partial C_m}{\partial T} \right)}{1 + \frac{2B_m}{v} + \frac{3C_m}{v^2}}$$

where,

c_i^o = ideal gas molar specific heat at constant pressure for gas i.

4.1 GAS PROPERTY DATABASE

In order to use the equations presented in the previous section to calculate the thermodynamic properties, it is necessary to know the B and C virial coefficients of each of the pure gas components and the mixed virial coefficients for all mixture combinations. In addition, the ideal gas enthalpies, entropies and specific heats are required for each gas component. Tables of compressibility data for the pure gases and the ideal gas enthalpies, entropies and specific heats are provided in reference [1]. B and C virial coefficients for the pure gases were obtained by using a least square fit of the compressibility function to isotherms at 10 degree increments from 180 °K to 800 °K and at 50 degree increments from 800 °K to 2000 °K.

Mixed virial coefficients were calculated from molecular theory using the Leonard-Jones (6-12) potential model. The following equations were used to calculate the virial coefficients based on the model:

$$B_{ij}(T) = (2\pi N_A / 3) \sigma_{ij}^3 B_{LJ}^*(T^*)$$

$$C_{ij}(T) = (2\pi N_A / 3)^2 \sigma_{ij}^6 C_{LJ}^*(T^*)$$

$$C_{ij}(T) = (2\pi N_A / 3)^2 \sigma_{ij}^6 C_{Lj}^*(T^*)$$

where $N_A = 6.02205E^{23}$ per mole (Avogadro's number)

$$T^* = kT / \varepsilon_{ij} \text{ or } T^* = kT / \varepsilon_{ij} \text{ or } T^* = kT / \varepsilon_{ij}$$

$$k = 1.3807E^{-23} \text{ J/K (Boltzmann constant)}$$

The equations and constants for calculating B_{Lj}^* and C_{Lj}^* are found in Hirshfelder, Curtis and Bird [4]. Values of potential parameters σ and ε/k for the pure gases were obtained by minimizing the errors in predicting the compressibility factors of the pure gases using the Leonard-Jones (6-12) potential. Mixed potential parameters were obtained by means of the following semi-empirical mixing rules:

$$\sigma_{12} = 0.5(\sigma_{11} + \sigma_{22})\xi^{-1/6}$$

$$(\varepsilon/k)_{12} = \sqrt{(\varepsilon/k)_{11}(\varepsilon/k)_{22}} / \xi^2$$

$$\sigma_{112} = \sqrt[3]{\sigma_{11}\sigma_{12}^2}$$

$$\sigma_{122} = \sqrt[3]{\sigma_{22}\sigma_{12}^2}$$

$$(\varepsilon/k)_{112} = \sqrt[3]{(\varepsilon/k)_{11}(\varepsilon/k)_{12}^2}$$

$$(\varepsilon/k)_{122} = \sqrt[3]{(\varepsilon/k)_{22}(\varepsilon/k)_{12}^2}$$

where

$$\xi = 1 + 0.892(3a_{11}t_{22}^* \sqrt{\varepsilon_{11} / \varepsilon_{22}} / 2\pi N_A \sigma_{11}^3) \text{ when gas 1 is non-water and gas 2 is water}$$

or

$$\xi = 1.0 \text{ when both gases are non-water}$$

and

a_{11} = polarizability of the apolar molecules

$$t^* = 8^{-0.5} \mu / \varepsilon \sigma^3$$

μ = dipole moment of the molecule

Some of the mixed potential parameters between N_2 , Ar and CO_2 with water were determined by Rabinovich [3] based on experimental data on the equilibrium fractional content of water vapor in the solvent gas. Where available, these mixed potential parameters were used instead of the ones derived from the mixing rules.

Based on the methods described, a database was developed containing all of the pure gas and mixed virial coefficients for the five gases at 10 degree increments from 180 °K to 800 °K and at 50 degree increments between 800 °K and 2000 °K. A similar database was developed for the ideal gas enthalpies, entropies and specific heats.

4.2 COMPUTATIONAL MODEL

With most of the functions, the mixture's pressure and temperature are known. Since the virial coefficients are functions only of temperature, the database is used to calculate mixed coefficients B_{gg} , B_{gw} , B_{ww} , C_{ggg} , C_{ggw} , C_{gww} and C_{www} based on the formulas identified above at four temperatures surrounding the desired temperature. Four point non-linear interpolation is used to calculate the mixed coefficients and their derivatives at the desired temperature.

Since most of the properties require knowledge of the specific volume of the mixture, the virial equation of state is used iteratively to calculate the specific volume. In cases where the temperature of the mixture is not known, iterative procedures are used to determine the temperature as well.

4.3 TRANSPORT PROPERTIES

Values for viscosity and thermal conductivity of individual gases at atmospheric pressure can be found in many references although there does not appear to be any definitive standard of accepted values as there are for steam and water. We found the most complete coverage by Vasserman, Kazavchinskii, and Rabinovich [2] who have surveyed the available literature and presented tables of values over a range of temperatures and pressures. We have used their tabular values of viscosity and thermal conductivity as the basis of our database for Nitrogen, Oxygen, Argon and Carbon Dioxide.

We have used the equations recommended by ASME [6] to compute the viscosity and thermal conductivity properties for water vapor. These are the same equations used in our WinSteam product.

There is little information available regarding the viscosity and conductivity of moist gases. In most practical cases, the relatively small quantity of water vapor in gas mixtures has a small effect on the overall transport properties, unlike the thermodynamic properties, which are greatly affected by moisture. Nonetheless, we have selected a method to account for the effects of moisture on viscosity based on kinetic theory as presented by Hirshfelder, Curtis and Bird [4].

4.3.1 Viscosity

We treat the gas as a binary mixture between the non-polar gases (N_2 , O_2 , Ar and CO_2) and water vapor. For the non-polar gases, the viscosity of the mixture can be calculated as follows:

$$\eta_g = \begin{array}{c} \left| \begin{array}{ccccc} H_{11} & H_{12} & H_{13} & H_{14} & x_1 \\ H_{12} & H_{22} & H_{23} & H_{24} & x_2 \\ H_{13} & H_{23} & H_{33} & H_{34} & x_3 \\ H_{14} & H_{24} & H_{34} & H_{44} & x_4 \\ x_1 & x_2 & x_3 & x_4 & 0 \end{array} \right| \\ \left| \begin{array}{cccc} H_{11} & H_{12} & H_{13} & H_{14} \\ H_{12} & H_{22} & H_{23} & H_{24} \\ H_{13} & H_{23} & H_{33} & H_{34} \\ H_{14} & H_{24} & H_{34} & H_{44} \end{array} \right| \end{array} \text{ where}$$

$$H_{ii} = \frac{x_i^2}{\eta_i} + \sum_{\substack{k=1 \\ k \neq i}}^4 \frac{2x_i x_k}{\eta_{ik}} \frac{M_i M_k}{(M_i + M_k)^2} \left[\frac{5}{3A_{ik}^*} \frac{M_k}{M_i} \right] \text{ and}$$

$$H_{ij} = -\frac{2x_i x_j}{\eta_{ij}} \frac{M_i M_j}{(M_i + M_j)^2} \left[\frac{5}{3A_{ij}^*} - 1 \right]$$

where,

η_i = coefficient of viscosity of pure gas component i

$$\eta_{ij} = 266.93 * 10^{-7} \frac{\sqrt{2M_i M_j T / (M_i + M_j)}}{\sigma_{ij}^2 \Omega_{ij}^{(2,2)*}(T_{ij}^*)}$$

$$T_{ij}^* = kT / \varepsilon_{ij} \quad \text{reduced temperature}$$

$\sigma_{ij}, \varepsilon_{ij} / T$ = parameters in the potential function characteristic of 1-2 interaction

x_i = mole fraction of component i

M_i = molecular weight of component i

$$A^* = \Omega^{(2,2)*} / \Omega^{(1,1)*}$$

$\Omega^{(i,i)*}$ = integrals for calculating the transport coefficients for the Leonard-Jones (6-12) potential

Once we have the viscosity of the non-polar gas mixture, we can use the equations for a polar/non-polar mixture. The equation for viscosity of a binary mixture is as follows:

$$1/\eta = \frac{X_\eta + Y_\eta}{1 + Z_\eta}$$

where

η = viscosity of the mixture

$$X_\eta = \frac{x_g^2}{\eta_g} + \frac{2x_g x_w}{\eta_{gw}} + \frac{x_w^2}{\eta_w}$$

$$Y_\eta = \frac{3}{5} A_{12}^* \left[\frac{x_g^2}{\eta_g} \left(\frac{M_g}{M_w} \right) + \frac{2x_g x_w}{\eta_g} \left(\frac{(M_g + M_w)^2}{4M_g M_w} \right) \left(\frac{\eta_{gw}^2}{\eta_g \eta_w} \right) + \frac{x_w^2}{\eta_w} \left(\frac{M_w}{M_g} \right) \right]$$

$$Z_\eta = \frac{3}{5} A_{12}^* \left[x_g^2 \left(\frac{M_g}{M_w} \right) + 2x_g x_w \left[\left(\frac{(M_g + M_w)^2}{4M_g M_w} \right) \left(\frac{\eta_{gw}}{\eta_g} + \frac{\eta_{gw}}{\eta_w} - 1 \right) \right] + x_w^2 \left(\frac{M_w}{M_g} \right) \right]$$

η_g = viscosity of dry gas mixture at the specified temperature

η_w = viscosity of water vapor at the specified temperature

$$\eta_{gw} = C_1 \frac{\sqrt{2M_g M_w T / (M_g + M_w)}}{\sigma_{gw}^2 \Omega_{12}^{(2,2)*}(T_{gw}^*)} \quad \text{and } C_1 = 266.93E-7$$

σ_{gw} = potential function parameter for mixture adjusted for one polar molecule

M_g = weighted average molecular mass of the dry gas mixture

To correct for pressure, we use the method of Chung et al. as described in Reid, Prausnitz and Poling [9]

4.3.2 Thermal Conductivity

In a similar manner, to calculate thermal conductivity we treat the gas as a binary mixture of the non-polar gases and water vapor.

For the non-polar gas mixture, we use the Wassiljewa equation with the Mason and Saxena modification described by Reid, Prausnitz and Poling [9].

$$\lambda_g = \frac{\sum_{i=1}^4 x_i \lambda_i}{\sum_{j=1}^4 x_j A_{ij}} \quad \text{where}$$

λ_g = thermal conductivity of the gas mixture

λ_i = thermal conductivity of component i

x_i, x_j = mole fraction of components i and j

$$A_{ii} = 1.0$$

$$A_{ij} = \frac{\varepsilon [1 + (\lambda_{tri} / \lambda_{tj})^{1/2} (M_i / M_j)^{1/4}]^2}{[8(1 + M_i / M_j)]^{1/2}}$$

ε = value that varies from 0.9 to 1.05 as a function of temperature

$$\lambda_{tri} / \lambda_{tj} = \frac{\Gamma_j [\exp(0.0464T_{ri}) - \exp(-0.2412T_{ri})]}{\Gamma_i [\exp(0.0464T_{rj}) - \exp(-0.2412T_{rj})]}$$

$$\Gamma = 210 \left(\frac{T_c M^3}{P_c^4} \right)^{1/6}$$

T_c, P_c = critical temperature and pressure

The equation for thermal conductivity of the moist gases is as follows:

$$1/\lambda = \frac{X_\lambda + Y_\lambda}{1 + Z_\lambda}$$

where,

λ = thermal conductivity of the mixture

$$X_\lambda = \frac{x_g^2}{\lambda_g} + \frac{2x_g x_w}{\lambda_{gw}} + \frac{x_w^2}{\lambda_w}$$

$$Y_\lambda = \frac{x_g^2}{\lambda_g} U^{(1)} + \frac{2x_g x_w}{\lambda_{gw}} U^{(y)} + \frac{x_w^2}{\lambda_w} U^{(2)}$$

$$Z_\lambda = x_g^2 U^{(1)} + 2x_g x_w U^{(y)} + x_w^2 U^{(2)}$$

$$U^{(1)} = \frac{4}{15} A_{12}^* - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right) \frac{M_g}{M_w} + \frac{1}{2} \frac{(M_g - M_w)^2}{M_g M_w}$$

$$U^{(2)} = \frac{4}{15} A_{12}^* - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right) \frac{M_w}{M_g} + \frac{1}{2} \frac{(M_w - M_g)^2}{M_g M_w}$$

$$U^{(Y)} = \frac{4}{15} A_{12}^* \left(\frac{(M_g + M_w)^2}{4M_g M_w} \right) \frac{\lambda_{gw}^2}{\lambda_g \lambda_w} \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right) - \frac{5}{32 A_{12}^*} \left(\frac{12}{5} B_{12}^* - 5 \right) \frac{(M_g - M_w)^2}{M_g M_w}$$

$$U^{(Z)} = \frac{4}{15} A_{12}^* \left[\left(\frac{(M_g + M_w)^2}{4M_g M_w} \right) \left(\frac{\lambda_{gw}}{\lambda_g} + \frac{\lambda_{gw}}{\lambda_w} \right) - 1 \right] - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right)$$

λ_g = Thermal conductivity of dry gas mixture at the specified temperature

λ_w = Thermal conductivity of water vapor at the specified temperature

$$\lambda_{gw} = C_2 \frac{\sqrt{T(M_g + M_w)/2M_g M_w}}{\sigma_{gw}^2 \Omega_{12}^{(2,2)*}(T_{gw}^*)} \text{ and } C_2 = 1989.1E-7$$

B_{12}^* = function of reduced temperature

To correct for pressure, we use the Stiel and Thodos modification as described in Reid, Prausnitz and Poling [9].

5 SPEED AND ACCURACY

5.1 SPEED OF CALCULATIONS

This section addresses the @Gas calculation speed as measured within Microsoft Excel. Performance within other applications is similar.

The time required to recalculate a spreadsheet is a function of many features of the computer system hardware and the nature of the spreadsheet. Since the supported spreadsheets use double precision math exclusively, calculation time is sensitive to the number and complexity of numerical equations used.

The time required to perform the calculations also varies depending on the specific functions. Some calculations are more complex than others. Some require iterations. The simplest functions run the fastest while those that are more complex and require iterations run slower. The table below lists times required to calculate some typical @Gas functions from Microsoft Excel.

Function	Calculation Time
GasPVXT	0.0002
GasPTXV	0.0002
GasPTXH	0.0002
GasPHXT	0.0003

Typical calculation times in seconds per calculation.
A calculation returns one property at one state point.

These times were measured on a computer using a 1.8 GHz Pentium IV processor. Calculation times will vary depending on your particular computer.

Note that the recalculation options selected will also affect perceived calculation time.

5.2 ACCURACY OF CALCULATIONS

Thermodynamic properties for the pure gases calculated by @Gas have been checked against the values published by NBS [1] and ASME [6] for water vapor. As shown on Tables 1 through 20, the calculated values show excellent agreement with the source data throughout most of the valid range. Some small differences can be observed at low temperatures and high pressures. This is due to the limitations of using a third order virial equation of state.

There is little published data on the properties of mixed gases. One method to illustrate the accuracy of the mixing equations is to compare the results of **@Gas** to data for dry air, which is a mixture of Nitrogen, Oxygen, Argon and a small amount of Carbon Dioxide. Tables 21 through 24 show the comparison with air for the thermodynamic properties.

As with the pure components, small errors can be observed at low temperatures and high pressures due to the limitations of the model. The tables show some differences in enthalpy, entropy and specific heat occurring at 850 °K and growing with temperature. This initially, was thought to be attributed to dissociation, but this was dismissed for two reasons. First, dissociation effects were not included below 1500 °K in reference 1. Second, the error is much greater than what can be attributed to dissociation above 1500 °K.

Further examination of the data tables suggests that the tables in reference 1 are in error. One would expect the thermodynamic properties to approach the ideal gas properties as the pressure is reduced to zero. While this is the case for temperatures up to 800 °K, it is not the case above 800 °K. Curiously, at 800 °K, the tables in reference 1 change from a temperature increment of 10 °K to 50 °K at the point where the error begins. Perhaps this change of temperature increment was not handled properly.

Comparison of data from Vasserman et al [2] in the temperature range from 850 °K to 1300 °K supports the conclusion that the tables from NBS [1] are in error. Unfortunately, the tables from Vasserman et al [2] do not contain data for temperatures above 1300 °K.

Thermodynamic properties for moist air are presented by ASHRAE [10] at atmospheric pressure for temperatures up to 200 deg C. The ASHRAE data is based on work done by Hyland and Wexler [8], who provide tables of calculated data at pressures up to 50 bar. Comparisons with this data are shown on Tables 29 through 40.

Data for Viscosity and Thermal Conductivity is taken from Vasserman et al [2] for the pure gases except for water vapor which is taken from ASME [6]. Tables 41 and 42 show excellent agreement with this data. As with the thermodynamic properties, the accuracy of the mixing equations for the transport properties are illustrated by comparison with dry air. These comparisons are shown in Table 43. The mixing equations for the transport properties are not as precise as those for the thermodynamic properties; however, in most cases the errors are less than 1%.

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 1 - COMPRESSIBILITY OF NITROGEN**

Temperature Range		Pressure							
From	To	0.01 atm		1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.000%	0.000%	0.001%	0.006%	0.006%	0.022%	0.056%	0.101%
260	300	0.000%	0.001%	0.001%	0.001%	0.005%	0.006%	0.011%	0.019%
310	350	0.000%	0.000%	0.000%	0.001%	0.004%	0.006%	0.016%	0.020%
360	400	0.000%	0.000%	0.000%	0.000%	0.001%	0.003%	0.005%	0.009%
410	500	0.000%	0.000%	0.000%	0.001%	0.001%	0.002%	0.005%	0.009%
510	600	0.000%	0.000%	0.000%	0.001%	0.001%	0.002%	0.007%	0.009%
610	700	0.000%	0.000%	0.000%	0.000%	0.001%	0.001%	0.003%	0.005%
710	800	0.000%	0.000%	0.000%	0.000%	0.001%	0.002%	0.002%	0.003%
850	1450	0.000%	0.000%	0.000%	0.001%	0.003%	0.006%	0.007%	0.012%
1500	2000	0.000%	0.000%	0.000%	0.000%	0.001%	0.002%	0.003%	0.006%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 2 - COMPRESSIBILITY OF OXYGEN**

Temperature Range		Pressure							
From	To	0.01 atm		1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.000%	0.000%	0.004%	0.012%	0.008%	0.034%	0.112%	0.199%
260	300	0.000%	0.000%	0.001%	0.001%	0.007%	0.008%	0.009%	0.021%
310	350	0.000%	0.000%	0.000%	0.000%	0.005%	0.006%	0.009%	0.010%
360	400	0.000%	0.000%	0.000%	0.000%	0.001%	0.002%	0.004%	0.006%
410	500	0.000%	0.000%	0.000%	0.001%	0.001%	0.002%	0.004%	0.006%
510	600	0.000%	0.000%	0.000%	0.001%	0.002%	0.002%	0.005%	0.006%
610	700	0.000%	0.000%	0.000%	0.001%	0.001%	0.001%	0.001%	0.003%
710	800	0.000%	0.000%	0.000%	0.000%	0.000%	0.001%	0.002%	0.004%
850	1450	0.000%	0.000%	0.000%	0.001%	0.001%	0.002%	0.006%	0.008%
1500	2000	0.000%	0.000%	0.000%	0.001%	0.001%	0.002%	0.002%	0.005%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 3 - COMPRESSIBILITY OF ARGON**

Temperature Range		Pressure							
From	To	0.01 atm		1 atm		10 atm		40 atm	
deg K	Deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.000%	0.001%	0.001%	0.002%	0.004%	0.007%	0.071%	0.213%
260	300	0.000%	0.000%	0.001%	0.001%	0.006%	0.007%	0.020%	0.030%
310	350	0.000%	0.001%	0.001%	0.001%	0.003%	0.005%	0.014%	0.020%
360	400	0.000%	0.000%	0.000%	0.001%	0.001%	0.002%	0.004%	0.012%
410	500	0.000%	0.000%	0.000%	0.000%	0.001%	0.003%	0.008%	0.012%
510	600	0.000%	0.000%	0.000%	0.001%	0.002%	0.002%	0.008%	0.013%
610	700	0.000%	0.000%	0.000%	0.001%	0.001%	0.002%	0.005%	0.010%
710	800	0.000%	0.000%	0.000%	0.001%	0.000%	0.001%	0.004%	0.007%
850	1450	0.000%	0.000%	0.000%	0.001%	0.001%	0.002%	0.006%	0.011%
1500	2000	0.000%	0.000%	0.000%	0.000%	0.001%	0.002%	0.002%	0.006%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 4 - COMPRESSIBILITY OF CARBON DIOXIDE**

Temperature Range		Pressure							
From	To	0.01 atm		1 atm		10 atm		40 atm	
deg K	Deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
200	250	0.001%	0.001%	NA	NA	NA	NA	NA	NA
260	300	0.000%	0.001%	0.004%	0.005%	NA	NA	NA	NA
310	350	0.000%	0.001%	0.003%	0.003%	NA	NA	NA	NA
360	400	0.000%	0.001%	0.001%	0.002%	NA	NA	NA	NA
410	500	0.000%	0.001%	0.001%	0.001%	NA	NA	NA	NA
510	600	0.001%	0.001%	0.001%	0.001%	NA	NA	NA	NA
610	700	0.001%	0.001%	0.001%	0.001%	NA	NA	NA	NA
710	800	0.000%	0.000%	0.000%	0.001%	NA	NA	NA	NA
850	1450	0.000%	0.000%	0.005%	0.008%	NA	NA	NA	NA
1500	2000	0.000%	0.000%	0.005%	0.006%	0.011%	0.028%	NA	NA

*NA indicates that CO₂ is not in vapor state in this range.

**COMPARISON OF RESULTS WITH ASME [6] DATA
TABLE 5 - COMPRESSIBILITY OF WATER VAPOR**

Temperature Range		Pressure							
From	To	0.01 atm		1 atm		10 atm		40 atm	
deg K	Deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
290	350	0.001%	0.002%	NA	NA	NA	NA	NA	NA
360	400	0.002%	0.002%	NA	NA	NA	NA	NA	NA
410	500	0.002%	0.002%	0.002%	0.003%	NA	NA	NA	NA
510	600	0.002%	0.002%	0.003%	0.003%	0.003%	0.003%	NA	NA
610	700	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%	0.005%
710	800	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%
850	1450	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%	0.004%
1500	2000	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%	0.002%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 6 - ENTHALPY OF NITROGEN**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.005%	0.022%	0.054%	0.221%	0.287%	1.235%
260	300	0.001%	0.002%	0.004%	0.009%	0.031%	0.074%
310	350	0.001%	0.001%	0.005%	0.006%	0.017%	0.024%
360	400	0.001%	0.001%	0.006%	0.006%	0.022%	0.025%
410	500	0.001%	0.001%	0.003%	0.005%	0.011%	0.019%
510	600	0.000%	0.001%	0.001%	0.005%	0.004%	0.007%
610	700	0.001%	0.001%	0.002%	0.005%	0.009%	0.009%
710	800	0.000%	0.001%	0.002%	0.002%	0.009%	0.010%
810	1450	0.000%	0.000%	0.001%	0.001%	0.004%	0.006%
1500	2000	0.000%	0.000%	0.002%	0.002%	0.008%	0.009%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 7 - ENTHALPY OF OXYGEN**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.005%	0.015%	0.041%	0.174%	0.287%	1.102%
260	300	0.002%	0.002%	0.005%	0.010%	0.028%	0.062%
310	350	0.001%	0.002%	0.009%	0.010%	0.018%	0.028%
360	400	0.001%	0.002%	0.006%	0.007%	0.025%	0.026%
410	500	0.001%	0.001%	0.003%	0.006%	0.010%	0.019%
510	600	0.000%	0.001%	0.001%	0.002%	0.006%	0.011%
610	700	0.000%	0.001%	0.002%	0.002%	0.007%	0.010%
710	800	0.000%	0.001%	0.002%	0.002%	0.006%	0.010%
810	1450	0.000%	0.001%	0.001%	0.001%	0.004%	0.007%
1500	2000	0.000%	0.000%	0.002%	0.002%	0.008%	0.009%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 8 - ENTHALPY OF ARGON**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.049%	0.376%	0.082%	0.529%	0.075%	0.199%
260	300	0.001%	0.002%	0.004%	0.007%	0.015%	0.032%
310	350	0.002%	0.002%	0.008%	0.011%	0.038%	0.056%
360	400	0.001%	0.002%	0.007%	0.010%	0.015%	0.033%
410	500	0.001%	0.001%	0.002%	0.005%	0.012%	0.027%
510	600	0.001%	0.001%	0.002%	0.003%	0.007%	0.015%
610	700	0.000%	0.001%	0.003%	0.003%	0.013%	0.022%
710	800	0.000%	0.001%	0.002%	0.003%	0.010%	0.018%
810	1450	0.000%	0.000%	0.002%	0.004%	0.004%	0.007%
1500	2000	0.000%	0.001%	0.002%	0.003%	0.012%	0.014%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 9 - ENTHALPY OF CARBON DIOXIDE**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	NA	NA	NA	NA	NA	NA
260	300	0.019%	0.030%	0.023%	0.057%	NA	NA
310	350	0.014%	0.021%	0.049%	0.064%	0.389%	0.864%
360	400	0.008%	0.011%	0.034%	0.041%	0.307%	0.436%
410	500	0.008%	0.011%	0.019%	0.027%	0.099%	0.153%
510	600	0.005%	0.009%	0.005%	0.010%	0.024%	0.064%
610	700	0.006%	0.011%	0.007%	0.012%	0.025%	0.035%
710	800	0.002%	0.003%	0.006%	0.012%	0.033%	0.037%
810	1450	0.002%	0.004%	0.003%	0.007%	0.012%	0.028%
1500	2000	**	**	**	**	**	**

** NBS data not available

**COMPARISON OF RESULTS WITH ASME [6] DATA
TABLE 10 - ENTHALPY OF WATER VAPOR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	290	NA	NA	NA	NA	NA	NA
290	370	NA	NA	NA	NA	NA	NA
380	450	0.013%	0.015%	NA	NA	NA	NA
460	530	0.017%	0.018%	0.013%	0.024%	NA	NA
540	600	0.021%	0.021%	0.026%	0.030%	0.006%	0.012%
610	700	0.022%	0.023%	0.022%	0.023%	0.021%	0.024%
710	800	0.026%	0.028%	0.026%	0.028%	0.026%	0.028%
850	1450	0.047%	0.064%	0.047%	0.064%	0.048%	0.064%
1500	2000	0.082%	0.093%	0.082%	0.093%	0.082	0.093%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 11 - ENTROPY OF NITROGEN**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.001%	0.003%	0.009%	0.037%	0.049%	0.208%
260	300	0.000%	0.000%	0.001%	0.002%	0.006%	0.011%
310	350	0.000%	0.000%	0.001%	0.001%	0.002%	0.003%
360	400	0.000%	0.000%	0.001%	0.001%	0.003%	0.004%
410	500	0.000%	0.000%	0.001%	0.001%	0.002%	0.003%
510	600	0.000%	0.000%	0.000%	0.000%	0.001%	0.001%
610	700	0.000%	0.000%	0.001%	0.001%	0.001%	0.002%
710	800	0.000%	0.000%	0.000%	0.001%	0.001%	0.002%
810	1450	0.000%	0.000%	0.000%	0.001%	0.001%	0.001%
1500	2000	0.000%	0.000%	0.000%	0.000%	0.001%	0.001%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 12 - ENTROPY OF OXYGEN**

Temperature Range		Pressure					
From	To	1	Atm	10	Atm	40	Atm
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.005%	0.015%	0.041%	0.174%	0.287%	0.102%
260	300	0.002%	0.002%	0.005%	0.010%	0.028%	0.062%
310	350	0.001%	0.002%	0.009%	0.010%	0.018%	0.028%
360	400	0.001%	0.002%	0.006%	0.007%	0.025%	0.026%
410	500	0.001%	0.001%	0.003%	0.006%	0.010%	0.019%
510	600	0.000%	0.001%	0.001%	0.002%	0.006%	0.011%
610	700	0.000%	0.001%	0.002%	0.002%	0.007%	0.010%
710	800	0.000%	0.001%	0.002%	0.002%	0.006%	0.010%
810	1450	0.000%	0.001%	0.001%	0.001%	0.004%	0.007%
1500	2000	0.000%	0.000%	0.002%	0.002%	0.003%	0.009%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 13 - ENTROPY OF ARGON**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.000%	0.001%	0.006%	0.022%	0.129%	1.102%
260	300	0.000%	0.000%	0.000%	0.001%	0.005%	0.062%
310	350	0.000%	0.000%	0.001%	0.001%	0.006%	0.028%
360	400	0.000%	0.000%	0.001%	0.001%	0.004%	0.026%
410	500	0.000%	0.000%	0.000%	0.001%	0.001%	0.019%
510	600	0.000%	0.000%	0.000%	0.001%	0.001%	0.011%
610	700	0.000%	0.001%	0.001%	0.001%	0.002%	0.010%
710	800	0.000%	0.000%	0.001%	0.001%	**	**
810	1450	0.000%	0.000%	0.000%	0.001%	**	**
1500	2000	0.000%	0.000%	0.000%	0.000%	**	**

** NBS data not available

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 14 - ENTROPY OF CARBON DIOXIDE**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	NA	NA	NA	NA	NA	NA
260	300	0.002%	0.003%	0.006%	0.014%	NA	NA
310	350	0.001%	0.003%	0.003%	0.005%	0.033%	0.086%
360	400	0.002%	0.006%	0.006%	0.007%	0.038%	0.050%
410	500	0.003%	0.004%	0.004%	0.006%	0.020%	0.025%
510	600	0.003%	0.002%	0.002%	0.004%	0.010%	0.016%
610	700	0.003%	0.001%	0.001%	0.003%	0.003%	0.006%
710	800	0.003%	0.001%	0.001%	0.003%	0.001%	0.002%
810	1450	0.002%	0.002%	0.002%	0.004%	0.003%	0.006%
1500	2000	**	**	**	**	**	**

** NBS data not available

**COMPARISON OF RESULTS WITH ASME [6] DATA
TABLE 15 – ENTROPY OF WATER VAPOR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	290	NA	NA	NA	NA	NA	NA
290	370	NA	NA	NA	NA	NA	NA
380	450	0.017%	0.020%	NA	NA	NA	NA
460	530	0.019%	0.020%	0.019%	0.030%	NA	NA
540	600	0.021%	0.022%	0.028%	0.030%	0.013%	0.020%
610	700	0.022%	0.022%	0.025%	0.025%	0.026%	0.028%
710	800	0.023%	0.024%	0.026%	0.027%	0.029%	0.030%
850	1450	0.033%	0.041%	0.037%	0.045%	0.040%	0.048%
1500	2000	0.048%	0.052%	0.053%	0.058%	0.056	0.061%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 16 – SPECIFIC HEAT OF NITROGEN**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.062%	0.182%	0.758%	2.899%	2.923%	9.543%
260	300	0.004%	0.005%	0.050%	0.057%	0.325%	0.368%
310	350	0.002%	0.003%	0.014%	0.029%	0.123%	0.206%
360	400	0.001%	0.002%	0.016%	0.022%	0.028%	0.053%
410	500	0.002%	0.003%	0.026%	0.027%	0.076%	0.084%
510	600	0.001%	0.003%	0.021%	0.024%	0.061%	0.076%
610	700	0.001%	0.002%	0.014%	0.017%	0.029%	0.041%
710	800	0.001%	0.001%	0.009%	0.011%	0.008%	0.015%
810	1450	0.001%	0.002%	0.004%	0.007%	0.013%	0.022%
1500	2000	0.001%	0.004%	0.006%	0.007%	0.005%	0.010%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 17 – SPECIFIC HEAT OF OXYGEN**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.043%	0.122%	0.466%	1.381%	2.495%	8.550%
260	300	0.001%	0.002%	0.047%	0.055%	0.326%	0.386%
310	350	0.001%	0.002%	0.011%	0.025%	0.111%	0.192%
360	400	0.002%	0.004%	0.014%	0.020%	0.023%	0.042%
410	500	0.002%	0.004%	0.020%	0.022%	0.062%	0.065%
510	600	0.001%	0.002%	0.012%	0.017%	0.044%	0.059%
610	700	0.001%	0.004%	0.004%	0.008%	0.015%	0.026%
710	800	0.001%	0.001%	0.001%	0.003%	0.004%	0.009%
810	1450	0.001%	0.001%	0.005%	0.008%	0.017%	0.029%
1500	2000	0.000%	0.001%	0.003%	0.004%	0.011%	0.016%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 18 – SPECIFIC HEAT OF ARGON**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.031%	0.093%	0.517%	1.643%	1.574%	4.829%
260	300	0.005%	0.007%	0.073%	0.096%	0.307%	0.575%
310	350	0.001%	0.003%	0.014%	0.029%	0.259%	0.437%
360	400	0.003%	0.004%	0.020%	0.026%	0.158%	0.355%
410	500	0.003%	0.005%	0.026%	0.028%	0.095%	0.261%
510	600	0.001%	0.003%	0.017%	0.022%	0.049%	0.068%
610	700	0.001%	0.002%	0.007%	0.012%	0.023%	0.047%
710	800	0.001%	0.002%	0.004%	0.008%	0.015%	0.022%
810	1450	0.001%	0.002%	0.008%	0.014%	0.043%	0.066%
1500	2000	0.001%	0.001%	0.001%	0.003%	0.023%	0.039%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 19 – SPECIFIC HEAT OF CARBON DIOXIDE**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	NA	NA	NA	NA	NA	NA
260	300	0.040%	0.052%	1.336%	4.255%	NA	NA
310	350	0.029%	0.097%	0.167%	0.229%	4.022%	9.111%
360	400	0.006%	0.008%	0.030%	0.052%	0.359%	0.849%
410	500	0.004%	0.007%	0.065%	0.078%	0.184%	0.286%
510	600	0.003%	0.007%	0.039%	0.051%	0.247%	0.328%
610	700	0.004%	0.007%	0.013%	0.023%	0.114%	0.178%
710	800	0.003%	0.007%	0.005%	0.017%	0.021%	0.043%
810	1450	0.006%	0.013%	0.009%	0.016%	0.072%	0.206%
1500	2000	**	**	**	**	**	**

** NBS data not available

**COMPARISON OF RESULTS WITH ASME [6] DATA
TABLE 20 – SPECIFIC HEAT OF WATER VAPOR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	290	NA	NA	NA	NA	NA	NA
290	370	NA	NA	NA	NA	NA	NA
380	450	0.102%	0.310%	NA	NA	NA	NA
460	530	0.080%	0.155%	0.334%	0.778%	NA	NA
540	600	0.065%	0.319%	0.414%	2.008%	0.731%	2.673%
610	700	0.065%	0.080%	0.045%	0.075%	0.146%	0.302%
710	800	0.093%	0.106%	0.093%	0.119%	0.087%	0.154%
850	1450	0.148%	0.197%	0.146%	0.276%	0.190%	0.693%
1500	2000	0.190%	0.218%	0.190%	0.217%	0.189%	0.216%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 21 - COMPRESSIBILITY OF DRY AIR**

Temperature Range		Pressure							
From	To	0.01 atm		1 atm		10 atm		40 atm	
Deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.001%	0.001%	0.001%	0.002%	0.018%	0.027%	0.124%	0.278%
260	300	0.001%	0.001%	0.000%	0.001%	0.004%	0.007%	0.010%	0.014%
310	350	0.001%	0.001%	0.000%	0.000%	0.002%	0.002%	0.010%	0.014%
360	400	0.001%	0.001%	0.000%	0.001%	0.002%	0.003%	0.002%	0.003%
410	500	0.001%	0.001%	0.000%	0.001%	0.002%	0.003%	0.009%	0.012%
510	600	0.001%	0.001%	0.001%	0.001%	0.001%	0.002%	0.011%	0.012%
610	700	0.001%	0.001%	0.001%	0.001%	0.000%	0.001%	0.007%	0.009%
710	800	0.001%	0.001%	0.001%	0.002%	0.001%	0.002%	0.003%	0.005%
810	1450	0.001%	0.001%	0.001%	0.002%	0.002%	0.003%	0.003%	0.005%
1500	2000	0.0038	0.167%	0.005%	0.017%	0.005%	0.007%	0.004%	0.011%

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 22 - ENTHALPY OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.004%	0.016%	0.031%	0.119%	0.125%	0.262%
260	300	0.001%	0.002%	0.004%	0.009%	0.037%	0.070%
310	350	0.001%	0.003%	0.005%	0.008%	0.007%	0.011%
360	400	0.002%	0.005%	0.008%	0.009%	0.006%	0.009%
410	500	0.001%	0.002%	0.005%	0.007%	0.005%	0.011%
510	600	0.001%	0.002%	0.001%	0.003%	0.005%	0.007%
610	700	0.001%	0.002%	0.001%	0.001%	0.007%	0.008%
710	800	0.001%	0.004%	0.002%	0.004%	0.007%	0.010%
810	1450	* 0.03%	* 0.10%	* 0.03%	* 0.09%	* 0.03%	* 0.10%
1500	2000	**	**	**	**	**	**

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 23 - ENTROPY OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.002%	0.003%	0.006%	0.022%	0.020%	0.052%
260	300	0.001%	0.002%	0.001%	0.002%	0.005%	0.006%
310	350	0.003%	0.004%	0.001%	0.002%	0.006%	0.008%
360	400	0.002%	0.004%	0.002%	0.004%	0.004%	0.007%
410	500	0.001%	0.004%	0.001%	0.003%	0.003%	0.005%
510	600	0.002%	0.004%	0.002%	0.004%	0.001%	0.003%
610	700	0.002%	0.003%	0.002%	0.004%	0.001%	0.002%
710	800	0.001%	0.003%	0.001%	0.003%	0.002%	0.003%
850	1450	0.005%	0.014%	0.003%	0.005%	0.005%	0.009%
1500	2000	**	**	**	**	**	**

**COMPARISON OF RESULTS WITH NBS [1] DATA
TABLE 24 - SPECIFIC HEAT OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.036%	0.098%	0.352%	1.026%	1.046%	3.162%
260	300	0.004%	0.005%	0.049%	0.061%	0.294%	0.382%
310	350	0.005%	0.007%	0.020%	0.034%	0.096%	0.170%
360	400	0.001%	0.002%	0.004%	0.007%	0.016%	0.033%
410	500	0.001%	0.003%	0.009%	0.012%	0.044%	0.056%
510	600	0.002%	0.003%	0.005%	0.010%	0.028%	0.038%
610	700	0.001%	0.003%	0.003%	0.007%	0.008%	0.022%
710	800	0.001%	0.002%	0.005%	0.024%	0.012%	0.038%
850	1450	* 0.47%	* 1.40%	* 0.48%	* 1.38%	* 0.50%	* 1.40%
1500	2000	**	**	**	**	**	**

Notes: *, ** - Questionable reference data

**COMPARISON OF RESULTS WITH HYLAND & WEXLER [8]
SATURATED HUMIDITY RATIO OF MOIST AIR
(kg of Water Vapor/kg of Dry Air)**

TABLE 2 - Pressure = 1 bar

Temp deg C	Hyland & Wexler	@Air	@Gas
0	0.00384	.00834	.00834
90	1.4833	1.4835	1.4833

TABLE 26 - Pressure = 5 bar

Temp deg C	Hyland & Wexler	@Air	@Gas
0	0.000775	0.000777	0.000777
90	0.10368	0.10375	0.10374
100	0.16201	0.16207	0.16205
150	13.041	12.989	12.989

TABLE 27 - Pressure = 10 bar

Temp deg C	Hyland & Wexler	@Air	@Gas
0	0.000394	0.000396	0.000396
90	0.04838	0.04844	0.04840
100	0.07251	0.07258	0.07257
150	0.5974	0.5069	0.5970
160	1.0718	1.0708	1.0709
170	2.5434	2.5400	2.5403

TABLE 28 - Pressure = 50 bar

Temp deg C	Hyland & Wexler	@Air	@Gas
0	9.09E-5	9.25E-5	9.27E-5
90	0.00985	0.00988	0.00989
100	0.01430	0.01434	0.01435
150	0.0736	0.0732	0.0733
160	0.0993	0.0986	0.0987
170	0.1336	0.1324	0.1325
180	0.1796	0.1778	0.1779
200	0.3306	0.3263	0.3263

**COMPARISON OF RESULTS WITH HYLAND & WEXLER [8]
SPECIFIC VOLUME OF SATURATED MOIST AIR
(m³/kg of Dry Air)**

TABLE 29 - Pressure = 1 bar

Temp	Hyland & Wexler		@Air		@Gas	
Deg C	Value	Uncert	Value	Error	Value	Error
0	0.78846	0.00010	0.78847	0.00001	0.78846	0.00000
90	3.4974	0.00029	3.4973	-0.0001	3.4976	0.0002

TABLE 30 - Pressure = 5 bar

Temp	Hyland & Wexler		@Air		@Gas	
Deg C	Value	Uncert	Value	Error	Value	Error
0	0.15657	0.00011	0.15657	0.00000	0.15657	0.00000
90	0.24273	0.00015	0.24270	-0.00003	0.24271	-0.00002
100	0.26904	0.00020	0.26902	-0.00002	0.26902	-0.00002
150	5.115	0.0063	5.117	0.002	5.116	0.001

TABLE 31 - Pressure = 10 bar

Temp	Hyland & Wexler		@Air		@Gas	
Deg C	Value	Uncert	Value	Error	Value	Error
0	0.078022	0.00015	0.078023	0.000001	0.078022	0.000000
90	0.11226	0.00017	0.11225	-0.00001	0.11225	-0.00001
100	0.11942	0.00022	0.11940	-0.00002	0.11940	-0.00002
150	0.23281	0.00165	0.23289	0.00008	0.23288	0.00007
160	0.32711	0.00120	0.32732	0.00021	0.32729	0.00018
170	0.61489	0.00152	0.61553	0.00064	0.61547	0.00058

TABLE 32 - Pressure = 50 bar

Temp	Hyland & Wexler		@Air		@Gas	
deg C	Value	Uncert	Value	Error	Value	Error
0	0.015331	0.00077	0.015324	-0.000007	0.015324	-0.000007
90	0.021310	0.00050	0.021302	-0.000008	0.021301	-0.000009
100	0.022073	0.00053	0.022066	-0.000007	0.022065	-0.000008
150	0.02727	0.00186	0.02729	0.00002	0.02729	0.00002
160	0.02885	0.00256	0.02888	0.00003	0.02888	0.00003
170	0.03077	0.00346	0.03082	0.00005	0.03081	0.00004
180	0.03315	0.00459	0.03323	0.00008	0.03323	0.00008
200	0.0402	0.0076	0.0404	0.0012	0.0404	0.0002

The differences in saturated humidity ratios between @Air or @Gas and Hyland & Wexler can be attributed mostly to the equations used to calculate the pressure of saturated vapor over liquid water. @Air and @Gas use the latest equations provided by IAPWS [7].

In the following comparisons, the properties calculated by @Air and @Gas use the saturated humidity ratio as calculated by Hyland & Wexler in order to show a comparison based on the same composition.

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APPENDIX I DETAILED FUNCTION LISTING

This section contains detailed descriptions of each of the @Gas functions which can be called from the GASPRP32.DLL (or GASPROPS.DLL) as listed below:

- **GasPTXV**
- **GasPVXT**
- **GasTVXP**
- **GasPTXH**
- **GasPTXS**
- **GasPTXHS**
- **GasPTXSS**
- **GasPTXC**
- **GasPTXM**
- **GasPTXK**
- **GasPTXW**
- **GasPXD**
- **GasXW**
- **GasWX**
- **GasXMW**
- **GasPHXT**
- **GasPSXT**
- **GasPTXL**
- **GasVapPT**
- **GasVapTP**
- **GasCondPTH**
- **GasCondPTS**
- **GasVer**

GasPTXV

GasPTXV(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the specific volume of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*specific volume***Description**

is the specific volume per mass of dry gas in units consistent with the selected unit set. If 16 is added to the unit set, output is per mass of wet gas.

Examples

P = 14.696 psia, T = 100 deg F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPTXV(14.696,100,0.740285,0.198589,0.008855,0.000298,0.051973,48) = 14.387 [ft³/lbm of wet gas]

GasPVXT

GasPVXT(*pressure, volume, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the temperature of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

specific volume

is the specific volume per mass of dry gas in units consistent with the selected unit set. If 16 is added to the unit set, specific volume is per mass of wet gas.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*temperature***Description**

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

Examples

P = 14.696 psia, V = 14.387 [ft³/lbm], N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPVXT(14.696,14.387,0.740285,0.198589,0.008855,0.000298,0.051973,48) = 100 deg F

GasTVXP

GasTVXP(*temperature, volume, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the pressure of the moist gas.

Arguments*temperature***Description**

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

specific volume

is the specific volume per mass of dry gas in units consistent with the selected unit set. If 16 is added to the unit set, specific volume is per mass of wet gas.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

Examples

T = 100 deg F, V = 14.387 [ft³/lbm], N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasTVXP(100,14.387,0.740285,0.198589,0.008855,0.000298,0.051973,48) = 14.696 [psia]

GasPTXH

GasPTXH(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the specific enthalpy of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*specific enthalpy***Description**

is the specific enthalpy per mass of dry gas in units consistent with the selected unit set and ASHRAE reference point. If 16 is added to the unit set, output is per mass of wet gas. If 8 is added to the unit set, enthalpy is referenced to absolute zero temperature.

Examples

P = 14.696 psia, T = 100 deg F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPTXH(14.696,100,0.740285,0.198589,0.008855,0.000298,0.051973,48) = 59.657[Btu/lbm of wet gas]

GasPTXS

GasPTXS(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the specific entropy of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*specific entropy***Description**

is the specific entropy per mass of dry gas in units consistent with the selected unit set and ASHRAE reference point. If 16 is added to the unit set, output is per mass of wet gas. If 8 is added to the unit set, entropy is referenced to absolute zero temperature.

Examples

P = 14.696 psia, T = 100 deg F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPTXS(14.696,100,0.740285,0.198589,0.008855,0.000298,0.051973,48) = 0.1154 [Btu/F/lbm of wet gas]

GasPTXHs

GasPTXHs(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the saturated specific enthalpy of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value

*specific enthalpy of gas
saturated with water vapor*

Description

is the specific enthalpy per mass of dry gas in units consistent with the selected unit set and ASHRAE reference point. If 16 is added to the unit set, output is per mass of wet gas. If 8 is added to the unit set, enthalpy is referenced to absolute zero temperature.

Examples

$P = 14.696$ psia, $T = 100$ deg F, $N_2 = 0.740285$, $O_2 = 0.198589$, $Ar = 0.008855$, $CO_2 = 0.000298$, $H_2O = 0.051973$

GasPTXHs(14.696,100,0.740285,0.198589,0.008855,0.000298,0.051973) = 68.806 [Btu/lbm of wet gas]

GasPTXSs

GasPTXSs(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the saturated specific entropy of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value

*specific entropy of gas
saturated with water vapor*

Description

is the specific entropy per mass of dry gas in units consistent with the selected unit set and ASHRAE reference point. If 16 is added to the unit set, output is per mass of wet gas. If 8 is added to the unit set, entropy is referenced to absolute zero temperature.

Examples

P = 14.696 psia, T = 100 deg F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPTXSs(14.696,100,0.740285,0.198589,0.008855,0.000298,0.051973,48) = 0.1319 [Btu/F/lbm of wet gas]

GasPTXC

GasPTXC(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the specific heat of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*specific heat***Description**

is the specific enthalpy per mass of dry gas in units consistent with the selected unit set and ASHRAE reference point. If 16 is added to the unit set, output is per mass of wet gas

Examples

P = 14.696 psia, T = 100 deg F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPTXC(14.696,100,0.740285,0.198589,0.008855,0.000298,0.051973,48) = 0.24757[Btu/lbm/F of wet gas]

GasPTXM

GasPTXM(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the dynamic viscosity of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*viscosity***Description**

is the dynamic viscosity based on the flow of dry gas in units consistent with the selected unit set and ASHRAE reference point. If 16 is added to the unit set, output is based on the mass of wet gas

Examples

P = 14.696 psia, T = 100 deg F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPTXM(14.696,100,0.740285,0.198589,0.008855,0.000298,0.051973,48) = 0.0457[lbm/hr/ft of wet gas]

GasPTXK

GasPTXK(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the thermal conductivity of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*conductivity***Description**

is the thermal conductivity of the gas mixture in units consistent with the selected unit set.

Examples

P = 14.696 psia, T = 100 deg F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPTXK(14.696,100,0.740285,0.198589,0.008855,0.000298,0.051973,32) = 0.01544[Btu/hr/ft/F]

GasPTXW

GasPTXW(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the saturated humidity ratio of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value

*humidity ratio of gas
saturated with water vapor*

Description

is the specific volume per mass of dry gas in units consistent with the selected unit set. If 16 is added to the unit set, output is per mass of wet gas.

Examples

P = 14.696 psia, T = 100 deg F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPTXW(14.696,100,0.740285,0.198589,0.008855,0.000298,0.051973,32) = 0.04324 [lbm water vapor/lbm of dry gas]

GasPXD

GasPXD(*pressure*, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [*unit set*])

returns the dew point temperature of the moist gas.

Arguments

pressure

Description

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value

dew point temperature

Description

is a value representing the temperature, in units consistent with the selected unit set, below which the moisture in the gas begins to condense.

Examples

P = 14.696 psia, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPXD(14.696,0.740285,0.198589,0.008855,0.000298,0.051973,48) = 92.68 [deg F]

GasXW

GasXW(X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set])
 returns the humidity ratio of the moist gas.

Arguments

X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

Description

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value

humidity ratio

Description

is a value representing the ratio of the mass of water vapor in the gas to the mass of all the other gas components.

Examples

N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasXW(0.740285,0.198589,0.008855,0.000298,0.051973,32) = 0.3409 [mass of water per mass of dry gas]

GasWX

GasWX(X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set])
 returns the mole fraction of water vapor.

Arguments

X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

Description

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value

water vapor mole fraction

Description

is a value representing mole fraction of water vapor in the gas.

Examples

N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, W = 0.0310

GasWX(0.740285,0.198589,0.008855,0.000298,0.0309,0) = 0.05197 [mass of water per mass of dry gas]

GasXMW

GasXMW(X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set])
 returns the molecular weight of the moist gas.

Arguments

X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

Description

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value

molecular weight

Description

is a value representing molecular weight of the dry gas. If 16 is added to the unit set, the molecular weight is per mass of wet gas.

Examples

N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasXMW(0.740285,0.198589,0.008855,0.000298,0.051973,48) = 28.3957 [lbs per mole of wet gas]

GasPHXT

GasPHXT(*pressure, enthalpy, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the temperature of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

specific enthalpy

is the specific enthalpy per mass of dry gas in units consistent with the selected unit set and ASHRAE reference point. If 16 is added to the unit set, enthalpy is per mass of wet gas. If 8 is added to the unit set, enthalpy is referenced to 0° K.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*temperature***Description**

is the gas's dry bulb temperature in units consistent with the selected unit set. If the resulting temperature is below the dew point, the value accounts for the condensed water.

Examples

P = 14.696 psia, H = 59.657 Btu/lb, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPHXT(14.696,59.657,0.740285,0.198589,0.008855,0.000298, 0.051973,48) = 100[deg F]

GasPSXT

GasPSXT(*pressure, entropy, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the temperature of the moist gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

specific entropy

is the specific entropy per mass of dry gas in units consistent with the selected unit set and ASHRAE reference point. If 16 is added to the unit set, entropy is per mass of wet gas. If 8 is added to the unit set, entropy is referenced to 0° K.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*temperature***Description**

is the gas's dry bulb temperature in units consistent with the selected unit set. If the resulting temperature is below the dew point, the value accounts for the condensed water.

Examples

P = 14.696 psia, S = 0.1154 Btu/lb/F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPSXT(14.696,0.1154,0.740285,0.198589,0.008855,0.000298, 0.051973,48) = 100[deg F]

GasPTXL

GasPTXL(*pressure, temperature, X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O} , [unit set]*) returns the mass of water condensed per mass of gas.

Arguments*pressure***Description**

is a value representing the absolute total pressure of the gas in units consistent with the selected unit set.

temperature

is a value representing the dry bulb temperature of the gas in units consistent with the selected unit set.

 X_{N_2} , X_{O_2} , X_{Ar} , X_{CO_2} , X_{H_2O}

the gas composition (N₂, O₂, Ar, CO₂, H₂O) of the gas. X_{N_2} , X_{O_2} , X_{Ar} and X_{CO_2} are entered as mole fractions of the dry gas with X_{H_2O} entered as a humidity ratio. All of the five arguments must be entered in order even if any are zero. If 32 is added to the unit set, all X values are entered as mole fractions of the wet gas. If 64 is added to the unit set, mass fractions are substituted wherever mole fractions are required.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*water condensed***Description**

is the mass of water condensed per mass of dry gas in units consistent with the selected unit set and ASHRAE reference point. If 16 is added to the unit set, output is per mass of wet gas. If temperature is above dew point, the function returns 0.

Examples

P = 14.696 psia, T = 50 deg F, N₂ = 0.740285, O₂ = 0.198589, Ar = 0.008855, CO₂ = 0.000298, H₂O = 0.051973

GasPTXL(14.696,50,0.740285,0.198589,0.008855,0.000298,0.051973, 32) = 0.02556 [lbm of water/lbm of wet gas]

GasVapPT

GasVapPT(*pressure*, [*unit set*]) returns the saturation temperature of the water vapor.

Arguments

pressure

Description

is a value representing the absolute total pressure of gas in units consistent with the selected unit set.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value

temperature

Description

is a value representing the saturation temperature of water vapor in units consistent with the selected unit set.

Examples

P = 14.696 psia

GasVapPT(14.696,0) = 211.95 deg F

GasVapTP

GasVapTP(*temperature*, [*unit set*]) returns the saturation temperature of the water vapor.

Arguments

temperature

Description

is a value representing the temperature of the gas in units consistent with the selected unit set.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value

pressure

Description

is a value representing the saturation pressure of water vapor in units consistent with the selected unit set.

Examples

T = 211.95 deg F

GasVapTP(211.95,0) = 14.696 psia

GasCondPTH

GasCondPTH(*pressure, temperature, [unit set]*) returns the specific enthalpy of compressed water.

Arguments*pressure***Description**

is a value representing the absolute total pressure in units consistent with the selected unit set.

temperature

is a value representing the temperature of the water in units consistent with the selected unit set.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*specific enthalpy***Description**

is the specific enthalpy per mass of water in units consistent with the selected unit set and referenced to saturated liquid water at the triple point.

Examples

P = 14.696 psia, T = 100 deg F

GasCondPTH(14.696, 100, 0) = 68.052 Btu/lbm

GasCondPTS

GasCondPTS(*pressure, temperature, [unit set]*) returns the specific entropy of compressed water.

Arguments*pressure***Description**

is a value representing the absolute total pressure in units consistent with the selected unit set.

temperature

is a value representing the temperature of the water in units consistent with the selected unit set.

unit set

0 or "ENG", 1 or "SI", 2 or "EngG", 3 or "SIF", 4 or "SIK", 5 or "MET", 6 or "METF"

Return Value*specific entropy***Description**

is the specific entropy per mass of water in units consistent with the selected unit set and referenced to saturated liquid water at the triple point.

Examples

P = 14.696 psia, T = 100 deg F

GasCondPTS(14.696, 100, 0) = 0.1296 Btu/F/lbm

GasVer

GasVer() returns the @Gas version and serial number.

Arguments

None

Return Value

Version and Serial Number

Description

is a floating-point number whose integer part represents the major version number of the DLL. The first digit to the right of the decimal point represents the minor version number. The remaining digits represent the serial number.

Examples

GasVer = 3.035999

The version number is 3.0. The serial number is 35999.

APPENDIX II @GAS ERROR CODES

If an error is encountered by an @Gas function during calculation of a gas property, the function returns a negative value (-1000 or lower). This Appendix presents the error numbers together with an explanation of each possible error condition. The header file GASERR.H defines mnemonic constants for the error codes. The mnemonics are listed below also.

The error codes listed below are accessible only from Windows programming languages such as Visual C++ or Visual BASIC. The interfaces provided for Excel, Mathcad, and 1-2-3 intercept these error numbers and return appropriate Excel, Mathcad, or 1-2-3 error values. This is done to avoid inadvertent use of an error value in a cell equation.

ERR_OUTOFRANGE(-1002): Out of Range

The input values represent a state point that is outside of the @Gas pressure or temperature range.

ERR_NOTAVAILABLE(-1003): Not Available

The property requested is not available at these conditions.

ERR_NOTDEFINED(-1004): Not Defined

The property requested is not defined at these conditions.

ERR_NOSAT(-1100): No Saturation

The temperature of the gas is above the saturation temperature of the water vapor.

ERR_H2O(-1200): H2O composition error

The H2O component is less than 0.

ERR_N2(-1300): N2 composition error

The Nitrogen component is less than 0.

ERR_O2(-1400): O2 composition error

The Oxygen component is less than 0.

ERR_CO2(-1500): CO2 composition error

The CO2 component is less than 0.

ERR_AR(-1600): AR composition error

The Argon component is less than 0.

ERR_MF(-1800): mole fraction error

None of the gas components entered were greater than 0.

ERR_THIGH(-2000): Temperature Too High

@Gas will accept a maximum temperature of 2000 deg K.

- ERR_TLOW(-2100) : Temperature Too Low**
@Gas will accept a minimum temperature of 180 deg K.
- ERR_PHIGH(-3000) : Pressure Too High**
@Gas will accept a maximum pressure of 50 bar.
- ERR_PLOW(-3100) : Pressure Too Low**
@Gas will accept a minimum pressure of 1 Pascal.
- ERR_VOLLOW(-4100) : Volume Too Low**
Specific volume is below the minimum allowed by @Gas.
- ERR_WHIGH(-7000) : Humidity Ratio Too High**
The humidity ratio specified is above the saturated humidity ratio for the gas pressure and temperature.
- ERR_WLOW(-7100) : Humidity Ratio Too Low**
The humidity ratio specified is below 0.
- ERR_HHIGH(-9000) : Enthalpy Too High**
The enthalpy specified represents a state point above the @Gas pressure and temperature limits.
- ERR_HLOW(-9100) : Enthalpy Too Low**
The enthalpy specified represents a state point below the @Gas pressure and temperature limits.
- ERR_SHIGH(-9200) : Entropy Too High**
The entropy specified represents a state point outside the @Gas pressure and temperature limits.
- ERR_SLOW(-9300) : Entropy Too Low**
The entropy specified represents a state point outside the @Gas pressure and temperature limits.
- ERR_INTERNAL (-9999) : Internal Error**
One of the iteration schemes has failed to converge. Contact Techware for support.