



Starling Associates, Inc.

2018-2019 Software Products Catalog

Since 1992, Starling Associates has been the defacto standard in natural gas measurement software, including natural gas and hydrocarbon properties software, natural gas flow meter software, natural gas dew point software, and natural gas thermodynamic properties software. Starling Associates software is used in gas metering, efm verification, gas accounting verification, meter sizing, gas volume calculations, and gas pipeline calculations. We know others check their software against Starling Associates software as the test for accuracy, making Starling Associates the de facto software standard. Starling Associates assures our customers of ACCURACY without COMPROMISE.

PRODUCT OVERVIEW

Starling Associates software products are grouped into three categories: Natural Gas Measurement products, Phase Behavior Suite of products, and one Natural Gas Properties product.

1. **Natural Gas Measurement** - The Natural Gas Measurement group consists of four independent software options: GOFW2015, GOFXL, GOFIntranet, and GOFLIBC/C++.
2. **Phase Behavior Suite** - The Phase Behavior Suite of products may be used independently or together depending on the end user's needs. The Phase Behavior Suite has three software options: PRDewPointCurveXL2017, PREnvelopeAndLiquidXL, C6PlusHCDPMatch.
3. **Natural Gas Properties** – Starling Associates offers GasProps2008. GasProps2008 accurately calculates 23 natural gas properties using equations in the gas industry standards AGA Report No. 8 and AGA Report No. 10.

Starling Associates can help you implement the newest industry standards in gas flow measurement. Depending on which solution your company selects, SAI software covers: AGA 8 Parts 1 and 2 (2017), AGA 3.3 (2013), AGA 8 (1994 Reprint, 1985), AGA 3 (1992, 1985), GPA 2172 (2009, 1996), AGA NX19 (1962). Also covered are parts of: AGA 7 (1996, Turbine Meters) and AGA 9 (2007, Ultrasonic Meters), and AGA 11 (2013, Coriolis Meters).

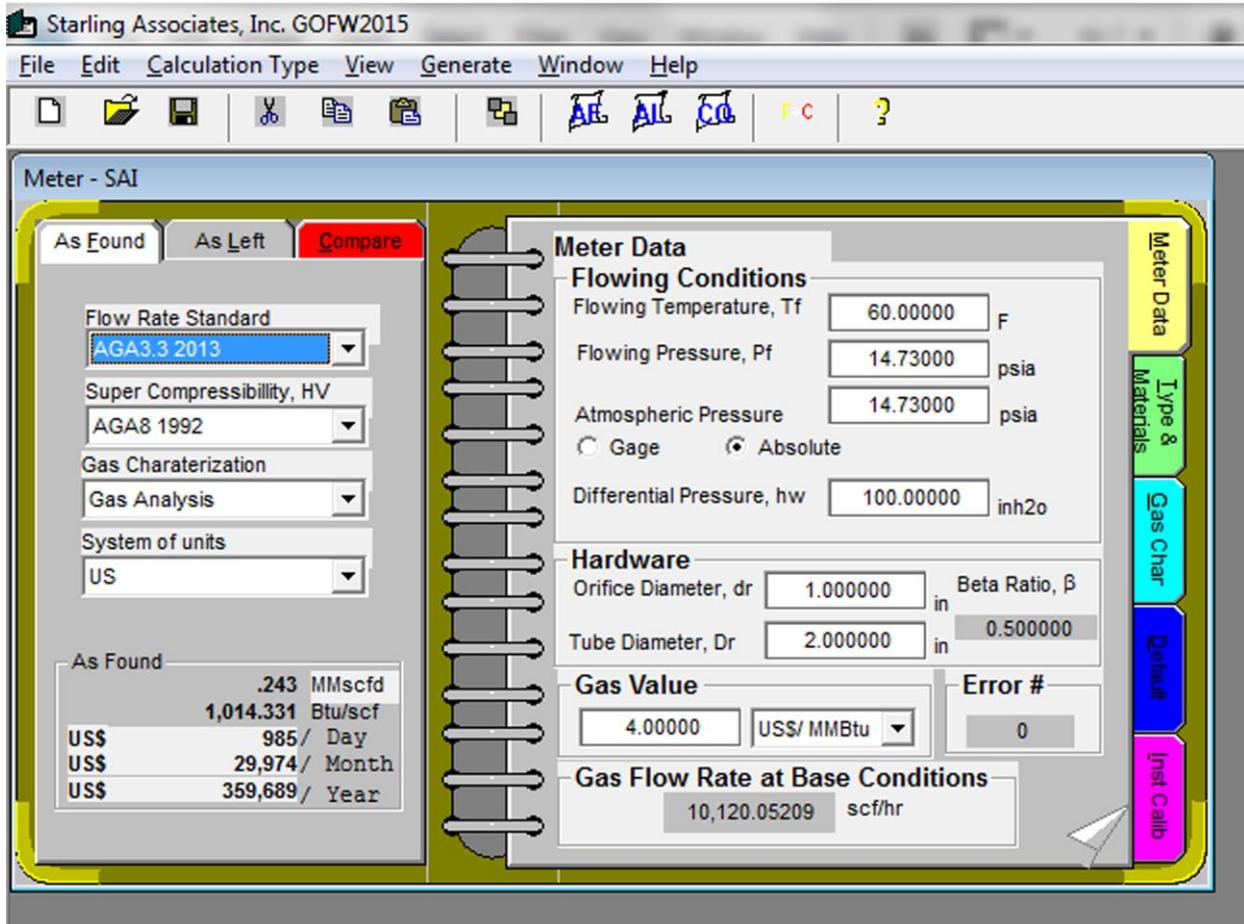
NATURAL GAS MEASUREMENT

The following is comparison table for SAI's Gas Measurement software products.

2018 SAI Gas Measurement Products				
For detailed information, licensing and other SAI Software, please visit StarlingAssoc.com .				
Updated: Feb 5, 2018				
	GOFXL	GOFW	GOFIntranet	GOFLIBC / C++
HOW IS IT USED?				
Type of Use	Excel in Windows	Windows Exe	Intranet Browser	C Code
Customizable by User?	Yes	No	Interface Only	Yes
STANDARDS COVERED				
AGA 3.3- 2013/API MPMS Ch. 14.4.3	Yes	Yes	Yes	Yes
AGA 3 - 2012 Part 1 / API MPMS Ch. 14.3.1	Yes	Yes	Yes	Yes
AGA 3 - 1992, API 14.3, GPA 8185-92	Yes	Yes	Yes	Yes
AGA 3 - 1985, API 2530 - 1985, GPA 8185-92	Yes	Yes	Yes	can be added
AGA 7 - 2006, 1996 (Turbine)	Yes	Yes	Yes	can be added
AGA 8 - 2017, Parts 1 and 2	Yes	Pending*	Pending*	Yes
AGA 8- 1994 Reprint, 1985	Yes	Yes	Yes	Yes
AGA 9 -2017, 2007 (Ultrasonic)	Yes	Yes	Yes	can be added
AGA 11 - 2013 (Coriolis)	Yes	Yes	Yes	can be added
AGA NX19- 1962	Yes	Yes	Yes	can be added
GPA 2145- 2016, 2009, 1996, 1986	Yes**	Yes**	Yes**	can be added
GPA 2172 - 2014	Yes	Pending*	Pending*	can be added
GPA 2172 -2009, 1996, 1986	Yes	Yes	Yes	can be added
METERS COVERED				
pipe tapped orifice meters	Yes	Yes	Yes	Yes
flange tapped orifice meters	Yes	Yes	Yes	Yes
turbine meters	Yes	Yes	Yes	can be added
ultrasonic meters	Yes	Yes	Yes	can be added
coriolis meters	Yes	Yes	Yes	can be added
COMMON USES CITED				
Speed of Sound using GERG 2008	Yes	Pending*	Pending*	Yes
Volumetric and Mass Flow Rates	Yes	Yes	Yes	Yes
Comparisons of Flow Rates for Meter Calibrations	Yes	Yes	Yes	Yes
Comparisons of Different Measurement Standards	Yes	Yes	Yes	Yes
In-House Verifications	Yes	Yes	Yes	Yes
Electronic Flow Measurement	Yes	Yes	Yes	Yes
Orifice Size from Volumetric Flowrate	Yes	Yes	Yes	Yes
Orifice Size from Tube Size	Yes	Yes	Yes	Yes
Differential Pressure from Volumetric Flowrate	Yes	Yes	Yes	Yes
Heating Value Calculations	Yes	Yes	Yes	can be added
Total Energy Calculations	Yes	Yes	Yes	can be added
* Pending means the software additions are in development.				
** Component heating values are used from GPA 2145.				

GOFW2015

GOFW2015 was primarily designed to assist field technicians with the management of natural gas measurement facilities. The software runs on Windows based computers and has the look and feel of a notebook on the computer screen. The software is popular in operations where simplicity of use is important and there is no need to customize the software.



GOFW2015 Example

The software covers: AGA 3.3 (2013), AGA 8 (1994 Reprint, 1985), AGA 3 (1992, 1985), GPA 2172 (2009, 1996), AGA NX19 (1962). Also covered are parts of: AGA 7 (1996, turbine meters) and AGA 9 (2007, Ultrasonic Meters), and AGA 11 (2013, Coriolis Meters).

Major types of meter calculations available include: flange tapped and pipe tapped orifice meters, linear meters, turbine meters, ultrasonic meters and coriolis meters.

HOW GOFW2015 CAN HELP YOU SOLVE PROBLEMS

Commonly cited uses by customers include: calculation of volumetric and mass flow rates, comparisons of flow rates for meter calibrations, comparisons of different measurement standards, verifications of in-house calculations, Electronic Flow Measurement (EFM), calculation of orifice size from volumetric flowrate or tube size, calculation of differential pressure from volumetric flowrate, calculation of heating values, and calculation of total energy.

GOFW2015 makes quantitative calculations of the effects of meter changes showing “As Found”, “As Left” and “Comparison” for volume, energy, monetary value and other pertinent quantities. All of this information can be recorded in several formats, including a “Crystal Reports” file. The files can be used for record-keeping purposes as well as for transmission to the office environment. In addition, the original data files created in the field can be saved on the laptop and uploaded to desktop office computers which use the GOFW2015 software.

Some special features in GOFW2015 are as follows:

- **Field Meter Test** - Record gas meter inspections
- **Meter Changes** - Record field measurement calibration and equipment changes
- **Volume Calculator** - Calculate natural gas volumes or other variables associated with gas measurement
- **Gas Quality Calculator** - From lab analysis data calculate associated variables such as heating value in BTU/scf and gas gravity (also calculate comparisons for different input data)
- **Lost Revenue Calculator** - Calculate gas revenue loss associated with meter changes and changes in input data, such as lab analysis data
- **Report Generator** – Automatically generate reports showing “As Found”, “As Left” and “Comparison” for volume, energy, monetary value, etc.
- **Units Converter** – Convert all units from US to metric or metric to US units

HISTORY OF GOFW2015

In 1996, Union Oil Company of California requested that SAI develop a product using the Microsoft Windows operating system which could be used by Unocal field technicians to manage natural gas measurement facilities, with an emphasis on knowing the differences between the “As Found” and “As Left” meter conditions and the effect on calculated quantities such as volume, energy, and monetary value.

In the period 1996-2000, a team led by Juan Luongo, then SAI President, developed CO\$TFLOW, a predecessor of GOFW2008. Unocal personnel involved included Myron Goforth and Steve Baldwin, gas plant and metering specialists with extensive field experience. Prior to the purchase of Unocal by Chevron, CO\$TFLOW was used extensively in Unocal gas measurement short courses organized by the John Campbell Co. and taught by Ken Starling, SAI founder, at Unocal locations in both the US and Thailand.

GOFXL

GOFXL is Starling Associates most popular natural gas measurement software that enables users to create customized solutions using Excel workbooks. Major types of meter calculations available include: flange tapped and pipe tapped orifice meters, turbine meters, ultrasonic meters and coriolis meters. GOFXL has proven valuable in the engineering design environment, the field environment and the office environment. In each application, customized GOFXL spreadsheet forms can be used if desired to achieve uniform style and format within the company.

GOFXLV5 Example 1 Volume Flow Rate versus Flowing Temperature					
2017 AGA8.2 GERG-2008 Properties, 2013 AGA3.3 Orifice Meter, 2014 GPA 2172 Heating Value, AGA8 Gulf Coast Gas Composition					
For details on each INPUT or OUTPUT see either pop-up comments or go to the tabs titled INPUTS or OUTPUTS					
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				INPUT=TF	OUTPUT=QV
				INPUT	INP INF INF OUTPUT
				VARIABLE	VAI VA I VA VARIABLE
				INDEX 1	INO INC INI INDEX
					12 0 0 0 75
INPUT	INPUT	INPUT	INPUT	INPUT	INP INF INF OUTPUT
ARRAY	ARRAY	ARRAY	ARRAY	VARIABLE	VAI VA I VA VARIABLE
	INDICES	NAMES	VALUES	VALUE 1	VAI VA I VA VALUE
Gas Flowrate Standard	1	OPTION	11	60	400077.692
Method for Gas Properties	2	METHOD	3	61	399450.766
Type of User Input of Gas	3	ITYPEB	1	62	398828.161
Gas Relative Density (SG)	4	GRGRIN	0.58102	63	398209.818
Gas Heating Value HV @	5	HVIN	1036.08	64	397595.679
HV Calc. Method	6	HVMETHOD	4	65	396985.688
Nitrogen Mole %	7	XP(2)	0.2595	66	396379.789
Carbon Dioxide Mole %	8	XP(3)	0.5956	67	395777.929
Hydrogen Mole % (For	9	XP(4)	0	68	395180.054
Carbon Monoxide Mole %	10	XP(5)	0	69	394586.113
Methane Mole %	11	C1	0	70	393996.054
Flowing Gas Temperature	12	TF	60	71	393409.827
Flowing Gas Pressure (psia	13	PF	1000	72	392827.384
Base Temperature	14	TB	60	73	392248.675
Base Pressure	15	PB	14.73	74	391673.655
Reference Temperature for	16	TGR	60	75	391102.277

GOFXLV5 Example

The software covers: AGA 8 Parts 1 and 2 (2017), AGA 3.3 (2013), AGA 8 (1994 Reprint, 1985), AGA 3 (1992, 1985), GPA 2172 (2009, 1996), AGA NX19 (1962). Also covered are parts of: AGA 7 (1996, Turbine Meters) and AGA 9 (2007, Ultrasonic Meters), and AGA 11 (2013, Coriolis Meters).

HOW GOFXL CAN HELP YOU SOLVE PROBLEMS

Commonly cited uses by customers include:

- **Meter Installation Design** - compare the effects of changing meter tube diameter and orifice diameter on the ranges of flow rate for acceptable limits of differential pressure without orifice plate deformation
- **Meter Changes** – calculate the effects of field measurement calibration and equipment changes
- **Volume and Mass Flow Rates Calculator** - calculate natural gas volumes or other variables associated with gas measurement
- **Differential Pressure Calculations** – calculate the differential pressure from volumetric flowrate
- **Heating Value and Total Energy** - calculate heating values and total energy using the latest standards
- **Comparisons of Standards** – perform calculations using different applicable measurement standards and then compare the calculations
- **Facilities Management** - use by field technicians in the inspection and management of natural gas measurement facilities
- **Flow Computer Validation** – check the calculations of an electronic flow meter over a period of recorded clock time
- **Verifications of In-House Calculations** – when calculations need to be verified for accuracy for either due diligence or as part of an agreement between multiple parties
- **API 21.1 Validation** - check the integrity of the time averaging of variables such as average differential pressure used to obtain the gas volume integrated over the time period (e.g., 3600 seconds) according to API 21.1, the standard for electronic measurement
- **SCADA Data Transfer Verification** – check the integrity of data transfers in SCADA systems which must use different protocols to obtain data from different manufacturers' flow computers
- **Accounting Calculations** - volume checking and recalculation in the accounting office environment

HISTORY OF GOFXL

The suggestion to provide gas measurement calculations in a spreadsheet format was made in 1992 by John Stuart of Pacific Gas and Electric in a meeting with Ken Starling, SAI founder. John, who was very active in gas measurement professional groups, had volunteered to review an MS DOS program for orifice metering developed by SAI using the 1992 revisions of the AGA 8/API 14.2 properties standard and the API 14.3/AGA 3/ANSI 2530-92/GPA 8185-92 orifice metering standard. John felt that a spreadsheet format would be especially useful when a large number of calculations need to be performed and/or compared.

Previous SAI products meeting these needs were GOFXL2015, GOFXL2002, and GOFXL2008, the predecessors to GOFXL v5. SAI products performed orifice and linear meter calculations in Microsoft Excel and were designed to meet the needs expressed by John Stuart and subsequently by other gas measurement experts.

GOFIntranet

GOFIntranet allows companies to create in-house custom natural gas properties and flow calculation applications for use in intranet applications installed on servers using Microsoft Windows operating systems. GOFIntranet has all of the calculation possibilities and standards implementations of GOFXL but in an intranet application. Therefore, the GOFIntranet.dll can be used for intranet-based calculations of natural gas properties and natural gas flowrates using orifice meters (both flange and pipe taps). Calculations of gas flowrates for linear meters also can be performed.

GOFIntranet was developed by Starling Associates and its founder, Kenneth E. Starling, long-time researcher in the accurate measurement of natural gas flow and principal author of the standard AGA Report No. 8. GOFIntranet has the latest standards implemented in its dll.

GOFINTRANET INSTALLATION

Starling Associates can work with companies that have different systems, but the baseline requirements are 32-bit microprocessor and Microsoft Windows server version 2003 or later.

For J2EE programmers, an interface known as GOFIntranet.jar is provided. GOFIntranet.jar is compatible with JVM version 1.5.0.22 and higher.

The **GOFIntranet.dll** interface is the function **GOFIntranet(InputArray,OutputArray)** where InputArray is an array of 93 double precision floating point input variables and OutputArray is an array of 106 double precision floating point output variables.

InputArray has options for calculation of variables that include: AGA 8 Parts 1 and 2 (2017), AGA 3.3 (2013), AGA 8 (1994 Reprint, 1985), AGA 3 (1992, 1985), GPA 2172 (2009, 1996), AGA NX19 (1962). Also covered are parts of: AGA 7 (1996, Turbine Meters) and AGA 9 (2007, Ultrasonic Meters), and AGA 11 (2013, Coriolis Meters).

Gas properties input choices include HV/SG/CO₂, SG/CO₂/N₂, Full Gas Analysis, Licensee Input of Gas Density or Compressibility Factors, HV/SG/CO₂/N₂, HV/CO₂/N₂, and SG/METHANE/CO₂/N₂. Error codes alert the user if their temperature/pressure entries are outside the range of standards.

OutputArray consists of variables such as gas volume flowrate, gas compressibility factor and supercompressibility factor, relative density, pipe Reynolds number and numerous factors involved in flowrate calculations.

A great strength of GOFIntranet is the flexibility it allows for development of custom applications for your in-house company servers. Starling Associates is available for helping a company with customization needs.

GOFLIBC/C++

GOFLIBC/C++ is provided in C Code, so it can be implemented on a server, mainframe, minicomputer and PC levels with various operating systems. GOFLIBC/C++ also can be implemented in firmware for use in control and electronic flow measurement software. The GOFLIBC/C++ computer code calculates natural gas properties and orifice gas flowrates for flange and pipe tapped orifice meters, and generates density, compressibility factor and supercompressibility factor outputs. Measurement units include SI, US, IP and metric. Instrument calibration corrections are allowed and warnings and errors can be generated.

GOFLIBC/C++ STANDARDS COVERED AND USES

GOFLIBC/C++ covers: AGA 8 Parts 1 and 2 (2017), AGA 3.3 (2013), AGA 8 (1994 Reprint), and AGA 3 (1992). SAI can work directly with customers to modify the code to their needs. For example, the software currently does not cover AGA 7 (1996, turbine meters) or GPA 2172 (2009, 1996), but these standards can be added based on customer needs.

Commonly cited uses by customers include: calculation of volumetric and mass flow rates, comparisons of flow rates for meter calibrations, comparisons of different measurement standards, verifications of in-house calculations, Electronic Flow Measurement (EFM), SCADA applications, and in-house accounting systems.

IMPLEMENTATION OPTIONS

GOFLIBC/C++ COMPANY allows use of the functions included in GOFLIBC/C++ within your company* to customize the gas flow rate calculations to your needs and create in-house applications.

GOFLIBC/C++ PLUS allows production of firmware and/or stand-alone executable software to be licensed by the licensee company, which is a single, legal entity.

GOFLIBC/C++ ENTERPRISE allows use of the functions included in GOFLIBC/C++ within your parent company and its affiliates and subsidiaries to customize the gas flow rate calculations to your needs and create in-house applications.

GOFLIBC/C++ ENTERPRISE-PLUS allows use of the functions included in GOFLIBC/C++ within your parent company and its affiliates and subsidiaries to customize the gas flow rate calculations to your needs and create in-house applications; additionally, the license allows production of firmware and/or stand-alone executable software to be licensed by the licensee parent company, its affiliates and subsidiaries.

GOFLIBC/C++ closely resembles the ancillary FORTRAN subroutines in which the standards were initially programmed, but with GOFLIBC/C++ you can perform the same calculations with a C compiler. GOFLIBC/C++ has been compiled with Microsoft C compiler version 7.0 and Borland C++ version 3.1. We have made an effort to remain as close to ANSI C as possible for portability among different C compilers and therefore we don't foresee any major changes going from different C compilers.

PHASE BEHAVIOR SUITE

The Starling Associates' Phase Behavior Suite consists of: PRDewPointCurveXL2017, PREnvelopeAndLiquidXL and C6PlusHCDPmatch. Which software a company decides to license depends on three considerations:

1. **Who will be the end user?** PRDewPointCurveXL2017 is an excellent choice for Field Technicians and Operators that prefer to have only basic features. In contrast, PREnvelopeAndLiquidXL is designed for Engineers and Supervisors desiring more analysis options in addition to all of the options in PRDewPointCurveXL2017. C6PlusHCDPmatch is also designed for Engineers and Supervisors and can be used as a stand-alone product or with PRDewPointCurveXL2017 and/or PREnvelopeAndLiquidXL.
2. **Is the system prone to two phases?** PREnvelopeAndLiquidXL software provides accurate calculations of hydrocarbon mixture phase envelopes and liquid drop out within the phase envelopes. PREnvelopeAndLiquidXL is therefore a better choice than PRDewPointCurveXL2017 when the system is prone to two phases.
3. **Is the gas very rich?** When a company has heavier hydrocarbons present (such as C6+ being greater than .01%), C6PlusHCDPmatch can be used to mathematically extend the gas analysis so the equation of state will more accurately match the single measured dew point. The output from C6PlusHCDPmatch can then be used as input to estimate the dew point in future calculations using PRDewPointCurveXL2017 or the dew point and liquid dropout using PREnvelopeAndLiquidXL. Since companies have been producing richer gases in recent years, C6PlusHCDPmatch has proven valuable for Engineers and Supervisors.

PRDewPointCurveXL2017 calculates the natural gas hydrocarbon dew point (HCDP) curve in a Microsoft Excel spreadsheet and provides a variety of outputs such as:

- Hydrocarbon Dew Point (HCDP) for Detailed Gas Analysis
- HCDP for Gas Analysis with Lumped Hexanes Plus
- HCDP using Hexanes Plus Estimated Composition at any Pressure
- Natural Gas Dew Point Curve
- HCDP Temperature versus Pressure Curve
- Table of HCDP Temp versus Pressure
- Cricondentherm and Cricondenbar Temperature and Pressure

PREnvelopeAndLiquidXL provides all of the calculations in PRDewPointCurveXL2017, but has the following outputs:

- Hydrocarbon Phase Envelope
- Liquid Drop Out in Phase Envelope
- Vapor/Liquid Quality Curves
- Lower Dewpoint and Upper Dewpoint.
- Table of Bubble Point Temp vs Pressure

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The Phase Behavior Suite of software products are shown in the following table. SAI Phase Behavior products are considered a "suite" since they can be used together depending on the needs of the user.

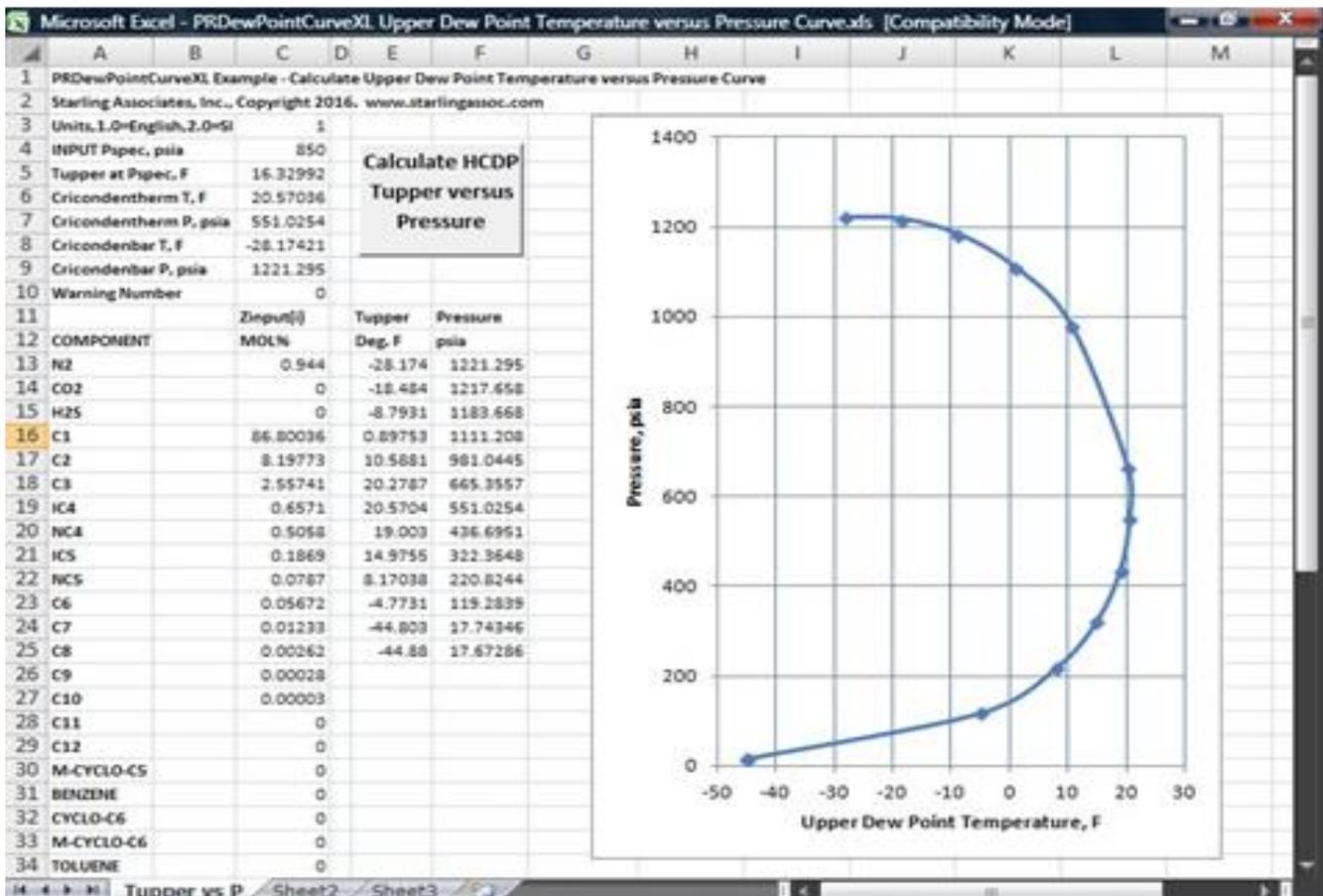
2018 SAI Phase Behavior Suite

	PRDewpoint CurveXL2017	PREnvelopeAnd LiquidXL	C6PlusHCDPmatch
PRODUCT SPECIFICATIONS			
Product Focus	Dew Points	Envelope, Percent Liquid Curves	C6+ Characterization, Dew Points
Suggested User Level	Field Technician / Operator	Engineer / Supervisor	Engineer / Supervisor
Option to use C6PlusHCDPmatch inputs	Yes ¹	Yes ¹	----
Max Hydrocarbon Component	C28	C28	C28
Maximum C6+ Mole Percentage	0.97%	0.97%	2.00%
Maximum C6+ Molecular Weight	97	97	102
User Interface	Excel	Excel	Executable
Operating System	Windows	Windows	Windows
Input and Output from/to Excel	Yes	Yes	Yes
English and SI Units	Yes	Yes	Yes
KEY CALCULATIONS²			
HCDP for Detailed Gas Analysis	Yes	Yes	Yes
HCDP using Hexanes Plus Estimated	Yes	Yes	Yes
Natural Gas Dew Point Curve	Yes	Yes	No
HCDP Temperature versus Pressure Curve	Yes	Yes	No
Table of HCDP Temp versus Pressure	Yes	Yes	No
Cricondenrtherm and Cricondenbar Temperature	Yes	Yes	No
Hydrocarbon Phase Envelope	No	Yes	No
Liquid Drop Out in Phase Envelope	No	Yes	No
Vapor/Liquid Percent Liquid Curves	No	Yes	No
Lower Dewpoint and Upper Dewpoint	No	Yes	No
Natural Gas Bubble Point Curve	No	Yes	No
Table of Bubble Point Temp vs Pressure	No	Yes	No
Matches Calculated to Measured HCDP	No	No	Yes
COMMON APPLICATIONS			
Good for verification of similar software	Yes	Yes	Yes
Control conditions to maintain operation in single phase gas region.	Yes	Yes	Yes
Decide max amounts of rich gases allowed at pipeline inlets based on HCDP calculations	Yes	Yes	Yes
Can be used for rich natural gases ³	No	Yes	Yes
Can be used for flowing conditions in vapor plus liquid 2 phase flow pipelines	No	Yes	No
Calculates liquid-gas ratio at input temperature and pressure	No	Yes	No
Calculate superficial gas velocity in pipeline flow	No	Yes	No
Output can be used in two phase flow calculations	No	Yes	No
Evaluate operation in the temperature-pressure	No	Yes	No
Estimates composition of rich gases ⁵	No	No	Yes
Can avoid expensive Extended Analysis ⁴	No	No	Yes
Significantly reduce sampling frequency	No	No	Yes
1 Interactivity between the products requires license of C6HCDPmatch and one of the other products.			
2. Calculations above can be performed at natural gas pipeline operating conditions, metering conditions, compressor inlet			
3. Rich natural gas is defined here as >0.1 C6+			
4. Extends Gas Analysis mathematically to match calculated HCDP with measured HCDP at pipeline pressure			

PRDewPointCurveXL2017

PRDewPointCurveXL2017 is primarily used in pipeline, compressor operations, production and processing operations. Using the natural gas composition, PRDewPointCurveXL calculates the natural gas hydrocarbon dew point (HCDP) curve in a Microsoft Excel spreadsheet. PRDewPointCurveXL outputs a table of the HCDP Tupper versus Pressure. Tupper is the highest temperature at a given pressure at which liquid starts to condense from the natural gas which has the input composition.

PRDewPointCurveXL also calculates the upper dew point temperature, Tupper at a user specified input pressure, Pspec. Pspec could be an expected operating condition, such as a natural gas pipeline operating pressure or the inlet pressure to a natural gas compressor or gas turbine. Below is a plot of the upper dew point temperature, Tupper, versus pressure can be added to the PRDewPointCurveXL spreadsheet using Microsoft Excel taskbar tools.

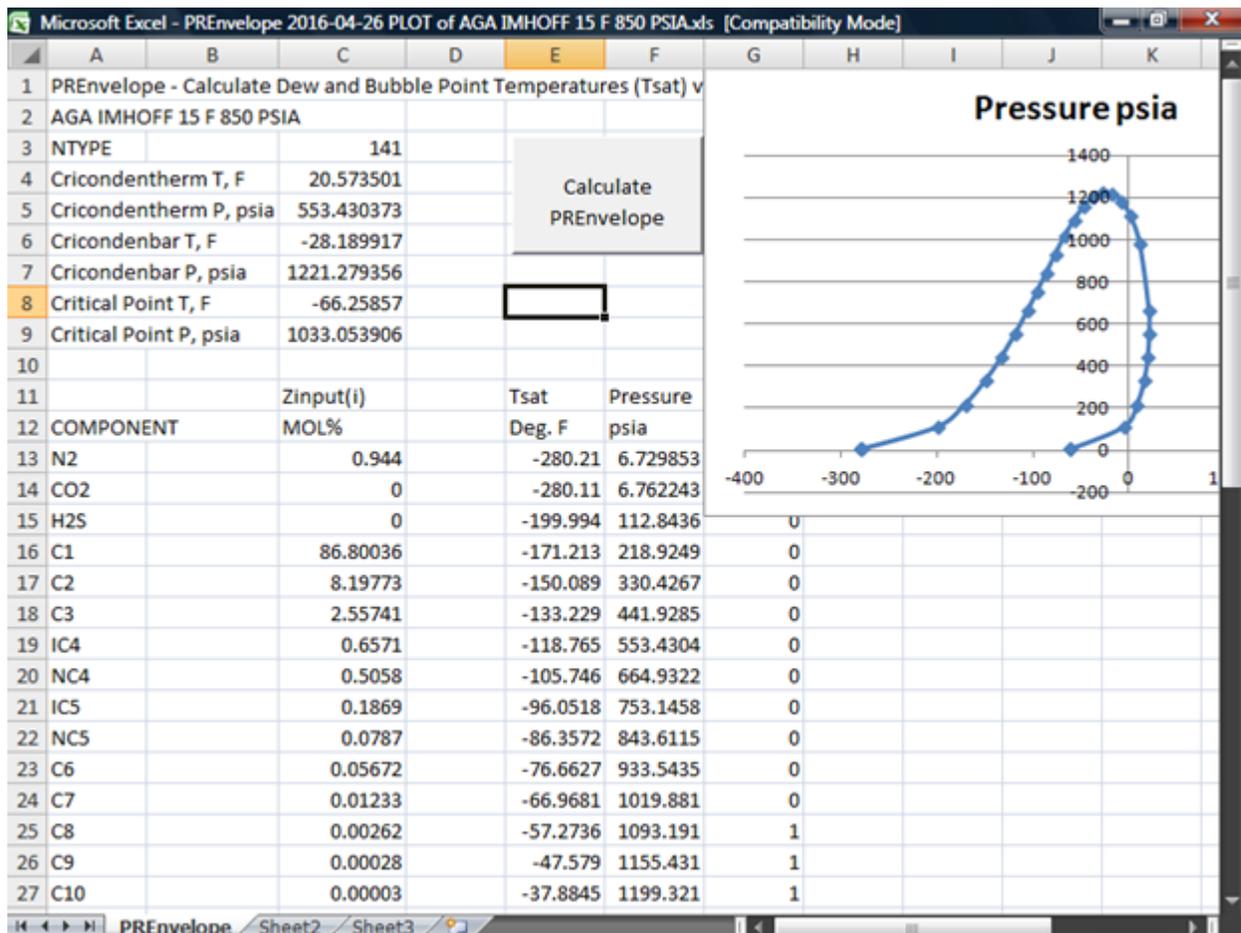


PRDewPointCurve2017 Example

Additional outputs are the cricondenthem and cricondenbar temperature-pressure conditions. The cricondenthem temperature is the maximum temperature of the two-phase vapor plus liquid region and therefore the input natural gas composition is single phase gas at all pressures for temperatures above the cricondenthem temperature. The cricondenbar pressure is the maximum pressure of the two-phase vapor plus liquid region and therefore the input natural gas composition is single phase at all temperatures for pressures above the cricondenbar pressure.

PREnvelopeAndLiquidXL

PREnvelopeAndLiquidXL software provides accurate calculations of hydrocarbon mixture phase envelopes and liquid drop out within the phase envelopes. The software is primarily intended for natural gas pipeline operations, but it can also be used in numerous other operations in the oil and gas industry. Calculations can be performed for lean processed natural gases as well as extremely rich natural gases from high pressure production separators. Calculations can be performed at natural gas pipeline operating conditions, metering conditions, compressor inlet conditions, gas turbine inlet conditions, separator vapor outlet conditions, and flowing conditions in vapor plus liquid two phase flow pipelines. An example of an envelope is provided below.



PREnvelopeAndLiquidXL Example

The example calculations which are presented in the PREnvelopeAndLiquidXL User's Manual emphasize applications in natural gas pipeline operations. For pipeline operations designed to avoid condensation in the pipeline resulting in two phase liquid plus gas flow, it is important that the pipeline operator can accurately calculate the flowing natural gas dew point curve. With an accurate natural gas composition as input, PREnvelopeAndLiquidXL will accurately calculate the phase envelope, which includes the natural gas dew point curve. Because the phase

envelope defines the two-phase liquid plus gas temperature-pressure region, pipeline operating conditions can be controlled to maintain operation in the single-phase gas region.

When there is condensation in the pipeline resulting in two phase liquid plus gas flow it is imperative that the pipeline operator be able to accurately calculate the amount of liquid condensed. If the amount of liquid condensed is sufficiently small, it will have only a small effect on pipeline operation provided that (1) the increased pressure drop is small, (2) the gas velocity is high enough to insure mist flow and (3) downstream separators, including the inlet separators at compressor stations, have sufficient capacity to handle the amounts of liquid entering the separators. GPA Project No. 081, sponsored by the Gas Processors Association, investigated these factors and determined that 0.002 gallons of liquid per thousand standard cubic feet of gas (GPM) has a negligible effect on pressure drop and should not disrupt pipeline operations.

In addition to the phase envelope, PREnvelopeAndLiquidXL calculates liquid drop out curves which can be used by the pipeline operator to judge the effects of pipeline operation within the temperature-pressure region of the phase envelope. For example, the user can choose to have the PREnvelopeAndLiquidXL software calculate the phase envelope plus liquid drop out curves for 0.001, 0.002 and 0.003 GPM. The PREnvelopeAndLiquidXL software also can be used to calculate the liquid drop out in GPM at a specified temperature and pressure inside the phase envelope. The volume of liquid hydrocarbon which must be handled by a separator at a specified temperature and pressure inside the phase envelope then can be determined by multiplication of the GPM by the natural gas flow rate in the pipeline.

C6PlusHCDPmatch

With C6PlusHCDPmatch the gas analysis is extended mathematically so the Peng-Robinson equation of state will match the single measured dew point taken from a typical gas chromatographic analysis coupled with a dew point temperature measurement at pipeline pressure. The extended analysis with C6PlusHCDPmatch can be used with confidence of acceptable accuracy even when the flowing gas composition changes within specified tolerance limits. In addition, by using C6PlusHCDPmatch a company can avoid an expensive extended analysis chromatogram. Dew points also can be calculated using a gas analysis alone.

The screenshot shows the 'Starling Associates C6PlusHCDPmatch: HCDP calculation or C6+ composition to match HCDP (Excel Input and Output)' window. It is divided into 'Inputs and Outputs' sections. A 'Calculate' button is visible between the input and output columns.

Inputs				Outputs			
CalcType	3	M-CYCLO-C5	0	Dew Point Temp	15.000382	M-CYCLO-C5	0.000000
UnitsType	1	BENZENE	0	C6+ Mol Wt	88.913067	BENZENE	0.000000
Pressure	850	CYCLO-C6	0	C6+ Mol %	0.071980	CYCLO-C6	0.000000
Dew Point Temp Input	15	M-CYCLO-C6	0	Sum Input Mol %	99.999980	M-CYCLO-C6	0.000000
C6+ Mol Wt Input	89.788	TOLUENE	0	Warning Code	0	TOLUENE	0.000000
N2	0.944	M-XYLENE	0	N2	0.944000	M-XYLENE	0.000000
CO2	0	O + P-XYLENE	0	CO2	0.000000	O + P-XYLENE	0.000000
H2S	0	C13	0	H2S	0.000000	C13	0.000000
C1	86.80036	C14	0	C1	86.800377	C14	0.000000
C2	8.19773	C15	0	C2	8.197732	C15	0.000000
C3	2.55741	C16	0	C3	2.557411	C16	0.000000
iC4	0.6571	C17	0	iC4	0.657100	C17	0.000000
nC4	0.5058	C18	0	nC4	0.505800	C18	0.000000
iC5	0.1869	C19	0	iC5	0.186900	C19	0.000000
nC5	0.0787	C20	0	nC5	0.078700	C20	0.000000
C6	0.05672	C21	0	C6	0.060238	C21	0.000000
C7	0.01233	C22	0	C7	0.009832	C22	0.000000
C8	0.00262	C23	0	C8	0.001605	C23	0.000000
C9	0.00028	C24	0	C9	0.000262	C24	0.000000
C10	0.00003	C25	0	C10	0.000043	C25	0.000000
C11	0	C26	0	C11	0.000000	C26	0.000000
C12	0	C27	0	C12	0.000000	C27	0.000000
		C28	0			C28	0.000000

C6PlusHCDPmatch Example

THE C6PlusHCDPmatch METHOD

Natural gas can be characterized in the region of pipeline operations from a typical gas chromatographic analysis with lumping of hexanes plus, coupled with a single chilled mirror or other dew point temperature measurement at pipeline pressure. A key to the characterization of the natural gas is the use of an equation of state which can describe the phase behavior of the natural gas. The Peng-Robinson equation of state has been tuned by Starling Associates, Inc. for natural gas dew points for use by C6PlusHCDPmatch. The resultant extended analysis can be used with confidence of acceptable accuracy even when the flowing gas composition changes within specified tolerance limits.

C6PlusHCDPmatch CALCULATION CHOICES

- **Calculate HCDP for Detailed Gas Analysis** --- Input composition and pressure, output HCDP (Hydrocarbon Dew Point)
- **Calculate HCDP for Gas Analysis with Lumped Hexanes Plus** --- Input composition, Hexanes Plus molecular weight and pressure, output HCDP (Hydrocarbon Dew Point) and Hexanes Plus estimated composition
- **Match Measured HCDP** --- Input Measured HCDP, composition (including Hexanes Plus mole percent) and pressure, output Hexanes Plus estimated composition which matches Measured HCDP (Hydrocarbon Dew Point)
- **Calculate HCDP using Hexanes Plus Estimated Composition at any Pressure** --- Input estimated composition and pressure, output HCDP (Hydrocarbon Dew Point)

HOW C6PlusHCDPmatch CAN HELP YOU SOLVE PROBLEMS

- The increase in production of natural gas has led to pipeline transportation of richer gases containing increasing amounts of hydrocarbons with molecular weights greater than the molecular weight of normal hexane (86.177). C6PlusHCDPmatch calculations can be used by the pipeline operator to choose operating controls to avoid condensation resulting in two phase liquid plus gas flow in the pipeline.
- Most natural gas pipeline operations include chromatographic analyses. The addition of dew point measurements by either manual or online automatic methods allows the pipeline operator to utilize C6PlusHCDPmatch calculations to decide the maximum amounts of rich gases allowed to enter the pipeline at inlet points along the pipeline.
- C6PlusHCDPmatch calculations can be used by pipeline operators to determine the difference between pipeline operating temperature and natural gas dew point at pipeline pressure. This difference represents the safety margin to avoid liquid drop out.

HISTORY OF C6PlusHCDPmatch

In 2000, prior to initiation of the API 14.1 program of experimental measurements of natural gas dew points at Southwest Research Institute, SAI founder Ken Starling served as a consultant in development of the research plan, a role he had previously held in 1985, prior to the dew point and liquid drop out measurements sponsored by Gasunie Research in the Netherlands.

Following the progress of both of these research projects, a need became apparent for a reliable method to accurately calculate dew points for natural gases in operating gas pipelines. The commonly used three step method of sampling, analysis and calculation can encounter undetected errors at each step. Sampling is difficult, accurate analysis is difficult and the resultant calculations of dew point and/or condensed liquid are uncertain.

The method developed and used by the C6PlusHCDPmatch software was to combine the direct measurement of dew point and the gas analysis so that the hexanes plus portion of the gas analysis is adjusted to match the measured dew point. This adjustment of the portion of the gas analysis which has the largest uncertainty yields calculation results in the region of the dew point which have much lower uncertainty than the commonly used three step method. This method was first presented in the paper "Peng-Robinson Equation of State Natural Gas Dew Points," by Kenneth E. Starling, AGA Operations Conference, Orlando, 2003.

NATURAL GAS PROPERTIES

Starling Associates offers one software product covering natural gas properties calculations.

GasProps2008

GasProps2008 accurately calculates 21 natural gas properties using equations in the gas industry standards AGA Report No. 8 and AGA Report No. 10. The research project to develop the equations used in GasProps2008 was led by Ken Starling, the founder of Starling Associates, Inc. The following is a screen capture of GasProps2008.

INPUT	INPUT	INPUT		OUTPUT	OUTPUT
ARRAY	ARRAY	ARRAY		ARRAY	ARRAY
INDICES	NAMES	VALUES	OutputIndex	NAMES	VALUES
1	CalcType	1.0	1.0	Speed of Sound	1314.260773
2	UnitsType	1.0	2.0	Critical Flow Factor	0.705646
3	Tf	50.00	3.0	Isentropic Exponent	1.327375
4	Pf	600.00	4.0	Specific Enthalpy	213.957302
5	Tb	60.0	5.0	Specific Entropy	2.150292
6	Pb	14.73	6.0	Molar Density	0.121408
7	XiC1	90.6724	7.0	Mass Density	2.136239
8	XiN2	3.1284	8.0	Relative Density (ideal gas)	0.607526
9	XiCO2	0.4676	9.0	Relative Density (real gas)	0.608630
10	XiC2	4.5279	10.0	Zb	0.997771
11	XiC3	0.8280	11.0	Zf	0.903542
12	XiH2O	0.0000	12.0	Square Root of (Zb/Zf)	1.050851
13	XiH2S	0.0000	13.0	Molecular Weight	17.595511
14	XiH2	0.0000	14.0	Cp (ideal gas)	0.492067
15	XiCO	0.0000	15.0	Cp	0.576644
16	XiO2	0.0000	16.0	Cv	0.393398
17	XiC4	0.1037	17.0	Cp/Cv	1.465802
18	XiNC4	0.1563	18.0	Specific Enthalpy (ideal gas)	234.261452
19	XiC5	0.0321	19.0	Molar Density at Tb,Pb	0.002647
20	XiNC5	0.0443	20.0	Mass Density at Tb,Pb	0.046578
21	XiNC6	0.0393	21.0	Status Code	9000.000000
22	XiNC7	0.0000	22.0	Error Code	0.000000
23	XiNC8	0.0000	23.0	Joule-Thomson Coefficient	0.061390
24	XiNC9	0.0000			
25	XiNC10	0.0000			
26	XiHe	0.0000			
27	XiAr	0.0000			
28	PlenumVel	0.0000			

GasProps2008 Example

GasProps2008 software is accessed in a Microsoft Excel spreadsheet enabling intuitive calculation of natural gas thermodynamic properties. The following table presents how GasProps2008 is used, what standards are the source of the calculations, and a list of the calculations with their common application.

Natural Gas Properties: GasProps2008	
HOW IS IT USED?	Explanation
User Interface	Excel in Windows
Customizable by User?	Yes
Suggested User Level	Engineer / Supervisor
English and SI Units	Yes
STANDARDS COVERED	
AGA Report No. 8	Yes
AGA Report No. 10	Yes
CALCULATION	Common Applications
Speed of Sound	Ultrasonic meter verification calculations
Critical Flow Factor	Critical flow prover calculations
Isentropic Exponent Kappa	Calculations of isentropic compression and expansion of gas
Specific Enthalpy	Heat exchanger calculations
Specific Entropy	Compressor calculations
Molar Density D at Tf,Pf	Conversion of volume flow rate at Tf,Pf to molar flow rate
Mass Density Rho at Tf,Pf	Conversion of mass flow rate to volume flow rate at Tf,Pf
Relative Density (ideal gas) Gr (ideal gas)	Molecular weight of gas divided by molecular weight of air
Relative Density (real gas) Gr (real gas)	Density of gas divided by density of air at Tb,Pb
Zb Compressibility Factor at Tb,Pb	Flow rate conversions from flowing to base conditions
Zf Compressibility Factor at Tf,Pf	Flow rate conversions from flowing to base conditions
Square Root of (Zb/Zf) Supercompressibility	Orifice meter flow rate equation factor
Molecular Weight Molar Mass	Moles to mass units conversion factor (mass/mole)
Cp (ideal) Ideal Gas Const. P, Heat Capacity	Calculation of ideal gas enthalpy changes
Cp Const. Pres. Heat Capacity	Calculation of enthalpy changes at constant pressure
Cv Const. Vol. Heat Capacity	Calculation of enthalpy changes at constant volume
Cp/Cv Heat Capacity Ratio	Used for adiabatic process calculations (no heat transferred)
Specific Enthalpy (ideal gas)	Calculation of ideal gas enthalpy changes
Molar Density at TbPb	Conversion of volume flow rate at Tb,Pb to molar flow rate
Mass Density at TbPb	Conversion of mass flow rate to volume flow rate at Tb,Pb
Joule-Thomson Coefficient	Temperature drop for regulator and valve calculations.

HOW GasProps2008 CAN HELP YOU SOLVE PROBLEMS

- **Sonic Prover Calculations** - the calculated speed of sound times the cross-sectional area at the minimum diameter of a sonic prover is the volume flow rate
- **Ultrasonic Meter Speed of Sound Validation** - check the calculations of the speed of sound used by the ultrasonic meter to calculate flow rate
- **Flow Computer Properties Validation** - check the gas properties calculations of an electronic flow meter
- **Joule-Thomson Temperature Drop Calculations** – calculate temperature drops across valves and pressure regulators to assess the potential for liquid water and hydrates
- **Compressor Design Calculations** - calculate natural gas compressor power requirements, number of compressor stages, intercooler duties and discharge temperatures
- **Compressor Troubleshooting Calculations** - compare actual operating conditions versus design conditions to determine deterioration in efficiency, increased power requirements, increased internal recycle, and if discharge temperature exceeds lubricant maximum
- **Heat Exchanger Design Calculations** - calculate natural gas heat exchanger duties and temperature profiles (GasProps2008 also can be used for air properties, and so for air coolers, and also for combustion gas, and so for heaters using combustion gas)
- **Heat Exchanger Operation and Troubleshooting Calculations** - monitor heat exchanger efficiency, determine changes in heat transfer coefficient and fouling factor, detect leaks

WHY GasProps2008 WAS DEVELOPED

The suggestion to provide gas properties calculations in a spreadsheet format was made in 2002 by Jim Witte of El Paso Corporation to Ali Quraishi of the American Gas Association around the time that AGA Report No. 10 was in final draft. Starting with the source code developed by Warren Peterson of Transcanada Pipelines, Ken Starling, SAI founder, developed the GasProps software. Because of Jim Witte's desire to have the Joule-Thomson coefficient included, a JT algorithm was developed for GasProps.