Energy and Flow Metering in the DeltaV System

This paper describes the capability within the DeltaV automation system to easily and accurately measure energy and flow of natural gas and other single-phase, Newtonian fluids through the use of pre-configured function blocks.

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Flow Metering Function Blocks

The AGA_SI and AGA_US function blocks are flow metering function blocks included in the DeltaV process automation system. These function blocks can be found in the Energy Metering palette which is part of the DeltaV Control Studio application. These blocks are designed to calculate the flow of natural gas through orifice and turbine meters, but can be used for other gases and liquids (virtually any single phase, Newtonian fluid under turbulent flow).



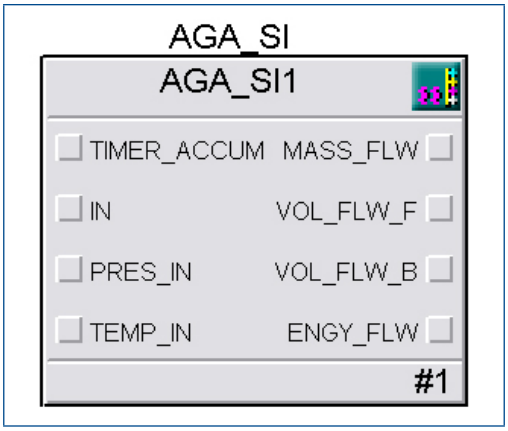
The AGA_SI function block is identical to the AGA_US block, except for the engineering units used. Each applicable parameter in the AGA_SI block has a particular SI engineering unit. If input or output parameters require other engineering units, conversion should be done upstream or downstream of the block. The other flow metering block, AGA_US, uses U.S. units.

The AGA_SI block calculates instantaneous mass flow, volumetric flow, and energy flow for natural gas using equations defined in AGA (American Gas Association) reports and ISO standards.

- Mass flow calculation for orifice metering per AGA3/1995 and ISO5167/1998
- Limits of use for orifice metering per AGA3/1995
- Calculation of densities and compressibility factors per AGA8/1994 (detail characterization method)
- Turbine metering calculations per AGA7/1996
- Calculation of gas heating value per ISO6976/1999 (real gas superior calorific value using 15/15 data)

The block calculates density for natural gases and other related hydrocarbon gases. For other fluids the density can be manually entered.

In addition to calculating instantaneous flow rates the block provides reset-able totalization parameters for base volumetric flow and energy flow.



IN is the differential pressure for an orifice meter in kPa (kilopascals) or volumetric flow from a PIN function block for a turbine meter in m3/hr (cubic meters per hour)

PRES_IN is the static pressure in kPa (kilopascals absolute)

TEMP_IN is the fluid temperature in deg C

TIMER_ACCUM is the input to reset totalization parameters typically wired from OUT_D of a DTE (Date Time Event) function block

MASS_FLW is the instantaneous mass flow rate in kg/hr (kilograms per hour)

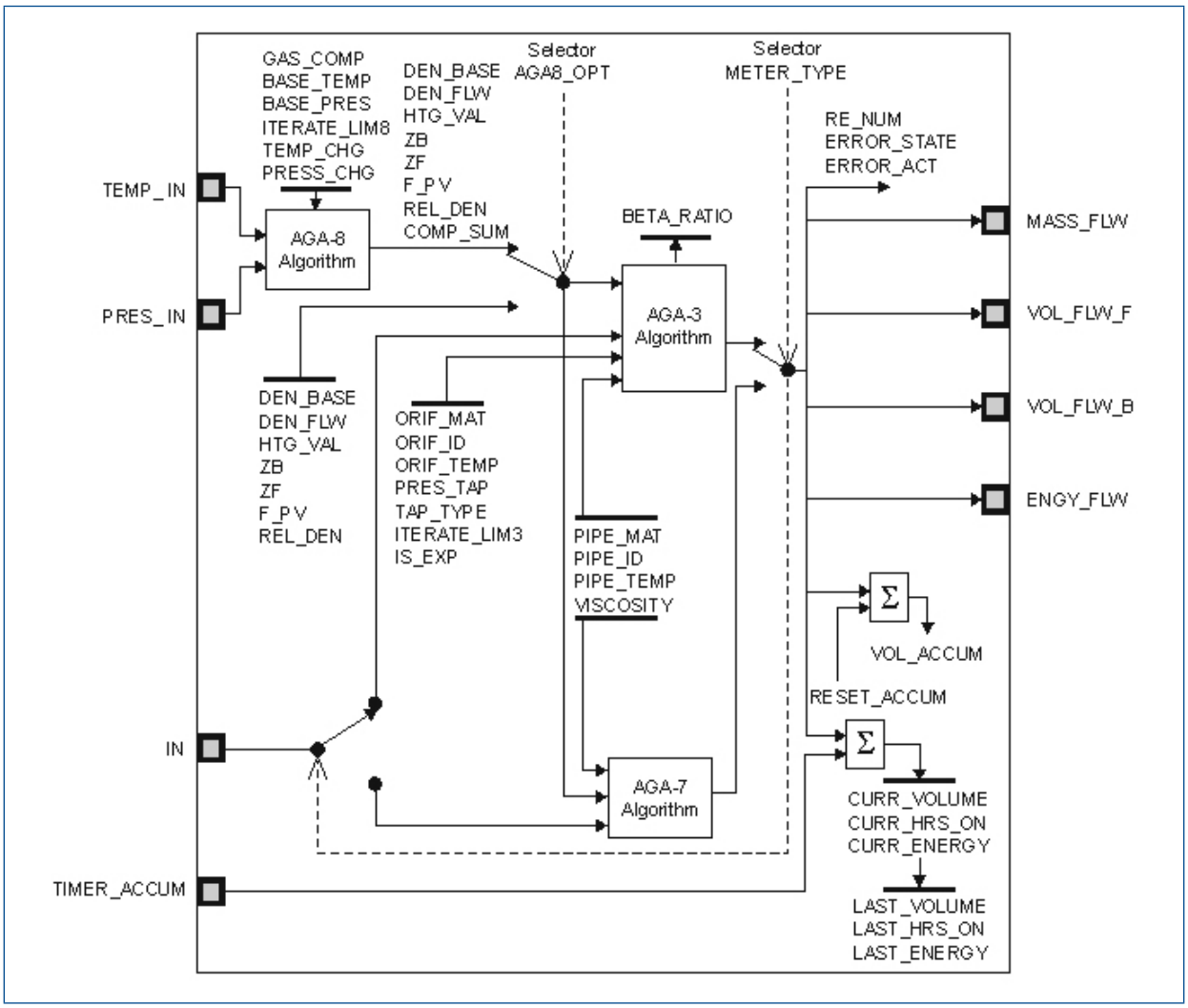
VOL_FLW_F is the volumetric flow rate at flowing conditions in m3/hr (cubic meters per hour)

VOL_FLW_B is the volumetric flow rate at base conditions in m3/hr (cubic meters per hour)

ENGY_FLW is the energy flow in GJ/hr (gigajoules per hour)

Schematic Diagram - AGA Function Blocks

The following figure shows the internal components of the AGA function block:



Block Execution - AGA Function Blocks

The user may specify the algorithms used by the block by means of the following parameters:

METER_TYPE specifies whether an orifice (differential pressure) or turbine (pulse) meter is being used.

AGA8_OPT determines whether the AGA8 parameters are to be calculated by the block or manually entered. The AGA8 parameters include DEN_BASE and DEN_FLW (base and flowing density) and the report parameters ZB, ZF, F_PV, and REL_DEN (compressibility factors, supercompressibility, and relative density). When manual entry is chosen, the block does not calculate HTG_VAL (gas volumetric heating value), which otherwise is calculated using the ISO6976 technique, not AGA8.

The AGA8 parameters are calculated using the mole fractions for the 21 components in GAS_COMP and the base and flowing temperatures and pressures using the detail characterization method. The AGA8 parameters are calculated whenever PRES_IN or TEMP_IN changes from the last AGA8 calculation value by the amount specified in the tunable PRES_CHNG and TEMP_CHNG parameters (but at a minimum of every 60 seconds). The AGA8 parameters are calculated whenever GAS_COMP changes. If the fluid is not a natural gas or other hydrocarbon gas whose components are included in GAS_COMP, choose to manually enter the AGA8 parameters.

For orifice meters TAP_TYPE specifies the type of differential pressure tap, either Flange, Radius (D-D/2), or Corner taps. The block does not calculate flow rates for pipe taps (2.5D-8D).

PRES_TAP specifies the location of the static pressure tap, either Upstream or Downstream of the orifice plate.

The AGA3/ISO5167 algorithm calculates the mass flow rate when METER_TYPE is Differential Pressure. The coefficient of discharge is a function of pipe Reynolds number, which is a function of mass flow. Therefore the calculation of mass flow is an iterative one. The parameter ITERATE_LIM3 specifies the maximum number of iterations allowed. The default value is generally sufficient, but may need to be increased for viscous liquids. The entire flow equation is calculated each block execution, so averaging techniques are not necessary. From the mass flow the block uses the base and flowing densities from AGA8 to determine volumetric flow rates at base and flowing conditions. Like AGA3, the AGA8 algorithms are iterative. ITERATE_LIM8 specifies the maximum iterations allowed. If an iteration limit is violated, the condition is indicated in ERROR_STATE, as are any violations of the limits of use for orifice metering (see Status Handling).

When METER_TYPE is Turbine, the value on IN is the volumetric flow rate at flowing conditions (expected to be wired from the output of a Pulse Input function block). AGA_SI converts this flow to volumetric flow at base conditions and mass flow using the two density values.

Energy flow rate is determined from volumetric flow at base conditions and the volumetric heating value per ISO6976. In the AGA_SI block this is the superior heating value (not inferior) and is for the real gas (not ideal gas). It is based on the mole fractions in GAS_COMP and 15/15 data from ISO6976, which corresponds to a base temperature of 15 deg C and base pressure of 101.325 kPa.

Totalization Parameters

The block accumulates base volumetric flow each scan into two parameters, CURR_VOLUME (reset by TIMER_ACCUM) and VOL_ACCUM (reset by RESET_ACCUM). CURR_VOLUME is intended for daily or shift totals. VOL_ACCUM is intended for ad hoc totals to monitor short-term contract usage. The block accumulates energy flow in CURR_ENERGY and flow hours in CURR_HRS_ON. Flow hours is the number of hours of flow through the pipe where VOL_FLW_B is greater than zero.

The reset parameter TIMER_ACCUM is intended to be wired from OUT_D of a Date Time Event (DTE) function block, which allows resetting at regular intervals. When TIMER_ACCUM is 0, the block allows the accumulation of CURR_VOLUME, CURR_ENERGY, and CURR_HRS_ON. When greater than 0, the block copies the three CURR_ parameters to the three LAST_ parameters and resets the CURR_ parameters. CURR implies today or this shift or whatever the current period represents.

All of the accumulation parameters retain their current value during a module (partial) download and a controller restart. The accumulation parameters have status (see Status Handling).

Status Handling - AGA Function Blocks

The block determines the status of the output parameters and the internal accumulation parameters.

The status of the output parameters is a function of the status of the input parameters and the value of ERROR_STATE.

When ERROR_STATE is other than Clear, it impacts the status of output parameters. The error states include:

- **Gas Composition Sum Not 100%** - The sum of the mole percents in GAS_COMP does not equal 100.00 and AGA8_OPT is Calculate AGA-8 parameters using Detail Method. Contributes to Bad status on the output parameters.
- **Invalid Pipe or Orifice Size** – Actual beta ratio is less than 0.1 or greater than 0.75, or orifice ID is less than 11.43 mm, or pipe ID is less than 48.26 mm. Applicable when METER_TYPE is Differential Pressure. Contributes to Uncertain status on the output parameters.
- **Reynolds Number Out of Range** – Calculated pipe Reynolds number is less than 4000. Applicable when METER_TYPE is Differential Pressure. Contributes to Uncertain status on the output parameters.
- **AGA-8 Algorithm Not Convergent** – The required iterations exceeded ITERATE_LIM8, thus the AGA8 algorithm did not converge. Applicable when AGA8_OPT is Calculate AGA-8 parameters using Detail Method. Contributes to Bad status on the output parameters (does not affect VOL_FLW_F when METER_TYPE is Turbine).
- **AGA-3 Algorithm Not Convergent** – The required iterations exceeded ITERATE_LIM3, thus the AGA3 algorithm did not converge. Contributes to Bad status on the output parameters.

The status of the output parameters is set to the worst of the status of the input parameters and the status based on ERROR_STATE.

The status of the accumulation parameters is Good until a value accumulated has Bad or Uncertain status. At that point the accumulation parameter has Uncertain status until it is reset.

There is a corresponding PCT_ parameter for each accumulation parameter. For example, CURR_VOLUME has PCT_CURR_VOLUME. The PCT_ parameter contains the percentage of the total in the corresponding parameter where the value being accumulated had Good status.

Parameters - AGA Function Blocks

The following table lists the system parameters for the AGA function block:

AGA Block Parameters

Parameter	Units	Description
AGA8_OPT	N/A	Determines whether the block should calculate the AGA8 parameters using the detail method or they are to be manually entered. AGA8 parameters include DEN_FLW, DEN_BASE, ZF, ZB, F_PV, and REL_DEN. AGA8_OPT can be either: ■ **Calculate AGA-8 parameters using Detail Method** - Select this option if the fluid is a natural gas. ■ **Manually enter the AGA-8 parameters** - Select this option for other single-phase, Newtonian fluids under turbulent flow. Manually enter DEN_FLW, DEN_BASE, VISCOSITY, and HTG_VAL (if applicable). Change HTG_VAL, ZF, ZB, F_PV, and REL_DEN to 0.0 when not applicable.
BASE_PRES	kPa (kilopascals absolute)	Base pressure, the reference pressure for base density and base volumetric flow.
BASE_TEMP	°C	Base temperature, the reference temperature for base density and base volumetric flow.
BETA_RATIO	N/A	Calculated ratio of orifice bore to pipe inside diameter after temperature correction. Has meaning when METER_TYPE is *Differential Pressure*.
COMP_SUM	None	The sum of the mole percents in GAS_COMP. If not between 99.995 and 100.005, results in a runtime ERROR_STATE of *Gas composition sum not 100%* if AGA8_Opt is *Calculate AGA-8 parameters using Detail Method*.
CURR_ENERGY	GJ (gigajoules)	The currently active accumulation of energy flow.
CURR_HRS_ON	Hours	The currently active accumulation of time with flow through the pipe (IN > LOW_CUT (differential pressure) or VOL_FLW_F > 0.0 (turbine)).
CURR_VOLUME	m3 (cubic meters)	The currently active accumulation of volumetric flow at base conditions.
DEN_BASE	kg/m3 (kilograms per cubic meter)	Mass density at base conditions. Calculated when AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*, otherwise retains its previous value or the value as entered.
DEN_FLW	kg/m3 (kilograms per cubic meter)	Mass density at flowing conditions. Calculated when AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*, otherwise retains its previous value or the value as entered.
ENGY_FLW	GJ/hr (gigajoules per hour)	Instantaneous energy flow.
ERROR_ACT	N/A	Indicates that an error condition is active (0 = no error, 1 = an error condition is active). The error is defined as text in ERROR_STATE.

ERROR_STATE	N/A	The error state of the block. When other than Clear indicates the validity of the calculations is questionable: ■ **Gas Composition Sum Not 100%** - The sum of the mole percents in GAS_COMP does not = 100.0 and AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*. Results in Bad status on output parameters. ■ **Invalid Pipe or Orifice Size** – Actual beta ratio is less than 0.1 or greater than 0.75, or orifice ID is less than 11.43mm, or pipe ID is less than 48.26mm. Applicable when METER_TYPE is *Differential Pressure*. ■ **Reynolds Number Out of Range** – Calculated pipe Reynolds number is less than 4000. Applicable when METER_TYPE is *Differential Pressure*. ■ **AGA-8 Algo Not Convergent** – The required iterations exceeded ITERATE_LIM8, thus the AGA8 algorithm did not converge. Applicable when AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*. ■ **AGA-3 Algo Not Convergent** – The required iterations exceeded ITERATE_LIM3, thus the AGA3 algorithm did not converge.
F_PV	N/A	Supercompressibility factor, the square root of the ratio of the compressibility factors (base to flowing). Calculated when AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*, otherwise retains its previous value or the value as entered.
GAS_COMP	Mole fractions as percents	An array containing the mole fractions of 21 gas components. 1. Methane 2. Nitrogen 3. Carbon Dioxide 4. Ethane 5. Propane 6. Water 7. Hydrogen Sulfide 8. Hydrogen 9. Carbon Monoxide 10. Oxygen 11. i-Butane 12. n-Butane 13. i-Pentane 14. n-Pentane 15. n-Hexane 16. n-Heptane 17. n-Octane 18. n-Nonane 19. n-Decane 20. Helium 21. Argon

HTG_VAL	MJ/m3 (megajoules per cubic meter)	Volumetric heating value. Calculated per ISO6976 from the mole fractions in GAS_COMP, the superior calorific values of the components, and compressibility factors of the components (15/15 data).
IN	kPa (kilopascals [differential pressure], m3/hr (cubic meters per hour [turbine])	When METER_TYPE is *Differential Pressure*, IN is the measured differential pressure. When METER_TYPE is *Turbine*, IN is the volumetric flow from a Pulse Input function block.
IS_EXP	N/A	Isentropic exponent of the natural gas or other fluid. Enter the value at expected flowing conditions. The default value is reasonable for natural gases. For an incompressible fluid enter –1.0. Not used when METER_TYPE is *Turbine*.
ITERATE_LIM3	N/A	The number of iterations limit for the AGA3 /ISO5167 mass flow calculation
ITERATE_LIM8	N/A	The number of iterations limit for the AGA8 density and compressibility factor calculations.
LAST_ENERGY	GJ (gigajoules)	The total accumulation of energy flow at the time of the last reset (using TIMER_ACCUM).
LAST_HRS_ON	Hours	The total accumulation of time with flow through the pipe at the time of the last reset (using TIMER_ACCUM).
LAST_VOLUME	m3 (cubic meters)	The total accumulation of base volumetric flow at the time of the last reset (using TIMER_ACCUM).
LOW_CUT	kPa (kilopascals)	Value of IN (differential pressure) below which flow is assumed to be zero. Not applicable when METER_TYPE is *Turbine*.
MASS_FLW	kg/hr (kilograms per hour)	Instantaneous mass flow.
METER_TYPE	N/A	Meter type for flow measurement. The value can be *Differential Pressure or Turbine*.
ORIF_ID	mm (millimeters)	Orifice plate bore diameter at reference temperature ORIF_TEMP. Not applicable when METER_TYPE is *Turbine*.
ORIF_MAT	N/A	Orifice plate material. The value can be Stainless Steel, Monel, or Carbon Steel. Not applicable when METER_TYPE is *Turbine*.
ORIF_TEMP	°C	Reference temperature for the orifice plate. Not applicable when METER_TYPE is *Turbine*.
PCT_CURR_ENERGY	Percent	The percentage of the total in CURR_ENERGY where ENGY_FLW had Good status when the value was accumulated.
PCT_CURR_HRS_ON	Percent	The percentage of the total time in CURR_HRS_ON where VOL_FLW_F had Good status when the time was accumulated.
PCT_CURR_VOLUME	Percent	The percentage of the total in CURR_VOLUME where VOL_FLW_B had Good status when the value was accumulated.
PCT_VOL_ACCUM	Percent	The percentage of the total in VOL_ACCUM where VOL_FLW_B had Good status when the value was accumulated.
PCT_LAST_ENERGY	Percent	The percentage of the total in LAST_ENERGY where ENGY_FLW had Good status when the value was accumulated.
PCT_LAST_HRS_ON	Percent	The percentage of the total time in LAST_HRS_ON where VOL_FLW_F had Good status when the time was accumulated.

PCT_LAST_VOLUME	Percent	The percentage of the total in LAST_VOLUME where VOL_FLW_B had Good status when the value was accumulated.
PIPE_ID	mm (millimeters)	Pipe internal diameter at reference temperature PIPE_TEMP.
PIPE_MAT	N/A	Pipe material. The value can be Stainless Steel, Monel, or Carbon Steel.
PIPE_TEMP	°C	Reference temperature for the pipe ID measurement.
PRES_CHNG	kPa (kilopascals)	The amount PRES_IN must differ from its value at the time of the previous AGA-8 calculation to trigger another AGA-8 calculation.
PRES_IN	kPa (kilopascals absolute)	Measured static pressure
PRES_TAP	N/A	Location of the static pressure tap, either Upstream or Downstream of the orifice plate. Not applicable when METER_TYPE is *Turbine*.
RE_NUM	N/A	Calculated Pipe Reynolds number.
REL_DEN	N/A	Real gas relative density (specific gravity). Calculated when AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*, otherwise retains its previous value or the value as entered.
RESET_ACCUM	N/A	Resets VOL_ACCUM when greater than zero, then the block changes RESET_ACCUM back to zero.
TAP_TYPE	N/A	Orifice meter tap type, either Flange Taps, Radius Taps (D-D/2), or Corner Taps.
TEMP_CHNG	°C	How much TEMP_IN must change from the last AGA8 calculation temperature in order to trigger another AGA8 calculation.
TEMP_IN	°C	Measured temperature.
TIMER_ACCUM	N/A	When 0, allows the accumulation of CURR_VOLUME, CURR_ENERGY, and CURR_HRS_ON. When greater than 0, copies the three CURR_ parameters to the three LAST_ parameters and resets the CURR_ parameters. TIMER_ACCUM is typically wired from a Date Time Event function block.
VISCOSITY	kg/m-hr (kilograms per meter per hour)	The absolute viscosity of the natural gas or other fluid. Enter the value at expected flowing conditions based on laboratory analysis or other method.
VOL_ACCUM	m3 (cubic meters)	Accumulation of volumetric flow at base conditions. It is reset using RESET_ACCUM, which is expected to be done manually at irregular time intervals. Similar to CURR_VOLUME, which is also an accumulation of base volumetric flow, but CURR_VOLUME expected to be reset automatically at regular time intervals (using TIMER_ACCUM).
VOL_FLW_B	m3/hr (cubic meters per hour)	Instantaneous volumetric flow at base conditions.
VOL_FLW_F	m3/hr (cubic meters per hour)	Instantaneous volumetric flow at flowing conditions.
ZB	N/A	Compressibility factor at base conditions. Calculated when AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*, otherwise retains its previous value or the value as entered.

ZF	N/A	Compressibility factor at flowing conditions. Calculated when AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*, otherwise retains its previous value or the value as entered.

Note *Default values and data type information for the parameters are available by expanding the Parameter View window.*

Application Information - AGA Function Blocks

The primary considerations when applying the AGA_SI block are

- What type of meter is involved? Is it an orifice or turbine meter?
- Is the fluid a natural gas or a related hydrocarbon gas whose components are included in the array in the GAS_COMP parameter? Or is the fluid a liquid or gas whose components are not in GAS_COMP?

With an **orifice meter** choose Differential Pressure as the METER_TYPE and wire the IN input from an Analog Input function block connected to a differential pressure transmitter. The engineering units must be kPa (kilopascals).

With a **turbine meter** wire the IN input from a Pulse Input function block. OUT of the PIN block must in units of cubic meters per hour. Therefore the PULSE_VAL in the PIN block must be in units of cubic meters per pulse (inverse of the K-Factor) and TIME_UNITS must be Hours.

If the fluid is **natural gas** or related hydrocarbon gas, choose the default value for AGA8_OPT so that the block calculates the base and flowing densities of the gas per AGA8 and the report parameters (base and flowing compressibility factors, supercompressibility, and relative density). The block also calculates the volumetric heating value of the gas (per ISO6976).

If the fluid is a **liquid or other gas**, use AGA8_OPT to choose to manually enter these parameters. Typically you would enter the two densities and leave the other parameters at their default value. If the notion of energy is applicable, enter the volumetric heating value of the fluid at base conditions.

Other Considerations

When you choose for the block to calculate the AGA8 parameters, configure the base temperature and pressure and enter the mole fractions of the components in GAS_COMP as percents. If you interface to an online gas chromatograph, use a Calc block expression to assign the value of the elements of GAS_COMP. For example, to assign the Methane mole percent

‘^/AGA_SI1/GAS_COMP[1][1]’ := ‘//GC01/R30001.CV’; where GC01 is the DST for a serial dataset

To assign the Nitrogen mole percent

‘^/AGA_SI1/GAS_COMP[2][1]’ := ‘//GC01/R30002.CV’; where GC01 is the DST for a serial dataset

If necessary, modify the value of one component before writing to GAS_COMP so that the sum of components is 100%. If the sum is not between 99.995 and 100.005, an error will occur in ERROR_STATE and the status of the outputs will be Bad.

Enter the absolute viscosity of the fluid at expected flowing conditions in the parameter VISCOSITY based on a laboratory analysis, calculation, or published data. The block does not calculate viscosity. The default value is reasonable for a natural gas. For orifice meters the value of viscosity impacts the calculated mass flow rate. For turbine meters viscosity is used only to calculate the pipe Reynolds number (which is also true for PIPE_ID, PIPE_MAT, and PIPE_TEMP).

For orifice meters enter a value for the isentropic exponent of the fluid in the parameter IS_EXP. This is the ratio of specific heats (constant pressure to constant volume). The default value is reasonable for natural gases. For an incompressible fluid enter a value of –1.0. The block does not use IS_EXP for turbine meters.

To reset the accumulation parameters CURR_VOLUME, CURR_ENERGY, and CURR_HRS_ON wire the TIMER_ACCUM input from the output of a Date Time Event function block. Configure the DTE block to produce a rising edge on its OUT_D parameter at the contract hour each day or at whatever interval you wish to reset the parameters. Configure the DTE block by setting INTERVAL_STR to the desired number of days, hours, minutes, or seconds between resets, for example P00001T00:00:00 for resetting daily or P00000T08:00:00 for resetting every eight hours. Then set TE_TIME_STR to the first time you want a reset to occur (in local time), for example, 2002-12-25T09:00:00 if the contract hour is 9 am. When TE_TIME_STR is a time in the past, the DTE block knows how to properly arm itself for the next reset upon any download.

Using AGA Function Blocks with DeltaV Live

DeltaV Graphics Studio contains GEMs for the AGA_SI and AGA_US function blocks. They can be found in the Graphics Studio Library Explorer, in the GEM Classes “AGA” folder. These GEMS show operating parameters for the configured function block and are applicable for orifice and turbine meters.

Using AGA Function Blocks with DeltaV Operate

DeltaV Operate has a dynamo set called AGA containing a group display faceplate for the AGA_SI and AGA_US function blocks. The faceplate shows operating parameters for the block and is applicable for orifice and turbine meters (the IN parameter value is not visible when METER_TYPE is Turbine). In configure mode drag the dynamo onto a picture. Enter the path for the AGA_SI or AGA_US function block in the edit dialog.

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