

AGA Calculations – 1985 Standard VS 1992 Standard

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Section 1 - BACKGROUND

This paper is intended to help bridge the gap between the Old AGA-3 equation (hereafter referred to as AGA-3-1985) and the New AGA-3 equation (hereafter referred to as AGA-3-1992). As such the paper begins with a background section aimed at assisting those who are mostly familiar with the *factored form* of the orifice metering equation.

Factored VS Fundamental flow rate equation form

Of the following two equations, which are published in the AGA-3-1985 standard?

- (a) equation 1
- (b) equation 2
- (c) both equation 1 and 2
- (d) don't know

$$Q_v = \frac{C_d}{\sqrt{1-\beta^4}} Y \frac{\pi}{4} d^2 \sqrt{2 g_c \rho_f \Delta P}$$

eq 1

$$Q_v = C' \sqrt{h_w P_f} \quad \text{where,}$$

$$C' = F_b F_r Y F_{pb} F_{tb} F_{if} F_{gr} F_{pv} \quad \text{eq 2}$$

The correct answer is (c). Both equations are actually published in the 1985 standard and they are both equivalent within their scope of applicability. Equation 2 is often referred to as the *factored* form of the AGA-3 equation. It can be found on page 38 of the 1985 standard as equations (59) and (60). Equation 1 is the fundamental orifice meter equation. It can be found on page 25 of the 1985 standard and is actually a combination of equations (3) and (7) on that page.

Equation 1 describes the theoretical basis, the physical and practical realities of an orifice flow meter. Equation 2, the *factored* equation, is based on or derived from equation 1. Why bring all this up now? If you are like this author was at one time, you might only be familiar with the *factored* equation. If so, I recommended you become more familiar with the fundamental form of the equation. Firstly,

because this form more readily facilitates comparing AGA-3-1985 and AGA-3-1992. Secondly, you will be more comfortable with the new AGA-3-1992 standard. Thirdly, because it more clearly describes orifice meter dynamics.

Why are there different forms of the equation anyway? The first *factored* form of the equation was introduced in 1935 with the publication of Gas Measurement Committee Report No. 2. Before that time the factors were not in use. Factors are a convention that allow various terms of the fundamental equation to be calculated individually. This allows tables to be generated for each factor which can then be used to *estimate* volumes. These tables were especially useful before the availability of computers and programmable calculators. They are still used and will continue to be used, but their usage is diminishing with the advent of electronic instrumentation.

C_d Coefficient of Discharge

If the old factored equation is all you have been using, you may have never really dealt with C_d. Basically, C_d is imbedded in the old *factored* equation as part of (F_b * F_r). Reviewing equation 1 of this document you will notice C_d is included as part of AGA-3-1985's fundamental equation. It has always been there, simply hidden by the factors. Most of the research and development undertaken over the last several years was for the purpose of deriving a more accurate, technically defensible correlation between a published C_d equation and actual laboratory data. This is at the heart of the changes in AGA-3-1992.

What is the purpose of C_d in the fundamental equation?

$$C_d = \frac{\text{true flow rate}}{\text{theoretical flow rate}}$$

The true flow rate is determined in a laboratory by weighing or by volumetric collection of the fluid over a measured time interval and the theoretical flow rate is calculated. Then a discharge coefficient (C_d) is computed as a correction factor to the theoretical flow rate. This data is all generated over varying flow rates, fluid types (Reynolds number

conditions) and various geometries (diameters). Once all the data is taken then an empirical equation is derived which allows us to compute C_D over many combinations of conditions.

That is what C_D , the coefficient of discharge is. It is a high falutin' fudge factor. The developers of the new equation have taken advantage of newer technology in more numerous testing labs to gather more real world data over a wider set of operating conditions. They have also postulated on a new form of the C_D equation that they believe more closely correlates to the fluid dynamics associated with the physics of an orifice meter. This means the new C_D is based more on first principles than the older one. You might say it has a higher falutin' index than the older coefficient of discharge.

Why does the theoretical equation not match the real world exactly?

In trying to keep orifice metering practical, simplifying assumptions are sometimes made. It is simply not always possible, practical or necessary to perfectly model the real world. Some of the things influencing the theoretical equation, causing it not to model the real world exactly are:

- (1) It is assumed there is no energy loss between the taps.
- (2) The velocity profile (Reynolds number) influences are not fully treated by the equation. It is assumed that some installation effects and causes of flow perturbations (changes) are insignificant.
- (3) Different tap locations affect the flow rate. Tap location is assumed for a given C_D .

Through rigorous testing, you could develop a unique C_D for each of your orifice meters. This technique, referred to as in-situ calibration, is something like proving a linear meter. However it is somewhat bothersome since you need a unique C_D for each expected flow rate. Economics usually make in-situ procedures unfeasible.

Therefore, the goal is to develop a *universal* C_D that everyone can use. To accomplish this, one must control their orifice meter installation well enough so that it replicates the same orifice meters used in the laboratory from which the *universal* C_D equation was derived. This is referred to as the law of similarity. If your orifice meter system is acceptably similar to the laboratory's then your C_D will be acceptably similar to the laboratory derived C_D . That is why

edge sharpness, wall roughness, eccentricity and flow conditioning, etc. are so important. Ideally your flow measurement system would be exactly the same as was used in the laboratory.

Density

If the old factored equation is all you have been using, you may have never really dealt with density. Looking back at Equation 1 of this document you will notice two symbols, ρ_f and ρ_b . The symbol ρ (pronounced rho) is used to represent density.

ρ_f = density at flowing conditions

ρ_b = density at base conditions

Most measurement systems do not have density as a live input, so density is computed from other data that is available. When the fluid being measured is a gas, density is computed from other data as follows:

Density at Flowing Conditions

$$\rho_f = \frac{P_f M_{r_{air}} G_i}{Z_f R (T_f + N_5)} \quad eq. 3$$

Density at Base Conditions

$$\rho_b = \frac{P_b M_{r_{air}} G_i}{Z_b R (T_b + N_5)} \quad eq. 4$$

Notice P_f , T_f , Z_f , G_i , P_b , T_b , and Z_b in eq 3 and eq 4. These represent temperatures, pressures, specific gravities and compressibilities. It is these variables that eventually make their way into the old factors F_{tb} , F_{pb} , F_{tf} , F_{gr} , and F_{pv} (see Section 3 of this document for more information). Leaving densities in the fundamental equation, rather than hiding them in a plethora (abundance) of factors, seems less confusing and more instructive.

Real VS Ideal Gas Specific Gravity

One other item of note regarding the density equations is that they are based on G_i , ideal gas specific gravity. Most systems have historically provided G_r , real gas specific gravity, which is different. Additionally AGA-8 requires G_r as an input, not G_i . Strictly speaking, G_i is related to G_r with the following equation.

$$G_i = G_r \left[\frac{P_{m_{air}} (T_{m_{gas}} + N_5) Z_{m_{gas}}}{P_{m_{gas}} (T_{m_{air}} + N_5) Z_{m_{air}}} \right]$$

Practically speaking the measurement system does not usually have enough information available to solve the above equation. Part 3 of the new standard makes the following statements regarding this issue.

*"the pressures and temperatures are defined to be at the same designated base conditions.....". And again in a following paragraph, "The fact that the temperature and/or pressure are not always at base conditions results in small variations in determinations of relative density (specific gravity). Another source of variation is the use of atmospheric air. The composition of atmospheric air - and its molecular weight and density - varies with time and geographical location."*³

Based on this, and several of the examples in the standard, the following simplifying assumptions are made:

$$P_{m_{air}} = P_{m_{gas}} = P_b$$

and

$$T_{m_{air}} = T_{m_{gas}} = T_b$$

so that,

$$G_i = G_r \left[\frac{Z_{b_{gas}}}{Z_{b_{air}}} \right] = G_r \left[\frac{Z_{b_{gas}}}{0.99959} \right]$$

eq. 5

This equation for G_i is exactly like the one shown as equation 3-48 on page 19 of Part 3 of the new standard.

Conclusion

These are the major new equation concepts you might need to learn if the older factored equation is all you are familiar with. A more detailed comparison between the *fundamental equation* and the *factored equation* is presented in Section 3. The following section summarizes changes to the new standard.

Section 2 - SUMMARY OF CHANGES TO THE STANDARD

Change 1, Document Organization

Rather than one document, the standard is now published in 4 parts, each of which is a unique document.

Part 1 - General Equations and Uncertainty Guidelines

The mass and volumetric flow rate equations and their theory are discussed. The empirical equations for C_d and Y are presented. Uncertainty guidelines are presented for determining possible errors associated with using the standard.

Part 2 - Specification and Installation Requirements

Mechanical specifications are presented for the orifice meter. In particular orifice plates, plate holders, sensing taps, meter tubes and flow conditioners are discussed.

Part 3 - Natural Gas Applications

The fundamental equation, as presented in Part 1, is not restricted to a specific fluid or system of units. Part 3 provides a guide for forcing the equation to compute volumes assuming the fluid is natural gas and the inch-pound system of units. It is in appendix B of this part that a factored form of the equation is developed.

Part 4 - Background, Development, Implementation Procedures and Subroutine Documentation

The history and evolution of the equation is included in this part beginning with Report No. 1 from the 1920s. A description of the research that was undertaken to derive the new equation is presented. Implementation procedures, guidelines, and subroutine recommendations are also documented to assist programmers with implementing the new equation on computers. Intermediate results are also available to assist with program verification. Inclusion of computer related documentation of this sort is completely new for the AGA-3 standard and recognizes both the need for a computer to solve the new equation and the availability of computers to accomplish this.

Change 2, The nomenclature of the fundamental equation was modified slightly.

It is important to note that the fundamental equation did not actually change. Since it is based on the actual physics of an orifice meter you would not expect it to change. However, nomenclature was slightly modified.

eq. 1, AGA-3-1985 Fundamental Equation

$$Q_v = \frac{\frac{C_d}{\sqrt{1-\beta^4}} Y \frac{\pi}{4} d^2 \sqrt{2 g_c \rho_f \Delta P}}{\rho_b}$$

eq. 7, AGA-3-1992 Fundamental Equation

$$Q_v = \frac{\frac{\pi}{4} N_c C_d E_v Y d^2 \sqrt{2 \rho_f \Delta P}}{\rho_b}$$

Table 2-1
Fundamental Equation Nomenclature Changes

AGA-3-1985 Equation	AGA-3-1992 Equation
$\frac{1}{\sqrt{1-\beta^4}}$ - velocity of approach equation	E_v - Velocity of Approach Symbol
$\sqrt{g_c}$ - Dimension Conversion Constant	N_c - Numeric Constant *

* N_c is combined with other constants before solving the equation. These other constants are a function of the system of units chosen.

Change 3, Cd-New coefficient of discharge solution requires an iterative solution

As was stated earlier, C_d is at the heart of the changes for AGA-3-1992. Many people spent substantial time and effort in various countries conducting tests to provide new data that could be used to empirically derive a better, more technically defensible coefficient of discharge.

Once the data was gathered and accepted, talented people, using computers, derived a C_d equation that has a high degree of correlation with all the new data. This means that, within the stated uncertainties of Part I of the new standard, you can feel confident that when applied as specified by the standard, the new C_d equation will produce dependable answers.

The tricky part about C_d is that one needs to know the flow rate to compute it. But one also needs the C_d to compute the flow rate. This is a sort of catch 22. In a situation like this we say the equation is *not in closed form*. This is why you will hear people say an *iterative solution* is required to compute the new C_d .

What does *iterative solution* mean? It means you, (or more likely a computer) begin with an estimate for C_d . Based on that C_d , an estimated Reynolds Number, Flow Rate and a subsequent new C_d are computed. The two C_d values (C_{d_old} and C_{d_new}) are compared and if they differ by more than an acceptable threshold, the process is repeated. Each time the process is repeated the most recent C_d is retained for comparison with the next one being computed. Eventually, the difference between C_{d_old} and C_{d_new} become so small it is safe to assume the proper C_d value has been obtained. API designers estimate that, most of the time, no more than three iterations will be required. I believe no more than 10 iterations were ever required on the test cases. An exact procedure is outlined in Part 4 of the new standard under Procedure 4.3.2.9. In that procedure the threshold for determining acceptable convergence is six significant digits (0.000005).

Change 4, Thermal effect corrections on Pipe and Orifice diameters are required

In the AGA-3-1985 standard an optional orifice thermal expansion factor, F_a , was specified to correct for the error resulting from thermal effects on the orifice plate diameter.

In the AGA-3-1992 standard this type of correction is not optional. It is required. Additionally you must also make corrections for thermal effects on the pipe diameter.

Another new requirement is that these corrections cannot be tacked onto the end of the equation as a factor. They are to be applied on the front end as adjustments to the diameters themselves. Therefore, the end user should be supplying diameters at a reference temperature (68 DegF), and the device solving the equation should be adjusting the

diameters based on the difference between the reference temperature and the actual fluid temperature.

This means that virtually none of the equation can be pre-computed and re-used. Even though the new equation does not have F_b , there are portions of the equation that depend only on the diameters. In the past, we would compute those portions of the equation only when the diameters manually changed. Now, since the diameters are a function of temperature they, and everything based on them, must be computed on a continual basis.

Assume the measurement system is supplied d_r , orifice diameter at reference temperature and D_r , pipe diameter and reference temperature. Before these diameters can be used anywhere in the flow rate calculation they must be corrected for thermal effects with the following equations.

Corrected orifice diameter

$$d = d_r \left[1 + \alpha_1 (T_f - T_r) \right]$$

Corrected pipe diameter

$$D = D_r \left[1 + \alpha_2 (T_f - T_r) \right]$$

Change 5, Downstream expansion factor, requires additional compressibility

The equations for upstream expansion factor have not changed. However to compute the downstream expansion factor, real gas effects must now be accounted for. This means an additional Z, compressibility calculation is required when computing the downstream expansion factor.

If your system measures static pressure downstream, but you do not want to incur the additional processing to compute another Z for the expansion factor there is something you can do.

You can compute the upstream pressure as follows and use it to compute the upstream expansion factor.

$$P_{f1} = P_{f2} + \frac{\Delta P}{N}$$

where N is a conversion constant from differential pressure to static pressure units.

If you employ this technique, you must be careful to use P_{f1} for all occurrences of static pressure in the flow rate equation. You cannot use upstream pressure in some places and downstream pressure in others.

Change 6, Fpv, supercompressibility is computed using AGA-8

Many people have been using NX-19 to compute Fpv for natural gas. The new standard specifies AGA-8.

A new AGA-8 standard was published in late 1992. That standard documents two possible ways to compute Fpv. One method is referred to as *gross method*, the other is referred to as *detailed method*. The *gross method* is supposed to be simpler to implement and require less computing power than the *detailed method*. Having worked with both, I can tell you that compared to either of these methods NX-19 processing requirements are relatively minuscule (small).

As a user, there are two major distinctions between the gross and detailed methods you should consider.

1. The *gross method* accepts the same composition data you are used to supplying for NX-19 (specific gravity, percent CO2 and N2). The *detailed method* requires a total analysis. What constitutes a total analysis depends on each measurement site. Generally, composition through C6s is considered a total analysis. Sometimes C7s or C8s or C9s might need to be broken out. The *detailed method* of the equation will support this if needed.
2. The *gross method* is applicable over a narrower range of operating conditions than the *detailed method*. The *gross method* was designed to be applicable for pipeline quality natural gas at normal pipeline pressures and temperatures. For example, the gross method supports up to 0.02% Hydrogen Sulfide, while the detailed method supports up to 100% Hydrogen Sulfide.

The following table summarizes the range of applicability for the two methods. The Normal Range column applies to the *gross method*. The Expanded Range column applies to the *detailed method*.

Table 2-2 - AGA-8 Ranges of Applicability

QUANTITY	NORMAL RANGE	EXPANDED RANGE
Relative Density (Gr)	0.56 to 0.87	0.07 to 1.52
Gross Heating Value	477 to 1150 Btu/scf	0.0 to 1800 Btu/scf
Mol Percent Methane	45.0 to 100.0	0.0 to 100.0
Mol Percent Nitrogen	0.0 to 50.0	0.0 to 100.0
Mol Percent Carbon Dioxide	0.0 to 30.0	0.0 to 100.0
Mol Percent Ethane	0.0 to 10.0	0.0 to 100.0
Mol Percent Propane	0.0 to 4.0	0.0 to 12.0
Mol Percent Butanes	0.0 to 1.0	0.0 to 6.0
Mol Percent Pentanes	0.0 to 0.3	0.0 to 4.0
Mol Percent Hexanes Plus	0.0 to 0.2	0.00 to Dew Point
Mol Percent Helium	0.0 to 0.2	0.0 to 3.0
Mol Percent Hydrogen	Assumed 0.0	0.0 to 100.0
Mol Percent Carbon Monoxide	Assumed 0.0	0.0 to 3.0
Mol Percent Argon	Assumed 0.0	0.0 to 1.0
Mol Percent Oxygen	Assumed 0.0	0.0 to 21.0
Mol Percent Water	0.0 to 0.05	0.0 to Dew Point
Mol Percent Hydrogen Sulfide	0.0 to 0.02	0.0 to 100.0
Flowing Pressure	1200 psia (8.3 MPa)	20,000 psia (140 MPa)
Flowing Temperature	32 to 130 Deg F (0 to 55 DegC)	-200 to 400 DegF (-130 to 200 DegC)

Note: This table taken from Table 1, page 3 of AGA-8 Standard⁵

Change 7, Implementation guidelines for computers are provided

As mentioned earlier, Part IV provides these guidelines and test cases to check out a program. Inclusion of computer related documentation of this sort is completely new for the AGA-3 standard and recognizes both the need for a computer to solve the new equation and the availability of computers to accomplish this.

Change 8, Older factored form of equation not as prominent

This has already been discussed. The factored approach is relegated to an appendix in Part 3 of the new standard. Strictly speaking, appendices are not considered a binding part of the standard. They exist for informational purposes. The implementation guidelines in Part IV do not even mention factors, as such. See Section 3 of this document for more detail.

Change 9, 50 ppm tolerance on computer solutions expected

Part 4 of the standard states,

"The implementation procedures in this document provide consistent computed flow rates for orifice meter installations which comply with other parts of this standard. A particular implementation may deviate from the supplied procedures only to the extent that the final calculated flow rate does not differ from

*that calculated using the presented implementation procedure using IEEE Standard 754 double precision arithmetic by more than 50 parts per million in any case covered by the standard."*⁴

Change 10, Pipe Taps not supported by new standard

The coefficient of discharge research did not include pipe taps. Since C_d is a function of tap location, the new C_d equation does not support pipe taps. The standard directs you back to the AGA-3-1985 standard to handle pipe taps.

Change 11, Zb for air changed

Air's compressibility at base conditions was changed from 0.99949 to 0.99959

Change 12, Uncertainty statement was revised

Optimistically, the AGA-3-85 uncertainty statement was approximately 0.5%. The new statement is approximately 0.5% for C_d plus uncertainty in other measured variables. Typical is probably between 0.6% and 0.7%.

This may sound as if the new equation has as much uncertainty as the old. However, it appears the AGA-3-1985 uncertainty statement was very optimistic and, strictly speaking, was not technically defensible over all the operating conditions for which it was being used.

The new standard is expected to improve the uncertainty by 0.1% - 0.5%.⁶

Regarding this issue, a summary of statements taken from Part 4 of the new standard follows:

The orifice equation in use through AGA-3-1985 was based on data collected in 1932/33 under the direction of Professor S.R. Beitler at Ohio State University (OSU). The results of these experiments were used by Dr. Edgar Buckingham and Mr. Howard Bean to develop the coefficient of discharge equation.

In the 1970's, researchers reevaluated the OSU data and found a number of reasons to question some of the data points. This analysis identified 303 technically defensible data points from the OSU experiments. Unfortunately it is not known which points were used by Buckingham/Bean to generate the discharge coefficient equation.

Statistical analysis of the Regression Data Set (the new data set) showed that in several regions, the Buckingham/Bean equations did not accurately represent that data.⁴

This means that the uncertainty statement in the AGA-3-1985 standard cannot be substantiated in all cases.

Changes 13-18, Changes to Part 2 - Specification and Installation Guidelines

Since this paper mostly deals with the equation, details about changes to the installation requirements are only mentioned in brief here.

- **Diameters' reference temperature is 68 Degrees Fahrenheit.**
- **Minimum orifice bore thickness is specified**
old no statement
new bore must be larger of
($e \geq 0.01d$) or ($e > 0.005$) inch
- **Orifice plate thickness specification was changed**
Table has same values, but statement restricting range of applicability to ($hw < 200$ in. H₂O) and ($T_f < 150$ DegF)
- **Meter tube roughness specification was changed**
old 300 microinches in all cases

new 300 microinches if Beta < 0.6 and
250 microinches if Beta \geq 0.6

- **Meter tube diameter tolerances were changed**

For Any Diameter

old range of 0.1 to 0.75 %
depending on Beta

new 0.25% regardless of Beta

For Max-Min Diameter

old range of 0.1 to 0.75 % depending on
Beta

new 0.5% regardless of Beta

- **Eccentricity requirement was changed**

old $\epsilon \leq 0.03 D_m$

new $\epsilon \leq \frac{0.0025 D_m}{0.1 + 2.3 \beta_m^4}$

- **Perpendicularity requirement added**

New statement that orifice plate plane must be kept at an angle of 90 degrees to the meter tube axis.

This concludes the overview of changes in the new orifice metering standard.

Section 3 - MORE ON FACTORS

In this section a table is developed to more clearly show the relationships between the fundamental and factored equation forms (both AGA-3-1985 and AGA-3-1992). A complete derivation of factors will not be shown here. Both the 1985 and 1992 standards already document those derivations. To be more instructive, the density terms of equations 1 and 2 are shown being calculated using density equations 3 and 4. Additionally, within the density equations, G_i is computed based on equation 5. These equation numbers refer to equations in this document.

1985-AGA-3 fundamental equation shown with density equations included

Substituting density equations (eq. 3 and eq. 4) and ideal gas gravity equation (eq. 5) into the AGA-3-1985 fundamental equation (eq. 1) results in equation A-1 as shown below.

$$\begin{array}{c}
 \rho_f = \frac{P_f M_{r,air} (G_i)}{Z_f R (T_f + N_5)} \quad \leftarrow \quad G_i = G_r \left[\frac{Z_{b,gs}}{Z_{b,air}} \right] \\
 \rho_b = \frac{P_b M_{r,air} (G_i)}{Z_b R (T_b + N_5)} \\
 Q_v = \frac{\frac{C_d}{\sqrt{1-\beta^4}} Y \frac{\pi}{4} d^2 \sqrt{2 g_c \rho_f \Delta P}}{\rho_b}
 \end{array}$$

Substituting equations as shown above results in equation A-1 below.

Equation A-1

$$Q_v = \frac{\frac{C_d}{\sqrt{1-\beta^4}} Y \frac{\pi}{4} d^2 \sqrt{2 g_c \left(\frac{P_f M_{r,air} \left(G_r \left[\frac{Z_{b,gs}}{Z_{b,air}} \right] \right)}{Z_{f,gs} R (T_f + N_5)} \right) \Delta P}}{\left(\frac{P_b M_{r,air} \left(G_r \left[\frac{Z_{b,gs}}{Z_{b,air}} \right] \right)}{Z_{b,gs} R (T_b + N_5)} \right)}$$

AGA-3-1992 fundamental equation shown with density equations included

Substituting density equations (eq. 3 and eq. 4) and ideal gas gravity equation (eq. 5) into the AGA-3-1992 fundamental equation (eq. 7) results in equation A-2 as shown below.

$$\begin{array}{c}
 \rho_f = \frac{P_f M_{r,air} (G_i)}{Z_f R (T_f + N_5)} \quad \leftarrow \quad G_i = G_r \left[\frac{Z_{b,gs}}{Z_{b,air}} \right] \\
 \rho_b = \frac{P_b M_{r,air} (G_i)}{Z_b R (T_b + N_5)} \\
 Q_v = \frac{\frac{\pi}{4} N_c C_d E_v Y d^2 \sqrt{2 \rho_f \Delta P}}{\rho_b}
 \end{array}$$

Substituting equations as shown above results in equation A-2 below.

Equation A-2

$$Q_v = \frac{\frac{\pi}{4} N_c C_d E_v Y d^2 \sqrt{2 g_c \left(\frac{P_f M_{r,air} \left(G_r \left[\frac{Z_{b,gs}}{Z_{b,air}} \right] \right)}{Z_{f,gs} R (T_f + N_5)} \right) \Delta P}}{\left(\frac{P_b M_{r,air} \left(G_r \left[\frac{Z_{b,gs}}{Z_{b,air}} \right] \right)}{Z_{b,gs} R (T_b + N_5)} \right)}$$

Table 3-1 Fundamental Equation Terms included in Factored Equation Terms

AGA-3-1985 Fundamental Term(s). From eq A-1	AGA-3-1985 Factor	AGA-3-1992 Fundamental Term(s). From eq A-2	AGA-3-1992 Factor (Part 3,AppendixB)
$\frac{\frac{C_d}{\sqrt{1-\beta^3}} \frac{\pi}{4} d^2 \sqrt{2g_c} \left(\frac{M_{r_{air}} \left(\left[\frac{1}{Z_{b_{air}}} \right] \right)}{R} \right)}{\left(\frac{M_{r_{air}} \left(\left[\frac{1}{Z_{b_{air}}} \right] \right)}{R} \right)}$	Fb * Fr	Not Applicable	Not Applicable
Y	Y	Y	Y
$\sqrt{\frac{Z_{b_{gas}}}{Z_{f_{gas}}}}$	F_{pv}	$\sqrt{\frac{Z_{b_{gas}}}{Z_{f_{gas}}}}$	F_{pv}
$\frac{\sqrt{G_r}}{G_r}$	F_{gr}	$\frac{\sqrt{G_r}}{G_r}$	F_{gr}
$\sqrt{\frac{1}{(T_f + N_s)}}$	F_{ff}	$\sqrt{\frac{1}{(T_f + N_s)}}$	F_{ff}
P_b	F_{pb}	P_b	F_{pb}
T_b	F_{tb}	T_b	F_{tb}
$\sqrt{P_f \Delta P}$	Extension	$\sqrt{P_f \Delta P}$	Extension
Not Applicable	Not Applicable	C_d	$(F_c + F_{sl})$
Not Applicable	Not Applicable	E_v	E_v
Not Applicable	Not Applicable	$\frac{\frac{\pi}{4} N_c \sqrt{2 \left(\frac{M_{r_{air}}}{R} \right)}}{\left(\frac{M_{r_{air}} \left(\left[\frac{1}{Z_{b_{air}}} \right] \right)}{R} \right)}$	F_n

Section 4 - PART 4's NEW EQUATION PROCEDURES

To date, most publications in the public domain, have included summaries of the new equations as presented in Parts 1 and 3 of the new standard. Since Part 4 of the new standard is intended as a guide for those taking on the task of implementing the equation, it seems appropriate to include a summary of it here. This does not provide all the necessary information to completely implement the new equation, but it should give you a feel for the scope of work involved.

General Outline of Solution Procedures

For this example it is assumed the fluid being measured is natural gas. The general outline of the solution procedures for flange-tapped orifice meters is as follows:

1. At T_f , calculate terms that depend only upon orifice geometry: d , D , β , E_v and C_d correlation terms.
2. Calculate the upstream flowing pressure, P_f from either P_{f2} or P_{f1} and D_p .
3. Calculate required fluid properties (G_i , Rho_f , and Rho_b) at T_f , P_f and other specified fluid conditions.
4. Calculate the upstream expansion factor.
5. Determine the converged value of C_d .
6. Calculate the final value of Q_b .

Detailed Outline of Solution Procedures

- 1. At T_f , calculate terms that depend only upon orifice geometry: d , D , b , E_v and orifice coefficient correlation terms.**

Calculate corrected orifice diameter

$$d = d_r \left[1 + \alpha_1 (T_f - T_r) \right]$$

Calculate corrected pipe diameter

$$D = D_r \left[1 + \alpha_2 (T_f - T_r) \right]$$

Calculate Beta

$$\beta = \frac{d}{D}$$

Calculate velocity of approach term

$$E_v = \frac{1}{\sqrt{1 - \beta^4}}$$

Note: In the following equations A0 through A6 and S1 through S8 are references to constants that are documented in the standard.

Calculate orifice coefficient of discharge constants

$$L_1 = L_2 = \frac{N_4}{D}$$

$$M_2 = \frac{2L_2}{1 - \beta}$$

$$T_u = \left[S_2 + S_3 e^{-8.5L_1} + S_4 e^{-6.0L_1} \right] \frac{\beta^4}{1 - \beta^4}$$

$$T_D = S_6 \left[M_2 + S_7 M_2^{1.3} \right] \beta^{1.1}$$

If $D > (A_4 N_4)$

Then $T_s = 0.0$

Else $T_s = A_3 (1 - \beta) \left(A_4 - \frac{D}{N_4} \right)$

Additional Tap Term for small diameter pipe

$$C_{d_0} = A_0 + A_1 \beta^2 + A_2 \beta^8 + T_U + T_D + T_S$$

$$C_{d_1} = A_5 \beta^{0.7} (250)^{0.7}$$

$$C_{d_2} = A_6 \beta^4 (250)^{0.35}$$

$$C_{d_3} = S_1 \beta^4 \beta^{0.8} (4.75)^{0.8} (250)^{0.35}$$

$$C_{d_4} = (S_5 T_U + S_8 T_D) \beta^{0.8} (4.75)^{0.8}$$

- 2. Calculate the upstream flowing pressure, P_f from either P_{f2} or P_{f1} and D_p**

$$P_f = P_{f_i} = \frac{\Delta P}{N_3} + P_{f_2}$$

- 3. Calculate required fluid properties (G_i , Rho_f , and Rho_b) at T_f , P_f and other specified fluid conditions.**

Using AGA-8 Compute Z_b Gas at (T_b and P_b) and Z_f Gas at (T_f and P_f). Then, compute G_i , Rho_f and

Rho_b using the following formulas

$$G_i = G_r \left[\frac{Z_{b_{gas}}}{Z_{b_{air}}} \right] \quad \text{Ideal Gas Gravity}$$

$$\rho_f = \frac{P_f M_{r_{air}} G_i}{Z_f R (T_f + N_5)} \quad \text{Flowing Density}$$

$$\rho_b = \frac{P_b M_{r_{air}} G_i}{Z_b R (T_b + N_5)} \quad \text{Base Density}$$

4. Calculate the upstream expansion factor.

Compute orifice differential to flowing pressure ratio, X

$$x = \frac{\Delta P}{N_3 P_f}$$

Compute expansion factor pressure constant Y_p

$$Y_p = \frac{0.41 + 0.35 \beta^4}{k}$$

Compute expansion factor

$$Y = 1 - Y_p x$$

5. Determine the converged value of C_d.

5.0 Calculate the iteration flow factor, F_i, and its component parts, F_{1c} and F_{1p}, used in the C_d convergence scheme.

$$F_{1c} = \frac{4000 N_{1c} D \mu}{E_v Y d^2}$$

Compute C_d's Iteration flow factor, F₁

$$F_{1r} = \sqrt{2 \rho_f \Delta P}$$

If $F_{1c} < 1000 F_{1r}$

$$\text{Then } F_1 = \frac{F_{1c}}{F_{1r}}$$

Else $F_1 = 1000$

5.1 Initialize C_d to value at infinite Reynolds number

$$C_d = C_{d_0}$$

5.2 Compute X, the ratio of 4000 to the assumed Reynolds number

$$X = \frac{F_1}{C_d}$$

5.3 Compute the correlation value F_c and it's derivative D_c of C_d at the assumed flow, X

If $(X < X_c)$

$$F_c = C_{d_0} + (C_{d_1} X^{0.35} + C_{d_2} + C_{d_3} X^{0.8}) X^{0.35} + C_{d_4} X^{0.8}$$

$$D_c = (0.7 C_{d_1} X^{0.35} + 0.35 C_{d_2} + 1.15 C_{d_3} X^{0.8}) X^{0.35} + 0.8 C_{d_4} X^{0.8}$$

Else

$$F_c = C_{d_0} + C_{d_1} X^{0.7} + (C_{d_2} + C_{d_3} X^{0.8}) \left(A - \frac{B}{X} \right) + C_{d_4} X^{0.8}$$

$$D_c = 0.7 C_{d_1} X^{0.7} + (C_{d_2} + C_{d_3} X^{0.8}) \frac{B}{X} + 0.8 C_{d_4} \left(A - \frac{B}{X} \right) X^{0.8} + 0.8 C_{d_4} X^{0.8}$$

5.4 Calculate the amount of change to guess for C_d

$$\delta C_d = \frac{C_d - F_c}{1 + \frac{D_c}{C_d}}$$

5.5 Update the guess for C_d

$$C_d = C_d - \delta C_d$$

5.6 Repeat steps 5.2, 5.3, 5.4 and 5.5 until the absolute value of δC_d is less than 0.000005.

6. Calculate the final value of Q_v, the flow rate at base conditions.

$$Q_v = \frac{\pi}{4} N_c C_d E_v Y d^2 \sqrt{2 \rho_f \Delta P} / \rho_b$$

Section 5 - PART 3's NEW EQUATION FACTORS

As stated earlier, a factored form of the new equation is developed in appendix B of Part 3 of AGA-3-1992. To date, most publications in the public domain, have included summaries of the new equation as presented in Parts 1 and 3 of the new standard. Since these presentations have not covered the factored form of the equation, a presentation of new equation procedures based on the factored equation form is included in this section.

For reasons stated earlier, the factored form is not recommended for most implementations. However, in the context of comparing the old and new equations, the factored equation is presented in this section for instructional purposes. As derived in Appendix B of Part 3, the factored equation form is as follows:

$$Q_v = F_n (F_c + F_{sl}) Y F_{pb} F_{tb} F_{tf} F_{gr} F_{pv} \sqrt{P_{f1} h_w}$$

General Outline of Solution Procedures

For this example it is assumed the fluid being measured is natural gas and that the inch-pound units of measure are used. The general outline of the solution procedures for flange-tapped orifice meters is as follows:

1. At T_f , calculate terms that depend only upon orifice geometry: d , D , β , E_v and F_n .
2. Calculate the upstream flowing pressure, P_f from either P_{f2} or P_{f1} and D_p .
3. Calculate factors associated with densities at T_f , P_f and other specified fluid conditions. These factors include F_{pb} , F_{tb} , F_{tf} , F_{gr} , and F_{pv} .
4. Calculate the upstream expansion factor.
5. Determine the converged value of C_d e.g. $(F_c + F_{sl})$.
6. Calculate the final value of Q_b .

Detailed Outline of Solution Procedures

1. At T_f , calculate terms that depend only upon orifice geometry: d , D , b , E_v and F_n .

Calculate corrected orifice diameter

$$d = d_r \left[1 + \alpha_1 (T_f - T_r) \right]$$

Calculate corrected pipe diameter

$$D = D_r \left[1 + \alpha_2 (T_f - T_r) \right]$$

Calculate Beta

$$\beta = \frac{d}{D}$$

Calculate velocity of approach term

$$E_v = \frac{1}{\sqrt{1 - \beta^4}}$$

Calculate F_n

$$F_n = 338.196 E_v d^2$$

2. Calculate the upstream flowing pressure, P_f from either P_{f2} or P_{f1} and D_p

$$P_f = P_{fi} = \frac{\Delta P}{N_3} + P_{f2}$$

3. Compute Factors associated with densities (ρ_{ob} and ρ_{of})

$$F_{pb} = \frac{14.73}{P_b}$$

$$F_{tb} = \frac{T_b + 459.67}{519.67}$$

$$F_{tf} = \sqrt{\frac{519.67}{T_f + 459.67}}$$

$$F_{gr} = \sqrt{\frac{1}{G_r}}$$

$$F_{pv} = \sqrt{\frac{Z_{b_{gas}}}{Z_{f_{gas}}}}$$

Compute $Z_{b_{gas}}$ and $Z_{f_{gas}}$ using appropriate AGA-8 method.

4. Calculate the upstream expansion factor.

Compute orifice differential to flowing pressure ratio,
x

$$x = \frac{\Delta P}{N_3 P_f}$$

Compute expansion factor pressure constant Yp

$$Y_p = \frac{0.41 + 0.35 \beta^4}{k}$$

Compute expansion factor

$$Y = 1 - Y_p x$$

5. Determine the converged value of C_d, e.g. (F_c + F_{sl}).

Step 5.1 Assume a value for Cd

Assume $C_d = (F_c + F_{sl}) = 0.6$

Step 5.2 estimate a value for Reynolds Number by
first estimating Q_v

$$Q_v = F_n (F_c + F_{sl}) F_{pb} F_{tb} F_{tf} F_{gr} F_{pv} \sqrt{P_f h_w}$$

$$R_{e_D} = 0.0114541 \frac{Q_v P_b G_r}{\mu D T_b Z_{b_{air}}}$$

Step 5.3 Calculate the orifice Calculation Factor F_c

$$F_c = 0.5961 + 0.0291\beta^2 - 0.2290\beta^8$$

$$+ \left(0.0433 + 0.0712 e^{-\frac{8.5}{D}} - 0.1145 e^{-\frac{6.0}{D}} \right) \left[1 - 0.23 \left(\frac{19,000\beta}{R_{e_D}} \right)^{0.8} \right] \left[\frac{\beta^4}{1 - \beta^4} \right]$$

$$- 0.0116 \left[\left(\frac{2}{D(1-\beta)} \right) - 0.52 \left(\frac{2}{D(1-\beta)} \right)^{1.3} \right] \beta^{1.1} \left[1 - 0.14 \left(\frac{19,000\beta}{R_{e_D}} \right)^{0.8} \right]$$

If (meter tube ID < 2.8 inches)

$$F_c = F_c + 0.003(1 - \beta)(2.8 - D)$$

Step 5.4 Calculate the orifice Slope Factor F_{sl}

$$F_{sl} = 0.000511 \left(\frac{1,000,000\beta}{R_{e_D}} \right)^{0.7}$$

$$+ \left[0.0210 + 0.0049 \left(\frac{19,000\beta}{R_{e_D}} \right)^{0.8} \right] \beta^4 \left(\frac{1,000,000\beta}{R_{e_D}} \right)^{0.35}$$

Step 5.5 Repeat steps 5.2 through 5.4 until C_d, e.g.
(F_c + F_{sl}) changes are acceptably small

7. Calculate the final value of Q_v, the flow rate at base conditions.

$$Q_v = F_n (F_c + F_{sl}) Y F_{pb} F_{tb} F_{tf} F_{gr} F_{pv} \sqrt{P_f h_w}$$

**Section 6 - TOTALFLOW's
IMPLEMENTATION OF NEW ORIFICE
EQUATION FOR GAS**

This section describes Totalflow's realtime implementation of the new orifice metering equations. As previously shown in Section 2, equation 7 of this document, the fundamental equation for volumetric flow rate is stated as follows.

$$Q_v = \frac{\frac{\pi}{4} N_c C_d E_v Y d^2 \sqrt{2 \rho_f \Delta P}}{\rho_b}$$

eq. 7 (restated), AGA-3-1992 Fundamental Equation

Form of the Equation

Part 4 of the new standard exists for the purpose of providing implementation procedures that, when followed, produce consistent results for most all computer systems. Additionally, Part 1 of the new standard recommends Part 4 procedures be followed.

The recommended implementation procedures provided in Chapter 14.3, Part 4, allows different entities using various computer languages on different computing hardware to arrive at nearly identical results using the same standardized input data.¹

Additionally, since Part 4's implementation uses the equation's fundamental form it is more easily adapted to a mass flow equation and can also be handily adapted to other sets of engineering units.

For these reasons this implementation is based on Part 4 of the new standard. This means that factors, as such, are not part of this implementation. However, the equation is still solved as a collection of various terms. These terms are themselves factors of the equation, but they are not the classic collection of factors historically associated with the AGA-3 equation.

The new standard has clearly relegated the older factored form of the equation to a less prominent position by putting it in an appendix. It is clear the authors of the new standard are moving toward the more fundamental form of the equation.

Integration and Time Related Issues

Equation 7 is a rate equation which must be integrated over time to produce a quantity (volume or mass). Since the orifice metering standard does not specify integration requirements, these techniques are

left to each system designer. Much of this section is devoted to describing techniques for integrating the fundamental flow rate equation to produce volume.

As illustrated below, portions of the equation are computed at different times. The possible times are:

Table 6-1 Names of Calculation Time Periods

Time Period	Description
CONST (constant)	Computed once, never change
SEC (second)	Computed once per second (sample period)
VOLP (Vol Period)	Computed once per volume calculation period (user adjustable)
NEW_VOL_CONST	Computed when static values are manually changed
NEW_COMP	Computed when new gas analysis data is received

Fig

To begin describing these time domain issues, the fundamental equation is rewritten such that the portion of equation 7 under the radical (e.g. $\sqrt{\quad}$) is set apart as a separate entity. Part 4 of the standard refers to this portion of the equation as F_{ip} . For consistency we refer to it likewise here.

This results in equations:

$$Q_v = \frac{\frac{\pi}{4} N_c C_d E_v Y d^2 F_{ip}}{\rho_b} \quad eq. 8$$

$$\text{where, } F_{ip} = \sqrt{2 \rho_f \Delta P} \quad eq. 9$$

Equation 9 above contains a flowing density term (ρ_f) that, as discussed in **Section 1** of this document, is computed using the following gas density equation.

$$\rho_f = \frac{P_f M_{r_{air}} G_i}{Z_f R (T_f + N_5)}$$

eq. 3 (restated) Density at Flowing conditions

Substituting equation 3's density solution into equation 9, results in the following equation for F_{ip} .

$$F_{ip} = \sqrt{2 \left[\frac{P_f M_{r_{air}} G_i}{Z_f R (T_f + N_5)} \right] \Delta P}$$

eq. 10 Fip with gas density equation included

Equation 10 above contains a ideal gas gravity term G_i that, as also discussed in **Section 1** of this document, is computed using the following equation.

$$G_i = G_r \left[\frac{Z_{b_{gas}}}{Z_{b_{air}}} \right]$$

eq. 5 (restated) G_i computed from G_r

Substituting equation 5's ideal gravity solution into equation 10, results in the following equation for F_{ip} .

$$F_{ip} = \sqrt{2 \left[\frac{P_f M_{r_{air}} G_r \left[\frac{Z_{b_{gas}}}{Z_{b_{air}}} \right]}{Z_f R (T_f + N_5)} \right] \Delta P}$$

eq. 11 Fip with G_r used instead of G_i

Equation 11 shows the form of F_{ip} used in this implementation to compute gas volumes. However, portions of F_{ip} are computed on different time

periods. To illustrate those portions of F_{ip} , the following equations are provided.

$$F_{ip_{const}} = \frac{2 M_{r_{air}}}{R}$$

eq. 12 Constants within Fip equation

$$F_{pv} = \sqrt{\frac{Z_{b_{gas}}}{Z_{f_{gas}}}}$$

eq. 13 Supercompressibility within Fip equation

$$Ext_{pt} = \sqrt{\frac{P_f \Delta P}{(T_f + N_5)}}$$

eq. 14 Extension within Fip equation

Restating the F_{ip} equation in terms of the variables solved for in equations 12, 13 and 14 results in an F_{ip} equation of the following nomenclature.

$$F_{ip} = Ext_{pt} F_{pv} \sqrt{\frac{F_{ip_{const}} G_r}{Z_{b_{air}}}}$$

eq. 15 Fip with time dependent factors shown

With this final representation of F_{ip} , we can now construct a table showing each portion of the flowrate equation (equation 8) and their respective computation time periods. See Table 6-2 on following page.

Table 6-2 Summary of Calculation Time Periods

Variable Name	Equation Being Computed	Time Period for Computation
$Q_v, C_d, E_v, Y, \frac{\pi}{4}, \text{ and } d^2$	See equations in Part 4 of standard or Section 4 of this document.	VOLP
ρ_b	$\rho_b = \frac{P_b M_{r,air} G_r}{Z_{b,air} R (T_b + N_5)}$	NEW_VOL_CONST and NEW_COMP
F_{ip}	$F_{ip} = Ext_{pt} F_{pv} \sqrt{\frac{F_{ip,const} G_r}{Z_{b,air}}}$	VOLP But portions are computed on different time periods as shown in following three table entries for $F_{ip,const}$, F_{pv} , and Ext_{pt}
$F_{ip,const}$	$F_{ip,const} = \frac{2 M_{r,air}}{R}$	CONST Computed once, never changes.
F_{pv}	$F_{pv} = \sqrt{\frac{Z_{b,gas}}{Z_{f,gas}}}$	VOLP
Ext_{pt}	$Ext_{pt} = \sqrt{\frac{P_f \Delta P}{(T_f + N_5)}}$	SEC The extension is computed and integrated each second until VOLP, when it is used in the volume calculation.

Static Pressure and Expansion Factor

As mentioned in Section 2 of this document, if downstream expansion factor is used then an additional Z (compressibility) calculation must be performed. To avert the need for this additional processing, this implementation always uses the upstream static pressure thereby allowing computation of the upstream expansion factor.

The user is allowed to specify either up or down stream for location of the static pressure sensing element. If the upstream location is specified, that pressure measurement is used without modification. However, if the downstream location is specified then the upstream pressure is computed as:

$$P_{f1} = P_{f2} + \frac{\Delta P}{N}$$

This logic and math execute each second thereby always providing the upstream static pressure for use throughout the whole equation.

Averaging Techniques

Type 1 Averages

Averages constructed from one second samples taken only during times of flow are maintained for the real time measured variables of differential pressure, static pressure, and flowing temperature.

Type 2 Averages

Averages constructed from all one second samples (regardless of flow) are also maintained for the same variables.

Type 1 averages are stored in the historical record for periods in which some quantity (volume or mass) accrued. Type 2 averages are stored for periods in which zero quantity accrued. This technique provides adequate volume adjustment averages for downstream processing but also supports site operations with averages for pressure and temperature even when there is no flowrate.

In older Totalflow devices Type 1 and 2 averages were always based on linear values. In newer Totalflow devices either linear or square root averages can be specified.

Other New Implementation Features

- Different Z (compressibility) calculation methods are available. These include the latest AGA-8 methods and NX-19. Additionally F_{pv} can be *turned off* if desired.
- VOLP, Volume calculation period defaults to one hour, but is user selectable. Selections offered are 1, 2, 5, 10, 30, and 60 minutes.
- Up to 23 composition variables for supporting AGA-8 detailed method are supported.
- Selectable static pressure tap location is supported.
- Selectable differential pressure tap type is supported.
- Higher static pressure transducers are supported. Up to 3500 psi is currently in use.

Algorithmic Detail of Realtime Implementation of New Equation for Gas

The following is a more detailed summary of periodic computations performed by this implementation for solving the new orifice equations (AGA-3-1992). The periods referred to in this section are those same periods summarized in Table 6-1. Please note that the following equations are based on using linear averages, if square root averages are selected, then square roots are performed before they one second summations take place.

CONST PERIOD

$$F_{ip_{const}} = \frac{2 M_{r_{air}}}{R}$$

NEW COMP PERIOD & NEW VOL CONSTS PERIOD

Currently the same calculations are being performed for each of these two periods. Future optimizations could result in different calculations being performed for each of these two periods.

Perform Fpv Pre-Calculations

IF (FpvMethod = AGA-8_{gross})

Compute AGA-8 gross method precalcs (e.g. AGA-8 terms that are function of composition)

Using AGA-8 gross method Compute Z_{b_{gas}}

ELSE IF (FpvMethod = AGA-8_{detail})

Compute AGA-8 detail method precalcs (e.g. AGA-8 terms that are function of composition)

Using AGA-8 detail method Compute Z_{b_{gas}}

ELSE IF (FpvMethod = NX19_FIXEDFTFP)

Accept user supplied Ft and Fp values

ELSE IF (FpvMethod = NX19)

IF ((G_r < 0.75) AND (CO₂ < 15%) AND
(N₂ < 15%))

Compute Ft and Fp using NX19 Gravity Method

ELSE

Compute Ft and Fp using Methane Gravity Method

ENDIF

ELSE IF (FpvMethod = NX19_GRAVITY)

Compute Ft and Fp using NX19 Gravity Method

ELSE IF (FpvMethod = NX19_METHANE-GRAVITY)

Compute Ft and Fp using NX19 Methane Gravity Method

ENDIF

Calculate Base Density

$$\rho_b = \frac{P_b M_{r_{air}} G_r}{Z_{b_{air}} R (T_b + N_5)}$$

SEC PERIOD

IF (Pressure Tap Downstream)

Calculated Upstream Static Pressure, Pf

$$Pf_{\text{sec}} = P_{f1} + \frac{Dp_{\text{sec}}}{N_5}$$

ELSE

$$Pf_{\text{sec}} = P_{f2}$$

ENDIF

$$Secs = Secs + 1$$

$$Pf_{\text{acc}} = Pf_{\text{acc}} + Pf_{\text{sec}}$$

$$Tf_{\text{acc}} = Tf_{\text{acc}} + Tf_{\text{sec}}$$

IF (DP > DP_ZERO_CUTOFF) (If Flow Exists)

$$\begin{aligned}Ext_{pt} &= \sqrt{\frac{Pf_{sec} Dp_{sec}}{(Tf_{sec} + N_5)}} \\Ext_{acc_{flow}} &= Ext_{acc_{flow}} + Ext_{pt} \\Dp_{acc_{flow}} &= Dp_{acc_{flow}} + Dp_{sec} \\Pf_{acc_{flow}} &= Pf_{acc_{flow}} + Pf_{sec} \\Tf_{acc_{flow}} &= Tf_{acc_{flow}} + Tf_{sec} \\Secs_{flow} &= Secs_{flow} + 1\end{aligned}$$

ENDIF

VOLP (VOL PERIOD)

(THIS ONLY EXECUTES IF THERE WAS FLOW DURING THE VOLP)

Construct averages from one second accumulators

$$\begin{aligned}Ext_{volp} &= \frac{Ext_{acc_{flow}}}{Secs} \\Dp_{volp} &= \frac{Dp_{acc_{flow}}}{Secs_{flow}} \\Pf_{volp} &= \frac{Pf_{acc_{flow}}}{Secs_{flow}} \\Tf_{volp} &= \frac{Tf_{acc_{flow}}}{Secs_{flow}}\end{aligned}$$

At T_f, calculate terms that depend only upon orifice geometry: d, D, b, E_v and orifice coefficient correlation terms.

Calculate corrected diameters and Beta

$$\begin{aligned}d &= d_r [1 + \alpha_1 (T_f - T_r)] \\D &= D_r [1 + \alpha_2 (T_f - T_r)] \\\beta &= \frac{d}{D}\end{aligned}$$

Calculate velocity of approach term

$$E_v = \frac{1}{\sqrt{1 - \beta^4}}$$

Calculate orifice coefficient of discharge constants

Note: In the following equations A0 through A6 and S1 through S8 are references to constants that are documented in the standard.

$$L_1 = L_2 = \frac{N_4}{D}$$

$$M_2 = \frac{2L_2}{1 - \beta}$$

$$T_u = \left[S_2 + S_3 e^{-8.5L_1} + S_4 e^{-6.0L_1} \right] \frac{\beta^4}{1 - \beta^4}$$

$$T_D = S_6 \left[M_2 + S_7 M_2^{1.3} \right] \beta^{1.1}$$

If $D > (A_4 N_4)$ Then $T_s = 0.0$

$$\text{Else } T_s = A_3 (1 - \beta) \left(A_4 - \frac{D}{N_4} \right)$$

Additional Tap Term for small diameter pipe

$$C_{d_0} = A_0 + A_1 \beta^2 + A_2 \beta^8 + T_U + T_D + T_S$$

$$C_{d_1} = A_5 \beta^{0.7} (250)^{0.7}$$

$$C_{d_2} = A_6 \beta^4 (250)^{0.35}$$

$$C_{d_3} = S_1 \beta^4 \beta^{0.8} (4.75)^{0.8} (250)^{0.35}$$

$$C_{d_4} = (S_5 T_U + S_8 T_D) \beta^{0.8} (4.75)^{0.8}$$

Calculate F_{pv} at T_f , P_f and other specified fluid conditions (using NEW_COMP precalcs).

IF (FpvMethod = OFF)

$$F_{pv} = 1.0$$

ELSE IF (FpvMethod = AGA-8_{gross})

Calculate $Z_{f_{gas}}$ using AGA-8_{gross} method then calculate F_{pv}

$$F_{pv} = \sqrt{\frac{Z_{b_{gas}}}{Z_{f_{gas}}}}$$

ELSE IF (FpvMethod = AGA-8_{detail})

Calculated $Z_{f_{gas}}$ using AGA-8_{detail} method then calculate F_{pv}

$$F_{pv} = \sqrt{\frac{Z_{b_{gas}}}{Z_{f_{gas}}}}$$

ELSE IF (FpvMethod = NX19_FIXEDFTFP OR NX19_GRAVITY OR NX19_METHANE-GRAVITY)

Calculate F_{pv} using NX19 method and previously supplied f_t and f_p

END IF

Calculate the upstream expansion factor.

Compute orifice differential to flowing pressure ratio, x

$$x = \frac{Dp_{volp}}{N_3 Pf_{volp}}$$

Compute expansion factor pressure constant Y_p

$$Y_p = \frac{0.41 + 0.35 \beta^4}{k}$$

Compute expansion factor

$$Y = 1 - Y_p x$$

Calculate F_{ip}

$$F_{ip} = Ext_{volp} F_{pv} \sqrt{\frac{F_{ip, const} G_r}{Z_{b, air}}}$$

Determine the converged value of C_d .

Cd_step.0 Calculate the iteration flow factor, F_i , and its component part, F_{ip} . Re-use the F_{ip} computed earlier. Then use these in the C_d convergence scheme.

$$F_{ic} = \frac{4000 N_{ic} D \mu}{E_v Y d^2}$$

Compute Cd's Iteration flow factor, F_I

If $F_{ic} < 1000 F_{ip}$

$$\text{Then } F_I = \frac{F_{ic}}{F_{ip}}$$

$$\text{Else } F_I = 1000$$

Cd_step.1 Initialize C_d to value at infinite Reynolds number

$$C_d = C_{d_0}$$

Cd_step.2 Compute X, the ratio of 4000 to the assumed Reynolds number

$$X = \frac{F_I}{C_d}$$

Cd_step.3 Compute the correlation value F_c and it's derivative D_c , of C_d at the assumed flow, X

If $(X < X_c)$

$$F_c = C_{d_0} + (C_{d_1} X^{0.35} + C_{d_2} + C_{d_3} X^{0.8}) X^{0.35} + C_{d_4} X^{0.8}$$

$$D_c = (0.7C_{d_1} X^{0.35} + 0.35C_{d_2} + 1.15C_{d_3} X^{0.8}) X^{0.35} + 0.8C_{d_4} X^{0.8}$$

Else

$$F_c = C_{d_0} + C_{d_1} X^{0.7} + (C_{d_2} + C_{d_3} X^{0.8}) \left(A - \frac{B}{X} \right) + C_{d_4} X^{0.8}$$

$$D_c = 0.7C_{d_1} X^{0.7} + (C_{d_2} + C_{d_3} X^{0.8}) \frac{B}{X} + 0.8C_{d_4} \left(A - \frac{B}{X} \right) X^{0.8} + 0.8C_{d_4} X^{0.8}$$

Cd_step.4 Calculate the amount of change to guess for C_d

$$\delta C_d = \frac{C_d - F_c}{1 + \frac{D_c}{C_d}}$$

Cd_step.5 Update the guess for C_d

$$C_d = C_d - \delta C_d$$

Cd_step.6 Repeat steps 2,3,4 and 5 until the absolute value of δC_d is less than 0.000005.

Calculate the final value of q_m , the mass flow rate at line conditions.

$$q_m = \frac{\pi}{4} N_c C_d E_v Y d^2 F_{ip}$$

Calculate the final value of Q_v , the volumetric flow rate at base conditions.

$$Q_v = \frac{q_m}{\rho_b}$$

Calculate the final value of Vol_b , the volume at base conditions for the Volume Period

$$Vol_b = Q_v * \frac{Secs}{N_{vtime}}$$

Section 7 - NOMENCLATURE

a₁	Linear coefficient of thermal expansion of the orifice plate material
a₂	Linear coefficient of thermal expansion of the meter tube material.
b	Beta. Ratio of orifice plate bore diameter to meter tube internal diameter (d/D) at flowing temperature, T _f .
C_d	Orifice plate coefficient of discharge.
C_{d0}	First flange-tapped orifice plate coefficient of discharge constant within iteration scheme.
C_{d1}	Second flange-tapped orifice plate coefficient of discharge constant within iteration scheme.
C_{d2}	Third flange-tapped orifice plate coefficient of discharge constant within iteration scheme.
C_{d3}	Forth flange-tapped orifice plate coefficient of discharge constant within iteration scheme.
C_{d4}	Fifth flange-tapped orifice plate coefficient of discharge constant within iteration scheme.
C_{d_f}	Orifice plate coefficient of discharge bounds flag within iteration scheme.
d	Orifice plate bore diameter calculated at flowing temperature T _t .
D	Meter tube internal diameter calculated at flowing temperature T _f .
d_r	Orifice plate bore diameter calculated at reference temperature T _r .
D_r	Meter tube internal diameter calculated at reference temperature T _r .
D_c	Orifice plate coefficient of discharge convergence function derivative.
DP	Orifice differential pressure.
e	Napierian constant, 2.71828.
E_v	Velocity of approach factor.
F_c	Orifice calculation factor for C _d (Used differently in Parts 3 and 4)
F_{sl}	Orifice Slope Factor for C _d
F_l	Iteration flow factor
F_{lc}	Iteration flow factor - independent factor.
F_{lp}	Iteration flow factor - dependent factor.
F_{mass}	Mass flow factor.
F_b	Basic orifice factor.
F_r	Reynolds number factor.
F_{pb}	Pressure base factor.
F_{tb}	Temperature base factor.
F_{tf}	Flowing temperature factor.
F_{gr}	Real gas gravity factor.
F_{pv}	Supercompressibility factor.
F_a	Orifice thermal expansion factor.
g_c	Dimensionless conversion constant.
G_i	Ideal gas relative density (specific gravity).
G_r	Real gas relative density (specific gravity).
k	Isentropic Exponent.
m	Mass.
M_{r_{air}}	Molar mass (molecular weight) of dry air.
N_c	Unit conversion factor (orifice flow).
N₁	Unit conversion factor (Reynolds number).
N₃	Unit conversion factor (expansion factor).
N₄	Unit conversion factor (discharge coefficient).
N₅	Unit conversion factor (absolute temperature).
N_{vtime}	Time Interval Constant used in flowrate integration algorithm to produce quantity volume
P_b	Base pressure.
P_f	Static pressure of fluid at the pressure tap.
P_{f1}	Absolute static pressure at the orifice upstream differential pressure tap.
P_{f2}	Absolute static pressure at the orifice downstream differential pressure tap.
P_{m_{air}}	Measured air pressure.
P_{m_{gas}}	Measure gas pressure.
p	Pi, 3.14159.....
q_m	Mass flow rate at actual line conditions
q_v	Volume flow rate at actual line conditions.
Q_v	Volume flow rate per hour at base conditions.

R	Universal gas constant.
Re_D	Pipe Reynolds number.
ρ_b	Density of the fluid at base conditions, (P _b , T _b).
ρ_{air}	Air density at base conditions, (P _b , T _b).
ρ_{gas}	Gas density at base conditions, (P _b , T _b).
ρ_f	Density of the fluid at flowing conditions, (P _f , T _f).
T_b	Base temperature.
T_{air}	Measured temperature of air.
T_{gas}	Measured temperature of gas.
T_f	Flowing temperature.
T_r	Reference temperature of orifice plate bore diameter and/or meter tube internal diameter.
T_d	Downstream tap correction factor.
T_s	Small meter tube correction factor.
T_u	Upstream tap correction factor.
Vol_b	Quantity Volume at base conditions
X	Reduced reciprocal Reynolds number (4000/Re _D).
X_c	Value of X where change in orifice plate coefficient of discharge correlation occurs.
Y	Expansion factor.
Y_p	Expansion factor pressure constant.
Z_b	Compressibility at base conditions (P _b , T _b).
Z_{air}	Air compressibility at air base conditions (P _b , T _b).
Z_{gas}	Gas compressibility at gas base conditions (P _b , T _b).
Z_f	Compressibility at flowing conditions (P _f , T _f).
Z_{air}	Air compressibility at air measurement conditions, (assumed P _b , T _b).
Z_{gas}	Gas compressibility at gas measurement conditions, (assumed P _b , T _b).

Section 8 - CITED PUBLICATIONS

1. American Petroleum Institute Measurement on Petroleum Measurement Standards (API MPMS) Chapter 14.3, Part 1; Also recognized as AGA Report No. 3 Part 1; Also recognized as GPA 8185-92, Part 3; Also recognized as ANSI/API 2530-1991, Part 1
2. American Petroleum Institute Measurement on Petroleum Measurement Standards (API MPMS) Chapter 14.3, Part 2; Also recognized as AGA Report No. 3 Part 2; Also recognized as GPA 8185-92, Part 2; Also recognized as ANSI/API 2530-1991, Part 2
3. American Petroleum Institute Measurement on Petroleum Measurement Standards (API MPMS) Chapter 14.3, Part 3; Also recognized as AGA Report No. 3 Part 3; Also recognized as GPA 8185-92, Part 3; Also recognized as ANSI/API 2530-1991, Part 3
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5. American Gas Association (AGA) Transmission Measurement Committee Report No. 8; Also recognized as API MPMS Chapter 14.2.
6. Teysandier, Raymond G.; Beaty, Ronald: *New orifice meter standards improve gas calculations*, Oil & Gas Journal, Jan. 11, 1993
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