

Manual of Petroleum Measurement Standards Chapter 21.1

Flow Measurement Using Electronic Metering Systems—Electronic Gas Measurement

ANSI/API MPMS CHAPTER 21.1
SECOND EDITION, FEBRUARY 2013

AGA REPORT NO. 13



AMERICAN PETROLEUM INSTITUTE



American Gas Association



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Flow Measurement Using Electronic Metering Systems— Electronic Gas Measurement

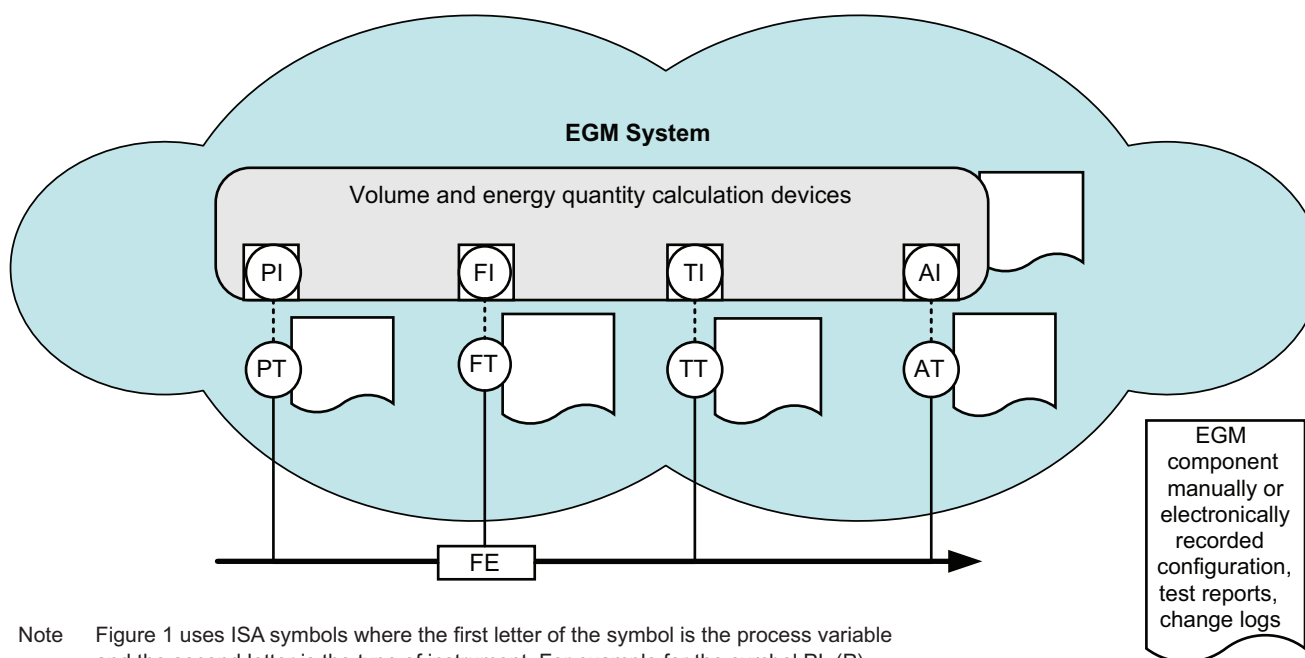
1 Scope

This standard describes the minimum specifications for electronic gas measurement systems used in the measurement and recording of flow parameters of gaseous phase hydrocarbon and other related fluids for custody transfer applications utilizing industry recognized primary measurement devices.

Electronic gas measurement (EGM) systems may be comprised of a number of components which work together to measure and record gas flow as shown in Figure 1. The components contained in the cloud are considered part of the EGM system. The components may be considered individually or be integral parts of the EGM system and the calculations may be performed onsite and/or off-site.

This standard provides the minimum reporting and change management requirements of the various intelligent components required for accurate and auditable measurement. The requirements can be met by a combination of electronically and/or manually recorded configuration, test reports, change record reporting of the electronic gas measurement system components and flow parameters. It is recognized that diagnostic capabilities of the newer meter and transmitter technologies are important but due to the device specific complexity, intelligent device diagnostics are out of scope for this standard.

For all existing installations, the decision to upgrade the system to satisfy the current standard is at the discretion of the parties involved.



Note Figure 1 uses ISA symbols where the first letter of the symbol is the process variable and the second letter is the type of instrument. For example for the symbol PI, (P) stands for pressure instrument and (I) stands for indicator. The process variables in the figure are pressure (P), flow rate (F), temperature (T), and analytical (A) and the types of instruments are indicator (I), transmitter (T), element (E).

Figure 1—Graphical Representation of an Electronic Gas Measurement (EGM) System and Its Relationship to Other Devices

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *Manual of Petroleum Measurement Standards (MPMS)*, Chapter 14.1, *Collecting and Handling of Natural Gas Samples for Custody Transfer*

API *Manual of Petroleum Measurement Standards (MPMS)*, Chapter 14.3, *Concentric, Square-Edged Orifice Meters* (ANSI ¹/API 2530, A.G.A. Report No. 3, GPA 8185) [All sections]

AGA Report No. 7 ², *Measurement of Gas by Turbine Meters*

AGA Report No. 8, *Compressibility Factors of Natural Gas and Other Hydrocarbon Gases*

AGA Report No. 9, *Measurement of Gas by Multipath Ultrasonic Meters*

AGA Report No. 11, *Measurement of Natural Gas by Coriolis Meter*

National Oceanic and Atmospheric Administration ³, *U.S. Standard Atmosphere*, U.S. Department of Commerce, National Technical Information Service, October 1976

3 Descriptions, Definitions, and Symbols

3.1 Description of an Electronic Gas Measurement System

For the purpose of this standard, the measurement system consists of primary, secondary, and tertiary devices.

The primary device defines the basic type of meter used for gas measurement, including, but not limited to, an orifice, turbine, ultrasonic, Coriolis, rotary, or diaphragm meter.

The secondary device produces data such as, but not limited to, static pressure, temperature, differential pressure, relative density, and other variables that are appropriate for inputs into the tertiary device discussed in this standard.

The tertiary device is one or more calculation devices that need to be programmed correctly to perform flow rate calculations within specified limits using information received from primary and/or secondary devices. Each primary device requires one or more specific or properly configured tertiary devices appropriate to the type of meter used.

Secondary devices are typically located with the primary device, but the tertiary device may be located remotely. The primary, secondary, and tertiary devices may be contained in one or more enclosures, or packaged separately.

3.2 Elements of a Gas Measurement System

3.2.1 Transducers/Transmitters

In electronic measurement systems, the secondary device is an electromechanical transducer that responds to an input of static pressure, temperature, differential pressure, frequency, relative density (specific gravity), or other

¹ American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org.

² American Gas Association, 400 N. Capitol St., NW, Suite 450, Washington, DC 20001, www.aga.org.

³ National Oceanic and Atmospheric Administration, 1401 Constitution Avenue, NW, Washington, DC 20230.

variable. Transducers respond to changes in the measured parameters with a corresponding change in electrical output. These devices are referred to as transmitters when they have been specifically designed to enhance the transmission of information from one location to another by the addition of an electronic circuit that converts the transducer output to a standard signal. The signal may be, but is not limited to, analog, digital, or frequency form.

3.2.2 Signal Processing

The electronic signals from the secondary devices transmit information to the tertiary device(s). The tertiary device(s) receive the information, combine it with programmed instructions, and calculates the quantity of gas flowing through the primary device.

3.2.3 System Uncertainties

While electronic flow measurement can provide a high degree of accuracy, it is important to realize that each primary, secondary, or tertiary device is subject to separate measurement uncertainties. Consider each device when viewing the overall uncertainty of the system.

3.2.4 Data Management

EGM systems must comply with audit trail/audit package requirements for reported volume, mass and/or energy quantities. All data editing of data in the EGM or other systems shall be identified. Quantity Transaction Records (QTRs) that are modified or corrected by systems, either manual or automatic, must be recorded and maintained as part of the audit trail (see Section 5, *Audit and Record Requirements*).

3.3 Definitions

The purpose of these definitions is to clarify the terminology used in the discussion of this standard only. The definitions are not intended to be an all-inclusive directory of terms used within the measurement industry, nor are they intended to conflict with any standards currently in use.

3.3.1

absolute static pressure

The flowing pressure referenced to an absolute vacuum.

NOTE Absolute static pressure can be measured directly or can be calculated by adding atmospheric pressure to gauge pressure.

3.3.2

accounting period

A defined time interval over which business transactions will be based.

3.3.3

accuracy

The ability to indicate values closely approximating the true value of the measured variable.

3.3.4

analog to digital converter

A/D converter

A signal processor that converts an electrical analog signal to a corresponding digital number.

3.3.5

atmospheric pressure

The pressure exerted by the weight of the atmosphere at a specific location.

3.3.6**audit trail****audit package**

The record for an EGM system shall contain verification or calibration measurements for all tertiary and secondary devices, actual specifications for the primary device, constant values, times and dates of any changes affecting reported volumes, and should include identification of individuals making the changes (see Section 5, *Audit and Record Requirements* and Section 6, *Data Availability Data Availability*).

3.3.7**average flowing differential pressure**

The flow time linear average of instantaneous differential pressures taken over a specified period of time.

3.3.8**average flowing pressure**

The flow time linear average of instantaneous flowing static pressures taken over a specified period of time.

3.3.9**average flowing temperature**

The flow time linear average of instantaneous flowing temperatures taken over a specified period of time.

3.3.10**calibration range****calibration span**

See span, limit, and range definitions.

3.3.11**certified thermometer**

An instrument that measures temperature with performance traceable to primary standards maintained by an internationally recognized standards organization such as the National Institute of Standards and Technology (NIST).

3.3.12**commissioning**

The process of the initial verification and documentation that the EGM system is installed and functioning according to its specification, design, and regulatory/contract requirements.

3.3.13**Configuration Log**

A record that contains and identifies all selected flow parameters used in the generation of a QTR.

3.3.14**constant flow parameter**

Any value that affects the quantity calculation, is not associated with a property or state of the flowing gas, and does not frequently change. Orifice plate bore diameter, meter tube internal diameter, linear meter pulse per unit volume factors, and base pressure are examples of constant flow parameters.

3.3.15**contract day**

A time period of 24 consecutive hours beginning at the time specified in the contract except for the days which have been adjusted for Daylight Savings Time.

3.3.16**differential meter**

A device that generates a differential pressure when placed in a flow stream.

3.3.17
differential pressure

The pressure difference between the differential meter upstream and downstream pressure taps used to calculate flow rate.

3.3.18
differential pressure transmitter

A sensing device that converts a differential pressure into an electrical signal.

3.3.19
electronic gas measurement
EGM

The process whereby gas flow rates are calculated by means of an electronic computer. Computations can be made directly at the site of the primary element or after transfer of the data to another computer at any off-site location. This transfer can be manual, using a data storage device, or automatic, using a communication system.

3.3.20
Event Log

A record that notes and records all exceptions and changes to the flow parameters contained within the Configuration Log that occur and have an impact on a QTR.

3.3.21
factory calibration

A maintenance process which uses a transmitter that is calibrated at a factory or calibration facility that is traceable to primary standards maintained by an internationally recognized standards organization such as the NIST.

3.3.22
flow computer

An arithmetic processing unit and associated memory that accepts electrically-converted signals representing input variables from a measurement system and performs calculations for the purpose of providing flow rate and total quantity data.

3.3.23
flow time

The period of time during the QTR when gas is flowing.

3.3.24
flow time linear average

The average value of a measured or calculated variable using only values taken when gas is flowing.

3.3.25
gauge line

The tubing that connects a tap on a meter run to a sensing device.

3.3.26
gauge pressure

The absolute static pressure minus the local atmospheric pressure at the time of measurement.

3.3.27
intelligent device

Any device which contains a microprocessor that is used for digital signal processing or calculation purposes.

3.3.28**input variable**

A data value associated with the flow or state of a gas that is input into the computer for the purpose of being part of a calculation. This input may be a measured variable from a transducer/transmitter or a manually entered fixed value. Static pressure, temperature, and relative density are examples of input variables.

3.3.29**integral value****IV**

The value resulting from the integration of the factored portion of the flow rate equations that best defines the conditions of continually changing flow over a specified time period.

3.3.30**linear meter**

A flow device that generates a signal, typically pulses, which is directly proportional to flow rate.

3.3.31**live input variable**

The output of any primary or secondary device which provides updates during a Quantity Calculation Period (QCP).

3.3.32**lower calibrated limit****lower range limit****lower user defined operating limit**

See span, limit, and range definitions.

3.3.33**manufacturer span**

See span, limit, and range definitions.

3.3.34**no flow cutoff**

The minimum value of the flow dependent variable, below which the signal is considered to be meter or flow noise. No flow rate or quantity shall be calculated below this value.

3.3.35**off-site**

A location not at the primary measurement device.

3.3.36**onsite**

The location of the primary measurement device.

3.3.37**pre-commissioning**

The process of reviewing and checking of commissioning documentation prior to performing onsite commissioning. (It can also be done as part of the onsite commissioning process.)

3.3.38**quantity**

The volume, mass, or energy accumulated during the QCP and/or reported in the QTR.

3.3.39
quantity calculation period
QCP

The period of time over which the calculated total quantity is to be integrated.

3.3.40
Quantity Transaction Record
QTR

A set of unedited historical data, calculated values, and information in a preset format that supports the determination of a quantity over a given period.

3.3.41
Quantity Transaction Record corrected
QTR_{corr}

The result of a change to a QTR.

3.3.42
Quantity Transaction Record time
QTR_{time}

The specific time in hours, minutes, and seconds logged at the beginning or completion of the QTR.

3.3.43
Rans methodology

A statistical evaluation method to determine the amount of measurement uncertainty that exists for any given flow pattern across an orifice plate or linear type meter for a specified flow parameter sampling frequency.

3.3.44
sampling frequency

The number of data values taken per unit of time (for example, 1/second) that a live input variable is retrieved.

3.3.45
sampling period

The time between the retrieval of live input variables.

3.3.46
Span, Limit, and Range Definitions

3.3.46.1
calibration range

The set of values as bounded by the upper and lower calibrated limits.

3.3.46.2
calibration span

The mathematical difference between the upper and lower calibrated limits.

3.3.46.3
lower calibrated limit

The minimum engineering value the unit was calibrated for by certified equipment (either factory or field) and, in all applications, cannot be less than the lower range limit.

3.3.46.4
lower range limit
LRL

The minimum engineering value that can be measured as specified by the manufacturer.

3.3.46.5**lower user defined operating limit**

The engineering value that is set by the operator which defines the minimum operating point for the unit and, in all applications, cannot be less than the lower calibrated limit.

3.3.46.6**manufacturer span**

The mathematical difference between the upper and lower range limits.

3.3.46.7**span**

The mathematical difference between upper and lower limits.

3.3.46.8**upper calibrated limit**

The maximum engineering value the unit was calibrated for by certified equipment (either factory or field) and, in all applications, cannot be greater than the upper range limit.

3.3.46.9**upper range limit****URL**

The maximum engineering value that can be measured as specified by the manufacturer.

3.3.46.10**upper user defined operating limit**

The maximum engineering value that is set by the operator which defines the highest operating point for the unit and, in all applications, cannot be greater than the upper calibrated limit.

3.3.46.11**user defined operating range**

The set of values as bounded by the upper and lower operating limits defined by the user.

3.3.46.12**user defined span**

The mathematical difference between the upper and lower operating limits defined by the user.

3.3.47**static pressure**

The force per unit area exerted by a gas at a selected point in the system and can be represented as gauge or absolute pressure.

3.3.48**static pressure transmitter**

A sensing device that converts the static pressure to an electrical signal.

3.3.49**temperature**

The value of thermal energy of the flowing gas.

3.3.50**temperature transmitter**

A sensing device that converts the fluid temperature into an electrical signal.

3.3.51**transducer**

A device that provides a usable output signal in response to a measurement.

3.3.52**type testing**

The verification and approval of EGM system algorithms and components that cannot be changed from their factory state. Type approval of the testing and calculations apply to the installed device.

3.3.53**uncertainty**

The amount by which an observed or calculated value may depart from the true value.

3.3.54**uncorrected quantity**

The quantity accumulated over the flow period at flowing conditions not corrected to standard conditions.

3.3.55**upper calibrated limit****upper range limit****upper user defined operating limit**

See span, limit and range definitions.

3.3.56**user configurable**

Refers to flow computers or EGM systems where the flow calculation algorithms cannot be altered by the user, but the components and ranges of the EGM system and other measurement characteristics can be configured using the manufacturer supplied user interface. These types of devices can be type approved.

3.3.57**user defined operating range****user defined span**

See span, limit and range definitions.

3.3.58**user programmable**

Refers to flow computers or EGM systems where the user can change the portion of the program which contains the flow calculation algorithm, and then compiles and downloads this program to the EGM device. These types of devices cannot be type approved and require individual device verification of the algorithms.

3.4 Symbols

This standard reflects electronic gas measurement symbols in general technical use.

Symbol	Represented Quantity
$C_d(FT)$	is the coefficient of discharge for a flange-tap orifice meter;
$Counts$	is the accumulation of meter pulses;
d	is the orifice plate bore diameter calculated at flow temperature (T_f);
DP_i	is the differential pressure at sample i ;
DP_{IV}	is the average differential pressure calculated from the IV (see Annex B);
DP_{Linear}	is the flow time linear average of differential pressure (see Annex B);

DP_Y	is the average differential pressure to be used in the expansion factor calculation. (DP_Y is the volume weighted average of differential pressure or calculated from DP_{Linear} and DP_{IV} using the equation in 4.4.4.4.);
DV_i	is the dynamic variables, representing the live input variables, taken at sample i ;
E_v	is the velocity of approach factor;
FT	is flange taps
ft	is the flow time
G_r	is the real gas relative density (specific gravity);
h_w	is the orifice differential pressure in inches of water column at 60°F;
h_{wi}	is the differential pressure at sample i ;
i	is the sample number;
IMV	is the integral multiplier value, representing the relatively static measured and calculated values;
IV	is the integral value;
\overline{IV}	is the average extension;
$k\text{-factor}$	is the single linear meter constant in counts per unit volume;
$k\text{-factor}_i$	is the multipoint linear meter constant in counts per unit volume calculated at interval i ;
mf_i	is the meter factor for period i (when multi-point meter factors are used);
n	is the number of samples taken over the QCP (i.e. QCP / Δt);
P_{atm}	is the atmospheric pressure;
P_b	is the pressure at base conditions;
P_f	is the pressure at flowing conditions;
P_{fi}	is the pressure at sample i ;
P_{f1}	is the flowing pressure (upstream tap), absolute;
P_s	is the standard pressure;
Q	is the flow rate;
Q_i	is the flow rate based on data taken at sample i ;
Q_f	is the flow rate at actual conditions;
Q_{fi}	is the flow rate at actual conditions based on data taken at sample i ;
t	is the time;
Δt_i	is the sampling interval;
T_b	is the temperature at base conditions;
T_f	is the flowing temperature, absolute;
T_s	is the standard temperature;
V	is the quantity accumulated between time t_0 and time t or quantity accumulated over the QCP;
Y_1	is the expansion factor (upstream tap);
Z_b	is the compressibility at base conditions;
Z_f	is the compressibility at flowing conditions;
Z_s	is the compressibility at standard conditions (P_s , T_s);
Z_{f1}	is the compressibility at flowing conditions (P_{f1} , T_f);

4 Electronic Gas Measurement System Algorithms

4.1 General

This section defines sufficient component and composite algorithms for both differential and linear meter measurement. The component algorithms define sampling and calculation methodologies and averaging techniques. As each component algorithm is applied to the appropriate flow equation, a composite algorithm is defined that will ensure an acceptable gas measurement system.

When applying these methods to differential pressure measurement, the appropriate flow equations are found in the latest revision of API *MPMS* Ch. 14.3, Parts 1 through 4 for orifice meters or other approved differential pressure metering standards for other differential meters.

The flow equations appropriate for application of these methods to linear meter measurement are found in the latest revision of AGA Report No. 7 for turbine meters or other approved linear metering standards for other linear meters.

All supporting equations referenced, such as the equations of state for compressibility calculated using the AGA Report No. 8, shall be consistently applied with the latest revision of the standard.

4.2 Overview

4.2.1 Intent

The intent of this section is to provide calculations for orifice (API *MPMS* Ch. 14.3) and linear (AGA Report No. 7) meters. For other approved metering standards, these methodologies shall be applied to their equations.

The effect of sampling and calculation frequencies during fluctuating flow and the application of the various algorithms have been addressed by computer modeling to assure a difference within $\pm 0.05\%$ when compared to one second sampling. A statistical model known as the Rans Methodology provides, in part, the basis for the recommended sampling and calculation frequencies to support limits for statistical uncertainty. This methodology is included in Annex A.

4.2.2 Total Quantity

In metering applications, a total quantity is determined by the integration of a flow rate equation over a defined time interval. In equation form, the calculation of total quantity is expressed as the following:

$$V = \int_{t_0}^t Q dt \quad (1)$$

where

V is the quantity accumulated between time t_0 and time t ;

Q is the flow rate;

t is the time and dt is the differential of time.

Some of the variables used in the determination of flow rate are typically not static. A true total quantity is the flow rate integrated during continuously changing conditions over a specified QCP. In reality, the variables used for flow

determination are not read continuously; they are taken at discrete sampling intervals. The integral form of the equation is approximated by the following:

$$V = \sum_{i=1}^{i=n} (Q_i \Delta t_i) \quad (2)$$

where

V is the quantity accumulated over the QCP;

i is the sample number;

Q_i is the flow rate based on data taken at sample i ;

Δt_i is the time between samples;

n is the number of samples taken over the QCP.

NOTE Time units for Q_i and Δt has to be consistent.

4.3 Quantity Calculation Period (QCP)

The maximum QCP shall be 5 minutes unless it can be shown that the error introduced by a longer QCP causes less than 0.05 % difference in the quantity calculation. In all cases the QCP shall not exceed one hour. The Rans methodology in Annex A can be used as a guide in estimating the variability errors.

A QCP should be designed so that an integer (whole) number of QCPs occur during one hour.

To aid in recalculation of incorrect constant flow parameter changes, a QCP should end and a new QCP should begin any time one or more constant flow parameters are changed.

4.4 Differential Meter Measurement

4.4.1 General

The flow rate (Q_i) can take several forms, depending on whether the ultimate quantity being measured is volume at flowing conditions, volume at base conditions, mass, or energy. For example the calculation of flow rate through a flange tapped orifice at standard conditions taken from API MPMS Ch. 14.3, Part 3 (Third Edition, August 1992) equation 3-6b is:

$$Q_v = 7709.61 C_d(FT) E_v Y_1 d^2 \sqrt{\frac{P_{f_1} Z_s h_w}{G_r Z_{f_1} T_f}} \quad (3)$$

where

7709.61 is the unit conversion factor;

$C_d(FT)$ is the coefficient of discharge for flange-tap orifice meter;

E_v is the velocity of approach factor;

Y_1 is the expansion factor (upstream tap);

d	is the orifice plate bore diameter calculated at flow temperature (T_f), in inches;
P_{f_1}	is the flowing pressure (upstream tap), in pounds force per square inch absolute;
Z_s	is the compressibility at standard conditions (P_s , T_s);
h_w	is the orifice differential pressure, in inches of water at 60 °F;
G_r	is the real gas relative density (specific gravity);
Z_{f_1}	is the compressibility at flowing conditions (P_{f_1} , T_f);
T_f	is the flowing temperature, in degrees Rankin.

Other forms of the equation or equations for other types of differential meters are acceptable.

The determination of a quantity from the flow rate equation shall be done in one of two ways;

- 1) the flow rate shall be calculated at the sampling frequency using the entire flow rate equation and summed (see 4.4.3), or
- 2) the flow rate equation shall be factored into static and live components which are then combined at the end of each QCP to obtain a quantity (see 4.4.4).

4.4.2 Sampling Flow Variables

Differential pressure, static pressure, and temperature shall be sampled at least once per second⁴ and shall be averaged using a flow time linear average as described in Annex B, *Averaging Techniques*. Other live input variables may be sampled at their update frequency.

A slower sampling frequency may be used if the Rans Methodology or another methodology can demonstrate that the difference in calculated quantity associated with a less frequent sampling time is no more than ± 0.05 % different than the quantity associated with a one second sampling frequency for a given application, and the slower sampling frequency is agreeable to the parties involved.

4.4.3 Quantity Determination from the Full Flow Rate Calculation

It is recognized that the most accurate method of determining a quantity from a series of instantaneous flow rate calculations is to calculate flow rate at the sampling frequency (minimum once per second). This will generally result in a calculation difference of less than 0.005 % (50 ppm per API *MPMS* Ch. 14.3, Part 4) when all the variables and calculations required by the applicable measurement standard (e.g. API *MPMS* Ch. 14.3, Part 3) and gas compressibility determined per the applicable standards (e.g. AGA Report No. 8) are included.

If the full flow rate calculation is used, a separate QTR Integral Value or Average Extension shall be calculated, stored, and reported for verification purposes. The calculation of the integral value is expressed as follows:

$$IV = \sum_{i=1}^{i=n} (\sqrt{h_{w_i} P_{f_i}} \Delta t_i) \quad (4)$$

⁴ Exactly consistent sample intervals may not be possible due to computer architecture and the complexity of the algorithms in question. However the effect of minor variations in the sample period will not be statistically significant if the average sample period is small compared to the observed variation in flow dynamics.

where

- h_{w_i} is the differential pressure at sample i ;
- P_{f_i} is the absolute static pressure at sample i ;
- Δt_i is the sampling interval;
- i is the sample number.

Some EGM systems report the average extension instead of integral value:

$$\overline{IV} = \frac{IV}{ft} \quad \text{or} \quad IV = \overline{IV} \times ft \quad (5)$$

where

- \overline{IV} is the average extension;
- IV is the integral value;
- ft is the flow time:

$$= \sum (\Delta t_i) \text{ for intervals when } \sqrt{h_{w_i} P_{f_i}} \text{ is greater than 0.}$$

It is acceptable to include the additional live input variables in the IV , such as flowing temperature (T_f) and relative density (G_r), if their average is reported in the QTR. Because the sampling frequency of relative density is generally much slower than once per second, IV 's containing relative density has to use the most recent value of relative density.

At a minimum, hourly quantities as defined in Section 6, *Data Availability* shall be calculated and maintained.

4.4.4 Quantity Determination from the Factored Flow Rate Calculation

4.4.4.1 General

If quantity is not calculated using the full flow rate calculation described in 4.4.3 then the method described in this section has to be used to determine volume.

Instead of calculating the entire flow rate equation at the sampling frequency, the flow equation is factored into two parts; one containing the live input variables that can change significantly with time, and one containing the static variables that remain relatively constant with respect to time.

$$Q_i = IMV \times DV_i \quad (6)$$

where

- Q_i is the flow rate based on data taken at sample i ;
- IMV is the Integral Multiplier Value, representing the static variables;
- DV_i is the Dynamic Variables, representing the live input variables, taken at sample i .

For calculations not done at the sampling frequency:

$$V = IMV \sum_{i=1}^{i=n} (DV_i \Delta t_i) \quad (7)$$

The term $\sum_{i=1}^{i=n} (DV_i \Delta t_i)$ is called the Integral Value (IV), such that $V = IMV \times IV$.

NOTE Using factored flow rate calculations in situations with high differential pressure/static pressure ratios and highly fluctuating flow will generally result in calculation differences greater than 0.05 % compared to the full flow rate calculation method if the DPY requirements of 4.4.4.4 are not followed.

4.4.4.2 Integral Value (IV) Calculation

An Integral Value (IV) is the value resulting from the integration of the factored portion of the flow rate equations that best defines the conditions of continually changing flow over a specified time period. The minimum requirements for the IV shall be the square root of the product of differential pressure and absolute static pressure calculated at the sampling interval. In equation form, the calculation of the IV is expressed as follows.

$$IV = \sum_{i=1}^{i=n} (\sqrt{h_{w_i} P_{f_i}} \Delta t_i) \quad (8)$$

where

h_{w_i} is the differential pressure at sample i ;

P_{f_i} is the absolute static pressure at sample i ;

Δt_i is the sampling interval;

i is the sample number.

Some EGM systems report the \overline{IV} instead of integral value:

$$\overline{IV} = \frac{IV}{ft} \quad \text{or} \quad IV = \overline{IV} \times ft \quad (9)$$

where

\overline{IV} is the average extension;

IV is the integral value;

ft is the flow time:

$$= \sum (\Delta t_i) \text{ for intervals when } \sqrt{h_{w_i} P_{f_i}} \text{ is greater than 0.}$$

It is acceptable to include the additional live input variables in IV , such as flowing temperature (T_f) and relative density (G_r), if their average is reported in the QTR. The sampling frequency of relative density (G_r) is generally much slower than once per second, IV 's containing relative density has to use the most recent value of relative density.

The IV shall not contain any constants or configurable/calculated variables. A list of live variables and the calculations of IV or \overline{IV} shall be stated in the Configuration Log (see 5.4).

For IV calculation whenever the sampled differential pressure is less than or equal to the no flow cutoff value (refer to 4.4.5), the value of h_{w_i} is zero.

Where multiple samples within one second have been taken and averaged over the one-second time period, the value of Δt will be $\frac{1}{3600}$ hours (one second), regardless of the sampling frequency.

4.4.4.3 Integral Multiplier Value (IMV) Calculation

IMV is the value resulting from the calculation of all factors of the flow rate equation that are not included in the IV . IMV shall be calculated at the end of each QCP using flow time linear average values of the live inputs with the exception of the gas expansion factor (Y).

4.4.4.4 Differential Pressure for Expansion Factor Calculations

Analysis of the expansion factor calculation has shown significant errors may be introduced in highly variable flow at high differential pressure/static pressure ratios which frequently occur at low operating pressure. Unless the full flow rate calculation described in 4.4.3 is used the expansion factor variability becomes significant and the expansion factor needs to be factored into its dynamic and static parts. Differential pressure is the dynamic portion of expansion factor and a flow-weighted differential pressure is required to calculate the QCP expansion factor.

$$\text{Flow Weighted Differential Pressure} \approx \frac{\sum_{i=1}^n (h_{w_i} IV_i)}{\sum_{i=1}^n IV_i} \quad (10)$$

because the expansion factor correction is small, the error introduced by using $\sqrt{h_{w_i}}$ as the IV is insignificant and DP_Y becomes:

$$\text{Flow Weighted Differential Pressure} \approx \left(\frac{\sum_{i=1}^n (h_{w_i} \sqrt{h_{w_i}})}{n} \right)^{2/3} \quad \text{or} \quad (11)$$

$$\text{Flow Weighted Differential Pressure} \approx \left(\frac{\sum_{i=1}^n (h_{w_i})^{3/2}}{n} \right)^{2/3}$$

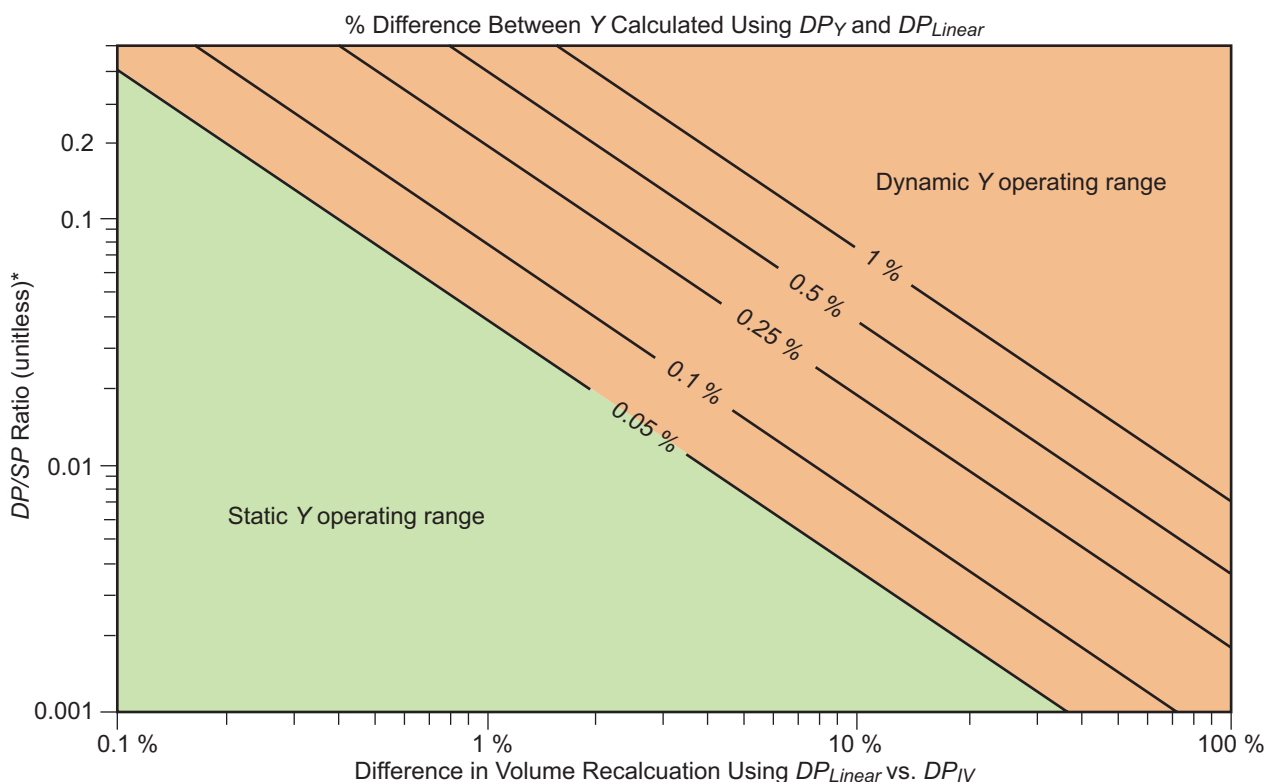
where

DP_Y is the differential pressure used to calculate the QCP expansion factor;

h_{w_i} is the differential pressure at sample i ;

IV_i is the integral value at sample i ;

i equals the sample number.



*Based on linear flow time averages of DP and SP and IV reported in the hour quantity transaction record.

Notes:

1. See Annex A.4.2 for additional details and examples of how this figure can be used.
2. If volume is calculated using the full flow rate calculation described in 4.4.3 there is no averaging error and the methods and requirements of this section do not apply.
3. DP_Y can be calculated from the differential pressure (DP_{Linear}) and integral value (IV or \overline{IV}) contained in the QTR.
4. Because DP_Y approaches DP_{Linear} as the flow fluctuation reduces, it is recommended that DP_Y be used in calculation of expansion factor in all QCP calculations.
5. To detect DP_Y and IV errors caused by gauge line amplification of flow noise, the differential pressure flow pattern shall be confirmed as real flow whenever the DP_{Linear} vs. DP_{IV} volume recalculation exceeds 10 % or the DP_Y vs. DP_{Linear} Y calculation exceeds 0.5 % as shown in Figure 2.

Figure 2—Estimated Expansion Factor Errors Based Hourly QTRs and DP/SP Ratios

Under highly variable flow at high differential pressure/static pressure ratios, either a new differential pressure average (DP_Y) needs to be added or an approximation of DP_Y needs to be calculated from the existing averages. DP_Y shall only be used as the value of differential pressure in the meter expansion factor calculation.

Using the two averages of differential pressure that can be obtained from the existing QCP, an approximation of DP_Y has been empirically derived ⁵.

$$DP_Y \approx \left[1 + 3.345 \times \left(\frac{\sqrt{DP_{Linear}}}{\sqrt{DP_{IV}}} - 1 \right) \right] \times DP_{Linear} \quad (12)$$

⁵ Gas Volume Calculation Errors in Highly Erratic Flow White Paper.

where

DP_{Linear} is the flow time linear average of differential pressure (see Annex B);

DP_{IV} is the average differential pressure calculated from the integral value (see Annex B).

Two remaining issues need to be addressed.

- 1) When should the expansion factor be considered dynamic?
- 2) Should DP_Y be calculated in addition to other averages of the differential pressure if calculations are being performed using the factored flow rate calculation method?

Figure 2 has been developed to answer the first question. It uses the DP_Y equation above to calculate the expansion factor error as a function of the differential pressure/static pressure ratio and flow variability estimated by the percent difference caused by recalculation using the DP_{Linear} and DP_{IV} averages. This recalculation difference can be estimated by:

$$\% \text{ Volume Difference} \approx \left(\sqrt{\frac{DP_{Linear}}{DP_{IV}}} - 1 \right) \times 100 \quad (13)$$

The expansion factor shall be characterized as static or dynamic based on Figure 2. The expansion factor can be considered static if the meter consistently operates at or below an error threshold of 0.05 % and dynamic for operating conditions that exceed this threshold. For static conditions the flow time linear average of differential pressure should be used to determine gas expansion factor if DP_Y is not used. For dynamic conditions DP_Y shall be used.

The frequency for demonstrating compliance shall be mutually agreed upon by the parties involved, and/or as required by law, statute, or regulation.

4.4.4.5 Volume Calculation

At the end of each QCP, the IMV is multiplied by the IV to obtain a total quantity for the QCP. At a minimum, hourly quantities as defined in Section 5 shall be calculated and maintained. If the QCP is less than one hour, the quantities for each QCP can be maintained and reported, or, the quantities determined for each QCP can be summed for each hour.

4.4.5 No Flow Cutoff

The no flow cutoff is used to address the differential pressure transmitter zero stability and site induced false flow. The recommended no flow cutoff value is determined by calculating 0.25 % of the user defined span of the differential pressure transmitter, not to exceed 0.5 in. H₂O of differential pressure. Additional consideration of documented site conditions may result in a no flow cutoff value that is above or below the recommended limit.

4.5 Linear Meter Measurement

The flow rate (Q_i) can take several forms, depending on whether the ultimate quantity being measured is volume at flowing conditions, volume at base conditions, mass, or energy. One example of the calculation of flow rate in general terms is:

$$Q_i = Q_f \left(\frac{P_f}{P_b} \right) \left(\frac{T_b}{T_f} \right) \left(\frac{Z_b}{Z_f} \right) \quad (14)$$

where

Q_i is the flow rate based on data taken at sample i ;

Q_f is the flow rate at flowing conditions;

P_f is the pressure at flowing conditions;

P_b is the base pressure;

T_f is the temperature at flowing conditions;

T_b is the base temperature;

Z_f is the compressibility at flowing conditions;

Z_b is the compressibility at base conditions.

Other forms of the equation or equations for other types of linear meters are acceptable.

The flow equation may be factored into two parts: one representing the actual volume and one containing the measured variable that remain relatively constant with respect to time.

$$Q_i = IMV \times Q_f \quad (15)$$

where

Q_i is the flow rate;

IMV is the Integral Multiplier Value, representing the relatively static measured and calculated values;

Q_f is the flow rate at flowing conditions.

Combining the factored form of the equation with the quantity calculation above, yields:

$$V = IMV \sum_{i=1}^{i=n} Q_{fi} \Delta t_i \quad (16)$$

The term $\sum_{i=1}^{i=n} Q_{fi} \Delta t_i$ is called the Integral Value (IV), such that $V = IMV \times IV$.

4.5.1 Sampling Flow Variables

The frequency or rate from a linear meter shall be sampled once every second or be continuously accumulated. If the flow rate is calculated for operational use from a low frequency meter, take care to use a calculation interval appropriate to the meter output.

Static pressure and temperature shall be sampled at least once per second⁶ and averaged using flow time linear averages. Other live input variables may be sampled at their update frequency.

⁶ Exactly consistent sample intervals may not be possible due to computer architecture and the complexity of the algorithms in question. However the effect of minor variations in the sample period will not be statistically significant if the average sample period is small compared to the observed variation in flow dynamics.

A slower sampling frequency may be used if the Rans Methodology can demonstrate that a difference in uncertainty associated with a less frequent sampling time is no more than $\pm 0.05\%$ greater than the uncertainty associated with the one second sampling frequency for a given application, and the slower sampling frequency is agreeable to the parties involved.

4.5.2 Integral Value (*IV*) Calculation

The Integral Value (*IV*) for linear meters is defined as:

$$IV = \sum_{i=1}^{i=z} Q_{fi} \Delta t_i \quad (17)$$

where

IV is the integral value;

Q_{fi} is the flow rate at flowing conditions;

Δt_i is the time between samples;

z is the number of samples taken over the QCP.

and:

$$z = \frac{QCP}{\Delta t}$$

NOTE See 4.3 for maximum QCP.

4.5.3 Integral Multiplier Value (*IMV*) Calculation

The Integral Multiplier Value (*IMV*) for linear meters is defined as:

$$IMV = \left(\frac{P_f}{P_b} \right) \left(\frac{T_b}{T_f} \right) \left(\frac{Z_b}{Z_f} \right) \quad (18)$$

where

IMV is the integral multiplier value;

P_f is the pressure at flowing conditions;

P_b is the base pressure;

T_f is the temperature at flowing conditions;

T_b is the base temperature;

Z_f is the compressibility at flowing conditions;

Z_b is the compressibility at base conditions.

and the values are based on flow time linear averages of the variables for the QCP.

4.5.4 Q_f —Flow Rate at Flowing Conditions

For synchronous linear meters such as turbine and rotary meters, Q_f is calculated by totalizing the pulse output. With the introduction of intelligent linear meters, the types of output have changed to include manufactured pulses, serial or analog rate and serial accumulator outputs. This has resulted in the need to redefine the calculation of Q_f .

Traditional synchronous meters have also been subjected to external linearization, utilizing multiple k -factors or meter factors, to reduce measurement uncertainty. Intelligent linear meters may have this linearization done within the meter or externally applied. This requires an understanding of how these factors are applied in the calculation of IV .

NOTE 1 In the following subsections: Counts/Flow Rate/Accumulator Difference is intended to be the non-linearized volumetric output of the meter at actual conditions and IV is intended to be the linearized volumetric output of the meter at actual conditions. The QTR ratio of IV divided by the non-linearized volumetric output is the QTR average meter linearization (See Annex J for examples of how these equations can be applied).

NOTE 2 The equations presented below may be adapted to different linear metering technologies and to support additional mathematical equations that give equivalent results.

NOTE 3 Some linear meter standards define k -factor as the inverse of the definitions in this section. Take care to use the correct mathematical definition when applying this standard to those metering technologies.

4.5.4.1 Linear Meters with Synchronous Pulse Outputs

$$IV = \sum_{i=1}^{i=n} Q_{fi} \Delta t_i \text{ is expressed as } \sum_{i=1}^{i=n} \frac{mf_i}{k\text{-factor}_i} \sum_{j=1}^{j=z} \text{Counts} \text{ or } \sum_{i=1}^{i=n} mf_i \sum_{j=1}^{j=z} \frac{\text{Counts}}{k\text{-factor}} \text{ or } \frac{1}{k\text{-factor}} \sum_{i=1}^{i=n} mf_i \sum_{j=1}^{j=z} \text{Counts} \quad (19)$$

where

Counts is the accumulation of meter pulses;

$k\text{-factor}$ is the single linear meter constant in counts per unit volume;

$k\text{-factor}_i$ is the multi-point linear meter constant in counts per unit volume calculated at interval i ;

mf_i equals 1 or mf_i equals the meter factor for period i (when multi-point meter factors are used);

j is the sampling period;

z is the number of samples per calculation period;

i is the calculation period;

n is the number of calculation per QTR period.

NOTE 1 Due to the mechanical design of these devices, the pulse is synchronized to the flow.

NOTE 2 j and z should be chosen such that $n = \text{QTR period} / (j \times z)$ is an integer.

NOTE 3 $\text{Counts}/k\text{-factor}$ is considered a variable input and this summation shall be reported in the QTR. (This value may be reported as $\text{frequency} = \text{Counts}/\text{flow time}$.)

4.5.4.2 Linear Meters with Manufactured Pulse Outputs

$$IV = \sum_{i=1}^{i=n} Q_{fi} \Delta t_i \text{ is expressed as } \sum_{i=1}^{i=n} \frac{mf_i}{k\text{-factor}_i} \sum_{j=1}^{j=z} \text{Counts} \text{ or } \sum_{i=1}^{i=n} mf_i \sum_{j=1}^{j=z} \frac{\text{Counts}}{k\text{-factor}} \text{ or } \frac{1}{k\text{-factor}} \sum_{i=1}^{i=n} mf_i \sum_{j=1}^{j=z} \text{Counts} \quad (20)$$

where

- Counts* is the accumulation of meter pulses;
- k-factor* is the single linear meter constant in counts per unit volume;
- k-factor_i* is the multi-point linear meter constant in counts per unit volume calculated at interval *i*;
- mf_i* equals 1 or *mf_i* equals the meter factor for period *i* (when multi-point meter factors are used);
- j* is the sampling period;
- z* is the number of samples per calculation period;
- i* is the calculation period;
- n* is the number of calculation per QTR period.

NOTE 1 Due to the manufactured nature of the meter pulse output, the meter manufacturer needs to ensure the manufactured pulses are synchronized to the flow.

NOTE 2 *j* and *z* should be chosen such that *n* = QTR period / (*j* × *z*) is an integer.

NOTE 3 *Counts/k-factor* is considered a variable input and this summation shall be reported in the QTR. (This value may be reported as *frequency* = *Counts/flow time*.)

4.5.4.3 Linear Meters with Rate Output

$$IV = \sum_{i=1}^{i=n} Q_{fi} \Delta t_i \text{ is expressed as } \sum_{i=1}^{i=n} mf_i Q_{mi} \Delta t_i \text{ or } \frac{1}{k\text{-factor}} \sum_{i=1}^{i=n} mf_i Q_{mi} \Delta t_i \quad (21)$$

where

- Q_{mi}* is the meter flow rate at actual flowing conditions for period *i*;
(units are volume/unit time if the *k-factor* is included in the meter flow rate or counts/unit time if the *k-factor* not included in the meter flow rate);
- mf_i* equals 1 or *mf_i* equals the meter factor for period *i* (when multi-point meter factors are used);
- i* is the calculation period;
- n* is the number of calculations per QTR period;
- k-factor* is the single linear meter constant in counts per unit volume.

NOTE 1 The meter output needs to be read at a frequency that is sufficient to correctly capture the fluctuation in the flow.

NOTE 2 The meter output may already be corrected for *k-factor*.

NOTE 3 $mf_i Q_{mi}$ is considered a variable input if a multi-point meter factor is used and its average shall be reported in the QTR.

4.5.4.4 Linear Meters with Accumulator Output

$$IV = \sum_{i=1}^{i=n} Q_{fi} \Delta t_i \text{ is expressed as (Accumulator Difference for the QTR) or } \sum_{i=1}^{i=n} mf_i \times \text{Accumulator Difference}_i \quad (22)$$

where

mf_i equals 1 or mf_i equals the meter factor for period i (when multi-point meter factors are used);

i is the calculation period;

n is the number of calculation per QTR period.

NOTE 1 The accumulator handles rate fluctuation and therefore does not need to be read more frequently than the QCP unless external meter factor corrections are being applied.

NOTE 2 The meter manufacturer needs to ensure that manufactured accumulations are synchronized to the flow.

NOTE 3 The meter output has to already be corrected for *k-factor* and meter factor.

NOTE 4 *Accumulator Difference* is considered a variable input if a multi-point meter factor is used and its accumulation shall be reported in the QTR.

4.5.5 No Flow Detection/No Flow Cutoff

No flow shall be defined as an absence of counts over a period of time.

The no flow cutoff is used to address the site induced false flow.

For pulse output meters, the recommended no flow cutoff value is 0 pulses/period of time. The time period is based on the expected frequency of the meter.

For rate output meters, the recommended no flow cutoff value is 0 for serial rate meters (or as recommended by the meter manufacturer) and 0.25 % of span for analog output rate meters.

In some cases the no flow cutoff is integral to the meter based on its operating characteristics. The meter manufacturer shall provide a description of this process and the no flow cutoff value.

Consideration of documented site conditions may result in an increased no flow cutoff value.

4.5.6 Volume Calculation

At the end of each QCP, the *IMV* is multiplied by the *IV* to obtain a total quantity for the QCP. At a minimum, hourly quantities as defined in Section 5 shall be calculated and maintained. If the QCP is less than one hour, the quantities for each QCP can be maintained and reported, or, the quantities determined for each QCP can be summed for each hour.

4.6 Value Determination For Live Inputs

At a minimum, the IV and hourly averages of all live inputs shall be maintained and reported (see Section 5). Flow time linear averages shall be used and must only include values taken when there is flow (above the no flow cutoff) unless there is no flow for the whole QTR. If the QCP is less than one hour, the averages for each QCP can be maintained and reported, or, the averages determined for each QCP can be combined to obtain an hourly average (see Annex B.4, *Calculation of QTR Averages*).

4.7 Compressibility, Density, Heating Value, and Composition

Compressibility, density, heating value and composition may be required in the calculation of mass, energy, and/or volume. They may be introduced into the calculation as a constant value, sampled input, or calculated value using a combination of constant values and sampled inputs. Increasing the frequency of updating/calculation of these variables can minimize mass, energy and/or volume calculation uncertainty. All sampled inputs should be determined using the techniques given in 4.4 and 4.5 and be consistent with the time interval of the calculations.

5 Audit and Record Requirements

5.1 Introduction

This section defines the minimum requirements of a QTR and QTR_{corr} documentation associated with the operation of an EGM, and the minimum data retention periods to report and verify the integrity of the measurement.

An EGM system shall be capable of establishing an audit trail by compiling and retaining sufficient data and information for the purpose of verifying daily and hourly quantities. This documentation shall include units of measure for all reported values.

The audit trail shall include, but is not limited to, QTRs, Configuration Logs, Event Logs, field test reports, QTR_{corr}, and reason for correction (edit). The records and reports in this section may be created onsite or off-site, or a combination of both and shall include units of measure where applicable.

The primary reason for retaining historical data is to provide support for the current and prior quantities reported on the measurement and quantity statements. The data will provide sufficient information to apply reasonable adjustments when the EGM equipment:

- requires correction for measurement errors or metering standards changes (see 5.7.1);
- has stopped functioning;
- is determined to be out of tolerance;
- has incorrectly recorded measurement parameters.

The data will also allow parties with a direct interest in the measurement results to independently verify the correctness of the reported gas quantities.

5.2 Quantity Transaction Record (QTR)

The QTR is the set of unedited historical data and information supporting the accounted quantity or quantities of volume, mass, or energy. The QTR will be identified by a unique identifier denoting a specific electronic metering device and primary device.

The QTR shall be collected and stored with enough resolution to allow recalculation within 50 ppm per API *MPMS* Ch. 14.3, Part 4. This can generally be achieved using single precision data.

5.2.1 Rounding and Reporting

QTRs should be collected and stored in non-rounded floating point or integer form. For reporting purposes these items may be displayed as rounded values but all calculations on the report should use the non-rounded values. Units of measure shall be displayed with each value reported, as appropriate.

5.2.2 QTR for Differential Type Meters

The QTR is the flow time linear average and summation of data collected and calculated during a maximum of 60 consecutive minutes. (See Annex B.4, *Calculation of QTR Averages*.) A QTR shall end, and a new record begins, at the end of each hour. This is a minimum requirement and shorter record intervals are acceptable.

There shall be a minimum of 24 hourly QTR's for each contract day (except for spring adjustment of daylight savings time where 23 hours are allowed). Additional QTR's may exist each time one or more constant parameters are changed.

The following data shall be contained in the QTR for each period:

- date and time or date/time identifier;
- quantity (volume, mass and/or energy);
- flow time;
- Integral value/Average extension;
- differential pressure average;
- static pressure average;
- temperature average.

Relative density, energy content, composition, and/or density averages shall be included if they are live inputs.

NOTE 1 Where possible, DP_{IV} should be calculated by the flow computer or host and stored as part of the QTR. (See Annex K for an example of using DP_{IV} to recalculate a QTR)

NOTE 2 Additional QTRs may exist each time one or more constant parameters are changed.

For EGM systems using off-site calculations, the minimum data set generated onsite shall include:

- date and time or date/time identifier;
- flow time;
- Integral value/Average extension;
- differential pressure average;
- static pressure average;
- temperature average.

5.2.3 Daily QTR for Differential Type Meters

The daily QTR is the flow time linear average or summation of QTRs calculated during a contract day (See Annex B.4, *Calculation of QTR Averages*). A daily QTR will end and a new daily record will begin at the end of each contract day.

The summation of the hourly values shall be equal to the daily report totals within the resolution of the flow computing system. If time or contract hour changes are made during a contract day, the affected totals from the EGM may not be the same; however, the final reported daily values shall match the sum of the hourly records.

The following data shall be collected in the daily QTR for each daily period:

- date and time or date/time identifier;
- quantity (volume, mass, and/or energy);
- flow time;
- Integral value/Average extension;
- differential pressure average;
- static pressure average;
- temperature average.

Relative density, energy content, composition and/or density averages shall be included if they are live inputs.

NOTE Where possible, DP_{IT} should be calculated by the flow computer or host and stored as part of the QTR.

5.2.4 QTR for Linear Type Meters

The QTR is the average and summation of data collected and calculated during a maximum of 60 consecutive minutes (See Annex B.4, *Calculation of QTR Averages*). A QTR shall end, and a new record begins, at the end of each hour. This is a minimum requirement and shorter record intervals are acceptable.

The following data shall be collected in the QTRs for each period:

- date and time or date/time identifier;
- quantity (volume, mass and/or energy);
- flow time;
- Integral value;
- meter output (accumulation or average);
- static pressure average (if required by meter type);
- temperature average (if required by meter type).

Composition, energy content, and relative density averages shall be included as required (to perform calculations) if they are live inputs.

If the primary device does not generate a pulse count, then a manufactured pulse is not required.

For EGM systems using off-site calculations, the minimum data set generated onsite shall include:

- date and time or date/time identifier;
- flow time;
- meter output (as defined in 4.5.4).

Averages of static pressure and temperature shall be included if they are live inputs.

IV or Average Extension shall be included if these calculations are performed onsite.

5.2.5 Daily QTR for Linear Type Meters

The daily QTR is the flow time linear average or summation of QTRs calculated during a contract day. (See Annex B.4, *Calculation of QTR Averages*.) A daily QTR will end and a new daily record will begin at the end of each contract day.

The summation of the QTR values shall be equal to the daily report totals within the resolution of the flow computing system. If time or contract hour changes are made during a contract day, the affected totals from the EGM may not be the same; however, the final reported daily values shall match the sum of the QTR records.

The following data shall be contained in the daily QTRs for each daily period:

- date and time or date/time identifier;
- quantity (volume, mass and/or energy);
- flow time;
- Integral value (see 4.5.2);
- meter output (accumulation or average);
- static pressure average (if required by meter type);
- temperature average (if required by meter type).

Composition, energy content, and relative density averages shall be included as required (to perform calculations) if they are live inputs.

5.3 Software/Firmware Identifiers

Unique identifiers shall be provided to identify the version of the software used in the EGM system. Version documentation shall include the calculation standards and their revision dates.

5.4 Configuration Log

5.4.1 General

The Configuration Log shall be part of the audit package for the accounting period. The log shall contain and identify all constant flow parameters, calculation method algorithms, and general information used in the generation of a QTR.

See Annex G for examples of typical configuration data for differential and linear meters.

5.4.2 Flow Computer Snapshot Report

It is recommended that a flow computer snapshot report be available to check the flow computer calculations by providing the current input variables and configuration constants. The snapshot report should capture a snapshot of the last QCP showing the input variables/input variable averages, integral value or average extension, configuration constants, calculated values and the algorithm used to calculate the QCP volume, mass and/or energy. If different averaging periods are used for the QCP calculation and the compressibility calculation, the averages used in the compressibility calculation for the QCP and the calculated compressibility should also be displayed in the report.

5.5 Event Log

The Event Log shall be a part of the audit package for the accounting period. The Event Log is used to note and to record exceptions and changes to the constant flow parameters contained in the Configuration Log that occur and that have an impact on a QTR. The events include, but are not limited to, changes or modifications to items in 5.4.

Each time a constant flow parameter that can affect the QTR is changed in the system, the old and new value, along with the date and time of the change, shall be logged.

The date and time of all events in the log shall be identified chronologically.

The Event Log shall have sufficient capacity and shall be retrieved at intervals frequent enough to maintain a continuous record of events for the life of the meter or the required data retention period as discussed in 6.4.

5.6 Alarm and Operating Data

The alarm log contains a record of operating exceptions and events. It may be combined with the Event Log or be maintained separately to prevent the loss of Event Log data.

Flow Operation Statistics: To aid in identifying operating problems, the EGM system may report:

- the period of time the differential pressure or meter output exceeds the configured high limit;
- the period of time differential pressure or meter output is between the configured low limit and the no flow cutoff;
- the period of time differential pressure or meter output is below the no flow cutoff.

5.7 Corrected Quantity Transaction Record (QTR_{corr})

QTR_{corr} results from editing the original QTR or a QTR_{corr}. The correction has to be performed off-site either in a measurement system or as a manual adjustment to the QTR produced by the tertiary device or as an adjustment made in an accounting system. Any calculation performed outside of the EGM system is considered an “off-site” calculation or adjustment. Changes or modifications to the original algorithms contained in the EGM device shall not be made without appropriate documentation.

The QTR_{corr} is required to reflect changes to the original constant and/or live inputs used in the calculation of the QTR. The QTR_{corr} may reflect a change in quantity if any constant and/or dynamic flow parameters are not correct. The correction of EGM may result from the following.

- Constant flow parameters were not available at the time of calculation; were entered incorrectly; or were found to be in error at a later time.
- Live input variables corrected as a result of calibration, failure, or deviant operating conditions of the measurement equipment.

If the above situations result in the need to correct the original parameters, a new QTR is recalculated and the QTR_{corr} shall:

- be clearly identified as a QTR_{corr} ;
- clearly indicate all data or values that have been corrected;
- include a reference for all corrections that can be used to obtain detailed documentation justifying the change made. This documentation is considered to be part of the QTR_{corr} and shall be available as part of the audit package.

The original QTRs shall remain intact as a permanent record. The combination of the original QTR, the final QTR_{corr} , and justification for all changes will provide a detailed tracking of the custody transfer quantities.

5.7.1 Recalculation of Data

Off-site final calculations and on-going revision to metering standards can be addressed by measurement systems using a recalculation and edit process of the QTR. The volume calculation can be corrected in the measurement system using the correction methodology.

$$\text{Corrected Volume} = \frac{\text{Recalculate Volume}_{\text{Corrected Values}}}{\text{Recalculate Volume}_{\text{Original Reported Values}}} \times \text{Reported Volume} \quad (23)$$

“Recalculate Volume_{Corrected Values}” would recalculate the volume using the new equations or changed variable(s) and “Recalculate Volume_{Original Reported Values}” would recalculate the volume using the equation or variable(s) used by the EGM. Multiplying this ratio times the EGM reported volume would correct the volume for these changes. (See Annex C.2.)

5.8 Test Record

A test shall be part of the audit package and consists of any documentation or record (electronic or hard copy) produced in the testing or operation of metering and analyzer equipment that would affect the calculation of measured quantities. The documentation shall include, but not be limited to, calibration/verification reports as defined in Section 8; but shall also include primary device inspection reports, equipment change tickets and peripheral equipment maintenance and inspection reports.

6 Data Availability

6.1 General

The requirements of this section are intended to ensure that the minimum necessary data is collected and retained in order to allow proper determination of the quantities measured by the EGM system. The EGM system may be comprised of a number of smart components, each with its own change management configuration and audit trail

capabilities. It should not be assumed that all of the capabilities are flow computer requirements, but are requirements of the system as described in Figure 1. The data shall be electronically or manually recorded. Accessing the information onsite through the use of portable data collection devices in lieu of viewing the information on a display is acceptable unless prohibited by statute, regulation, tariff, or contract.

6.2 Onsite Data Requirements

- 1) A minimum of seven days of hourly (or more frequent) QTRs as described in 5.2.

NOTE For EGM systems performing off-site calculations quantity (volume/energy/mass) may not be included in the QTR.

- 2) A minimum of seven days of daily operational data to include, but not limited to, daily quantity and flow time totals and daily averages of static pressure and temperature. For differential meters, daily operational averages of differential pressure shall also be available.

NOTE This requirement is operational and can be amended based on agreement of the parties involved.

- 3) Constant flow parameters and manually entered input variables that affect the quantity calculation including, but are not limited to, meter specific parameters (i.e. meter run tube internal diameter, orifice plate bore diameter, no flow cutoff, Venturi throat diameter, static pressure tap location, meter and/or *k-factors*), base pressure and temperature, and the calibrated range of any transducers providing a live input to the flow calculation.
- 4) Current values for live input variables or calculated variables including, but not limited to, the values of static pressure, temperature, flow rate, accumulated quantity, and any current alarm or error conditions. For differential meters, the value of differential pressure has to also be available.

NOTE For EGM systems performing off-site calculations flow rate and quantity (volume/energy/mass) may not be available.

- 5) Current value of gas analysis data including, but not limited to, gas composition, relative density / density, and energy content, regardless of whether this data is a live input or constant value.

NOTE This requirement does not apply to EGM systems performing off-site calculations.

- 6) Equipment information including, but not limited to, the unique identification number of the metering system.

6.3 Off-Site Data Requirements

- 1) Electronic or hard copy records of event, alarm and test records shall be available including, but not limited to the following:
 - Old and new values for changes to any constant flow parameters and manually entered input variable that will affect calculated quantities (see 5.4);
 - A complete summary of all event or error conditions affecting measurement, including a description of each alarm condition (see 5.5);
 - The date and time of all events and alarms;
 - Test records with “as-found” and “as-left” values for all calibrated or verified equipment including static pressure, temperature, differential pressure and other primary and secondary equipment (see 5.8).
- 2) Original and Corrected QTRs (as described in 5.2 and 5.7)

6.4 Data Retention

The off-site retention period for the EGM audit trail data shall be defined by regulation, statute, tariff, or contract.

7 Commissioning

7.1 General

Commissioning is the process of the initial verification and documentation that the EGM system is installed and functioning according to its specification, design, and regulatory/contract requirements.

Most of the individual devices which make up the EGM system will be type tested prior to start of the final site integrated EGM system commissioning. Although this type testing is not part of the commissioning process, verification of the test result documentation and EGM system configuration to these test certificates is an important part of commissioning.

NOTE 1 Primary device manufacturing, testing and mechanical meter run installation requirements are out of scope for this document; however confirmation that this documentation has been completed and the primary device instrumentation is correctly configured and operating is in scope.

NOTE 2 Secondary device testing is out of scope for this document; however confirmation that this documentation has been completed and review of factory calibration certificates is in scope.

NOTE 3 Tertiary device type testing is out of scope for this document; however confirmation that this testing has been successfully completed and documented is in scope.

NOTE 4 This document specifies calculation algorithms and requires that these algorithms be tested. Flow computer testing protocols are out of scope for this document, however no testing protocols exist. Dynamic input testing is strongly recommended and Annex E, *Example Flow Computer Variable Input Type Testing—Differential Meters*, contains examples of some suggested algorithm tests.

NOTE 5 See Annex F for a suggested commissioning checklist.

7.2 Documentation Review

7.2.1 Primary Device

Primary device calibration and/or inspection reports should be available onsite and reviewed during the commissioning process. These reports or the report reference number should be included in the site commissioning documentation.

7.2.2 Secondary Devices

The range, operating, and environmental limits for all transducers/transmitters involved in EGM shall be clearly stated and provided with the equipment. The manufacturer should also provide documentation that states the combined accuracy effect of linearity, hysteresis, and repeatability, the effect of temperature and/or static pressure on zero and span and other factors such as vibration, power variation, and mounting position sensitivity that should be considered when selecting and maintaining this equipment.

The manufacturer should provide field commissioning and calibration/verification procedures. These procedures, including diagnostic software if available, should be onsite and followed during the commissioning process.

For factory calibrated or tested devices, the manufacturer shall provide documentation of the testing and accuracy verifications, including equipment specification and performance documentation. This data shall be reviewed prior to

the start of, or onsite during commissioning. A record of the device documentation reference numbers shall be retained onsite and should be included in the site commissioning documentation.

7.2.3 Tertiary Devices

The internal calculations of the EGM devices shall be verified by testing and the test results documented.

For type tested devices, this documentation should be reviewed prior to commissioning or onsite during commissioning and referenced in the site commissioning documentation. Type testing is limited to user configurable devices.

User programmable devices require individual device testing and documentation. These tests should be included in the site commissioning documentation.

7.3 Final Integrated EGM System Site Commissioning

7.3.1 General

The integrated EGM system site testing and commission process can be divided into four process blocks:

- the meter/primary device flow element and meter run;
- secondary devices/primary device instrumentation and electronics;
- tertiary devices;
- end-to-end operational check.

NOTE 1 Figure 3 uses ISA symbols where the first letter of the symbol is the process variable and the second letter is the type of instrument. For example for the symbol PI, P stands for pressure instrument and I stands for indicator. The process variables in the figure are pressure (*P*), flow rate (*F*), temperature (*T*), analytical (*A*), and the types of instruments are indicator (I), transmitter (T), element (E).

NOTE 2 EGM systems can contain a number of intelligent devices with specific configuration and commissioning requirements. Manufacturers of EGM devices should provide detailed installation, configuration and commission procedures along with electronic or manual reporting which documents the EGM device configuration and diagnostic data.

NOTE 3 The amount of commissioning work can be minimized by maximizing the pre-commissioning verification of device algorithms and specification compliance and minimizing the site configuration and wiring.

7.3.2 Primary Device Commissioning

Follow the manufacturer and, where available, industry standard meter commissioning and verification procedures. (For example AGA Report No. 3/API MPMS Ch. 14.3 for orifice meters, AGA Report No. 9 for ultrasonic meters, AGA Report No. 11 for Coriolis meters, etc.)

Verify the required meter test documentation has been completed and that the required meter data is available for use in the secondary and tertiary device configuration and verification process.

7.3.3 Secondary Devices Commissioning

Verifications shall be done when a transmitter is first installed and after it is zeroed, commissioned and stable. The commissioning process prior to the final verification may include zeroing of the transmitter, verification and for field calibrated devices, calibration if required. Follow the manufacturer and, where available, industry standard commissioning and calibration procedures. See Section 8.

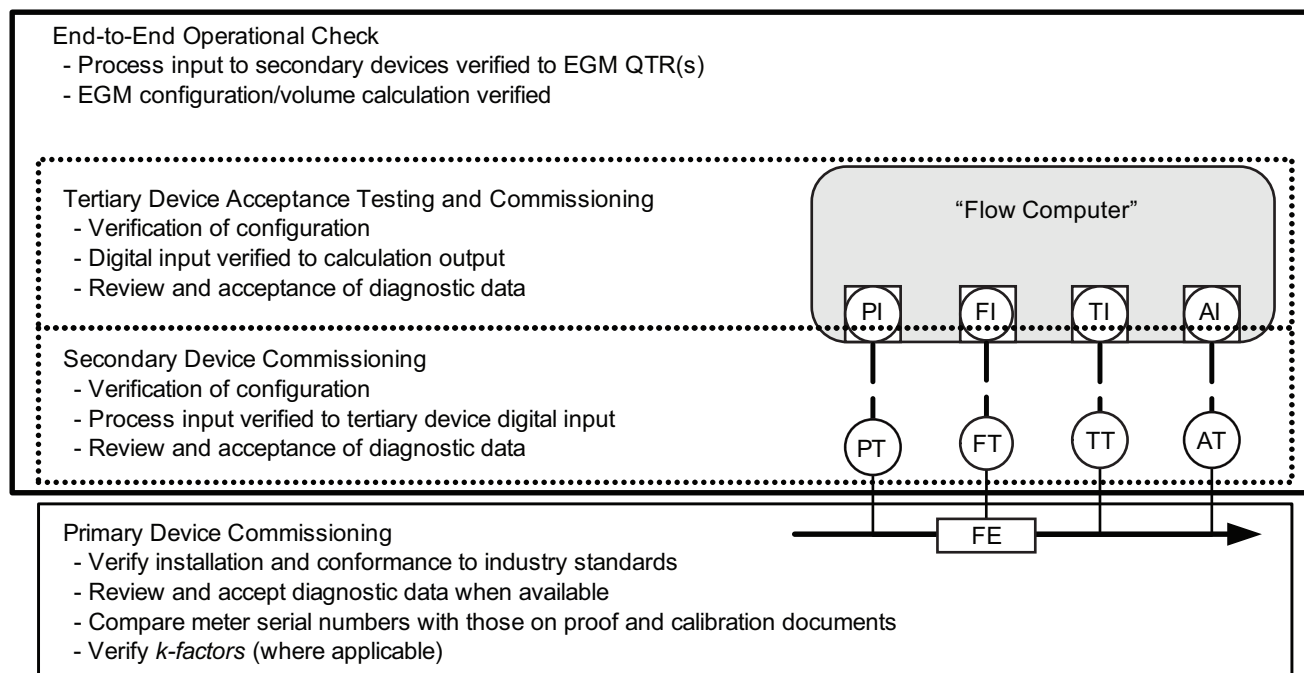


Figure 3—Conceptual Representation of an EGM System

Differential Pressure: At a minimum, verifications shall be performed at these pressure points under atmospheric conditions and in the following sequence:

- zero;
- approximately 25 % of user defined operating range or transmitter calibration span;
- approximately 50 % of user defined operating range or transmitter calibration span;
- 100 % of user defined operating range or transmitter calibration span;
- approximately 80 % of user defined operating range or transmitter calibration span;
- approximately 20 % of user defined operating range or transmitter calibration span; and
- zero.

Static Pressure: At a minimum, verifications shall be performed at these static pressure points in the following sequence:

- zero (atmospheric pressure);
- expected operating static pressure;
- 100 % of user defined operating range or transmitter calibration span;
- expected operating static pressure; and
- zero (atmospheric pressure).

NOTE For absolute or “sealed-gauge” pressure transmitters the atmospheric pressure should be measured and used in the calibration, zero adjust and/or verification process.

Temperature: At a minimum, verifications shall be performed at these points using:

- a temperature bath at a point below expected operating temperature;
- a temperature bath at a point above expected operating temperature; and
- flowing gas temperature or a temperature bath at expected operating temperature.

Other Secondary Devices: At a minimum, verifications shall be performed at the points recommended by the manufacturer.

7.3.4 Tertiary Devices Commissioning

Follow the manufacturer and where available industry standard commissioning and calibration/verification procedures.

For tertiary devices that are user programmable or the calculation algorithms have not been type verified, the internal calculations of the EGM devices shall be verified and documented.

7.3.5 End-to-End Operational Check—Integrated System Commissioning

As a final commissioning step, the site configuration should be checked and a quantity recalculation done based on QTRs and configuration data within 30 to 90 days of first flow.

For larger volume facilities a final commissioning verification check may also include simulating the static pressure, temperature and flow inputs for one QCP or QTR. This will verify the flow computer wiring, configuration and averaging/calculation process onsite prior to placing the station in service.

7.4 Commissioning Documentation

A commissioning test report or checklist and all EGM component documentation and commissioning tests shall be available for review.

8 Equipment Verification and Calibration

This verification and calibration section describes the minimum requirements for verifying and calibrating EGM components used for custody transfer.

8.1 Components Requiring Verification/Calibration

The following EGM components require verification/calibration:

- static pressure transmitters;
- differential pressure transmitters;
- temperature transmitters;
- on-line analyzers, where applicable;
- other EGM devices, where applicable.

8.2 Verification and Calibration

8.2.1 General

EGM components and their individual transducers, transmitters, and analyzers are substantially different in their methods of calibration. Some have zero, span, and linearity adjustments and some only zero and span. Others are calibrated electronically (intelligent devices such as so-called ‘smart’ transmitters) and require no mechanical adjustments. Their signal output can be a voltage, current, pulse frequency, or other forms of data signals. For this reason, refer to the manufacturer’s operation guide for step-by-step calibration procedures.

The results of all verifications and calibrations shall be recorded and included as part of the audit package.

Verification is the process of confirming or substantiating accuracy of an EGM device by the use of measurement or reference standards. The frequency and requirements for periodic verification to certified test equipment shall be based on contract/regulatory requirements or mutual agreement.

Redundancy Verification is confirming the device accuracy at operating conditions over a period of time as a percent of reading difference between the flow time linear average of the custody device and an independent check device. Redundancy verification is a continuous type of verification. The frequency and requirements for periodic verification of one or both of the redundant transmitters to certified test equipment shall be based on contract/regulatory requirements or mutual agreement.

Calibration is the adjustment of an EGM device or components to conform to certified reference standards to provide accurate values over the EGM’s user defined operating range. A calibration will only be necessary during initial installation of the unit, following replacement of a transmitter, other critical components, or whenever the verification test determines a difference between the value measured or produced by the certified reference standard and that of the value measured and utilized by the EGM that exceeds the limit set by regulations, statutes, contractual agreements, or company policies.

8.2.2 Verification/Calibration of Pressure and Temperature Devices

8.2.2.1 General

The verification/calibration of EGM systems can be accomplished with three different maintenance practices as outlined in Table 1.

Table 1—Maintenance Practices

Maintenance Practice	Verification	Calibration
Field calibrated	Comparison to verification equipment	Field calibrated
Factory calibrated	Comparison to verification equipment	Factory/laboratory calibrated
Transmitter redundancy	Comparison periodically to verify with redundant transmitter	Field or factory/laboratory calibrated

Field calibrated transmitters have field based verification, zero adjust and calibration with the field calibration being the as-left transmitter calibration.

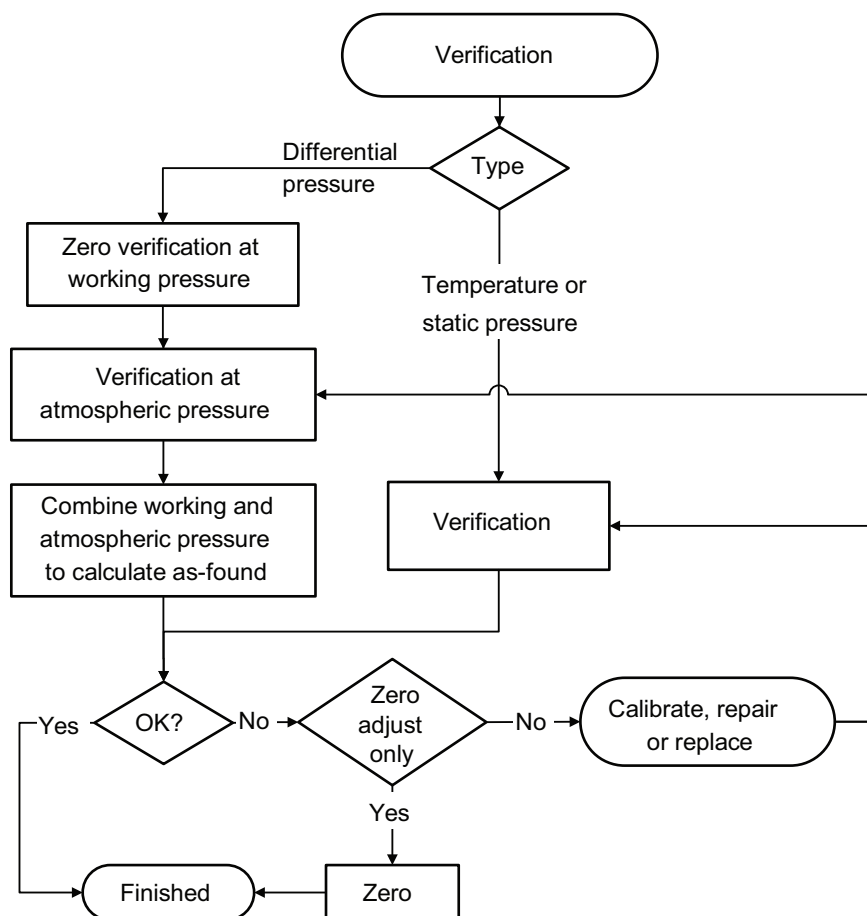
Factory calibrated transmitters have field based verification and zero adjust with the factory/laboratory calibration being the as-left transmitter calibration. This process only allows the transmitter to be zeroed and verified in the field and failure of the transmitter to meet verification tolerances after a zero adjustment requires the transmitter to be replaced or be field calibrated and adhere to practices and guidelines for a field calibrated device. If a field calibration is performed, this device is no longer considered factory calibrated. Factory calibration certificates shall clearly identify the calibrated range.

Transmitter redundancy is verification to a secondary independent transmitter. The primary transmitter is calibrated using either the field or factory maintenance practice.

The frequency of verification shall be based on contract/regulatory requirements or mutual agreement and upper and lower user defined operating limits shall be clearly identified and available for review.

Prior to any verification, check sensing lines and valves from calibration/verification equipment to the EGM device to ensure no leaks. Check for bypass (equalizer) valve leakage between the high and low pressure taps.

The flow chart in Figure 4 summarizes the verification/calibration requirement for pressure and temperature devices. The requirements in 8.2.2.3, 8.2.2.4, and 8.2.2.5 provide additional detail and should be referenced when clarification of the summary is required.



NOTE 1 All values shall be verified to the flow computer and all verification and adjustment results recorded.

NOTE 2 Where possible the transmitter raw sensor readings should be recorded.

Figure 4—Verification/Calibration Process

8.2.2.2 Verification Tolerance

Verification tolerances may be specified based on contractual or regulatory requirements or calculated using statistical means. For equipment that is operating properly, the difference in readings determined during verification is normally less than the root mean square of the 2 sigma (95 % confidence level) transmitter reference uncertainty and verification equipment accuracy. This tolerance can be expressed by:

$$\text{Tolerance} = \sqrt{(\text{Transmitter Uncertainty})^2 + (\text{Verification Equipment Accuracy})^2} \quad (24)$$

For example: If a differential pressure transmitter with a calibrated range of 100 in. of water column at 60 °F (in. H₂O); linearity/hysteresis/repeatability uncertainty of 0.1 % (95 % confidence level) of user defined operating range using verification equipment with an accuracy of 0.1 % (95 % confidence level) of reading is verified at 20 in. H₂O:

- transmitter uncertainty will be 0.1 % of 100 in. H₂O = 0.1 in. H₂O;
- the verification equipment accuracy of 0.1 % of 20 in. H₂O = 0.02 in. H₂O;
- the combined verification tolerance will be $\sqrt{(0.1)^2 + (0.02)^2} = 0.102$ in. H₂O .

Verifications shall compare the verification equipment value to the EGM's digital reading used in the determination of flow rate and volume.

If the device verification cannot be brought into tolerance by zeroing, after the verification is complete, the transmitter shall be calibrated or replaced.

8.2.2.3 Differential Pressure

Differential pressure transmitters may be verified at either atmospheric pressure or working pressure. Based on the verification device being used, the "Verification at Atmospheric Pressure" or "Verification at Working Pressure" test points as described below shall be used.

Verifications at Atmospheric Pressure: At a minimum, verifications shall be performed at:

- working pressure zero prior to de-pressuring the transmitter;
- atmospheric pressure—zero;
- atmospheric pressure—approximately 50 % of upper user defined operating limit or average flowing differential pressure;
- atmospheric pressure—upper user defined operating limit;
- atmospheric pressure—zero; and
- working pressure zero.

NOTE The "as found" values for differential pressure obtained at atmospheric pressure should be corrected to working pressure values (see example in Annex H).

Verifications at Working Pressure: At a minimum, verifications shall be performed at:

- working pressure—zero;

- working pressure—approximately 50 % of upper user defined operating limit or average flowing differential pressure;
- working pressure—upper user defined operating limit;
- working pressure—zero.

Redundancy Verification: Daily, weekly or monthly percent of reading comparisons between the primary and the check redundant transmitters may be performed in place of periodic verifications. (Annex I provides an example of a Redundancy Verification Report).

Calibration: If verifications fail to meet the verification tolerance requirements, the device shall be zeroed, calibrated or replaced.

- **For field calibrated devices**, a calibration shall be conducted according to the manufacturer's recommended procedures and adjustments made to eliminate errors. A verification shall be done before any calibration adjustments are made to the transmitter and an "as-left" verification shall be done after the adjustments unless it is calculated and recorded as part of the EGM adjustment process and calculation of the as-left is agreed to by the parties involved.
- **For factory calibrated devices**, if zero adjust of the transmitter cannot correct the verification error, the device shall be replaced and verification done."

Zero Adjustments: Compensation of intelligent transmitters reduces their sensitivity to operating static pressure and temperature changes. This reduction may not eliminate zero changes and the transmitters should be zeroed at their average operating conditions. To avoid excessive zero adjustments, a two step process to managing zero adjustments is recommended.

- For zero errors exceeding the transmitter tolerance requirements, the transmitter zero shall be adjusted.
- For zero errors within the transmitter tolerance requirements, the transmitter zero shall be zeroed unless trend data is available that supports that the zero deviation is not biased over time.

Transmitter Sensor Values: The sensor values may be recorded in addition to the as-found/as left engineering values. This is not a requirement but may aid the user in diagnosing transmitter drift over a designated time period.

8.2.2.4 Static Pressure

Verifications: Shall be done at 3 points:

- atmospheric pressure;
- operating pressure;
- upper user defined operating limit.

Unless the operating pressure percent fluctuation is less than 50 % of normal operation for the previous year and the station is operating in the normal operating range at the time of verification (see Annex D calculation of normal operation and percent fluctuation). Under these conditions:

- the static pressure may be verified at atmospheric, mid-range and operating pressure; or
- single point operating verifications may be used for intelligent transmitters.

The use of absolute or sealed gauge pressure transmitters further complicates the verification and zero adjustment process; see 8.3.3 for additional consideration when verifying these types of transmitters. For user defined operating ranges below 250 psig, atmospheric pressure has to be measured and accounted for in the verification and zero adjustment process.

Redundancy Verifications: Daily, weekly or monthly percent of reading comparisons are performed between the primary and secondary transmitter. Annex I provides an example of a Redundancy Verification Report.

Calibration: If verifications fail to meet the verification tolerance requirements, the device shall be zeroed, calibrated or replaced.

- **For field calibrated devices**, a calibration shall be conducted according to the manufacturer's recommended procedures and adjustments made to eliminate errors. A verification shall be done before any calibration adjustments are made to the transmitter and an "as-left" verification shall be done after the adjustments unless it is calculated and recorded as part of the EGM adjustment process and calculation of the as-left is agreed to by the parties involved.
- **For factory calibrated devices**, if zero adjustments of the transmitter cannot correct the error, the data shall be recorded and the device shall be replaced.

Zero Adjustments: Compensation of intelligent transmitters reduces their sensitivity to temperature changes. This reduction does not eliminate zero changes and the transmitters should be zeroed. To avoid excessive zero adjustments, a two-step process for managing zero adjustments is recommended.

- For zero errors exceeding the transmitter tolerance requirements, the transmitter zero shall be adjusted.
- For zero errors within the transmitter tolerance requirements, the transmitter zero shall be zeroed unless trend data is available that supports that the zero deviation is not biased over time.

Transmitter Sensor Values: The sensor values may be recorded in addition to the as-found/as left engineering values. This is not a requirement but may aid the user in diagnosing transmitter drift over a designated time period.

8.2.2.5 Temperature

Verifications: As a minimum verifications shall be done at one point, as close to operating temperature as practical. The verification shall be done using a test thermowell, thermometer and flowing gas temperature (if the station is flowing) or a bath and test thermometer.

Redundancy Verifications: Daily, weekly or monthly percent of reading comparisons are performed between the primary and check redundant transmitter may be used in place of periodic verification. Should the redundancy verification fail to meet its tolerance requirements, the verification process shown above shall be followed. (Annex I provides an example of a Redundancy Verification Report.)

Calibration: If verifications fail to meet the verification tolerance requirements, the device shall be calibrated or replaced. Prior to calibration the device wiring shall be checked for correct termination and absence of corrosion at its connection points and repaired if necessary.

- **For field calibrated devices**, a calibration shall be conducted according to the manufacturer's recommended procedures and adjustments made to eliminate errors. A verification shall be done before any calibration adjustments are made, referred to as "as-found" verification, and a verification shall be done after the adjustments unless it is calculated and recorded as part of the EGM adjustment process, referred to as "as-left" verification.

- **For factory calibrated devices**, if repair of wiring problems cannot correct the verification error, the device shall be replaced.

Bias Adjustments: RTDs have a linearization curve and are often calibrated with a bias adjustment. If an RTD calibration requires a bias adjustment, the temperature should be verified at a second point to confirm that there is no span related calibration error.

Transmitter Raw Sensor Values: The raw sensor values may be recorded in addition to the as-found/as left engineering values. This is not a requirement but may aid the user in diagnosing transmitter drift over a designated time period.

8.2.3 Verification/Calibration of On-line Analyzers

Verification: The accuracy of an analyzer should be periodically verified using a certified reference standard in addition to any device specific automated verification and calibration procedures. In addition the accuracy of an analyzer should be verified on a defined schedule using a reference standard. The output of the analyzer should be verified through the EGM device.

NOTE If the analyzer utilizes an onsite reference standard, a second certified reference standard should be used.

Calibration: If verifications fail to meet the accuracy requirements, the device shall be calibrated according to the manufacturer's recommended procedures, repaired or replaced.

Onsite Calibration Standards: Many on-line analyzers utilize an onsite calibration gas mixture of known composition for automatic verification and calibration. The gas should be kept in a specified temperature range and periodically checked to ensure that the composition has not changed (see API MPMS Ch. 14.1).

Sensor Values: Where possible, raw sensor values should be recorded in addition to as-found/as-left values. For example: gas chromatograph raw sensitivity factors should be recorded in addition to as-found/as-left reading.

8.2.4 Verification/Calibration of Other EGM Equipment

EGM systems may contain primary and secondary equipment that requires verification and whose requirements have not been specified in 8.2.2 and 8.2.3. Verification procedures for these devices are generally device and manufacturer specific. The manufacturer should provide a detailed verification procedure for their devices which includes:

- a device accuracy verification and calibration procedure;
- a recommended change management process for configuring, checking and recording device configuration changes that affect the calculated quantity; and
- a procedure for using and recording device diagnostics which include how to interpret the results and recommended corrective actions.

These procedures should include any industry standard audit and verification recommendations.

The output of the digital primary and/or secondary device should be verified through the EGM device.

The current configuration, the results of verification tests and configuration changes should be provided as part of the audit package for these devices.

8.3 Ambient Temperature, Line Pressure, and Atmospheric Pressure Effects

8.3.1 Ambient Temperature Effect

EGM components are typically installed in an uncontrolled environment. Responses of these components under a variety of ambient temperature conditions could affect the performance and accuracy of flow measurement. Ambient temperature changes or extremes may cause a significant systematic deviation from the expected measurement accuracy. Ambient operating temperature and its corresponding effect on measurement uncertainty (that is, percent full scale/degrees temperature change from reference) should be listed in the manufacturer's performance specifications and should be considered when selecting and installing EGM equipment. During verification/calibration, ambient temperature should be recorded.

8.3.2 Line-Pressure Effect

In practice, differential pressure transducers/transmitters are calibrated at atmospheric pressure. When a differential pressure component is placed in service at higher static pressure conditions, line pressure may cause a shift in calibration. It is recommended that the differential zero be checked at both atmospheric pressure and line pressure. Specifications on line pressure effects and compensation techniques should be provided by the manufacturer and be considered when determining the measurement uncertainty of the system.

8.3.3 Atmospheric Pressure Effect

Gauge pressure transmitters have been used in EGM systems and have been converted to absolute pressure using a configured average atmospheric pressure. An estimate of average atmospheric pressure can be calculated using data from the "US Standard Atmosphere (1976)" based on elevation:

In SI units:

$$\text{Average Atmospheric Pressure Estimate} = 101.325 \times (1 - 0.00002256 \times \text{Elevation})^{5.25577} \text{ kPa, for Elevation in Meters}$$

In USC units:

$$\text{Average Atmospheric Pressure Estimate} = 14.696 \times (1 - 0.00000686 \times \text{Elevation})^{5.25577} \text{ psi, for Elevation in Feet}$$

Errors in atmospheric pressure become more significant to EGM system uncertainty as the operating pressure is reduced. The use of absolute or sealed gauge pressure transmitters can reduce the static pressure uncertainty of low pressure EGM systems by accounting for the atmospheric pressure changes.

Calibration and verification procedures for absolute or sealed gauge pressure transmitters need to consider atmospheric pressure that can change by as much as ± 0.5 psi from average atmospheric pressure conditions. This requires atmospheric pressure to be either measured or its variability included in the calculation of verification tolerances.

8.4 Verification and Calibration Equipment

Improvements in transmitter accuracy can result in difficulty obtaining field verification/calibration equipment that is significantly more accurate than the transmitter being verified/calibrated. In some cases this may lead to a maintenance practice of using factory calibrated devices and only verifying the device to verification tolerances in the field (see 8.2).

Where possible, verification/calibration equipment should be at least twice as accurate as the device being calibrated. As a minimum standard, calibration/verification equipment shall have either an accuracy less than or equal to 0.1 % of the span/operating range of the device being calibrated or less than or equal to 0.1 % of reading. Temperature standards shall have an accuracy of less than or equal to 0.5 °F/0.3 °C. This will make the verification/calibration

equipment for EGM systems reasonably available. Use of calibration equipment that is less accurate than the equipment being calibrated will add significantly to the calibration uncertainty and needs to be considered in the facility uncertainty calculation.

Calibration/verification equipment with a specification that is different from the span/operating range of the device being calibrated needs to be converted to the device range accuracy specification. For example:

- A 1,000 psig pressure calibrator with a specification of 0.05 % of span that is used to calibrate a transmitter with a 250 psig user specified operating range, has a % of user specified accuracy specification of:

$$\% \text{ of span specification} \times \frac{\text{specified span}}{\text{span/operating range}} = 0.05 \% \times \frac{1000}{250} = 0.2 \% \text{ does not meet this requirement.}$$

- A pressure calibrator with a 16 psig range (approximately 443 in. of water column at 60 °F designated as "H₂O based on 16 × 27.707) and a specification of 0.05 % of reading plus a floor term of 0.005 % of full scale that is used to calibrate a transmitter with a 100 "H₂O user specified operating range, has a % of user specified accuracy specification of:

$$\frac{\% \text{ of Reading} \times \text{span} + \text{floor term}}{\text{span/operating range}} = \frac{0.05 \% \times 100 + 0.005 \% \times 443}{100} = 0.072 \% \text{ meets this requirement.}$$

9 Security and Data Integrity

9.1 Introduction

Security is required to prevent unauthorized alterations which affect the measurement integrity. This may include, but is not limited to, primary, secondary and tertiary devices, data collection systems, data editing processes, quantity calculation systems, and data storage systems.

It is recognized that some devices provide additional functions other than measurement. In such cases, additional functionality shall not affect the measurement calculations and data integrity.

9.2 Restricting Access

Systems shall be designed to deny unauthorized access for the purpose of altering any input variables and data that may affect measurement. The EGM system operator should consider assigning unique codes or security measures to individuals in order to ensure all parties gaining access are identifiable and accountable.

Security measures, other than the electronic means described above, may be utilized to deny unauthorized access to the system. These measures may include mechanical devices and/or additional levels of electronic security such as data encryption.

Security measures shall be utilized to maintain the data integrity any time data is collected from the system. Security measures shall be used every time changes or edits are performed that will alter quantities being measured.

9.3 Intelligent Device Data Communication Integrity

Error checking shall be utilized each time data is communicated from intelligent primary and secondary devices to the EGM device to ensure data integrity. If errors in communication are detected, the system shall prevent the use of this incorrect or corrupted data and indicate the failure.

Appropriate means shall be implemented to ensure the data from intelligent primary and secondary devices is not altered or replaced by the communication process.

9.4 Integrity of Logged Data

All data records as required in this standard shall be stored in such a way that they cannot be altered. Procedures shall be implemented to detect deleted or lost records.

There shall be no changes to the original data. Any alterations or corrections to the original data or calculated values shall be stored separately and shall not alter the original data. Both the original and the final adjusted data shall be retained.

9.5 Algorithm Protection

The software version that contains the algorithm in the EGM used to calculate quantities shall be protected from alterations. If a change to the software needs to be made, the existing software version should be removed and a new version shall be installed in the device. Each software version shall have a unique identifier that is retained in the EGM.

9.6 EGM Memory Protection

The EGM device shall provide a backup power supply, or nonvolatile memory, capable of retaining all data in the unit's memory for a period not less than thirty-five days.

When primary power is lost and subsequently restored, the time and date of the failure and the time and date of the return to normal status shall be logged into the audit trail.

9.7 Integrity of Transferred Data

Error checking shall be utilized each time data is transferred from a system capable of storing data to any other system capable of storing data. If errors are detected, the system shall prevent the use of incorrect data.

Annex A (informative)

Rans Methodology for Estimating Sampling Frequency and Calculation Algorithm Errors

This annex is a simplification of the methodology presented in the first edition of this standard. The annex was originally written as a stand-alone white paper and can be greatly simplified based on the acceptance that:

$$V = IMV \times IV$$

where

V is the volume for calculation interval and volume can be physical volume, energy or mass based on the equation used;

IMV is the integral multiplier value, representing the static variables for the calculation interval;

IV is the integral value, representing the summation of the dynamic variable for the calculation interval.

(See 4.4, *Differential Meter Measurement* and 4.5, *Linear Meter Measurement*)

Annex A.6 has been added and provides an additional method to deal with deterministic flow patterns when one second data is available. It also addresses expansion factor and averaging algorithm errors for differential producers with fluctuating flow and high differential pressure to static pressure ratios.

A.1 Sampling Frequency Integration Error

This section estimates:

- integration and calculation error for EGM systems doing calculations at the sampling frequency;
- integration error (IV error) for EGM systems using the factors calculation method (Annex A.2 estimates the IMV calculation error for these systems).

Integration of a quantity can be mathematically defined as:

$$Q = \int_{t_0}^{t_1} q(t) dt \equiv \lim_{n \rightarrow \infty} \frac{1}{n} \sum_{i=0}^n q_i \Delta t \quad (\text{A.1})$$

where

Q is the quantity (volume, energy or mass) over the integration interval from time t_0 to time t_1 ;

$q(t)$ is the quantity rate as a function of time;

q_i is the quantity rate for sample i ;

n is the number of samples;

Δt is the time interval between samples.

Approximate numerical integration values can be calculated for n less than ∞ as long as n is large relative to the changes of q over the integration interval. A conservative estimate of integration error caused by a numerical integration interval $-n$, can be calculated based on the following assumptions.

- The calculation/sampling interval is statistically independent of flow rate.
- The maximum change in flow rate during any calculation/sampling interval can be estimated.
- The desired integration accuracy is known.

The maximum calculation error possible, for a single calculation/sampling interval, can be estimated if the maximum change in the flow rate during any calculation/sample interval can be determined. The flow pattern that would cause the largest calculation/sample interval error is a step pattern. The maximum error would occur if the flow rate was sampled just prior to a step change. The error for the integration interval would be equal to the step change in flow rate (see Figure A.1).

For other samples of this step flow pattern and other flow patterns the error will be less than this maximum (see Figure A.2, Figure A.3, and Figure A.4).

Using this worst case error, the maximum calculation error can be estimated using the following equation:

$$e_{max} = \frac{\Delta q_{max}}{q_{avg}} \quad (A.2)$$

where

e_{max} is the maximum IV calculation error for one sampling interval;

Δq_{max} is the maximum quantity change (volume, mass, energy) during one sample interval;

q_{avg} is the average quantity (volume, mass, energy) for the integration interval.

If the calculation/sampling interval is independent of flow rate, the integration error can be estimated by applying statistical principles related to the standard deviation. (Statistically, n is assumed to be large.)

$$\sigma_x^- = \frac{\sigma}{\sqrt{n}} \quad (A.3)$$

where

σ^- is the mean standard deviation of the integration interval;

σ is the standard deviation;

n is the number of samples per integration interval.

If the distribution of the calculation/sampling interval errors is assumed to be a normal distribution, then the error calculated from Equation A.2 could be used as an estimate of the standard deviation. Because the error estimate

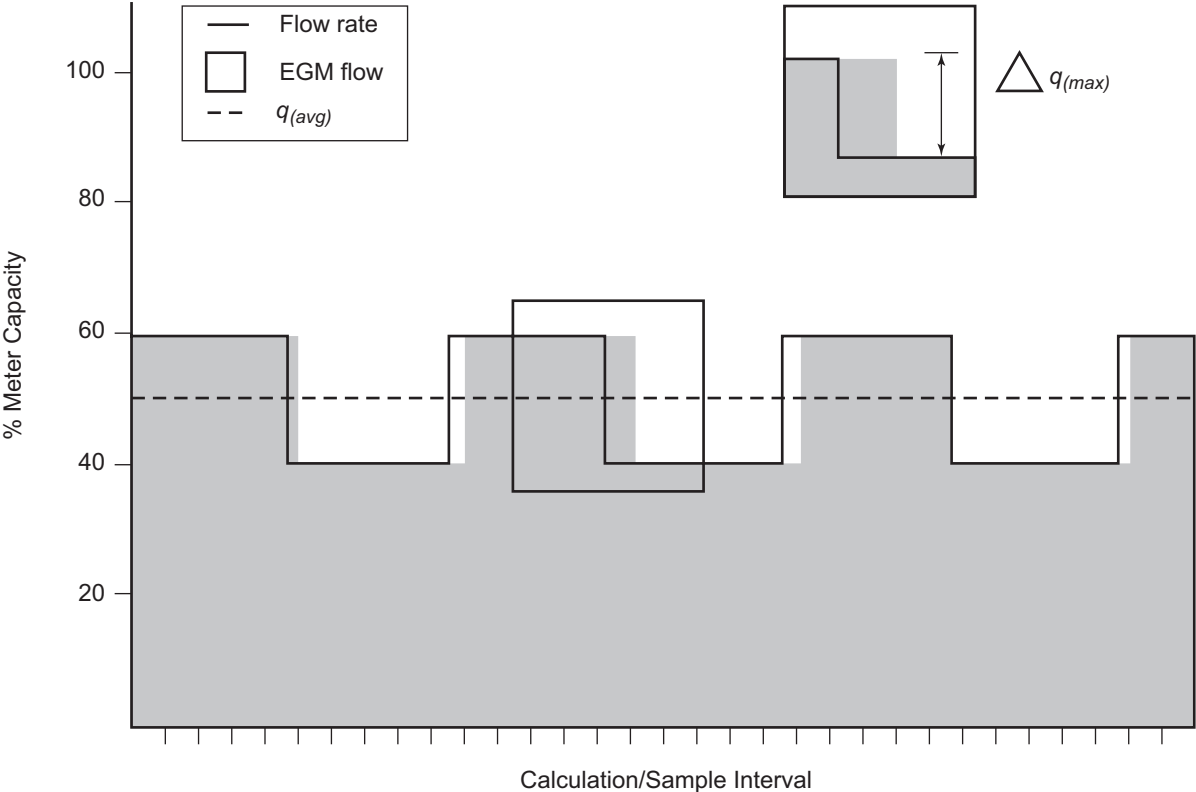


Figure A.1

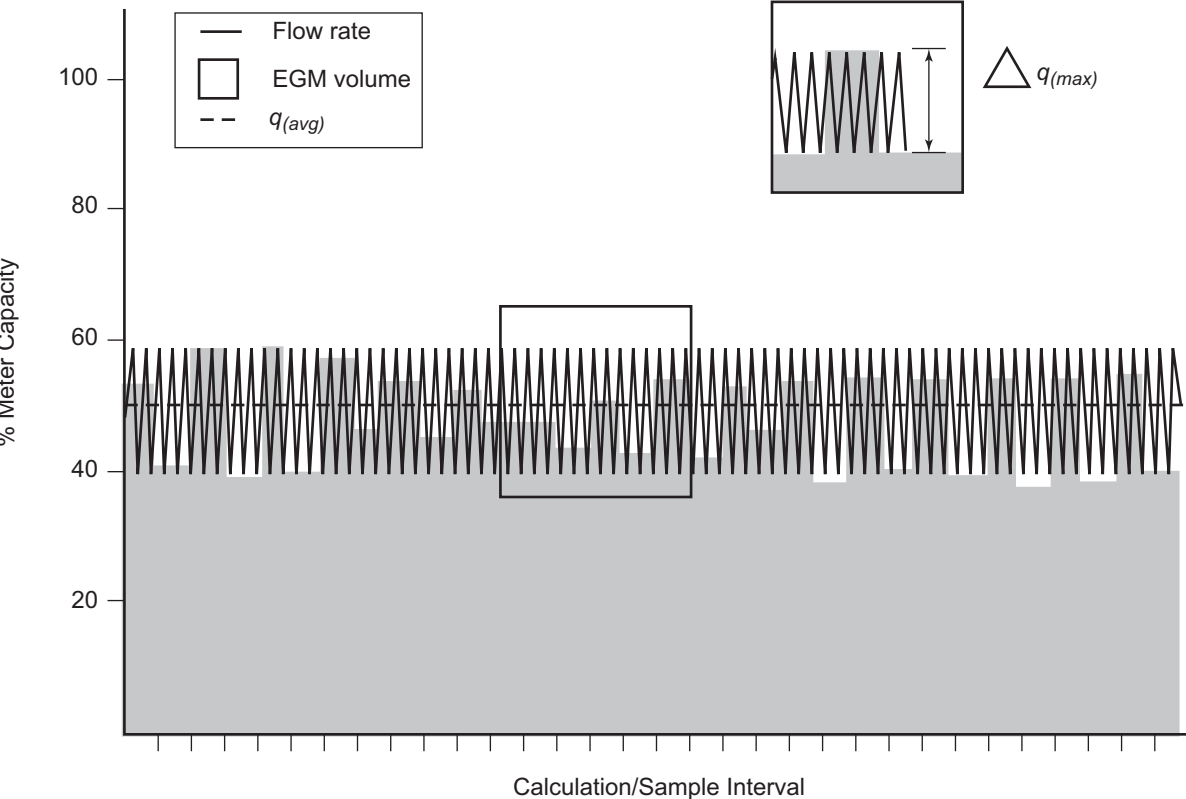
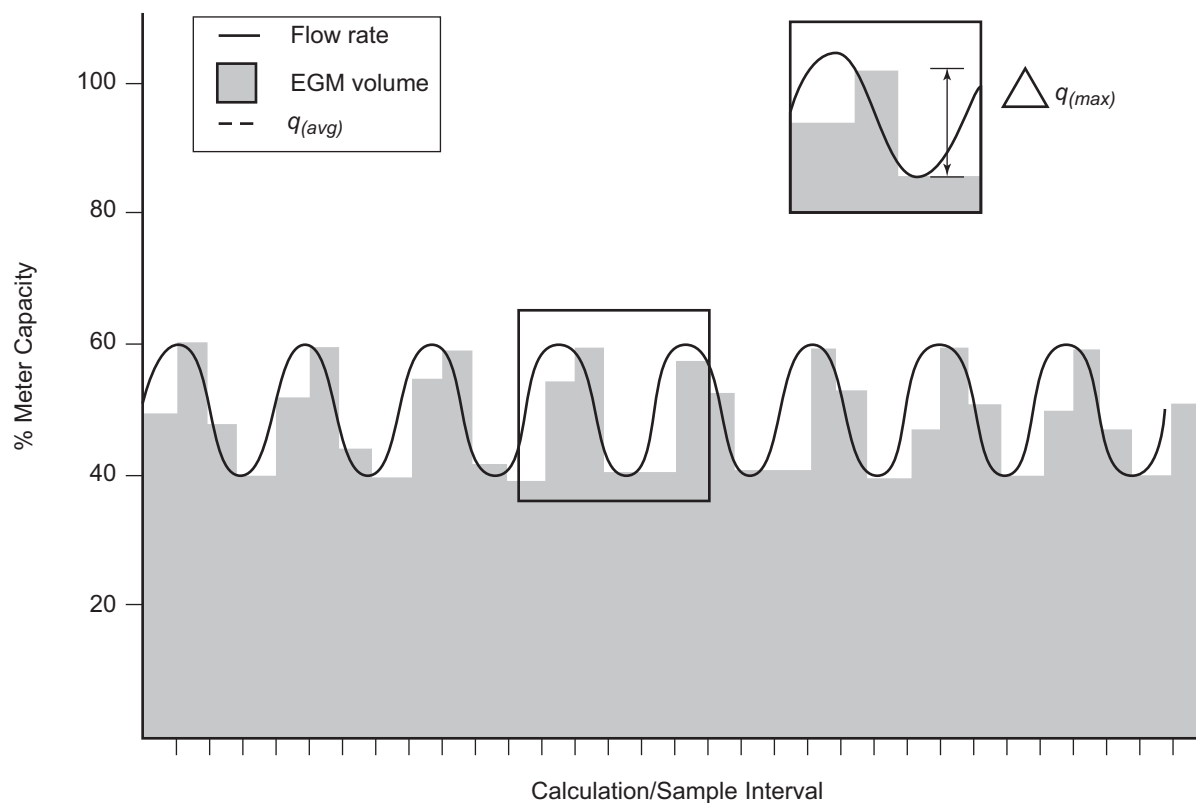
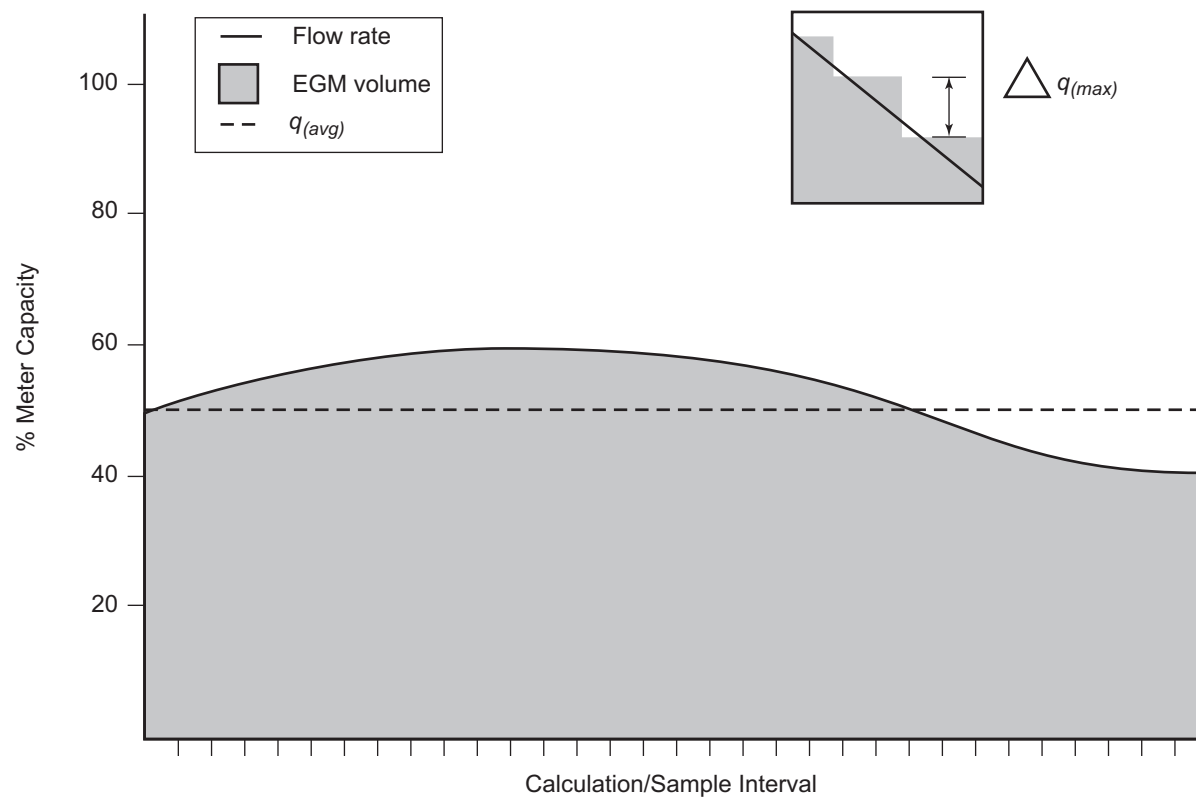


Figure A.2

**Figure A.3****Figure A.4**

from Equation A.2 is conservative, its value can be assumed to be the 3σ (approximately 99 % confidence level) value of this normal distribution and the error value of the mean of these errors can be estimated using:

$$3\sigma_x = \frac{3\sigma}{\sqrt{n}} \quad (\text{A.4})$$

$$\therefore e_{\text{integration interval}} = \frac{e_{\max}}{\sqrt{n}} \quad (\text{A.5})$$

where

$e_{\text{integration interval}}$ is the error over the integration interval.

Solving for n , the number of samples required to obtain the desired accuracy for the integration interval can be determined:

$$n = \left(\frac{e_{\max}}{e_{\text{integration interval}}} \right)^2 \quad (\text{A.6})$$

NOTE The integration interval used in this calculation is generally one day and can be as long as one month if the requirement is to estimate the monthly measurement impact.

A.2 Error Caused by Using Variable Averages in the *IMV* Calculation

This section provides a way to estimate the *IMV* calculation error for EGM systems using the factors based calculation method.

Annex A.3 discusses reducing the *IMV* error by moving these variables from the *IMV* calculation to the *IV* calculation, if these live input variables are available. This technique reduces the error introduced by using averages to calculate *IMV* variables at the quantity calculation period (QCP).

Annex A.4 provides a method to estimate the error caused by calculating *IMV* from the remaining variable averages.

A.3 Deciding What Variables the *IV* Calculation Should Include

Based on the assumption that a parameter is constant over the Quantity Calculation Period (QCP), the *IV* calculation can be simplified by moving the parameter from the *IV* side of the equation to the *IMV* side. For example, if C_{meter} is approximately constant for the QCP, then C_{meter} does not need to be included in the *IV* and can be calculate as part of *IMV*. However, if the variability of the parameter is large, the averages used to calculate the parameter do not use flow time averages, the parameter is not linear as a function of flow, etc., then error is introduced into the *IMV* calculation.

Some examples of which variable to include in the *IV* and which can be included in the *IMV* are:

- 1) Assume that all of the differential producer process variables except for differential pressure are constant for a one-second time interval. Differential pressure is sampled n times per second. For the one-second calculations, the flow equation from Section 4.4 simplifies to:

$$V = NC_d(FT)E_v Y_1 d^2 \sqrt{\frac{P_{f_1} Z_s}{G_r Z_{f_1} T_f}} \sum_{i=1}^n (\sqrt{h_{w_i}} \Delta t) \quad (\text{A.7})$$

where

- V is the volume;
- N is the unit and flow time conversion factor (based on the volume integration interval and sample interval);
- $C_d(FT)$ is the coefficient of discharge for flange-tap orifice meter;
- E_v is the velocity of approach factor;
- Y_1 is the expansion factor (upstream tap);
- d is the orifice plate bore diameter calculated at flow temperature (T_f), in inches;
- P_{f1} is the flowing pressure (upstream tap), in pounds force per square inch absolute;
- P_s is the standard pressure;
- Z_s is the compressibility at standard conditions (P_s, T_s);
- h_w is the orifice differential pressure;
- G_r is the real gas relative density (specific gravity);
- Z_{f1} is the compressibility at flowing conditions (P_{f1}, T_f);
- T_f is the flowing temperature;
- T_s is the standard temperature;
- Δt is the sample interval.

or

$$IMV = NC_d(FT)E_vY_1d^2\sqrt{\frac{P_{f1}Z_s}{G_rZ_{f1}T_f}} \quad (A.8)$$

and

$$IV = \sum_{i=1}^n \sqrt{h_{wi}} \quad (A.9)$$

- 2) Assume that all of the process variables except for differential pressure and static pressure are constant for a one-minute time interval. For differential pressure and static pressure sampled n times per minute, the flow equation becomes:

$$V = NC_d(FT)E_vY_1d^2\sqrt{\frac{Z_s}{G_rZ_{f1}T_f}} \sum_{i=1}^n (\sqrt{h_{wi}P_{f1}}\Delta t) \quad (A.10)$$

or

$$IMV = NC_d(FT)E_v Y_1 d^2 \sqrt{\frac{Z_s}{G_r Z_{f1} T_f}} \quad (A.11)$$

and

$$IV = \sum_{i=1}^n (\sqrt{h_{wi} P_{f1}} \Delta t)$$

NOTE Z_f is a function of pressure, but has been assumed to be constant. Dependent on the change in this parameter over the calculation interval, a calculation error will be introduced.

- 3) Assume that all of the process variables except for differential pressure, static pressure, temperature, and specific gravity are constant for a five-minute time interval. For differential pressure, static pressure, temperature, and gravity that are sampled n times per five minutes, the flow equation becomes:

$$V = NC_d(FT)E_v Y_1 d^2 \sqrt{\frac{Z_s}{Z_{f1}}} \sum_{i=1}^n \left(\sqrt{\frac{h_{wi} P_{f1}}{G_r T_f}} \Delta t \right) \quad (A.12)$$

or

$$IMV = NC_d(FT)E_v Y_1 d^2 \sqrt{\frac{Z_s}{Z_{f1}}} \quad (A.13)$$

and

$$IV = \sum_{i=1}^n \left(\sqrt{\frac{h_{wi} P_{f1}}{G_r T_f}} \Delta t \right)$$

NOTE G_r is a live value, but may update at a slower frequency than the other variables.

A.4 Estimating the *IMV* Error Caused by Variables Which are Treated as Constants

A.4.1 General

Two issues contribute to the *IMV* calculation error:

- 1) The first calculation error, introduced by assuming a variable parameter is constant, will be approximately zero if the variable is linear over the integration interval and the flow weighted value of the variable is calculated. However, for audit purposes the flow time linear averages shall be calculated and reported for all input parameters. This often results in only flow time linear averages being available for the *IMV* calculation, not flow weighted averages and results in an increased *IMV* calculation error.
- 2) The second calculation error is introduced because most of the variable parameters are not linear.

For example expansion factor (Y) is a function of differential pressure/static pressure and should be linear.

$$Y \propto \frac{\text{differential pressure}}{\text{static pressure}}$$

However if the differential pressure and static pressure are flow time averaged and not flow weight averaged, expansion factor (Y) becomes a function of differential pressure/static pressure and IV . If the square root of differential pressure is used as a first order approximation of IV , then:

$$Y \propto \frac{\text{differential pressure} \times \sqrt{\text{differential pressure}}}{\text{static pressure}} \text{ or } \frac{(\text{differential pressure})^{1.5}}{\text{static pressure}}$$

This non-linearity not only turns into a calculation error, but as the differential to static pressure ratio increases, this error turns into a significant bias. See Annex A.6 for a detailed explanation of this error and an estimated correction factor for differential pressure to address this bias.

A.4.2 Estimating Methodology for IMV Errors

A conservative estimate of the error from each parameter is the following:

- 1) To estimate the maximum and minimum of the value of the IMV calculated parameter based on an estimate of the maximum and minimum value of one process variable.
- 2) Repeat this estimate for each remaining process variables.
- 3) Assume the calculation error for each process variable to be:

$$e_{\text{integration}} = \frac{\left(\frac{\text{Parameter}_{\text{max}} - \text{Parameter}_{\text{min}}}{2} \right)}{\text{Parameter}_{\text{avg}}} \quad (\text{A.14})$$

- 4) Assume the calculation error for each process variable to be 100 % correlated and sum the errors to calculate the total IMV error.

$$e_{\text{total}} = e_{\text{parameter}_1} + e_{\text{parameter}_2} + \dots \quad (\text{A.15})$$

- 5) Use the correction factor from Figure A.5 to account for the flow variability. This figure is an estimate of the error caused by using flow time linear averages versus flow weighted averages. For example:

- in transmission measurement, where the flow rate can be fairly constant, the flow rate variability can be less than 10 % and results in a Flow Rate Fluctuation Correction Factor of approximately 0.01;
- in plunger lift operation, where the flow rate is quite variable, the flow rate variability can be as high as 100 % and results in a Flow Rate Fluctuation Correction Factor of 1.

NOTE Figure A.5 was developed empirically by assuming a direct correlation between the parameter being calculated and the change in flow rate. The maximum difference between the volume calculated using flow weighted averages and flow time linear averages was determined for a step change in flow rate.

- 6) If periods of “no flow” occur during the QCP, the flow weight factor for that QCP would be 100 %.
- 7) For flow with a deterministic flow pattern, the error for each QCP of the flow pattern needs to be calculated and the flow weighted average of the errors used. Alternatively the methodology in Annex A.6 can be used.

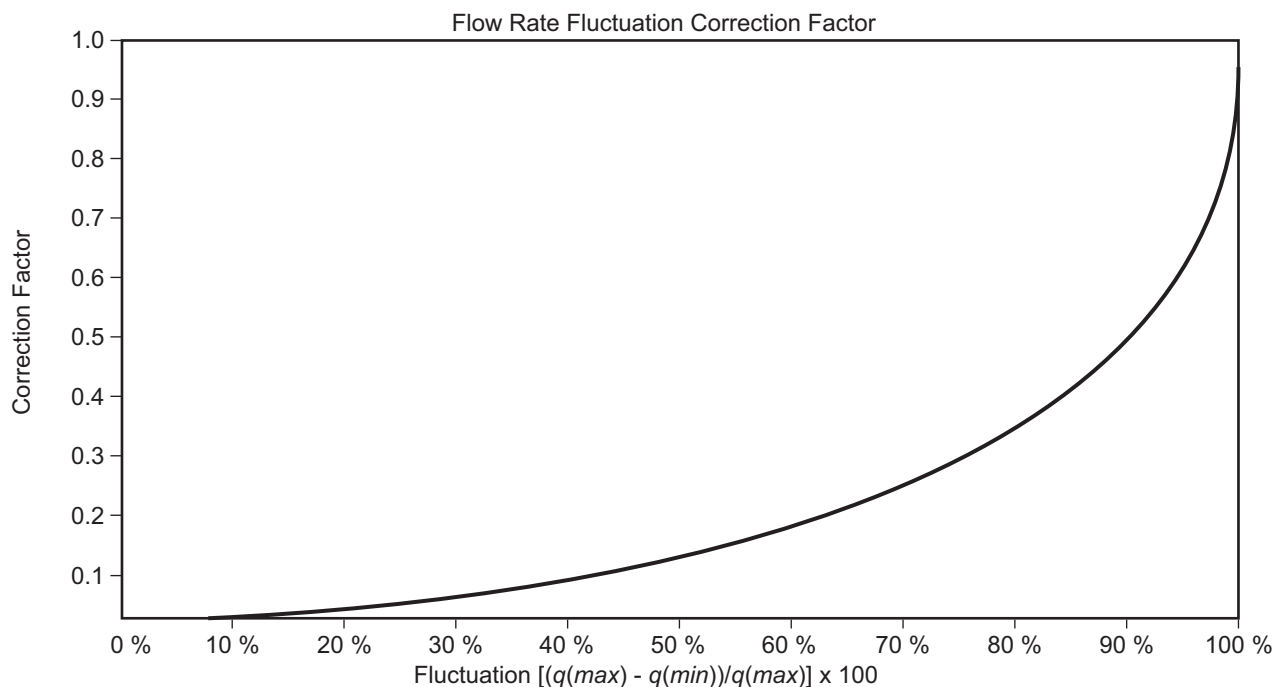


Figure A.5—Flow Rate Fluctuation Correction Factor

A.5 Maximum Allowable *IV/IMV* Error

Where operating considerations require less or more frequent sampling and calculation rates, the design criteria shall meet a daily error not to be greater than 0.5 %. The error associated with the calculation methodology should be calculated by adding the calculation/sampling interval error (Equation A.5) and the integration interval error (Equation A.15).

NOTE The *IMV* error estimating methodology assumes a worst case error. Actual errors will be approximately 10 % to 50 % of this worst case error.
For example a 0.5 % daily error calculated using this methodology is more likely to have an actual error in the range of 0.05 % to 0.25 %.

A.6 Estimating Integration Error from One Second Logged Data

Annex A.1 and Annex A.2 provide a methodology for estimating the error associated with calculation frequency when the variable error is linear and assuming worst case correlation. If the error isn't linear (expansion factor calculated using DP_{Linear}) or the characteristics of the variables are deterministic (plunger lift flow cycling) a different estimation technique may be required.

Figure A.6 shows an example of one-second log data captured from the flowing cycle of a plunger lift well.

This one-second data can be used to calculate the integration errors ($e_{integration}$) introduced by different flow computer averaging algorithms and calculation frequencies. By comparing the different algorithm averages and volume calculations based on these averages to the calculations based on the one-second logged data, $e_{integration}$ can be calculated.

For example: the one-second sampled data from Figure A.6 can be used to calculate the one-minute averages in Figure A.7. The one-minute averages can then be used to calculate one-minute volumes and compared to volume calculated from the one-second data. In this example, the hourly volume calculated from the one-second data is 5.5737 and the volume calculated from the one-minute data using *IV* and the flow time linear average differential pressure is 5.5764, a difference of 0.048 %.

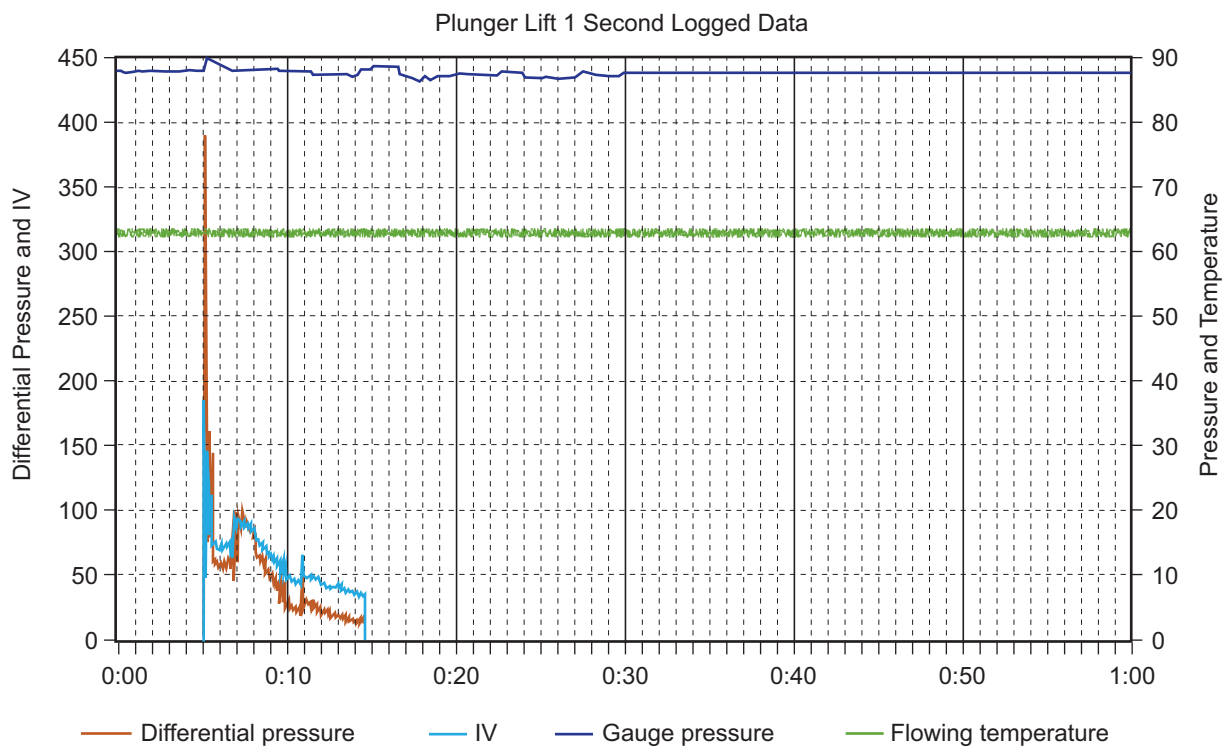


Figure A.6—One Second Logged Data

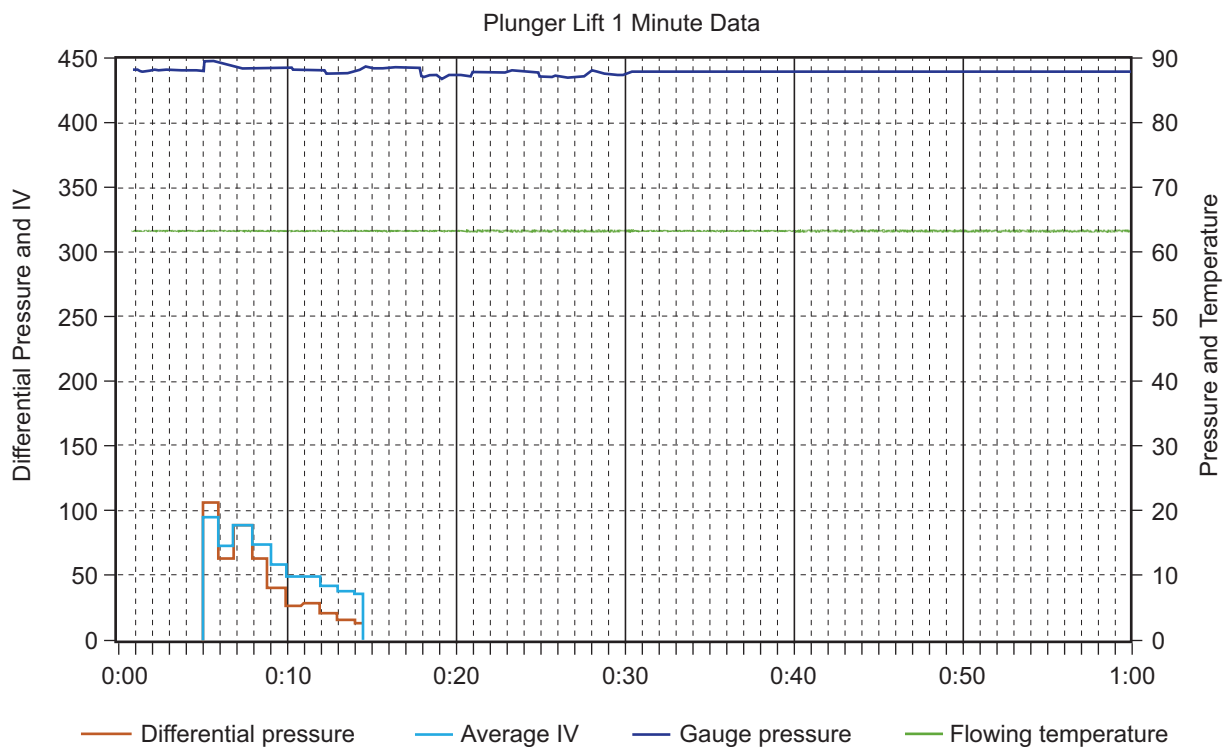


Figure A.7—One Minute Flow Time Linear Averages of Logged Data

A.7 Estimating the Expansion Factor Error Introduced by Differential Pressure Averaging Methods

The QCP differential pressure used to calculate the expansion factor should be flow weighted (approximately $DP \times DP^{0.5}$). Under fluctuating flow, this flow weighted differential pressure average (DP_Y which is approximately $DP^{1.5}$) can be significantly higher than the differential pressure flow time linear average (DP_{Linear}) or the differential pressure average calculated from the integral value (DP_{IV} which is approximately $DP^{0.5}$). Figure A.8 shows an approximate comparison of the relative values of the one-second data that should be used to calculate the averages and the respective QTR differential pressure average calculated from this data. By calculating the differential pressure using the different algorithms and QCP averages, the volume for each QCP can be calculated and compared to the volume calculated from the one-second data.

Table A.1 shows the effect of using different differential pressure averaging techniques on the calculated expansion factor/volume.

- The column “Volume Calculated from 1 Second Data” shows the volume calculations done at the one-second sampling rate.
- The column “Differential Pressure Calculated using Flow Time Averaging (DP_{Linear})” shows the flow time linear average of the differential pressure and the calculated volume. This calculation uses the integral value (IV) and the expansion factor calculated from DP_{Linear} .
- The column “Differential Pressure Calculated from IV (DP_{IV})” shows the differential pressure calculated from the integral value (IV). This is equivalent to using the integral value (IV) and the expansion factor calculated from DP_{IV} .
- The column “Differential Pressure Calculated using Y Adjustment Equation (DP_Y)” shows the DP_Y differential pressure (using the adjustment process shown in 4.3.3.3, *Differential Pressure for Expansion Factor Calculations*) and the calculated volume. This calculation uses the integral value (IV) and the expansion factor calculated from DP_Y .

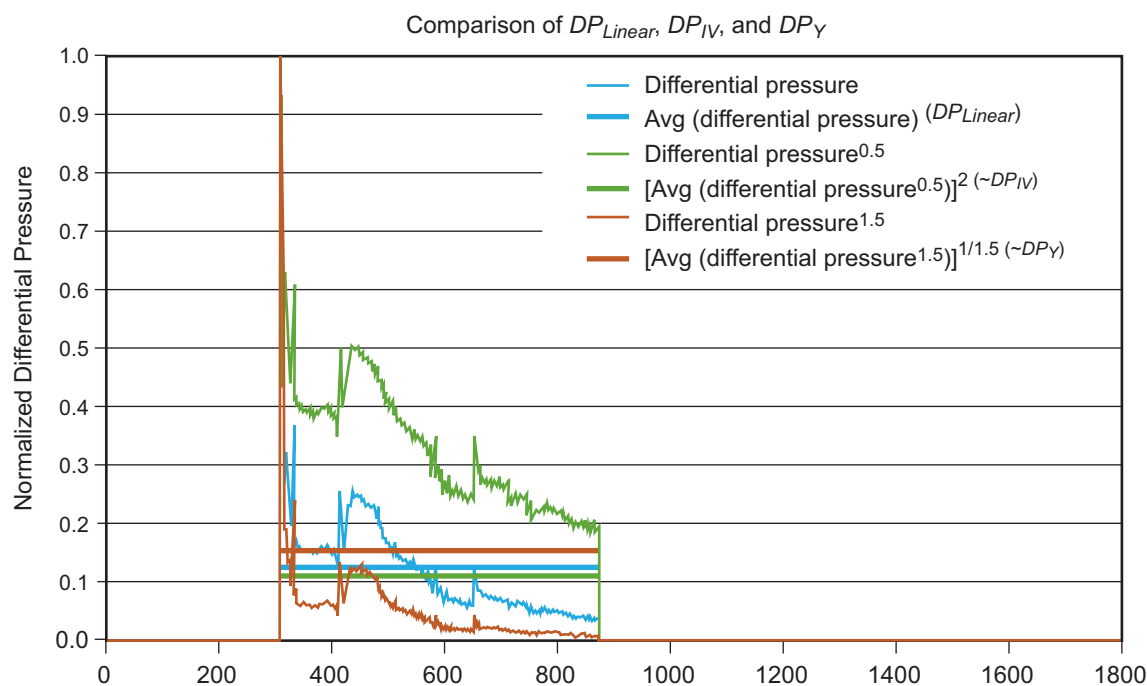


Figure A.8—Comparison of Differential Pressure Averages

Table A.1—Algorithm Flow Pattern/Calculation Frequency Check of Data in Figure A.6

Minute	Flow Time	Volume Calculated from 1-Second Data	Differential Pressure Calculated using flow Time Averaging (DP_{Linear})		Differential Pressure Calculated from IV (DP_{IV})		Differential Pressure Calculated using Y Adjustment Equation (DP_Y)		Differential Pressure— IV Weighted Flow Time Averaging ($DP_{Linear IV Weighted}$)	
			Differential Pressure	1-Minute Volume	Differential Pressure	1-Minute Volume	Differential Pressure	1-Minute Volume	Differential Pressure	1-Minute Volume
0:01:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
0:02:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
0:03:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
0:04:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
0:05:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
0:06:00	51	0.7537	105.225	0.7560	96.679	0.7572	119.482	0.7546	126.430	0.7539
0:07:00	60	0.7177	62.968	0.7178	62.534	0.7178	63.626	0.7177	63.907	0.7177
0:08:00	60	0.8518	89.448	0.8519	89.236	0.8519	89.766	0.8518	89.846	0.8518
0:09:00	60	0.7134	62.349	0.7135	61.998	0.7135	62.880	0.7134	63.059	0.7134
0:10:00	60	0.5763	40.520	0.5763	40.171	0.5764	41.050	0.5763	41.215	0.5763
0:11:00	60	0.4722	27.038	0.4722	26.852	0.4722	27.320	0.4722	27.440	0.4722
0:12:00	60	0.4814	28.027	0.4814	27.972	0.4814	28.109	0.4814	28.136	0.4814
0:13:00	60	0.4178	21.103	0.4178	21.035	0.4178	21.204	0.4178	31.239	0.4173
0:14:00	60	0.3838	17.805	0.3838	17.763	0.3838	17.889	0.3838	17.889	0.3838
0:15:00	35	0.2056	14.925	0.2056	14.914	0.2056	14.942	0.2056	14.947	0.2056
0:16:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
0:17:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
0:18:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
0:19:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
0:20:00	0	0.0000	0.0000	0.0000	0.000	0.0000	0.000	0.0000	0.00	0.0000
Total		5.5737		5.5764		5.5778		5.5747		5.5734
% Difference from 1 Second Data				0.048 %		0.073 %		0.018 %		-0.007 %

The column “Differential Pressure— IV Weighted Flow Time Averaging ($DP_{Linear IV Weighted}$)” shows the flow time linear average of differential pressure weighted using the IV ($DP_{Linear IV Weighted} = \sum(DP \times IV) / \sum(IV)$) and the volume calculated using IV and the expansion factor calculated from $DP_{Linear IV Weighted}$. It represents the best differential pressure average for calculating the QCP expansion factors, but would require an additional average of differential pressure to be added to the QTR.

A.8 Managing the Expansion Factor Error Introduced by Differential Pressure Averaging Methods

A.8.1 General

If the DP/SP (differential pressure/static pressure) ratio is high and the differential pressure is varying, the expansion factor bias error introduced by using the wrong differential pressure average can become significant.

To address this issue requires either:

- determining that the DP/SP (differential pressure/static pressure) ratio and flow fluctuation are low enough that no significant error is introduced;

- introducing an additional differential pressure average and using it to calculate the expansion factor (Y);
- calculating an estimated flow weighted differential pressure from the existing QTR data and using it to calculate the expansion factor (Y).

An empirically derived estimate of the flow weighted differential pressure for use in the expansion factor calculation (DP_Y) is:

$$DP_Y = \left[1 + 3.345 \times \left(\frac{\sqrt{DP_{Linear}}}{DP_{IV}} - 1 \right) \right] \times DP_{Linear} \quad (\text{A.16})$$

where

DP_Y is the estimate of average differential pressure to use in the expansion factor (Y) calculation;

DP_{Linear} is the flow time linear average of differential pressure;

DP_{IV} is the differential pressure calculated from the integral value (IV);

$\left(\frac{\sqrt{DP_{Linear}}}{DP_{IV}} - 1 \right) \approx$ % volume error between using DP_{Linear} or DP_{IV} in an estimated IV calculation.

A comparison of the expansion factor (Y) calculated from DP_Y and DP_{Linear} can be used as an estimate of the calculation error if the correct differential pressure is not used in the expansion factor calculation (see Figure A.9).

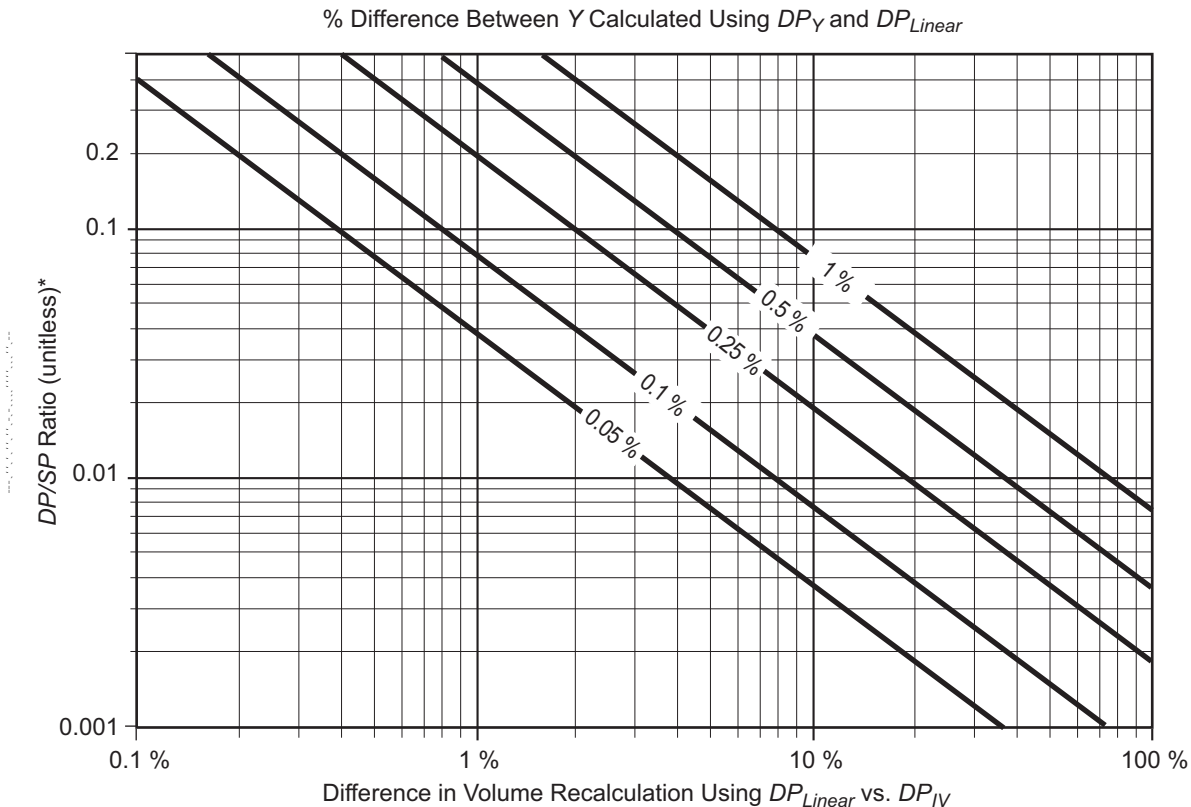


Figure A.9—Estimated Expansion Factor Error Using Hourly QTR Recalcs and DP/SP Ratios

This figure is useful in estimating if there is a significant calculation error in flow computers using factored flow rate calculation and not using DP_Y to calculate the expansion factor. For these flow computers a flow pattern check should be done if the estimated error exceeds 0.1 % or the difference in volume recalculation using DP_{Linear} versus DP_{IV} exceeds 10 %.

- For flow computers using factored flow rate calculations and DP_Y to calculate the expansion factor, a flow pattern check should be done if the estimated error exceeds 0.5 % or the difference in volume recalculation using DP_{Linear} versus DP_{IV} exceeds 10 %.

For flow computers using factored flow rate calculations, if the flow pattern/calculation frequency check exceeds 0.05 %:

- The estimated DP_Y may be used to calculate the expansion factor at each calculation cycle. If the calculation error is reduced below 0.05 % a flow computer using this calculation should be used; or
- A flow computer with a calculation frequency that reduces this calculation error below 0.05 % should be used; or
- A flow computer that calculates at the sampling frequency should be used.

NOTE Calculation of volume at the sampling frequency will eliminate the expansion factor differential pressure averaging error and other averaging errors. Users of these flow computers can ignore this section.

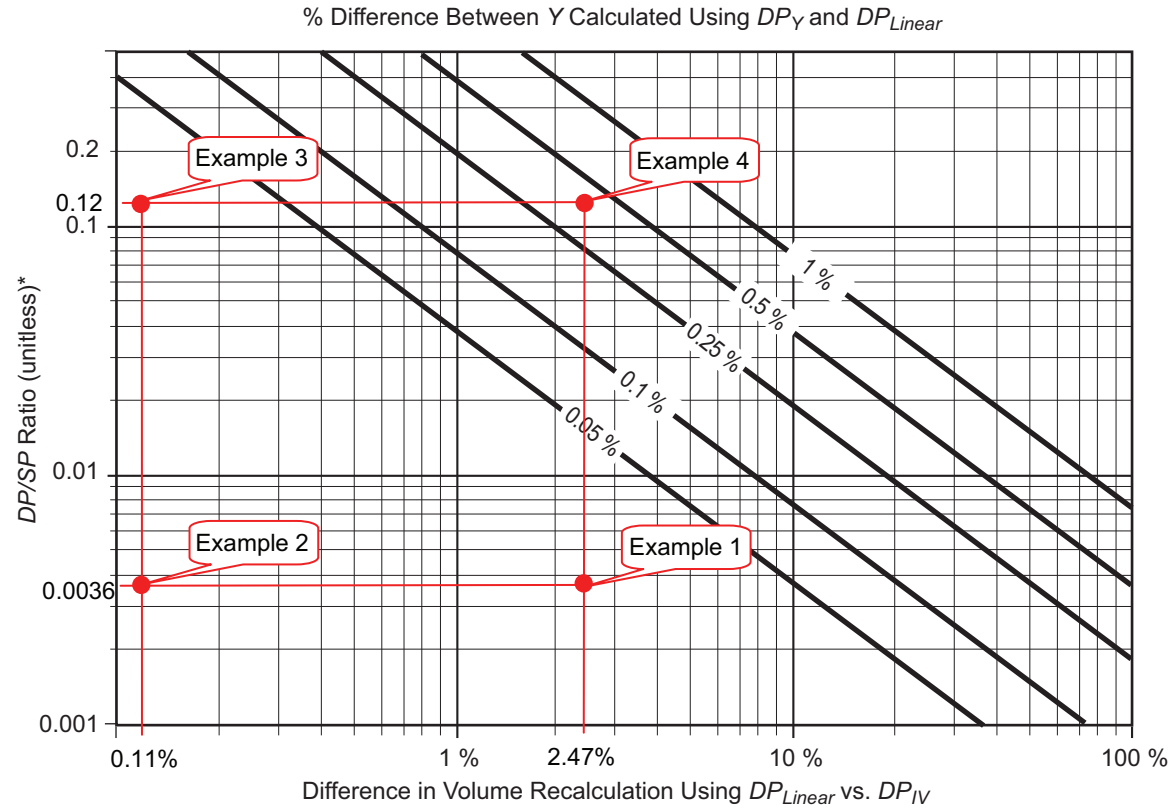
A.8.2 Examples Using Figure A.9 To Estimate DP_{Linear} Errors

Table A.2 shows four example QTRs and the calculation of DP_{IV} , Pressure Ratio and the DP_{IV} to DP_{Linear} recalculation difference based on the QTR data.

Figure A.10 shows four example data points plotted on Figure A.9, “Estimated Expansion Factor Error Using Hourly QTR Recalculations and DP/SP Ratios.”

Table A.2—Table of Example QTRs Used to Check DP_Y vs. DP_{Linear} Expansion Factor Errors

Example	QTR							Calculations		
	DP (inches)	Pressure (psia)	Temperature (°F)	Average IV (DP*Pressure) ^{0.5}	Flow Time (seconds)	Volume	Energy	DP_{IV}	DP/SP Ratio	DP_{IV} to DP_{Linear} Recalc Difference
1	100.0000	1000.0000	60.0000	324.0370	3600	52.9692	55.6706	105.0000	0.0036	2.47 %
2	100.0000	1000.0000	60.0000	316.5614	3600	53.2764	55.9935	100.2111	0.0036	0.11 %
3	100.0000	30.0000	60.0000	54.8300	3600	5.9692	6.2736	100.2111	0.1203	0.11 %
4	100.0000	30.0000	60.0000	56.1249	3600	6.0038	6.3100	105.0000	0.1203	2.47 %



* Based on linear flow time averages of DP and SP and IV reported in the hour quantity transaction record.

Figure A.10—Example Calculations Plotted on the Expansion Factor Error Graph

Annex B (normative)

Averaging Techniques

B.1 Averaging Method

The averaging technique required by this standard is flow time linear averaging. Flow time refers to the requirement that when there are periods of partial flow, these values shall only be calculated during the periods of flow as shown in Annex B.2. When there is no flow for the entire period, these values shall be calculated as shown in Annex B.3. These averages are indicated by the subscript “Linear” throughout this standard, for example DP_{Linear} .

NOTE Any algorithm yielding the same results may be used.

B.2 Calculation for Sample Periods with Flow

For calculation periods where there is flow (i.e. DP or linear meter output is greater than the no flow cutoff), the formula for flow time linear averaging is shown below.

$$\bar{v}_f = \frac{1}{t_f} \sum_{i=1}^k v_i \Delta t_i F_i \quad (B.1)$$

where

i is the index specifying the sample period;

k is the total samples in calculation period;

Δt_i is the time interval for sampling period i ;

t_f is the $t_f = \text{Flow Time} = \sum_{i=1}^k \Delta t_i F_i$;

v_f is the average of input variable during calculation periods with flow;

v_i is the input variable value at sample period i ;

F_i is the flow dependency factor. Zero if no flow at sample period i , and one if flow at sample period i .

B.3 Calculation for Sample Periods with No Flow

For calculation periods where there is no flow, the formula for flow time linear averaging is shown below.

$$\bar{v}_n = \frac{1}{t_n} \sum_{i=1}^k v_i \Delta t_i \quad (B.2)$$

where

\bar{v}_n is the average of input variable during calculation periods without flow;

t_n is the no flow time = $\sum_{i=1}^k \Delta t_i$;

v_i is the input variable value at sample period i .

NOTE This calculation should be used to calculate and report QTR averages if there is no flow for the entire QTR period.

B.4 Calculation of QTR Averages

Hourly QTR averages calculated from QCPs or QTRs and Daily QTR averages calculated from QTRs shall be flow time linear averages of the QTR averages.

$$\text{QTR Average} = \frac{\sum \text{QCP Average} \times \text{QCP Flow Time}}{\sum \text{QCP Flow Time}} \quad (\text{B.3})$$

$$\text{Daily QTR Average} = \frac{\sum \text{QTR Average} \times \text{QTR Flow Time}}{\sum \text{QTR Flow Time}}$$

The QTR value of IV and flow time (FT) shall be calculated as a summation QCP values. The Daily QTR value of IV and FT shall be calculated as a summation of QTR values. If the QTR or Daily QTR report an average extension, the calculated average extension shall be a flow time average calculated as shown above. This will allow the most accurate calculation of daily DP_{IV} values and QTR recalculations.

NOTE These requirements also apply to the calculation of Monthly QTRs.

B.5 Calculation of DP_{IV} From the Integral Value

Calculation of a formulaic weighted average of differential pressure can be done using the QTR values of IV , the flow time linear averages of the variables used in the calculation of IV and flow time.

The minimum requirement for IV is:

$$IV = \sum_{i=1}^{i=n} (\sqrt{h_{w,i}} P_{f,i} \Delta t_i) \quad (\text{B.4})$$

where

- $h_{w,i}$ is the differential pressure at sample i ;
- $P_{f,i}$ is the absolute static pressure at sample i ;
- Δt_i is the sampling interval.

and the average IV is:

$$\overline{IV} = \frac{IV}{FT} \quad (\text{B.4})$$

where

- \overline{IV} is the average extension;
- IV is the integral value;
- FT is the flow time.

Under these conditions $DP_{IV} = \frac{(\overline{IV})^2}{\bar{P}_f}$ where \bar{P}_f = flow time linear average of pressure.

For other integral value equations:

$$IV = \sum_{i=1}^{i=n} \left(\sqrt{\frac{h_{w,i} P_{f,i}}{T_{f,i}}} \Delta t_i \right) \quad DP_{IV} = \frac{\bar{T}_f}{\bar{P}_f} \left(\frac{IV}{t_f} \right)^2 \quad \text{where} \quad \begin{array}{l} \bar{T}_f = \text{Flow Time Linear Average of Temperature} \\ t_f = \text{Flow Time} \end{array}$$

$$IV = \sum_{i=1}^{i=n} \left(\sqrt{\frac{h_{w,i} P_{f,i}}{\bar{S}G_{f,i} T_{f,i}}} \Delta t_i \right) \quad DP_{IV} = \frac{\bar{S}G_f \bar{T}_f}{\bar{P}_f} \left(\frac{IV}{t_f} \right)^2 \quad \text{where} \quad \bar{S}G_f = \text{Flow Time Linear Average of Temperature}$$

$$IV = \sum_{i=1}^{i=n} \left(\sqrt{h_{w,i} P_{f,i}} \Delta t_i \right) \quad DP_{IV} = \frac{1}{\bar{P}_f} \left(\frac{IV}{t_f} \right)^2 \quad \text{where} \quad \bar{\rho}_f = \text{Flow Time Linear Average of Density}$$

etc.

Use of this technique calculates a formulaic weighted average of differential pressure that can be:

- 1) Used in volume recalculations for software and systems that don't use the integral value such as commercial flow calculation verification software and measurement systems that recalculate volumes but don't use the integral value. (For high differential pressure to static pressure ratios and fluctuating flow, the effect of using DP_{IV} and not DP_Y in the expansion factor recalculation will need to be considered and may require separate calculations to correct for this bias.)
- 2) Used to calculate DP_Y . For high differential pressure/pressure ratios ($\Delta P/P$) with fluctuating differential pressure, use of DP_{IV} and DP_{Linear} are required to calculate DP_Y for use in expansion factor calculation (Y) used in the IMV (see 4.4.4).
- 3) Used to identify flow variability and the operating problems, such as gauge line amplification, when compared to the flow time linear average of differential pressure (DP_{Linear}) reported in the QTR. A first order approximation of the volume recalculation differences between DP_{IV} and DP_{Linear} is:

$$\% \text{ Volume Difference} \approx \left(1 - \frac{\sqrt{DP_{Linear}}}{\sqrt{DP_{IV}}} \right) \times 100$$

NOTE DP_{IV} can be calculated after the fact from existing QTRs either manually or by host measurement systems.

Annex C (informative)

Correction Methodology

C.1 Introduction

The hourly and daily QTRs contain reported volume, energy and live input operating data. Recalculation of volume from the configuration and QTR averages will result in errors caused by not accounting for the operating dependencies that correlate with each other.

C.2 Correction Methodology

$$\text{Corrected Volume} = \frac{\text{Recalculated Volume}_{\text{Corrected Values}}}{\text{Recalculated Volume}_{\text{Original Reported Values}}} \times \text{Reported Volume}$$

Use of this correction methodology addresses a number of correction issues:

The first issue it addresses is errors that would be introduced if the corrected volume was directly recalculated using a mixture of corrected and originally reported configuration values and averages.

- For example if the plate size was incorrectly entered and the volume was recalculated from the reported averages and configuration data, calculation errors would be introduced because the recalculation does not include the operating dependencies that were accounted for in the original QTR reported volume.

The second issue it addresses is trying to come up with a number of different correction processes to handle each type of correction.

- For example to correct for the plate size that was incorrectly entered, correction ratios of the coefficient of discharge, velocity of approach factor and Reynolds number recalculation iterations would need to be calculated and multiplied by the reported volume to obtain a corrected volume. Other correction types would require other ratios to be calculated.
- By always calculating the corrected volume based on the ratio of the recalculated volume using original and corrected configuration/average values divided by the recalculated volume using the originally reported configuration/average values, the ratios that are required for the correction are correctly calculated and the ratios that aren't required cancel out.

The result is a correction methodology that works for all types of corrections and accounts for operating dependencies in the original reported volume. It is equally applicable to differential and linear meters.

NOTE 1 IV or DP_{IV} should be used in the integral value portion of volume recalculations when available (see B.5 and Annex K).

NOTE 2 DP_Y should be used to calculate the expansion factor in cases where the differential pressure to static pressure is high and the differential pressure is fluctuating (see A.8).

C.3 Volume Correction Factor

Some centralized measurement management systems organize the terms of the correction methodology to allow part of the correction process to be calculated as the measurement is received. The factor is used as a recalculation validation and is stored for use if future recalculations are required.

By defining a volume correction factor (VCF) as:

$$VCF = \frac{\text{Reported Volume}}{\text{Recalculated Volume}_{\text{Original Reported Values}}}$$

The correction methodology becomes:

$$\text{Corrected Volume} = VCF \times \text{Recalculated Volume}_{\text{Corrected Values}}$$

Annex D (normative)

Calculation of Normal Operating Range and Percent Fluctuation

Normal Operating Range—The range 5 % to 95 % of the operating value calculated from the frequency of occurrence based on a year of operating data.

Percent Fluctuation—The percent fluctuation is calculated from the normal operating range as:

$$\% \text{ Fluctuation} = \frac{95 \% \text{ Value} - 5 \% \text{ Value}}{95 \% \text{ Value}}$$

where

95 % Value is the 95th percentile calculated from the frequency of occurrence of the operating data

5 % Value is the 5th percentile calculated from the frequency of occurrence of the operating data

NOTE 1 By defining the normal operating range based on a year of operating data, seasonal operating conditions are factored into the range calculation.

NOTE 2 To address short term abnormal operating conditions which could expand the range to excessive limits, the lower 5 % and upper 5 % of the operating data is excluded from the range calculation.

NOTE 3 The limits should not be defined based on standard deviation assuming a normal distribution as the data may not be normally distributed. (See Figure D.3, “Example of Operating Pressure that is Not Normally Distributed.”)

NOTE 4 The operating data may need to be limited to periods of flow if the operating data is not calculated for no-flow conditions.

Example Calculation

Figure D.1 shows pressure operating data for a year where the facility was flowing for 89.6 % of the year. The 95th percentile value is 6,458 kPa (937 psi), the 5th percentile value is 4,358 kPa (632 psi) and the percent fluctuation is 32.5 %.

Figure D.2 shows the frequency distribution of the operating data in D.1.

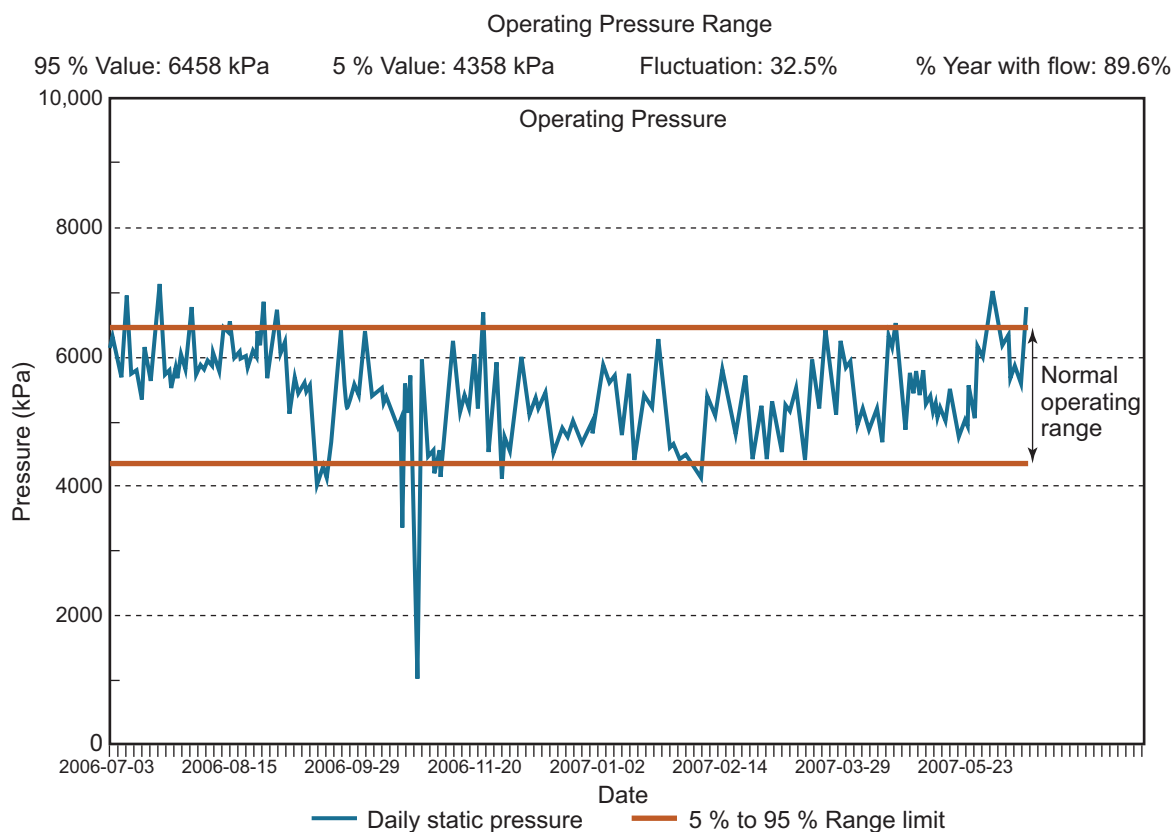


Figure D.1—Typical Operating Pressure/Calculated Normal Operating Range

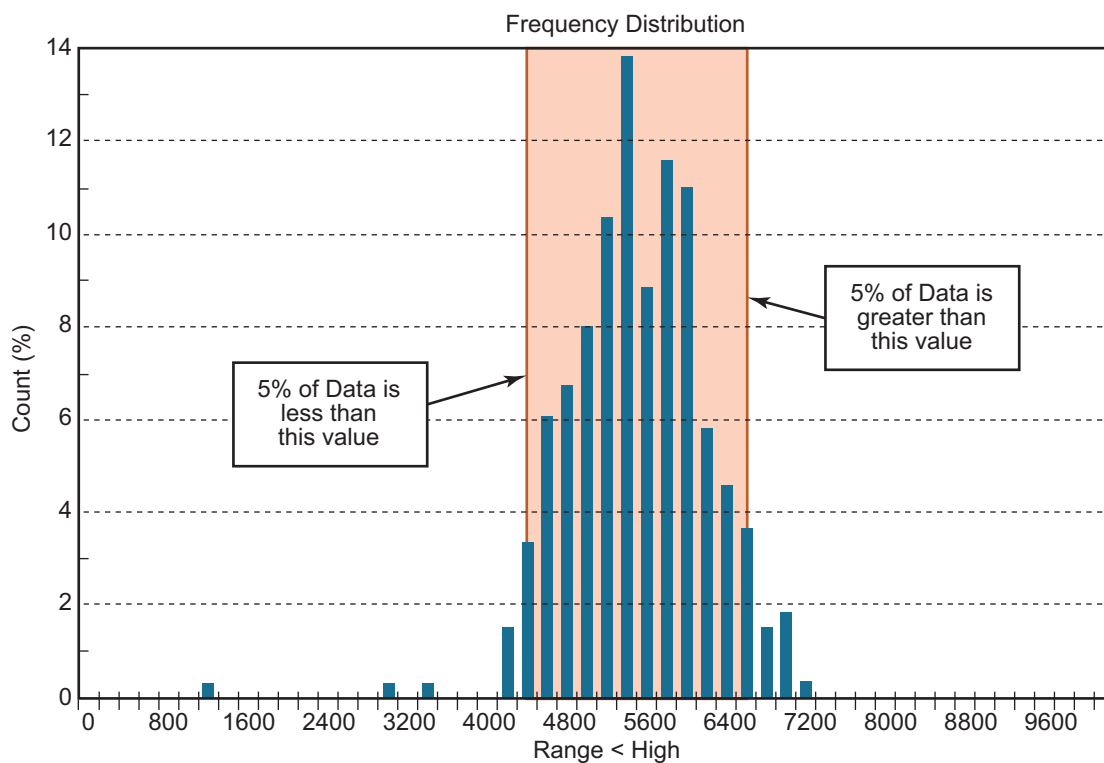


Figure D.2—Frequency Distribution Showing 5th Percentile and 95th Percentile

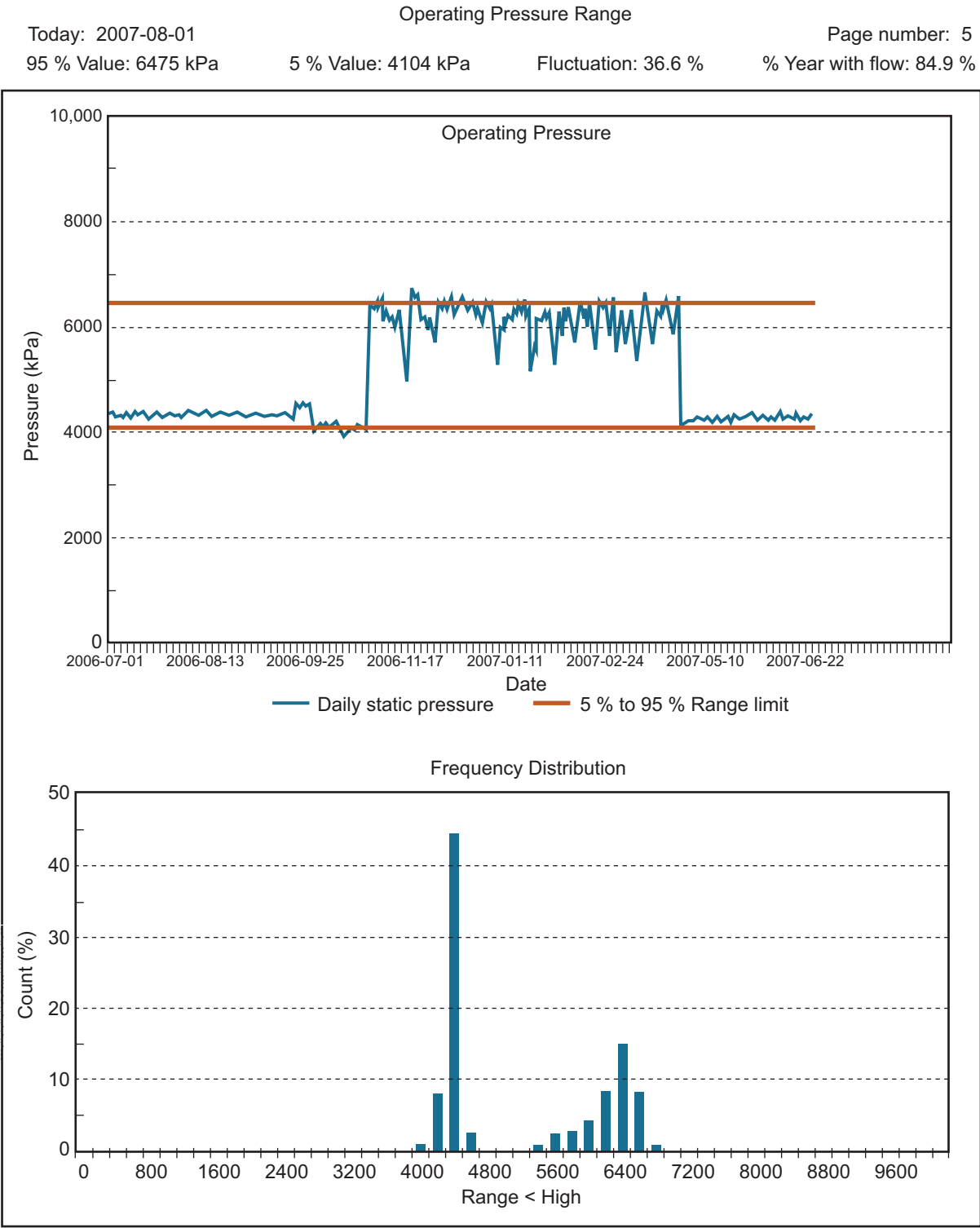


Figure D.3—Example of Operating Pressure that is Not Normally Distributed

Annex E (informative)

Example Flow Computer Variable Input Type Testing - Differential Meters

E.1 Introduction

E.1.1 General

Dynamic algorithm tests should be done as part of the flow computer acceptance testing and are proposed for inclusion in API *MPMS* Ch. 22.

Until these formal testing protocols are developed the example variable input tests in this appendix, flow calibration facilities with dynamic testing protocols or other dynamic testing protocols may be used to perform dynamic algorithm testing. This “type testing” is intended to be done as part of factory or user acceptance testing and is not part of the final integrated EGM system site commissioning.

E.1.2 Simulation of Inputs

For flow computers with analog transmitters, the differential pressure input can be simulated using a function generator(s) to simulate the flow computer inputs.

For flow computers using digitally interfaced or integral transmitters, the differential pressure input can be simulated using a function generator and I/P (current to pressure) transmitter.

E.1.3 Data Collection and Algorithm Verification

These tests are intended to test the flow computer algorithm only and not the performance of the secondary devices. As such, the simulated inputs have to be considered and accounted for in the algorithm testing.

- For flow computers that can log the fixed/variable process inputs along with a time stamp these differences can be significantly minimized or eliminated.
- For flow computers that can't log this information a second flow computer or data acquisition system can be used to measure and log the process variables. Take care to calibrate the second flow computer/data acquisition system to the flow computer under test in order to minimize comparison differences.

Figure E.1 provides a block diagram of the data acquisition and verification process.

NOTE The output of digital function generators provide flow computer inputs that have very accurate and repeatable flow computer wave form and frequency inputs. The output of digital function generators combined with an I/P provides flow computer inputs that have repeatable wave form and frequency inputs. The I/P output response tends to distort the function generator input and may result in an over-damped or under-damped output. This effect has to be accounted for by independently measuring the I/P output at a frequency equal to or faster than the flow computer sampling frequency. After calibrating the independent transmitters to the flow computer transmitters or adjusting for calibration differences, these measurements can be used to calculate the expected flow computer averages, integral value and flow time for testing purposes. See Figure E.2 and Figure E.3 for examples of I/P outputs.

E.2 Test 1—Square Wave Test

E.2.1 General

The square wave input should have a minimum value below the no flow cutoff, a maximum value of approximately 80 % of calibrated range and a frequency that will result in one or more complete cycles during the EGM volume calculation interval.

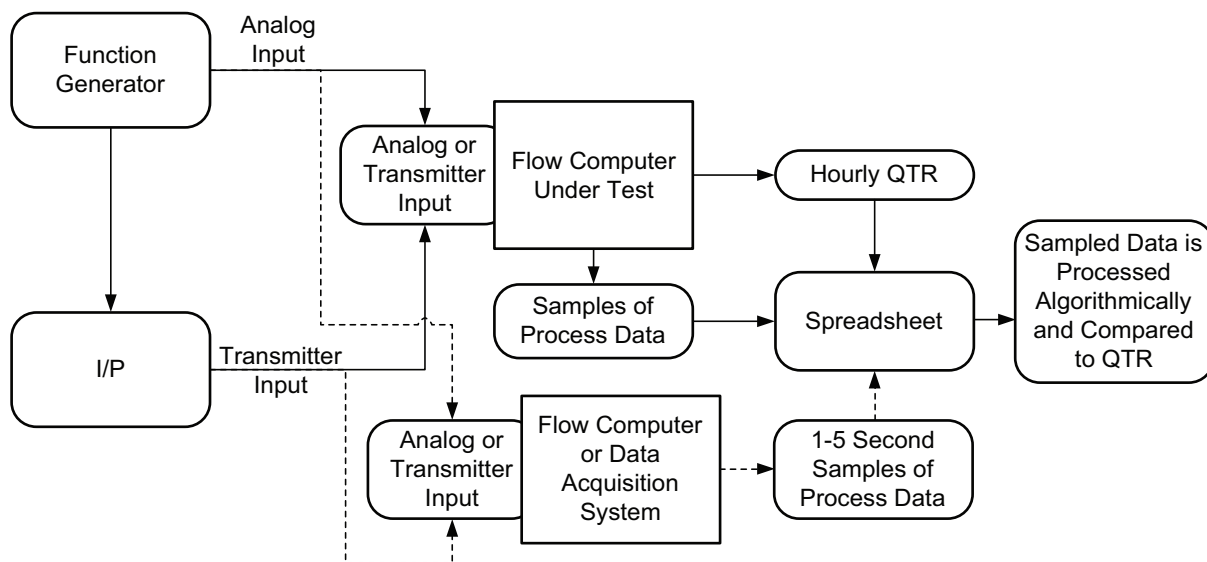


Figure E.1—Block Diagram of Test Set-up and Algorithm Verification Process

E.2.2 Objective

To test the flow computer flow time calculation algorithm.

- By using a square wave that alternates between “on-flow” for 50 % of the calculation interval and off flow for 50 % of the calculation interval, issues with calculating and reporting flow time can be exposed.

To test the calculation of averages of integral value and differential pressure, static pressure, and temperature averages.

- Because the averages are only done when the differential pressure is above the no flow cutoff, the averages of differential pressure should be approximately equal to the maximum square wave differential pressure value for either linear or square root averages.

E.2.3 Expected Results

E.2.3.1 Expected Results for Flow Time

Testing of a flow computer with one-second sampling and a one-minute calculation interval with a 1/60 hertz square wave will expose rounding or truncating issues in the one-hour reported flow time. For a one-hour test the flow time should be 50 % of the hour or 1800 seconds. For flow computer inputs simulated directly from the function generator this estimate is reasonably accurate but for inputs simulated from a function generator and I/P the flow computer input may be distorted and the flow time should be calculated from the independent measurements.

An estimate of the maximum flow time error for the above example is:

- The maximum flow time error for the one-minute calculation is ± 1 second in 30 seconds or $1 \div 30 = 1.67\%$.
- The error should be random over the one-hour accumulation interval so the error should reduce by the square root of the number of samples or $1.67\% \div \sqrt{60} = 0.22\%$.
- Using the 0.22 % (4 seconds) as a 1σ uncertainty estimate, the 3σ uncertainty estimate would be 0.66 % (12 seconds).

- The one-hour flow time should match to within 0.22 % to 0.66 % (4 seconds to 12 seconds) of the estimated/calculated flow time for either flow computer simulated input condition.

E.2.3.2 Expected Results for Differential Pressure

Testing of a flow computer with one-second sampling and a one-minute calculation interval with a 1/60 hertz square wave will result in a differential pressure that is equal to the square wave maximum value. For a one hour test with differential pressure alternating between below no flow cutoff and 80 %, the differential pressure average should be 80 % for a flow computer with inputs simulated directly from the function generator. For inputs simulated from a function generator and I/P, the differential pressure should be calculated from the independent measurements.

For a differential pressure range of 100 in. H₂O the average differential pressure should be 80 % of 100 in. H₂O or 80 in. H₂O. An estimate of the maximum flow differential pressure error for the above example is:

- The maximum differential pressure error for the one-minute calculation is ± 1 one sample being between no flow cutoff and 80 in. H₂O or a maximum error of $(80 \div (80 \times 30))100 = 3.33 \%$.
- The error should be random over the one-hour accumulation interval so the error should reduce by the square root of the number of samples or $3.3\% \div \sqrt{60} = 0.43\%$.
- Because the maximum one-minute error is used, the 3σ uncertainty estimate stays at 0.43 % (0.35 in. H₂O) and the 1σ uncertainty estimate is 0.14 %.
- The one-hour flow time averages should match to within 0.14 % to 0.43 % (0.11 to 0.35 in. H₂O) of the estimated/calculated differential pressure for either flow computer simulated input condition.

Figure E.2 and Figure E.3 show measured differential pressure outputs simulated by a function generator and I/P.

NOTE The static pressure, on differential pressure digital transmitters with integral upstream static pressure measurement, will have the same pressure as the differential pressure simulated input. Because this value of static pressure may be significantly below the desired static pressure range, three techniques may be used to get the static pressure into a more typical range.

- 1) Use a fixed value of static pressure.
- 2) Configure an atmospheric pressure that will result in a desired static pressure. (For example a differential pressure of 80 in. H₂O is approximately 2.89 psi. Configuring an atmospheric pressure of 500 psi will result in a simulated static pressure of 500 psia to 502.89 psia.)
- 3) Calibrate the static pressure transmitter to output a static pressure that is a multiple of the simulated pressure. (For example a differential pressure of 80 in. H₂O is approximately 2.89 psi. Calibrating the static pressure to 100 times the simulated input will result in a simulated static pressure of 0 psi to 289 psia.)

E.2.3.3 Expected Results for Static Pressure, Temperature, and Integral Value Calculation Checks

Static pressure, temperature and integral value calculations should be checked. If fixed values of pressure and temperature are used their averages should be exact. If live inputs of pressure and temperature are used, their estimated values and expected errors should be calculated the same way as differential pressure.

NOTE 1 For static pressure using an exaggerate atmospheric pressure, the static pressure averaging error should be significantly reduced from the differential pressure error. For example a static pressure with an atmospheric pressure of 500 psi and an 80 in. H₂O simulated differential pressure would have an input range of 500 psi to 502.89 psi and the square wave should have a value of 502.89.

NOTE 2 For static pressure using an exaggerate static pressure range, the static pressure average error would be larger than the differential pressure due to the range of the real static pressure and transmitter accuracy limitations.

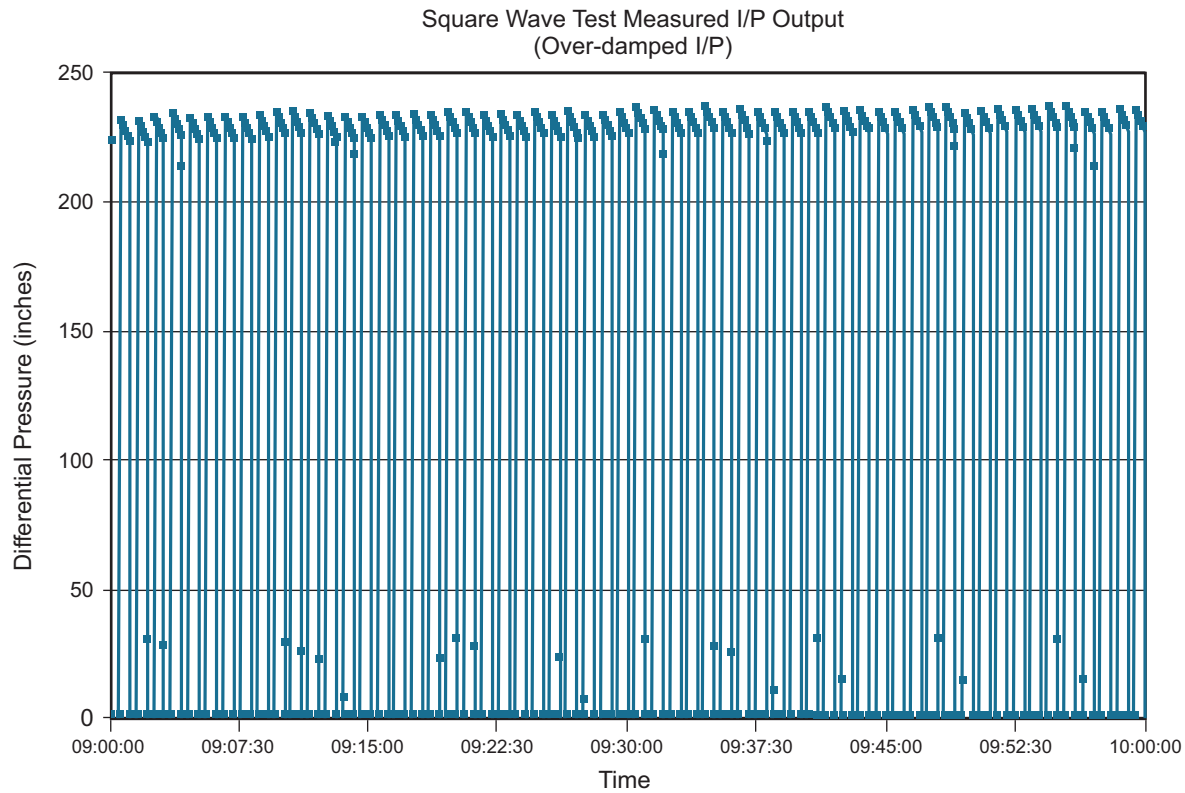


Figure E.2—Example of an Over-damped I/P Output

E.2.3.4 Expected Results for Volume Recalculation Check

The hourly volume should be re-calculated using the differential pressure calculated from the integral value as shown in Annex D. Recalculation results in the hundreds of ppm range can be expected unless the static pressure stability is excessive due to use of an exaggerated static pressure range and/or limited static pressure transmitter accuracy.

E.3 Test 2—Saw Tooth Wave Test

E.3.1 General

The saw tooth wave should have an minimum input of approximately 10 % of calibrated range below the no flow cutoff, a maximum input of approximately 80 % of calibrated range and a frequency that results in 3 to 10 even cycles during the one hour accumulation interval.

E.3.2 Objective

*To test the averaging algorithm under a set of conditions that can reasonably accurately simulated using an I/P and to test the type of input averaging (i.e. linear flow time or square root flow time averaging)—*Because the value of differential is uniformly increased/decreased between the low differential pressure no flow cutoff and the minimum/maximum differential pressure, these values can be used to estimate the value of the linear or square root averages or estimated using the independent I/P output measurements.

*To test the calculation of flow time—*Flow time can be estimated from the no flow cutoff and the saw tooth maximum and minimum values.

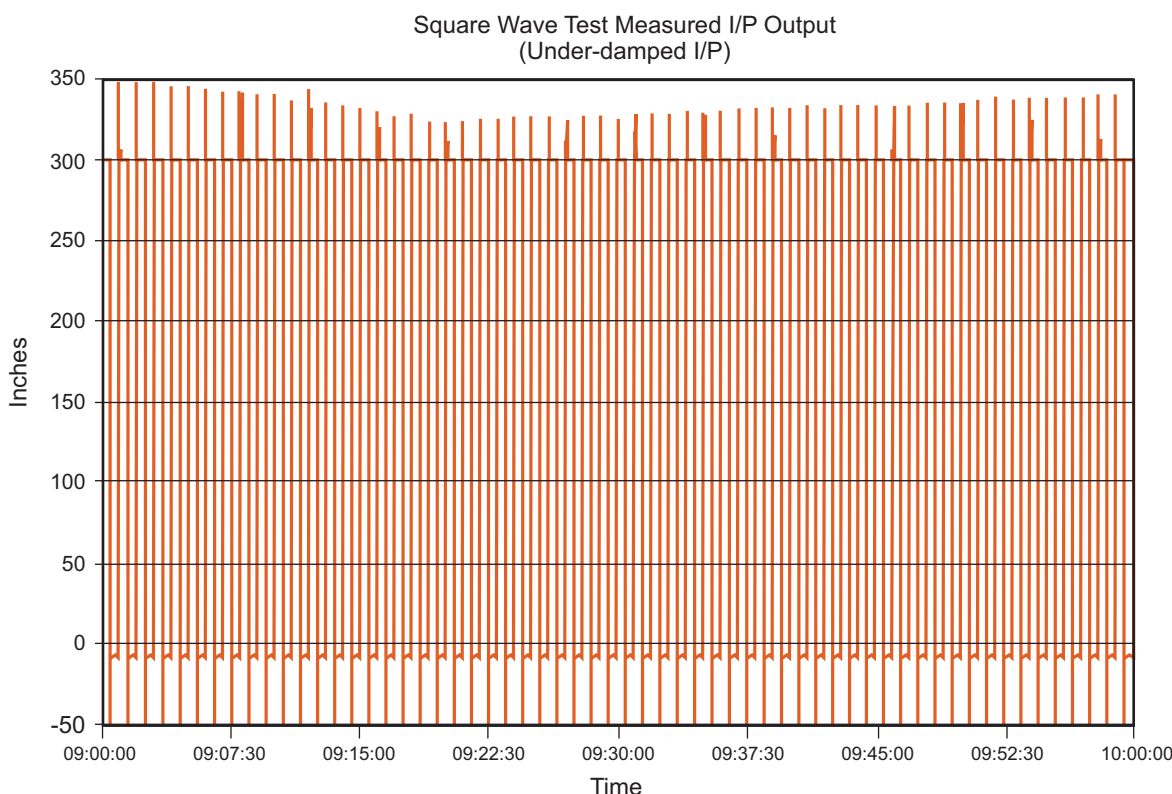


Figure E.3—Example of an Over-damped I/P Output

E.3.3 Examples Of I/P Simulated Saw Tooth Outputs

Two examples of measured I/P outputs are shown below. Figure E.4 shows an I/P with poor output control. In this case the independent measurements of the simulated output need to be used to calculate the estimated averages. Figure E.5 shows an I/P output with good output control. In this case the averages can be calculated from either the no flow cutoff and the minimum/maximum differential pressure or the independent measurements of the simulated output.

NOTE The static pressure, on differential pressure digital transmitters with integral upstream static pressure measurement, will have the same pressure as the differential pressure simulated input. Because this value of static pressure may be significantly below the desired static pressure range, three techniques may be used to get the static pressure into a more typical range.

- 1) Use a fixed value of static pressure.
- 2) Configure an atmospheric pressure that will result in a desired static pressure. (For example a differential pressure of 80 in. H₂O is approximately 2.89 psi. Configuring an atmospheric pressure of 500 psi will result in a simulated static pressure of 500 psia to 502.89 psia.)
- 3) Calibrate the static pressure transmitter to output a static pressure that is a multiple of the simulated pressure. (For example a differential pressure of 80 in. H₂O is approximately 2.89 psi. Calibrating the static pressure to 100 times the simulated input will result in a simulated static pressure of 0 psi to 289 psia.)

E.3.4 Expected Results

E.3.4.1 Expected Results for Averages and Flow Time Calculations

Similar flow time and average/integral value calculations to those calculated for the square wave test are expected.

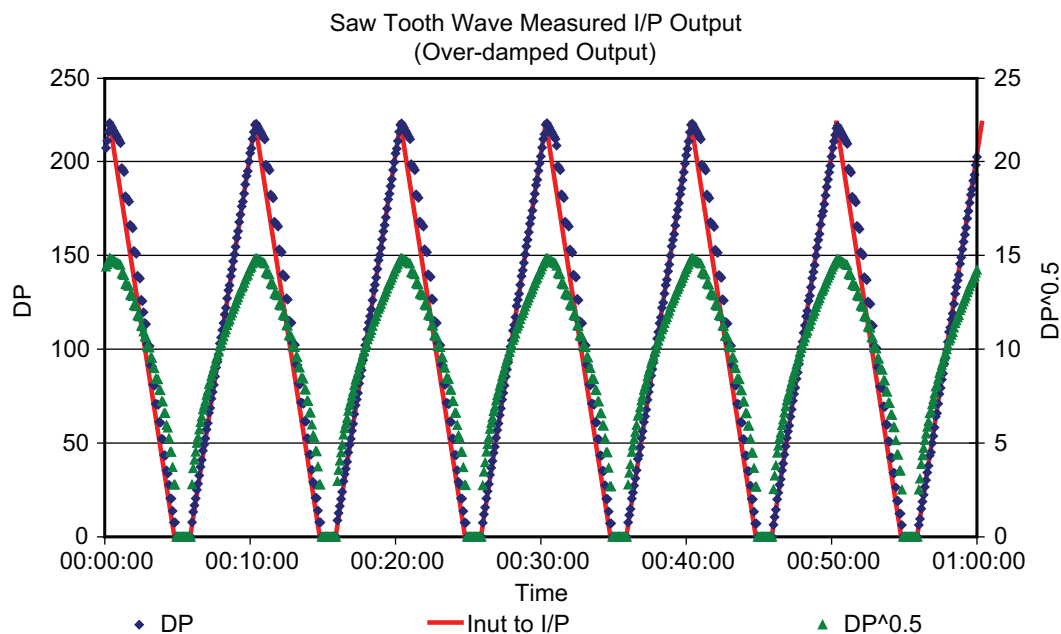


Figure E.4—I/P with Poor Output Control

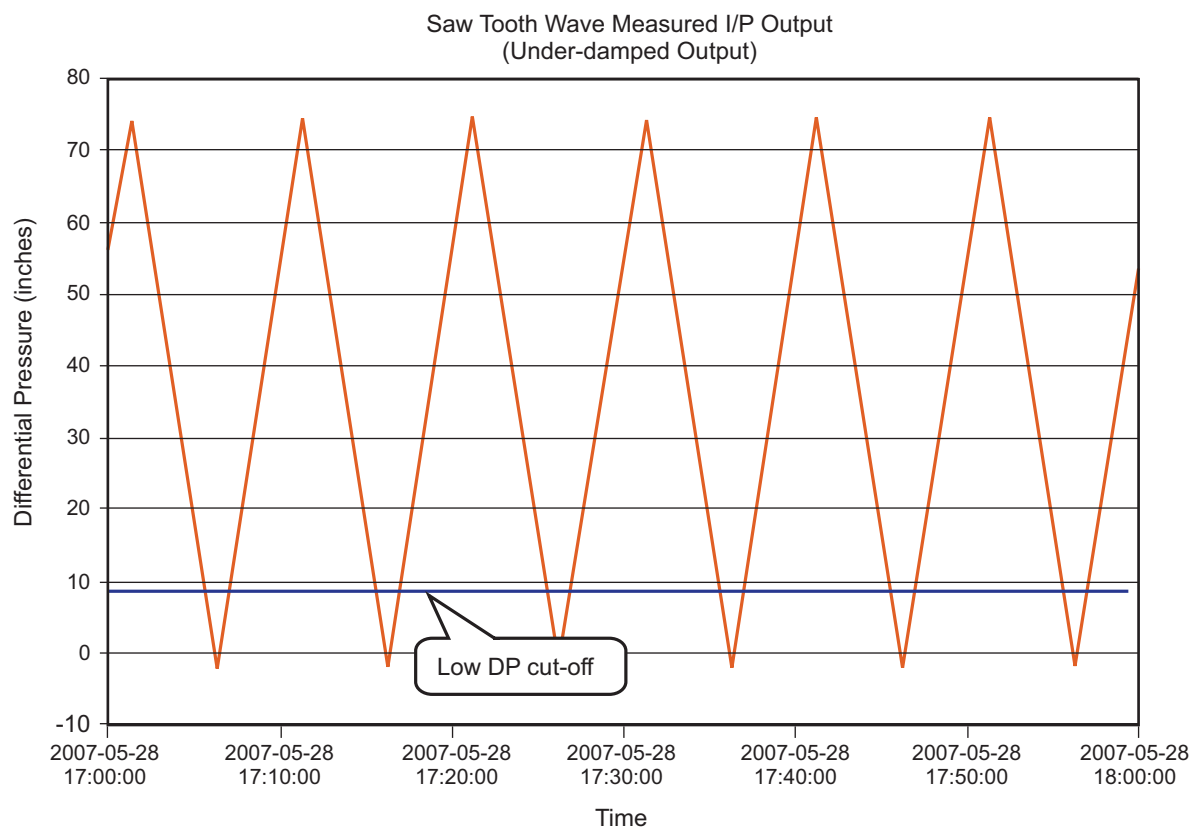


Figure E.5—I/P with Good Output Control

NOTE The one exception will be pressure averages if the static pressure is calibrated to a multiple of the actual static pressure. The difference is an indication of transmitter accuracy limitations, not flow computer averaging algorithm problems.

E.3.4.2 Expected Results for Volume Recalculation

Similar flow volume recalculation results to those calculated for the square wave test are expected.

NOTE The one exception will be if the static pressure is calibrated to a multiple of the actual static pressure. This will cause additional differences to be introduced to due changing pressure in the compressibility calculations for each integral value period versus using the hourly average pressure to calculate compressibility in the one hour recalculation.

E.4 Why Use Simulated Inputs That Repeat an Integer Number of times for the Hour or Comparison Period?

By using simulated inputs that repeat an integer number of times during the comparison period, time differences between the averages calculated by the flow computer and the estimates/measurements are minimized.

This can be demonstrated by exaggerating the off-set in the differential pressure trends that are used in independent and flow computer averaging algorithm processes. Figure E.5 shows the differential pressure trend starting 5 minutes later than the flow computer. Notice the highlighted last five minutes of the trend on the late trend on the left and the highlighted first five of the trend on the right.

The highlighted portion of the graphs in Figure E.6 are magnified in Figure E.7 and demonstrates that the last five minutes of the late trend matches the first five minutes of the on-time trend. Since both algorithms use the same trend from 17:05 to 18:00 and the start and end trends match, the one hour trends processed by both algorithms are the same and the time difference is negated. This compensation effect is independent of time difference as long as the trend multiple is an integer of the comparison interval.

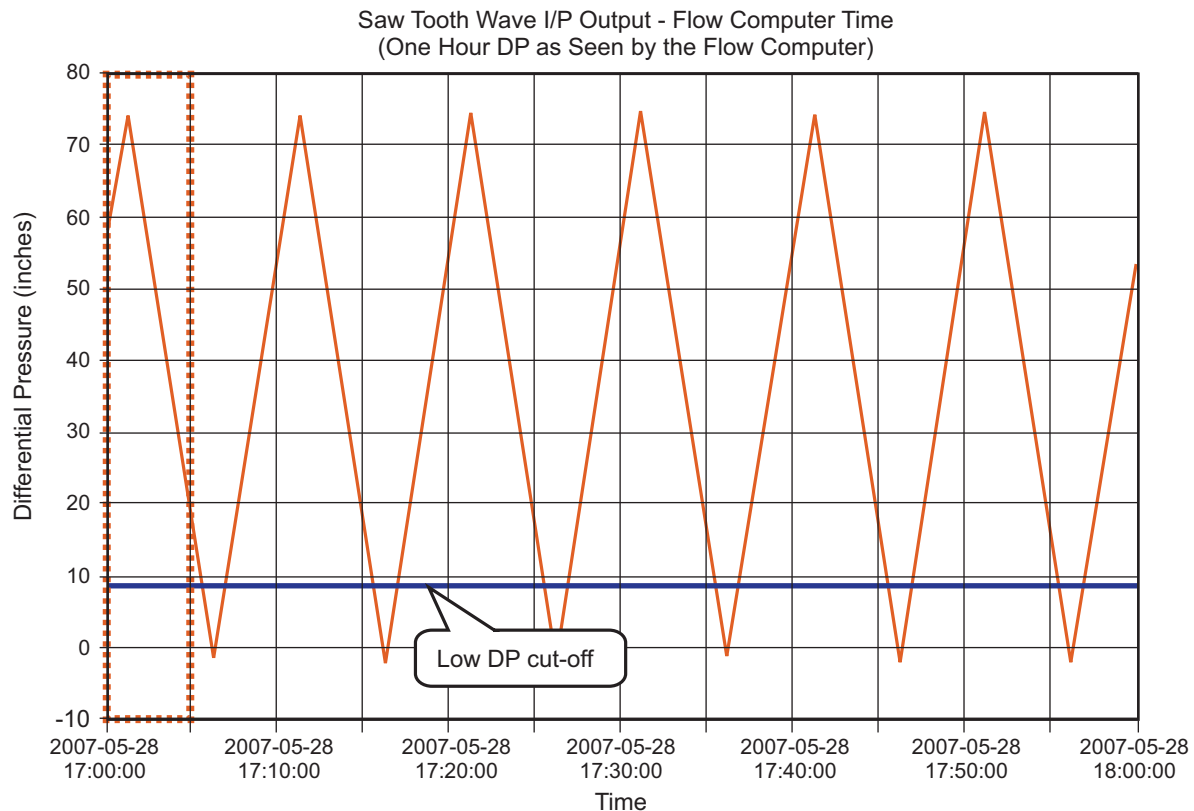
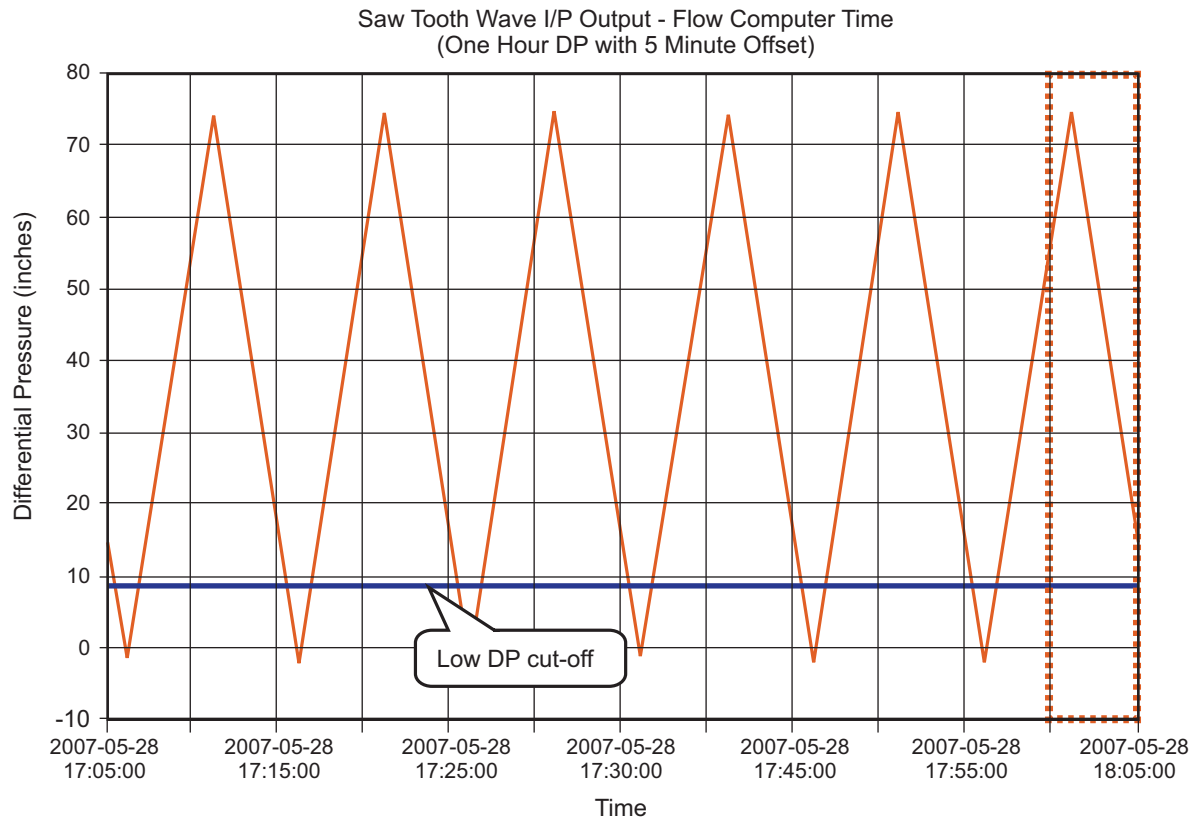


Figure E.6—Example of One Hour Differential Pressure Trend with a Five Minute Offset

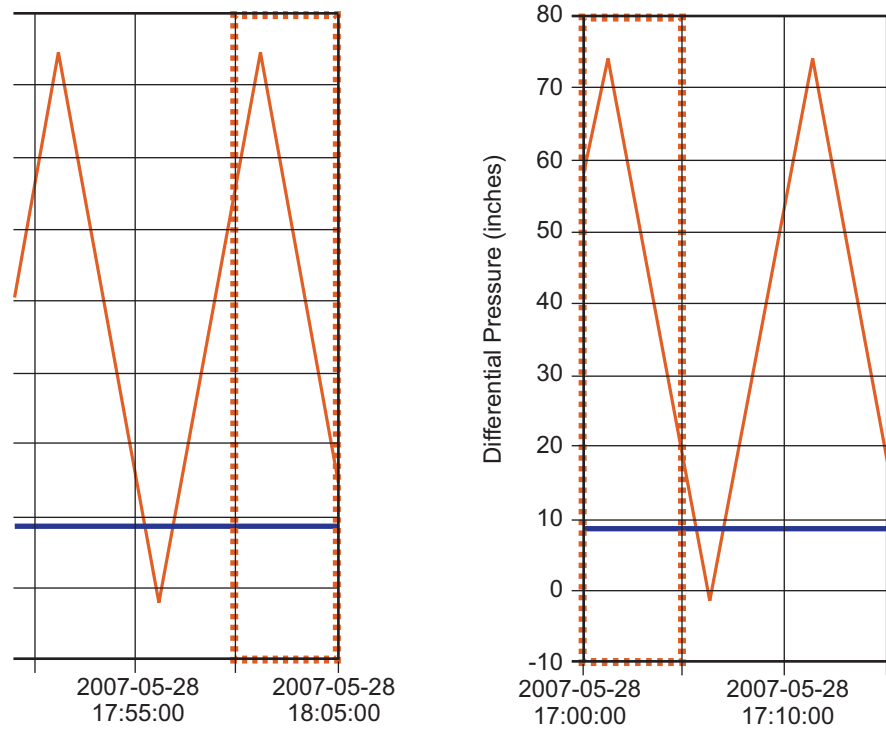


Figure E.7—Notice Late Trend Last Five Minutes Matches First Five Minutes of the On-time Trend

Annex F (informative)

Example Commissioning Checklist

F.1 Commissioning Tasks—Before First Delivery of Gas

Completed

1. Design and install new primary runs and secondary elements in accordance with current applicable industry standards and company policies.	
2. Obtain inspection documentation for primary elements such as tube micrometer, hydro-test, and x-ray reports.	
3. Obtain secondary device manufactures' specifications and any device specific testing and/or calibration data.	
4. Verify transducer/transmitter is properly sized for anticipated flow parameters of static and differential pressures.	
5. Program/configure flow computer with all applicable parameters needed to correctly calculate gas volumes and/or energy.	
6. Install and test EGM communications equipment, if applicable.	

F.2 Commissioning Tasks—During or shortly After First Delivery of Gas

Completed

1. Check all fittings for leaks.	
2. Verify all manifold valves are in proper positions.	
3. Verify the operation of the gas measurement equipment.	
4. Perform verification test of all measuring devices associated with the station.	
5. Check that the flow computer has been programmed with the correct configurations for that station.	
6. Check that the transducers/transmitters are operating within the verified ranges.	
7. Perform a spot flow calculation to confirm the flow computer is calculating within stated company tolerances.	
8. Pull a spot sample of the gas.	
9. Perform spot check for gas quality if applicable such as H ₂ S or CO ₂ .	
10. Fill out proper company documentation to show "new connect" of gas measurement station.	

Annex G (informative)

Examples of Configuration Log Data

G.1 Differential Meter

General Information

Meter identifier

Date and time collected

Contract hour

Atmospheric pressure (P_{atm} , psia) for sites with gauge transmitters

Pressure base (P_b)

Temperature base (T_b)

Timestamp Definition (i.e. QTR Start and End Time relative to timestamp)

Primary Device Data

Orifice	Other Differential Meter Types
Meter tube reference inside diameter (in.)	Type (Venturi, Pitot tube...)
Meter tube material	Material
Meter tube reference temperature (°F)	Reference temperature (°F)
Meter tube static pressure tap location (upstream/ downstream)	Size (in.)
Orifice plate reference bore size (in.)	Beta/Area ratio
Orifice plate material	Discharge coefficient
Orifice plate reference temperature (°F)	Factors necessary to calculate discharge coefficient (slope factors, offsets...)

Secondary Device Information

Calibrated or user defined span—differential pressure (in. H₂O)

No flow cutoff (in. H₂O)

Calibrated or user defined span—static pressure (psi)

Static pressure—absolute or gauge

Calibrated or user defined operating range—Temperature or Fixed Temperature if not live (°F)

Gas composition (if not live) (list mol% of each component used in the F_{pv} calculation)

Relative density (if not live)

Compressibility (if not live)

Energy content (if not live) (BTU/cubic foot)

Calculation Data (This data is required, but may be supplied as device documentation and not be included in the configuration report)

- Discharge coefficient calculation method/reference (e.g. AGA 1992)
- Gas expansion factor method/reference (e.g. AGA 1992)
- Compressibility calculation method/reference (e.g. AGA 8, Detail)
- Quantity Calculation Period (minutes)
- Sampling rate (samples per second)
- Variables included in the integral value (e.g. differential pressure, static pressure)
- Base compressibility of air
- Absolute viscosity (cP)
- Ratio of specific heats
- Meter elevation (feet msl) or contract value of atmospheric pressure
- Other factors used to determine flow rate

Alarm Set Points (Operating data that may or may not be included in the configuration report)

- Differential Pressure Low (in. H₂O)
- Differential Pressure High (in. H₂O)
- Static Pressure Low (psi)
- Static Pressure High (psi)
- Flowing Temperature Low (°F)
- Flowing Temperature High (°F)

G.2 Linear Meters

General Information

- Meter Identifier
- Date and Time
- Contract Hour
- Atmospheric Pressure (P_{atm} , psia) for sites with gauge transmitters
- Pressure Base (P_b)
- Temperature Base (T_b)
- Timestamp Definition (i.e., QTR Start and End Time relative to timestamp)

Secondary Device Information

- Calibrated static pressure span (psi)
- Static pressure—absolute or gauge
- Calibrated flowing temperature zero (°F)
- Calibrated flowing temperature span (°F)

Calculation Data

Meter factor

k-factor

Relative density (If Not Live)

Compressibility (If Not Live)

Gas components (If Not Live)

In addition for linear meters such as Coriolis and ultrasonic meters

Linear (Coriolis Meter)

Mass flow parameters

Density parameters

Temperature and pressure coefficients of meter dimension

Meter factor (pulses/unit quantity) or Frequency full scale/quantity full scale

Calibration coefficients

No flow cutoff

Volume/Mass output selected (uncorrected or corrected)

Software/Firmware version

Linear (Ultrasonic Meter)

Path length dimensions

Path angles

Meter coefficients effecting calculated quantities. Example: axial swirl, Reynolds number, path compensation, etc.)

Transducer characteristics

VOS ranges

Gas velocity ranges

Calibration coefficients (dry and/or wet) and (forward and reverse)

If linearization is used, then linearization flow rate values shall be logged

Meter factor (*k-factor*, pulses/ft³) or frequency full scale/Volume full scale

Meter correction factor method

Timing constants

No flow cutoff

Inside diameter D_i

Outside pipe dimension

Temperature and pressure coefficients of meter dimension

Software/Firmware version

Volume/Mass output selected (uncorrected or corrected)

Device specific parameters effecting calculated gas quantities

Annex H (informative)

Calculation of Differential Pressure “As-Found”

Differential pressure transmitters are normally calibrated and verified at atmospheric pressure; however they are operated at an elevated working pressure. The change from atmospheric pressure to working pressure may introduce a zero and span calibration shift.

The span shift in digitally characterized transmitters is often in the order of $\pm 0.1\%$ of reading and for older analog transmitters, a span compensation factor can be employed as either in the flow computer span compensation factor or as a span calibration factor is incorporated into the atmospheric pressure calibration for the expected operating pressure.

The zero shift can be compensated for by zeroing the transmitter at working pressure, however the “as-found” verification has to be calculated from a combination of working pressure zero and the atmospheric pressure span. Figure H.1 (Steps 1 to 5) and Figure H.2 (Steps 6 to 9) show an example for a 100 in. H₂O DP transmitter with a working pressure to atmospheric pressure shift and no atmospheric or working pressure adjustments.

$$DP_{WP} = DP_{AP} + C_{SP} \quad (H.1)$$

where

DP_{WP} is the differential pressure at working pressure;

DP_{AP} is the differential pressure at atmospheric pressure;

C_{SP} is the static pressure correction.

and:

$$C_{SP} = Z_{WP} - Z_{AP}$$

where

Z_{WP} is the zero at working pressure;

Z_{AP} is the zero at atmospheric pressure.

Step 1: Verify transmitter at working pressure = 0.06 in. in cell F3

Step 2: De-pressure transmitter and verify 0 in., 20 in., 40 in., 60 in., 80 in., 100 in., 70 in., 50 in., and 30 in. As-found atmospheric pressure (AP) values recorded in cells F4 to F12 and approximate percent of volume error recorded in cells G5 to G11.

Step 3: Calculate the WP Zero minus the AP Zero = 0.4784" in cell I4

Step 4: Calculate the “Equivalent” Working Pressure verification by adding the WP Zero minus the AP Zero = 0.4784" in cell I4 to the As-Found values in F4 to F12. The results are recorded in cells J4 to J12 and the approximate percent of volume error recorded in cells K5 to K11.

- Step 5: The Transmitter Zero, Span and Linearity/ Hysteresis is calculated to determine if more than a Transmitter Zero adjustment is required.
- Step 6: The As-Left Verification at atmospheric pressure (AP) is recorded in cells S4 to S13 and the approximate percent of volume error recorded in cells T5 to T12 if a calibration is required
- Step 7: The transmitter is pressured up and the As-Found working pressure (WP) zero is recorded in cell V14 and the atmospheric pressure zero to working pressure is calculated and recorded in cell V4.
- Step 8: The transmitter is zeroed at working pressure and the working pressure (WP) zero is recorded in cell W14.
- Step 9: The as-left verification is calculated by adding the as-left zero in cell W14-V14+V4 to the as-left values in cells S4 to S13. These values are recorded in cells W4 to W13 and the approximate percent of volume error is recorded in cells X5 to X11.

The resulting As-Found/As-Left Verification is highlighted with a grey background in Figure H.1 and Figure H.2, and summarized in Figure H.3.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
		Working Pressure (WP)	Atmospheric Pressure (AP)		Atmospheric Pressure Verification Before Adjustment (AP)				WP Zero minus AP Zero	Calculated "Equivalent" Working Pressure					Transmitter Zero, Span, Linearity and Hysteresis Analysis		
1	DP Range						%										
2	100.00	Engineering	Engineering		Raw	As-Found	Volume		As-Found	As-Found	Diff.	%		Zero	Linearity Hysteresis	Span	
3		0			1.0035	0.06	--										
4	0.00%		0.00		1.0082	-0.42	--		0.4787	0.06	0.06	--		0.06			
5	20.00%		20.00		1.8110	19.61	0.98%			20.09	0.09	-0.22%			0.01		
6	40.00%		40.00		2.6131	39.62	0.48%			40.10	0.10	-0.12%			0.00		
7	60.00%		60.00		3.4157	59.65	0.29%			60.13	0.13	-0.11%			0.02		
8	80.00%		80.00		4.2079	79.67	0.21%			80.15	0.15	-0.09%			0.02		
9	100.00%		100.00		5.0198	99.67	0.17%			100.15	0.15	-0.07%				0.09	
10	90.00%		90.00		4.6186	89.67	0.18%			90.15	0.15	-0.08%			0.01		
11	70.00%		70.00		3.8171	69.66	0.24%			70.14	0.14	-0.10%			0.02		
12	50.00%		50.00		3.0156	49.66	0.34%			50.14	0.14	-0.14%			0.03		
13	30.00%		30.00		2.2145	29.67	0.55%			30.15	0.15	-0.25%			0.06		

Figure H.1—Calculation of “Equivalent” Working Pressure As-found and Calibration Error

	A	B	C	Q	R	S	T	U	V	W	X
1	DP Range	Working Pressure (WP)	Atmospheric Pressure (AP)		Atmospheric Pressure Verification				WP Zero after Return to WP	As Left After WP Zero Adjustment	
2	100.00	Engineering	Engineering		Raw	As-Left	%		As-Found	As-Left	%
3		0									--
4	0.00%		0.00		1.0082	-0.42	--		0.4700	0.05	--
5	20.00%		20.00		1.8110	19.61	0.98%			20.08	-0.20%
6	40.00%		40.00		2.6131	39.62	0.48%			40.09	-0.11%
7	60.00%		60.00		3.4157	59.65	0.29%			60.12	-0.10%
8	80.00%		80.00		4.2079	79.67	0.21%			80.14	-0.09%
9	100.00%		100.00		5.0198	99.67	0.17%			100.14	-0.07%
10	90.00%		90.00		4.6186	89.67	0.18%			90.14	-0.08%
11	70.00%		70.00		3.8171	69.66	0.24%			70.13	-0.09%
12	50.00%		50.00		3.0156	49.66	0.34%			50.13	-0.13%
13	30.00%		30.00		2.2145	29.67	0.55%			30.14	-0.23%
14		0			1.0058				0.05	0.05	

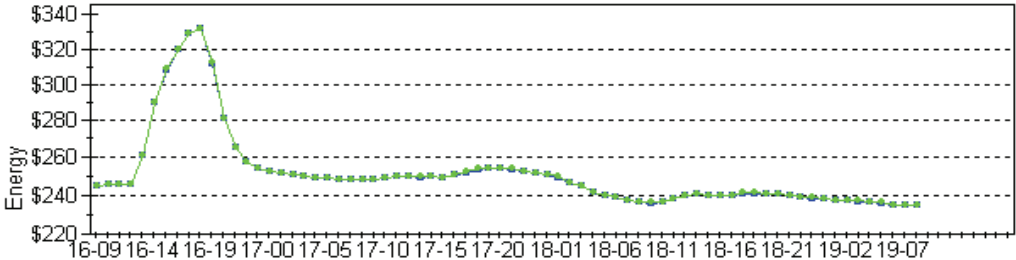
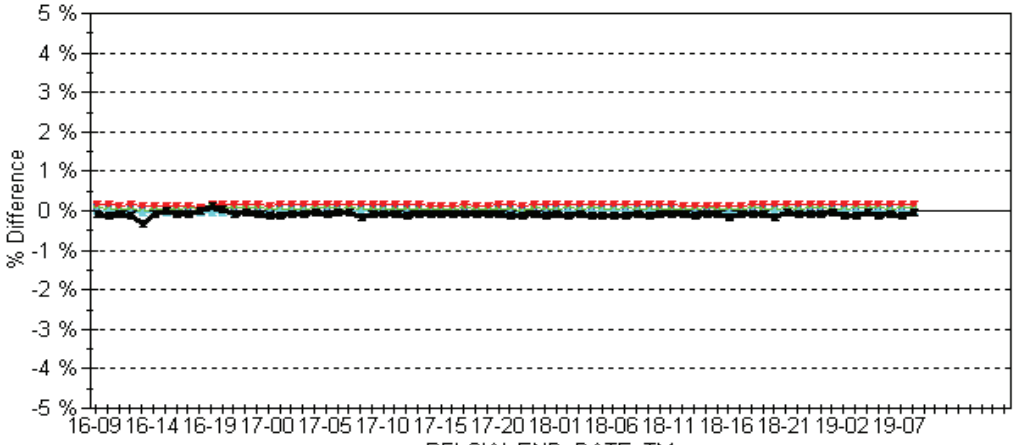
Figure H.2—Atmospheric Pressure/Calculation of “Equivalent” Working Pressure As-left

Engineering	As-Found	% Volume	As-Left	% Volume
0.00	0.06	--	0.05	--
20.00	20.09	-0.22%	20.08	-0.20%
40.00	40.10	-0.12%	40.09	-0.11%
60.00	60.13	-0.11%	60.12	-0.10%
80.00	80.15	-0.09%	80.14	-0.09%
100.00	100.15	-0.07%	100.14	-0.07%
90.00	90.15	-0.08%	90.14	-0.08%
70.00	70.14	-0.10%	70.13	-0.09%
50.00	50.14	-0.14%	50.13	-0.13%
30.00	30.15	-0.25%	30.14	-0.23%

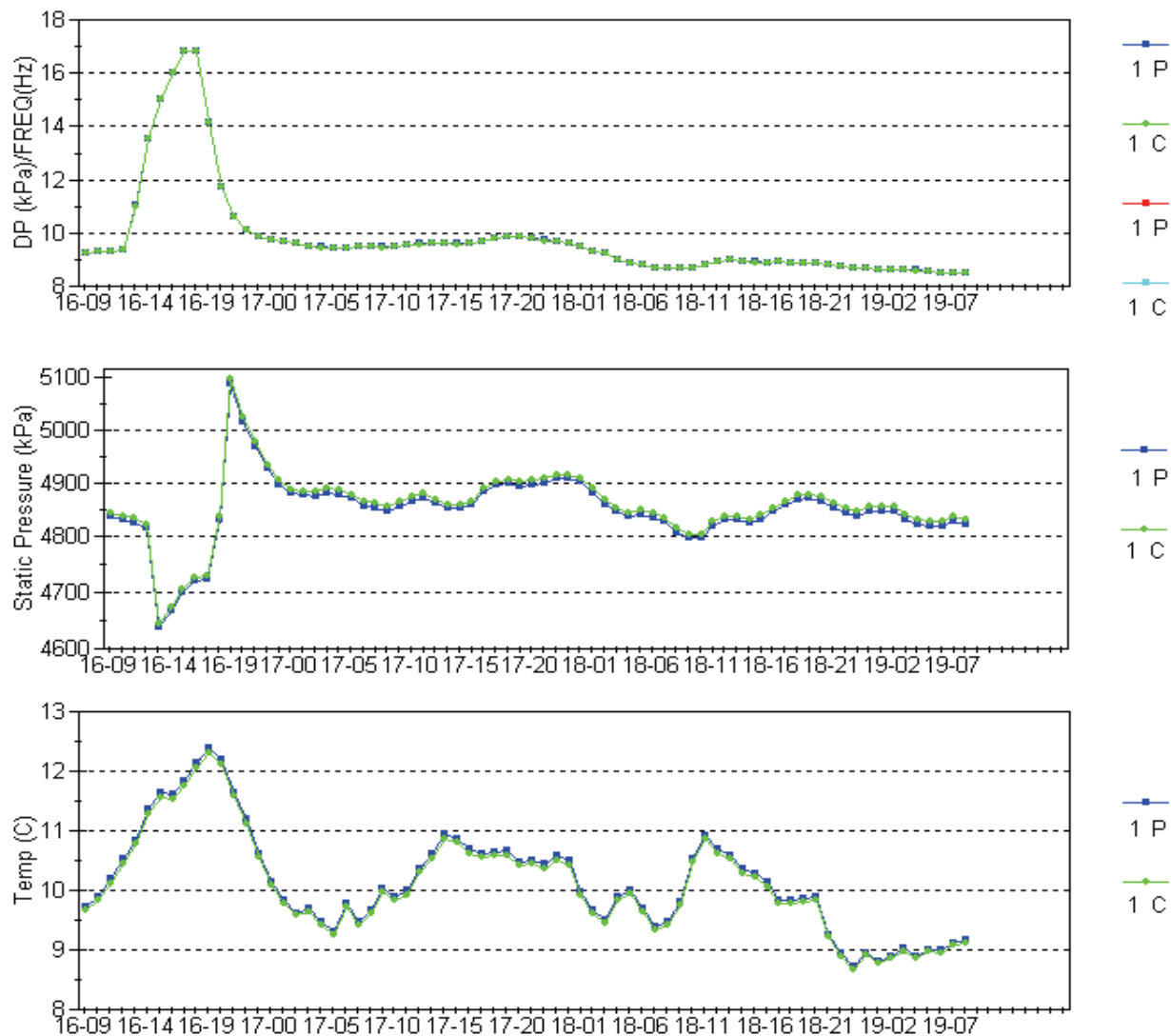
Figure H.3—Calculated “Equivalent” Working Pressure As-Found/As-Left Verifications

Annex I (informative)

Example of a Redundancy Verification Report

Station:	Comparison Period: 2002-03-16 to 2002-03-18																		
Average Redundancy Comparisons																			
	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 40%;"></th> <th style="width: 30%;">Average % of Reading</th> <th style="width: 30%;">Action Required?</th> </tr> </thead> <tbody> <tr> <td>Average Volume Comparison:</td> <td>0.02%</td> <td>Comparison OK</td> </tr> <tr> <td>Average Energy Comparison:</td> <td>0.02%</td> <td>Comparison OK</td> </tr> <tr> <td>Average DP Comparison:</td> <td>-0.10%</td> <td>Comparison OK</td> </tr> <tr> <td>Average SP Comparison:</td> <td>0.15%</td> <td>Comparison OK</td> </tr> <tr> <td>Average Temperature Comparison:</td> <td>0.01%</td> <td>Comparison OK</td> </tr> </tbody> </table>		Average % of Reading	Action Required?	Average Volume Comparison:	0.02%	Comparison OK	Average Energy Comparison:	0.02%	Comparison OK	Average DP Comparison:	-0.10%	Comparison OK	Average SP Comparison:	0.15%	Comparison OK	Average Temperature Comparison:	0.01%	Comparison OK
	Average % of Reading	Action Required?																	
Average Volume Comparison:	0.02%	Comparison OK																	
Average Energy Comparison:	0.02%	Comparison OK																	
Average DP Comparison:	-0.10%	Comparison OK																	
Average SP Comparison:	0.15%	Comparison OK																	
Average Temperature Comparison:	0.01%	Comparison OK																	
Orifice Plate Check																			
Date: 2002-03-17																			
Condition: Good - Slight film of liquid found on upstream surface. Cleaned and returned to service.																			
Reviewed By: _____	Date: _____																		
Approved By: _____	Date: _____																		
<p>Monday, February 24, 2003 Page 1</p> <p>STN NO: 1 P Compared to 1C MNEMONIC:</p>																			
																			
 <p style="text-align: center;">PFLOW_END_DATE_TM 2002-03-16 09:00:00 To 2002-03-19 08:00:00</p>																			

Hourly Redundancy Comparisons



Annex J (informative)

Examples of Applying Linear Meter Equations ⁷

J.1 Linear Meter with Synchronous Pulse Outputs

Example 1—Typical of a turbine meter with linearization done in the flow computer:

$$IV = \sum_{i=1}^{i=n} \frac{mf_i}{k\text{-factor}} \sum_{j=1}^{j=z} \text{Counts} \quad (\text{J.1})$$

— Sampling/calculation conditions:

- frequency sampled at 2 second intervals;
- volume calculated at 60 second intervals;
- meter factor of 1.00325; and
- *k-factor* table:

Frequency (Hz)	<i>k-factor</i> (pulses/ft ³)
0	16.95
50	16.95
100	16.96
150	16.94
200	16.94

— Equation terms for Hourly QTRs:

- Counts* equals the frequency (Hz) × 2 seconds;
- j* equals the sampling frequency = 2 seconds;
- z* equals 30;
- i* equals (*j* × *l*) = 60 seconds;
- n* equals 3600/*i* = *n*/(*j* × *l*) = 60;
- mf_i* equals 1.00325;

⁷ The examples in this Annex are merely examples for illustration purposes only. [Each company should develop its own approach.] They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

$k\text{-factor}_i$ is the table lookup of *Frequency* for calculation interval i .

Example 2—Typical of a turbine meter with flow computer linearization and the meter factor table as a function of uncorrected volumetric flow rate:

$$IV = \sum_{i=1}^{i=n} mf_i \sum_{j=1}^{j=z} \frac{Counts}{k\text{-factor}} \quad (J.2)$$

— Sampling/calculation conditions:

- turbine meter with a single $k\text{-factor}$ used to convert the output to 10 cubic feet per count, $k\text{-factor} = 0.1$ (pulses/ft³);
- counter read every 10 seconds;
- volume calculated at 10 seconds intervals;
- Mf table:

Uncorrected Volumetric Rate (ft ³ /sec)	Mf
0	1.0032 (100.32 %)
50	1.0032 (100.32 %)
100	1.0030 (100.30 %)
150	1.0025 (100.25 %)
200	1.0020 (100.20 %)

— Equation terms for Hourly QTRs:

Counts is the counter difference;

Uncorrected Volumetric flow rate (ft³/sec)
 $= Counts/k\text{-factor}/\text{calculation interval} = Counts/0.1/10 = Counts:$

j equals the sampling frequency = 10 seconds;

z equals 1;

i equals $(j \times z) = 10$;

n equals $3600/(j \times z) = 3600/i = 360$ (360 calculations at 10 second intervals);

$k\text{-factor}$ equals 0.1;

mf_i is the table lookup of *Uncorrected Volumetric Rate* for calculation interval i .

Example 3—Turbine meter with flow computer linearization and a meter factor table that is a function of frequency

$$IV = \frac{1}{k\text{-factor}} \sum_{i=1}^{i=n} mf_i \sum_{j=1}^{j=z} Counts \quad (J.3)$$

— Sampling/Calculation conditions:

- change gears installed to convert the output to 1 cubic foot per count;
- counter read every 60 seconds;
- volume calculated at one minute intervals;
- Mf table:

Frequency (Hz)	Mf
0	1.0032
300	1.0032
600	1.0030
900	1.0025
1200	1.0020

— Equation terms for Hourly QTRs:

$Counts$ is the counter difference;

$Counts$ is read every 60 seconds, therefore $frequency = Counts/60$;

j equals the sampling frequency = 60 seconds;

z equals 1;

i equals $(j \times z) = 60$;

n equals $3600/(j \times z) = 3600/i = 60$;

$k\text{-factor}$ equals 1;

mf_i is the table lookup of $Frequency$ for calculation interval i .

J.2 Linear Meter with Manufactured Pulse Outputs

Example 1—Typical of an ultrasonic meter factory adjusted to 1,000 pulses per cubic foot and linearization done in the flow computer:

$$IV = \sum_{i=1}^{i=n} \frac{mf_i}{k\text{-factor}} \sum_{j=1}^{j=z} Counts \quad (J.4)$$

- Sampling/calculation conditions:
 - frequency sampled at 1 second intervals;
 - volume calculated at 60 second intervals;
 - meter factor of 1.00; and
 - *k-factor* table:

Frequency (Hz)	<i>k-factor</i> (pulses/ft ³)
0	1001.95
50	1001.95
100	1000.96
150	1000.94
200	1000.94

- Equation terms for Hourly QTRs;
 - Counts* equals the frequency (Hz) × 1 second;
 - j* equals the sampling frequency = 1 second;
 - z* equals 60;
 - i* equals (*j* × *z*) = 60 seconds;
 - n* equals 3600/*i* = *n*/(*j* × *z*) = 60;
 - mf_i* equals 1;
 - k-factor_i* is the table lookup of *Frequency* for calculation interval *i*.

Example 2—Typical of an ultrasonic meter with flow computer linearization and the meter factor table as a function of uncorrected volumetric flow rate:

$$IV = \sum_{i=1}^{i=n} mf_i \sum_{j=1}^{j=z} \frac{Counts}{k-factor} \quad (J.5)$$

- Sampling/Calculation conditions:
 - ultrasonic meter with *k-factor* to convert the output to 0.001 cubic feet per count, *k-factor* = 1,000 (pulses/ft³);
 - counter read every 1 second;
 - volume calculated at 60-second intervals;

— *Mf* table:

Uncorrected Volumetric Rate (ft ³ /sec)	<i>Mf</i>
0	1.0032 (100.32 %)
500	1.0032 (100.32 %)
1000	1.0030 (100.30 %)
1500	1.0025 (100.25 %)
2000	1.0020 (100.20 %)

— Equation terms for Hourly QTRs:

Counts is the counter difference;

Counts/k-factor is read every 1 second, therefore *Uncorrected Volume* (ft³/sec) = *Counts*/1000/1;

j equals the sampling frequency = 1 second;

z equals 60;

i equals (*j* × *z*) = 60;

n equals 3600/(*j* × *z*) = 3600/*i* = 60 (60 calculations at 1 minute intervals);

k-factor equals 1000;

mf_i is the table lookup of *Uncorrected Volumetric Rate* for calculation interval *i*.

Example 3—Typical of an ultrasonic meter with flow computer linearization and a meter factor table that is a function of frequency:

$$IV = \frac{1}{k\text{-factor}} \sum_{i=1}^{i=n} mf_i \sum_{j=1}^{j=z} Counts \quad (J.6)$$

— Sampling/Calculation conditions

— ultrasonic meter with an output to 0.001 cubic feet per count;

— counter read every 60 seconds;

— volume calculated at one hour intervals;

— *Mf* table:

Frequency (Hz)	<i>Mf</i>
0	1.0032
3000	1.0032
6000	1.0030
9000	1.0025
12,000	1.0020

— Equation terms for Hourly QTRs:

- Counts* is the counter difference;
- Counts* is read every 60 seconds, therefore *frequency* = *Counts*/60;
- j* equals the sampling frequency = 60 seconds;
- z* equals 1;
- i* equals (*j* × *z*) = 60;
- k-factor* equals 1000 (pulses/ft³);
- n* equals 3600/(*j* × *z*) = 3600/*i* = 60;
- mf_i* is the table lookup of *Frequency* for calculation interval *i*.

J.3 Linear Meters with Rate Output

Example 1—Typical of an ultrasonic meter with a modbus uncorrected volumetric flow rate register:

$$IV = \sum_{i=1}^{i=n} mf_i Q_{fi} \Delta t_i$$

(J.7)

— Sampling/Calculation conditions:

- register read every 1 second;
- modbus register is *Uncorrected Volumetric flow rate* in (ft³/minute);
- *Mf* table:

Frequency (Hz)	<i>Mf</i>
0	1.0032
3000	1.0032
6000	1.0030
9000	1.0025
12,000	1.0020

— Equation terms for Hourly QTRs:

- Uncorrected Volumetric Flow Rate* equals the register value;
- i* equals the calculation period = 1 second;
- n* equals 3600/*i* = 3600;
- k-factor* equals 1;
- mf_i* is the table lookup of *Uncorrected Volumetric Rate* for calculation interval *i*.

Annex K (informative)

Example of Using DP_{IV} , DP_Y , and a Volumetric Flow Rate Calculator to Recalculate a QCP or QTR

Most volume verification software calculates flow rate and does not directly support QCP calculation of volume which use an IV or QTR recalculation of volume using the reported IV . This problem can be addressed using a three step process to convert the reported flow rate into accumulated volume:

- 1) Calculate the Flow Rate using the DP_{IV} calculated from the average IV (\overline{IV}).

This step corrects for the major portion of the volume calculation error introduced by using a linear average of differential pressure and may be all that is required depending on the necessary level of recalculation accuracy. (See % DP_{Linear} Recalculation Bias in Figure K.1, "Differences Between DP_{IV} and DP_{Linear} and Recalculated Volumes, Using Hourly QTR Data for a Plunger Lift Production Area.")

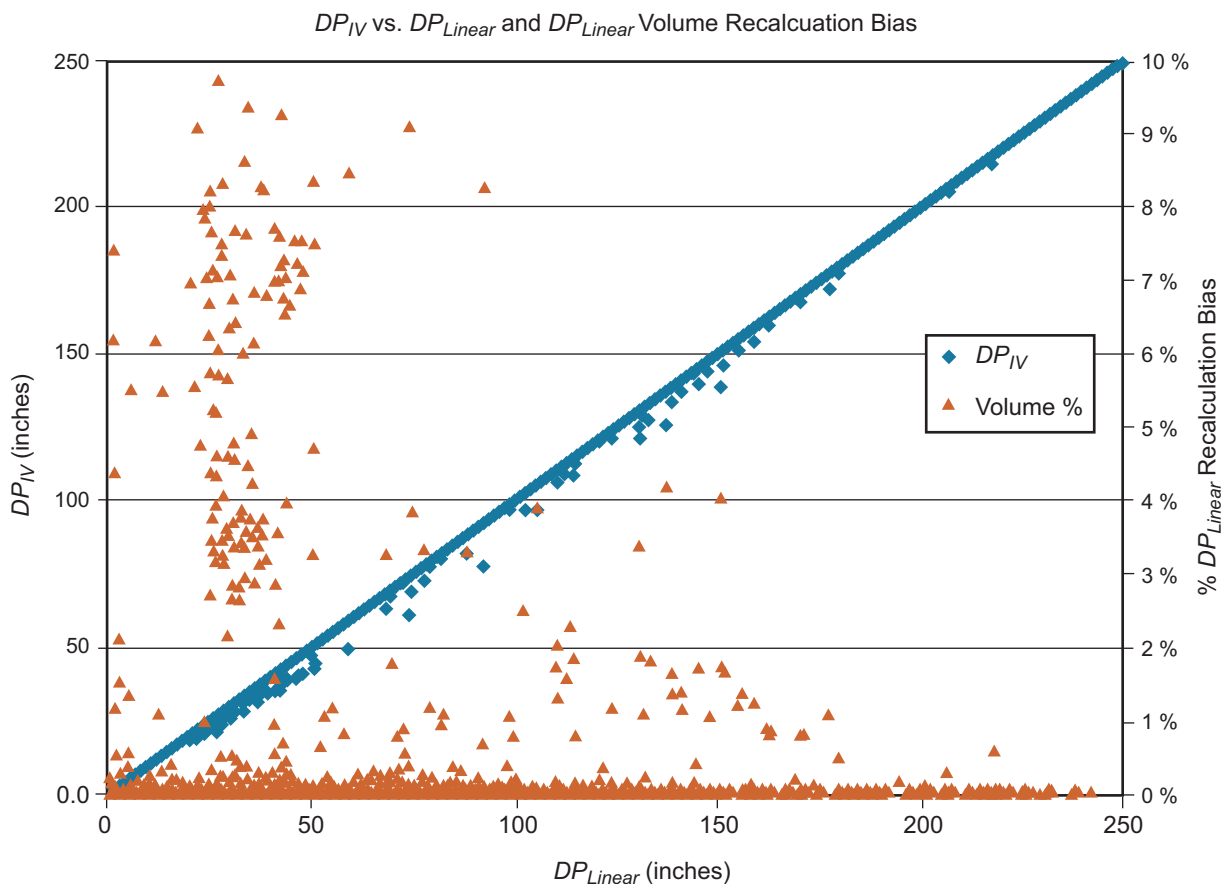


Figure K.1—Differences Between DP_{IV} and DP_{Linear} and Recalculated Volumes, Using Hourly QTR Data for a Plunger Lift Production Area

- 2) Correct the flow rate for expansion factor errors caused by using DP_{IV} .

$$\text{Corrected Flow Rate} = \text{Reported Flow Rate} \times \frac{Y(\text{calculated using } DP_{Linear} \text{ or } DP_Y)}{Y(\text{calculated using } DP_{IV})}$$

(See Figure K.2, “Differences Between DP_{IV} , DP_{Linear} and DP_Y Calculated from Hourly QTR Data for a Plunger Lift Production Area” and Figure K.3, “Differences Between Expansion Factor (Y) Calculated Using DP_{IV} , DP_{Linear} and DP_Y for a Plunger Lift Production Area.”)

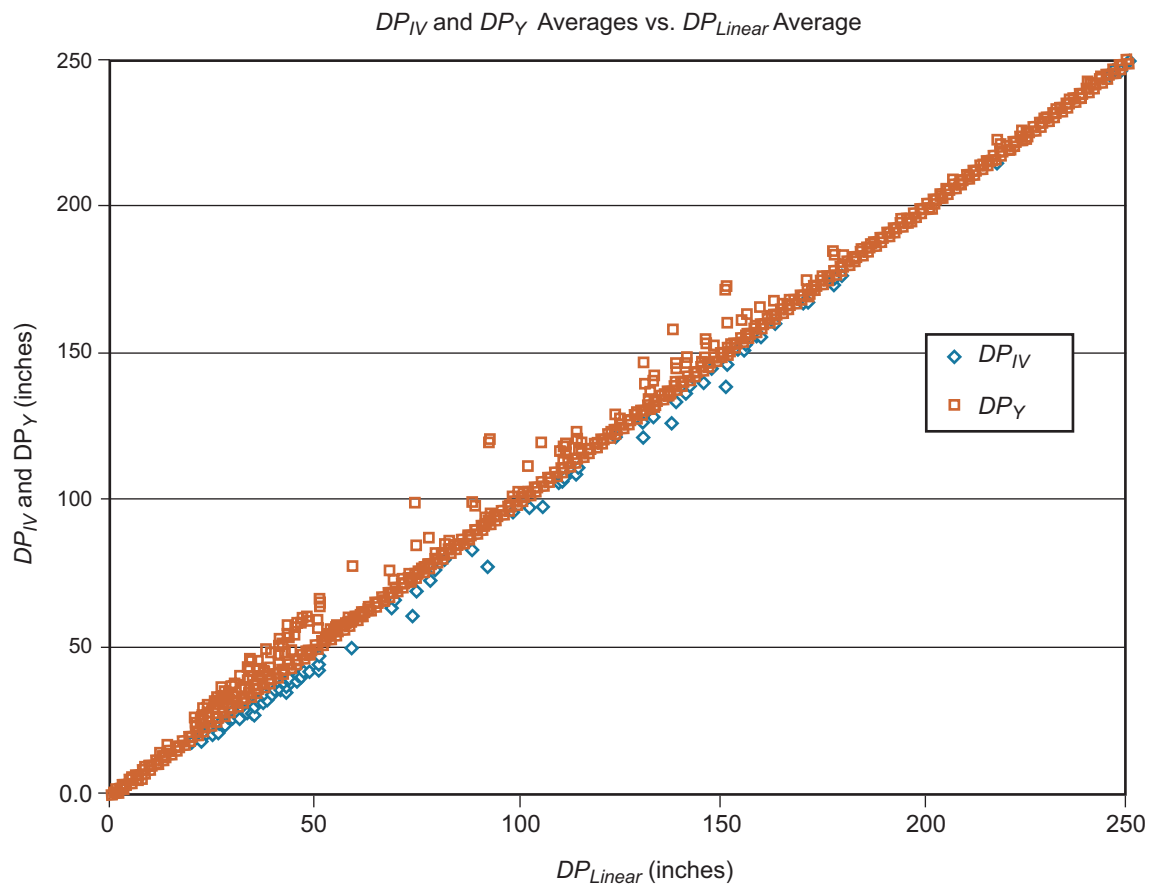


Figure K.2—Differences Between DP_{IV} , DP_{Linear} and DP_Y Calculated from Hourly QTR Data for a Plunger Lift Protection Area

- 3) Convert the flow rate into an accumulated volume for the calculation interval:

$$\text{Accumulated Volume} = \text{Flow Rate} \times \frac{\text{Flow Time}}{\text{Flow Rate Interval Converted to Flow Time Units}}$$

For example, a flow rate of 100,000 cubic feet per hour and a flow time of 3,240 seconds would equate to:

$$100,000 \times \frac{3240}{1 \text{ hour} \times 60 \text{ minutes/hour} \times 60 \text{ seconds/minute}} = 90,000 \text{ cubic feet}$$

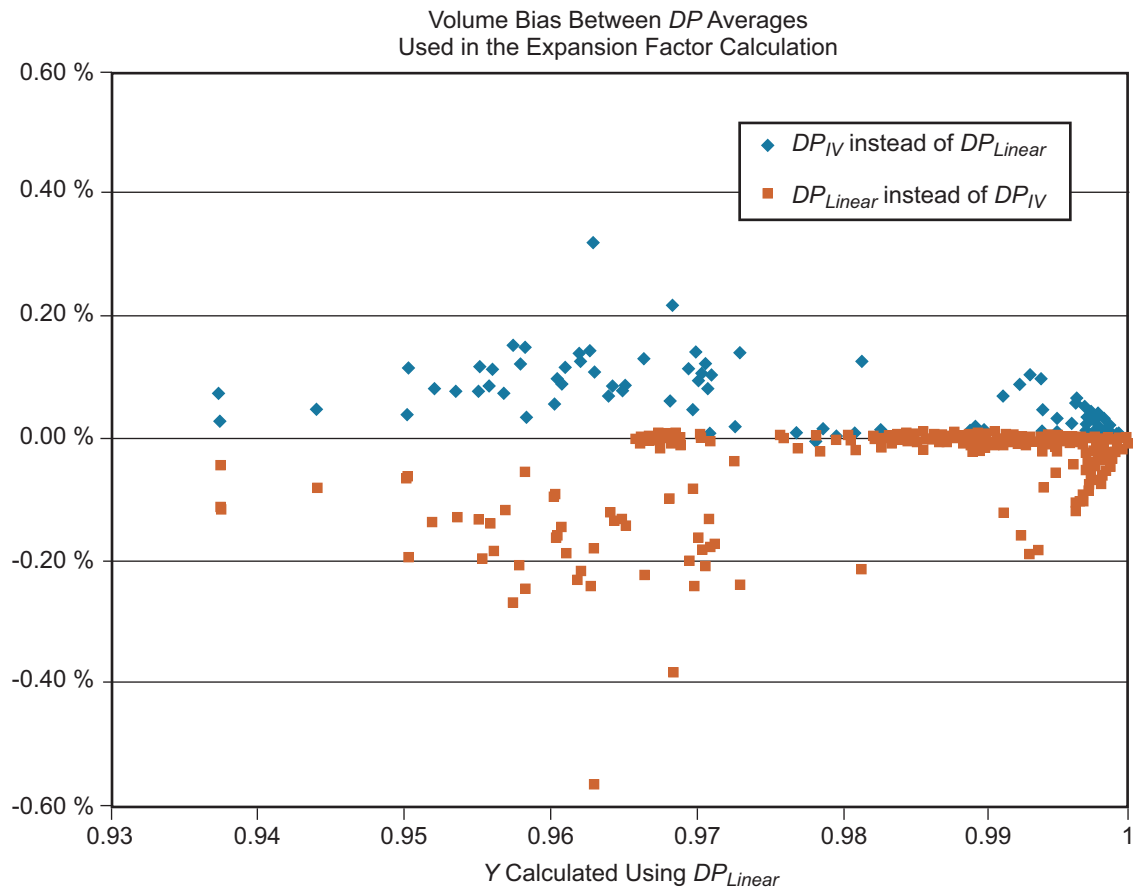


Figure K.3—Differences Between Expansion Factor (Y) Calculated Using DP_{IV} , DP_{linear} , and DP_Y for a Plunger Lift Production Area

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- [3] GPA Std 2261⁸, *Analysis for Natural Gas and Similar Gaseous Mixtures by Gas Chromatography*
- [4] GPA Std 2286, *Tentative Method of Extended Analysis for Natural Gas and Similar Gaseous Mixtures by Temperature Programmed Gas Chromatography*
- [5] ISA-5.5⁹, *Graphic Symbols for Process Displays*

⁸ Gas Processors Association, 6526 E. 60th Street, Tulsa, Oklahoma 74145, www.gasprocessors.com.

⁹ The Instrumentation, Systems, and Automation Society, 67 Alexander Drive, Research Triangle Park, North Carolina, 22709, www.isa.org.

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