AUDITING ELECTRONIC GAS MEASUREMENT PER API MPMS, CHAPTER 21.1

Keith Fry

Howard Measurement Company
1637 Enterprise Street
Athens, TX 75751

Introduction

Advances in technology during the last decades of the 20th century led the gas measurement industry from the pneumatic / mechanical age to the electronic / digital age. While these advances allowed the industry to improve the accuracy of gas measurement, they also brought an abundance of data with additional complexity. Flow measurement information was inconsistent and often incomplete among manufacturers and data service providers. Those responsible for custody transfer and interested parties needed assurances of the integrity and accuracy of the measurement processes. The industry's response was to standardize electronic gas measurement, resulting in API's *Manual of Petroleum Measurement Standards* (*MPMS*), Chapter 21, Section 1 - Flow Measurement Using Electronic Metering Systems (API 21.1). API 21.1 standardized how the components of an electronic gas measurement system should work together to provide accurate and auditable gas measurement.

Auditing electronic gas measurement systems involves reviewing and examining the electronic measurement process and data. An adequate review of the data cannot be performed without a minimum amount of information. The API 21.1 standard provides the minimum requirements for "compiling and maintaining sufficient data and information" for verification and application of reasonable adjustments to electronic gas measurement systems.

API 21.1 Audit and Record Requirements

Section 5 of API 21.1 provides the minimum information required for an auditable gas measurement system. These requirements include, quantity transaction records, software and/or firmware identifiers, configuration logs, event logs, field test reports, corrected quantity transaction records, and a reason for each correction. It should be noted these are minimum requirements. Additional information can be made available and often aids analysts and auditors in the verification process and making any required adjustments to reported values.

Quantity Transaction Records (QTR)

The Quantity Transaction Records (QTRs) provide detailed process information for auditing electronic gas measurement (EGM) systems. A QTR is a record of unedited historical data and other information used to identify the device(s). Collated with other measurement data, quantities of volume, mass, and/or energy are calculated and reported in the QTR. It is collected and stored in non-rounded floating point or integer form with enough precision to allow for recalculation. The QTR may be reported with less numerical precision, but the QTRs used for auditing are to use all unrounded values.

The requirements for QTRs vary by the meter type (differential or linear), record period (hourly or daily), and where calculated (onsite or offsite). An hourly QTR is the data collected and calculated during a maximum of 60 consecutive minutes. One QTR ends, and the next QTR begins, at the end of each hour. Excluding hours adjusted for Daylight Saving Time, there are at least 24 hourly QTRs each day. There may be additional QTRs, and a QTR should end, and another begin, when parameters that affect quantity calculations change within the hour. Daily QTRs are the daily summation or average of the hourly QTRs, beginning and ending at the contract hour.

Meter types and the location of their quantity calculating device (the quantity calculating device is referred to as the "tertiary" device in API 21.1) determine the minimum data elements required for each QTR. All averages are flow time linear averages. Gas pressure and temperature are not required for mass measuring devices and density, energy content, and composition averages are required if they are live inputs (highlighted in the following table).

Quantity Transaction Record Data	Differential Onsite	Differential Offsite	Linear Onsite	Linear Offsite
Date and Time or Date/Time Identifier	✓	✓	✓	✓
Sum of Quantity (Volume, Energy, and/or Mass) ($Q_{v,e,m}$)	✓		✓	
Sum of Flow Time (t_f)	✓	✓	✓	✓
Integral Value (IV) or Average Extension ($\overline{IV}$)	✓	✓		
Meter Output (Accumulation or Average)			✓	✓
Average Differential Pressure (DP_{Linear})	✓	✓		
Average Static Pressure ($\bar{P}_f$)	✓	✓	✓	✓
Average Temperature ($\bar{T}_f$)	✓	✓	✓	✓
Average Density ($\overline{\rho_f}$), Heating Value, and/or Composition	✓	✓	✓	✓

Fig. 1 Quantity Transaction Record (QTR) Requirements

Examining QTR trends allow the data analyst and auditor to find instances of meter performance degradation, meter or gauge line freezing, accumulation of liquids in meters, pulsation-induced gauge line amplification, and other measurement anomalies.

<u>Differential Type Meters</u>

The Second Edition of API 21.1 (2013) changed all average values in QTRs with flow time to be reported as flow time linear averages. Prior to this edition, averaging types were not specified and most differential readings were reported as a root-mean-squared (formulaic average) value. The flow time linear average of differential pressure, when compared to the formulaic average, allows the analyst and auditor to troubleshoot measurement problems and determine the applicable correction types. Although simplifying the averaging process and providing better information for the auditor, this change added complexity to making corrections.

The Integral Value (IV) or average Integral Value ($\overline{IV}$; also known as the average extension) is found in the QTRs of differential type meters. At a minimum, the IV is the sum of the square root of the products of the differential and static pressures from the process sample data. However, temperature may be included in the IV and density is to be included if it is a live input.

DP_{IV} is a value useful to the auditor of a differential meter. DP_{IV} represents the root-mean-squared value of the individual samples of differential recordings during the period of the QTR. It should be calculated by the flow computer or host system and stored as part of the QTR. If not stored as part of the QTR, the DP_{IV} can be approximated from the IV, given the flow time linear averages of the other process data elements used to calculate the IV. This procedure is demonstrated in Annex B of API 21.1. DP_{IV} can be approximated by the calculation:

$$DP_{IV} \approx \frac{\bar{\rho} \times \bar{T}_f}{\bar{P}_f} \left(\frac{IV}{t_f} \right)^2$$

where:

DP_{IV}	$\approx$	root-mean-squared differential pressure
$\bar{\rho}$	$=$	flow time linear average density (= 1.0 if density is not included in IV)
$\bar{T}_f$	$=$	flow time linear average temperature (= 1.0 if temperature is not included in IV)
$\bar{P}_f$	$=$	flow time linear average static pressure
IV	$=$	integral value
t_f	$=$	time flowing

DP_{IV} is useful to the auditor because it allows for:

1) Recalculating quantities if the auditor's measurement system recalculates without the use of an IV,
2) Estimating DP_Y for use in recalculating the expansion factor (Y), when the QTR doesn't contain DP_Y,
3) Identifying flow variability to determine when and how to apply corrections, and
4) Identifying operating problems, such as gauge line amplification.

DP_Y represents the volume-weighted average differential pressure. Errors in recalculating the expansion factor (Y) will result with highly variable flow at high differential to static pressure ratios, if recalculated with DP_{IV} or the flow time linear average differential pressure (DP_{Linear}). However, if DP_Y is not provided in the QTR, it can be approximated from DP_{IV} and DP_{Linear}:

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

where:

DP_Y	$\approx$	volume-weighted average differential pressure
DP_{Linear}	$=$	flow time linear average differential pressure
DP_{IV}	$\cong$	root-mean-squared differential pressure

For differential-type meters, if DP_{IV} varies significantly from DP_{Linear}, quantity corrections will be based on DP_{IV} values, not DP_{Linear}. When DP_{IV} is significantly different than DP_{Linear}, as is the case when differential pressure varies during the quantity transaction period, it may require corrections to be based on previous or subsequent flow rates instead of adjusting differential readings. If differential pressure varies during the QTR period and the differential pressure to static pressure ratio is high, DP_Y is to be used for expansion factor (Y) recalculations, and not DP_{Linear}.

Configuration Logs

The configuration log contains the constant flow parameters associated with the measurement, the calculation methods, and other general information used to calculate values in the QTR. Collating data from the configuration log with the live data in the QTR allows the auditor to recreate the total quantity calculated by the flow computer or host system. A list of common constant flow parameters for each meter type is listed in the informative Annex G of API 21.1.

Event and Alarm Logs

The event log identifies any changes to the constant flow parameters contained in the configuration log that affect the calculated quantities. Each event record contains, at a minimum: 1) the parameter changed, 2) the old value, 3) the new value, and 4) the date and time it was changed. Sometimes configuration record changes are not recognized from a volume statement when changed, and then changed back, during the same contract day. Review of the event records allows the auditor to find erroneous changes to the meter's configuration log that were later changed back to the original value. Because event records contain the date and time of the change, the auditor can also confirm the configuration log changes are reported at the correct date and time.

The auditor should watch for documentation indicating a change in a constant flow parameter that is not reflected in the configuration log or event log. Conversely, changes to the configuration log should be supported with documentation to validate a change.

Alarm logs track operating exceptions and events, such as when a flow parameter or meter output exceeds a higher limit or goes below a lower limit. Alarm logs allow users and auditors to determine if a flow parameter falls outside of its operating range and determine when adjustments should be made.

Corrected Quantity Transaction Records

A corrected QTR is a copy of a QTR that has been edited and is part of the custody transfer quantity. Corrected QTRs are included in the audit package. Corrected QTRs do not replace original QTRs, but are reported along with the original QTRs as part of the audit package. The original QTRs remain intact and unedited. Each corrected QTR is required to include the changes to the original constant or live values used to calculate a corrected quantity and provide a reason for the correction. QTRs are to be corrected when:

1) Constant flow parameters were unknown at the time of calculation, were entered incorrectly, or were found to be in error, or
2) Live input variables were found to be in error as a result of equipment verification, equipment failure, or deviant operating equipment or conditions.

Field Test Reports

Field test reports record many, if not all, of the constant flow parameters contained in the configuration log. The auditor should compare the data on the field test reports to the data in the configuration log. Changes to the configuration log noted on the field test reports should be found in the event log and the configuration record.

The 2013 version of API 21.1 added guidance for setting the no flow cutoff value. The no flow cutoff is “the minimum value of the flow dependent variable, below which the signal is considered to be meter or flow noise.” Field test reports should indicate how the no flow cutoff is set. For pulse output meters, API 21.1 recommends 0 pulse/time period, 0 for serial rate meters, or 0.25% of span for analog meters, subject to manufacturers’ recommendations. For differential-producing meters, the recommended no flow cutoff is 0.25% of the user defined span of the differential transmitter or 0.5 inches of water column, whichever is less.

Field test reports should also show the verification and calibration information of the transmitters (secondary devices), and analyzers (auxiliary devices). Significant calibration adjustments may require adjustments to previous quantity calculations. Contracts usually spell out the magnitude of adjustments that will require recalculation. If not, the auditor should report what the volume is believed to have been if all instruments were operating correctly.

Other notes on field test reports may describe issues that will cause errors in quantity determinations. To correct certain types of errors, measurement data can be adjusted mathematically and quantities recalculated. Otherwise, comparison of quantities before and/or after the measurement error was corrected may provide insight to the amount of adjustment required for the correction.

EGM component verification and calibration procedures vary by manufacturer and model. API 21.1 also provides the minimum requirements for verification and calibration of differential pressure, static pressure, and temperature. The results of all verifications and calibrations are to be recorded and included as part of the audit package. The auditor should verify the test reports indicate manufacturer-recommended or industry-standard commissioning and calibration procedures were followed.

Commissioning

Different meter types will have different requirements for commissioning. API 21.1 defines the minimum requirements for commissioning common secondary devices.

For commissioning differential pressure at atmospheric pressure according to API 21.1, readings shall be verified at the following pressures and in the following sequence: atmospheric pressure zero, approximately 25% of user defined operating range or transmitter calibration span (TCS), approximately 50% of TCS, 100% of TCS, approximately 80% of TCS, approximately 20% of TCS, and atmospheric pressure zero, again.

For commissioning static pressure, readings shall be verified at the following pressures and in the following sequence: atmospheric pressure, expected operating pressure, 100% of TCS, expected operating pressure, and atmospheric pressure, again.

For commissioning temperature, readings shall be verified using a temperature bath at temperatures above, below, and at the expected operating temperature. When gas is flowing near the expected operating temperature and a test thermowell is available, the expected operating temperature can be verified using the flowing gas instead of a bath.

The commissioning process should include end-to-end checks. When large quantities are being transferred, these checks may include simulating live data for a period of time and verifying the correct calculation of rates or QTRs. Within the first 90 days of flow, quantity recalculations based on QTRs and configuration data should be verified through the entire electronic gas measurement and reporting system.

Equipment Verification and Calibration

After commissioning, minimum subsequent verification and calibration rules are less stringent.

For differential pressure verified from atmospheric pressure, readings are to be verified at 6 points: working pressure zero, atmospheric pressure zero, approximately 50% of the TCS or the average flowrate differential pressure, TCS, atmospheric pressure zero, and working pressure zero. If the test instrument allows for verification at working pressure, the atmospheric pressure zero tests are skipped and the other differential pressures are tested above working pressure. Readings tested from atmospheric pressure should be corrected by any offset in working pressure zero to determine if the transmitter should be zeroed, calibrated, or replaced.

For static pressure, readings are to be verified at 3 points: atmospheric pressure, operating pressure, and TCS. If verifying an intelligent transmitter, only a single point at operating pressure needs to be verified.

For temperature, a single reading is to be verified, as close to operating temperature as practical.

If the transmitter can be brought into tolerance by zeroing, a calibration is unnecessary. Frequent unnecessary calibrations can create errors in quantity calculations.

Along with these common verifications, other EGM equipment and analyzers are to be periodically verified and, if found out of tolerance, they also should be zeroed, calibrated, or replaced. Analyzers should be tested with a certified reference standard.

API 21.1 also allows for redundancy verification. Redundancy is a duplicate measurement of the same process. Periodically, the redundant measurements are compared to the custody transfer measurements and if the difference exceeds an allowed tolerance, efforts are made to resolve the issue. Corrections and audits can be minimized with this method and troubleshooting differences can usually be done quickly, especially when redundant and custody transfer device sizes are the same.

These are minimum verification and calibration requirements. Manufacturers' guidelines and company policies may state additional verification or calibration requirements. The auditor should confirm the minimum requirements for verification and calibration have been met. If the minimum requirements are not met, the accuracy of the calculated quantities are questionable.

Gas Analysis Reports

Gas analysis reports communicate the quality of the gas measured, its components, and its physical properties. There are many options available for reporting density and heating value found on analysis reports. When auditing volumes, the auditor should confirm the analysis calculations and correct application of the values for real density, water vapor content, and heating value per real volume.

If the installation doesn't use live gas quality data, some operations will put a generic analysis in the tertiary device or host measurement system and adjust the quantity later in the measurement accounting software according to the latest spot or composite gas analysis. Others may retroactively apply the analysis to the beginning of an accounting period and update the tertiary device after the analysis becomes available to the field or SCADA technician. The application of gas analysis data is dictated by contract or company policy. The auditor should confirm the applications are correct and consistent.

Data Retention

API 21.1 does not prescribe a data retention period, but defers to other business or governmental requirements. Custody transfer contracts may include data retention periods or specify how many prior months or years a correction can be applied to. Governing statutes, regulations, or tariffs may require an even longer retention period.

A Proven Strategy for a Successful Audit

One strategy for auditing has proven to provide successful results. This strategy may take longer than a perfunctory review of the data, but is more likely to point out errors in original measurements and corrected QTRs. This strategy involves:

1) Recreating the quantities from the original measurement data,
2) Correcting these quantities for any incorrectly recorded measurement parameters, measurement errors, standard changes, and/or contract terms,
3) Adjusting for equipment found to be out of verification tolerance,
4) Estimating any missing or erroneous data,
5) Reconciling any difference between the results of these steps to the custody transfer corrected QTRs, and
6) Reporting the findings of the audit.

The audit package includes the original QTRs that can be input into a quantity calculating measurement system. Quantity Correlation Factors, called Volume Correction Factors (VCFs) in Annex C of API 21.1, can be calculated to correct the quantities calculated to each of the original QTRs. VCFs that deviate significantly from the value of 1.0 may indicate widely varying flow, corrupted measurement data, or unequal parameters or methods used to recalculate the original quantities.

The VCF-adjusted QTRs should be corrected for any incorrect meter parameters that were found during the review of the configuration logs, field test reports, and analysis reports. These include any outdated standard algorithms used to calculate the quantities. Constant flow parameters in the configuration log are updated for any difference between those used and the terms of the custody transfer contract or governing regulations. Any documented measurement errors or errors found during the QTR trend review can be adjusted accordingly.

Next, corrections can be made for any calibration adjustments made to the equipment resulting from verification tests. Once all adjustments have been made to existing data, missing and corrupt data can be estimated.

Check meters provide the best means of estimating missing, erroneous, or corrupted QTRs. If a check meter is not available and the contract does not provide methods for estimating, estimates can be made from averaging the previous QTRs, before the problem occurred, and/or subsequent QTRs, after the problem was corrected.

The auditor's corrected QTRs can then be compared to the corrected QTRs being audited and a reconciliation of differences attempted. If the audited quantities are found valid, the auditor can adjust theirs to match the parameters and methods used to create the audited QTRs. Otherwise, the auditor reports the quantity difference in their auditor's report.

Auditor's Report

The auditor's report provides the results of the audit. It should include the scope of the audit, the findings, and any recommendations.

The scope of the audit includes the station or system and the time period audited. If available and warranted, what prompted the examination of the data or system may be included.

The findings of the audit are the focus of the report. Although likely to focus attention on unreconciled differences, the auditor's report may also indicate when best practices were followed or the original methods used to correct quantities made practical sense. When the differences are not reconciled, the auditor's report should state the error in the original corrected QTRs or the rationale used by the auditor to calculate a different quantity.

Where differences still exist or API 21.1 requirements were not followed, the auditor should suggest remedies. Sometimes remedies are not quantifiable. In this case, the auditor may suggest best practices which would lead to more accurate future volumes or avoid potential mismeasurement. Other times, remedies are stated in a quantity or monetary value from an error in the original custody transfer transaction.

Conclusion

API 21.1 provides the minimum requirements for auditing electronic gas measurement systems, which include QTRs, configuration logs, event logs, and alarm logs. Dovetailing the data from these requirements with the other requirements of API 21.1, field test reports and gas quality analysis reports, the auditor can verify the corrected QTRs and the reasons the original QTRs were corrected. The findings, agreeable or disagreeable, are reported by the auditor in the auditor's report. Using the API 21.1 standard for electronic gas measurement provides interested parties with assurances their gas measurements are accurate and auditable.

References

Manual of Petroleum Measurement Standards, Chapter 21, Section 1, "Flow Measurement Using Electronic Measurement Systems," 2013, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.