MEASUREMENT ERROR AND ASSOCIATED LOST AND UNACCOUNTED FOR

Duane A. Harris

Flow-Cal, Inc.
2525 Bay Area Boulevard, Suite 500
Houston, TX 77058

Introduction

Given volatile natural gas prices and increased regulation by federal and state governments, the natural gas measurement industry has assumed an "every drop counts" approach to operations. As a result, issues such as measurement error and unaccounted-for (UAF) gas are under much closer scrutiny.

Production, gathering, midstream, pipeline, and distribution companies are all responsible for managing UAF. Long gone are the days when the cost and impact of UAF was passed directly to the customer, with virtually no requirements for managing and reducing costs associated with the loss.

Historically, UAF has resulted from a combination of factors, but current industry trends have introduced new complexities to the issue. For instance, growing interest in shale plays has given rise to many company mergers and acquisitions, which have resulted in diversified oil and gas operations. An increasing number of producers and midstream companies must now track and balance multiple fluids in their systems, including natural gas, natural gas liquids (NGLs), and "heavier" hydrocarbons (i.e., longer-chain hydrocarbon molecules). At the same time, measurement departments are faced with increasingly ambitious UAF loss targets.

In light of these industry dynamics, reviewing the latest concerns with measurement errors and UAF issues, and the processes for identifying and mitigating them, has become imperative.

Lost and Unaccounted-For Review

Gain or loss is the difference between physical input and output of a pipeline system.

- A **loss** occurs when the physical inputs are greater than outputs of the system.
- A **gain** occurs when the physical outputs are greater than inputs of the system.

Figure 1 provides a simplified view of a system, such as a gathering network, pipeline, or local distribution utility. This illustration shows 100 MMBTU entering the system and 95 MMBTU exiting, resulting in a loss of 5 MMBTU. The company is able to accurately account for 4 MMBTU of that loss, such as gas used to fuel compressors, leaving 1 MMBTU that cannot be accounted for accurately.

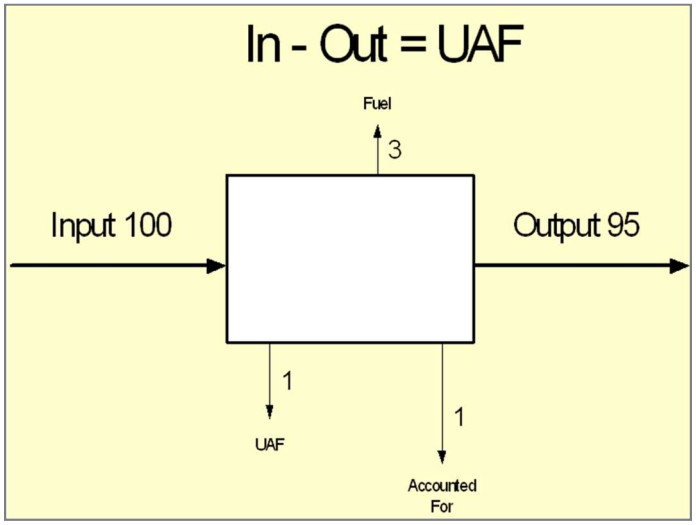

Figure 1. UAF Demonstration

Causes of Unaccounted-For Loss

Causes of UAF generally fall under these categories:

- Measurement errors
- Actual losses, such as leaks or theft
- Unreported use, such as unmeasured fuel
- Losses caused by system operation events, such as a relief valve opening
- Line pack (gas) or line fill (liquids) changes and timing issues
- Third-party measurement

Measurement Errors

Although most of the aforementioned losses are real (i.e., actual losses of measurable quantities), losses due to measurement errors only exist "on paper." In fact, in rare instances, measurement errors can result in a net gain.

In a measurement system, there are numerous sources of measurement uncertainty. The more meter classes and types involved in an UAF loss for a gas company, the more complicated the actual determination of the loss becomes. Tracking multiple fluids, such as natural gas, NGLs, and heavier hydrocarbons, further complicates measurement and system balancing. Frequent mergers and acquisitions in the industry also complicate the process, as these situations require management to integrate numerous entities that previously operated with little or no coordination.

Measurement problems that contribute to UAF may include:

- Measurement accounting, calculation, or procedure errors
- Incorrect entry of parameters used in flow calculations
- Incorrect compensation for the effects of ambient temperature, atmospheric pressure, and line pressure
- Incorrect "no flow" detection
- Poor or incorrect documentation and processing of meter tests, calibration, and verification
- Lack of coordination, resulting in difficulty integrating information at the meter level, such as calibration/verification, flow information, and gas quality information
- Meter inaccuracies due to faulty equipment
- Improperly-sized meter (flow falls outside of range for accurate measurement)
- Improper transmitter ranges (flow falls outside of range for accurate measurement)
- Incorrect orifice plate size, dirty plate, or incorrect plate installation in an orifice flow meter
- Long gauge lines from flow element to pressure transmitter(s)
- Flow pulsation
- Dirty or damaged meter tubes
- Undetected equipment failures
- Incorrect input/output coding or data entry errors (i.e., "keypunch" errors)

Understanding the fundamental areas that impact measurement accuracy and uncertainty is essential to measurement integrity in an organization. The knowledge base required to recognize data entry errors and the timing of meter characteristic events can easily correct a loss impact of up to ±2% on an individual flow meter.

Actual Losses

Leakage losses could be occurring constantly through any connections or process equipment, including:

- Regulators/controllers
- Dehydrators
- Heaters

- Couplings

In addition, venting could be occurring without the knowledge of operations or field staff. Theft of gas could also be taking place through unknown connections or connections thought to be out of service.

Unreported Use

Legitimate, but unreported usage of gas in a system typically includes:

- Fuel
- Construction activity
- Other uses within the company

Losses Caused by System Operations

Losses can also occur through circumstances considered to be normal, day-to-day operations. These losses are sporadic and, if not well documented, can be very difficult to track down and account for properly.

Natural gas escaping through a relief valve is the most notable loss in this category; however, other common operations, such as taking a meter, compressor, or other process unit out of service, can also result in losses large enough to require accounting.

Even the timing of such operational events can create an appearance of unaccounted-for losses, as when a loss event occurs toward the end of an accounting period but the report is delayed.

Line Pack/Line Fill Changes and Timing Issues

In pipeline operations, line pack/line fill changes help quantify the inventory left in a pipeline or withdrawn from a pipeline to track daily and monthly gains and losses more accurately.

The delta (change) in line pack can swing drastically from January 1st @ 9:00 a.m. to February 1st @ 9:00 a.m. It is important to capture this swing in line pack to effectively balance a system on a daily, monthly, and annual basis. Line pack / line fill changes should never continually grow. Generally, the greatest swing in line pack recorded for a single day should, essentially, be the same as for a single month or for a single year.

Third-Party Measurement

After assessing all potential measurement problems in the system of a company, the measurement team will be ready to consider errors resulting from third-party measurement.

The UAF Reduction Process

The UAF reduction process requires multi-disciplined teams to "roll up their sleeves" and assess system details one-by-one. The audit and investigation processes are considerable. As a result, incorporating corrective action is of utmost importance, not only as remedial activities, but also, as part of day-to-day operating procedures of the company going forward.

UAF reduction process activities generally fall under:

- Leak/theft audits and surveys
- Operations audits
- Segmentation
- Metering improvements
- Third-party measurement improvements
- Analysis/quality improvements
- Measurement process improvements

Leak/Theft Audits and Surveys

The investigation process is primarily a detailed audit of the system to identify all sources:

- Leak report survey
- Gas control log notes

- Soap test equipment (for locating gas leaks)
- Identification of all unmeasured venting of gas
- Performance of annual meter usage comparisons

Operations Audit

This audit addresses how an organization handles line pack, unmeasured fuel, unmeasured company use gas, retrograde condensate, timing of reported loss events, and missing loss events.

- Unreported loss
  - Identify all unmeasured fuel
  - Identify all company use gas loss
  - Quantify and report construction activity in a timely manner
- Line pack
  - Quantify line pack and line fill in segments (see "Segmentation" below)
  - Maintain calibration of pressure and temperature transmitters used for line pack calculations
- Timing of UAF events
  - Coordinate loss events to the correct day and time
  - Coordinate with operations to ensure all loss events are recorded

Segmentation

As a day-to-day practice, segmentation greatly simplifies a system by dividing it into smaller portions in which UAF losses can be more easily isolated. Segmentation reduces the number of meters that must be inspected when a loss is detected and helps with the detection of smaller-volume issues that can affect the balance.

It is up to the company to decide where to segment. A segment could be based on a length of pipe, a compressor station, state/province boundary, country, or any other logical entity. Each segment should include meters that are configured in locations that allow balancing, e.g., if the receipts are added up and the deliveries are subtracted, one should approach a zero balance.

A detailed segment balance relationship should be established for every gathering segment, processing plant balance, pipeline segment, and distribution segment. Where possible, companies should create balances that leverage field-to-sales, check-to-sales, or similar comparisons. Logical representations of the physical relationships of meters in a system enable companies to identify underlying issues when problems occur.

Identified relationships should include:

Inlets

- Physical receipt meters
- Storage withdrawal
- Plant receipt meters
- Pipeline interconnects

Outlets

- Physical delivery meters
- Storage injection
- Measured fuel
- Plant deliver meters
- Pipeline interconnects

- Unmeasured fuel
- Accounted-for gas to atmosphere
- Retrograde condensate
- Water/water vapor
- Delta line pack (±)

Accounting and reporting requirements, per segment, are as follows:

- Calculated and percentage UAF gas loss (volume, energy, and mass)
- Hourly, daily, and monthly station, segment, and balance summaries
- Station, segment, and balance summary-level validation
- Hourly, daily, and monthly meter-level validation
  - Contract quantities
  - Reasonable hourly, daily, and monthly quantities
  - Plunger lift wells

Ultimately, segmentation is only helpful when it is done properly. Segmentation metering should be installed and maintained as custody transfer-quality metering. Companies often terminate segments with non-custody transfer check meters. Due to the measurement uncertainty of such meters, this could defeat the purpose of segmentation. In addition, testing and sampling should follow the same procedures as custody transfer metering.

Metering Improvements

Meter inspection can considerably reduce the UAF loss for a company - and explain a "gain" or a "loss." Relative to meter inaccuracies affecting UAF, the following practices have proven to be effective:

- Verify orifice plates sizes and condition
- Minimize gauge line lengths (connecting flow elements to pressure transmitters)
- Maintain beta ratios within specified allowable limits
- Inspect meter tube(s)
- Validate certification of calibration equipment
- Ensure field understanding of test and calibration standard operating procedures
- Review all test and calibration reports for accuracy and process all required prior-period adjustments (PPAs)

It is also important to review field inspection, calibration, and verification reports to confirm they are being completed in accordance with SOPs and in a timely manner.

Additionally, the importance of a clean meter cannot be overemphasized (see Figure 2). Before meter cleaning, the reading difference between the meter shown and a downstream check meter was 0.5%. After cleaning, the difference was 0.03%.

Figure 2. Measurement Accuracy Improvements Resulting from Meter Tube and Flow Conditioner Cleaning

Additional common errors and mitigation processes include:

- Incorrect input/output coding:
    - Develop communication framework to verify meter coding
    - Consider meter-behind-meter scenarios, in which gas has already been accounted for by a preceding meter
    - Ensure the meter is properly accounted for in the correct pipeline segment through proper segmentation
- Data entry (keypunch) errors:
    - Utilize validation and exception reporting to identify errors
    - Utilize a master-data-level validation tool to identify field-related keypunch errors

Third-Party Measurement Improvements

Armed with up-to-date knowledge regarding how their own measurement processes affect UAF, team members can request audit information on third-party measurements and perform periodic witness tests on an ongoing basis.

Analysis/Quality Improvements

Traditional "back to basics" issues, like those for metering, focus on inspection, calibration, quality relationships, and validation:

- Ensure timely gas quality data through resources such as online chromatographs, daily chromatographs, monthly samples, and annual samples.
- Verify that continuous samplers are functioning properly.
- Address issues related to the meter pressure base, heating value pressure base, and proper coding of meters and their relationships to regional chromatographs to minimize the UAF impact.

Operators of shale gas systems and systems that balance a combination of natural gas and NGLs have recently encountered a variety of analysis and sampling issues. Among these are measuring and sampling of gas that is at the hydrocarbon dew point pressure and temperature and sampling non-stabilized liquids that are at their flash point.

- Follow the procedures described in the GPA Midstream standard GPA 2166 (titled "Obtaining Natural Gas Samples for Analysis by Gas Chromatography") for purging a natural gas sample cylinder for composite sampling.
- Use data validations on all analysis information, whether the data originate from a live chromatograph or laboratory sample analysis (for more on validations, see "Measurement Process Improvements" below).

Measurement Process Improvements

In response to evolving audit requirements resulting from the Sarbanes-Oxley Act of 2002 (SOX), the development of the second (2013) edition of Chapter 21.1 of the American Petroleum Institute (API) Manual of Petroleum Measurement Standards (MPMS) (titled "Flow Measurement Using Electronic Metering Systems - Section 1: Electronic Gas Measurement"), Chapter 21.2 of the API MPMS (titled "Flow Measurement Using Electronic Metering Systems - Section 2: Electronic Liquid Measurement"), and the Alberta Energy Regulator Directive 17 have helped North American gas companies make significant improvements to their measurement processes. Along the way, the companies have also identified and mitigated significant UAF losses.

Measurement application software is now able to compile metering and analysis information from widely varying sources, synchronize their timing, validate the information, recognize errors, and perform accurate recalculations. It can unify measurement processes that were previously never conducted in a coordinated manner.

Such applications allow measurement departments to:

- Improve measurement operating procedures (through inspection, calibration, verification, and scheduling of field tasks)
- Easily identify critical issues at the meter, station, segment, and system balance levels
- Resolve measurement issues prior to closing and eliminate PPAs
- Identify trends in transmitter, flow computer, primary device, and related equipment failures
- Apply a consistent validation approach throughout an organization
- Improve communication and resolution management between field and office staff

- Enhance identification understanding for field and office staff
- Provide timely and accurate information to customers in near real time
- Improve customer service

The applications allow for improvement across the measurement system of a company and incorporation of the following reporting processes into day-to-day procedures:

- Measurement system data
- Third-party reported volumes
- Processing plants
- System loss events
- Meter station operations
- Unaccounted-for gas volume reports
- Field verification of meter station data

Figure 3 depicts a modern software application environment containing the operational attributes described above, which enables integration of the measurement process.

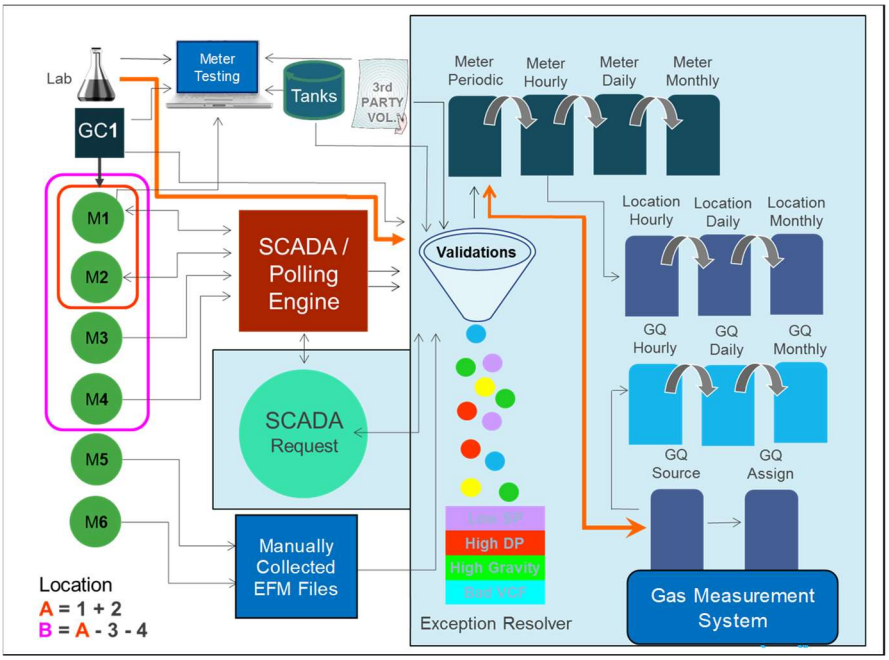

Figure 3. A Contemporary Software Application Environment Enables Integration of the Measurement Eco-system

Mass balancing is another balancing view capability that applies to systems that track multiple fluids. Operators of these systems have found that volumetric balancing is prone to under-reporting or entirely missing quantities of lighter hydrocarbons in the presence of heavier hydrocarbons. Mass balancing accurately accounts for light hydrocarbons, even in the presence of liquids.

Conclusions

Causes of UAF fall under a broad range of categories, including actual losses from leaks or theft, unreported internal use, system operation events, or timing and measurement errors.

To counter these challenges, the industry is using proven UAF mitigation techniques, employed in conjunction with new technology. Operators can more quickly pinpoint anomalies, improve the measurement process and improve system balancing. A continual focus on UAF identification and reduction at the segment level will allow users to vastly improve overall measurement integrity through on-going processes.