API *MPMS* Chapter 23.2
Reconciliation of Liquid Tank Car(s) Quantities
Third Edition

XXX 202X

Contents

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1. Scope

1.1 General

Provide methodologies and processes to monitor liquid tank car movements' quantity loss/gain ratios, levels, and performance of tank car measurement systems. The document is intended to assist the user to identify loss/gain of a tank car system under normal operating conditions.

Provides operational and statistically based tools for identifying when a system has deviated from normal, as defined by the operator, the magnitude of the deviation, and guidelines for identifying the causes of those variations. Trouble-shooting suggestions are also presented.

This document does not establish industry standards for loss/gain performance level range because each system has its own characteristics and exhibits its own loss/gain level range and/or patterns.

1.2 Field of Application

The primary application of this publication is in custody transfer measurement systems in which there is provision for measuring any liquid inventory used for reconciliation and all liquids that enter and exit the tank car.

The applications and examples in this document are intended primarily for custody transfer pipeline systems, but the principles may be applied to any system that involves the measurement of liquids into and out of the system and possibly inventory of liquids within the system. Such systems may include pipelines, marine terminals, marine voyages, bulk loading or storage terminals, tank farms, and rail and trucking systems.

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 3.1A, S*tandard Practice for the Manual Gauging of Petroleum and Petroleum Products*

API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 3.2, Standard Practice for Gauging Petroleum and Petroleum Products in Tank Cars

API MPMS Ch. 4.1, *Proving Systems*, Ch. 13.2, *Methods of Evaluating Meter Proving Data*, and Ch. 13.3 *Measurement Uncertainty*

API Manual of Petroleum Measurement Standards (MPS) Chapter 5, Metering (all relevant chapters)

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 7, *Temperature Determination* (all relevant chapters)

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 8, *Sampling* (all relevant chapters)

API Manual of Petroleum Measurement Standards (MPS) Chapter 11.1, Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils

API Manual Petroleum Measurement Standards (MPMS) Chapter 11.3.4, Miscellaneous Hydrocarbon Product Properties—Denatured Ethanol and Gasoline Component Blend Densities and Volume Correction Factors

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 12, *Calculation of Petroleum Quantities* (all relevant chapters)

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API Manual of Petroleum Measurement Standards (MPMS) Chapter 12.1.1, Calculation of Static Petroleum Quantities—Upright Cylindrical Tanks and Marine Vessels

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 12.1.2, *Calculation of Static Petroleum Quantities, Part 2—Calculation Procedures for Tank Cars*

API MPMS Ch. 12.2, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors.*

API Manual of Petroleum Measurement Standards (MPMS Chapter 12.3, Calculation of Volumetric Shrinkage Resulting from Blending Light Hydrocarbons with Crude Oil

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 13.2, *Methods of Evaluating Meter Proving Data*

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 13.3, *Measurement Uncertainty*

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 17.1, *Guidelines for Marine Inspection*

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 17.2, *Measurement of Cargoes on Board Tank Vessels*

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 17.4, *Method for Quantification of Small Volumes on Marine Vessels (OBQ/ROB)*

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 17.5, *Guidelines for Voyage Analysis and Reconciliation of Cargo Quantities*

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 17.6*, Guidelines for Determining Fullness of Pipelines Between Vessels and Shore Tanks*

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 17.10, *Measurement of Cargoes on Board Marine Gas Carriers* (all relevant chapters)

API Manual of Petroleum Measurement Standards (MPMS) Chapter 19, Evaporation Loss Measurement (all relevant chapters)

Association of American Railroads AAR [1] *Scale Handbook*

GPA Midstream Guideline PFPDM-23, *Guidelines for Pipeline Fill, Pack, and Determination Methodology* National Institute of Standards and Technology NIST [2] *Handbook 44*

3 Terms and Definitions

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[1] Association of American Railroads, 425 3rd Street, SW, Washington, DC 20024, www.aar.org.
[2] National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD, www.nist.gov.

For the purposes of this document, the following terms and definitions apply.

3.1

action limits
Control limits applied to a control chart or log to indicate when action is necessary to inspect or calibrate equipment and possibly issue a correction ticket. Action limits are normally based on 95 percent to 99 percent confidence levels for statistical uncertainty analyses of the group of measurements.
central mean value.

3.2
control chart
A graphical method for evaluating whether meter proving operations are in or out of a state of statistical control.

3.3
control chart or log of fixed limit
A control chart or log whose control limits are based on adopted fixed values applicable to the statistical measurements displayed on the log or chart. Historically, fixed limits have been used to control the limits on meter factor changes.

3.4
control limits
Limits applied to a control chart or log to indicate the need for action and/or whether or not data is in a state of statistical control. Several control limits can be applied to a single control chart or log to determine when various levels of action are warranted. Terms used to describe various control limits are "warning," "action," and "tolerance" limits.

3.5
repeatability
A measure of the agreement between the results of successive measurements of the same variable carried out by the same method, with the same instrument, at the same location, and within a short period of time.

3.8

standard deviation
The root mean square deviation of the observed value from the average.

3.9
statistical control
The data on a control chart are in a state of statistical control if the data hover in a random fashion around a central mean value, and at least 99 % of the data are within the three standard deviation control limits, and the data do not exhibit any trends with time.

3.10
systems tolerance limits
Control limits that define the extremes or conformance boundaries for variations to indicate when an audit or technical review of the facility design, operating variables, and/or computations may need to be conducted to determine sources of errors and changes that may be required to reduce variations. Tolerance limits are normally based on 99 % or greater confidence levels and are used interchangeably with upper and lower control limits (UCLs and LCLs, respectively).

3.11
three standard deviation limit
A control limit equal to three standard deviations from the arithmetic mean of the set.

3.12
transloading
The transfer of a liquid hydrocarbon commodity from one bulk carrier to another bulk carrier where the quantity and quality transferred is measured via a measurement system.

3.13
warning limits
Control limits applied to a control chart or log to indicate when meter proving equipment, operating conditions, or computations should be checked because meter factors are outside pre-established limits. Warning limits are

normally based on 90 to 95 percent confidence levels for assessing statistical uncertainty in the group of measurements.

4 Measurement Data Analysis

4.1 General

Data may be presented in the form of control charts, trending charts, or cumulative charts. Guidelines on such charts may include control limits and trending lines. Charts used for monitoring measurement systems should be living documents and should be updated whenever new data is available.

Accumulating data for some period of time and periodically updating charts (e.g. semiannually) serves no useful purpose. Charts and monitoring procedures can be effective only if charts are current and used as constructive tools.

4.2 Loss/Gain Analysis

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Losses and gains can be real (e.g., leaks, evaporation, theft, shrinkage, or when unmeasured or unaccounted liquid is removed or added to the system) or apparent (e.g., errors in measurement, tickets, or procedures). Often, there is no physical loss/gain, just measurement inaccuracies or accounting discrepancies. The combination of these may result in a system being outside of normal or acceptable limits.

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Loss/gain analysis typically involves collecting data, calculating loss/gain, and plotting loss/gain on any of several different types of charts. These charts may include control limits or other analytical guides that are derived from some simple statistical tools as per the equations described in the following sections. The tools described in this document may be used by anyone and do not require an understanding of statistics.

Loss/gain may be reported in units of volume (e.g. gallons or kiloliters) or mass (e.g. lb or metric tons).

The two basic loss/gain equations (not all inclusive) are shown below. One expresses a loss as a negative value and the other expresses the loss as a positive value. Other loss/gain equations are in common usage.[1]

It is important to keep in mind which convention is being used to correctly decide whether the loss/gain values represent losses or gains.

Loss expressed as a negative number can be calculated with Equation 1:

$$L / G = (D - R) + (CI - OI)$$

where,

CI is the closing inventory in the system at the end of the time period, *D* is the sum of deliveries out of the system during the time period, *OI* is the opening inventory in the system at the start of the period,

R is the sum of receipts into the system during the time period, and Loss expressed as a positive number can be calculated with Equation 2:

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$$L / G = (R - D) + (OI - CI)$$

(1)

If only an absolute value for loss/gain is necessary to express relative distance of the variance from zero, it can be calculated as shown in Equation 3:

[1] For example, EI HM32 uses the following equations:

Opening Inventory + Receipts – Deliveries = Book Stock
Loss or gain can be obtained from: Physical Inventory – Book Stock = Loss or Gain.

By convention, gains are positive and losses are negative.

$$L/G = |(CI + D) - (OI + R)| \tag{3}$$

System Gain: If (*CI* + *D*) > (*OI* + *R*) System Loss: If (*OI* + *R*) > (*CI* + *D*)

In such case, loss/gain is always an absolute value.L/G

When expressed in percent, the actual loss/gain quantity is divided by the quantity of total receipts for a receipt-based system or by the quantity of total deliveries for a delivery-based system and multiplied by 100. Receipt based systems typically have consistent receipt volumes and delivery-based systems typically have consistent delivery volumes.

For Receipt-based systems, see Equation 4:

$$L/G\ \% = (L/G \div R) \times 100 \tag{4}$$

For Delivery-based systems, see Equation 5:

$$L/G\ \% = (L/G \div D) \times 100 \tag{5}$$

For Average-based systems, see Equation 6:

$$L/G\ \% = \left(L/G \div \left(\frac{(R+D)}{2}\right)\right) \times 100 \tag{6}$$

In the equations above, variables shall be expressed in like units of measure. Variables calculated under the same conditions (mass, or gross standard volume [GSV] and net standard volume [NSV]), yield the most meaningful information.

NOTE Refer to API MPMS Ch. 12.1.1, *Calculation of Static Petroleum Quantities, Part 1—Upright Cylindrical Tanks and Marine Vessels*, Ch. 12.1.2, *Calculation of Static Petroleum Quantities, Part 2—Calculation Procedures for Tank Cars*, and Ch. 12.2, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors*.

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4.2.2 Factors to account for in the loss/gain equations

4.2.2.1 Change in line fill quantity conditions

Line fill volume may be considered static but depending on the conditions of the line fill it may impact apparent loss/gain.

Change in line fill volume may contribute significantly to system inventory. Pipelines should be completely empty or completely full at the beginning and end of the time period. If possible, line fill should be corrected for current conditions, including temperature, pressure and density.

NOTE 1 Refer to equations for the effect of pressure on steel of pipe (CPS), and for the effect of temperature on steel of pipe (CTS) listed in *API MPMS Chapter 12.2, Section 9.5*

NOTE 3 For additional information on line fill, refer to GPA Midstream Guideline PFPDM-23, *Guidelines for Pipeline Fill, Pack, and Determination Methodology*

4.2.2.2 Additional factors to account for in the loss/gain equations

Several additional factors may impact loss / gain equations, including:

— Cavern inventory (generally salt caverns are not included in loss/gain systems)

— Line fill volume may change due to a project or maintenance work

— Slack line

NOTE See API MPMS Chapter 17.6, *Guidelines for Determining the Fullness of Pipelines Between Marine Vessels and Shore Facilities*, for determination of pipeline fullness

4.2.2.3 Custody meter and tank transfer tickets

Perhaps the most common errors occurring on manually calculated measurement tickets are arithmetic errors and wrong correction factors applied.

Tickets that do not get into the accounting process on time will cause an apparent loss/gain in the current accounting period and an offsetting gain or loss in the following period.

4.2.2.4 Sump tanks

Sumps collect drips and drains from several sources and may add a bias to a system loss/gain if the sumps are emptied by pumping into a pipeline system without being measured. Usually, sump volumes are small enough to not impact the overall loss/gain for the system. However, the volumes may be significant if sumps accumulate large volumes, such as frequent drain downs from provers or pig traps.

4.2.2.5 Unmeasured Volumes

Factors to consider when unmetered volumes are present in the system or are estimated:

— Pipeline relief events and/or unmetered product flaring

— Pigging

— Line emptying

— Project work

— Chemical Additive injection

— Theft

— Tank evaporation

— Product growth or shrinkage

NOTE See API MPMS Ch. 12.3, *Volumetric Shrinkage Resulting from Blending Light Hydrocarbons With Crude Oils*

4.3 Control Charts

4.3.2 General

4.3.1.1 Once the reconciliation of the system (or a part of the system) is complete, its results shall be compared to the criteria and limits established by the operator. If the system's loss/gain meets the established criteria, and there are no known issues associated with the system's performance during the timeframe being evaluated, then no further action may be required. It is a good practice to always develop control charts to conduct further data analysis to ensure that all components of the system were in control, and no special cause variations were present, which could mask a potential issue with either equipment or processes. Detailed analysis (segmenting system into smaller segments) may be desirable on the complex systems with multiple inlets and outlets and with multiple parties in the system. The overall loss/gain may stay well within the acceptable limits, but some segments can show larger variances which can seriously affect the involved parties.

4.3.1.2 If the system's loss/gain is found outside of the established criteria, then further data analysis and investigation of the excessive variances should be conducted. Various control charts and other troubleshooting tools and techniques included in this document can help operator to identify the cause of the problem and work on necessary corrections.

NOTE See *Section 5* and *Annex A* for troubleshooting suggestions and techniques.

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4.3.1.3 To ensure accurate measurement, it's essential to continuously monitor measurement results to determine if systems, or equipment and procedures, perform as expected and operate within acceptable limits. Utilizing control charts can facilitate this process.

4.3.1.4 Control limits are often determined by historical performance of the system. In other cases, the control limits are set on an established value (e.g., contractual limits). Due to inherent issues (built in biases, e.g.) with both of those models, consideration should be given to establishing control limits based on the capabilities of the equipment in the loss/gain system. Statistical analysis of the uncertainties of the measurement equipment (i.e., meters, prover, e.g.) and procedures (verification/calibration frequencies, tolerances, e.g.) can also be utilized to establish control limits.

4.3.3 Evaluation of System Performance with Control Charts

4.3.2.1 Control charts are the most common method of ascertaining system loss/gain performance. Control charts display a collection of data over some period of time and include the control limits. Control charts help to define normal trends of a system and may indicate when something has changed. Typical loss/gain charts, as shown in Figure 1, indicate a system's performance based on a percentage of throughputs over time. Typically, because accounting systems encompass a 30-day period, monthly evaluations of a system are commonly used to evaluate performance. Control charts may be prepared for any time span (e.g., weekly or daily) if adequate data are available.

4.3.2.2 Control charts may be maintained for entire systems or for individual segments of a system if measurement and records are available at the junctures of segments. The limits of the control charts will depend on the accuracy of the available measurement systems.

4.3.2.3 The data on control charts should remain near or around a target value and can be represented by a horizontal line on the chart. This target value is generally based on the anticipated or expected loss/gain of the system (typically at or near 0 %). The control chart also includes UCLs and LCLs that may be:

1. Defined statistically as two and three standard deviations above and below the target value or
2. Defined as engineering, historical or contractual limits, which are values based on experience or performance objectives

4.3.2.4 Standard deviation is a statistical measure of the spread of a data set with respect to the mean value of the set the specific number of deviations as determined by the user(s).

Figure 1 shows the example of a typical control chart.

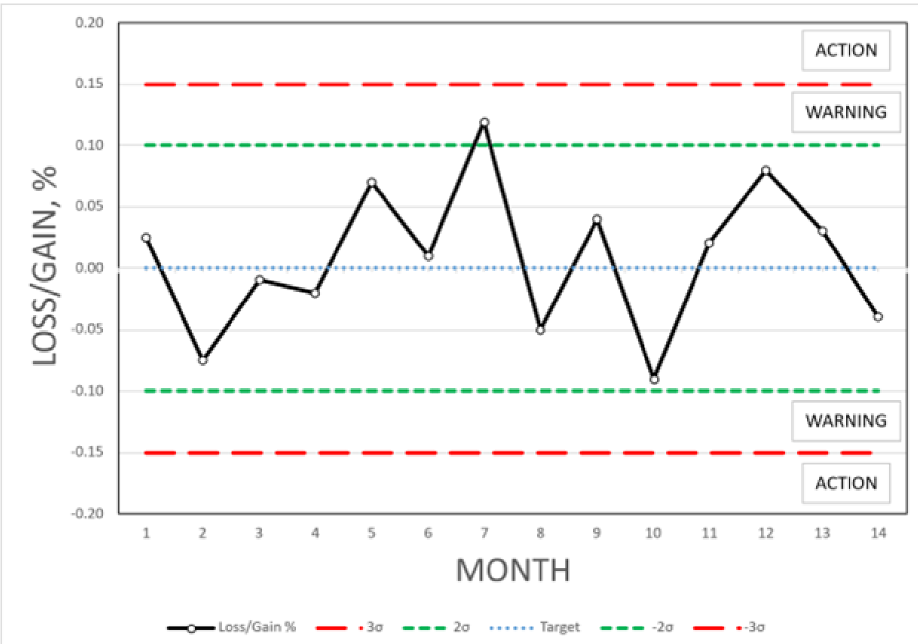

Figure 1 – Sample Control Chart

4.3.2.5 The data collected is plotted in a control charts to compare the actual versus the expected system performance. The data trends and the control chart limits can be used to predict near-future performance. Any data point that is known to be the result of a special cause should be shown on the control chart but should not be included in the calculation of target, standard deviation, or control limits, and the number of data points shall be adjusted accordingly. A special cause is an event (e.g., meter failure, late run ticket, line displacement with water for hydrostatic pressure test) that results in mismeasurement for a given period of time but is not a part of the normal operation of the system.

4.3.2.6 Charts can be used to determine system stability, cyclical trends, or step changes in performance. One of the most important benefits of using charts to assess performance is the instant visual representation it provides.

4.3.2.7 The adage "a picture paints a thousand words" best summarizes the effectiveness of control charting.

4.4 Pipeline System Control Charts

4.4.1 A useful tool for monitoring pipeline systems is the control chart that shows loss/gain as percent of throughput over time. Total receipts are used for throughput in receipt-based systems, and total deliveries are used for delivery-based systems.

4.4.2 For historical performance-based control limits to be statistically significant, a minimum of 30 data points is required. For practical purposes, control limits for a pipeline system that is monitored monthly will often be based on monthly loss/gain data. For our purposes, the 24 data points are acceptable. It is common practice to set limits at the beginning of each calendar year based on the prior history. These limits are carried forward for the calendar year unless there is a change in the process that would require new limits. Until enough data is collected to establish historically performance-based control limits, reasonable control limits should be established and applied by the system operator.

NOTE When calculating limits based on historical data, pay careful consideration to outliers. Outliers are data points that are notably different from other data points, and they can cause problems in statistical procedures. There are several statistical outlier tests that can be used to remove biases caused by outliers.

4.4.3 Setting fixed limits for loss/gain, without regard to actual data, may be required for contractual reasons. Whenever possible, it is more practical to set limits based on historical data. Care should be taken to avoid bias conditions or outliers affecting the control limit calculations. A pipeline system tends to operate at a level of performance that is dictated by, but not limited to, physical configuration, equipment, procedures, maintenance practices, environmental conditions, and employee training. All these factors combine to produce a natural randomness and, sometimes, a natural bias in a system. For systems that have other constraints, it may be desirable to include a second set of limits.

Figure 2 shows the loss/gain data for two years. This data may be used to set control limits for the following year.

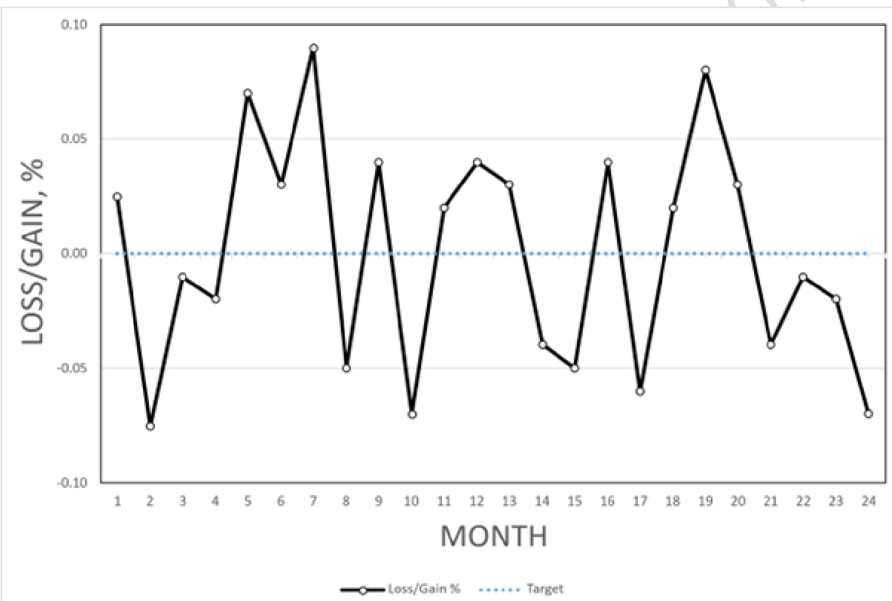

Figure 2 – Two Years of Data for Control Limits

Figure 3 shows the first three-month data compared with the two-year historical control limits.

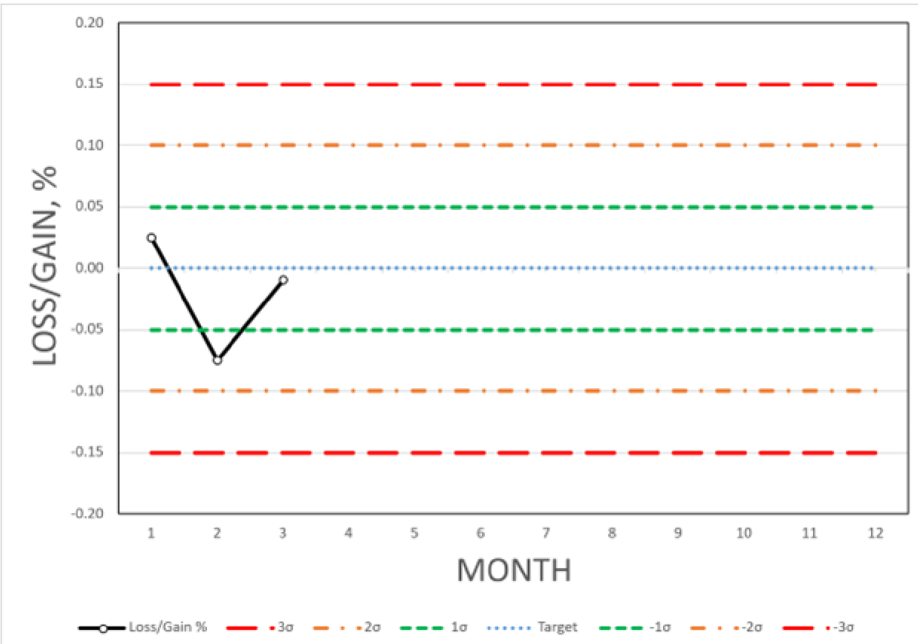

Figure 3 – Control Chart for the Following Year

4.4.4 Users should determine whether a system is stable and in control. A system is said to be stable if the data exhibit only random fluctuations around the mean without trends. A system is generally considered to be in control if the data are all within control limits that have been established from the data. Data points outside the control range indicate poor control.

4.4.5 When physical or operational changes are made to a system, the loss/gain pattern for the system change. When this happens, the prior two-year history may not be suitable for setting the control limits. In such cases, a moving range chart may be used until sufficient history is developed to define the system's new pattern. In a moving range chart, the mean and standard deviation are recalculated each time new data are available using all data since the change. The resulting mean and control limit lines on the control chart may exhibit an immediate step change to a new level of control or may change gradually for some period of time until the system stabilizes at a new level of control.

4.5 Meter Factor Control Charts

4.5.1 Control charts can be used for tracking various parameters. Control charts that monitor meter performance will have meter factor plotted as a function of either time or volume throughput.

NOTE For additional guidance on uncertainties in meter data, see API MPMS Ch. 13.2, *Methods of Evaluating Meter Proving Data*.

4.6 Trending Charts

4.6.1 Trending charts may be used when data exhibit a definite upward or downward trend and may not hover around a simple horizontal mean value. Such charts may be shown as a trending run chart merely to show a trend in the data or may resemble a control chart with lines representing average performance (similar to "mean") and control limits that follow the upward or downward trend of the data.

4.6.2 12-month rolling average charts are often trending charts that can assist in identifying process issues as shown in Figure 4. 12-month rolling average control chart tolerance should be tighter than monthly control charts because normal monthly fluctuations should smooth out over a 12-month period. As shown in Figure 4, the 12-month tolerances are 50% of the monthly tolerances.

4.6.3 The calculation of the 12-month rolling average is not the average of the loss/gain % averaged over the previous 12 months. Depending on whether the system is receipt-based, delivery-based or average-based, it is calculated as follows in Equation 9:

$$\text{12-month average \%} = \left(\frac{\sum \text{last 12-months } \frac{L}{G} \text{ volume}}{\sum \text{last 12-months (receipts, deliveries, or average)}} \right) \times 100 \tag{9}$$

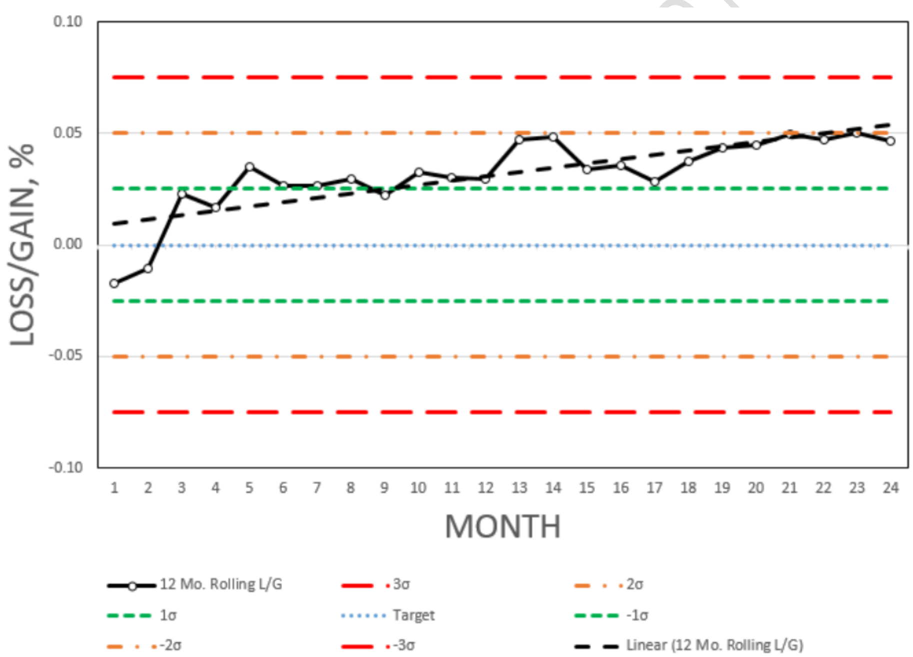

Figure 4 – 12 month Rolling Average

4.7 Cumulative Charts

4.7.1 Cumulative charts are similar to trending charts but plot the cumulative values of some variable such as loss/gain vs time. The cumulative value is obtained by arithmetically (i.e., keeping the plus and minus signs) adding the value of each data point to the sum of all the data points preceding it in a sequence of data.

4.7.2 The data in cumulative charts do not hover around a central mean value. They exhibit an upward or downward trend. The shape of the curve is the main characteristic of cumulative charts, and changes in shape or general trend are very important.

4.7.3 Loss/gain data may be plotted on cumulative charts. In Figure 5, the loss/gain quantities are measured in barrels, but other volume or mass quantities may be used as appropriate.

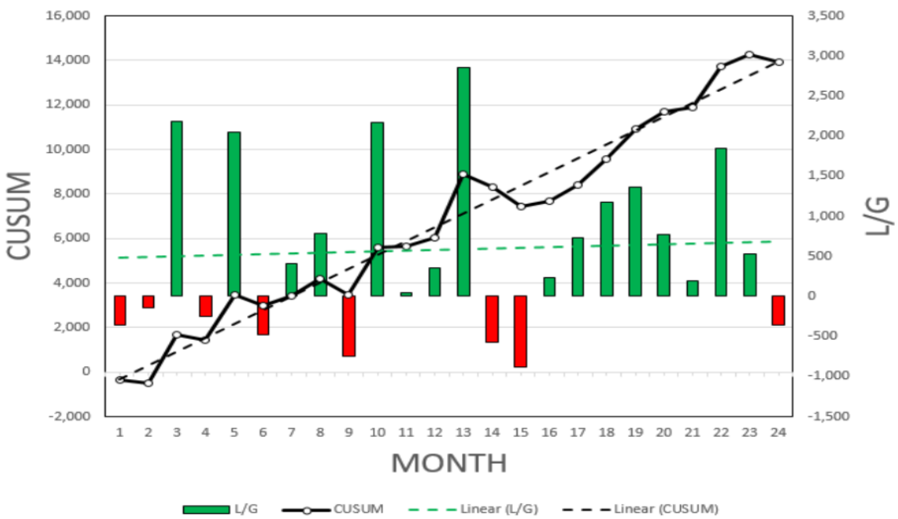

Figure 5 – Cumulative Chart – CUSUM vs Loss/Gain

4.7.4 Cumulative loss/gain charts can be informative to the practiced eye. They often indicate the onset of a trend before it is evident on a conventional control chart. A system that is performing normally will generally exhibit a steady trend. A sudden shift in the pattern or a definite change in the rate of trend (change in general slope of the data) usually indicates that something abnormal happened.

4.7.5 The cumulative chart can also be useful for visually demonstrating the quality of sediment and water (S&W) measurement in a crude liquid system by plotting GSV and NSV on the same chart as shown in Figure 6. In this chart, the first eight months are typical of a system with consistent S&W measurement. The NSV line may be a bit below the GSV. However, if the two lines are close together and essentially parallel, S&W measurement is consistent and uniform. If, on the other hand, the two lines diverge, as shown during the last eight months in Figure 6, S&W measurement is not consistent and/or is not uniform. This could signal an opportunity to improve S&W measurement in the system. Figure 6 depicts a potential issue with the delivery S&W measurement and Figure 7 depicts a potential issue with the receipt S&W measurement.

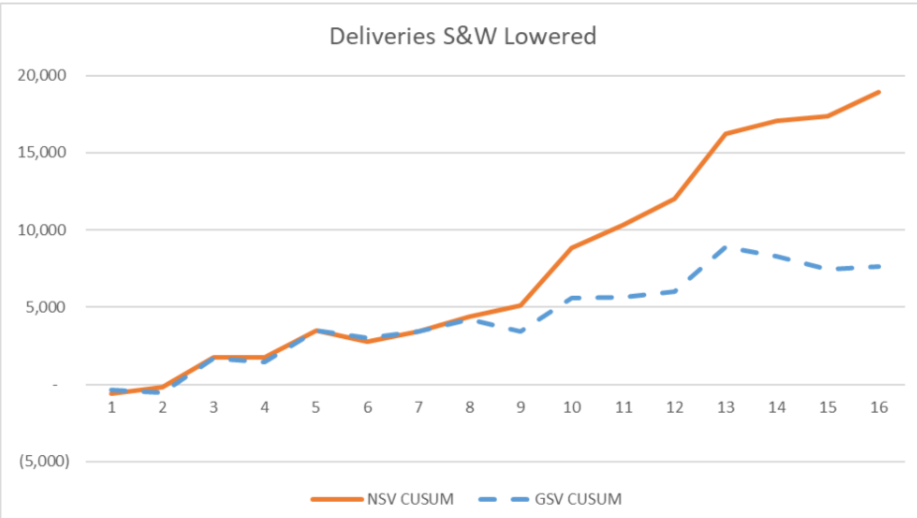

Figure 6 – Example 1 of Cumulative NSV and GSV

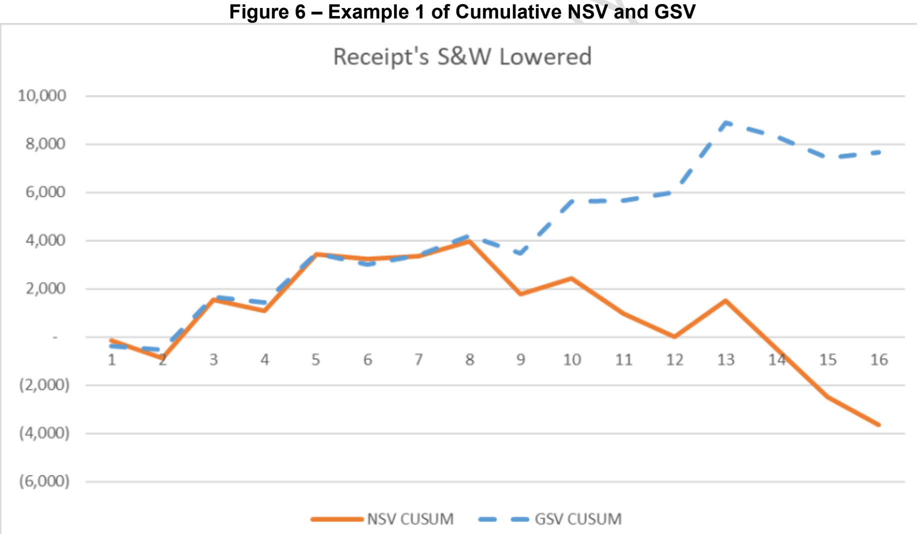

Figure 7 – Example 2 of Cumulative NSV and GSV

4.7.6 Uncertainty in S&W results can be caused by sampling equipment type and installation, frequency of sampling, stream mixing ahead of the sampler, withdrawing the laboratory portion of sample from the field sample container, maintaining the integrity of the sample between the field and the laboratory, handling and remixing in the laboratory, and the S&W measurement process. Variability at any stage of the process can lead to an incorrect result. Individual companies may set acceptable tolerances based on experience for use in their operations.

5 Troubleshooting

5.1 General

Whenever loss/gain exceeds established limits, an investigation should be initiated to determine the cause and whether adjustments are required to bring a system into balance. Troubleshooting liquid tank car losses involves an understanding of the loss/gain process and may require collecting and analyzing data, interviewing personnel, and visiting facilities to assess equipment performance and witness measurement activities. Ultimately, loss/gain investigations should include a conclusion of the findings along with recommendations for corrections and improvements (see Annex A, Troubleshooting Guides for Measurement Operations).

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5.2 The Troubleshooting Process

5.2.1 Analyzing Measurement Data

The first step in identifying loss/gain requires a review of the measurement data. Amount of tolerance loss/gain result may indicate a system is out of tolerance. Start by carefully reviewing the report and ensure that the data is accurate and timely. Computer-generated reports are only as good as the data entered. It is important to first understand the data entry process and then the integrity of the data used to populate the report.

With the increasing number of automatic data acquisition and processing tools and options, the data validation is an extremely important step of each reconciliation process. The risks associated with data manipulation, built-in biases and errors shall be recognized. All tools and systems from the source through the final report should be validated and included into the troubleshooting process.

5.2.2 Sources of Errors or Variances for Consideration

Custody measurement records such as manual gauge, meter measurement, proving reports, scale tickets, and meter performance logs (but not limited to these items listed) should be obtained and reviewed. Reviewing measurement calculations is one method of checking for measurement errors. Often, human error, equipment failure, or software errors can quickly be identified.

Reviewing records and historical data is of key importance. Look for patterns, often hidden among the noise caused by large month-to-month variations. Look for step changes linked to operational changes at the facility. There are many possible operational changes that can affect reported losses. Some items that should be investigated are as follows but not limited to:

- personnel,
- procedures,
  - facility operating conditions,
  - pigging operations,
  - variables associated with DRA injection,
  - product flaring, vaporization, or vapor recovery,
  - evaporation,
  - software/calculations,
  - missing data (e.g., run tickets),
  - weather conditions,
- security, data security
- physical or data theft

5.2.3 Interviewing Personnel

The best method of identifying change is by interviewing the personnel responsible for the system(s) and data. This includes the measurement technician, gauger, or operator, as well as the electrical and mechanical technicians performing work at the sites. The key to obtaining useful information from field personnel is to establish a dialogue that is nonconfrontational. Sharing ownership of the problem, as well as the credit for the resolution, is often the best approach.

5.2.4 Facility

Another step in the process involves a visit to the facilities to review the equipment and the measurement procedures. Determine if the proper procedures are being followed in accordance with company and industry guidelines. Observe piping details, equipment placement, and other visual records that may be indicators to or influence the measurement performance.

5.3 Inaccuracies and Uncertainties

Many everyday things can cause inaccuracy or uncertainty in measurement and contribute to loss/gain in a system.

When a measurement of a quantity, the result that we obtain is not the actual true value of the quantity but only an estimate of the value. This is because no instrument is perfect; there will always be a margin of doubt about the result of any measurement. The uncertainty of a measurement is the size of this margin of doubt.

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To fully express the result of a measurement, the following three numbers are required.

1) The measured value. This is the figure indicated on the measuring instrument.
2) The uncertainty of the measurement. This is the margin or interval around the indicated value inside which you would expect the true value to lie with a given confidence level.
3) The level of confidence attached to the uncertainty. This is a measure of the likelihood that the true value of a measurement lies in the defined uncertainty interval. In industry, the confidence level is usually set at 95 %.

Often the terms "inaccuracy" and "uncertainty" are confused and used interchangeably. As provided above, uncertainty is the margin of doubt associated with a measurement. Inaccuracy (or error) is the difference between the measured value and the true value.

5.4 Meters and Meter Proving

The overall performance of measurement by a meter depends on the condition of the meter and its tertiary devices, the temperature and pressure corrections, the proving system, the frequency of proving, and the variations between operating and proving conditions. These are a few, but not conclusive, conditions and factors for consideration when investigating loss/gain variances. For further details, see all relevant sections of API *MPMS* Ch. 5.

Users shall refer to API MPMS Ch. 4.1, *Proving Systems*, Ch. 13.2, *Methods of Evaluating Meter Proving Data*, and Ch. 13.3 *Measurement Uncertainty*, for the uncertainties of Flow Metering and Meter Proving as appropriate.

NOTE Refer to Annex A of this chapter, Troubleshooting Guides for Measurement Operations

5.5 Tanks

The physical closing tank gauge reading from the previous period should match the physical opening tank gauge reading for the current period.

Tanks that are gauged for inventory and that are active at the time of gauging should be allowed to rest long enough to be gauged without liquid moving in or out.

Accurate month-end inventory gauges are especially important because they are used to balance and close out pipeline and/or terminal inventories and to issue customer and billing reports.

Multiple customers may share the same storage in a fungible tank, and loss/gain offsets from month to month can be difficult to allocate.

Users shall refer to API MPMS Ch. 3.1A, *Standard Practice for the Manual Gauging of Petroleum and Petroleum Products*, for information on uncertainties relating to tank measurement.

NOTE Refer to Annex A of this chapter, *Troubleshooting Guides for Measurement Operations*

5.6 Scales

Measurement systems used during the loading or unloading of rail tank cars should be consistent with, ASTM, GPA, NIST, Handbook 44, AAR Scale Handbook Standards, or other recognized regulatory bodies governing commercial and industrial scales.

5.7 Tank Car and Truck

5.7.1 General

Tank car gauging may consist of four measurements: liquid level, pressure, temperature, and density. Liquid levels are determined via outage or innage measurements. Temperature is determined via traceable measurement devices in contact with the liquid product or using thermowells. Pressure is determined via traceable measurement devices through available connections on the tank cars and trucks and the sample for density should be representative of the tank car after isolation from process piping.

5.7.2 Liquid Level Determination

5.7.2.1 General Purpose Cars and Trucks

Once the car is loaded, a gauge shall be taken at the reference gauge point. The reference gauge point is defined in API *MPMS* Ch. 3.2. The contents shall be allowed to cease motion before the gauge is taken, as any motion can result in an inaccurate volume of liquid measured. Liquid-level measurement shall be taken at the same time the temperature (and pressure if applicable) is obtained. The various types of gauging are discussed in API *MPMS* Ch. 3.2 and 12.1.2. Two percent markers are not measurement devices. Sampling shall follow API *MPMS* Ch. 8.1 or 8.2.

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5.7.2.2 Pressure Cars and Trucks

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Pressure cars have a secured hatch that usually contains thermowells, magnetic float gauges, and loading valves permanently installed. Gauges are taken from an installed magnetic float gauge. This gauge only indicates outages. Magnetic float gauges are designed for service with a specific car and a specific product. When the reference density cannot be ascertained visually, the manufacturer shall be contacted to determine the reference density. An outage offset may have to be calculated if the gauge's reference density is different from that of the product. Refer to API *MPMS* Ch. 12.1.2 for further details.

5.7.3 Temperature Determination

Temperature determination errors may cause measurement inaccuracies. Information regarding thermometer/temperature device or temperature determination uncertainties such as (but not inclusive) device not fully stabilized, improper location (away from midpoint), device out of calibration, inadequate liquid in thermowell, liquid in glass separation, or weak battery in electronic thermometer shall be verified. Refer to API *MPMS* Ch. 7 for additional information and guidance on temperature determination.

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Temperature measurement is used to correct for liquid volume and the tank car shell expansion, using CTL (correction, temperature, liquid) and CTS (correction, temperature, steel) values. The CTL calculation requires an input of degrees; refer to API *MPMS* Ch. 11.1 and Ch. 12.1.2. Errors in temperature determination can affect the CTL calculation. For reconciliation purposes, consistent temperature compensation methods should be used at the loading and unloading facilities.

5.7.4 Pressure Determination

Pressure shall be measured at a point that is representative of the pressure of the vapor space of the car. Measuring pressure below the liquid/vapor line adds positive bias in the calculation due to head pressure. Refer to API *MPMS* 17.10.

Pressure measurement is used to correct for liquid compressibility and the tank car shell expansion, using CPL (correction, pressure, liquid) and CPS (correction, pressure, steel) values. The CPL calculation requires an input of pounds per square inch gauge, refer to API *MPMS* Ch. 11.1 and Ch. 12.1.2. Errors in atmospheric pressure determination will affect the CPL calculation. For reconciliation purposes, consistent pressure compensation methods should be used at the loading and unloading facilities.

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5.7.5 Tank Car and Truck Capacity Table

Measurements taken shall be aligned with the type of capacity table used. Refer to (API *MPMS* Ch. 3.2) to determine the liquid or vapor volume in the tank car using capacity tables. The capacity table maximum volume is used to determine the correction table adjustment factor (CTAF), which is applied to quantity calculation (API *MPMS* Ch. 12.1.2).

5.7.6 Volume Corrections

Volume corrections shall be applied to the liquid and tank car shell, which are affected by temperature and pressure. Refer to (API *MPMS* Ch. 12.1.2). The properties of the liquid, characteristics of the tank car (material and insulation type), and the tank car volume shall be known to accurately determine such correction factors.

5.8 Heel Measurement

Measurement of small quantities, including onboard quantity (OBQ) and remaining onboard (ROB), on board tank car(s) and truck(s) are performed in the same manner as that of gauging liquid levels or by use of weigh scales. Small quantities may not be detectable and are subject to being measured incorrectly by manual gauging methods due to various conditions, including clingage/bottoms, tank car or truck design, gauge locations, e.g. Fixed slip-tube and magnetic measurement equipment does not measure free water and liquid level if the liquid levels fall beyond the device's measurement range. Additionally, the temperature measurements of small onboard quantities may not be determined by use of thermometer wells when the wells do not fully extend into the lower portion of the tank car. These are a few, but not conclusive, conditions and factors for consideration when investigating loss/gain variances. Heel measurements performed, may exhibit measurement uncertainty.

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These measurement uncertainties as related to manual, automatic, and weigh scale measurements can include improper system design, installation, maintenance, operation, testing, and procedures. Identifying such measurement uncertainties to aid in the quantity/quality reconciliation process shall be made using the latest editions of API *MPMS* Ch. 3.2, 12.1.2, 17.2, 17.4, and 17.10 and AAR *Scale Handbook*, NIST *Handbook 44*, as applicable, or an equivalent standards body.

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5.9 Transloading Measurement

Transloading operations can be done utilizing meter or manual measurements. Depending on which method(s) used will determine the measurement uncertainties when performing the reconciliation.

Transloading metering systems use many of the same components associated with loading; there are some special considerations that need to be addressed for proper measurement. The typical components of a transloading system are a meter, a pump, an air eliminator, strainers, check valves, and proving connections. This system may be a permanent installation or portable. When a portable system is used, it is important to mitigate any system interference; the metering device's principle of operation should be considered.

Note: For manual measurements regarding transloading, refer to section 5.8.1.

Measurement equipment and processes exhibit measurement uncertainty. These measurement uncertainties as related to transloading measurements may include improper design, installation, maintenance, operation, and testing. Identifying such measurement uncertainties to aid in the quantity/quality reconciliation process shall be made using the applicable API standards, including API *MPMS* Ch. 6.2A or an equivalent standards body for verifying measurement equipment certification, calibration, maintenance, operation, and testing. In addition, if truck and tank car loading or offloading for high vapor pressure products are equipped with vapor equalization lines to the supply or receiving vessel(s) or vapor recovery systems, the vapor volumes should be measured and accounted for in the final reconciliation.

5.10 Quality Determination

The shipment of liquid commodities may result in quality differences between the load and discharge facilities. These quality differences may be caused by several factors as related to load and discharge facilities. Evaluating individual steps that comprise the product mixing, sample extraction and collection, sample handling and remixing, and sample analysis processes may identify the cause(s) of the quality differences. Use of inaccurate quality data such as density, water, may result in error in the quantity determined.

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To reconcile this error, this standard along with relevant API, ASTM, and GPA procedures shall be used. User should be aware that different testing and sampling methods used may yield different results.

Considerations should be given to determine the nature and quantities of material in the transfer line piping system. When line contents are questionable or when the possibility of product contamination exists, line samples should be collected and tested to verify compatibility with the product that will be transferred. Alternatively, transfer system line contents may be loaded into one cargo compartment (rail car, truck, vessel) to be gauged, sampled, and tested. Special care should be taken to determine a sampling point as line samples may not be representative due to sample location limitations.

5.11 Line Condition

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Line conditions may cause gains, losses, and differences if not properly verified and accounted for. These differences, gains, or losses may be caused by the line conditions that are not properly verified or reconciled both before and after the transfer.

Considerations should also be given to determine the condition of the transfer system line(s) (see API *MPMS* Ch. 17.6) before and after transfer, recording the method used for line verification, the line condition, and the total capacity of the transfer system piping used

5.12 System Controls

5.13 General

The shipment of liquid commodities by rail tank cars may result in volume or mass differences between the loading receipt point and the unloading delivery point quantities. These differences can be caused by physical or apparent loss/gains that can occur, as shown in Figure 17, during

1) loading from tanks or transloading from trucks or vessels to rail cars;
2) in transit; and
3) unloading to tanks or transloading from rail cars to trucks or vessels.

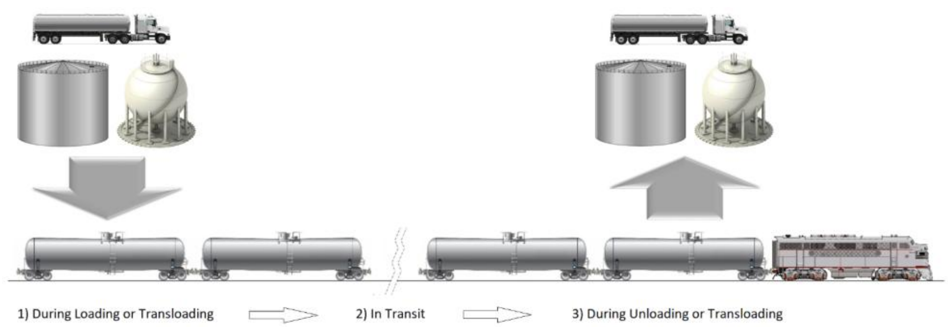

Figure 17—Points in Which Gains or Losses Can Occur

5.13.1 Physical Gains or Losses

Physical gains or losses are differences in product quantity and/or quality that are related to an actual physical loss/gain. These differences may be the result of one or more of the following factors.

a) **Evaporation:** A real source of loss is evaporation and venting. The empty space in a tank above a volatile liquid, such as gasoline, is filled with varying concentrations of vapor from the liquid. When the contents of the vapor space are expelled from the tank during filling of the tank or diurnal breathing, the vapors in the expelled air are lost. Refer to API *MPMS* Ch. 19.

   Tank evaporation losses can be minimized by using floating roof tanks, which eliminate the air space above the liquid contents of a tank, or by connecting the roof vents of cone roof tanks to a vapor recovery system. Some states require evaporation loss prevention to reduce air pollution. Tank car evaporation losses can be minimized by using properly maintained tank car dome lid seals, along with minimizing time dome lids are open during operations and/or measurement processes.

b) **Volume Growth or Shrinkage:** While physical mass gain is not possible, some products with the ability to absorb water or to blend with other components or additives may show some volumetric gain or loss. Blending gasoline with ethanol produces an endothermic reaction that simultaneously reduces the temperature and produces a slight volumetric increase. Refer to API *MPMS* Ch. 11.3.4. Depending on how the blending and measurement equipment is arranged at the loading terminal, this volumetric increase may be measured or not, but the growth may continue occurring inside the tank cars. This volumetric gain can be accounted for if both the loading and unloading facility use the summed component volume calculation method. Similarly, volumetric shrinkage can also occur due to mixing stocks with significantly different gravities or chemical composition, but these can also be accounted for by using the summed component volume calculation method. Methods for evaluating shrinkage during blending of light hydrocarbons with crude oil are given in API *MPMS* Ch. 12.3.

c) **Product Diversion:** This can occur inadvertently as a result of improper lineup, faulty relief systems, leaks (in tanks, pipelines, hoses, valves, tank cars, e.g.) operator error, or intentionally as theft.

5.13.2 Apparent Gains or Losses

Apparent gains or losses are differences in product quantity and/or quality that are not related to a physical loss/gain. Apparent losses include errors related to measurement tickets that can possibly be corrected and differences due to uncertainties in the measurement systems that generally cannot be removed. The majority of individual losses and gains are apparent rather than real and may fall into the following categories.

a) **Measurement Errors:** Includes errors associated with measurement procedures, equipment, and operator performance. These errors can be in liquid level, meter or weigh scale measurements, determining temperature, pressure, sampling, tank calibration, and laboratory testing methods.

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Meters that are not proved, meter factors not applied to the registered volume, or improperly applied meter factors that do not correspond, within a range, to the fluid, the flow rate, temperature, or pressure, are causes of volume overage or shortage.

Equipment malfunction or equipment that is not periodically calibrated, certified, or verified—such as thermometers, temperature and pressure transmitters, hydrometers, density meters, pycnometers, meter provers, weigh scales, ATGs, manual gauge tapes, sampling systems, and centrifuge tubes—may be inaccurate. If so, this may add a bias to the system loss/gain.

Care should be observed at the end of every transloading or unloading procedure, as air may enter the system and cause measurement errors. Mechanical meters such as PDs (positive displacement) and turbines tend to over register when air/liquid mixtures are present in such devices whereas Coriolis and ultrasonic meters tend to under register under the same conditions. Properly designed air elimination systems that ensure the flow measurement devices are always full of liquid or algorithms that correct for the presence of air are recommended in order to minimize the measurement errors created by this condition.

When using weigh scales, direct static weighing of individual tank cars before and after product transfer provide the most accurate measurement of the net weight loaded into or unloaded from the tank cars. Sometimes, the net weight is determined by weighing the loaded tank car and subtracting the car's stenciled tare weight. Care should be observed as the stenciled tare weights are not always accurate. These weights are normally obtained when the cars are manufactured, and they may change over the life of the tank cars.

Coupled-in-motion scales are also used, but they are subject to more sources of measurement uncertainty, and as such, it may be required to observe more care for these scales in custody transfer measurements

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b) **Ticket Calculation Errors:** Perhaps the most common errors occurring on manually calculated measurement tickets are arithmetic errors and wrong correction factors pulled from tables. Computer programs and calculators have reduced the risk of mathematical errors, but the product calculations should always be checked when a large discrepancy occurs.

c) **Product Drainage:** Sumps collect drips and drains from several sources and may add a bias to a system loss/gain if the sumps are emptied by pumping into a facility or transport system without being measured. Usually, sump volumes are small enough to be insignificant. However, the volumes may be significant if sumps accumulate large volumes, such as frequent drain downs from facility load/receipt systems, provers, or scraper traps.

5.14 Explainable Loss/Gain

5.14.1 General

Losses or gains can occur in liquid commodities and may be attributed to several causes such as measurement errors, evaporation, poor product handling procedures, and even theft. These should be investigated whenever established limits are exceeded. Collecting data and analyzing equipment performance is necessary to troubleshoot and understand the loss/gain.

5.14.2 Loss/Gain Inaccuracies

Certain loss/gain inaccuracies can be explained and quantified, whereas others can be explained but not quantified. Likewise, minor meter imbalances or recurring hourly shortages/overages can be the result of many factors.

Additional areas of concern are listed below but are not all inclusive.

— inaccurate pressure compensation;

— measurement system design error;

— meter slippage from frequent start-stop operation;

— analytical quality issues;

— inaccurate temperature compensation;
— Fahrenheit vs Celsius temperature corrections (i.e. 15 °C or 60 °F);
— pressure corrections (i.e. psia or psig);
— seasonal meter proving error;
— leak or puncture diversion of flow, spills;
— DRA (drag reducing agent)-laden product;
— evaporation;
— reference gauge point discrepancies;
— tank bottom flexing;
— tank datum plate movement;
— volumetric shrinkage (see API *MPMS* Ch. 12.3);
— calibration of tables;
— measurement performance (manual and dynamic);
— errors in calculation;
— temperature inaccuracies;
— line conditions;
— methodology of testing;
— product compatibility;
— vapor capture;
— weight in air vs weight in vacuo;
— proper accounting for vapor volumes (open and close of each transferring container);
— lack of meter and or density monitoring techniques when using displacement gas for purging product from delivery container to receiving container.

Loss/Gain tolerances should be based on standard volume (i.e. observed volume corrected to the reference temperature and pressure) or on true mass (i.e. apparent mass in air corrected to the mass of air).

5.14.3 Bias

Examples of system bias include, but are not limited to, the following:

— methods of analysis, i.e. S&W;
— different performance of meters;
— meter proving practices;
— meter proving frequency;
— measurement systems—tanks vs meters;
— liquid properties;
— volume correction tables (i.e. 6B or 6C);
— wax deposition;
— viscosity;
— tank capacity table error;

— tank bottom flexing;

— tank datum plate movement;

— inadequate meter backpressure;

— incorrect reference gauging point;

— pressure: psia vs psi;

— line fill;

— tank capacity table error.

5.15 Marine Measurements

The shipment of liquid commodities by tank car(s) as transferred to or from marine vessels may result in a difference between the load and discharge. Identifying such differences in measurement shall be referenced using this standard and API *MPMS* Ch. 17.1, 17.2, 17.4, and 17.5, which provide recommended practices for performing marine vessel inspections, measurements, and reconciliation.

6 Reconciliation

A loss/gain investigation is successful when the cause has been identified and the appropriate actions are taken to resolve or correct the problem. An investigation should include thorough documentation of the findings, so there is a clear understanding of the problem, what lead to a loss/gain, and what is required to resolve the problem.

Due to instrument or mechanical failures, the accuracy of measurement becomes compromised and an adjustment for the measurement period in question should be required until the equipment is either repaired or replaced. Such adjustments can be made based on the available secondary measurement data, such as tank gauging or meter information from upstream or downstream of the failed measurement equipment.

Once the cause of any loss/gain has been identified it may be possible to go back and correct measurement reports for the period of time. Any adjustments shall be agreed upon by the affected parties and should be justified and follow the agreed upon procedures, contractual obligations, and established rules and regulations.

Measurement tickets that do not get into the accounting process on time can cause an apparent loss or gain in the current accounting period and an offsetting gain or loss in the following period.

Timing discrepancies, period to period, in opening/closing measurement readings and inventory information can be a major factor in properly establishing loss/gain for an accounting period. Time-stamped data from SCADA systems can be very useful in identifying problems.

The closing tank gauge reading from the previous period should match the opening tank gauge reading for the current period. If a time lapse occurs between movements, the opening gauge of the movement may not match the previous closing gauge due to differences that arise to any evaporation or ambient temperature effects between the movements.

Accurate month-end inventory gauges are very important because they are used to balance and close out system inventories and to issue customer reports and billing. Multiple customers may share the same storage in a commingled tank, and loss/gain offsets from month to month can be difficult to allocate. Month-end gauges are also useful to identify trends that may reveal a bias (e.g. a systematic error).

7 Calculating Statistical Uncertainties

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For determination of measurement uncertainty, refer to API MPMS 13.3 for methods discussed.

API *MPMS* Ch. 13.2 points out that "minimizing systematic and random errors, estimating remaining errors, and informing affected parties of errors" are becoming increasingly important to industry. A consistent basis of estimating the size and significance of errors is essential for communication between affected parties. A consistent basis for estimating and controlling errors can help to avoid disputes on the accuracy of activities and equipment related to meter proving operations.

A wide range of designs, equipment, and service operating conditions are experienced in meter proving operations. Because of these variations, it is impractical to establish fixed procedures for maintenance, calibration, and proving activities for all installations. Meter proving factors (meter factors) should be monitored to detect trends or sudden deviations as an indication of when to perform maintenance and/or calibration of measurement equipment.

Stable operating conditions are particularly important during meter proving operations, as changes in any operating condition (flow rate, temperature, pressure, viscosity, API gravity) can cause changes to the meter factor. Therefore, operating changes during and between meter proving runs should be minimized so that any variations in meter pulses or meter factors are primarily due to performance of the meter or proving system.

Annex A
(Informative)

Troubleshooting Guides for Measurement Operations

See the Troubleshooting Guides in Excel attachment to this document

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