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MEASUREMENT ACCURACY AND SOURCES OF ERROR IN TANK GAUGING

Class # 2270

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Introduction

Upright cylindrical storage tanks are used not only to store liquid petroleum between custody transfers for inventory purposes, but to measure the quantities of those transfers. As in all measurements for custody transfer, it is essential to identify the sources of error in the measurement processes and to keep the impact of those sources to a minimum.

The following items will be considered in this discussion:

- Tank Capacity Table
- Tank Conditions
- Tank Gauging
- Tank Temperature
- Tank Sampling and Testing
- Abridged Examples of Uncertainty

Tank Capacity Table

Upright cylindrical tanks are not exact cylinders. For that reason the tank must be calibrated and a tank capacity table prepared. Thus the tank capacity table provides the means for determination of the total observed volume (TOV) of all liquids in the tank at a given liquid level. The tank capacity table is prepared from field measurement data taken to describe the geometric shape and dimensions of the tank at each condition of fill. In this process, generically known as tank strapping, the diameter of the tank is determined by one of several available means in accordance with the American Petroleum Institute (API) Manual of Petroleum Measurement Standards (MPMS) including: Chapter 2.2A, Manual Tank Strapping Method (MTSM); Chapter 2.2B, Optical Reference Line Method, (ORLM); Chapter 2.2C, Optical Triangulation Method (OTM); and, Chapter 2.2D, Electro-optical Distance Ranging Method (EODR). Many other measurements are taken in order to fully define the volumes for each course and the incremental volumes at each liquid level. Anything which adds liquid volume or displaces liquid volume is taken into account. This includes positive deadwood (e.g., man-ways and cleanout doors), negative deadwood (e.g., internal structures and piping), and head stress calculations. All deadwood must be accounted for in its elevation range. All head stress must be accounted for at each incremental level of fill.

Steel expands and contracts under stress in a predictable manner which can be calculated; but, the measured circumference/diameter/radius of the tank does change with its first filling. Therefore, it is a major mistake to ever calibrate a tank that has not been filled at least once prior to its calibration with a liquid at least as dense as its intended liquid service. Since water has a higher density than most petroleum liquids, this requirement is normally satisfied by the hydrostatic test being performed after construction, but before the calibration of the tank.

The volumes obtained by tank strapping can have a high degree of confidence but they do depend upon diligent application in the performance of tank strapping. This diligence includes proper positioning, handling and tensioning of the tapes being used, and keeping the calibration equipment (e.g., strapping tapes, optical plummets, optical theodolites and total stations) in good repair. Good record keeping, and timely verification/calibration of the tank strapping equipment, with traceability to a national metrological institute (e.g., National Institute of Standards and Technology in the USA), is essential.

Tanks in general should be re-calibrated every fifteen years, whenever construction work is performed on the tank, or measurement discrepancies suggest the possibility of the tank being out of calibration. A new tank capacity table should be re-calculated and issued whenever the service API gravity changes by more than ten degrees, the floating roof has changed in weight, or the legs have been set to land the roof at a different elevation.

In addition to tank re-calibrations being performed at maximum fifteen year intervals, it is recommended in API MPMS 2.2A that five year inspections be made. These inspections include verifications of the diameter of the bottom course, shell thicknesses and the absence of excessive tank tilt.

Tank Conditions

For the tank to be a suitable measuring device it must be free of certain kinds of damage. An extreme case of damage might be a tank that has been struck by lightning causing a dent on one side. More subtle kinds of damage can occur when the tank foundation has become compromised allowing the tank to tilt. When a tank tilts excessively, stresses may change the geometric shape of the tank and the liquid surface is no longer a true circle. This can be corrected by tank strapping if the tilt is not too severe.

In tanks with floating roofs, the weight of the roof displaces in own weight in the product in which it is floating. The volume thus displaced can be included in the tank table, with small corrections being made at the time of gauging, or it may be calculated in its entirety at the time of gauging. Either way, it is assumed that the roof weight is constant. This kind of tank has three zones. The bottom zone is where the roof is fully landed on its legs. The second zone, called the critical zone, is where the roof is between the fully landed position and the freely floating position. The third zone is the working zone which is above the critical zone.

Ideally, all custody transfers take place with both the opening and closing gauges being taken in the working zone because any errors in the roof weight are essentially cancelled out from opening to closing gauges if the product service density at tank liquid temperature remains the same. The calculations for opening and closing will account for changes in the density at tank liquid temperature if the roof weight is reasonably true.

Snow or water on a floating roof changes the weight of the floating roof. A snowfall before opening gauge that is left intact until the closing gauge is taken might have minimal effect; but a snowfall occurring during a custody transfer causing more weight to be on the roof at the closing gauge than during the opening gauge would cause a measurement error. An overriding concern though would be that if enough weight by snow or water is added to the floating roof it will sink to the bottom. This would require taking the tank out of service to repair any associated damages and to re-float the roof.

It is acceptable to have one of the gauges (opening or closing) in the bottom zone, but in this case the transferred quantity becomes somewhat more sensitive to any inaccuracy in the roof weight. That is because there is no cancelling effect since the roof legs are simple deadwood in the bottom zone and the roof weight forms the volume displacement in the working zone.

It is never acceptable to have one of the gauges in the critical zone. There is great uncertainty in this zone and taking one of the gauges in the critical zone almost assures that there will be a significant measurement discrepancy.

Un-slotted stilling wells are sometimes used to reduce emissions, but this practice greatly compromises measurement accuracy. For purposes of custody transfer, stilling wells for gauging must be slotted. This allows for proper sampling and level gauging. An un-slotted stilling well can create a difference between the gauged liquid level in the tank and its true liquid level. It can also compromise the quality of a sample taken through the stilling well and can even adversely affect the tank temperature determination.

Bottom deflections are one of the most exasperating problems in tank measurement. A one-time deflection at the beginning of the tank's service might have minimal effects if it does not rise and fall with emptying and filling. On the other hand, intermittent rising and falling of a portion of the floor could have very adverse affects by causing a tank to understate some of its receipts and overstating some of its deliveries. All of this can usually be mitigated by simply keeping the liquid level in the tank, for both opening and closing gauges, in the working zone on floating roof tanks, and keeping a similar level in cone roof tanks.

Bottom deflections can also cause changes in gauge heights although the change in gauge height is not in itself a measure of the extent of the bottom deflection. Observed gauge heights, which indicate changes from the reference gauge height, can be caused by movements of the datum plate or the reference gauge point.

Sediment build ups on tank floors are also vexing problem. Extreme cases can make it difficult to verify the reference gauge height. Attempts to quantify sediment buildup through the gauging well remain elusive, but there has been some success, when time allowed, for the laborious process of gauging through the floating roof leg wells when the roof is floating. This usually takes place only when a tank facility is changing owners. Even then there is a high uncertainty involved in the measurement of these residual volumes.

Tank Gauging

The volumes determined by liquid level measurements can have a high degree of confidence but they do depend upon diligent application in the performance of tank gauging. This diligence includes proper handling of the gauge tape and bob, keeping the gauging equipment in good repair. Good record keeping, and timely verification/calibration of the tank gauging equipment, treating the gauge tape and bob as a single unit, with traceability to a national metrological institute (e.g., National Institute of Standards and Technology in the USA), is essential.

Tank capacity tables can be made to accommodate either innage or ullage (outage) gauging. In theory they both obtain the same results but there are practical reasons why one is chosen over the other. Whether gauging by innage or ullage, at least two successive gauges should be made. If the liquid levels determined by gauging agree to the same nearest 1/8th inch, the gauging may optionally stop. If they do not agree to the same nearest 1/8th inch, but do agree within 1/8" of each other, a third gauge should be taken and the process continued until three successive liquid levels are determined within a range of 1/8th inch. In that case the three successive gauges within a range of 1/8th inch should be averaged. This practice minimizes gauging uncertainty. In any case it is essential to gauge from the precise gauge reference point as described on the tank capacity table for all of the gauges. Minimizing uncertainty in gauging requires

The gauge reference height, or certified distance from the datum to the gauge reference point in the gauge hatch, is noted on the tank capacity table. It should always be verified by taking an observed reference height from the reference point and any discrepancies should be reported.

Innage gauging is the determination of the vertical distance from the datum to the liquid level. Innage gauging relies on just touching the datum plate so that the gauging bob does not lean over and wet too much tape, thus causing an over reading. Errors in innage gauging may occur by touching the datum too hard (leaning), by debris on the datum itself, or by gauging from a hatch location other than the gauge referent point. It may also be caused by trying to use the tape reel mechanism to lower the bob to the datum rather a controlled wrist action.

Ullage (outage) gauging is the determination of the vertical distance from the gauge reference point to the liquid level. The ullage tank capacity table is prepared in such a way that the actual liquid innage is given for each ullage gauge level. This method is often used on heavy, opaque and viscous oils in order to minimize the amount of tape be wetted by the oil. Heavy oils often present a soft and imprecise datum over time so ullage gauging is often preferred for these oils. Ullage gauging is used for marine vessels carrying crude oil because of the soft bottoms frequently observed as well as to minimize contact with structural material in the lower regions of the ship's tanks. Contact with structural materials is often exacerbated by the ship's "out of trim" orientation. Errors in ullage gauging occur whenever the gauge reference point or even a gauging platform has moved slightly. Gauge reference point movement is usually undetectable unless it is possible to verify the gauge reference point.

Gauging of upright cylindrical tanks by manual gauging is described in API MPMS 3.1A and by automatic gauging in API MPMS 3.1B.

Tank Temperature

It is unfortunate that tank temperatures often stratify both horizontally and vertically. It is thought that the horizontal stratification is not as severe as the vertical but nonetheless does occur and some tests have been startling. At this time there is not much that can be done about horizontal stratification but vertical stratification can be dealt with fairly effectively. Tank temperature measurements are taken in a single column of oil defined by the gauge hatch location. For tanks with volumes of 1,000 barrels or less, it is common practice to take a temperature mid-way in the oil column. For tanks with volumes of 1,000 barrels or more, it is a common practice to take a temperature in the middle of the upper third of the oil column, another one in the middle of the middle third of the oil column, and a third one in the middle of the lower third of the oil column, which are then averaged.

When gauging production lease tanks, temperatures are usually taken by means of a liquid-in-glass cup-case thermometer which may require, depending upon the density of the oil and the difference between ambient temperature and oil temperature, from 15 to 45 minutes of stabilization time. Even so, the procedures involved in gauging a lease tank allow for this. Errors in these temperature measurements occur when there is failure to detect, by skipping the visual inspection step in the process, a separation in the mercury column, when the thermometer is not kept immersed in the tank liquid for the proper amount of time and when too much time is taken to read the thermometer once it is brought up and out of the tank liquid. It is recommended to verify the liquid-in-glass cup-case thermometer once per year at three points, and to make a monthly check at a single service temperature, all done in a manner traceable to NIST.

The liquid-in-glass cup-case type thermometer can be used in the larger tanks as well but they become less practical due to the additional readings taken. Therefore, when taking a temperature at two or three different levels, it is more practical to use an electronic thermometer. When using these type thermometers the equilibrating time is kept to a minimum and the readings can be taken while the temperature probe is in the zone being measured. It is recommended to verify the electronic thermometer once per month at three points, and to make a daily check at a single service temperature, all done in a manner traceable to NIST.

While taking accurate temperatures in an upright cylindrical storage tank are challenging, it must be emphasized that doing the best job of which one is capable in this regard is very important in order to minimize uncertainty in tank measurements. To give some idea of the impact, a one degree error causes a 0.03% error in the volume of No. 6 fuel oil, a 0.05% error in the volume of 40 ºAPI crude oil and 0.06% error in the volume of gasoline.

Tank Sampling and Testing

Sampling in an upright cylindrical tank is performed in a single column of oil beneath the gauge hatch. Ideally the tank would be well mixed before sampling but that is not always the case. For that reason, sampling is performed in such a manner as to obtain a reasonable representation of the whole. To this end, core samples are taken in lease tanks in the upper and lower zones for quality and merchantability, and in the middle for density. In larger tanks, running (or sometimes all levels) samples are often taken for quality and density. The level of free water is often determined using water finding paste. The subject of manual sampling is covered in API MPMS Chapter 8.1. Errors in sampling occur by taking core samples at improperly selected elevations, by taking running samples at an irregular pace, or by under-filling or over-filling the sample container used for running or all-levels samples. Errors in the detection of free water occur by accepting less than clear water cuts when using water paste and by allowing a core sample to lean over when taking a clearance sample. Errors in testing occur when tank temperature thermometers are read at an angle rather than perpendicular to the thermometer stem, when observed temperatures for density determination are read too soon (before stabilization), when gravities are read without taking into account the meniscus on the density stem, and when centrifuge tubes do not display a clear S&W cut, thus indicating something was flawed in the centrifuge procedure.

Abridged Estimates of Uncertainty

Description	50 ft Diameter Tank	50 ft Diameter Tank
Vertical length of column of oil	40 feet	10 feet
Tank table volume for the vertical column of oil	13988.54 barrels	3497.13 barrels
Uncertainty in tank strapping circumference	0.015 feet	0.015 feet
Uncertainty in tank gauging length in inches	0.250 inch	0.250 inch
Uncertainty in temperature reading	2 degrees F	2 degrees F
Coefficient of temperature expansion per degree F	0.0005	0.0005
Contribution from uncertainty in tank circumference	0.019 %	0.019 %
Contribution from uncertainty in level determination	0.052 %	0.208 %
Contribution from uncertainty in temperature	0.100 %	0.100 %
Overall uncertainty from the above contributions alone	0.114 %	0.232 %

Description	300 ft Diameter Tank	300 ft Diameter Tank
Vertical length of column of oil	40 feet	10 feet
Tank table volume for the vertical column of oil	503,587.39 barrels	125,896.85
Uncertainty in tank strapping circumference	0.035 feet	0.035 feet
Uncertainty in tank gauging length in inches	0.250 inch	0.250 inch
Uncertainty in temperature reading	2 degrees F	2 degrees F
Coefficient of temperature expansion per degree F	0.0005	0.0005
Contribution from uncertainty in tank circumference	0.007 %	0.007 %
Contribution from uncertainty in level determination	0.052 %	0.208 %
Contribution from uncertainty in temperature	0.100 %	0.100%
Overall uncertainty from the above contributions alone	0.113 %	0.231 %

Conclusion

The above values were used for illustration only and in real situations the values could be much different. They are also only an abridged list of the uncertainty contributing elements in tank measurement. This information clearly demonstrates how uncertainties in liquid level determination are greater, on a volume percentage basis, for transfers using only a small portion of the tank. Bottom deflection, temperature stratification, datum or reference point movement and human errors are just some of the elements that can sometimes make the overall uncertainties for tank movements pass 0.30 % and approach or even exceed 0.50 %. Attention to detail in the art of tank measurement is required in order to mitigate excessive uncertainties.

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References for Further Reading:

ISHM Paper in 2012: Measurement Accuracy and Sources of Error in Tank Gauging

API MPMS Chapter 2 Tank Calibration

API MPMS Chapter 3 Tank Gauging

API MPMS Chapter 7 Temperature Determination

API MPMS Chapter 8 Sampling

API MPMS Chapter 9 Density Determination

API MPMS Chapter 10 Sediment and Water

API MPMS Chapter 11 Physical Properties

API MPMS Chapter 12 Calculation of Petroleum Quantities

API MPMS Chapter 13 Statistical Aspects of Measuring and Sampling

Hydrocarbon Processing, Aug. 01, 2010: Estimating Tank Calibration Uncertainty

Hydrocarbon Processing, Nov. 01, 2001: Tank Gauging or Metering – Guidelines for Selection