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Accuracy of Metering Versus Tank Gauging of Vessel Delivered Petroleum Liquids

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Abstract

The volume of petroleum delivered from a transporting vessel (truck transport, rail tank car, barge or tanker) into a storage tank is more accurately measured by a metering system than by tank gauging. The relative significance of various factors affecting the accuracy of volumetric measurements obtained by metering and tank gauging are discussed. The factors discussed include variations in operating conditions (e.g., temperature, pressure, viscosity and entrained air) and other inherent accuracy considerations (e.g., self-checking feature, volume resolution, linear measurement accuracy and tank dimensional corrections).

Introduction

The tank gauging of ships and barges is recognized as **not** being as accurate as metering or shore tank gauging; and shore tank gauging is not as accurate as metering. Recently, the U.S. Customs updated "19 CFR Part 151" relating to the importing of petroleum and petroleum products. The following quotes are from the Federal Register, Volume 45, No. 106, dated Friday, May 30, 1980, commenting on the subject:

"Customs agrees that vessel ullages are not the most accurate methods of measuring the quantity unladen."

"The figure derived from the shore measurement (Customs approved positive displacement meters, turbine meters and shore tank gauging) will be the gross quantity unladen and ordinarily will be the basis for determining the net quantity unladen."

"Experience has shown that Customs approved meters are generally as accurate or more accurate than gauging as a method of measurement."

"However, if shore measurements are unavailable or inadequate, Customs then will use vessel ullages to determine the gross quantity unladen."

This paper explains why metering systems are more accurate than tank gauging systems for measuring the volume of petroleum transferred from a delivery vessel (truck transport, rail tank car, barge or tanker) into a storage tank.

The term Metering System as used herein is considered to consist of the following components:

1. Positive Displacement (P.D.) or Turbine Meter(s).
2. Air Eliminator(s).
3. Strainer(s).
4. Prover.
5. Temperature and Pressure Measuring Devices.

The term Tank Gauging System as used herein is considered to consist of the following components:

1. Storage Tank or Vessel.
2. Liquid Level Sensing Device - Automatic or manual.
3. Gauge Table - Calculated from linear tank dimensional measurements and adjusted for:
   a. Circumferential measurement corrections.
   b. Tank Volume change due to liquid head (pressure).
   c. Tank Volume change due to tank temperature.
   d. Tilt from vertical position.
   e. Deadwood.
   f. Floating or variable volume roofs (where applicable).
   g. Irregular or unstable tank bottoms (buckling).

In analyzing the accuracy of these two volumetric measuring techniques, the following factors that could influence measurement accuracy are discussed:

1. Operating Condition Variations - Temperature, Pressure, Viscosity and Entrained Air.
2. Inherent Accuracy Considerations - Self-checking Feature, Volume Indicator Tolerance, Linear Measurement Accuracy and Tank Dimensional Corrections (Tank tilt, deadwood, floating or variable volume roofs and irregular or unstable tank bottoms).

Operating Condition Variations

1. **Temperature Variations**

   Metering - The thermal expansion of most petroleum products is fairly large, in the order of 0.04-0.07%/° F. Therefore, this factor is significant and requires that accurate temperature measurements be made. A metering system will have a temperature probe in the piping near the meter to continuously integrate or correct the output of the meter for temperature variations.

   Tank Gauging - Since the effect of fluid temperature variations on fluid volume is significant, accurate tank fluid temperature measurements are needed. There are many variables that influence the accuracy of the temperature measurement of fluids in tanks: (1) probe size (point or column), (2) number of probes (one or more), (3) probe location(s), (4) fluid temperature variation (vertically, radially and/or circumferentially), (5) ambient temperature and (6) volume of piping between the delivery vessel and the tank. With reference to (6), the larger the piping volume, the more significant it becomes because this volume of piping is part of the "tank" and any difference between the fluid temperature in the pipe at the beginning and end of the delivery is normally unknown and thus not taken into account.

   Summary - This factor is significant and accurate fluid temperature measurement techniques are necessary. With metering, the entire fluid delivery passes by the temperature probe, whereas with tank gauging the temperature probe sees only a very small sample of the delivery. How well this small sample represents the total delivery is critical.

2. **Pressure Variations**

Metering - The compressibility of most petroleum products is insignificant, in the order of 0.0004 - 0.0006%/psi (0.04 - 0.06 for 100 psi). Thus pressure measurements are not critical nor are fluctuations in pressure significant. The compressibility of the fluid can be easily accounted for when calculating net volume.

Tank Gauging - Since the fluid pressure is only that caused by the fluid head, fluid pressures in tanks are insignificant. This results in the compressibility of the fluid in tanks being insignificant (less than 0.01%).

Summary - In metering this factor is easily accounted for and in tank gauging it can be ignored.

3. **Viscosity Variations**

Metering - While a change in viscosity can change the readout of a meter, by proving the meter on the products being delivered, this possible variation is eliminated.

Tank Gauging - Viscosity effects for tank gauging involve "clingage" to tank walls. Typical errors due to clingage are as follows:

Tank Diameter (Feet)	Percent Error for Varying Thickness		
	1/16"	1/8"	1/2"
50	0.04%	0.08%	0.33%
100	0.02%	0.04%	0.17%
200	0.01%	0.02%	0.08%

Summary - The effect of this factor on metering accuracy is eliminated by proving the meter on the actual product. In tank gauging tank wall clingage or buildup can be a problem that must be resolved by periodic tank cleaning. In addition, it should be noted that clingage can vary (both increase or decrease) with time. The resultant can be significant inaccuracies that are usually undetectable.

4. **Entrained Air**

Metering - Any air eliminator worthy of the name should be able to collect and vent off slugs or large bubbles of air. Entrained air in the form of small bubbles is a different situation. While a meter will measure air as well as liquid, there is a chance that if small amounts of air (0 - 5% free air) are present in the system, it will be dissolved into the product, and therefore not occupy any volume, by the time the product passes through the meter. Petroleum products can dissolve large amounts of air. The amount of air which can be dissolved increases with increased pressure and decreased temperature. Since under system pressure, air compresses, occupying less volume, the measurement error due to unvented or undissolved air being metered is usually insignificant compared to the total volume throughput.

Tank Gauging - Slugs or large bubbles of air should not cause any error because they will normally rise quickly in the tank and will not affect the level measurement. But if the air is introduced late in the delivery during final stripping operations and the air slug does not get to the tank but is caught in the piping, a significant measurement error could result. Small bubbles of entrained air will usually be dissolved in the product. However, since the amount of air that can be dissolved at high pressure is greater than at low pressure, there is the real possibility that some of the dissolved air will come out of solution in the form of tiny bubbles once the pressure is reduced to atmospheric pressure in the tank. In heavier oils such as #6 fuel oil, these tiny air bubbles will usually remain entrained in the liquid until after tank readings have been taken, resulting in a measurement error.

Summary - With regards to slugs or large bubbles of air, they should not be a problem to either system unless trapped in the piping at the end of a delivery in a tank gauging system. With regards to entrained air in the form of small bubbles, they should be dissolved. However, the amount that can be dissolved is greater in the metering system because of the higher pressure (system pressure at the meter versus atmospheric pressure in the tank). Also, any entrained air would occupy much less volume going through the meter at system pressure than in the tank at atmospheric pressure. For example, 1,000 gallons of small air bubbles at atmospheric pressure in the tank would only occupy 200 gallons in a metering system at 60 psig.

Inherent Accuracy Considerations

1. **Self-Checking Feature**

Metering - A meter and a prover are both volumetric measuring devices which are compared to each other. The meter factor, representing their relationship, can vary slightly with changes in operating conditions (e.g., viscosity and flow rate). As historical data is developed, the meter factor becomes an indication of the condition of the meter/prover system. In other words, for a given set of conditions, a meter factor can be predicted before a proving is made. Therefore, if the meter factor departs from that prediction, a change in the system is indicated which should be identified and (if warranted) corrected. In a meter/prover system the meter is the active measuring device and the prover is the in-place reference. The prover in turn is calibrated by the water draw method with containers traceable to the National Bureau of Standards.

Tank Gauging - Tank Gauging is a single measuring device with no second measuring device (prover) with which to compare measurement results. While large changes or problems will be discovered merely because they are obvious, small ones can go unnoticed. If a problem is suspected, it may become necessary to calibrate the tank to re-establish its accuracy, which is an involved and time consuming procedure compared to proving a meter.

Summary - A meter/prover system has a self-checking feature by virtue of being two measuring devices which compare themselves. This permits immediate detection of possible errors. Tank gauging, being one measuring device, does not have this feature.

2. **Volume Indicator Tolerance**

Metering - The meter registration starts at zero (no tolerance involved) and increases to the quantity delivered. It uses a meter factor that is established by proving. The meter volume normally must agree with the prover volume, on five consecutive proving runs, within plus or minus 0.025%. In other words, the meter should measure the quantity delivered accurately to within 0.025% of its reference, the prover.

Tank Gauging - Two readings are needed to determine the volume of a delivery, the starting level and the finishing level. There is a tolerance involved in each reading. Since the reading error does not vary but the distance between readings will, the percent

(%) error will vary with delivery volume. For example, a 1/8 inch reading tolerance for a 10 foot change in height results in a plus or minus 0.2% vertical measurement tolerance whereas a 1/16 inch reading tolerance on a 30 foot change in height results in a plus or minus 0.03% vertical measurement tolerance.

Summary - The accuracy tolerance of the meter volume reading with respect to its reference, the prover, is typically better than 0.025% for all deliveries. The accuracy tolerance of the tank gauge volume reading with respect to its reference, the gauge tables, can be nearly as good as the meter for relatively large deliveries; but will be quite large for relatively small deliveries.

3. **Linear Measurement Accuracy**

   Metering - The calibrated volume of the prover is determined by a water draw and not by measuring the physical size of the prover.

   Tank Gauging - When a tank is strapped, the importance of the circumferential measurement varies with tank size. A one inch variation in circumference on a 20 foot diameter tank is a 0.27% change in volume while a one inch change in circumference on a 200 foot diameter tank is a 0.027% change in volume.

   Summary - The volume of the prover is traceable to the NBS by water drawing it with containers calibrated by NBS. When the tank volume is calculated, its volume is not traceable to a volume standard but uses a length standard which in turn is used to calculate a volume. Water drawing is recognized as being more accurate than calculating a volume as evidenced by the fact that when there is the option to do either, as with test measures and provers, they are water drawn, not measured and calculated.

4. **Tank Dimensional Corrections** - Tank tilt, deadwood, floating or variable volume roofs, irregular or unstable tank bottoms.

   Metering - These do not apply.

   Tank Gauging - These are all factors that must be measured, their volumes calculated and then used to adjust the gauge tables.

   Summary - The comments of the preceding section apply here also.

Conclusion

There is no doubt that both metering and tank gauging can be very accurate, very inaccurate or anything in-between. However, when all the factors affecting accuracy are considered, metering would be selected over tank gauging as the more accurate system for measuring the volume of petroleum delivered from a transporting vessel (e.g., truck transport, rail tank car, barge or tanker) into a storage tank.

Of the inaccuracies caused by operating condition variations, the most common is the error caused by inaccurate determination of fluid temperature. The metering system senses product temperature throughout the entire delivery, while the tank gauging system measures temperature from a sample only, which may or may not be representative of the volume delivered.

The inherent accuracy considerations also favor the metering system. The metering system, with its two independent active measuring elements (the meter and prover), is a self-checking volumetric measuring system. The meter measures the volume delivered and the prover periodically checks the meter's accuracy. The tank gauging system has only one active measuring element, the level gauge, and therefore has no self-checking feature. Thus if there is a disagreement with a tank gauge measurement, there is no reference (e.g., no independent prover) to decide the issue like there is with a metering system.

With metering, the relationship between the meter and prover is known and the prover is calibrated with containers traceable to the National Bureau of Standards (NBS). The level gauge has its own errors and tolerances, and the tank itself is calibrated by linear measurement and calculation, which is not directly traceable to volume standards of NBS. In other words, the calibrated volume of the tank cannot be established to the same level of accuracy as water drawn provers.

Therefore, from the standpoint of obtaining the highest degree of volumetric measurement accuracy, a metering system with an associated prover would be selected over tank gauging.

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The specifications contained herein are subject to change without notice and any user of said specifications should verify from the manufacturer that the specifications are currently in effect. Otherwise, the manufacturer assumes no responsibility for the use of specifications which may have been changed and are no longer in effect.

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