LIQUID ALLOCATION MEASUREMENT

API CHAPTER 20.1

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INTRODUCTION

An *allocation* meter is one whose purpose is to determine which portion of the royalty meter's volume is attributable to a particular lease, well, or measurement point.

Some allocation points fall under federal guidelines, while others fall under other regulatory bodies. Individual contractual agreements must meet and will often exceed regulatory guidelines. Therefore, certain accuracy and procedural standards are set. These standards are intended to treat all producers uniformly, to be fair to the small producer as well as the larger ones.

In September 1993, the American Petroleum Institute published MPMS Chapter 20, Section 1, entitled "Allocation Measurement". Chapter 20 is a document outlining a set of recommended standards, to be used as a general guideline in all allocation applications.

APPLICATIONS

In some cases, the oil being metered has been stabilized at atmospheric pressure. This *weathered* oil has lost most of its dissolved natural gas and must be pumped, or by some other means, moved through the meter. This is the most desirable situation for metering. The weathered oil will typically remain stable, with a minimum of gas break out. A stable liquid, in a well-designed system with flow conditioners and at least the minimum requirements of straight uninterrupted piping are the keys to producing a well developed flow profile.

In other cases, however, the fluid to be metered is at its equilibrium pressure or *bubble point*. At the bubble point, the fluid is stable, but if a drop in pressure or an increase in temperature occurs, gas begins to break out. When two-phase flow occurs in liquid measurement, accuracy will be sacrificed. Typically, when gas breakout occurs, volumes through the meter will be overstated. Therefore, when metering in this situation, special consideration must be given to at least *minimize* two-phase flow. If the meters are installed below the liquid level of the vessel, the static head pressure will assist in keeping the liquid stable. Sufficient backpressure must also be maintained on the metering system to minimize two-phase flow.

METERS

There are two basic types of meters used in allocation measurement, and even though other types do exist, we will focus on only two.

POSITIVE DISPLACEMENT METERS

There are several types of positive displacement meters on the market, and all operate on basically the same principle. Fluid enters the meter, rotates some type of internal mechanism, and exits the meter. By precise gearing configurations, output rotations are transformed into meaningful revolutions. These revolutions equate to a volume- per-revolution value. The volume is then counted on an indicating totalizer. Components may be added to the meter *stack*, which is the area between the meter and the indicating totalizer, to provide pulse or pulse stream outputs. It is important; however, to keep this to a minimum, since added components increase the torque load on the meter. . A switch located on the final component, the indicating totalizer, can generally provide the output needed to signal the sampler, run the meter fail circuit, and provide a signal to the S&W monitor, (if used). Today's technology offers temperature-averaging devices as an alternative to mechanical compensators, so ideally the only components in the meter stack should be a mechanical calibrator and a right angle drive. The calibrator adjusts the meter's output revolutions, when warranted, and the right angle drive provides a location to mount a photoelectric transmitter while proving the meter. This reduces the torque load between the meter and the totalizer, and reduces the possibility of problems unrelated to the measuring element. Positive displacement meters offer extremely accurate measurement, so long as they are operated within their parameters. Positive displacement meters are typically used in situations where the fluid is weathered, since not only does two-phase flow sacrifice accuracy, but can be damaging. The internal rotating device is designed for the resistance of liquid, but if the fluid is allowed to flash into a two-phase stream, the liquid volume of the total stream will be overstated. If a positive displacement meter is allowed to over-spin, the meter internals may be damaged. Repair costs are substantial.

TURBINE METERS

Turbine meters are a type of inferential meter which infer volume through the velocity of the fluid. Whereas the positive displacement meter uses the rotation of an internal element, gearing, and shaft-driven revolutions to indicate volume, the turbine meter does not. This type of meter has an internal rotor, which is turned by the flowing stream. Some types have a ring with magnets attached, and when turning, cause a magnetic fluctuation, or *sine wave,* when passing the proximity of the magnetic pickup. The magnetic pickup, which is positioned in a threaded receiver in the external body, delivers the pulse stream to the final destination, a totalizer, flow computer, telemetry, etc. Other types of turbine meters utilize a rotor coated with a para-magnetic material, and when passing the proximity of the pickup, creates the same type of fluctuation.

These frequency of these sine waves, or the *pulse stream,* is directly proportional to the flowrate through the meter.

A problem may occur when the totalizer is not mounted directly to the meter, or where there are long sections of cable causing the meter's signal strength to weaken. In this scenario, a preamplifier should be used to eliminate the possibility of lost production due to low signal strength.

The totalizer must be programmed with the correct *k-factor*, or pulses per unit of volume, for the desired increments.

EXAMPLE: A turbine meter that generates 38000 pulses per barrel (nominal)
The desired totalizer increments - barrels and tenths of barrels
38000 pulses/bbl. X .10 = 3800 k factor per 10^{th} of a bbl.

By totalizing pulses and using the correct k-factor, gross volume is indicated. Special consideration must be given to turbine meter applications to achieve the desired results. Flow conditioners placed upstream of the meter will aid in producing a good flow profile. Positioning a turbine meter immediately downstream of bends or commingling streams subjects the meter to a swirling, erratic flow, or a poorly developed flow profile and should be avoided. It is recommended that a flow conditioner be used with ten diameters of straight pipe upstream of the meter and ten diameters downstream. If a flow conditioner is not utilized, twenty pipe diameters upstream and ten downstream is generally the rule.

VOLUME CORRECTIONS

A typical allocation system meters fluid from one or more wells and then re-injects this fluid back into a commingled stream. The metered volumes at the allocation skid will be later used to determine what percentage of the total quantity is to be a*llocated* back to a particular well or lease, as earlier stated. Therefore, the allocation system must provide us with valuable information, to be used in the calculations converting gross indicated volumes to net volumes.

1) **METER FACTOR (MF)-** The mathematical correction that is used to adjust the *indicated* volume to the *actual volume metered*. This is determined by meter *proving*, and will be discussed later.

   Example: Indicated volume = 1000 barrels
   Meter factor = .9990
   The actual volume metered was 999 barrels

2) **CTL**- the mathematical correction used to convert gross volumes to standard volumes at the temperature base, 60 degrees F. This is to be applied only where there is no mechanical device or real-time system doing this automatically. This factor is to be found in Table 6-A for generalized crudes .The API

gravity must first be determined using a hydrometer, and then corrected to the base, 60 degrees F. using Table 5A. This corrected gravity is crucial, since lighter products expand more due to the effects of temperature than heavier ones. The rate of expansion for a particular product is known as the C of E, or the *coefficient of expansion.* Once the corrected gravity and the flowing temperature are determined, the CTL can be obtained in Table 6A, and then applied directly to the gross volume.

CTL= 1 +/- (differential temp. from 60 deg. X coefficient of thermal expansion per deg. F.)

Example: API gravity (corrected to 60 deg.)
41.5
Metering temp. = 71 deg. F
The *coefficient of thermal expansion* (C of E) is .051% per degree F. for that particular crude. The CTL is .9944

3) **SHRINKAGE FACTOR (Sf)** - The correction factor used to correct the gross volumes, metered at operating conditions, to stock tank, or atmospheric conditions. If the oil is metered at a pressure above atmospheric, the fluid will retain lighter hydrocarbons in a liquid state that will turn to gas at stock tank conditions. In this situation, the meter will indicate a greater volume than will be recovered at the time of sales measurement, which is generally at atmospheric pressure. To determine shrinkage, a representative sample is caught and maintained as near to metering conditions as possible. The sample is then transported to a location with specialized equipment, capable of transferring the sample into a known volume, and then flashing it into a certified receiver, which represents stock tank conditions. The amount recovered is then compared to the beginning known volume, and after the appropriate corrections are applied, a mathematical factor developed. There are variations to these tests, and methods to determine shrinkage by laboratory analysis are available.

4) **SEDIMENT & WATER (S&W)** - Sediment and water are substances that are not marketable and should therefore be deducted from the delivered volume. The maximum allowable limit is typically 1%, but may be less for individual contracts. A proportional-to-flow sampling system is a typical means of determining the S&W content at the end of each metering period. A truly representative composite sample removes any doubt, and leaves little room for disagreements by partners or witnesses. In some cases, water will stay in solution; that is to say that it will not readily separate from the oil. In these cases, the use of solvents and/or heat may be necessary get a definite separation and an accurate accounting of sediment and water content.

The S&W content is deducted from the delivered volume by multiplying the percentage, (.1% would be expressed as .001), against the delivered volume.

Example: 1000 barrels metered
.1% S&W determined

1000x.001=1 barrel
1 barrel is thus subtracted from the metered volume.

INDICATED VOLUMExMFxCTLxSFxS&W= NET VOLUME

5) **CPL-** the mathematical correction used to correct volumes back to the standard base pressure of 0 psig. This correction factor is not substantial in low-pressure crude oil applications, where the system pressure is low and the product equilibrium pressure is at or near atmospheric pressure.
There are cases, typically in light crudes or natural gas liquids, (NGLs), where the factor becomes significant, depending on the API or specific gravity, the flowing temperature, and the operating and equilibrium pressures involved. CPL is derived from all three of these process variables. For crude oils, this correction is found in API table 11.2.1.

$$\textbf{CPL=} \quad \frac{1}{1-\ (Po-Pe)F}$$

Where: Po= Operating pressure (psig)
Pe= Equilibrium pressure of the metered fluid
F= The compressibility factor

This factor is used in the proving sequence, to correct both meter and prover for the effect of compressibility on the fluid. It is then sometimes used as a final multiplier to convert a mechanical

meter factor into a composite meter factor. If this is done, it should be remembered that the CPL applied to the meter and prover during the proving calculations is calculated using the *proving* pressure. The final CPL is calculated using *normal operating pressure*, which may be different than the proving pressure. If CPL is used on the run ticket, or applied by an on-line densitometer, then it would not be used in conjunction with the meter factor on the proving report.
This is an often misused or misapplied factor. Special care must be given the application of CPL.

METER PROVING

Meter proving involves the use of a known volume to determine the error between a meter's indicated volume and the actual amount delivered. This known volume can be supplied by either a volumetric prover or a master meter. Since we know that no meter is perfect, it stands to reason that we must identify the amount of error, and we must make sure that we meet two major criteria…. the first being meter repeatability and the second being meter factor shift.

The term *repeatability,* as defined in liquid meter proving applications, refers to a meter's ability to demonstrate consistency. This tells us whether or not the meter is in good mechanical condition. A damaged or worn meter will let you know if it has problems, if you know where to look. This is critical, because if the meter does not repeat to within an acceptable limit, the meter fails.

We expect to have normal wear in our meters, since moving parts deal with friction and friction means wear on mechanical parts. This normal wear would be expected to show up as a gradual meter factor increase; that as the measuring element wears, more and more fluid is not being metered and a higher multiplier is needed to account for it. When foreign matter, such as sand or welding slag, is introduced into the meter, irregular damage may result. This type of damage may cause the meter to not repeat, since the wear or damage is uneven. So it becomes important that we monitor meter wear, as well as repeatability, making sure that we stay within acceptable limits.

Meter factor shift from proving to proving tells us whether or not we are within these limits, but only after meter repeatability has been established. The factor shift allowable from proving to proving in typical allocation application is normally 2%, but may be less, depending on the individual contract.

Keeping records on individual meters becomes valuable when troubleshooting potential problems, so trends in factor shift can readily be identified. The repeatability and factor shift guidelines are documented in API Chapter 20.1.

METHODS OF PROVING-MASTER METER

A master meter is a meter, either turbine or positive displacement, that is proved at various flowrates fluids similar to the stream being metered, then used to prove another meter. The master shall have no means of adjustment, such as calibrators or temperature conpensators. Typically, the meter is proved using a volumetric prover, and is proved at four or more rates through the range of the meter. Each proving requires 5 runs repeatable to within .05%. Then the meter factors, or k-factors, at each rate are averaged, to develop the meters *mean average meter factor.* Each individual factor is then compared to the *mean,* making sure that it does not exceed .0050 deviation. When the mean factor deviates one percent from the original mean, .0100, the meter must be inspected and/or repaired and reproved. In this way, we know how the meter performs at any point in its flow range. Turbine meters, much more than positive displacement meters, are greatly affected by changes in velocity, so it becomes clear why attention must be paid to identify flowrate.

Differences in viscosity also greatly affects a meter's performance, a turbine meter more so than a positive displacement meter. Any significant changes in the fluid viscosity to be metered should be duly noted, and may warrant reproving.

METER PROVING-ON SITE

The most common method for proving a separator meter is the indirect method, or master meter method. Using the master meter, we must determine the flow rate of the fluid while proving. If the fluid is being pumped, or otherwise moved in a continuous manner, the rate can be determined by timing the incoming pulses on the prover counter and dividing by the appropriate *k-factor*, or pulses per unit of volume, that the master meter develops. When a level controller is being used, and a control valve opens and closes in short cycles, the time of the cycle, or *dump*, can be determined. If the amount of fluid per dump can be established, rate can be determined.

Volume per dump divided by minutes per dump gives the volume dumped per minute.

Example: If one dump moves 15 gallons and the duration of the dump is 30 seconds, the rate through the system is 30 gallons per minute.
15 gallons/30 seconds x 60 seconds per minute = 30 gpm.

With the rate established, we can look to our master meter documentation to see exactly how the master meter performed at that exact rate. Knowing this, and having the two meters in series, we can determine the amount of error in the meter being proved. Special consideration must be given to the master meter installation. The master meter is installed preferably downstream of the meter being proved, but can be installed upstream, if sufficient backpressure is maintained. The isolation valve that routes the fluid through the master meter must be checked and demonstrate a bubble-tight seal. The appropriate correction factors must then be applied to both meters, correcting the fluid being metered for both pressure and temperature, mathematically correcting the volumes to the standard conditions, 60 degrees F. and 0 psig, (equilibrium vapor pressure for light liquids.) As with almost all proving situations, if the fluid is equalized at a lower pressure, then pumped or otherwise moved through the meter, the appropriate CPL must be applied. In this case, the CPL is applied directly to the *mechanical* meter factor, which now becomes a *composite* meter factor.

A volumetric prover may also be used to prove allocation meters. The prover provides a known volume between detector switches, where an oversized displacer moves with the flow, isolating the fluid segment. With the prover in series with the meter being proved, pulses from the meter are gathered on a prover counter, the counter starting and stopping as the displacer activates each switch. Knowing the prover's volume between detector switches, and the amount of pulses, or k-factor, of the meter being proved, we can make the appropriate amount of proving runs and again determine repeatability and meter factor.
Care should be given to verifying the pulse output of the photoelectric transmitter used when proving a positive displacement meter. A means is provided for this verification, utilizing an internal switch within the transmitter, which will activate the gate circuit on the prover counter. With the internal disc having 1000 individual slots, this is sometimes called the 1000 pulse check. The test should show 1000 pulses for each revolution, without fail.

Several things can happen within the proving system that can cause problems that may appear to be meter problems, if you don't know what to look for. Valves that isolate flow streams in and out of the prover and the 4-way divert valve must demonstrate an absolute seal; otherwise, the meter will see more fluid than the prover, and a downward meter factor shift will occur. Since normal meter wear should result in more fluid going around the measuring element and therefore a higher meter factor, a downward factor shift should alert you immediately.

TRANSFER PROVING

A transfer proving is a direct proving of a meter at one location under similar flow and fluid conditions, then installing the meter at another location. Generally, the meter is proved using a volumetric prover. This is common where the fluid production rate is low, and on site proving is not practical. Several different rotation schemes are used, rotating as few as two meters and as many as four. This method is very economical and provides sufficient accuracy, again taking care to operate the meter as it was designed to be.

When a meter is proved in this scenario, it will require 5 of 6 consecutive proving runs, repeatable to within .25%, (.0025). The meter can be proved, then stored, with a time period of six months before putting the meter in service. These meters are given a mechanical meter factor only, and if CPL is needed it will be applied in the field.

CALCULATING THE METER FACTOR

When the desired number of proving runs is obtained within the specified tolerance, the metered volume will be adjusted for temperature and pressure. The base prover must also be adjusted for temperature. Correction factors for CTL are found in API MPMS, Chapter 11, Section 1 for relative density and API gravity. The meter factor is derived by comparing the corrected prover volume to the corrected meter volume.

CORRECTED PROVER VOLUME
Or
CORRECTED MASTER METER VOLUME
(EQUATION 1)
CORRECTED METERED VOLUME

A final compressibility factor may be added to the meter factor, as discussed earlier, if applicable. This factor is omitted from the meter factor if it is applied on the run ticket, if it is applied in the volume determination by the accounting section, or by an on line densitometer.

$$CPL = \frac{1}{1 - (Po - Pe) F} \quad \text{(EQUATION 2)}$$

Where: Po= Operating pressure -PSIG
Pe= Equilibrium pressure of the fluid being metered
F= Compressibility factor for hydrocarbons

When the vapor pressure of the product is at atmosphere or less, then Pe=0.

The basic equations for pipe prover and master meter to calculate meter factor are:

PIPEPROVER

$$MCF = \frac{(BPV) \times (Ctsp) \times (Cpsp) \times (Ctlp) \times (Cplp)}{MR \times (Ctlm \times Cplm)} \quad \text{(EQUATION 3)}$$

MASTER METER

$$MCF = \frac{(MMV) \times (MMF \times Ctlm \times Cplm)}{MR \times (Ctlm \times Cplm)} \quad \text{(EQUATION 4)}$$

NOTE: Ctlm = 1.0000 if the meter is temperature compensated.

Such that:
MMF = Master Meter Factor
MCF = Meter Correction Factor
BPV = Base Prover Volume
MR = Meter Registration
MMV = Master Meter Volume
Ctlp = Correction for the Temperature of the Liquid in the Prover
Cplp = Correction for the Pressure of the Liquid in the Prover
Ctsp = Correction for the Temperature of the Steel in the Prover
Cpsp = Correction for the Pressure of the Steel in the Prover
Ctlm = Correction for the Temperature of the Liquid in the Meter
Cplm = Correction for the Pressure of the Liquid in the Meter
Cplo = Correction for the Pressure of the Liquid in the Meter at Normal Operating Conditions

After double checking all the corrections and calculations, the new meter factor is compared to the previous factor. If a computer is used to perform the calculations, it is wise to check all data entries. Meter factor documentation should be current. If the meter factor is for a new installation or if there has been any changes in conditions or repairs to the system, this should also be recorded.

SAMPLING

A representative sample must be obtained to complete the proving process. This sample is used to correct the metered liquid for the API gravity, (relative density). Samples should be collected by a proportional to flow sampler. When determining the gravity and S&W content of the liquid, calibrated centrifuge tubes and certified hydrometers should be used.

Since questions may arise regarding the quality of a product, samples should be collected at the time of proving, including a third party referee sample to be sent to a laboratory for analysis in the event of a dispute. NGL samples are used to determine the composition of the product. Great care and caution must be used when transferring the collected sample to a transfer cylinder so as not to lose the light ends from the sample. As in a mass measurement system, the volumes are calculated from the component analysis from the sample taken from the composite sampler.

ACCOUNTING PROCEDURES- VOLUMETRIC

Liquid gathering systems where liquids are allocated from a custody transfer point back to locations where initial injection takes place requires volume correction factors to be applied applicably to each initial injection point. These “allocation points” under normal conditions will deliver product under pressure.

Shrinkage Factor

Injection points delivering production to a gathering system under pressure will require a volume correction factor to correct the metered volume to stock tank, or atmospheric conditions. API Chapter 20.1 stipulates the procedures for determining shrinkage factors. , as mentioned previously

Sediment and Water (S&W) Factor

Any stream delivering production to a gathering system will require an S&W determination. This determination will be in accordance with the contract between the parties involved.

AVAILABLE PRODUCTION CALCULATION

The following formula is to be used to calculate theoretical productions, (Available Production) from each injection point to a gathering system:

GROSS METER READINGS (DIFFERENCE)
X
METER FACTOR APPLICABLE DURING THE ACCOUNTING PERIOD
X
SHRINKAGE FACTOR
X
S&W FACTOR

TEMPERATURE CORRECTION

Each gathering system may or may not contractually require temperature correction on initial injection production from allocation points. If required, temperature correction devices may be installed on each location, or temperature correction factors may be used on each stream injecting into the system.

PRESSURE CORRECTION

CPL will be applied as needed during proving and on the run tickets, or as an on-going correction using pressure inputs from the system.

INVENTORIES OR STOCKS

If a gathering system has liquid storage capacity, the volumes stored are known as inventories or stocks. The following formula is to be used to calculate each injection point's Closing Inventories for the accounting period:

Production
+
Opening Inventory
-
Sales

Opening Inventories are simply the previous accounting period's calculated closing inventories. In the case of new injection points during any accounting period, the beginning inventories equal zero.

CORRECTED PRODUCTION

To calculate actual Corrected production for any injection point into an allocation type gathering system, the following formula must be applied:

Sales
+
Closing Inventories
-
Opening Inventories

Sales for any injection point are simply prorated on " Available to Sales" which is calculated by adding Corrected Production to Opening Inventories. This is done to ensure that no negative closing inventories are calculated.

CONCLUSION

When new technology and methods are developed and then accepted by the industry, we should initiate the use of the same. As a measurement technician, you should be motivated to stay abreast of any new developments.

This paper deals with just a few of the many aspects of allocation measurement. To attempt to address such a broad spectrum in such a short amount of time would be impossible.

The complete package of meter provings, analytical data, and the verification of all readout equipment must be proven, not *assumed.*