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CALCULATION OF LIQUID PETROLEUM QUANTITIES
CLASS 2050

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INTRODUCTION

In the Petroleum industry as hydrocarbons are purchased, sold or transferred there are two key elements that must be determined. These elements are the quantity and quality of the hydrocarbon in question. This paper will address one of those elements, the determination of the quantity of the hydrocarbon in the transaction.

The determination of the quantity of hydrocarbon can be further subdivided into:

> Static quantity determination and
> Dynamic quantity determination

Static quantity is determined when the hydrocarbon is measured under non-flowing conditions, such as when contained in a tank, rail car, truck or vessel. Conversely Dynamic quantity determination occurs when the hydrocarbon is measured under flowing conditions.

This paper will address the calculation procedures for petroleum quantities under flowing and non-flowing conditions. The same attention to detail and precision used in determining the primary measurement values (such as temperature and pressure) must be applied to the calculation procedures to maintain the same level of precision.

The petroleum industry has developed standardized calculation methods, which are expressed in the API Manual of Petroleum Measurement Standards.

These standards have undergone extensive revisions, necessitated by the move from mainframe-computers to; PC's, servers, etc. Mainframes and their rigorous (rigid) programming language's, such as Fortran, addressed rules of sequence, rounding and truncation. Whereas the use of different computer languages on different computer hardware did not always yield the same identical results using the same primary measurement values. Therefore the revised standards rigorously specify the equations for computing correction factors, rules for rounding, calculation sequence and discrimination levels, with no deviations allowed. This allows the goal; which is to allow different operators, using different hardware and computer languages the ability to obtain identical results from the same primary measurement data, to be achieved.

REFERENCE (STANDARD) CONDITIONS

The primary measurement data is normally acquired at operating conditions, which vary greatly. Therefore reference or standard conditions have been established, whereby the primary measurement data, at operating conditions, are corrected to reference or base conditions, using correction factors. This allows two or more different parties to make a comparison of different transactions on the same basis.

The reference (base) conditions for the measurement of liquids having a vapor pressure equal to or less than atmospheric at base temperature are as follows:

United States Customary (USC) Units:
Temperature—60.0 °F
Pressure—14.696 psia

International System (SI) Units:
Temperature—15.00 °C
Pressure—101.325 kPa

For liquids having a vapor pressure greater than atmospheric at base temperature, the base pressure shall be the equilibrium vapor pressure at base temperature.

CALCULATIONS, GENERAL

Our goal is to calculate the volume of liquid hydrocarbon (petroleum) involved in the transfer, expressed at reference conditions. We've identified that both primary measurement data (field data) and correction factors are needed to complete our calculation procedure.

The industry standards provide guidance to understanding the relationship of uncertainty and precision as it's used to understand accuracy. There is a natural hierarchy of accuracy in petroleum measurement. This natural hierarchy of accuracy, often referred to as a traceability chain, is comprised of both bias and random uncertainty components.

The uncertainty is dependent not just on the hardware or equipment, but also on the hardware's performance, the software's performance, the method of calculation, the method of calibration, the calibration equipment, the calibration procedures and the human factor. In general the further away from a country's national primary volumetric and/or mass standard an instrument is calibrated against, the higher its uncertainty.

Additionally it should be noted that the discrimination level for calculations is dependent on the discrimination level of the primary measurement device. For example, if a thermometer, graduated in whole °F increments, is used to determine the temperature. Its maximum level of discrimination is 0.5 °F, not 0.1 °F or 0.01 °F.

MEASUREMENT TICKET

The measurement ticket is the legal document that acknowledges the transfer of petroleum liquids. It shall contain all primary (field) data required to calculate the metered quantities. This is also referred to as the Net Standard Volume (NSV). Additionally it documents the agreement between the representatives of the interested parties of the measured quantities and qualities of liquid transferred.

DETERMINATION of LIQUID VOLUME

Our ultimate objective in volume calculations is to determine the Net Standard Volume (NSV). The NSV is defined as the equivalent volume of a liquid at its base conditions that does not include non-merchantable items such as sediment and water. It can further be expressed as:

$$NSV = GSV \times CSW$$

The Gross Standard Volume (GSVm) for meters is the meters indicated volume (IVm) or registration, corrected for the meter's performance factor (MF) and the effect of temperature (CTL) and pressure (CPL) on the liquid density. This can be expressed as the following equation:

$$GSVm = IVm (CTL \times CPL \times MF)$$

The indicated volume (IVm) can be further defined as the difference between the meters opening and closing readings, as shown below:

$$IVm = MRc - MRo$$

Therefore the Net Standard Volume equation can be expressed as:

$$NSVm = [IVm (CTL \times CPL \times MF)] \times CSW$$

The Gross Standard Volume (GSVt) for tanks or other static vessels is the tanks indicated volume (IVt), corrected for the effect of temperature (CTL) on the liquid density. Additional correction factors may include the amount of free water (Cfw); the displacement of the floating roof (Cfr); the effect of temperature on the shell of the tank (Ctsh); and the effect of temperature on the length of the gauging tape (Ctt). This can be expressed as the following equation:

$$GSVt = IVt (CTL)$$
$$Or$$
$$GSVt = GOV (CTL)$$

The indicated volume (IVt) can be further defined as the Total Observed Volume (TOV) in the tank (container) corrected for free water volume, displacement of the floating roof (if applicable), the effect of temperature on the shell of the tank, as shown below:

$$IV = TOV \ (x \ Ctsh) \ (\pm \ Cfr) \ (-Cfw)$$
$$Or$$
$$GOV = TOV \qquad (x \ Ctsh) \ (\pm \ Cfr) \ (-Cfw)$$

In strict accordance with the calculation standard this value is properly referred to as the Gross Observed Volume (GOV). The Total Observed volume (TOV) is determined by adjusting the tank gauge or liquid level determination by the effect of temperature on the length of the gauging tape (Ctt). Using this adjusted level determination and the Tank Capacity Table the TOV is determined.

Therefore the Net Standard Volume equation can be expressed as:

$$NSVt = GSVt \times CSW$$

CORRECTION FACTORS

As we have discussed corrections factors are necessary to correct the measured volume of petroleum liquid to its volume at reference conditions. The NSV equation utilizes multiple types of correction factors depending on whether one is measuring in a static or dynamic mode:

- ♦ Adjusting metered volume to base conditions
- ♦ Adjusting tank volume to base conditions
- ♦ Adjusting for the meter's performance
- ♦ Adjusting for the tank's unique parameters such as Ctsh or Cfr
- ♦ Adjust for non-merchantable quantities

LIQUID DENSITY CORRECTION FACTORS

Liquid density correction factors adjust the metered volume to base conditions to reflect changes in the density due to the effects of temperature and pressure upon the liquid. These factors are:

CTL corrects for the effect of temperature on the liquid density.

CPL corrects for the effect of compressibility on the liquid density.

Correction for the Temperature on the Liquid (CTL)

When petroleum liquid is subjected to changes in it's temperature, its density will increase or decrease as the temperature falls or rises. This change is proportional to the thermal coefficient of expansion of the liquid, which varies with base density and the liquid temperature.
The correction factor used to adjust the metered volumes for the temperature effect is called CTL, which are specified in the Physical Properties standards of either the API MPMS Ch 11.1 or the appropriate ASTM standard (D 1250) for Crude Oils or Refined Products. Various other products, such as LPG, NGL, aromatics have different standards which define their thermal expansion and/or contraction amount.

Correction for the Pressure on the Liquid (CPL)

When petroleum liquids are subjected to changes in pressure, its density will increase or decrease as the pressure increases or decreases. This effect necessitates an adjustment to reflect reference conditions, which is called CPL. This CPL factor is a function of the liquid's compressibility (F), base pressure (Pb), equilibrium vapor pressure (Pe) and the weighted average pressure (PWA). In turn the compressibility (F) is a function of the liquid's base density (RHOb) and weighted average temperature (TWA).

The equations and the compressibility factor's (F) are specified in the API Manual of Petroleum Measurement Standards. The basic correction factor for the effect of pressure on the liquid is calculated from the following equation:

$$CPL = 1/(1 - [PWA - (Pe - Pb)] \times [F])$$

Where:

Pb = base pressure in psi
Pe = equilibrium vapor pressure at operating temperature in psia
PWA = weighted average pressure in psig
F = compressibility factor for the liquid

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METER FACTORS

A meter's performance will change over time, this change can be due to mechanical wear or to a change in the physical properties of the liquid being metered. Therefore a meter is proved or verified to establish its meter factor (MF), which is used to adjust the indicated volume of a meter during a transfer.

During a proving operation the indicated volume of a meter is compared to the precisely known volume in the prover, both corrected to standard conditions. This ratio is called the meter factor (MF). Typically three or more consecutive runs or passes of the displacer, agreeing within a range of 0.05%, constitute a proving. A meter factor is calculated for each run and if within the specified tolerance, the average is the resultant meter factor used for that transfer.

Therefore the meter factor (MF) can be expressed as the following base equation:

$$MF = NPV \div NMV$$

Where:

MF = Meter Factor
NPV = Net Prover Volume
NMV = Net Meter Volume

Let's now look at the development of the net prover volume and the net meter volume and their component parts.

Normally neither the prover nor the metered liquids are at the exact same operating conditions (temperature and pressure). Therefore they need to be corrected back to the volume they would represent at reference conditions so that they can be compared or ratio.

The net prover volume calculation starts with the base prover volume (BPV). The base prover volume is a precisely determined volume, stated at reference conditions, for the calibrated portion of the prover.

The primary method used to determine the BPV is the water-draw calibration method; a secondary method is the master meter or reference prover method. In the water draw method the volume is determined using volumetric field standard test measures, certified by the National Institute of Standards and Technology (NIST).

The process of calibrating a meter prover is a very precise and exacting process, in both the calculations and procedures involved. We will not address this process in this discussion, except to make use of the end result, the base prover volume (BPV). Both the calculations and the process are specified in the industry standards.

The volume of the prover at operating conditions may be more or less than its base prover volume, because of the effect of both temperature and pressure on the steel of the prover and the liquid.
Correction factors are used to adjust the base prover volume for these effects.

The correction factors can be divided into steel correction factors and liquid correction factors as follows:

Steel Correction Factors

CTSp corrects for thermal expansion and/or contraction of the steel in the prover shell due to the average prover liquid temperature.

CPSp corrects for the pressure expansion and/or contraction of the steel in the prover shell due to the average prover liquid pressure.

Liquid Correction Factors

CTLp corrects for the effect of the average prover temperature on the liquid density.

CPLp corrects for the effect of compressibility or average prover pressure

Correction for the effect of Temperature on Steel (CTSp)

Any metal container will change its volume when subjected to changes in temperature. This change in volume is proportional to the cubical coefficient of thermal expansion of the material.

Therefore the CTS for the prover can be calculated from this equation:

$$\text{CTSp} = 1 + [(T - Tb) \times Gc]$$

Where:

Gc = mean coefficient of cubical expansion per degree temperature of the material of which the container is fabricated between Tb and T.

Tb = base temperature

T = mean liquid temperature in the prover

The cubical coefficient of expansion (Gc) may be determined either from the actual material of construction or from nominal tables as published in the industry standards

The above CTS equation needs a slight modification for use with small volume provers, which use externally mounted detectors. This is because the detectors are normally mounted on a different type of metal than the prover shell and which expand/contract differently. The modified equation is as follows:

$$\text{CTSp} = (1 + [(Tp - Tb) \times (Ga)]) \times (1 + [(Td - Tb) \times (Gl)])$$

Where:

Ga = area thermal coefficient of expansion for the prover shell

Gl = linear thermal coefficient of expansion on the displacer shaft

Tb = base temperature

Td = temperature of the detector mounting shaft or displacer shaft

Tp = average temperature of the prover shell

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Correction for the effect of Pressure on Steel (CPSp)

A metal container will change its volume when subjected to internal pressures, because the walls stretch elastically. The amount of change is dependent upon the material's modulus of elasticity, wall thickness and pressure. This adjustment can be calculated from:

$$CPSp = 1 + ([(P – Pb) \times (ID)] \div (E \times WT))$$

Where:
- P = internal operating pressure of prover
- Pb = base pressure
- ID = internal diameter of prover
- E = modulus of elasticity of prover material
- WT = wall thickness of the prover shell

The modulus of elasticity (E) can either be determined for a specific prover or the values contained in the industry standards.

Correction for the effect of Temperature on the Prover Liquid (CTLp)

Correction for the effect of Pressure on the Prover Liquid (CPLp)

These two correction factors are determined in the same manner, as we have previously indicated. However, the temperatures and pressures used must be the weighted averages from the prover variables while in a proving mode.

CALCULATION OF NET PROVER VOLUME (NPV)

Errors and a lowering of the precision can occur when multiplying a large number by a small number repeatedly and in sequencing and rounding differences of mathematical calculations between different machines and programs.

Therefore the industry standards have specified a method that combines correction factors in a specified sequence and maximum discrimination levels. This method specifies that the correction factors are to be multiplied serially and then rounded to the required number of decimal places, before multiplying against the volume component. For example:

$$NPV = BPV \times (CTSp \times CPSp \times CTLp \times CPLp)$$

The net meter volume (NMV) is determined in much the same manner as that used for determining the prover volume. First the meters indicated volume is determined and then it's adjusted or corrected for the effects of the meter's temperature and pressure on the liquid.

The meter's indicated volume is calculated by dividing the pulses generated during a proving run by the meter's nominal pulse per unit volume value or K-factor. This can be expressed as:

$$IVm = N \div KF$$

Where:
    IVm = indicated volume of liquid through the meter
    N   = pulses generated during a proving run
    KF   =nominal pulses per unit volume (K-factor)

Correction for the effect of Temperature on the Liquid in the meter (CTLm)

Correction for the effect of Pressure on the Liquid in the meter (CPLm)

These two correction factors are determined in the same manner, as we have previously indicated. However, the temperatures and pressures used must be the weighted averages from the meter variables while in a proving mode.

CALCULATION OF NET METER VOLUME (NMV)

The same rules and methods whole true for calculating NMV as for NPV. Therefore the correction factors are multiplied serially and rounded before being multiplied against the volume component.

$$NMV = IVm \times [CTLm \times CPLm]$$

CALCULATION OF THE METER FACTOR

Having calculated both the prover and meter volumes and corrected them to the same basis, we can now calculate the meter's performance factor as shown:

$$MF = NPV \div NMV$$

$$MF = [BPV \times (CTSp \times CPSp \times CTLp \times CPLp)] \div [IVm \times (CTLm \times CPLm)]$$

Correction for the effect of Temperature on the Steel Shell of the Tank (Ctsh)

Any metal container will change its volume when subjected to changes in temperature. This change in volume is proportional to the coefficient of area expansion of the material.
Therefore the Ctsh for the tank can be calculated from this equation:

$$Ctsh = 1 + [(T - Tb) \times Ga]$$

Where:
Ga = coefficient of area expansion per degree temperature of the material of which the container is fabricated between Tb and T.
For Carbon Steel: 0.0000124
For Stainless Steel: 0.0000177
Tb = base temperature
T = mean temperature of the tank walls

The mean temperature of the tank walls (T) is determined as follows:

$$T = [(Tl \times 9) + Ta] / 10$$

Where:
Tl = average liquid temperature within the tank at time of gauging
Ta = average ambient temperature around the tank at time of gauging

CORRECTION FOR SEDIMENT AND WATER (CSW)

The last correction factor that must be determined is the adjustment for the non-merchantable component of hydrocarbon liquids such as crude oil or fuel oil. This correction factor is used to adjust the volumes transferred (at reference conditions) for these non-merchantable quantities. This factor can be expressed as follows:

$$CSW = 1 - (\%S\&W/100)$$

SUMMARY

Having determined the meters indicated volume (IVm), corrected for its performance factor (MF) and the effect of temperature (CTL) and pressure (CPL) on the liquid density the volume at standard conditions can now be calculated. This is also referred as Gross Standard Volume (GSVm), as expressed in this equation:

$$GSVm = IVm (CTL \times CPL \times MF)$$

Having determined the tanks observed or indicated volume (IVt), corrected for the effect of temperature (CTL) on the liquid density the volume at standard conditions can now be calculated. Additional correction factors may include the amount of free water (Cfw); the displacement of the floating roof (Cfr); the effect of temperature on the shell of the tank (Ctsh); and the effect of temperature on the length of the gauging tape (Ctt). This is also referred as Gross Standard Volume (GSVt) expressed as the following equation:

$$GSVt = IVt (CTL)$$
or
$$GSVt = [TOV (\times Ctsh \pm Cfr -Cfw)] (CTL)$$

However this represents the total volume of hydrocarbon transferred at reference conditions, including both merchantable and non-merchantable components. We are really interested only in the merchantable portion of the transaction, because after all we only want to pay for hydrocarbons that can add value.

Therefore we have to perform one other calculation, which determines the Net Standard Volume (NSV). The NSV is the equivalent volume of liquid at its base conditions that does not include non-merchantable components, such as sediment and water. The equation is as follows:

$$NSV = GSV \times CSW$$

Or

For Meters
$$NSV = [IV \times (CTL \times CPL \times MF)] \times CSW$$

For Tanks
$$NSV = [[TOV (\times Ctsh \pm Cfr -Cfw)] (CTL)] \times CSW$$

The calculation of petroleum quantities requires an exacting attention to detail and precision not only in the calculation process, but also in the underlying supporting processes, such as the primary measurement value determination, calibration of instrumentation such as temperature and pressure transmitters, tank calibration, gauge tape verification or calibration, density meters and/or thermohydrometers, and meter provers.

The final output of the calculation process for volumes almost always has one more calculation performed, which is the translation from a volume expression of the transaction to a financial monetary expression. Therefore this illustrates the critical importance that the parties involved in the transaction have a clear understanding of their mutual agreements and the need for an audit trail and security of the entire data handling and calculation process. No changes, unilateral or not, by one party are acceptable without the agreement of all parties involved prior to any changes.