CHAPTER 3

Petroleum Quantity Calculation

3.1 Calculated Data

The data points presented in Table 3-3 are necessary for the calculation process and are calculated or extracted using the input data from Table 3-1.

The input or observed data in Table 3-1 must be gathered as a first step in the calculation process.

Table 3-1 Significant Digits

Units	No,of Decimals	Units	No,of Decimals
Liters	...,xxx.0	API Gravity @ 60 F	xxx.x
Gallons	...,xxx.xx	CTL	x.xxxx
Barrels	...,xxx.xx	Density lbs / gl	xx.xxx
Cubic meters	...,xxx.xxx	Density kg / m^3	xxx.x
Pounds	...,xxx.0	Relative density	x.xxxx
Kilograms	...,xxx.0	S & W %	xx.xxx
Short tons	...,xxx.xxx	Temperature F	xxx.x
Metric tons	...,xxx.xxx	TSh (See page 7)	xxx.0
Long tons	...,xxx.xxx	CTSh	x.xxxxx

3.2 Abbreviations

The designation of corrections and correction factors by abbreviations rather than words is recommended to abbreviate the expression, facilitate, algebraic manipulation, and reduce confusion. Definitions are listed in 3.2.1 – 3.2.15.

3.2.1. CSW: Correction for sediment and water.

3.2.2. CTL: Correction for temperature of the liquid. Compensates for the effect of temperature on a liquid. Corrects a volume at an observed temperature to a standard temperature. This is the same as VCF.

3.2.3. CTSh: Correction for temperature of the shell. The correction factor for the effect of the temperature, both ambient and liquid, on the shell of the tank.

3.2.4. FRA: Floating roof adjustment. The adjustment made to offset the effect of the displacement of the floating roof.

3.2.5. FW: Free water quantity deduction (may include bottom sediments). The water present in a container that is not suspended in the liquid hydrocarbon.

3.2.6. GOV: Gross standard volume. The total volume of all petroleum liquids and sediment and water, excluding free water, at observed temperature and pressure.

3.2.7. GSV: Gross standard volume, The total volume of all petroleum liquids and sediment and water, excluding free water, corrected by the appropriate volume correction factor (CTL) for the observed temperature and API gravity, relative density, or density to a standard temperature such as 60 $^{\circ}$F or 15 $^{\circ}$C.

3.2.8. NSV: Net standard volume. The total volume of all petroleum liquids, excluding sediment and water and free water, corrected by the appropriate volume correction factor (CTL) for the observed temperature and API gravity, relative density, or density to a standard temperature such as 60 °F or 15 °C.

3.2.9. TCV: Total calculated volume. The total volume of all petroleum liquids and sediment and water corrected by the appropriate volume correction factor (CTL) for the observed temperature and API gravity, relative density, or density to a standard temperature such as 60°F or15°C and all free water measured at observed temperature (gross standard volume plume plus free water).

3.2.10. TOV: Total observed volume. Total measurement volume of all petroleum liquids, sediment and water, free water, and bottom sediments at observed temperature.

3.2.11. TSh: Temperature of the tank shell.

3.2.12. VCF: Volume correction factor. This is the same as CTL. These two symbols are interchangeable. CTL is used in all equations in this standard.

3.3 Calculation of Gross Observed Volume (GOV)

To calculate the GOV for shore tanks, deduct any free water (FW) from the total observed volume (TOV) and multiply the result by the tank shell temperature correction (CTSh); then, apply the floating roof adjustment (FRA), where applicable.

$$\text{GOV} = \left[(\text{TOV} - \text{FW}) \times \text{CTSh} \right] \pm \text{FRA} \qquad (3\text{-}1)$$

3.3.1 Total Observed Volume (TOV)

The TOV is obtained form the shore tank' s capacity table and is entered with the observed innage (depth of a liquid in a tank) or ullage.

Note: Tank volume measurements can be made using the tank strapping/linear measurement function. Based on the level of product in a tank, the conversion can be used to determine the corresponding volume quantity. International Standard ISO 7507-1 will serve as a guide for determining tank volume quantities.

Table 3-2 Observed Data

Shore Tanks	Marine Vessel's Tanks
Recorded reference gauge height a height	Recorded reference gauge
Observed reference gauge height height	Observed reference gauge
Innage or ullage of liquid level	Innage or ullage of liquid level
Innage or ullage of free water level level	Innage or ullage of free water
Average tank temperature $^{\circ}$F or $^{\circ}$ C $^{\circ}$C	Average tank temperature $^{\circ}$F or
Density @ tank temperature	Density @ tank temperature
Percentage of sediment and water water	Percentage of sediment and
Ambient air temperature	Forward draft reading
	After draft reading List

Table 3-3 Calculated Data

Shore Tanks	Marine Vessel's Tanks
Density @ tank temperature	Vessel 's trim
Floating roof correction	Density @ tank temperature
Tank shell temperature correction	Trim correction and list correction
Total observed volume	Total observed volume
Free water volume	Free water volume
Correction for temperature of liquid	Correction for temperature of liquid
Free water volume	Free water volume
Correction for temperature of liquid	Correction for temperature of liquid
Gross standard volume	Gross standard volume
Sediment and water (volume or factor)	Sediment and water (volume or factor)
Net standard volume	Net standard volume
Weight conversion factor	Weight conversion factor
Apparent mass (weight in air)	Apparent mass (weight in air)
Mass (weight in vacuum)	Mass (weight in vacuum)

3.3.2 Adjustment for Presence Of Free Water (FW) and Tank Bottom Sediments

It is necessary to determine the amount of FW and bottom sediments, if any, before and after each product movement into or out of a tank so that the appropriate corrections can be made. This adjustment (FW) will always be in the form of a volumetric deduction. The amount of the deduction can be determined by converting the FW level gauge to a volume through use of the tank 's capacity table.

3.3.3 Correction for the Effect of Temperature on the Steel Shell of the Tank (CTSh)

Any tank, when subjected to a change in temperature, will change its volume accordingly. Assuming that they have been calibrated in its accordance with API MPMS Chapter 2, upright cylindrical tanks have capacity tables based on a specific tank shell temperature. If the observed tank shell temperature differs form the capacity table tank shell temperature, the volumes extracted from that table will need to be corrected accordingly.

Storage tanks differ from test measures in size and wall thickness. Differences also occur because the tanks cannot readily be sheltered from the elements. Therefore, ambient temperatures as well as product temperatures must be considered when calculating an appropriate correction for the effect of temperature on the shell of the tank. The correction factor for the effect of temperature on the shell of the tank is called CTSh and may by the following: Cross-sectional area correction,

$$CTSh = 1+2\alpha\Delta T + \alpha^2\Delta T^2 \qquad (3\text{-}2)$$

Where:

α = Linear coefficient of expansion of the tank shell material [see note4]

ΔT = Tank Shell Temperature (TSh) - Base Temperature (T_B)

Note 1: Base Temperature (T_B) is the tank shell temperature for which the capacity table volumes were calculated to in the U.S., this is usually 60°F

Note 2: The base temperature is usually stated on the capacity table. If this is not the case, contact the company that generated the table. Some capacity tables make reference to an operating product temperature; this should not be confused with the base temperature, which is a tank shell temperature.

Note 3: When calculating ΔT it is important to maintain the arithmetic sign as this value can be positive or negative and must be applied as such in the CTSh formula.

Note 4: See Table B-2 Appendix B for linear expansion coefficients of various metals.

3.3.3.1 For non - insulated metal tanks, the temperature of the shell may be computed as follows (refer to Appendix B):

$$T_S = \left[(7 \times T_L) + T_a \right] \div 8 \qquad (3\text{-}3)$$

Where:

T_L = liquid temperature.

T_a = ambient temperature.

3.3.3.2 For insulated metal tanks, the temperature of the shell may be taken as closely approximating the adjacent liquid temperature, in which case, $T_s = T_L$

3.3.3.3 In applying these principles to upright cylindrical tanks, the horizontal cross-sectional area may be taken as a function of tank calibration. The coefficient determined from Equation 1 is predicated on a thermal expansion for low-carbon steel per degree $^{\circ}F$.

Note: The cross-sectional correction (Equation 1) will have to be modified for stainless steel tanks based upon the coefficient of expansion for the type of stainless steel.

3.3.3.4 The third dimension needed to generate volume-height is a function of gauging and should be considered separately. The volumes reflected on tank tables are derived form area times incremental height, Therefore, K- factors for correction of areas have the same ratio as volume corrections and may be applied directly to tank table volumes.

3.3.3.5 The shell temperature correction factor is to be applied to volumes obtained from capacity tables that are at 60 $^{\circ}$F and are unrelated to the corrections designed to account for volume expansion and contractions of the product itself. Depending upon certain requirements, this shell temperature correction factor may by built into the capacity table for a specific operating temperature.

3.3.4 Floating Roof Adjustment (FRA)

The displacement of liquid petroleum product in a tank resulting from a floating roof will be taken into account when calculating volume using tank strapping/Linear measurement function. A critical height can be defined, below which dips cannot be taken, or a special conversion is required.

The correction for the displacement of the floating roof can be addressed in one of two ways:

a. If the roof correction is calculated into the tank capacity table using a reference density, a secondary correction must be calculated for any difference between the references. Such tables will contain a notation similar to the following.

b. If the capacity table has been prepared as a table of gross or open-tank capacity, commonly referred to as a shell capacity table, the roof deduction is calculated by dividing the weight of the floating roof by the weight per unit volume at standard temperature multiplied by the CTL to bring this to observed conditions.

$$\text{Roof correction} = \frac{\text{Weight (apparent mass) of roof}}{\text{Density} \times \text{CTL}} \quad (3\text{-}4)$$

Note: The density units must be consistent to both the CTL and the units of the roof weight, in addition to being a density in air. For example, if the density is lbs/gal @ 60 ^{o}F, then the roof weight must be in pounds and the CTL applicable to standard temperature of 60 ^{o}F. Additionally, this particular example will yield a roof correction in gallons. If the table units are in barrels, it will be necessary to divide the result by 42.

Note: No floating roof correction will be accurate if the liquid level falls inside the floating roof's critical zone regardless of table style.

Note: If significant amount of water, ice, or snow is present on a floating roof, it should either be removed or its weight estimated and calculated into the roof correction.

Note: Roof corrections are not applicable for volumes below the critical zone.

3.4 Calculation of Gross Standard Volume (GSV)

The GSV is calculated by multiplying the GOV by the correction for the effect of temperature on liquid (or volume correction factor).

$$GSV = GOV \times CTL \tag{3-5}$$

3.5 Correction for the Effect of Temperature on a Liquid (CTL) or Volume Correction Factor (VCF)

If a quantity of oil is subjected to a change in temperature, its volume will increase as the temperature rises or decrease as the temperature falls. The volume change is proportional to the thermal coefficient of expansion of the liquid, which varies with varies with density (API gravity) and temperature. The correction factor is to adjust the volume of liquid at observed temperature to its volume at a standard temperature. The most common standard temperatures are 60 ^{o}F, 15 ^{o}C, and 20 ^{o}C (68 ^{o}F).

These correction factors can be obtained from the petroleum measurement tables, which can found in API MPMS Chapter 11.1, ASTM D-1250, or IP –200. These tables are entered with the observed average temperature and an API gravity at 60 °F, a density at 5 °C a relative density at 60°F/ 60°F, or a coefficient of thermal expansion. To determine which table is applicable, refer to Table 3-3.

Many products, especially petrochemicals, may have specific volume correction factor tables, developed by the manufacturer. These individual tables have their application is the same. The use of these tables should by mutual agreement of all parties concerned.

These correction factors uses a convergence technique to determine the API gravity at 60°F that corresponds to an API gravity observed at some temperature other than 60°F. Since the equations are expressed in terms of density, the API gravity is converted to density by following relationship:

$$\rho_T = \frac{141.5 * 999.012}{131.5 + API} \tag{3-6}$$

Where ρ_T = density at temperature t

API = observed API gravity

999.012 = density of water at 60 °F, Kg/m^3

The coefficient of thermal expansion at the base temperature, 60°F, is related to the density at the base temperature by

$$\alpha_{60} = \frac{K_0}{\rho^2_{60}} + \frac{K_1}{\rho_{60}} \tag{3-7}$$

The values of ρ_T and α_{60} are used in the volume correction faction equation to compute ρ_{60}.

$$VCF = \frac{\rho_T}{\rho_{60}} = EXP\,[-\alpha_{60}\Delta t\,(1 + 0.8\,\alpha_{60}\Delta t)] \tag{3-8}$$

$$\text{Thus}\quad \rho_T = \rho_{60}\,EXP\,[-\alpha_{60}\Delta t\,(1 + 0.8\,\alpha_{60}\Delta t)] \tag{3-9}$$

Where ρ_{60} = density at the base temperature

$$\Delta t = t - 60.0 \tag{3-10}$$

3.5.1 Parameter Determination and Results

The values of K_0 and K_1 were established for each major group from a simultaneous nonlinear regression of all data points within that group to Equations (3-7) and (3-8). In this case the parameters were K_0 and K_1 for the group and the vector of 60 °F densities for each sample. See Table 3-4.

Table 3-4 Constant Values for Calculate Thermal Expansion

$$\alpha_T = \frac{K_0 + K_1\rho_T}{\rho_T^2}$$

Table	Product	Density Range °API	Constant
6A	Crude Oil	0.0 – 100.0	K_0 = 341.0957 K_1 = 0.0
5B,6B	Fuel Oil	0.0 - 37.0	K_0 = 103.8720 K_1 = 0.2701

Table 3-4 Constant Values for Calculate Thermal Expansion (continues)

$$\alpha_T = \frac{K_0 + K_1 \rho_T}{\rho_T^{\,2}}$$

Table	Product	Density Range °API	Constant
5B	Jet Group	37.1– 50.0	K_0 = 330.3010 K_1 = 0.0
6B	Jet Group	37.1– 48.0	K_0 = 330.3010 K_1 = 0.0
5B	Gasolines	50.1 – 85.0	K_0 = 192.4571 K_1 = 0.2438
6B	Gasolines	52.1 – 85.0	K_0 = 192.4571 K_1 = 0.2438

These table gives the values of API gravity at 60 °F corresponding to an API hydrometer reading at observed temperatures other than 60 °F. In converting the API hydrometer reading at the observed temperature to the corresponding API gravity at 60 °F, two correction are necessary: the first arises from the change in volume of the glass hydrometer with temperature (stem correction) and the second from the change in volume of the products with temperature. Both have been applied in this table. The value of API gravity at 60 °F in these table are the result of this program which is the standard.

The temperature ranges of these table are:

°API	°F
0 - 40	0 - 300
40 – 50	0 – 250
50 – 85	0 – 200

The values of API gravity at 60 °F given in this table are based on data from the U.S. National Bureau of Standards and from other published data. Portions of the gravity and temperature ranges represent area s beyond these data. Thus, mathematical techniques were employed to extrapolate beyond the gravity and temperature ranges of the given data to determining the value of API gravity at 60 °F for these areas.

3.5.2 Hydrometer Corrections

Table 5B must be entered with an API hydrometer reading measured with a soft glass hydrometer calibrated at 60 °F and with an observed temperature.

A correction to the glass hydrometer reading has been incorporated into the table to account for the thermal expansion of glass. The hydrometer constant, as defined in the Report on the Development, Construction, Calculation, and Preparation of the ASTM – IP Petroleum Measurement Table (196), varies with temperature according to the following:

$$HYC = 1 - 0.00001278(t - 60^{\circ}F) - 0.0000000062(t - 60^{\circ}F)^2 \qquad (3\text{-}11)$$

3.5.3 Method of calculation

Step 1: Round input variables

a) Round API gravity to nearest 0.1

API = XXX.X rounded

b) Round observed temperature to nearest 0.1

T = XXX.X rounded

Step 2: Calculate difference in observed temperature and base temperature and base temperature

From equation (10):

Base Temperature = 60.0

Δt = T – 60.0

Δt = XXX.X – 60.0

Step 3: Compute hydrometer correction term (optional)

From equation (11):

HYC = 1.0 – .00001278 * Δt - .0000000062 * Δt^2

Term1 = .00001278 * Δt = .00XXXXXX rounded

Term2 = .0000000062 * Δt^2 = .00XXXXXX rounded

HYC = X.XXXXXXXX

Step 4: Convert API gravity to density, Kg/m^3

From equation (6):

$$\rho = \frac{141.5 * 999.012}{131.5 + API}$$

ρ = 141360.1980 / XXX.X = XXX.XX rounded

Step 5A: Application of hydrometer correction

$\rho_T = \rho$ * HYC = XXXX.XX

Step 5B: Initialize 60 °F density

$\rho_{60} = \rho_T$ = XXX.XX

Step 6A: Calculate coefficient of thermal expansion

From equation (7):

$$\alpha_{60} = \frac{K_0 + K_1 \rho_{60}}{\rho_{60}^2}$$

K_0 = XXXX.XXXX

K_1 = .XXXX

Term1 = K_0 / ρ_{60} = .XXXXXXXX truncated.

Term2 = Term1/ ρ_{60} = .00XXXXXXXX truncated.

Term3 = K_1 / ρ_{60} = .00XXXXXXXX truncated.

α_{60} = Term2 + Term3 = .000XXXX rounded.

Step 6B: Calculated of α_{60} for straight line segment

$$\alpha_{60} = A + \frac{B}{\rho_{60}^{2}}$$

Term1 = B / ρ_{60} = X.XXXXXX truncated.

Term2 = Term1/ ρ_{60} = .XXXXXXXX rounded.

α_{60} = A+ Term2 = .000XXXX rounded

Step 7: Calculate volume correction factor

From equation (8):

$$VCF = EXP\,[-\,\alpha_{60}\Delta t\,(1 + 0.8\,\alpha_{60}\Delta t)]$$

a) calculate exponent

Term1 = α_{60} * Δt = .XXXXXXXX truncated

Term2 = 0.8 * Term1 = .XXXXXXXX truncated

Term3 = Term1 * Term2 = .XXXXXXXX rounded

Term4 = -Term1 – Term3 = .XXXXXXXX

b) calculated exponential

VCF = EXP (Term4) = X.XXXXXX rounded

Step 8: Calculate exponential

$$\rho_{60} = \frac{\rho_T}{VCF} = XXXX.XXX$$

Since the equation for ρ_{60} cannot be solved explicitly, a successive approximation iterative scheme is used to obtain a solution. The initial estimate of ρ_{60} is the value of the density at observed temperature t. This approximation is substituted into the right hand side of the equation to obtain a second value approximation. This process of substituting into the right hand side of the equation and estimating a new value from the other is repeated until two consecutive results are in agreement to the desired degree of accuracy. For table 5B, a converged solution is reached when the change in density is less than 0.05 Kg/m^3 in two successive passes. If the computed value of the 60 °FAPI gravity is not on the same curve as the observed API gravity, the parameter K_0 and K_1 used to determine the coefficient of thermal expansion must be redefined and the convergence technique repeated. A straight line interpolation is used to connect the jet fuel curve with gasoline curve when the solution is between 48 and 52 °API. When this occurs, the coefficient of thermal expansion is defined as:

$$\alpha_{60} = A + \frac{B}{\rho_{60}^2} \qquad (3\text{-}12)$$

Where A = -.00186840

B = 1489.0670

In this case, the tolerance is increased to 0.07 Kg/m^3.

3.6 Sediment and Water (S & W)

Crude oil and some liquid petroleum products contain sediment and water suspended or entrained throughout that fluid. The quantity of sediment and water is determined by laboratory analysis of a representative sample and is expressed as a percentage, usually volume percent. For information on how sediment and water analysis is performed, refer to API MPMS Chapter 10 or its ASTM equivalents.

When automatic sampling systems are employed for product transfer, tanks with varying densities (crude oil systems, for example) will need to accumulate base data differently, than for transfers that do not include the use of an automatic sampler. While the volume calculation procedures for movements into a tank involving an automatic sampling system will be the same, the method of collecting the base information will be different. (Movements out of a tank are less affected as there is less blending of densities taking place.) However, it may by necessary to report the density, as determined from the automatic sampling system, somewhere on the measurement ticket or report. Regardless, it will still be necessary to sample the tank before and after a receipt because of the following:

At the beginning of the transfer, there is nothing in the sampler and therefore nothing on which to base opening measurements.

After the transfer, the incoming product has been blended with whatever was in the tank. In order for CTL and FRA to be correct, they will have to be based on the density of the product as found in the tank

The tank's FW level must be left the same on the closing report as on the opening report. All deducted water volumes should come from the sampler and be accounted for in the form of correction for S & W (CSW).
S & W are usually only deducted on crude oil cargoes. Petroleum products are not usually corrected for S & W unless required as a commercial condition or other specific required as a commercial condition or other specific requirement; therefore net standard volume = GSV.

3.7 Calculation of Net Standard Volume (NSV)

To calculate NSV, multiply the GSV by the CSW.

$$NSV = GSV \times CSW \tag{3-13}$$