Electronic Liquid Flow Computer

Smith Meter® microFlow.net Liquid

Calculations

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Bulletin TP06006

microFlow.net

Caution

The default or operating values used in this manual and in the program of the microFlow.net are for factory testing only and should not be construed as default or operating values for your metering system. Each metering system is unique and each program parameter must be reviewed and programmed for that specific metering system application.

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Volume Calculations

Volume Calculations for Indicated Volume

$$\text{Indicated Volume} = \frac{\text{Input Pulses}}{\text{K Factor}}$$

Volume Calculations for Gross

$$\text{Gross Volume} = \frac{\text{Meter Factor} \times \text{Input Pulses}}{\text{K Factor}}$$

Volume Calculations for Gross @ Standard Temperature (GST)

$$\text{GST Volume} = \frac{\text{CTL} \times \text{Meter Factor} \times \text{Input Pulses}}{\text{K Factor}}$$

Volume Calculations for Gross Standard Volume (GSV)

$$\text{GSV Volume} = \frac{\text{CTPL} \times \text{Meter Factor} \times \text{Input Pulses}}{\text{K Factor}}$$

Mass Calculations

A.

$$\text{Mass} = \text{Gross Volume} \times \text{Observed Density}$$

or

$$\text{Mass} = \text{GST} \times \text{Reference Density}$$

B. Mass calculation using reference density

1. Program entry conditions

   a. A non-zero reference density entry.

   b. Valid density units select entry.

   c. Valid entries for GST compensation.

   d. Mass units

2. Hardware conditions

   a. A temperature probe installed. (*Note:* Maintenance temperature may be used instead of a temperature probe.)

3. Definition

   With this method the reference density and GST volume are used to calculate the mass. Therefore, the reference density program code must contain a non-zero entry, temperature must be installed, and GST compensation must be available.

4. Calculation method

$$\text{Mass} = \text{GST Volume} \times \text{Reference Density}$$

C. Mass calculation using a Densitometer

1. Program entry conditions

   a. Valid density units select entry.

   b. Valid densitometer configuration entries.

   c. Mass units.

2. Hardware conditions

a. A densitometer installed.

3. Definition

This method uses the densitometer input as the line density for calculating mass totals.

4. Calculation method

$$\text{Mass} = \text{Gross Volume} \times \text{Observed Density}$$

Meter Factor Linearization Calculations

The non-linearity of the meter calibration curve for each product can be approximated through use of a linearization method by entering meter factors at up to four different flow rates.

The meter factors used will be determined from a straight line interpolation of the meter factor and its associated flow rate.

Graphically, the linearization method used can be represented as a point slope function between points:

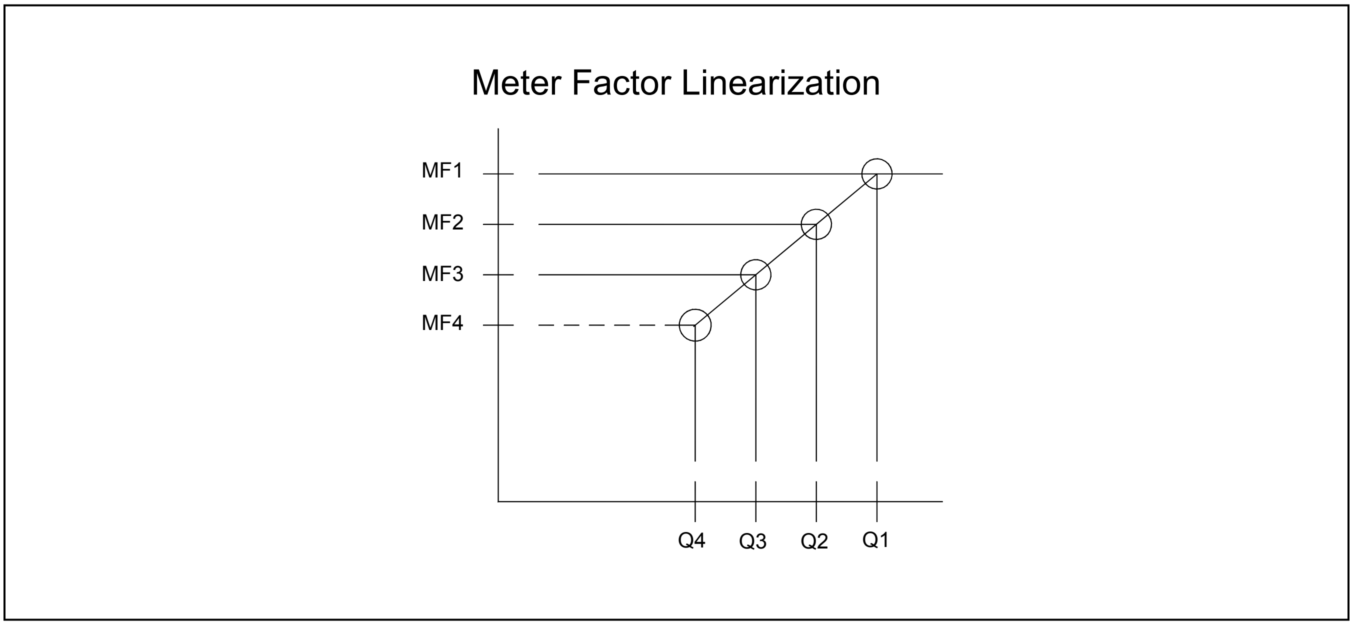

Figure 1. Meter Factor vs. Flow Rate

where: MF1, MF2, MF3, MF4 = meter factors 1, 2, 3, and 4
Q1, Q2, Q3, Q4 = associated flow rates 1, 2, 3, and 4

The number of factors used is determined by the programming. Up to four factors are available at corresponding flow rates. (See the meter factors and flow rate program codes.)

The input meter pulses may also be monitored by the unit to verify the integrity of the meters and/or transmitters. This is accomplished through pulse comparator circuitry. The pulse comparator verifies the integrity of the meter and the voltage sense verifies the integrity of the transmitter. The type and resolution of the pulse input stream to the unit is also programmable.

The input resolution, pulse and transmitter integrity, meter factors and their controls and adjustments may be defined through use of program parameters.

Section III – Meter Factor Linearization Calculations

A. Calculations for meter factors between the flow points:

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

where:

m = slope (to be calculated)

y_2 = Meter factor at the lower flow rate

y_1 = Meter factor at the higher flow rate

x_1 = Flow rate for the meter factor of y_1

x_2 = Flow rate for the meter factor of y_2

B. After calculating *m*, calculate the straight line equation:

$$y - y_1 = m(x - x_1)$$

so

$$y = m(x - x_1) + y_1$$

where:

x = the present flow rate
y = the unknown meter factor.

C. Meter Factor calculating methods

1. The four-point linearization method uses four sets of the flow rate and associated meter factor program codes.

Method:

1. From zero to factor 4 flow, factor 4 will be used.
2. Linearize from factor 4 flow to factor 3 flow.
3. Linearize from factor 3 flow to factor 2 flow.
4. Linearize from factor 2 flow to factor 1 flow.
5. From factor 1 flow up, factor 1 will be used.

2. The three-point linearization method uses three sets of the flow rate and associated meter factor program codes.

   Method:

   1. From zero to factor 3 flow, factor 3 will be used.
   2. Linearize from factor 3 flow to factor 2 flow.
   3. Linearize from factor 2 flow to factor 1 flow.
   4. From factor 1 flow up, factor 1 will be used.

3. The two-point linearization method uses two sets of the flow rate and associated meter factor program codes.

   Method:

   1. From zero to factor 2 flow, factor 2 will be used.
   2. Linearize from factor 2 flow to factor 1 flow.
   3. From factor 1 flow up, factor 1 will be used.

4. The single-point method uses one meter factor program code.

   Method:

   1. Factor 1 will be used at all flow rates.

Section IV – Temperature Calculations

Volume Correction for Temperature (CTL) Calculation

1. Volume correction factor terms, formulas and constants:

a) Definition of terms

t = Actual Temperature - Reference Temperature

k_0 and k_1 = API product range constants

A and B = API product special range constants

$_{t}$ = density @ actual temperature

$_{60}$ = density @ reference temperature

= coefficient of expansion

b) Formulas used

1. calculation

a. Using k_0 and k_1 constants

$$\alpha = \frac{k_0}{\rho_{60}^{2}} + \frac{k_1}{\rho_{60}}$$

b. Using A and B constants

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

2. CTL calculation

$$\frac{\rho_t}{\rho_{60}} = e^{(-\alpha \ x \ \Delta t \ (1 + 0.8\alpha \ x \ \Delta t \ ))}$$

3. $_{t}$ calculation

$$\rho_t = \rho_{60} \ x \ e^{(-\alpha \ x \ \Delta t \ (1 + 0.8\alpha \ x \ \Delta t \ ))}$$

4. API to density calculation

$$\rho_{60} = \frac{141.5 \ x \ \text{weight of water at ref. conditions}}{131.5 + \text{API}}$$

5. Relative density to density calculation

$$\rho_{60} = \text{Relative Density x Weight of water at reference conditions}$$

c) Constants used

1. Weight of water at reference conditions

Weight	Temperature
999.102 Kg/M^3	15 C
62.367 Lbs/Ft^3	60 F

2. k_0 and k_1 constants for different API products

API Table	Range	k_0	k_1
5A, 6A, 23A, 24A, 53A and 54A Crude Oils	API -10 to 100 RD 0.6112 to 1.1646 DEN 38.12 to 72.63 LB/F^3 DEN 610.6 to 1163.5 KG/M^3	341.0957	0.0
5B, 6B, 23B, 24B, 53B and 54B Diesel, Heating and Fuel Oils	API -10 to 37.1 RD 0.8391 to 1.1646 DEN 52.33 to 72.63 LB/F^3 DEN 838.3 to 1163.5 KG/M^3	103.8720	0.2701
5B, 6B, 23B, 24B, 53B and 54B Jet Fuels and Kerosene	API 37.1 to 48.0 RD 0.7883 to 0.8391 DEN 49.16 to 52.33 LB/F^3 DEN 787.5 to 838.3 KG/M^3	330.3010	0.0
5B, 6B, 23B, 24B, 53B and 54B Gasolines and Napthanes	API 52.0 TO 100 RD 0.6112 to 0.7711 DEN 38.12 to 48.09 LB/F^3 DEN 610.6 to 770.3 KG/M^3	192.4571	0.2438
5D, 6D, 23D, 24D, 53D and 54D Lube Oils	API -10 to 45 RD 0.80168 to 1.1646 DEN 50.00 TO 72.63 LB/F^3 DEN 800.9 TO 1163.5 KG/M^3	0.0	0.34878
23	API 89 to 205 RD 0.42 to 0.64 DEN 26.22 to 39.95 LB/F^3	N/A	N/A
23E and 24E Light Hydrocarbons	RD 0.3500 to 0.6880	N/A	N/A
53	API 89 to 205 RD 0.42 to 0.64 DEN 420.0 to 640.0 KG/M^3	N/A	N/A
59A and 60A Crude Oils	API 0 to 100 RD 0.6110 to 1.0760 DEN 38.11 to 67.11 LB/F^3 DEN 610.5 to 1075.0 KG/M^3	613.9723	0.0

API Table	Range	k_0	k_1
59B and 60B Diesel, Heating, and Fuel Oils	API 0 to 37 RD 0.8400 to 1.0760 DEN 52.38 to 67.11 LB/F^3 DEN 839.0 to 1075.0 KG/M^3	186.9696	0.4862
59B and 60B Jet Fuels and Kerosenes	API 37.1 to 47.9 RD 0.7890 to 0.8395 DEN 49.19 to 52.35 LB/F^3 DEN 788.0 to 838.5 KG/M^3	594.5418	0.0
59B and 60B Gasolines and Napthanes	API 52.1 TO 85 RD 0.6535 to 0.7705 DEN 40.77 to 48.07 LB/F^3 DEN 653.0 to 770.0 KG/M^3	346.4228	0.4388
59D and 60D Lube Oils	API -10 to 45 RD 0.8008 to 1.1652 DEN 49.94 TO 72.67 LB/F^3 DEN 800.0 TO 1164.0 KG/M^3	0.0	0.6278
BR1P and BR2P (API tables for Brazil)	RD 0.498 to 0.9693	N/A	N/A

3. A and B constants (Special Range)

API Table	Range	A	B
Special Range (F)	API 48 to 52 RD 0.7711 to 0.7883 DEN 48.09 to 49.16 LB/F^3 DEN 770.3 to 787.5 KG/M^3	-0.00186840	1489.0670
Special Range (C)	API 48 to 52 RD 0.7711 to 0.7883 DEN 48.09 to 49.16 LB/F^3 DEN 770.3 to 787.5 KG/M^3	-0.0336312	2680.321

4. Old Tables 6, 24 and 54

Note: *This is the range for the look-up table. Above this range, an algorithm is used.*

API Table	Range
6	API 100 to 150 RD 0.5000 to 0.6000 DEN 31.18 to 37.42 LB/F^3
24	API 100 to 150 RD 0.5000 to 0.6000 DEN 31.18 to 37.42 LB/F^3
54	API 100 to 150 RD 0.5000 to 0.6000 DEN 499.5 to 599.4 KG/M^3

Section IV – Temperature Calculations

Volume Correction Factor Calculation Options

A. Coefficient of expansion used (table 6C or 54C)

1. Program entry conditions
   a. Correct entry in API table (Parameter 412)
   b. Valid entry in reference density (Parameter 413)

2. Hardware conditions
   a. A temperature probe installed.

   *(**Note:** Maintenance temperature may be used instead of a temperature probe.)*

3. Calculation method
   a. Input temperature units.
   b. Calculate delta t (t).
   c. Coefficient of expansion entry (Parameter 413) will be used as alpha.
   d. Calculate the CTL.

$$CTL = e^{(-\alpha \times \Delta t\,(1\,+\,0.8\alpha\,\times\,\Delta t))}$$

B. API tables with API product range A, B, or D (with reference density)

1. Program entry conditions:
   a. A valid API table entry (Parameter 412).
   b. A valid reference density entry (Parameter 413).
   c. A valid density units entry (Parameter 411).
   d. A valid temperature units entry (Parameter 401).
   e. A valid reference temperature entry (Parameter 402).

2. Hardware conditions:
   a. A temperature probe installed.

   *(**Note:** Maintenance temperature may be used instead of a temperature probe.)*

3. Definition:

   In this mode of operation, the microFlow.net software will calculate the CTL using the k_0 and k_1 constants of the API product range selected. (If API product range B is selected, it will use the k_0 and k_1 constants for the product range it is measuring.) All related entries shown above must correspond. If table 53 or 54 is used, the temperature units must be in Celsius.)

4. Calculation method for reference density at 60°F
   a. Input temperature units.
   b. Calculate delta t (t).
   c. Calculate the alpha and the CTL using the reference density entered.
      1. Calculate alpha with the proper k_0 and k_1 constants for API product range selected.
      2. Calculate CTL.
   d. Calculate the CPL.
   e. Calculate the CTPL.

$$CTPL = CTL \times CPL$$

5. Calculation method for reference density at 15°C or 20°C.
   a. Calculate the correction factors (CTL_{60}) for the density at 60°F (p60) corresponding to the metric base density at the metric base temperature (15°C or 20°C) using the procedure defined in step C.4.
   b. Using the calculated base density at 60°F (p60), calculate the CTL* to correct the live density using the procedure defined in step B.4.
   c. Calculate the CTL to correct the volume to the metric base temperature.

$$CTL = CTL^*/CTL_{60}$$
$$CTPL = CTL \times CPL$$

*(**Note:** * indicates an intermediate CTL value used for the CTL calculation per API Chapter 11.1.)*

C. API tables with API product range A, B, or D (live density)

1. Program entry conditions:
   a. A valid API table entry (must be an odd-numbered table) (Product Parameter 412).
   b. A valid density units entry (Parameter 411).
   c. A valid temperature units entry (Parameter 401).
   d. A valid reference temperature entry (Parameter 402).

2. Hardware conditions
   a. A temperature probe installed.
   *(**Note:** Maintenance temperature may be used instead of a temperature probe.)*
   b. A densitometer installed.

3. Definition:

   In this mode of operation, the micrLoad.net software will calculate the CTL using the k_0 and k_1 constants of the API product range selected. (If API product range B is selected, it will use the k_0 and k_1 constants for the product range it is measuring.) All related entries shown above must correspond. If table 53 or 54 is used, the temperature units must be in Celsius. Density units selected must match the densitometer output.

4. Calculation method for live density at 60°F
   a. Input temperature units.
   b. Calculate delta t (t).
   c. Input density units.
   d. Calculate the density corrected to reference temperature using Newton's method, which will in turn calculate the required CTL and CTPL.

      1. Calculate alpha selecting proper k_0 and k_1 constants for API product range selected (Parameter 412).
      2. Calculate the CTL, CPL and CTPL.
      3. Calculate the corrected density.
      4. Check for convergence of the solution. (A converged solution is reached when a change in density is less than 0.05 kg/m^3 in two successive passes.)
      5. For API product range B only, check to see that the k_0 and k_1 constants used are in the range of the corrected density calculated. If not, repeat steps 1 through 4 with the correct constants.

5. Calculation method for live density at 15°C or 20°C.
   a. Calculate the correction factors (CTL*) for the density at 60°F (p60) corresponding to the observed density at observed temperature and pressure using the procedure defined in step C.4.
   b. Using the corresponding density at 60°F (p60), calculate the associated metric base density. Call the CTL associated with this step CTL_{60} using the procedure defined in step B.4.
   c. Calculate the CTL to correct the volume to the metric base temperature.

$$CTL = CTL^*/CTL_{60}$$
$$CTPL = CTL \times CPL$$

*(**Note:** * indicates an intermediate CTL value used for the CTL calculation per API Chapter 11.1.)*

D. API (old) tables 24 and 54 with API range 100 to 150

1. Program entry conditions:
   a. A valid API table entry (Parameter 412).
   b. A valid reference density entry (Parameter 413).
   c. A valid density units entry (Parameter 411).
   d. A valid temperature units entry (Parameter 401).
   e. A valid reference temperature entry (Parameter 402).

2. Hardware conditions:
   a. A temperature probe is installed.
   *(**Note:** Maintenance temperature may be used instead of the temperature probe.)*

3. Definition:

   In this mode of operation, the microFlow.net software will use the reference density and the current temperature to retrieve the CTL from the selected table. (If table 24 is selected, temperature units must be Fahrenheit. If table 54 is selected, temperature units must be Celsius.)

4. Calculation method

   a. Input temperature units.
   b. Using the temperature and reference density, go to the proper table (24 or 54) and select the proper CTL.

RTD Temperature Input Conversion

The resistance temperature detector (RTD) supplies resistance from which temperature may be calculated. The Callendar-Van Dusen equation is used to approximate the RTD curve.

$$T = \frac{-A + \sqrt{A^2 - 4B\left(1 - \frac{R}{R(0)}\right)}}{2B}$$

Where:

T = temperature in Celsius
R = resistance at temperature T
R(0) = resistance at 0 C
A = 3.9083 e-3
B = -5.775 e-7

Volume Correction for Pressure (CPL) Calculation

1. Definition of terms

    P = pressure
    P_e = equilibrium pressure (Vapor pressure @ temperature)
    F = compressibility factor (API Chapters 11.2.1 or 11.2.2)
    CPL = correction for pressure on a liquid

2. Formula used

    a.

$$CPL = \frac{1}{1 - (P - P_e) \times F}$$

    b.

$$API = \frac{141.5 \times \rho_{60} H_2O}{\rho_{60} Product} - 131.5$$

    c. For -10 to 90 API (-10 to 100 per API Chapter 11.1)

$$F = e^{A + (B \times T) + \frac{C}{\rho^2} + (D \times \frac{T}{\rho^2})}$$

Note this calculation is used for densities from -10 to 100 API for products included in API Chapter 11.1 (5A, 5B, 5D, 6A, 6B, 6C, 23A, 23B, 23D, 24A, 24B, 24D, 53A, 53B, 53D, 54A, 54B, 54C, 54D). Otherwise this calculation is used for densities from -10 to 90 API.

where:

A, B, C and D = constants
T = temperature (F or C dependent)
= grams/cm^3 @ 60 F or grams/cm^3 @ 15 C

	A	B	C	D
F	-1.99470	0.00013427	0.79392	0.0023260
C	-1.62080	0.00021592	0.87096	0.0042092

Note that *F* is scaled before usage in the CPL formula above. If temperature is in degrees Fahrenheit, *F* is multiplied by 0.00001. If temperature is in degrees Celsius, *F* is multiplied by 0.000001.

d. For 91 to 220 API (101 to 220 per API Chapter 11.1)

$$F = \frac{1}{A + (D_p \, x \, B)}$$

where:

A and B = Calculated variables based on temperature & density
D_p = Pressure above equilibrium in (PSI or Kpa dependent) (i.e., Pressure – Vapor Pressure)

$$A * 10^{-5} = A_1 * TR^2 + A_2 * TR^2 * G^2 + A_3 * TR^2 * G^4 + A_4 * TR^3 * G^6 + A_5$$
$$+ A_6 * TR^3 * G^2 + A_7 * TR^3 * G^4 + A_8 * TR * G^2$$
$$+ A_9 * TR * G + A_{10} * TR + A_{11} * G$$

If temperature units are degrees Celsius, then A = A * 6.894757E0

$$B * 10^{-5} = B_1 * TR^2 + B_2 * TR * G^2 + B_3 * G + B_4 * G^2$$

where:
TR = Temperature, in degrees Rankine
G = Relative density
A_1 = -2.1465891E-6
A_2 = +1.5774390E-5
A_3 = -1.0502139E-5
A_4 = +2.8324481E-7
A_5 = -0.95495939E0
A_6 = +7.2900662E-8
A_7 = -2.7769343E-7
A_8 = +0.036458380
A_9 = -0.05110158E0
A_{10} = +0.00795529E0
A_{11} = +9.13114910E0
B_1 = -6.0357667E-10
B_2 = +2.2112678E-6
B_3 = +0.00088384E0
B_4 = -0.00204016E0

Vapor Pressure Calculations

A. Linearization method: Calculate the slope of a line between two points :

1. Calculate m.

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

where:

m = Slope (to be calculated)
y_2 = Vapor pressure @ x_2 in PSI, Bars or Kg/cm^2.
y_1 = Vapor pressure @ x_1 in PSI, Bars or Kg/cm^2.
x_1 = Temperature for vapor pressure of y_1
x_2 = Temperature for vapor pressure of y_2

(*Note:* Temperature may be in degrees C or F.)

2. After calculating *m*, calculate the straight line equation:

$$y - y_1 = m(x - x_1)$$

so

$$y = m(x - x_1) + y_1$$

where:

x = the present temperature
y = the unknown vapor pressure

B. GPA TP-15 Method: Calculate vapor pressure through the use of the following formula as outlined in the GPA TP-15.

$$Vapor\ Pressure = e^{A0 + A1\ x\ relative density + \frac{B0 + B1\ x\ relative density}{temperature\ °F + 443}}$$

Where A_0, A_1, B_0, and B_1 are constants dependent on the range of the density.

Note that this method requires GST compensation installed as the relative density is used in the calculation.

Load Average Values

The load average temperature, pressure, density, and meter factor will be accumulated in a volume-weighted method (see below). At the start of any batch, a reading of each load average parameter installed will be taken. This will be the value used for the initial average. Thereafter, another sample will be taken along with the accumulated volume to determine the load average value. Samples will be taken only when flow is in progress. The following formula will be used to calculate the load average value.

Load Average Value (LAV) Formula:

$$\text{LAV} = \frac{\sum (\Delta \text{ Volume x Current parameter reading})}{\text{Total Volume}}$$

Load average temperature, pressure and density values will only be calculated when correct entries have been made in the temperature, pressure or density program codes. If a probe or transducer alarm occurs, the corresponding current reading will stop being used in the calculation of the load average value. The current load average value for the failed probe or transducer stands until flow goes to zero. At this point the alarm must be cleared and the problem corrected for normal load average calculations to resume.

Auto Prove Meter Factor Calculations

The following equations are used by the microFlow.net to calculate the new meter factor.

CTSP (Correction for Temperature on Steel of a Prover)

$$CTSP = 1 + ((T - t_{ref}) * y)$$

where

T = temperature of the prover

y = coefficient of cubical expansion, a constant, 0.0000186 for mild steel

t_{ref} = reference temperature (System Parameter 402)

CTLP (Correction for Temperature on Liquid in a Prover)

$$CTLP = e^{(\alpha \bullet \Delta t(1 + 0.8\alpha \bullet \Delta t))}$$

where

e = the exponential constant

t = temperature = actual temperature of the prover - reference temperature (System Parameter 402)

= k0/($_{60}$)^2 + (k1/ $_{60}$)

where

k0 and k1 are constants determined based on the product group

$_{60}$ = (141.5 * weight of H_2O)/(131.5 + API)

OR

= A + (B/($_{60}$)^2)

where

A and B are constants for a special range of API gravities

$_{60}$ = (141.5 * weight of H_2O)/(131.5 + API)

Combined Correction Factor (CCF) For a Prover

CCFP = CTSP * CTLP

where

CTSP and CTLP are as shown above

Corrected Prover Volume

Corrected Prover Volume = Base Prover Volume * CCFP

where

Base Prover Volume is as determined by a waterdraw

CCFP is as shown above

Corrected Meter Volume

Corrected Meter Volume = CTPLM * Raw Meter Volume

where

CTPLM is as shown earlier

Meter Factor

Meter Factor = Corrected Prover Volume / Corrected Meter Volume

where

Corrected Prover Volume and Corrected Meter Volume are as shown above

Average Meter Factor

Average Meter Factor = Sum of Meter Factors/Number of Meter Factors

Note that the buffer of meter factors saved for calculating an average meter factor is cleared whenever a meter factor is saved or a new flow rate is selected for proving.

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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