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## Addendum 2

Note: Added text is highlighted. Deleted text is indicated by strikethrough.

### 11.1.1.5 Changes to Previous Standards

- The term “compressibility coefficient” and symbol “ $F_p$ ” are used in other standards in a different way. The term and symbol were changed to “scaled compressibility factor” and “ $F_s$ ,” respectively, to distinguish the difference.
- Section 11.1.2.5.13 was updated to reference API MPMS Chapter 11.3.4 for density and volume corrections of gasohol blends.
- Sections were added for guidance on volume corrections for ethanol, vacuum gas oil (VGO), and naptha.
- Clarification was added to the use of the terms “standard,” “observed,” and “alternate” conditions.
- Clarification was added, and examples were updated, to show final density and volume results should be calculated with unrounded  $C_{TL}$  and  $C_{PL}$  values or an unrounded  $C_{TPL}$  value.
- Wording was added to indicate the examples are provided to guide users in developing computer implementations of the Standard, but are not part of the Standard.
- If other standards call for use of a  $C_{TL}$  factor, alone, ~~or, an~~ <sup>an equivalent  $C_{TPL}$  factor may be calculated by using a gauge pressure of zero.</sup>
- Steps in Sections 11.1.8.23 and 11.1.8.24 were updated to use an arbitrary input density as required in the implementation procedures.
- Section C.7 was added to Appendix C to guide users in converting thermal expansion coefficients to temperature units other than  $^{\circ}\text{F}^{-1}$ .
- Appendix F was added to show how the equilibrium vapor pressure of liquids affects the calculations.

### 11.1.2.2 Scope

As this Standard will be applied to a variety of applications the output parameters specified in this Standard ( $\rho$ ,  $\rho_{60}$ ,  $\rho_T$ ,  $C_{TL}$ ,  $F_p F_s$ ,  $C_{PL}$ , and  $C_{TPL}$ ) may be used as specified in other API *Manual of Petroleum Measurement Standards* (MPMS) Chapters.

This Standard provides general procedures for the conversion of input data to generate  $\rho$ ,  $\rho_{60}$ ,  $\rho_T$ ,  $C_{TL}$ ,  $F_p F_s$ ,  $C_{PL}$ , and  $C_{TPL}$  values at the user specified base temperature and pressure ( $T_b$ ,  $P_b$ ).

### 11.1.2.5.3 LPG and NGL

LPGs (Liquefied Petroleum Gases) and NGLs (Natural Gas Liquids) are predominantly butane and propane separated from natural gasoline or natural gas or produced during refinery processing. Most LPGs and NGLs are less dense than the liquids covered by this Standard. **API MPMS Chapter 11.2.4/GPA 8217 “Temperature Correction for the Volume of NGL and LPG Tables 23E, 24E, 53E, 54E, 59E, 60E”** ~~Gas Processors Association (GPA) Technical Publication TP-25 Temperature Correction For The Volume Of Light Hydrocarbons~~ (or its successor) should be used for the temperature portion of the volume correction factors for liquids with  $60^{\circ}/60^{\circ}$

relative densities of 0.3500 to 0.6880 (272.8 to 74.2°API at 60 °F, or 349.7 to 687.3 kg/m<sup>3</sup> at 60 °F). The tables in this Standard generally apply to products that do not have to be stored in pressurized containers at normal temperatures.

#### 11.1.2.5.13 Gasohol Blends of Gasoline and Ethanol

Gasohol is a mixture of gasoline and 10 vol% ethanol. Based on data (available at API) obtained at the University of Missouri—Rolla, gasohol is best represented as a special application with a 60°F thermal expansion factor (–) of  $714.34 \times 10^{-6} \text{ } ^\circ\text{F}^{-1}$ .

There are several defined blend ranges within fuel specifications which are frequently referred to by the upper limit of the volume percent of ethanol in the blend. For example, E10 refers to a blend which contains up to 10 volume percent of ethanol. Research by the API has shown that when the gasoline blendstock (often referred to as a blendstock for oxygenate blending, BOB) and ethanol are blended there is an increase in the total volume and the coefficient of thermal expansion. Based upon this research, API developed methodologies which are summarized in API *MPMS* Chapter 11.3.4 to cover density and volume correction factors for blends of denatured ethanol and gasoline blend components ranging from 0 % up to 95 % denatured ethanol. Refer to API *MPMS* Chapter 11.3.4 for volume correction of gasoline and ethanol blends.

#### 11.1.2.5.14 Ethanol

Refer to API *MPMS* Chapter 11.3.3 for volume correction of fuel grade ethanol.

#### 11.1.2.5.15 Vacuum Gas Oil (VGO)

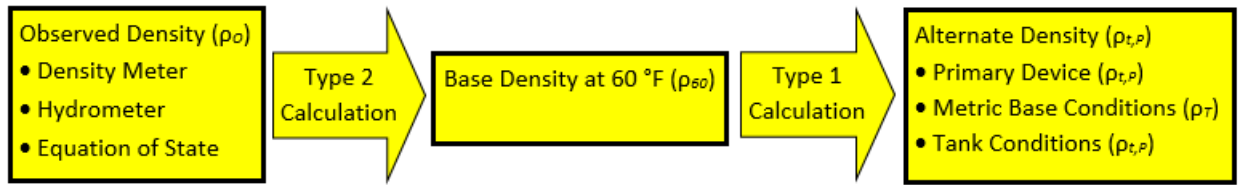
Vacuum gas oil is a distillation product of crude oil generally with a boiling range between 310°C to 600°C. This group of materials was included in the data base for Fuel Oils group of the products tables and was best represented by the products tables.

#### 11.1.2.5.16 Naphtha

Naphtha is a general term for flammable hydrocarbon mixtures. In the refining industry, petroleum naphtha typically has a boiling range between 35°C and 205°C and consists of hydrocarbons containing between 4 and 11 carbon atoms. Virgin naphtha was included in the data base for the Gasolines group of the product tables and was best represented by the products tables. Heavy naphtha was significantly better represented by the products tables for this group.

#### 11.1.3.1 Distinction Between “Standard,” “Base,” “Observed,” and “Alternate” Conditions

- The “alternate” conditions are any other temperature and pressure conditions to which the observed or standard density can be corrected/adjusted. Alternate conditions may be flowing conditions at the primary device or base temperatures other than 60 °F, such as 15 °C, 20 °C, 30 °C, etc.



### 11.1.3.3 Calculation of CTL and CPL Factors in this Standard

$$C_{PL} = \frac{1}{1 - F_P F_s (P - P_e)} \quad (15)$$

...where  $\alpha_T$  is the thermal expansion coefficient at the base temperature  $T$ ,  $\Delta t$  is the difference between the alternate temperature and the base temperature,  $F_P F_s$  is the scaled compressibility coefficient factor, and  $\delta_T$  is a small base temperature correction value.

In the examples within this document, the term “P in psi” is reported in Step 3. It is actually a differential pressure of base pressure or alternate pressure from the standard base fluid pressure. As stated in the standard, the base fluid pressure is the maximum of the equilibrium pressure or atmospheric pressure. In many cases, it is numerically equivalent to either the alternate or base pressure as reported in psig.

... $F_P F_s$  was correlated to this same base density and the temperature  $t$  at which the compression occurs.

$$F_P F_s = \exp \left\{ A + Bt + \frac{C + Dt}{\rho^{*2}} \right\} \quad (17)$$

There was one set of coefficients for the  $F_P F_s$  scaled compressibility factor ( $A = -1.99470$ ,  $B = 0.00013427$ ,  $C = 793920$ ,  $D = 2326$ ; based on density in  $\text{kg/m}^3$  at 60 °F the A, B, C, and D values) but several sets of coefficients for the  $\alpha_{60}$  thermal expansion coefficient (the K0, K1, and K2 values) depending upon the liquid’s classification and density at 60 °F.

### 11.1.3.5 Iteration Scheme to Determine Base Density from Observed Density

Because  $\alpha_{60}$  and  $F_P F_s$  in Equations (16) and (17) are direct functions of the 60 °F density  $\rho_{60}$ , the CTL and CPL equations are also direct functions of  $\rho_{60}$ .

2...

- Calculate the  $F_P F_s$  value using Equation (17). Calculate the CPL using Equation (18).

### 11.1.3.9 Rounding of Values

~~Previous versions of the Table values required rounding at various stages of the calculation procedures. The Implementation Procedures are now written with no rounding of initial or intermediate values. The final VCF is rounded to five decimal places. Rounding of input values is only to be used when creating tabular representations of the results from these Implementation Procedures. When the tabular representations are calculated, the initial and final values are to be rounded for display, but intermediate values are never to be rounded.~~

Although previous versions of this standard required values to be rounded at various stages within the calculation procedures, the calculations procedures are now written with no rounding of initial, intermediate or final values. Other applications may require rounding of inputs prior to using this standard or rounding of results from this standard (e.g.  $C_{TL}$ ,  $C_{PL}$ ,  $C_{TPL}$ , or density) for their own purposes.

However, calculations using the rounded results will differ slightly from results obtained by direct application of this standard.

The procedures within this standard for creating tabular representations that reproduce the format of the historical tables require rounding of the initial and final values be rounded for display as indicated in Section 11.1.5.4, but intermediate values are never to be rounded.

### 11.1.5 Implementation Procedures - General

If these examples are used to test one's own computer implementation of the procedures, it is required that at least eight of the significant digits be matched for all applicable output values.

The actual API MPMS Chapter 11.1 Standard consists of the explicit implementation procedures. Sample tables, flow charts, and specific examples created from a computerized version of these implementation procedures are presented within. The examples are to provide guides and check points to those who wish to implement a computerized procedure to represent the Standard, however these are not a part of the actual Standard.

#### 11.1.5.2 Method to Calculate Thermal Expansion Factor from Density Measurements Calculation Procedure

Step 8: Go to Step 46 and repeat iteration five times.

~~Step 10: Round the values of  $\alpha_{60}$  and  $\rho_{60}$  to be consistent with 11.1.5.4.~~

Step 104: Exit from this procedure.

The resulting coefficient of thermal expansion (to six digits) is  $\alpha_{60} = 446.655 \times 10^{-6} \text{ } ^\circ\text{F}^{-1}$  and the calculated density at 60°F (to six digits) is  $\rho_{60} = 867.756 \text{ kg / m}^3$ . ~~When rounded consistent with 11.1.5.4 the results are  $\alpha_{60} = 446.7 \times 10^{-6} \text{ } ^\circ\text{F}^{-1}$  and  $\rho_{60} = 867.8 \text{ kg/m}^3$ .~~

#### 11.1.5.4 Rounding of Values for Generating Tables

This procedure gives instructions and increments for rounding density, temperature, pressure, thermal expansion coefficient, and volume correction factor values. These rounding rules are needed ~~to generate the final volume correction factor due to temperature and pressure and~~ to generate the tables in printed tabular (historical) format. All input values must be rounded when generating the tables in historical format.

#### 11.1.5.5 Other Implementation Considerations

- Where a calculation within an existing standard makes use of a CTL factor alone, an equivalent value CTPL is calculated with gauge pressure set to zero.

#### 11.1.6.1 Method to Correct a Measured Volume to Base Conditions and Density from Base Conditions to an Alternate Temperature and Pressure

##### Output Values

$F_p F_s$  Scaled compressibility factor (psi<sup>-1</sup>)

## Calculation Procedure

Step 6: Calculate the scaled compressibility factor  $F_p F_s$ . Use the equation:

$$F_p F_s = \exp \left( -1.9947 + 0.00013427 \cdot t^* + \frac{793920 + 2326.0 \cdot t^*}{\rho^{*2}} \right)$$

Step 8: Calculate the VCF, the combined temperature and pressure correction,  $C_{TPL}$  :

$$C_{TPL} = C_{TL} \cdot C_{PL}$$

~~Round this value of CTPL consistent with 11.1.5.4.~~

## Example Calculations

API MPMS 11.1.6.1 Customary Units, Example 1

Step 6 - Calculate scaled compressibility factor  $F_p F_s$   
 $F_p F_s$  for psi .....0.305779891997

Step 9 - Calculate volume at base conditions  
and density at alternate conditions  
Volume at base conditions 1020.6035499 1020.605122738520  
Density at t & P, kg/cu m 978.1780343640 978.178034364001  
°API at t & P .....13.0143512059 13.014351205924

API MPMS 11.1.6.1 Customary Units, Example 2

Step 6 - Calculate scaled compressibility factor  $F_p F_s$   
 $F_p F_s$  for psi ..... 0.427958509999

Step 9 - Calculate volume at base conditions  
and density at alternate conditions  
Volume at base conditions 269.543405269.543897945183  
Density at t & P, kg/cu m 1098.43913558821098.439135588250  
API at t & P .....2.8076041994-2.807604199393

API MPMS 11.1.6.1 Customary Units, Example 3

Step 6 - Calculate scaled compressibility factor  $F_p F_s$   
 $F_p F_s$  for psi .....0.384339609206

Step 9 - Calculate volume at base conditions  
and density at alternate conditions  
Volume at base conditions 12060.32972 12060.306544023900  
Density at t & P, kg/cu m 941.3353501926 941.335350192585  
°API at t & P .....18.6704615375 18.670461537516

API MPMS 11.1.6.1 Customary Units, Example 4

Step 6 - Calculate scaled compressibility factor  $F_p F_s$   
 $F_p F_s$  for psi .....0.664706197066

Step 9 - Calculate volume at base conditions  
and density at alternate conditions  
Volume at base conditions 988.46 988.457250925006  
Density at t & P, kg/cu m 784.3590249208 784.359024920833

API MPMS 11.1.6.1 Customary Units, Example 5

Step 6 - Calculate scaled compressibility factor  $F_p F_s$   
 $F_p F_s$  for psi .....0.608111538634

Step 9 - Calculate volume at base conditions  
and density at alternate conditions  
Volume at base conditions 10043.2 10043.2031139630  
Density at t & P, kg/cu m 790.9208921357 790.920892135717

°API at t & P .....~~47.2293336231~~ 47.229333623094

API MPMS 11.1.6.1 Customary Units, Example 6  
 Step 6 - Calculate scaled compressibility factor  $F_{ps}$   
 $F_{ps}$  for psi .....0.993527440282  
 Step 9 - Calculate volume at base conditions  
 and density at alternate conditions  
 Volume at base conditions ~~15.2973184~~ 15.297347711445  
 Density at t & P, kg/cu m ~~683.0806148596~~ 683.080614859578

API MPMS 11.1.6.1 Customary Units, Example 7  
 Step 6 - Calculate scaled compressibility factor  $F_{ps}$   
 $F_{ps}$  for psi .....0.346454796729  
 Step 9 - Calculate volume at base conditions  
 and density at alternate conditions  
 Volume at base conditions ~~198.374589~~ 198.375152591264  
 Density at t & P, kg/cu m ~~1024.3915370787~~ 1024.39153707874

API MPMS 11.1.6.1 Customary Units, Example 8  
 Step 6 - Calculate scaled compressibility factor  $F_{ps}$   
 $F_{ps}$  for psi .....0.732650236105  
 Step 9 - Calculate volume at base conditions  
 and density at alternate conditions  
 Volume at base conditions ~~97.0715818~~ 97.071544792923  
 Density at t & P, kg/cu m ~~786.9754991473~~ 786.975499147299  
 °API at t & P .....~~48.1253684558~~ 48.125368455774

API MPMS 11.1.6.1 Customary Units, Example 15  
 Step 6 - Calculate scaled compressibility factor  $F_{ps}$   
 $F_{ps}$  for psi .....4.092820997603  
 Step 9 - Calculate volume at base conditions  
 and density at alternate conditions  
 Volume at base conditions ~~868.29~~ 868.288296906632  
 Density at t & P, kg/cu m ~~530.2025789330~~ 530.202578932960  
 °API at t & P .....~~135.116515303~~ 135.116515303434

### 11.1.6.2 Method to Correct Volume and Density from Observed Conditions to Customary Base Conditions

#### Output Values

$F_{ps}$  Scaled compressibility factor ( $\text{psi}^{-1}$ )

#### Intermediate Values

$F_{ps}^{(m)}$  Scaled compressibility factor on the  $m$ -th iteration ( $\text{psi}^{-1}$ )

#### Calculation Procedure

Step 7: After the convergence criterion in Step 4 is met, set the value of  $\rho_{60}$  to the last  $\rho_{60}^{(m)}$  value and set the value of  $C_{TPL}$  to the last  $C_{TPL}^{(m)}$  value. Check this  $\rho_{60}$  value to determine if it is in the range of this Standard. If  $\rho_{60} < \rho_{60,\min}$  or  $\rho_{60} > \rho_{60,\max}$  then this  $\rho_{60}$  value is out of range. Set an error condition (such as setting all output values to zero) and exit the procedure. Round this value of  $C_{TPL}$  consistent with 11.1.5.4.

## Example Calculations

### Example 1

Step 3  
FpS(m).....0.583649345323      0.567047025149      0.567045450015  
Step 7  
FpS for psi.....0.567045450015  
Step 8  
Volume at base conditions.~~989.97~~ **989.966310837071**

### Example 2

Step 3  
FpS(m).....0.476986337657      0.602443036118      0.603436463770  
0.603436540820  
Step 7  
FpS for psi.....0.603436540820  
Step 8  
Volume at base conditions.~~694333.73394~~ **694331.004655808**

### Example 3

Step 3  
FpS(m).....0.489197521374      0.484824153195      0.484824263921  
Step 7  
FpS for psi.....0.484824263921  
Step 8  
Volume at base conditions.~~28.349287~~ **28.349285764593**

### Example 4

Step 3  
FpS(m).....0.578821088788      0.572609812544      0.572609969057  
Step 7  
FpS for psi.....0.572609969057  
Step 8  
Volume at base conditions.~~199.74612~~ **199.746592435773**

### Example 5

Step 3  
FpS(m).....0.512082157017      0.539941779272      0.539959172137  
0.539959363768  
Step 7  
FpS for psi.....0.539959363768  
Step 8  
Volume at base conditions.~~10197.174195~~ **10197.1874770065**

### Example 6

Step 3  
FpS(m).....1.118639209920      0.910912736669      0.910920838482  
0.910923457238  
Step 7  
FpS for psi.....0.910923457238  
Step 8  
Volume at base conditions.~~949.54~~ **949.542039808338**

### Example 7

Step 3  
FpS(m).....0.535641758165      0.519613454257      0.519616156675  
Step 7  
FpS for psi.....0.519616156675  
Step 8  
Volume at base conditions.~~4943.8~~ **4943.80898893649**

### Example 8

Step 3  
FpS(m).....0.445753246624      0.438941834085      0.438941943315  
Step 7  
FpS for psi.....0.438941943315  
Step 8  
Volume at base conditions.~~2483.575~~ **2483.58068028317**

### Example 9

Step 3

$F_{PS}(m)$  ..... 1.460680703550      1.459310478928      1.459310590459  
 Step 7  
 $F_{PS}$  for psi ..... 1.459310590459  
 Step 8  
 Volume at base conditions. ~~902.303118~~ **902.306662720965**

#### Example 12

Step 1  
 Density less than 470.34 kg/cu m - outside limits of table

### 11.1.6.3 Method to Correct Volume and Density from Observed Conditions to Alternate Conditions

#### Output Values

$F_{P,o}$   $F_{s,o}$  Scaled compressibility factor at the observed temperature ( $\text{psi}^{-1}$ )  
 $F_P$   $F_s$  Scaled compressibility factor at the alternate temperature ( $\text{psi}^{-1}$ )

#### Calculation Procedure

Step 1: Use the observed values  $\rho_o$ ,  $t_o$ , and  $P_o$  and determine the density at base conditions,  $\rho_{60}$ , using the procedure in 11.1.6.2. If this procedure returns with an error condition, exit this procedure. Retain the values of  $\rho_{60}$ ,  $C_{TL,o}$ ,  $F_{PS,o}$ ,  $C_{PL,o}$ , and  $C_{TPL,o}$  in the procedure. ~~Round this value of  $C_{TPL,o}$ .~~

Step 2: With the  $\rho_{60}$  value found in Step 1, calculate the corresponding  $\rho$  density value at alternate conditions  $t$  and  $P$  using the procedure in 11.1.6.1. If this procedure returns with an error condition, exit this procedure. Retain the values of  $C_{TL}$ ,  $F_{PS}$ ,  $C_{PL}$ , and  $C_{TPL}$  in the procedure. ~~Round this value of  $C_{TPL}$ .~~

#### Example Calculations

##### Example 1

Step 1  
 $F_{PS}(m)$  .....  
 $F_{PS,o}$  .....  
 Step 2  
 $F_{PS,psi}$  .....  
 Step 3  
 Volume at base conditions. ~~989.99~~ **989.990602512848**  
 Volume at alternate t & P. ~~936.630178718~~ **936.634084363292**

##### Example 2

Step 1  
 $F_{PS}(m)$  .....  
 $F_{PS,o}$  .....  
 Step 2  
 $F_{PS,psi}$  .....  
 Step 3  
 Volume at base conditions. ~~10879.492266~~ **10879.5060165477**  
 Volume at alternate t & P. ~~12729.4654849~~ **12729.4544055576**

##### Example 3

Step 1  
 $F_{PS}(m)$  .....  
 $F_{PS,o}$  .....  
 Step 2  
 $F_{PS,psi}$  .....

Step 3  
 volume at base conditions..~~284.4366525~~ 284.436940266107  
 volume at alternate t & P..~~295.586162551~~ 295.586050990898

#### Example 4

Step 1  
 FpS(m).....  
 FpS,o.....

Step 2  
 FpS,psi.....

Step 3  
 volume at base conditions..~~14.893489~~ 14.893534494788  
 volume at alternate t & P..~~14.0912728374~~ 14.091278574412

#### Example 5

Step 1  
 FpS(m).....  
 FpS,o.....

Step 2  
 FpS,psi.....

Step 3  
 volume at base conditions..~~101454.97086~~ 101455.297101008  
 volume at alternate t & P..~~105593.167078~~ 105593.062530991

#### Example 6

Step 1  
 FpS(m).....  
 FpS,o.....

Step 2  
 FpS,psi.....

Step 3  
 volume at base conditions ..~~495.107662~~ 495.109922341430  
 volume at alternate t & P ..~~451.316428903~~ 451.319834324387

#### Example 7

Step 1  
 FpS(m).....  
 FpS,o.....

Step 2  
 FpS,psi.....

Step 3  
 volume at base conditions ..~~9866.2~~ 9866.18119471803  
 volume at alternate t & P ..~~10084.9424007~~ 10084.9644601740

#### Example 8

Step 1  
 FpS(m).....  
 FpS,o.....

Step 2  
 FpS,psi.....

Step 3  
 volume at base conditions ..~~260.1176~~ 260.117009046524  
 volume at alternate t & P ..~~259.943437897~~ 259.942678128494

#### Example 9

Step 1  
 FpS(m).....  
 FpS,o.....

Step 2  
 FpS,psi.....

Step 3  
 volume at base conditions ..~~917.103012~~ 917.103113370660  
 volume at alternate t & P ..~~928.382863795~~ 928.381502424912

#### Example 12

Step 1  
 FpS(m).....  
 FpS,o.....

Step 2  
 FpS,psi.....

Step 3  
 volume at base conditions ..~~992.66~~ 992.655673734276  
 volume at alternate t & P ..~~1001.96828537~~ 1001.96012648983

### Example 13

Step 1  
 $F_{PS}(m)$  .....  
 $F_{PS,o}$  .....  
 Step 2  
 $F_{PS,psi}$  .....  
 Step 3  
 Volume at base conditions ..977.66 977.659505441647  
 Volume at alternate  $t$  &  $P$  ..1175.02974652 1175.02276434999

### Example 18

Step 1  
 $F_{PS}(m)$  .....  
 $F_{PS,o}$  .....  
 Step 2  
 $F_{PS,psi}$  .....  
 Step 3  
 Volume at base conditions ..1035.5 1035.49894579718  
 Volume at alternate  $t$  &  $P$  ..1034.8066795 1034.80349068147

## 11.1.7.1 Method to Correct a Measured Volume to Metric Base Conditions and Density from Metric Base Conditions to an Alternate Temperature and Pressure

### Output Values

$F_{PS}$  Scaled compressibility factor ( $\text{kPa}^{-1}$  or  $\text{bar}^{-1}$ )

### Intermediate Values

$F_{PS,psi}$  Scaled compressibility factor ( $\text{psi}^{-1}$ )

### Calculation Procedure

Step 3: Using this value of  $\rho_{60}$ , calculate the density value at the alternate conditions  $t$  and  $P$  using the procedure in 11.1.6.1. There are associated factors that must be adjusted to take into account that the reference temperature is not 60°F and the originally input pressure is not in customary units. Call these factors  $C_{TL}^*$ ,  $C_{TPL}$ ,  $C_{TPL}^*$ , and  $F_{PS,psi}$ .

Step 4: Calculate the correction factors for the metric base temperature by combining the correction factors for 60°F. The temperature correction factor is:

$$C_{TL} = \frac{C_{TL}^*}{C_{TL,60}}$$

and the combined temperature and pressure correction factor is:

$$C_{TPL} = C_{TL} \cdot C_{PL}$$

Round this value of  $C_{TPL}$  consistent with 11.1.5.4.

## Example Calculations

### API MPMS 11.1.7.1 Metric units. Example 1

Input Data  
Volume at ~~observed~~ alternate t & P 9885

Step 1 - Convert to customary units  
P alternate, PSI .....~~356.792849987~~ 356.792849987316

Step 3 - Correct 60°F/0 psi density to alternate conditions:  
Fps,psi .....

Step 4 - Modify Ctl and Ctpl for temperature base of 15°C  
Fps,bar .....

Step 5 - Calculate volume at base conditions and density at alternate conditions  
Volume at base conditions ....~~10380.73275~~ 10380.7584211291  
Density, kg/cu m, at t & P ...~~811.030845~~ 811.032850646233

### API MPMS 11.1.7.1 Metric units. Example 2

Input Data  
Volume at ~~observed~~ alternate t & P 397498

Step 1 - Convert to customary units  
P alternate, PSI .....~~357.518038707~~ 357.518038706803

Step 3 - Correct 60°F/0 psi density to alternate conditions:  
Fps,psi .....

Step 4 - Modify Ctl and Ctpl for temperature base of 15°C  
Fps,bar .....

Step 5 - Calculate volume at base conditions and density at alternate conditions  
Volume at base conditions ....~~419376.28992~~ 419374.335003641  
Density, kg/cu m, at t & P ...~~814.807392~~ 814.803593787420

### API MPMS 11.1.7.1 Metric units. Example 3

Input Data  
Volume at ~~observed~~ alternate t & P 48.75

Step 1 - Convert to customary units  
P alternate, PSI .....~~10.8778307923~~ 10.877830792296

Step 3 - Correct 60°F/0 psi density to alternate conditions:  
Fps,psi .....

Step 4 - Modify Ctl and Ctpl for temperature base of 15°C  
Fps,kPa .....

Step 5 - Calculate volume at base conditions and density at alternate conditions  
Volume at base conditions ....~~45.8488875~~ 45.848935043908  
Density, kg/cu m, at t & P ...~~814.088144~~ 814.088988184753

### API MPMS 11.1.7.1 Metric units. Example 4

Input Data  
Volume at ~~observed~~ alternate t & P 200.2

Step 1 - Convert to customary units  
P alternate, PSI .....~~247.289353345~~ 247.289353344868

Step 3 - Correct 60°F/0 psi density to alternate conditions:  
Fps,psi .....

Step 4 - Modify Ctl and Ctpl for temperature base of 15°C  
Fps,bar .....

Step 5 - Calculate volume at base conditions and density at alternate conditions  
Volume at base conditions ....~~198.173976~~ 198.174129078352  
Density, kg/cu m, at t & P ...~~785.46978~~ 785.470386731631

API MPMS 11.1.7.1 Metric units. Example 5

Input Data  
Volume at ~~observed~~ alternate t & P 1502.3

Step 1 - Convert to customary units  
P alternate, PSI .....~~124.732459752~~ 124.732459751663

Step 3 - Correct 60°F/0 psi density to alternate conditions:  
Fps,psi .....

Step 4 - Modify Ctl and Ctpl for temperature base of 15°C  
Fps,bar .....

Step 5 - Calculate volume at base conditions and density at alternate conditions  
Volume at base conditions ....~~1593.534679~~ 1593.53956665203  
Density, kg/cu m, at t & P ...~~819.201779~~ 819.204291636398

API MPMS 11.1.7.1 Metric units. Example 6

Input Data  
Volume at ~~observed~~ alternate t & P 1000

Step 1 - Convert to customary units  
P alternate, PSI .....~~179.121613713~~ 179.121613713145

Step 3 - Correct 60°F/0 psi density to alternate conditions:  
Fps,psi .....

Step 4 - Modify Ctl and Ctpl for temperature base of 15°C  
Fps, kPa .....

Step 5 - Calculate volume at base conditions and density at alternate conditions  
Volume at base conditions ....~~984.12~~ 984.119864783435  
Density, kg/cu m, at t & P ...~~646.862076~~ 646.861987122152

API MPMS 11.1.7.1 Metric units. Example 7

Input Data  
Volume at ~~observed~~ alternate t & P 47.85

Step 1 - Convert to customary units  
P alternate, PSI .....~~657.746168574~~ 657.746168574179

Step 3 - Correct 60°F/0 psi density to alternate conditions:  
Fps,psi .....

Step 4 - Modify Ctl and Ctpl for temperature base of 15°C  
Fps,bar .....

Step 5 - Calculate volume at base conditions and density at alternate conditions  
Volume at base conditions ....~~45.789579~~ 45.789533747419  
Density, kg/cu m, at t & P ...~~614.164092~~ 614.163485038521

API MPMS 11.1.7.1 Metric units. Example 8

Input Data  
Volume at ~~observed~~ alternate t & P 1000

API MPMS 11.1.7.1 Metric units. Example 9

Input Data  
Volume at ~~observed~~ alternate t & P 1000

Step 1 - Convert to customary units  
P alternate, PSI .....~~1500.12538513~~ 1500.12538512960

API MPMS 11.1.7.1 Metric units. Example 10

Input Data  
Volume at ~~observed~~ alternate t & P 1000

API MPMS 11.1.7.1 Metric units. Example 11

Input Data

Volume at observed alternate t & P 1000

Step 1 - Convert to customary units  
P alternate, PSI .....1500.12538513 1500.12538512960

### 11.1.7.2 Method to Correct Volume and Density from Metric Observed Conditions to Metric Base Conditions

#### Output Values

$F_{ps}$  Scaled compressibility factor ( $\text{kPa}^{-1}$  or  $\text{bar}^{-1}$ )

#### Intermediate Values

$F_{ps,psi}$  Scaled compressibility factor ( $\text{psi}^{-1}$ )

#### Calculation Procedure

Step 2: Calculate the correction factors for the density at  $60^\circ\text{F}$ ,  $\rho_{60}$ , corresponding to the observed density  $\rho_o$  at conditions  $t_{o,^\circ\text{F}}$  and  $P_{o,psi}$  using the procedure in 11.1.6.2. If this procedure returns with an error condition, exit this procedure. There are associated factors that must be adjusted to take into account that the reference temperature is not  $60^\circ\text{F}$  and the pressure is not in customary units. Call these factors  $C_{TL}^*$ ,  $C_{PL}$ ,  $C_{TPL}^*$ , and  $F_{ps,psi}$ .

Step 4: Calculate the correction factors for the metric base temperature by combining the correction factors for  $60^\circ\text{F}$ . The temperature correction factor is:

$$C_{TL} = \frac{C_{TL}^*}{C_{TL,60}}$$

and the combined temperature and pressure correction factor is:

$$C_{TPL} = C_{TL} \cdot C_{PL}$$

Round this value of consistent with 11.1.5.4.

#### Example Calculations

##### Example 1

Step 1  
P observed, pressure, psi ..1451.10262769 1451.10262769232

Step 2  
 $F_{ps(m)}$  .....  
 $F_{ps,psi}$  .....

Step 3  
 $F_{ps,psi}$  .....

Step 4  
 Fps,kPa .....  
 Step 5  
 Volume at base conditions ..~~9354.7~~ 9354.69615495167

#### Example 2

Step 2  
 Fps(m) .....  
 Fps,psi .....

Step 3  
 Fps,psi .....

Step 4  
 Fps,kPa .....

Step 5  
 Volume at base conditions ..~~989.51~~ 989.507855127724

#### Example 3

Step 1  
 P observed, pressure, psi ..~~16.6793405482~~ 16.679340548188

Step 2  
 Fps(m) .....  
 Fps,psi .....

Step 3  
 Fps,psi .....

Step 4  
 Fps,kPa .....

Step 5  
 Volume at base conditions ..~~158685.93324~~ 158686.597577785

#### Example 4

Step 1  
 P observed, pressure, psi ..~~163.167461884~~ 163.167461884443

Step 2  
 Fps(m) .....  
 Fps,psi .....

Step 3  
 Fps,psi .....

Step 4  
 Fps,bar .....

Step 5  
 Volume at base conditions ..~~99548.41275~~ 99548.0050864555

#### Example 5

Step 1  
 P observed, pressure, psi ..~~375.256154785~~ 375.256154785441

Step 2  
 Fps(m) .....  
 Fps,psi .....

Step 3  
 Fps,psi .....

Step 4  
 Fps,kPa .....

Step 5  
 Volume at base conditions ..~~398.4413595~~ 398.441894541839

#### Example 6

Step 1  
 P observed, pressure, psi ..~~266.144260052~~ 266.144260051514

Step 2  
Fps(m) .....  
Fps,psi .....

Step 3  
Fps,psi .....

Step 4  
Fps,kPa .....

Step 5  
Volume at base conditions ..~~2026.841696~~ 2026.85124325365

#### Example 7

Step 1  
P observed, pressure, psi ..~~248.014542064~~ 248.014542064354

Step 2  
Fps(m) .....  
Fps,psi .....

Step 3  
Fps,psi .....

Step 4  
Fps,kPa .....

Step 5  
Volume at base conditions ..~~91112.73737~~ 91113.0086949391

#### Example 8

Step 1  
P observed, pressure, psi ..~~57.2899088394~~ 57.289908839427

Step 2  
Fps(m) .....  
Fps,psi .....

Step 3  
Fps,psi .....

Step 4  
Fps,kPa .....

Step 5  
Volume at base conditions ..8378.286189 8378.27232014771

#### Example 9

Step 1  
P observed, pressure, psi ..~~451.067383521~~ 451.067383520550

Step 2  
Fps(m) .....  
Fps,psi .....

Step 3  
Fps,psi .....

Step 4  
Fps,bar .....

Step 5  
Volume at base conditions ..~~103.57~~ 103.569988613388

#### Example 10

Step 1  
P observed, pressure, psi ..~~14.5037743897~~ 14.503774389728

Step 2  
Fps(m) .....  
Fps,psi .....

Step 3  
Fps,psi .....

Step 4  
 $F_{PS}$ , kPa .....

Step 5  
Volume at base conditions ..883.1234754 883.123317595915

Example 11

Density less than 470.45 kg/cu m - outside limits of table

Example 12

Step 1  
P observed, pressure, psi ..1500.05286626 1500.05286625765

Example 14

Step 1  
P observed, pressure, psi ..1500.05286626 1500.05286625765

Example 15

Step 1  
P observed, pressure, psi ..1500.05286626 1500.05286625765

Example 17

Step 2  
 $F_{PS}$ (m) .....

### 11.1.7.3 Method to Correct Volume and Density from Observed Metric Conditions to Alternate Metric Conditions

#### Output Values

$F_{PS,o}$  Scaled compressibility factor at the observed temperature (kPa<sup>-1</sup> or bar<sup>-1</sup>)  
 $F_{PS}$  Scaled compressibility factor at the alternate temperature (kPa<sup>-1</sup> or bar<sup>-1</sup>)

#### Intermediate Values

$F_{PS,o,psi}$  Scaled compressibility factor at observed temperature (psi<sup>-1</sup>)  
 $F_{PS,psi}$  Scaled compressibility factor at alternate temperature (psi<sup>-1</sup>)

#### Calculation Procedure

Step 2: Calculate the density at 60°F,  $\rho_{60}$ , corresponding to the observed density  $\rho_o$  at conditions  $t_{o,^{\circ}F}$  and  $P_{o,psi}$  using the procedure in 11.1.6.2. If this procedure returns with an error condition, exit this procedure. There are associated factors that must be adjusted to take into account that the reference temperature is not 60°F and the pressure is not in customary units. Call these factors  $C_{TL,o}^*$ ,  $C_{PL,o}$ ,  $C_{TPL,o}^*$ , and  $F_{PS,o,psi}$ .

Step 3: Using this value of  $\rho_{60}$  from Step 2, calculate the correction factors for the density  $\rho$  at the alternate temperature and pressure  $t_{^{\circ}F}$  and  $P_{psi}$  using the procedure in 11.1.6.1. If this procedure returns with an error condition, exit this procedure. There are associated factors that must be adjusted to take into account that the reference temperature is not 60°F and the pressure is not in customary units. Call these factors  $C_{TL}^*$ ,  $C_{PL}$ ,  $C_{TPL}^*$ , and  $F_{PS,psi}$ .

Step 5: Calculate the correction factors for the metric base temperature by combining the correction factors for 60°F. The temperature correction factor is:

$$C_{TL,o} = \frac{C_{TL,o}^*}{C_{TL,60}}$$

$$C_{TL} = \frac{C_{TL}^*}{C_{TL,60}}$$

and the combined temperature and pressure correction factor is:

$$C_{TPL,o} = C_{TL,o} \cdot C_{PL,o}$$

$$C_{TPL} = C_{TL} \cdot C_{PL}$$

~~Round this value of consistent with 11.1.5.4.~~

## Example Calculations

### Example 1

Step 2  
Fps(m) .....  
Fps,o,psi .....

Step 3  
Fps,psi .....

Step 4  
Fps,psi .....

Step 5  
Fps,o,kPa .....  
Fps,kPa .....

Step 6  
Volume at base conditions ..1234.537198500 1234.53727908176  
Volume at alternate conditions 1324.085071914 1324.08293887418

### Example 2

Step 1  
P observed pressure, PSI ...31.1831149379 31.183114937916  
P alternate pressure, PSI ..353.16690639 353.166906389884

Step 2  
Fps(m) .....  
Fps,o,psi .....

Step 3  
Fps,psi .....

Step 4  
Fps,psi .....

Step 5  
Fps,o,bar .....  
Fps,bar .....

Step 6  
Volume at base conditions ..1065.250000000 1065.25481274655  
Volume at alternate conditions 1167.499616405 1167.51092161033

### Example 3

Step 2  
 $F_{PS}(m)$  .....  
 $F_{PS,o,psi}$  .....  
 Step 3  
 $F_{PS,psi}$  .....  
 Step 4  
 $F_{PS,psi}$  .....  
 Step 5  
 $F_{PS,o,kPa}$  .....  
 $F_{PS,kPa}$  .....  
 Step 6  
 Volume at base conditions ..~~242.362515000~~ **242.362757386791**  
 Volume at alternate conditions ~~253.450996078~~ **253.449951373001**

### Example 4

Step 1  
 Convert to customary units  
 P observed pressure, PSI ...~~374.922567974~~ **374.922567974477**  
 P alternate pressure, PSI ..~~508.35729236~~ **508.357292359977**  
 Step 2  
 $F_{PS}(m)$  .....  
 $F_{PS,o,psi}$  .....  
 Step 3  
 $F_{PS,psi}$  .....  
 Step 4  
 $F_{PS,psi}$  .....  
 Step 5  
 $F_{PS,o,kPa}$  .....  
 $F_{PS,kPa}$  .....  
 Step 6  
 Volume at base conditions ..~~9944.853375000~~ **9944.84454329600**  
 Volume at alternate conditions ~~10740.162400778~~ **10740.1454288640**

### Example 5

Step 1  
 Convert to customary units  
 P observed pressure, PSI ...~~266.144260052~~ **266.144260051514**  
 P alternate pressure, PSI ..~~1499.98034739~~ **1499.980347385700**  
 Step 2  
 $F_{PS}(m)$  .....  
 $F_{PS,o,psi}$  .....  
 Step 3  
 $F_{PS,psi}$  .....  
 Step 4  
 $F_{PS,psi}$  .....  
 Step 5  
 $F_{PS,o,kPa}$  .....  
 $F_{PS,kPa}$  .....  
 Step 6  
 Volume at base conditions ..~~16.150516000~~ **16.150478106258**  
 Volume at alternate conditions ~~16.378670885~~ **16.378581579726**

### Example 6

Step 1  
 Convert to customary units  
 P observed pressure, PSI ...~~247.724466577~~ **247.724466576560**  
 P alternate pressure, PSI ..~~50.4731348763~~ **50.473134876255**  
 Step 2

Fps(m) .....  
Fps,o,psi .....

Step 3

Fps,psi .....

Step 4

Fps,psi .....

Step 5

Fps,o,kPa .....  
Fps,kPa .....

Step 6

Volume at base conditions ..204.024795000 204.025679340181  
Volume at alternate conditions 191.072022589 191.073619112863

#### Example 7

Step 1

Convert to customary units

P observed pressure, PSI ...57.2899088394 57.289908839427  
P alternate pressure, PSI ..943.470524052 943.470524051827

Step 2

Fps(m) .....  
Fps,o,psi .....

Step 3

Fps,psi .....

Step 4

Fps,psi .....

Step 5

Fps,o,kPa .....  
Fps,kPa .....

Step 6

Volume at base conditions ..985.510000000 985.506440925726  
Volume at alternate conditions 1022.886264090 1022.88543009788

#### Example 8

Step 1

Convert to customary units

P observed pressure, PSI ...451.067383521 451.067383520550  
P alternate pressure, PSI ..197.97652042 197.976520419791

Step 2

Fps(m) .....  
Fps,o,psi .....

Step 3

Fps,psi .....

Step 4

Fps,psi .....

Step 5

Fps,o,bar .....  
Fps,bar .....

Step 6

Volume at base conditions ..207.179427600 207.178930937679  
Volume at alternate conditions 213.151945102 213.151916988322

#### Example 9

Step 1

Convert to customary units

P observed pressure, PSI ...20.3052841456 20.305284145620  
P alternate pressure, PSI ..1499.6902719 1499.69027189791

#### Example 11

Step 1

Convert to customary units

P observed pressure, PSI ...1500.05286626 1500.05286625765

P alternate pressure, PSI ...1500.05286626 1500.05286625765

#### Example 12

##### Step 1

Convert to customary units

P observed pressure, PSI ...1500.05286626 1500.05286625765

P alternate pressure, PSI ...1500.05286626 1500.05286625765

#### Example 13

##### Step 1

Convert to customary units

P observed pressure, PSI ...1500.05286626 1500.05286625765

### 11.1.8 Use of Implementation Procedures to Generate Correction Factors in Tabular Format

#### Petroleum Measurement Tables

| Table Description                                                                        | Table Designations | Base Temperature | Input Value            | Pressure Value & Units | Output & Units                   |
|------------------------------------------------------------------------------------------|--------------------|------------------|------------------------|------------------------|----------------------------------|
| ...                                                                                      | ...                | ...              | ...                    | ...                    | ...                              |
| Compressibility Factors for Hydrocarbons Related to API Gravity and Metering Temperature | 1984 Ch. 11.2.1    | 60°F             | Base °API              | 0 psig                 | $F_{ps}$<br>(psi <sup>-1</sup> ) |
| Compressibility Factors for Hydrocarbons Related to Density and Metering Temperature     | 1984 Ch. 11.2.1M   | 15°C             | Base kg/m <sup>3</sup> | 0 kPa (gauge)          | $F_{ps}$<br>(kPa <sup>-1</sup> ) |

#### 11.1.8.23 Instructions to Generate Tables 6C & 24C — Volume Correction Factors for Individual and Special Applications Volume Correction to 60°F Against Thermal Expansion Coefficients at 60°F

Step 1: Hold pressure at 0 psig. Set input  $\rho_{60}$  to 840 kg/m<sup>3</sup>. Note: This density value is used only for CPL calculations that will not affect the table results.

#### 11.1.8.24 Instructions to Generate Tables 54C & 60C — Volume Correction Factors for Individual and Special Applications Volume Correction to 15°C or 20°C Against Thermal Expansion Coefficients

Step 1: Hold pressure at 0 kPa (gauge). Set input  $\rho_{15}$  (Table 54C) or  $\rho_{20}$  (Table 60C) to 840 kg/m<sup>3</sup>. Note: This density value is used only for CPL calculations that will not affect the table results.

#### 11.1.8.25 Instructions to Generate 1984 Chapter 11.2.1 Compressibility Factor Table — Compressibility Factors for Hydrocarbons Related to API Gravity and Metering Temperature

**Output Variables:**  $F_{ps}$  at input temperature.

Step 4: Determine the  $F_{ps}$  values using the procedure in 11.1.6.1. Any commodity group can be specified. Round the  $F_{ps}$  value consistent with instructions in 11.1.5.4.

(1981) Chapter 11.2.1 Table. Compressibility Factor Against API Gravity at 60°F

Scaled Compressibility Factor ( $F_{ps}$ ), 1/psig

#### 11.1.8.26 Instructions to Generate 1984 Chapter 11.2.1M Compressibility Factor Table — Compressibility Factors for Hydrocarbons Related to Density and Metering Temperature

**Output Variables:**  $F_{ps}$  at input temperature.

Step 4: Determine the  $F_{ps}$  values using the procedure in 11.1.7.1. Specify the commodity type “A.” Round the  $F_{ps}$  value consistent with instructions in 11.1.5.4.

(1981) Chapter 11.2.1M Table. Compressibility Factor Against 15°C Base Density

Scaled Compressibility Factor ( $F_{ps}$ ), 1/psig

## Appendix C

### C.7 Conversion of Thermal Expansion Coefficient to Other Temperature Units

As explained in Appendix C, Section C.5.2, there is only one value of alpha to be used with this standard,  $\alpha_{60}$ , the coefficient of thermal expansion at 60 °F of the fluid. This  $\alpha_{60}$  has to be used with the specified thermal expansion correlation used within this standard. The value of  $\alpha_{60}$  used for internal calculations has units of °F<sup>-1</sup>. However, it is acceptable to report the units in either °C<sup>-1</sup> or °F<sup>-1</sup>. The conversion from  $\alpha_{60}$ , in °C<sup>-1</sup> to °F<sup>-1</sup> is given by:

$$\alpha_{60} (^\circ\text{C}^{-1}) = \alpha_{60} (^\circ\text{F}^{-1}) \times 1.8$$

Values of  $\alpha$  reported using other correlations or at other temperatures such as at 15 °C or 20 °C will differ from the  $\alpha_{60}$  required by this standard. The value of  $\alpha_{60}$  must be determined from density data following the procedures in Appendix E.

Values of  $\alpha_{15}$  and  $\alpha_{20}$  in °C<sup>-1</sup> can be estimated from the value of  $\alpha_{60}$  in °F<sup>-1</sup> by the equation:

$$\alpha_T = 1.8 \alpha_{60} (1 + 0.8 \alpha_{60} (2\gamma + \delta))$$

Where  $\delta = 0.01374979547$  and  $\gamma = -1.000254$  (for 15 °C) or 8.002046 (for 20 °C).

The following examples taken from the Sections 11.1.7.1, 11.1.7.2, 11.1.7.3 in the body of this document illustrate this conversion for  $\alpha_{60}$ .

# API MPMS 11.1.7.1 Metric Units, Example 7

A volume of a specialized liquid is measured at observed conditions of temperature and pressure. The base density at 15°C is known. Calculate the volume at base conditions and correct the base density to an alternate condition.

| Input Data                        |                    |
|-----------------------------------|--------------------|
| Commodity .....                   | Specialized Liquid |
| Alpha at 60°F per °C .....        | 0.0008041662       |
| T base temperature, °C .....      | 15                 |
| t alternate temperature, °C ..... | 89.9               |
| P alternate pressure, bar .....   | 45.35              |
| Base density, kg/cu m .....       | 641.8              |
| Volume at alternate t & P .....   | 47.85              |

Computed Data - last digit is rounded for display purposes

| Step 1 - Convert to customary units |                  |
|-------------------------------------|------------------|
| t alternate temperature, °F ....    | 193.820000000000 |
| T base, °F .....                    | 59.000000000000  |
| P alternate, PSI .....              | 657.746168574179 |
| Alpha at 60°F per °F .....          | 0.000446759000   |

Step 2 - Correct base metric (observed) density to 60 °F & 0 psi reference conditions:

| Iteration(m) .....    |                  |                  |
|-----------------------|------------------|------------------|
|                       | 0                | 1                |
| Rho60(m) .....        | 641.800000000000 | 641.513362513010 |
| Rho60*(m) .....       | 641.801971246791 | 641.515332879412 |
| Ctl,60(m) .....       | 1.000446814523   | 1.000446814523   |
| d_alpha(m) .....      | 0.000000000000   | 0.000000000000   |
| Rho60(m)xCtl,60(m) .. | 642.086765560782 | 641.800000000000 |
| delta Rho60(m) .....  | -0.286765560782  | -0.000000000000  |
| E(m) .....            | -0.286637486990  |                  |
| Dt(m) .....           | -0.000000000000  |                  |
| Dp(m) .....           | -0.000000000000  |                  |
| delta Rho(m) .....    | -0.286637486990  |                  |
| Rho60(m+1) .....      | 641.513362513010 |                  |
| Rho60 .....           | 641.513362513010 |                  |
| Ctl,60 .....          | 1.000446814523   |                  |

| Step 3 - Correct 60°F/0 psi density to alternate conditions: |                  |
|--------------------------------------------------------------|------------------|
| t, °F .....                                                  | 193.820000000000 |
| t corrected to IPTS-68 °F .....                              | 193.861860191643 |
| Rho60* .....                                                 | 641.515332879412 |
| alpha60 .....                                                | 0.000446759000   |
| delta t, °F .....                                            | 133.854985291643 |
| Ctl* .....                                                   | 0.939260765097   |
| Fs,psi .....                                                 | 2.875296454594   |
| P in psi .....                                               | 657.746168574179 |
| Cpl .....                                                    | 1.019276716462   |
| Ctpl* .....                                                  | 0.957366628549   |

| Step 4 - Modify Ctl and Ctpl for temperature base of 15°C |                 |
|-----------------------------------------------------------|-----------------|
| Ctl .....                                                 | 0.938841277179  |
| Ctpl .....                                                | 0.956939054283  |
| Ctpl, rounded .....                                       | 0.95694         |
| Fs,bar .....                                              | 41.702651081010 |

| Step 5 - Calculate volume at base conditions and density at alternate conditions |                  |
|----------------------------------------------------------------------------------|------------------|
| Volume at base conditions .....                                                  | 45.789533747419  |
| Density, kg/cu m, at t & P .....                                                 | 614.163485038521 |

# API MPMS 11.1.7.2 Metric Units, Example 8

## Input Data

|                                  |                    |
|----------------------------------|--------------------|
| Commodity .....                  | Specialized Liquid |
| Base temperature, °C .....       | 15                 |
| Alpha at 60°F per °C .....       | 0.00103734         |
| t observed temperature, °C ..... | 29.18              |
| P observed pressure, kPa .....   | 395                |
| Observed density, kg/cu m .....  | 853.7              |
| Volume at observed t & P .....   | 8501.3             |

Computed Data - last digit is rounded for display purposes

## Step 1

Convert to customary units

|                                 |                 |
|---------------------------------|-----------------|
| t observed temperature °F ..... | 84.524000000000 |
| T base temperature, °F .....    | 59.000000000000 |
| P observed, pressure, psi ..... | 57.289908839427 |
| Alpha at 60°F per °F .....      | 0.000576300000  |

## Step 2

Correcting observed density to 60°F & 0 psi reference conditions

|                           | Iteration(m) ..... | 0                | 1                | 2 |
|---------------------------|--------------------|------------------|------------------|---|
| Rho60(m) .....            | 853.700000000000   | 865.737133188744 | 865.736878409727 |   |
| Rho60*(m) .....           | 853.703382379864   | 865.740563260019 | 865.740308479993 |   |
| Ctl,60(m) .....           | 0.985804899058     | 0.985804899058   | 0.985804899058   |   |
| d_alpha(m) .....          | 0.000000000000     | 0.000000000000   | 0.000000000000   |   |
| Fs(m) .....               | 0.535684525741     | 0.515951854357   | 0.515952255703   |   |
| Cpl(m) .....              | 1.000306987389     | 1.000295675745   | 1.000295675975   |   |
| Ctpl(m) .....             | 0.986107528730     | 0.986096377657   | 0.986096377884   |   |
| Rho60(m)xCtpl,60(m) ..... | 841.839997277023   | 853.700251040320 | 853.700000000005 |   |
| delta Rho60(m) .....      | 11.860002722977    | -0.000251040320  | -0.000000000005  |   |
| E(m) .....                | 12.027088707301    | -0.000254579903  |                  |   |
| Dt(m) .....               | 0.000000000000     | 0.000000000000   |                  |   |
| Dp(m) .....               | -0.000834457947    | -0.000781516392  |                  |   |
| delta Rho(m) .....        | 12.037133188744    | -0.000254779017  |                  |   |
| Rho60(m+1) .....          | 865.737133188744   | 865.736878409727 |                  |   |

Output values

|              |                  |
|--------------|------------------|
| Rho60 .....  | 865.736878409727 |
| Ctl* .....   | 0.985804899058   |
| Fs,psi ..... | 0.515952255703   |
| Cpl .....    | 1.000295675975   |
| Ctpl* .....  | 0.986096377884   |

## Step 3

Correcting 60°F density to 15°C base conditions:

|                                 |                  |
|---------------------------------|------------------|
| t, °F .....                     | 59.000000000000  |
| t corrected to IPTS-68 °F ..... | 59.006621316269  |
| Rho60* .....                    | 865.740308479993 |
| alpha60 .....                   | 0.000576300000   |
| delta t, °F .....               | -1.000253583731  |
| Ctl .....                       | 1.000576349988   |
| Fs,psi .....                    | 0.475019162473   |
| P in psi .....                  | 0.000000000000   |
| Cpl .....                       | 1.000000000000   |
| Ctpl .....                      | 1.000576349988   |
| Density, kg/cu m, at 15°C ..... | 866.235845849433 |
| Ctl,60 .....                    | 1.000576349988   |

## Step 4

Modify Ctl\* factor and calculate Ctpl factor for base temperature of 15°C

|                     |                |
|---------------------|----------------|
| Ctl .....           | 0.985237057692 |
| Ctpl .....          | 0.985528368620 |
| Ctpl, rounded ..... | 0.98553        |
| Fs,kPa .....        | 0.074832551126 |

## Step 5

Volume at base conditions ..... 8378.27232014771

# API MPMS 11.1.7.3 Metric Units, Example 7

## Input Data

|                                 |                    |
|---------------------------------|--------------------|
| Commodity .....                 | Specialized Liquid |
| Alpha at 60°F per °C .....      | 0.001037412        |
| t observed, °C .....            | 29.2               |
| P observed pressure, kPa .....  | 395                |
| Base temperature, °C .....      | 15                 |
| t alternate temp, °C .....      | 55.05              |
| P alternate pressure, kPa ..... | 6505               |
| Observed density, kg/cu m ..... | 853.7              |
| Volume at observed t & P .....  | 1000               |

Computed Data - last digit is rounded for display purposes

## Step 1

Convert to customary units

|                                  |                  |
|----------------------------------|------------------|
| T base, °F .....                 | 59.000000000000  |
| t observed, °F .....             | 84.560000000000  |
| t alternate temperature, °F .... | 131.090000000000 |
| P observed pressure, PSI .....   | 57.289908839427  |
| P alternate pressure, PSI .....  | 943.470524051827 |
| Alpha at 60°F per °F .....       | 0.000576340000   |

## Step 2

Correcting observed density to 60°F & 0 psi reference conditions

| Iteration(m) .....        | 0                | 1                | 2                |
|---------------------------|------------------|------------------|------------------|
| Rho60(m) .....            | 853.700000000000 | 865.756362250420 | 865.756106602179 |
| Rho60*(m) .....           | 853.703382614631 | 865.759792635963 | 865.759536986708 |
| Ctl,60(m) .....           | 0.985782987747   | 0.985782987747   | 0.985782987747   |
| d_alpha(m) .....          | 0.000000000000   | 0.000000000000   | 0.000000000000   |
| Fs(m) .....               | 0.535748682507   | 0.515981715023   | 0.515982117769   |
| Cpl(m) .....              | 1.000307024167   | 1.000295692863   | 1.000295693093   |
| Ctpl(m) .....             | 0.986085646948   | 0.986074476741   | 0.986074476968   |
| Rho60(m)xCtpl,60(m) ..... | 841.821316799279 | 853.700251891176 | 853.700000000005 |
| delta Rho60(m) .....      | 11.878683200722  | -0.000251891176  | -0.000000000004  |
| E(m) .....                | 12.046299667265  | -0.000255448429  |                  |
| Dt(m) .....               | 0.000000000000   | 0.000000000000   |                  |
| Dp(m) .....               | -0.000834628468  | -0.000781592986  |                  |
| delta Rho(m) .....        | 12.056362250420  | -0.000255648241  |                  |
| Rho60(m+1) .....          | 865.756362250420 | 865.756106602179 |                  |
| Output values             |                  |                  |                  |
| Rho60 .....               | 865.756106602179 |                  |                  |
| Ctl,o .....               | 0.985782987747   |                  |                  |
| Fs,o,psi .....            | 0.515982117769   |                  |                  |
| Cpl,o .....               | 1.000295693093   |                  |                  |
| Ctpl,o .....              | 0.986074476968   |                  |                  |

## Step 3

Correcting 60°F and 0 psi density to alternate conditions:

|                                 |                  |
|---------------------------------|------------------|
| t, °F .....                     | 131.090000000000 |
| t corrected to IPTS-68 °F ..... | 131.115680255004 |
| Rho60* .....                    | 865.759536986708 |
| alpha60 .....                   | 0.000576340000   |
| delta t, °F .....               | 71.108805355004  |
| Ctl* .....                      | 0.958556488638   |
| Fs,psi .....                    | 0.599894402634   |
| P in psi .....                  | 943.470524051827 |
| Cpl .....                       | 1.005692042841   |
| Ctpl* .....                     | 0.964012633237   |
| Density at t & P, kg/cu m ..... | 834.599824066622 |

## Step 4

Correcting 60°F density to 15°C base conditions:

|                                       |                  |
|---------------------------------------|------------------|
| t, °F .....                           | 59.000000000000  |
| t corrected to IPTS-68 °F .....       | 59.006621316269  |
| Rho60* .....                          | 865.759536986708 |
| alpha60 .....                         | 0.000576340000   |
| delta t, °F .....                     | -1.000253583731  |
| Ctl .....                             | 1.000576389985   |
| Fs,psi .....                          | 0.474992948912   |
| P in psi .....                        | 0.000000000000   |
| Cpl .....                             | 1.000000000000   |
| Ctpl .....                            | 1.000576389985   |
| Density, kg/cu m, at 15°C/0 kPa ..... | 866.255119751516 |
| Ctl,60 .....                          | 1.000576389985   |

## Step 5

Modify Ctl\* factor and calculate the Ctpl factor for 15°C base conditions:

|              |                |
|--------------|----------------|
| Ctl,o .....  | 0.985215119619 |
| Ctl .....    | 0.958004304551 |
| Ctpl,o ..... | 0.985506440926 |

|                                  |                  |
|----------------------------------|------------------|
| Ctp1,o, rounded .....            | 0.98551          |
| Ctp1 .....                       | 0.963457306095   |
| Ctp1, rounded .....              | 0.96346          |
| Fs,o,kPa .....                   | 0.074836882253   |
| Fs,kPa .....                     | 0.087007330735   |
| Step 6                           |                  |
| Volume at base conditions .....  | 985.506440925726 |
| Volume at alternate conditions . | 1022.88543009788 |

## Appendix G — Examples Calculations including Equilibrium Vapor Pressure

The  $P_e$  value used in Equation 15 shall be in the same units and qualifier (absolute or gauge) as the observed or alternate pressure.

Equilibrium pressure varies with the temperature of the liquid. Therefore, different equilibrium pressures may be required for observed or alternate temperatures.

The following examples taken from the Sections 11.1.6.1, 11.1.6.2, 11.1.6.3, 11.1.7.1, 11.1.7.2, and 11.1.7.3 in the body of this document illustrate the calculations for liquids with equilibrium vapor pressures greater than atmospheric pressure.

API MPMS 11.1.6.1 Customary Units, Example 6  
A volume of a refined product is measured at observed conditions of temperature and pressure. The base  $\text{kg/m}^3$  is known. Calculate the volume at base conditions and correct the base density to an alternate condition.

Input Data

|                                           |                             |
|-------------------------------------------|-----------------------------|
| Commodity .....                           | Generalized Refined Product |
| t alternate temperature, °F .....         | 27.3                        |
| P alternate pressure, PSI .....           | 1234.51244.5                |
| $P_e$ at alternate temperature, PSI. .... | 10.0                        |
| Base density, $\text{kg/cu m}$ .....      | 657.3                       |
| Volume at alternate t & P .....           | 14.72                       |

Computed Data - last digit is rounded for display purposes

Calculation of Intermediate Results  
 $P_{alt} - P_{ealt}$ , PSI ..... 1234.500000000000

Step 1 - Check input values for range excursion  
All input values within range  
Calculation of volume correction factor

Step 2 - Shift temperature t to IPTS-68 temperature scale  
t corrected to IPTS-68 ( $t^*$ ) .... 27.298898616759

Step 3 - Shift  $\rho_{60}$  to IPTS-68 temperature scale  
Using gasoline coefficients:

|                     |                  |
|---------------------|------------------|
| K0 .....            | 192.457100000000 |
| K1 .....            | 0.243800000000   |
| K2 .....            | 0.000000000000   |
| A .....             | 0.000005612455   |
| B .....             | 1.545657407721   |
| $\rho_{60}^*$ ..... | 657.303689061482 |

Step 4 - Determine coefficient of thermal expansion  
 $\alpha_{60}$  ..... 0.000816362130

Step 5 - Calculate temperature correction factor  $C_{t1}$   
 $\Delta t$  ..... -32.707976283241  
 $C_{t1}$  ..... 1.026475833518

Step 6 - Calculate scaled compressibility factor  $F_p$   
 $F_s$  for psi ..... 0.993527440282

Step 7 - Calculate pressure correction factor  $C_{p1}$   
 $C_{p1}$  ..... 1.012417396817

Step 8 - Calculate the Volume Correction Factor  $C_{tp1}$   
 $C_{tp1}$  ..... 1.039221991267  
 $C_{tp1}$ , rounded ..... 1.03922

Step 9 - Calculate volume at base conditions  
and density at alternate conditions  
Volume at base conditions ..... 15.297347711445  
Density at t & P,  $\text{kg/cu m}$  ..... 683.080614859578

# API MPMS 11.1.6.2 Customary Units, Example 6

## Input Data

|                                  |                             |
|----------------------------------|-----------------------------|
| Commodity .....                  | Generalized Refined Product |
| t observed temperature, °F ..... | 139                         |
| P observed pressure, PSI .....   | 100108                      |
| Pe at observed temperature, PSI. | 8.0                         |
| Rel density, observed t & P .... | 0.7322                      |
| Volume at observed t & P .....   | 1000                        |

Computed Data - last digit is rounded for display purposes

## Calculation of Intermediate Results

|                           |                  |
|---------------------------|------------------|
| Density kg/cu meter ..... | 731.479515200000 |
| Pobs - Peobs, PSI .....   | 100.000000000000 |

## Step 1

All input data within range of procedure

## Step 2

Initial density, kg/cu m ..... 731.479515200000

|                      |                  |                    |                  |                  |
|----------------------|------------------|--------------------|------------------|------------------|
| Iteration(m) .....   | 0                | 1                  | 2                | 3                |
| Step 3               |                  |                    |                  |                  |
| Commodity .....      | gasoline         | gasoline           | gasoline         | gasoline         |
| Rho60(m) .....       | 731.479515200000 | 770.352202009943   | 770.350382398833 | 770.349794252060 |
| K0(m) .....          | 192.457100000000 | 1.489067000000e+03 | 192.457100000000 | 192.457100000000 |
| K1(m) .....          | 0.243800000000   | 0.000000000000     | 0.243800000000   | 0.243800000000   |
| K2(m) .....          | 0.000000000000   | -0.001868400000    | 0.000000000000   | 0.000000000000   |
| A(m) .....           | 0.000004764222   | 0.000004405447     | 0.000004405346   | 0.000004405351   |
| B(m) .....           | 1.519043562955   | 7.831444710641     | 1.506108416142   | 1.506108606983   |
| Rho60*(m) .....      | 731.483000127510 | 770.355595657728   | 770.353776055661 | 770.353187910199 |
| alpha60(m) .....     | 0.000692983108   | 0.000640779647     | 0.000640782868   | 0.000640783604   |
| Ctl(m) .....         | 0.944443401311   | 0.948677400428     | 0.948677139402   | 0.948677079691   |
| d_alpha(m) .....     | 1.500000000000   | 8.500000000000     | 1.500000000000   | 1.500000000000   |
| Fs(m) .....          | 1.118639209920   | 0.910912736669     | 0.910920838482   | 0.910923457238   |
| Cpl(m) .....         | 1.001119891965   | 1.000911743255     | 1.000911751372   | 1.000911753995   |
| Ctpl(m) .....        | 0.945501075887   | 0.949542350649     | 0.949542097086   | 0.949542039808   |
| Rho60(m)xCtpl(m) ... | 691.614668611132 | 731.482040724130   | 731.480117593762 | 731.479515000034 |
| Step 4               |                  |                    |                  |                  |
| delta Rho60(m) ..... | 39.864846588868  | -0.002525524130    | -0.000602393762  | 0.000000199966   |
| Step 5               |                  |                    |                  |                  |
| E(m) .....           | 42.162666553771  | -0.002659727740    | -0.000634404481  |                  |
| Dt(m) .....          | 0.089311509196   | 0.465134152690     | 0.082082941045   |                  |
| Dp(m) .....          | -0.004676769130  | -0.003432954458    | -0.003433001237  |                  |
| delta Rho(m) .....   | 38.872686809943  | -0.001819611110    | -0.000588146773  |                  |
| Rho60(m+1) .....     | 770.352202009943 | 770.350382398833   | 770.349794252060 |                  |

Step 6, iteration(m) ..... 1

2

3

## Step 7

Density at 60°F is within range of procedure

## Output values

|                        |                  |
|------------------------|------------------|
| Density at 60°F .....  | 770.349794252060 |
| Relative density ..... | 0.771108565080   |
| Ctl .....              | 0.948677079691   |
| Fs for psi .....       | 0.910923457238   |
| Cpl .....              | 1.000911753995   |
| Ctpl .....             | 0.949542039808   |
| Ctpl, rounded .....    | 0.94954          |

## Step 8

Volume at base conditions ..... 949.542039808338

# API MPMS 11.1.6.3 Customary Units, Example 3

## Input Data

|                                        |                             |
|----------------------------------------|-----------------------------|
| Commodity .....                        | Generalized Refined Product |
| t observed temperature, °F .....       | 68.02                       |
| t alternate temperature, °F .....      | 150.3                       |
| P observed pressure, PSI .....         | 11                          |
| Pe at observed temperature, PSI .....  | -9.3                        |
| Forcing negative pressure(s) to zero   |                             |
| P alternate pressure, PSI .....        | 534.540                     |
| Pe at alternate temperature, PSI ..... | 6.0                         |
| Rho, observed rel density .....        | 0.8665                      |
| Volume at observed t & P .....         | 285.45                      |

Computed Data - last digit is rounded for display purposes

## Calculation of Intermediate Results

|                           |                  |
|---------------------------|------------------|
| Density kg/cu meter ..... | 865.647364000000 |
| Pobs - Peobs, PSI .....   | 11.000000000000  |
| PaIt - Pealt, PSI .....   | 534.000000000000 |

## Step 1

Correcting observed density to 60 °F & 0 psi reference conditions:

|                       | Iteration(m) ..... | 0                | 1                | 2                |
|-----------------------|--------------------|------------------|------------------|------------------|
| Commodity .....       |                    | fuel oil         | fuel oil         | fuel oil         |
| Rho60(m) .....        |                    | 865.647364000000 | 868.730560425361 | 868.730481427765 |
| K0(m) .....           |                    | 103.872000000000 | 103.872000000000 | 103.872000000000 |
| K1(m) .....           |                    | 0.270100000000   | 0.270100000000   | 0.270100000000   |
| K2(m) .....           |                    | 0.000000000000   | 0.000000000000   | 0.000000000000   |
| A(m) .....            |                    | 0.000003098089   | 0.000003083723   | 0.000003083724   |
| B(m) .....            |                    | 1.307601778625   | 1.306845058542   | 1.306845077883   |
| Rho60*(m) .....       |                    | 865.650045852404 | 868.733239349982 | 868.733160352460 |
| alpha60(m) .....      |                    | 0.000450635987   | 0.000448546437   | 0.000448546490   |
| Ctl(m) .....          |                    | 0.996381066426   | 0.996397864928   | 0.996397864500   |
| d_alpha(m) .....      |                    | 1.300000000000   | 1.300000000000   | 1.300000000000   |
| Fs(m) .....           |                    | 0.489229213867   | 0.484844362415   | 0.484844473663   |
| Cpl(m) .....          |                    | 1.000053818110   | 1.000053335724   | 1.000053335737   |
| Ctpl(m) .....         |                    | 0.996434689772   | 0.996451008530   | 0.996451008114   |
| Rho60(m)xCtpl(m) ...  |                    | 862.561062599229 | 865.647443076884 | 865.647363997953 |
| delta Rho60(m) .....  |                    | 3.086301400771   | -0.000079076884  | 0.000000002047   |
| E(m) .....            |                    | 3.097344394420   | -0.000079358527  |                  |
| Dt(m) .....           |                    | 0.004725499180   | 0.004703462163   |                  |
| Dp(m) .....           |                    | -0.000136764923  | -0.000134578693  |                  |
| delta Rho(m) .....    |                    | 3.083196425361   | -0.000078997596  |                  |
| Rho60(m+1) .....      |                    | 868.730560425361 | 868.730481427765 |                  |
| Output values         |                    |                  |                  |                  |
| Rho60 .....           |                    | 868.730481427765 |                  |                  |
| Ctl,o .....           |                    | 0.996397864500   |                  |                  |
| Fs,o .....            |                    | 0.484844473663   |                  |                  |
| Cpl,o .....           |                    | 1.000053335737   |                  |                  |
| Ctpl,o .....          |                    | 0.996451008114   |                  |                  |
| Ctpl,o, rounded ..... |                    | 0.99645          |                  |                  |

## Step 2

Correcting 60°F and 0 psi density to alternate conditions:

|                                 |                  |
|---------------------------------|------------------|
| t, °F .....                     | 150.300000000000 |
| t corrected to IPTS-68 °F ..... | 150.330786371419 |
| A .....                         | 0.000003083724   |
| B .....                         | 1.306845077883   |
| Rho60* .....                    | 868.733160352460 |
| alpha60 .....                   | 0.000448546490   |
| delta t, °F .....               | 90.323911471419  |
| Ctl .....                       | 0.959034901244   |
| Fs,psi .....                    | 0.631776484622   |
| P in psi .....                  | 534.000000000000 |
| Cpl .....                       | 1.003385106716   |
| Ctpl .....                      | 0.962281336729   |
| Ctpl, rounded .....             | 0.96228          |
| Density at t & P, kg/cu m ..... | 835.963128925946 |

## Step 3

|                                 |                  |
|---------------------------------|------------------|
| Volume at base conditions ..... | 284.436940266107 |
| Volume at alternate t & P ..... | 295.586050990898 |

# API MPMS 11.1.7.1 Metric Units, Example 7

A volume of a specialized liquid is measured at observed conditions of temperature and pressure. The base density at 15°C is known. Calculate the volume at base conditions and correct the base density to an alternate condition.

| Input Data                             | Specialized Liquid |
|----------------------------------------|--------------------|
| Commodity .....                        |                    |
| Alpha at 60°F per °F .....             | 0.000446759        |
| T base temperature, °C .....           | 15                 |
| t alternate temperature, °C .....      | 89.9               |
| P alternate pressure, bar .....        | 45.3546.56         |
| Pe at alternate temperature, bar ..... | 1.21               |
| Base density, kg/cu m .....            | 641.8              |
| Volume at alternate t & P .....        | 47.85              |

Computed Data - last digit is rounded for display purposes

Calculation of Intermediate Results  
 Palt - Pealt, bar ..... 45.350000000000

Step 1 - Convert to customary units  
 t alternate temperature, °F ..... 193.82  
 T base, °F ..... 59  
 P alternate, PSI ..... 657.746168574179

Step 2 - Correct base metric (observed) density to 60 °F & 0 psi reference conditions:

| Iteration(m) .....       | 0                | 1                |
|--------------------------|------------------|------------------|
| Rho60(m) .....           | 641.800000000000 | 641.513362513010 |
| Rho60*(m) .....          | 641.801971246791 | 641.515332879412 |
| Ctl,60(m) .....          | 1.000446814523   | 1.000446814523   |
| d_alpha(m) .....         | 0.000000000000   | 0.000000000000   |
| Rho60(m)xCtl,60(m) ..... | 642.086765560782 | 641.800000000000 |
| delta Rho60(m) .....     | -0.286765560782  | -0.000000000000  |
| E(m) .....               | -0.286637486990  |                  |
| Dt(m) .....              | -0.000000000000  |                  |
| Dp(m) .....              | -0.000000000000  |                  |
| delta Rho(m) .....       | -0.286637486990  |                  |
| Rho60(m+1) .....         | 641.513362513010 |                  |

|              |                  |
|--------------|------------------|
| Rho60 .....  | 641.513362513010 |
| Ctl,60 ..... | 1.000446814523   |

Step 3 - Correct 60°F/0 psi density to alternate conditions:

|                                 |                  |
|---------------------------------|------------------|
| t, °F .....                     | 193.820000000000 |
| t corrected to IPTS-68 °F ..... | 193.861860191643 |
| Rho60* .....                    | 641.515332879412 |
| alpha60 .....                   | 0.000446759000   |
| delta t, °F .....               | 133.854985291643 |
| Ctl* .....                      | 0.939260765097   |
| Fs,psi .....                    | 2.875296454594   |
| P in psi .....                  | 657.746168574179 |
| Cpl .....                       | 1.019276716462   |
| Ctpl* .....                     | 0.957366628549   |

Step 4 - Modify Ctl and Ctpl for temperature base of 15°C

|                     |                 |
|---------------------|-----------------|
| Ctl .....           | 0.938841277179  |
| Ctpl .....          | 0.956939054283  |
| Ctpl, rounded ..... | 0.95694         |
| Fs,bar .....        | 41.702651081010 |

Step 5 - Calculate volume at base conditions and density at alternate conditions

|                                  |                  |
|----------------------------------|------------------|
| Volume at base conditions .....  | 45.789533747419  |
| Density, kg/cu m, at t & P ..... | 614.163485038521 |

# API MPMS 11.1.7.2 Metric Units, Example 3

## Input Data

|                                    |                       |
|------------------------------------|-----------------------|
| Commodity .....                    | Generalized Crude Oil |
| Base temperature, °C .....         | 15                    |
| t observed temperature, °C .....   | -50                   |
| P observed pressure, kPa .....     | 115127.9              |
| Pe at observed temperature, kPa .. | 12.9                  |
| Observed density, kg/cu m .....    | 722.6                 |
| Volume at observed t & P .....     | 145902                |

Computed Data - last digit is rounded for display purposes

## Calculation of Intermediate Results

|                         |                  |
|-------------------------|------------------|
| Pobs - Peobs, kPa ..... | 115.000000000000 |
|-------------------------|------------------|

## Step 1

Convert to customary units

|                                 |                 |
|---------------------------------|-----------------|
| t observed temperature °F ..... | -58             |
| T base temperature, °F .....    | 59              |
| P observed, pressure, psi ..... | 16.679340548188 |

## Step 2

Correcting observed density to 60°F & 0 psi reference conditions

|                          | Iteration(m) ..... | 0                | 1                | 2                | 3 |
|--------------------------|--------------------|------------------|------------------|------------------|---|
| Rho60(m) .....           | 722.600000000000   | 664.214217743108 | 663.869893343631 | 663.869868377549 |   |
| K0(m) .....              | 341.095700000000   | 341.095700000000 | 341.095700000000 | 341.095700000000 |   |
| K1(m) .....              | 0.000000000000     | 0.000000000000   | 0.000000000000   | 0.000000000000   |   |
| K2(m) .....              | 0.000000000000     | 0.000000000000   | 0.000000000000   | 0.000000000000   |   |
| A(m) .....               | 0.000004491036     | 0.000005315280   | 0.000005320795   | 0.000005320796   |   |
| B(m) .....               | 2.000000000000     | 2.000000000000   | 2.000000000000   | 2.000000000000   |   |
| Rho60*(m) .....          | 722.603245212681   | 664.217748214555 | 663.873425646187 | 663.873400680238 |   |
| alpha60(m) .....         | 0.000653245504     | 0.000773134926   | 0.000773937117   | 0.000773937176   |   |
| Ctl,60(m) .....          | 1.075025061700     | 1.088269020951   | 1.088357010727   | 1.088357017112   |   |
| d_alpha(m) .....         | 2.000000000000     | 2.000000000000   | 2.000000000000   | 2.000000000000   |   |
| Fs(m) .....              | 0.476890642768     | 0.601186188829   | 0.602118614321   | 0.602118682034   |   |
| Cpl(m) .....             | 1.000079548542     | 1.000100283948   | 1.000100439501   | 1.000100439513   |   |
| Ctpl(m) .....            | 1.075110578376     | 1.088378156864   | 1.088466324763   | 1.088466331160   |   |
| Rho60(m)xCtl,60(m) ..... | 776.874903934710   | 722.916246070126 | 722.600022928389 | 722.600000000760 |   |
| delta Rho60(m) .....     | -54.274903934710   | -0.316246070126  | -0.000022928389  | -0.000000000760  |   |
| E(m) .....               | -50.483089857305   | -0.290566351531  | -0.000021064858  |                  |   |
| Dt(m) .....              | -0.135152229527    | -0.155826567176  | -0.155960587255  |                  |   |
| Dp(m) .....              | -0.000200798113    | -0.000299597651  | -0.000300373710  |                  |   |
| delta Rho(m) .....       | -58.385782256892   | -0.344324399478  | -0.000024966082  |                  |   |
| Rho60(m+1) .....         | 664.214217743108   | 663.869893343631 | 663.869868377549 |                  |   |
| Output values            |                    |                  |                  |                  |   |
| Rho60 .....              | 663.869868377549   |                  |                  |                  |   |
| Ctl* .....               | 1.088357017112     |                  |                  |                  |   |
| Fs,psi .....             | 0.602118682034     |                  |                  |                  |   |
| Cpl .....                | 1.000100439513     |                  |                  |                  |   |
| Ctpl* .....              | 1.088466331160     |                  |                  |                  |   |

## Step 3

Correcting 60°F density to 15°C base conditions:

|                                 |                  |
|---------------------------------|------------------|
| t, °F .....                     | 59.000000000000  |
| t corrected to IPTS-68 °F ..... | 59.006621316269  |
| A .....                         | 0.000005320796   |
| B .....                         | 2.000000000000   |
| Rho60* .....                    | 663.873400680238 |
| alpha60 .....                   | 0.000773937176   |
| delta t, °F .....               | -1.000253583731  |
| Ctl .....                       | 1.000773959950   |
| Fs,psi .....                    | 1.134306792464   |
| P in psi .....                  | 0.000000000000   |
| Cpl .....                       | 1.000000000000   |
| Ctpl .....                      | 1.000773959950   |
| Density, kg/cu m, at 15°C ..... | 664.383677067826 |
| Ctl,60 .....                    | 1.000773959950   |

## Step 4

Modify Ctl\* factor and calculate Ctpl factor for base temperature of 15°C

|                     |                |
|---------------------|----------------|
| Ctl .....           | 1.087515323806 |
| Ctpl .....          | 1.087624553315 |
| Ctpl, rounded ..... | 1.08762        |
| Fs,kPa .....        | 0.087329935201 |

## Step 5

|                                 |                  |
|---------------------------------|------------------|
| Volume at base conditions ..... | 158686.597577785 |
|---------------------------------|------------------|

# API MPMS 11.1.7.3 Metric Units, Example 4

## Input Data

|                                      |                             |
|--------------------------------------|-----------------------------|
| Commodity .....                      | Generalized Refined Product |
| t observed, °C .....                 | 22.25                       |
| P observed pressure, kPa .....       | 2585                        |
| Pe at observed temperature, kPa      | -7.1                        |
| Forcing negative pressure(s) to zero |                             |
| Base temperature, °C .....           | 15                          |
| t alternate temp, °C .....           | 102.35                      |
| P alternate pressure, kPa .....      | 3505                        |
| Pe at alternate temperature, kPa     | 329                         |
| Observed density, kg/cu m .....      | 817.55                      |
| Volume at observed t & P .....       | 9987.5                      |

Computed Data - last digit is rounded for display purposes

## Calculation of Intermediate Results

Pobs - Peobs, kPa ..... 2585.000000000000

## Step 1

Convert to customary units

|                                  |                  |
|----------------------------------|------------------|
| T base, °F .....                 | 59.000000000000  |
| t observed, °F .....             | 72.050000000000  |
| t alternate temperature, °F .... | 216.230000000000 |
| P observed pressure, PSI .....   | 374.922567974477 |
| P alternate pressure, PSI .....  | 508.357292359977 |

## Step 2

Correcting observed density to 60°F & 0 psi reference conditions

|                           | Iteration(m) ..... 0 | 1                | 2                |
|---------------------------|----------------------|------------------|------------------|
| Commodity .....           | jet fuel             | jet fuel         | jet fuel         |
| Rho60(m) .....            | 817.550000000000     | 820.654189975112 | 820.654110634883 |
| K0(m) .....               | 330.301000000000     | 330.301000000000 | 330.301000000000 |
| K1(m) .....               | 0.000000000000       | 0.000000000000   | 0.000000000000   |
| K2(m) .....               | 0.000000000000       | 0.000000000000   | 0.000000000000   |
| A(m) .....                | 0.000003397406       | 0.000003371753   | 0.000003371754   |
| B(m) .....                | 2.000000000000       | 2.000000000000   | 2.000000000000   |
| Rho60*(m) .....           | 817.552777542898     | 820.656957011782 | 820.656877671821 |
| alpha60(m) .....          | 0.000494172179       | 0.000490440783   | 0.000490440878   |
| Ctl,60(m) .....           | 0.994033154874       | 0.994078287334   | 0.994078286187   |
| d_alpha(m) .....          | 2.000000000000       | 2.000000000000   | 2.000000000000   |
| Fs(m) .....               | 0.579000765408       | 0.572745475182   | 0.572745633293   |
| Cpl(m) .....              | 1.002175527183       | 1.002151973087   | 1.002151973683   |
| Ctpl(m) .....             | 0.996195701022       | 0.996217517055   | 0.996217516497   |
| Rho60(m)xCtpl,60(m) ..... | 814.439795370921     | 817.550079497508 | 817.549999999757 |
| delta Rho60(m) .....      | 3.110204629079       | -0.000079497508  | 0.000000000243   |
| E(m) .....                | 3.122081962296       | -0.000079799347  |                  |
| Dt(m) .....               | 0.012023019412       | 0.011931385668   |                  |
| Dp(m) .....               | -0.006259201048      | -0.006144683052  |                  |
| delta Rho(m) .....        | 3.104189975112       | -0.000079340229  |                  |
| Rho60(m+1) .....          | 820.654189975112     | 820.654110634883 |                  |
| Output values             |                      |                  |                  |
| Rho60 .....               | 820.654110634883     |                  |                  |
| Ctl,o .....               | 0.994078286187       |                  |                  |
| Fs,o,psi .....            | 0.572745633293       |                  |                  |
| Cpl,o .....               | 1.002151973683       |                  |                  |
| Ctpl,o .....              | 0.996217516497       |                  |                  |

## Step 3

Correcting 60°F and 0 psi density to alternate conditions:

|                                 |                  |
|---------------------------------|------------------|
| t, °F .....                     | 216.230000000000 |
| t corrected to IPTS-68 °F ..... | 216.277130766009 |
| A .....                         | 0.000003371754   |
| B .....                         | 2.000000000000   |
| Rho60* .....                    | 820.656877671821 |
| alpha60 .....                   | 0.000490440878   |
| delta t, °F .....               | 156.270255866009 |
| Ctl* .....                      | 0.921879416463   |
| Fs,psi .....                    | 0.960919556350   |
| P in psi .....                  | 508.357292359977 |
| Cpl .....                       | 1.004908884069   |
| Ctpl* .....                     | 0.926404815644   |
| Density at t & P, kg/cu m ..... | 760.257920070010 |

## Step 4

Correcting 60°F density to 15°C base conditions:

|                                 |                  |
|---------------------------------|------------------|
| t, °F .....                     | 59.000000000000  |
| t corrected to IPTS-68 °F ..... | 59.006621316269  |
| A .....                         | 0.000003371754   |
| B .....                         | 2.000000000000   |
| Rho60* .....                    | 820.656877671821 |
| alpha60 .....                   | 0.000490440878   |
| delta t, °F .....               | -1.000253583731  |
| Ctl .....                       | 1.000490495623   |
| Fs,psi .....                    | 0.546539446476   |
| P in psi .....                  | 0.000000000000   |
| Cpl .....                       | 1.000000000000   |
| Ctpl .....                      | 1.000490495623   |
| Density, kg/cu m, at 15°C/0 kPa | 821.056637883991 |
| ctl,60 .....                    | 1.000490495623   |

#### Step 5

Modify Ctl\* factor and calculate the Ctpl factor for 15°C base conditions:

|                       |                |
|-----------------------|----------------|
| ctl,o .....           | 0.993590934183 |
| Ctl .....             | 0.921427460327 |
| Ctpl,o .....          | 0.995729115724 |
| Ctpl,o, rounded ..... | 0.99573        |
| Ctpl .....            | 0.925950640907 |
| Ctpl, rounded .....   | 0.92595        |
| Fs,o,kPa .....        | 0.083069734480 |
| Fs,kPa .....          | 0.139369604520 |

#### Step 6

|                                  |                  |
|----------------------------------|------------------|
| Volume at base conditions .....  | 9944.84454329600 |
| Volume at alternate conditions . | 10740.1454288640 |

# **Manual of Petroleum Measurement Standards Chapter 11—Physical Properties Data**

## **Section 1—Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils**

**Adjunct to: ASTM D 1250-04 and IP 200/04**

MAY 2004

ADDENDUM 1, SEPTEMBER 2007

ADDENDUM 2, MAY 2019



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## Chapter 11 — Physical Properties Data

### Section 1 — Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils

NOTE: This version of API MPMS Chapter 11.1 includes modifications published in May 2019 as Addendum 2. Added text is highlighted in yellow. Deleted text is indicated by strikethrough. Modifications published in September 2007 as Addendum 1 have already been incorporated and are not specifically indicated, although a summary of the changes is given in 11.1.1.5.

#### 11.1.0 Implementation Guidelines

This Standard (Revised Standard) is effective upon the date of publication and supersedes the previous edition of the Standard(s) (Previous Standard(s)) referenced in Appendix A of this Revised Standard. ~~However, due to the nature of the changes in this Revised Standard, it is recognized that guidance concerning an implementation period may be needed in order to avoid disruptions within the industry and ensure proper application. As a result, it is recommended that this Revised Standard be utilized on all new applications no later than TWO YEARS after the publication date. An application for this purpose is defined as the point where the calculation is applied.~~

Once the Revised Standard is implemented in a particular application, the Previous Standard will no longer be used in that application.

If an existing application complies with the Previous Standard(s) then it shall be considered in compliance with this Revised Standard.

However, the use of API standards remains voluntary and the decision on when to utilize a standard is an issue that is subject to the negotiations between the parties involved in the transaction.

#### 11.1.1 Introduction & History

The density and therefore the volume of hydrocarbons is sensitive to temperature and pressure. Volume Correction Factors (VCFs) are used to correct observed volumes to equivalent volumes at a standard temperature and pressure. These standard, or base, conditions serve as a way to use volumetric measures equitably in general commerce. This Standard establishes a procedure for crude oils, liquid refined products, and lubricating oils by which density measurements taken at any temperature and pressure can be corrected to an equivalent density at the base conditions. The Standard also provides a method for making a conversion to alternate base temperatures.

The volume correction factors, in their basic form, are the output of a set of equations derived from and based on empirical data relating to the volumetric change of hydrocarbons over a range of temperatures and pressures. Traditionally, the factors have been listed in a tabular format called the Petroleum Measurement Tables. In order to introduce this document and the work that serves as its foundation, a short history of these Tables is warranted.

##### 11.1.1.1 Early Temperature and Pressure Correction Tables

Correction factors to account for the thermal expansion of liquid hydrocarbons were first formally developed in 1916 by the National Bureau of Standards (United States) under *Circular No. 57*. These data were based on density and temperature pairs documented in the National Bureau of Standards (NBS) *Technologic Paper No. 77*. *Circular No. 57* was superseded in 1924 by *Circular No. C154* which in turn was superseded by a more widely known *Circular C410*, in 1936. By 1945 The Institute of Petroleum (IP) was publishing the *Tables for Measurement of Oil* in British units.

The compressibility standard (API Standard 1101, Appendix B, Table II) for hydrocarbons in the 0 to 90° API gravity ranges was developed in 1945 by Jacobson, et al. It was based on limited data obtained mostly on pure compounds and lubricating oil type materials. Standard 1101 was developed without the aid of a mathematical model.

##### 11.1.1.2 1952 Temperature Correction Tables

In 1952 the British and the American temperature correction factor tables were joined together and made available in three units of measure: US units, British (Imperial) units, and metric units. These tables were called The Petroleum Measurement Tables and were published jointly by the American Society for Testing and Materials (ASTM) and the IP. These tables are commonly referred to as the 1952 Tables, or “Blue Book Tables.”

The 1952 Tables contained many sets of correction and conversion factor tables used in the measurement of hydrocarbon liquids. The tables were numbered one through fifty-eight, each dealing with a particular conversion of units, correction of density, or correction of volume. This 1952 document reflects the evolution of the correction factor tables for the correction of density or gravity to base temperature, and the correction of volume to base temperature against density at base temperature. The following shows many of the 1952 Tables which dealt with density and volume correction. These Tables were available in two volumes, US and metric versions.

| <b>1952 Tables, Density and Volume Correction Tables<sup>1</sup></b> |                                                                                            |                   |                  |
|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------|------------------|
| Table No.                                                            | Description                                                                                | Density Units     | Base Temperature |
| 5                                                                    | API Gravity Reduction to 60°F                                                              | °API              | 60°F             |
| 6                                                                    | Reduction of Volume to 60°F Against API Gravity at 60°F                                    | °API              | 60°F             |
| 7                                                                    | Reduction of Volume to 60°F Against API Gravity at 60°F (Abridged Table)                   | °API              | 60°F             |
| 23                                                                   | Reduction of Observed Specific Gravity to Specific Gravity 60/60°F                         | Relative Density  | 60°F             |
| 24                                                                   | Reduction of Volume to 60°F Against Specific Gravity 60/60°F                               | Relative Density  | 60°F             |
| 25                                                                   | Reduction of Volume to 60°F Against Specific Gravity 60/60°F (Abridged Table)              | Relative Density  | 60°F             |
| 33                                                                   | Specific Gravity Reduction to 60°F for Liquefied Petroleum Gases and Natural Gasoline      | Relative Density  | 60°F             |
| 34                                                                   | Reduction of Volume to 60°F Against Specific Gravity 60/60°F for Liquefied Petroleum Gases | Relative Density  | 60°F             |
| 53                                                                   | Reduction of Observed Density to Density at 15°C                                           | kg/m <sup>3</sup> | 15°C             |
| 54                                                                   | Reduction of Volume to 15°C Against Density at 15°C                                        | kg/m <sup>3</sup> | 15°C             |

In 1965, the American Petroleum Institute (API) adopted these 1952 Tables.

### 11.1.1.3 1980 Temperature Correction Tables

In 1974 the API started an initiative to re-confirm the temperature correction factor tables. This resulted in a major work program of density measurements made by the National Bureau of Standards under contract to the API. The effort culminated in re-writing major sections of the 1952 Tables to produce new density and volume correction tables, commonly referred to as the 1980 Tables. Refer to Appendix A for more information on this work.

The 1980 Tables separated the density and volume correction tables into two major commodity groups: crude oils and refined products. Tables were also produced for a third grouping known as “special applications.” A letter designation was added to the table numbering system devised in 1952: “A” for crude oil, “B” for refined products, and “C” for special applications. The table designations established are shown in the following table.

<sup>1</sup> Tables 53 and 54 were first published in 1953 by IP.

| 1980 Tables, Density and Volume Correction Tables                   |                   |            |                                   |                  |                     |
|---------------------------------------------------------------------|-------------------|------------|-----------------------------------|------------------|---------------------|
| Description                                                         | Density Units     | Base Temp. | Commodity Based Table Designation |                  |                     |
|                                                                     |                   |            | Crude Oil                         | Refined Products | Special Application |
| API Gravity Correction to 60°F                                      | °API              | 60°F       | 5A                                | 5B               |                     |
| Correction of Volume to 60°F Against API Gravity at 60°F            | °API              | 60°F       | 6A                                | 6B               | 6C                  |
| Correction of Observed Specific Gravity to Specific Gravity 60/60°F | Relative Density  | 60°F       | 23A                               | 23B              |                     |
| Correction of Volume to 60°F Against Specific Gravity 60/60°F       | Relative Density  | 60°F       | 24A                               | 24B              | 24C                 |
| Correction of Observed Density to Density at 15°C                   | kg/m <sup>3</sup> | 15°C       | 53A                               | 53B              |                     |
| Correction of Volume to 15°C Against Density at 15°C                | kg/m <sup>3</sup> | 15°C       | 54A                               | 54B              | 54C                 |

Tables for lubricating oils, the “D” tables, were developed and released in 1982. They were issued as a FORTRAN program but the API did not publish the implementation procedures. The IP published implementation procedures for the D tables in 1984 as part of their Petroleum Measurement Paper No. 2.

Since the 1980 Tables did not deal with the density range for LPGs and NGLs, the 1952 Tables remained in use for these products. This changed in October 1998 with the publication of GPA TP-25, *Temperature Correction for the Volume of Light Hydrocarbons*, in which the calculation for the temperature correction factor was modified. These tables carry the 23E and 24E designations.

The 1980 Tables constituted a major data collection and analysis effort. The NBS performed temperature/density measurements on a set of crude oil and refined product samples that spanned the world. (Refer to Appendix A of *Base Data-1980*, for more information on this work.) Most importantly, the 1980 Tables replaced the 1952 *printed* Tables with *mathematical equations*. Because the equations were now the basis for the Standard, the tables could easily be incorporated into computer subroutines via implementation procedures. It is these *implementation procedures* which the 1980 document made *the Standard*, not the table of numbers themselves.

In 1980, the implementation procedures became the first attempt to provide the petroleum industry with a means to produce identical numbers on a variety of computer hardware and software configurations. Due to computer hardware and software dissimilarities and relatively low capabilities, users would frequently get different answers from the same subroutine. Therefore, before its release, the procedure was modified in order to ensure consistent answers between different computer configurations. This made the procedure very complex which, in turn, resulted in an increased risk of programming errors by users.

#### 11.1.1.4 1981 Pressure Correction Tables

In 1981, a working group of the Committee on Static Petroleum Measurement was set up to revise the compressibility tables of Standard 1101. This group performed an extensive literature search and found only three sources of compressibility information. The resulting database was broader than that used in the previous Standard and replaced the discontinued Standard 1101, Appendix B, Table II, 0-100°API gravity portion. There were two versions of this 1981 Standard: Chapter 11.2.1 using customary units and Chapter 11.2.1M using metric units. Unlike the 1980 temperature correction factor tables, the *compressibility table values* were the Standard, *not the underlying equations*. Compressibility tables for LPGs and NGLs were addressed by Chapters 11.2.2 and 11.2.2M.

#### 11.1.1.5 Changes to Previous Standards

Between the initial issuance of the 1980 Tables and the mid-1990s, a number of needs arose within the petroleum industry and a number of enhancements occurred in computer technology. These needs and enhancements prompted several changes to be made to the Standard that are contained herein and are highlighted here:

- The 1980 Tables were based on data obtained using the International Practical Temperature Scale 1968 (IPTS-68). This has been superseded by the International Temperature Scale 1990 (ITS-90). The Standard takes this into account by correcting the input temperature values to an IPTS-68 basis before any other calculations are performed. Standard densities are also adjusted to take into account the small shifts in the associated standard temperatures.
- The accepted value of the standard density of water at 60°F has changed slightly from the value used in the 1980 Standard. This new water density only affects the inter-conversion of density values with relative density and API gravity. The impact would be seen in Tables 5, 6, 23, and 24.
- In 1988 the IP produced implementation procedures for 20°C (Tables 59 A, B and D and 60 A, B and D) by extending the procedures used for the 15°C Tables. This was in response to the needs of countries that use 20°C as their standard temperature. Although API never published these tables, they were adopted internationally as the reference document for International Standard ISO 91-2. ISO 91-2 complements ISO 91-1, the Standard for temperatures of 60°F and 15°C that is based on Volume X. This revision incorporates the 20°C tables.
- Tables for lubricating oils were developed and approved as a part of the Standard but were never fully documented. Only the FORTRAN code was published by the API in Appendix A and B of the printed 5D and 6D Tables. Implementation procedures for the lubricating oil tables first appeared in the IP's *Petroleum Measurement Paper No 2: Guidelines for Users of the Petroleum Measurement Tables* (API Standard 2540; IP 200; ANSI/ASTM D 1250), and later in their 20°C tables. The implementation procedures are now incorporated in this Standard.
- For business reasons the Tables have been extended to lower temperatures and higher densities (i.e., lower API gravities).
- Real-time density measurement using density meters has become more prevalent in the industry for input into VCF calculations. These density measurements are often made at pressures greater than atmospheric. This pressure effect must be taken into account simultaneously with any temperature effect when determining the density at standard conditions. Hence, pressure and temperature corrections have been combined into one procedure.
- Rounding and truncation of initial and intermediate values have been eliminated. Rounding will only be applied to the final VCF values.
- The previous Standard used a format that resulted in CTL values rounded 4 or 5 decimal digits, depending upon whether the CTL value was greater than or less than one. The final VCF values will now be rounded to a consistent 5 decimal digits. The Standard also provides a mechanism to provide unrounded factors that, when combined, give the overall rounded CTPL.
- Implementation procedures needed to be updated to reflect changes in computer technology. The 1980 Tables implementation procedure used integer arithmetic in order to allow all existing computer equipment to achieve consistent results. With the advent of the IEEE Standards and the predominance of 32 bit and higher level machines, this complexity of the 1980 procedure was no longer needed. This procedure now uses a double-precision floating-point math procedure.
- Flow computers in the field became common for real-time measurement of petroleum fluids. These require improved convergence methods for the correction of observed density to base density. A more robust convergence scheme now accomplishes this calculation.
- The range of application for the 1980 Chapter 11.2.1 method has been extended to be consistent with the range used here. This is so that a single pressure correction method could be used. Since the 1980 Chapter 11.2.1M method was not completely consistent with the 11.2.1 method, it has been withdrawn. The implementation procedure for the pressure correction is now the standard, not the printed table values.
- When the number of decimal digits is increased and the floating-point math format used, discrepancies between the previous 60°F, 15°C and 20°C Tables become apparent. Starting from the same input density

and temperature, each table may produce a slightly different VCF value for the same output temperature. These differences had been concealed in the 1980 Tables by the rounding and truncation procedures. This revision adopts a new procedure for calculating CTL and CPL factors for the metric tables. The procedure ensures that the results are the same as those obtained using the 60°F tables.

- Previous editions of the printed Tables assumed that density measurements were made with a glass hydrometer. The odd-numbered printed 1980 Tables all included a hydrometer correction on the observed density. In this Standard, no glass hydrometer corrections are applied. It is assumed that any densities measured with a glass hydrometer will be corrected before applying the calculations. Methods to correct glass hydrometer readings for use in this Standard are given in API MPMS Chapter 9.

#### Summary of Changes in Addendum 1:

- The term “Correction for Temperature and Pressure of a Liquid” (CTPL) was added to replace the term “Volume Correction Factor” (VCF). (Where there is no pressure correction then the Correction for Temperature (CTL) will replace Volume Correction Factor (VCF).
- The constants A, B, C, and D in Section 11.1.3.3 were replaced with numerical values.
- The following sentence was added to Section 11.1.3.4: For liquids with equilibrium vapor pressure less than atmospheric pressure, the  $P_e$  value in Equation 15 shall be atmospheric pressure. This reference was also added to various sections where there are examples in the document.
- A reference to round CTPL according to API MPMS Chapter 12 was added to Section 11.1.3.9. Also, the clarification: if there is no guidance for specific application, then the CTPL shall be rounded to 5 decimal places.

#### Summary of Changes in Addendum 2:

- The term “compressibility coefficient” and symbol “ $F_p$ ” are used in other standards in a different way. The term and symbol were changed to “scaled compressibility factor” and “ $F_s$ ,” respectively, to distinguish the difference.
- Section 11.1.2.5.13 was updated to reference API MPMS Chapter 11.3.4 for density and volume corrections of gasohol blends.
- Sections were added for guidance on volume corrections for ethanol, vacuum gas oil (VGO), and naphtha.
- Clarification was added to the use of the terms “standard,” “observed,” and “alternate” conditions.
- Clarification was added, and examples were updated, to show final density and volume results should be calculated with unrounded CTL and CPL values or an unrounded CTPL value.
- Wording was added to indicate the examples are provided to guide users in developing computer implementations of the standard, but are not part of the standard.
- If other standards call for use of a CTL factor alone, an equivalent CTPL factor may be calculated by using a gauge pressure of zero.
- Steps in Sections 11.1.8.23 and 11.1.8.24 were updated to use an arbitrary input density as required in the implementation procedures.
- Section C.7 was added to Appendix C to guide users in converting thermal expansion coefficients to temperature units other than °F-1.
- Appendix G was added to show how the equilibrium vapor pressure of liquids affects the calculations.

These updates and changes are designed to make the Standard more consistent and meet industry needs. No new hydrocarbon samples or data were taken. The basic equation forms and the associated constants used to define the temperature and pressure correction factors were not changed. Ranges of density and temperature over which certain parameters apply have been slightly changed.

#### 11.1.1.6 Customary Temperature & Pressure Correction Tables

This Standard incorporates both the temperature and pressure corrections into a single, unified procedure. Creating a full "three dimensional" table representation of the Standard with all possible values of temperature, pressure, and density would produce such a large number of results as to be unmanageable. This procedure is to be used in its algorithmic form.

Previous versions of this Standard had separate tables for the temperature and pressure corrections. These can still be created as specific cases of the general procedure. The 1980 temperature correction tables can be generated by setting the pressure to the base value (one atmosphere). The pressure correction tables can be generated by printing the compressibility factor at the base pressure.

Detailed instructions on how to use the implementation procedures to generate the traditional tables are given in 11.1.8.

#### 11.1.2 Purpose

The purpose of the Petroleum Measurement Tables is to establish a standard set of temperature and pressure related corrections to volume and density based on documented test data. The procedures explained within are designed to allow users to program computer equipment to produce correction factors consistent with those produced by other users employing different computer equipment, yet following the same programming procedure.

##### 11.1.2.1 Significance

Oil producers, carriers, refiners, and marketers use the Tables to correct petroleum densities and volumes to the base temperatures of 60°F, 15°C, or 20°C, the standard temperatures adopted internationally by the petroleum industry. The Tables provide a means for parties to make consistent and fair fiscal transactions. The Tables also provide governmental agencies with a means to equitably assess any applicable taxes and tariffs.

##### 11.1.2.2 Scope

This Standard provides the algorithm and implementation procedure for the correction of temperature and pressure effects on density and volume of liquid hydrocarbons which fall within the categories of crude oil, refined products, or lubricating oils; NGLs and LPGs are excluded from consideration in this Standard. The combination of density and volume correction factors for both temperature and pressure is collectively referred to in this Standard as a Correction for Temperature and Pressure of a Liquid (CTPL). The temperature portion of this correction is termed the Correction for the effect of Temperature on Liquid (CTL), also historically known as VCF (Volume Correction Factor). The pressure portion is termed the Correction for the effect of Pressure on Liquid (CPL). As this Standard will be applied to a variety of applications the output parameters specified in this Standard ( $\rho$ ,  $\rho_{60}$ ,  $\rho_T$ , CTL,  $F_p$ ,  $F_s$ , CPL, and CTPL) may be used as specified in other API *Manual of Petroleum Measurement Standards (MPMS)* Chapters.

Including the pressure correction in this Standard represents an important change from the "temperature only" 1980 Tables. However, if the pressure is one atmosphere (the standard pressure) then there is no pressure correction and this Standard will give CTL values consistent with the 1980 Tables.

This Standard provides general procedures for the conversion of input data to generate  $\rho$ ,  $\rho_{60}$ ,  $\rho_T$ , CTL,  $F_p$ ,  $F_s$ , CPL, and CTPL values at the user specified base temperature and pressure ( $T_b$ ,  $P_b$ ). This section is then followed by two sets of procedures for computing volume correction factor, one set for data expressed in customary units (temperature in °F, pressure in psig), the other for the metric system of units (temperature in °C, pressure in kPa or bar). In contrast to the 1980 Tables, the metric procedures require the procedure for customary units be used first to compute density at 60°F. This value is then further corrected to give the metric output.

The procedure recognizes three distinct commodity groups: crude oil, refined products, and lubricating oils. A special application category is also provided which provides volume correction based on the input of an experimentally derived coefficient of thermal expansion.

### 11.1.2.3 Temperature, Pressure, and Density Limits

The limits on this Standard are defined in a mixture of terms of customary and metric units. The following table shows the defining limits and their associated units. These values are shown in ***bold italics***. Also shown in the table are the limits converted to their equivalent units (and, in the case of the densities, other base temperatures).

|                                                | Crude Oil                                                    | Refined Products  | Lubricating Oils              |
|------------------------------------------------|--------------------------------------------------------------|-------------------|-------------------------------|
| <b><i>Density, kg/m<sup>3</sup> @ 60°F</i></b> | <b><i>610.6 to 1163.5</i></b>                                |                   | <b><i>800.9 to 1163.5</i></b> |
| Relative Density @ 60°F                        | 0.61120 to 1.16464                                           |                   | 0.80168 to 1.1646             |
| API Gravity @ 60°F                             | 100.0 to -10.0                                               |                   | 45.0 to -10.0                 |
| kg/m <sup>3</sup> @ 15°C                       | 611.16 to 1163.79                                            | 611.16 to 1163.86 | 801.25 to 1163.85             |
| kg/m <sup>3</sup> @ 20°C                       | 606.12 to 1161.15                                            | 606.12 to 1160.62 | 798.11 to 1160.71             |
| <b><i>Temperature, °C</i></b>                  | <b><i>-50.00 to 150.00</i></b>                               |                   |                               |
| °F                                             | -58.0 to 302.0                                               |                   |                               |
| <b><i>Pressure, psig</i></b>                   | <b><i>0 to 1,500</i></b>                                     |                   |                               |
| kPa (gauge)                                    | 0 to 1.034×10 <sup>4</sup>                                   |                   |                               |
| bar (gauge)                                    | 0 to 103.4                                                   |                   |                               |
| <b><i>α<sub>60</sub>, per °F</i></b>           | <b><i>230.0×10<sup>-6</sup> to 930.0×10<sup>-6</sup></i></b> |                   |                               |
| per °C                                         | 414.0×10 <sup>-6</sup> to 1674.0×10 <sup>-6</sup>            |                   |                               |

Note that only the precision levels of the defining values shown in this table are correct. The other values showing converted units have been rounded to the significant digits shown; as rounded values, they may numerically fall just outside of the actual limits established by the defining values.

In 1980 the correlation for CTL was chosen so that it would be monotonic with respect to temperature (both the function and its temperature derivative). It also did not have any discontinuities over a very wide range of temperatures and densities. This does not say that the correlation is valid outside the data that was used to generate it. Due to needs of industry to accommodate commerce at temperature and density ranges well outside those originally tested, the limits of density and temperature have been extended. This extension is purely mathematical. The algorithms that correctly predict volume correction within the original test limits have simply been applied to regions beyond the original temperature and density limits.

The following figures show the range of the original data, the extensions to give the previous standards, and the current extensions for the Generalized Crude Oils, Generalized Refined Products, Generalized Lube Oils, Special Applications, and the compressibility factors. Computed values in any of these extended regions should be used with caution. Currently, there are no data in these regions to establish uncertainty.

