Manual of Petroleum Measurement Standards Chapter 11.2.4

Temperature Correction for the Volume of NGL and LPG Tables 23E, 24E, 53E, 54E, 59E, and 60E

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Nomenclature

A, B, C	parameters in Section 5.1.2 quadratic equation
C_{TL}	temperature correction factor
h_2	scaling factor
k_1, k_2, k_3, k_4	parameters in saturation density equation
T_B	base temperature (60 °F, 15 °C, or 20 °C)
T_{BK}	base temperature (288.15 K, or 293.15 K)
T_c	fluid critical temperature (K)
$T_{c,ref}$	reference fluid critical temperature (K)
T_F	observed measurement temperature (°F or °C)
$T_{r,x}$	reduced observed temperature
T_x	observed temperature (K)
V_{60}/V_{Tx}	ratio of volume at 60 °F to volume at temperature T_x. Is the basic definition of C_{TL}
X	interpolating factor
Z_c	critical compressibility factor
α, β, ϕ	parameters in Section 5.1.2 quadratic equation
δ	interpolation variable
τ	parameter in saturation density equation
τ_x	parameter in saturation density equation at observed temperature
γ_x	relative density at observed temperature
$\gamma_{x,high}$	relative density at the observed temperature corresponding to the upper boundary for the 60 °F relative density
$\gamma_{x,low}$	relative density at the observed temperature corresponding to the lower boundary for the 60 °F relative density
$\gamma_{x,mid}$	relative density at the observed temperature corresponding to the intermediate 60° F relative density used in Section 5.1.2 iteration procedure
$\gamma_{x,trial}$	trial relative density at the observed temperature used in Section 5.1.2 iteration procedure
γ_{TB}	relative density at the base temperature, T_B
γ_{60}	relative density at a base temperature of 60 °F
γ_{Tx}	relative density at the observed temperature, T_x
$\gamma_{60,high}$	upper bound for the observed fluid's 60 °F relative density
$\gamma_{60,low}$	lower bound for the observed fluid's 60 °F relative density
$\gamma_{60,mid}$	intermediate 60 °F relative density value used in Section 5.1.2 iteration procedure
$\gamma_{60,trial}$	trial 60 °F relative density value used in Section 5.1.2 iteration procedure
ρ_c	critical molar density (kmol/m^3)
ρ_{60}	density at a base temperature of 60 °F (kg/m^3)
ρ_{15}	density at a base temperature of 15 °C (kg/m^3)
ρ_{20}	density at a base temperature of 20 °C (kg/m^3)
ρ^{sat}	saturation molar density (kmol/m^3)
ρ_{60}^{sat}	saturation molar density at 60 °F (kmol/m^3)
ρ_T^{sat}	saturation molar density at observed temperature (kmol/m^3)
ρ_{w60}	density of water at 60 °F (kg/m^3)

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Temperature Correction for the Volume of NGL and LPG Tables 23E, 24E, 53E, 54E, 59E, and 60E

Implementation Guidelines

This revised standard is effective upon the date of publication and supersedes the ASTM-IP 1952 Petroleum Measurement Tables, GPA 2142, GPA TP-16, Tables 33 and 34 of API *MPMS* Chapter 11.1-1980 Volumes XI/XII (Adjuncts to ASTM D1250-80 and IP 200/80), and API/ASTM/GPA TP-27. However, due to the nature of the changes in this revised standard and the fact that it is or may be incorporated by reference in various regulations, it is recognized that guidance concerning an implementation period may be needed in order to avoid disruptions within the industry and ensure proper application. An application, for this purpose, is defined as the point where the calculation is applied.

The actual standard represented by this report consists of the explicit implementation procedures. Sample tables and other examples created from a computerized version of these implementation procedures are presented within. However, these are for examples only and do not represent the standard.

Once the revised standard is implemented in a particular application, the previous standard will no longer be used in that application.

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

1 Introduction

For custody transfer purposes, natural gas liquid (NGL) and liquefied petroleum gas (LPG) volumes are generally stated at a fixed base temperature and saturation pressure. As most volume transfers occur at temperatures and pressures other than standard conditions, these volumes are adjusted to standard conditions through the use of correction factors. The document is specifically titled as being suitable for NGL and LPG liquids. Light hydrocarbon mixtures containing significant quantities of methane, carbon dioxide and nitrogen which have density ranges which overlap those contained in these tables can be encountered. However, the two-fluid correlation which is the basis of these tables was not calibrated for such mixtures. Separate factors for temperature (C_{TL}) and pressure (C_{PL}) are used to make these corrections. This document presents a new method to calculate temperature correction factors. Pressure correction factors are not within the scope of this document, but can be calculated using American Petroleum Institute *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 11.1-2004 [1] (which superseded Chapter 11.2.1-1984 [2] and 11.2.1M-1984 [3]), Chapter 11.2.2-1986/GPA 8286-86 [4] or Chapter 11.2.2M-1986/GPA 8286-86 [5], depending on product type.

Previously, most NGL and LPG temperature correction factors have been obtained from a variety of sources:

— ASTM-IP “Petroleum Measurement Tables” [6], published in 1952. This publication is limited to a 60 °F relative density range of 0.500 and higher.

— GPA Standard 2142, “Standard Factors for Volume Correction and Specific Gravity Conversion of Liquefied Petroleum Gases” [7], published in 1957, also contains the same correction factors as the 1982 ASTM-IP document.

— GPA TP-16 “Composite Pressure and Temperature Volume Correction Factor Tables for Liquefied Petroleum Gas (LPG) and Natural Gasoline” [8], published in 1988. It is limited to the following products: HD-5 Propane with relative densities of 0.501, 0.505, and 0.510; iso-butane at a relative density of 0.565; normal butane at a relative density of 0.585; and natural gasoline (12-14 psia RVP) at a relative density of 0.664.

— API *MPMS* Chapter 11.1-1980/ASTM D1250-80 Volume XII, Table 33 “Specific Gravity Reduction to 60 °F For Liquefied Petroleum Gases and Natural Gasoline” [9].

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— API *MPMS* Chapter 11.1-1980/ASTM D1250-80 Volume XII, Table 34 “Reduction of Volume to 60 °F Against Specific Gravity 60/60 °F For Liquefied Petroleum Gases” [9].

— API/ASTM/GPA 8117 “Temperature Correction for the Volume of Light Hydrocarbons” [10].

— API/ASTM/GPA TP-27 “Temperature Correction for the Volume of NGL and LPG” [11].

With the publication of this document, the above API, ASTM and GPA documents should no longer be used for NGL and LPG temperature correction factors. Text for GPA 8217 as approved is included without technical change in this present document. Some edits have been made to align flow charts with examples shown so that they may be consistent.

2 Scope

The actual standard represented by this report 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.

This standard covers a 60 °F relative density range of 0.3500 to 0.6880 which nominally equates to a density at 15 °C of 351.7 kg/m^3 to 687.8 kg/m^3 and a density at 20 °C of 331.7 kg/m^3 to 683.6 kg/m^3. The temperature range of this standard is –50.8 °F to 199.4 °F (–46 °C to 93 °C). At all conditions, the pressure is assumed to be at saturation conditions (also known as bubble point or saturation vapor pressure).

NOTE These are nominal ranges which are further refined within the standard by correlation limits to be the ranges bounded by the points in Table 1:

Table 1—*MPMS* 11.2.4 Correlation Limits

Relative Density (60 °F/60 °F)	Lower Temperature Limit (°F)	Upper Temperature Limit (°F)	Lower Temperature Limit (°C)	Upper Temperature Limit (°C)	Lower Temperature Limit (K)	Upper Temperature Limit (K)
0.35000	–50.8	87.4	–46.0	30.8	227.15	303.93
0.35599	–50.8	88.9	–46.0	32.2	227.15	305.32
0.42928	–50.8	140.9	–46.0	60.5	227.15	333.65
0.47038	–50.8	174.8	–46.0	79.3	227.15	352.48
0.49935	–50.8	199.4	–46.0	93.0	227.15	366.15
0.68800	–50.8	199.4	–46.0	93.0	227.15	366.15

As shown in Figure 1, which follows:

Input range—the box defined in the scope of the standard as a (60 °F/60 °F) relative density of 0.35 to 0.688 and –46 °C to 93 °C.

Correlation range—the polygon defined by line segments connecting the relative densities and critical temperatures of the reference fluids in Table 1 of the standard for the upper boundary, –46 °C for the lower temperature boundary, the relative density of EE (68/32) for the lower relative density boundary and the relative density of n-heptane for the upper relative density boundary. See Figure 1 in this document for an illustration.

The calculation method was developed from GPA RR-148 “Volume Correction Factors for Natural Gas Liquids—Phase II” [12] and API/ASTM/GPA Technical Publication, TP-25, September, 1998 [10]. The implementation

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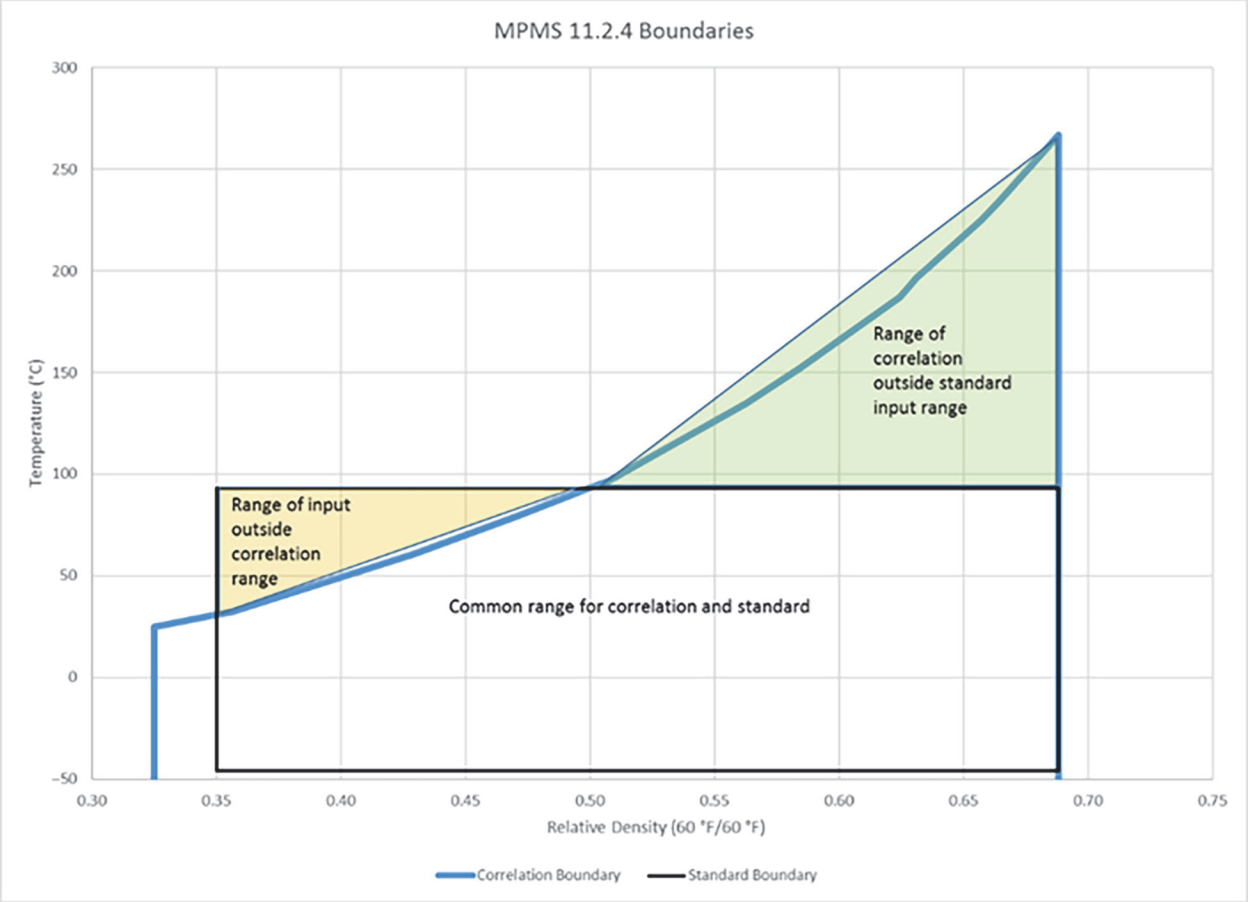


Figure 1—*MPMS* 11.2.4 Boundaries

procedures for Tables 23E and 24E are entirely consistent with those presented in API/ASTM/GPA Technical Publication, TP-27. Supporting data can be found in GPA RR-147 "Density Measurements on Natural Gas Liquids" [13]. GPA RR-133 "Volume Correction Factors for Natural Gas Liquids—Phase I" [14] should no longer be used, as GPA RR-148 completely replaced it.

The implementation procedures describe how to:

1) calculate the C_{TL} given an appropriate density factor at the basis temperature and an observed temperature, and

2) calculate the appropriate density factor at basis temperature given a relative density at an observed temperature.

The implementation procedures are presented in pairs by base temperature. First the procedures for Tables 23E and 24E at a 60 °F base temperature are given. The procedure for Table 23E makes use of the procedure described in Table 24E thus Table 24E is presented first. These are followed by procedures for Tables 54E and 53E at a base temperature of 15 °C which themselves make use of procedures in described in Tables 23E and 24E; these in turn are followed by the procedures for Tables 60E and 59E at a base temperature of 20 °C which also make use of procedures in described in Tables 23E and 24E.

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3 Significant Digits

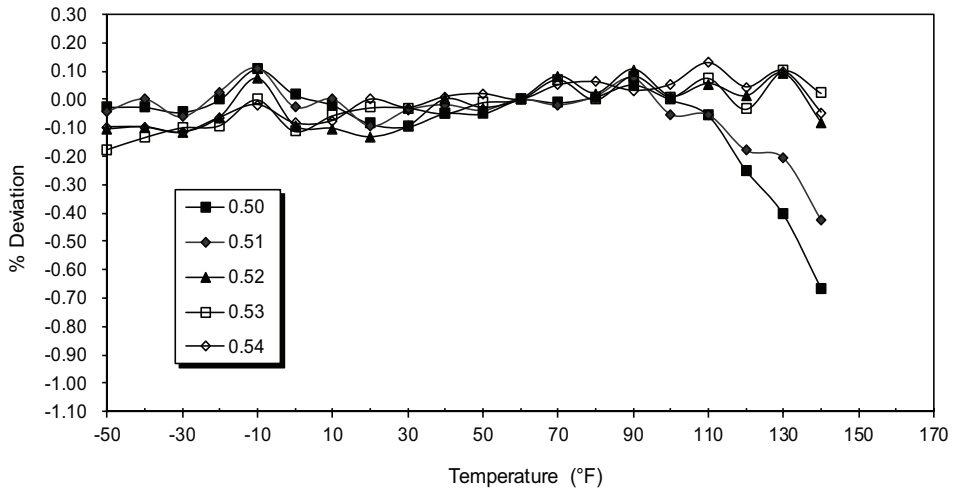
It is intended that all future temperature correction factors be used with five decimal digits (e.g., 0.xxxxx or 1.xxxxx). As a result, this document contains C_{TL} values with only five decimal digits. This is a departure from both the 1952 "ASTM-IP Petroleum Measurement Tables" and GPA TP-16, which give either 3 or 4 decimal digits.

4 Comparison to the Previous Standards

As the 1952 ASTM-IP standard is limited to a low-end relative density of 0.50, a comparison can only be made at higher relative densities. The following charts show how the standards compare. The calculations are performed at 10 °F and 5 °C increments. It can be noted that the deviation plots for the 0.50 to 0.59 relative densities (500 to 590 kg/m^3 densities) are "ragged" in appearance, while the deviation plots for the higher relative densities are "smooth."This can mostly be attributed to the 1952 ASTM-IP Standard's rounding method: C_{TL} values under relative density 0.60 contain 3 decimal digits while C_{TL} values greater than 0.600 contain 4 decimal digits.

NOTE Negative deviations indicate that the new table C_{TL} is lower than the old (1952) ASTM table C_{TL}. Positive deviations indicate that the new table C_{TL} is higher than the old (1952) ASTM table C_{TL}.

Chart 1: C_{TL} Deviations of New Table 24E Values Compared to Old Table 24 Values



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Chart 2: C_{TL} Deviations of New Table 24E Values Compared to Old Table 24 Values

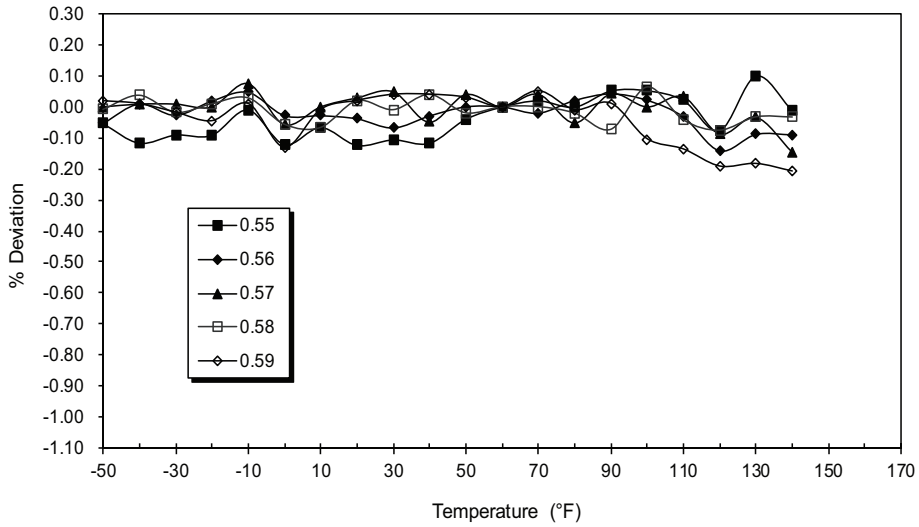
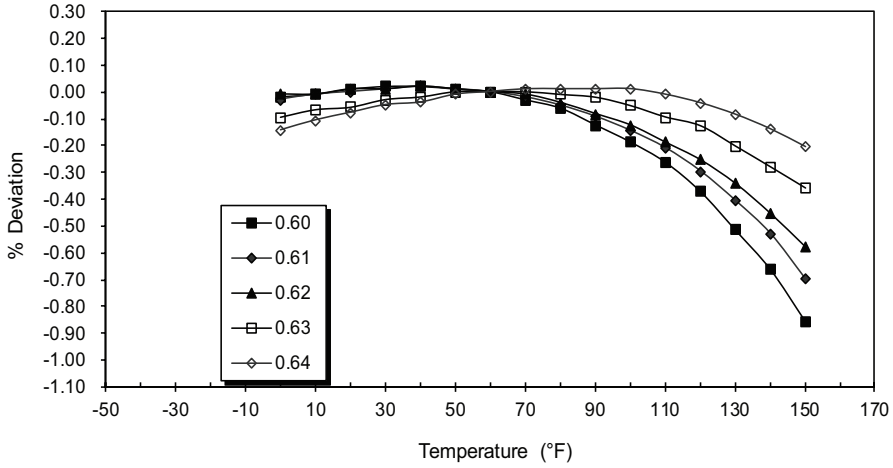


Chart 3: C_{TL} Deviations of New Table 24E Values Compared to Old Table 24 Values



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Chart 4: C_{TL} Deviations of New Table 24E Values Compared to Old Table 24 Values

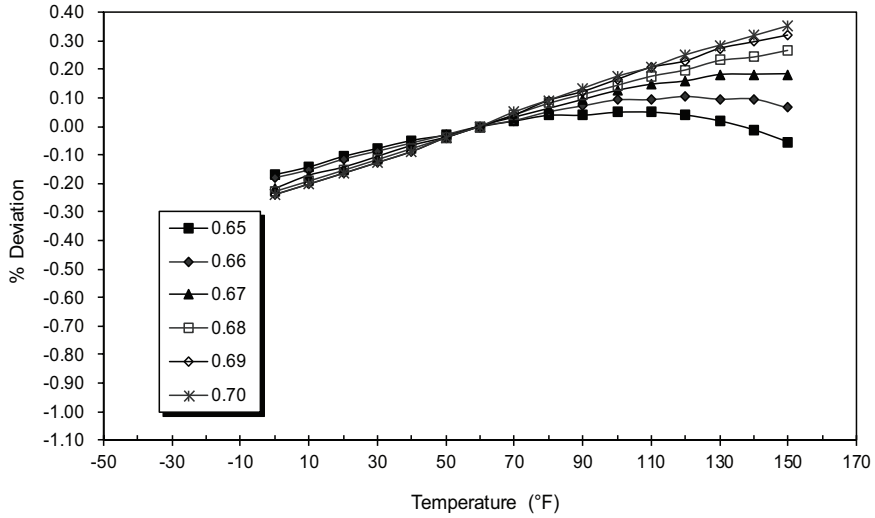
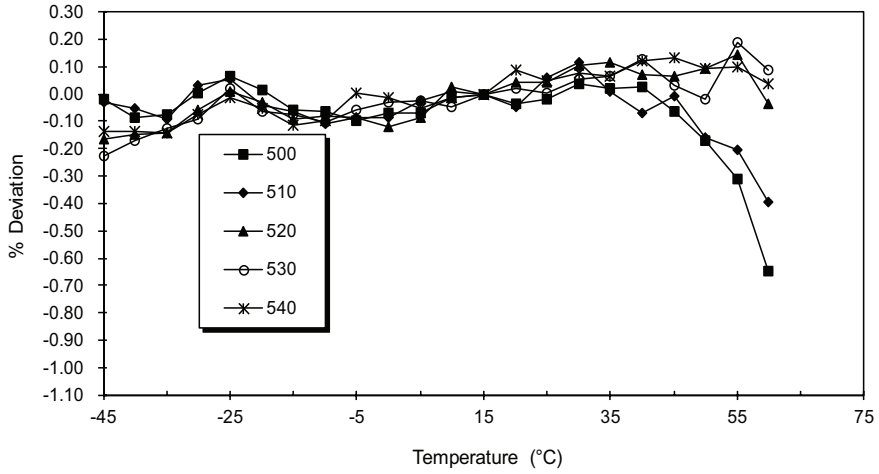


Chart 5: C_{TL} Deviations of New Table 54E Values Compared to Old Table 54 Values



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Chart 6: C_{TL} Deviations of New Table 54E Values Compared to Old Table 54 Values

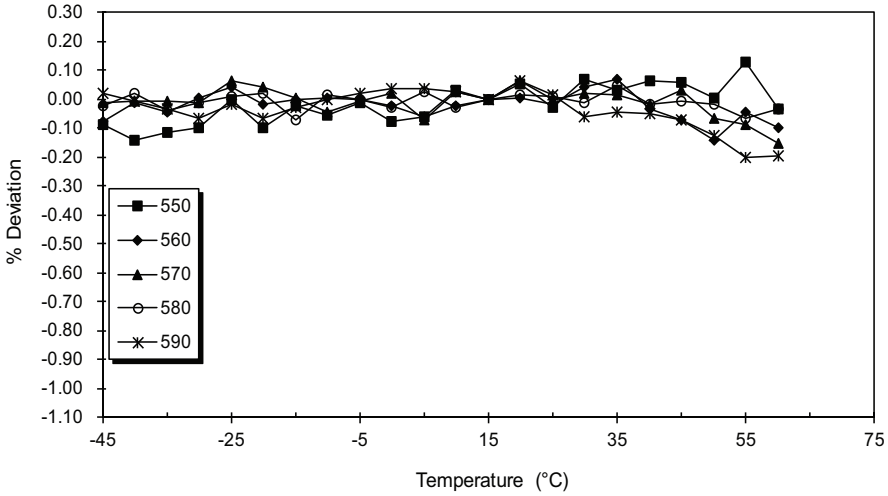
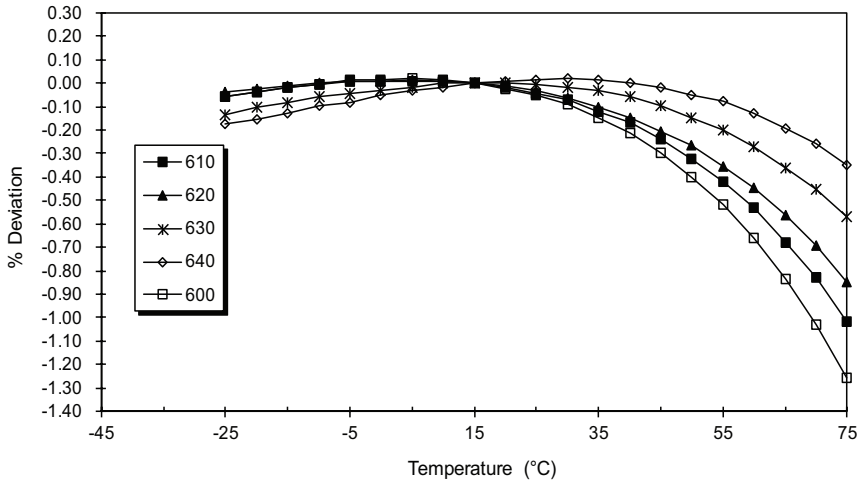
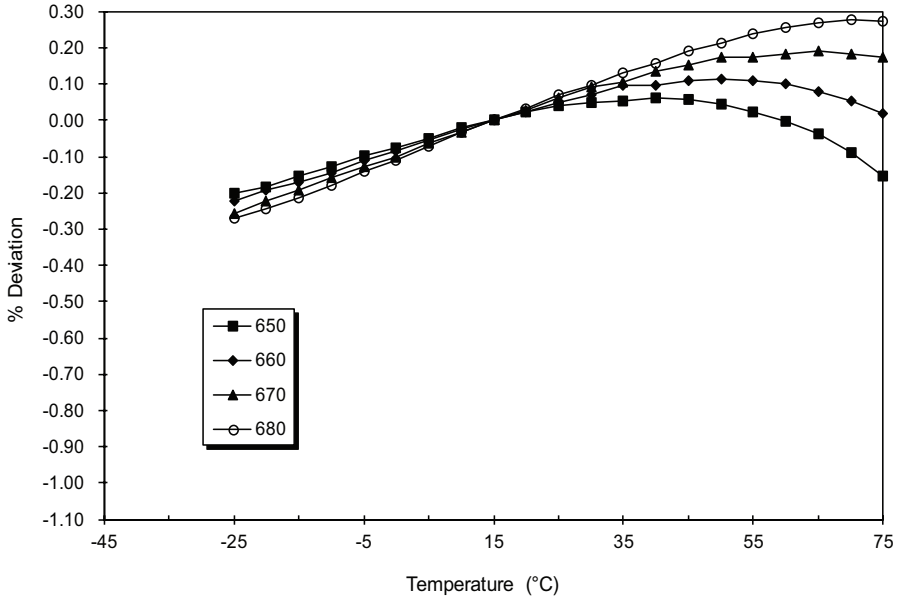


Chart 7: C_{TL} Deviations of New Table 54E Values Compared to Old Table 54 Values



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Chart 8: C_{TL} Deviations of New Table 54E Values Compared to Old Table 54 Values



5 Implementation Procedures

The methods to calculate C_{TL} from Tables 24E, 54E, and 60E and relative density at the base temperature from Tables 23E, 53E and 59E follow. These methods are called implementation procedures, which are similar to the methods described and found in American Petroleum Institute *MPMS* Chapter 11.1.

All calculations are to be performed using double precision (i.e. long floating point, eight byte, or 64-bit) arithmetic. This should allow the computer program to recognize the difference between 1.0 and $1.0 + \varepsilon$ for absolute values of ε on the order of 10^{-16}.

Examples are presented for each of the procedures described, they cover the range of the tables. Even though double precision was used for these example calculations, only twelve decimal digits are printed here. If one uses these examples to test their own computer implementation of these procedures, it is suggested that at least eight of the significant digits be matched. The exceptions to this are for the variables α, β, A, B, and C of Table 23E (Section 5.1.2). These may show greater deviation, but the resulting $\gamma_{60,trial}$ and $\gamma_{x,trial}$ values should match within eight significant digits.

5.1 CTL (Table 24E) and Relative Density (Table 23E) for NGL and LPG using a 60 °F Base Temperature

5.1.1 Implementation Procedure for Table 24E (60 °F Basis)

This section presents the implementation procedure T24 for the computation of Temperature Correction Factor, C_{TL}. The C_{TL} is used to calculate volumes of fluid at the base temperature from volumes at some known measurement temperature. The fluids are characterized by the specification of relative density at the base temperature, 60 °F.

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5.1.1.1 Inputs and Outputs

Inputs: Relative density at 60 °F, γ_{60}
Observed temperature, T_F (°F)

Output: Temperature Correction Factor, C_{TL} (from T_F to T_B)

5.1.1.2 Outline of Calculations

The calculations are performed using an extended two-fluid corresponding states equation. By comparing densities at 60 °F, two reference fluids are selected so that one is slightly more dense, and one is slightly less dense than the observed fluid. The densities of these reference fluids are then scaled to the observed reduced temperature (reduced by the critical temperature of the fluid of interest). The Temperature Correction Factor is then computed from the reference fluid densities. See Figure 2 for a general flow chart of the calculation procedure.

5.1.1.3 T24 Implementation Procedure

T24/Step Number — Operation/Procedure at that step

T24/1: Round the relative density γ_{60} to the nearest 0.0001 and round the observed temperature T_F to the nearest 0.1 °F.

Temperature rounding examples: –0.05 rounds to –0.1; –0.049 rounds to 0.0, –0.051 rounds to –0.1. Density rounding examples follow: 0.35555 rounds to 0.3556, 0.355549 rounds to 0.3555, 0.40289 rounds to 0.4029.

T24/2: Convert the rounded observed temperature to units of kelvin, T_x:

$$T_x = \frac{T_F + 459.67}{1.8}$$

T24/3: The resultant temperature T_x and relative density γ_{60} must fall within the following ranges:

Temperature between 227.15 K and 366.15 K, inclusive (equivalent to –46 °C to 93 °C, or –50.8 °F to 199.4 °F)
Relative density between 0.3500 and 0.6880, inclusive.

If these values do not fall in these ranges, then the standard does not apply. Flag this result (possibly by returning a –1 for C_{TL}) and exit this procedure.

T24/4: Determine the two adjacent reference fluids to be used for the calculations. The rounded 60 °F relative density γ_{60} will fit between two reference fluids' 60 °F relative densities as listed in Table 2. Choose the lowest density reference fluid that has a density value greater than or equal to γ_{60} and refer to this fluid using the subscript "2." Also use the next lowest density reference fluid and refer to this fluid using the subscript "1."

T24/5: Using Table 2, 60 °F relative densities, compute the interpolation variable, δ:

$$\delta = \frac{\gamma_{60} - \gamma_{60,1}}{\gamma_{60,2} - \gamma_{60,1}}$$

T24/6: From Table 2 critical temperatures, calculate the fluid critical temperature, T_c:

$$T_c = T_{c,1} + \delta(T_{c,2} - T_{c,1})$$

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T24/7: Compute the fluid's reduced observed temperature, $T_{r,x}$:

$$T_{r,x} = \frac{T_x}{T_c}$$

If the reduced temperature $T_{r,x}$ is greater than 1.0, then the fluid is at supercritical conditions and cannot exist as a liquid. Flag this result (possibly by returning a –1 for C_{TL}) and exit this procedure.

T24/8: Compute the reduced temperature at 60 °F, $T_{r,60}$:

$$T_{r,60} = \frac{519.67}{1.8T_c}$$

T24/9: From Table 2 critical compressibility factors, Z_c, and critical densities, ρ_c, calculate the scaling factor, h_2:

$$h_2 = \frac{Z_{c,1} \times \rho_{c,1}}{Z_{c,2} \times \rho_{c,2}}$$

T24/10: Calculate the saturation density for both reference fluids at 60 °F using the 60 °F reduced temperature, $T_{r,60}$. For each fluid, the equations to calculate the saturation density at any reduced temperature T_r are:

$$\tau = 1 - T_r$$

$$\rho^{sat} = \rho_c \left(1 + \frac{(k_1 \times \tau^{0.35}) + (k_3 \times \tau^2) + (k_4 \times \tau^3)}{1 + (k_2 \times \tau^{0.65})} \right)$$

where the k_1, k_2, k_3, and k_4 parameters are different for each reference fluid and are listed in Table 2. Refer to the calculated density for the first reference fluid as $\rho_{60,1}^{sat}$ and for the second reference fluid as $\rho_{60,2}^{sat}$.

T24/11: Calculate the interpolating factor X:

$$X = \frac{\rho_{60,1}^{sat}}{1 + \delta \left(\frac{\rho_{60,1}^{sat}}{h_2 \times \rho_{60,2}^{sat}} - 1 \right)}$$

T24/12: Obtain the saturation density for both reference fluids at reduced observed temperature $T_{r,x}$ using the procedure in Step T24/10. Refer to the calculated density for the first reference fluid as $\rho_{x,1}^{sat}$ and that for the second reference fluid as $\rho_{x,2}^{sat}$.

T24/13: Calculate the Temperature Correction Factor at the observed temperature, C_{TL}:

$$C_{TL} = \frac{\rho_{x,1}^{sat}}{X \left[1 + \delta \left(\frac{\rho_{x,1}^{sat}}{h_2 \times \rho_{x,2}^{sat}} - 1 \right) \right]}$$

T24/14: Round the Temperature Correction Factor C_{TL} to the nearest 0.00001. Exit this procedure.

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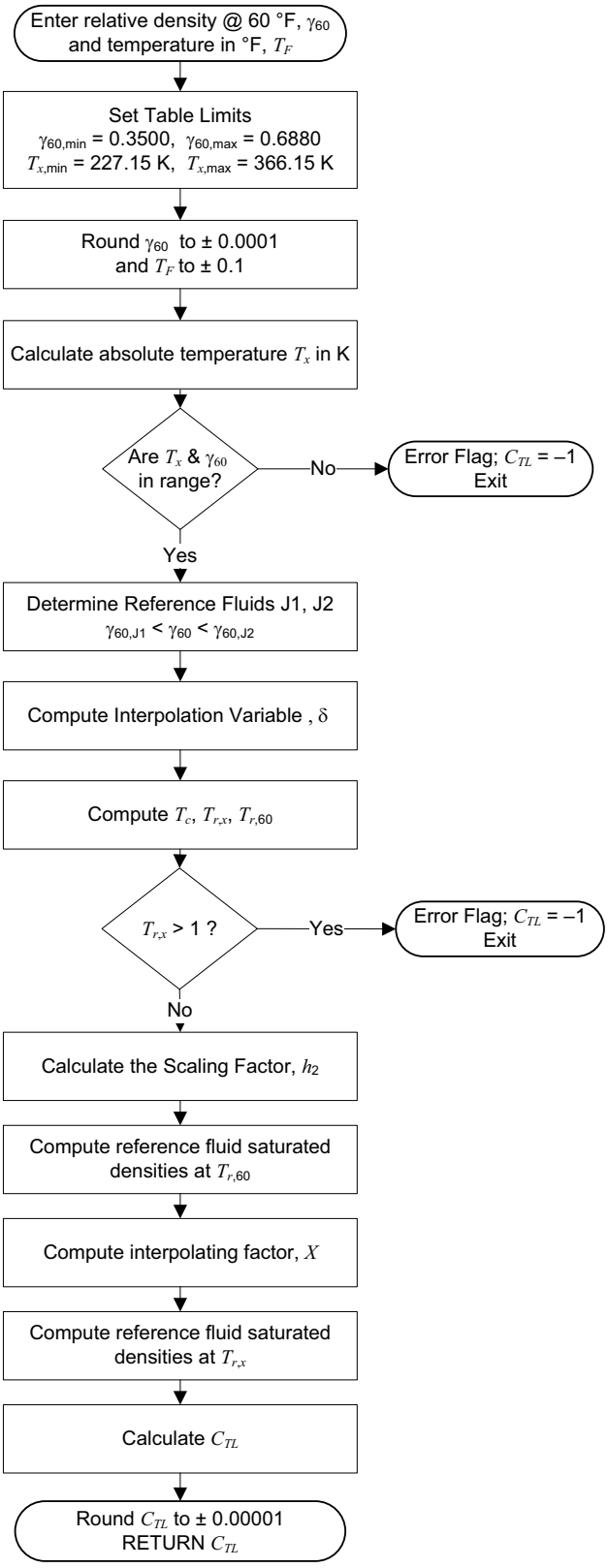


Figure 2—Flow Chart of Implementation Procedure for Table 24E

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Table 2—Reference Fluid Parameters

No.	Fluid Name	γ_{60}	T_c	Z_c	ρ_c	k_1	k_2	k_3	k_4
1	EE (68/32) [a]	0.325022	298.11	0.27998	6.250	2.54616855327	–0.058244177754	0.803398090807	–0.745720314137
2	Ethane	0.355994	305.33	0.28220	6.870	1.89113042610	–0.370305782347	–0.544867288720	0.337876634952
3	EP (65/35) [b]	0.429277	333.67	0.28060	5.615	2.20970078464	–0.294253708172	–0.405754420098	0.319443433421
4	EP (35/65) [c]	0.470381	352.46	0.27930	5.110	2.25341981320	–0.266542138024	–0.372756711655	0.384734185665
5	Propane	0.507025	369.78	0.27626	5.000	1.96568366933	–0.327662435541	–0.417979702538	0.303271602831
6	i-Butane	0.562827	407.85	0.28326	3.860	2.04748034410	–0.289734363425	–0.330345036434	0.291757103132
7	n-Butane	0.584127	425.16	0.27536	3.920	2.03734743118	–0.299059145695	–0.418883095671	0.380367738748
8	i-Pentane	0.624285	460.44	0.27026	3.247	2.06541640707	–0.238366208840	–0.161440492247	0.258681568613
9	n-Pentane	0.631054	469.65	0.27235	3.200	2.11263474494	–0.261269413560	–0.291923445075	0.308344290017
10	i-Hexane	0.657167	498.05	0.26706	2.727	2.02382197871	–0.423550090067	–1.152810982570	0.950139001678
11	n-Hexane	0.664064	507.35	0.26762	2.704	2.17134547773	–0.232997313405	–0.267019794036	0.378629524102
12	n-Heptane	0.688039	540.15	0.26312	2.315	2.19773533433	–0.275056764147	–0.447144095029	0.493770995799

NOTE 1 γ_{60} is the fluid relative density at 60 °F and saturation pressure.

NOTE 2 T_c is the fluid critical temperature in kelvin.

NOTE 3 Z_c is the fluid critical compressibility factor.

NOTE 4 ρ_c is the fluid critical density (kmol/m^3).

NOTE 5 k_1, k_2, k_3, and k_4 are saturation density fitting parameters.

[a] EE (68/32) denotes a 68 mole % ethane + 32 % ethylene mixture.

[b] EP (65/35) denotes a 65 mole % ethane + 35 % propane mixture.

[c] EP (35/65) denotes a 35 mole % ethane + 65 % propane mixture.

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5.1.1.4 Examples for Section 5.1.1 (Table 24E)

(See Table 2 for properties of the Reference Fluids)

Example 24/1 – Use EE (68/32) and Ethane

Input Data	
Relative density @ 60°F (γ_{60})	0.350130
Observed temperature, °F (T_F)	-48.0200
Computed data - last digit is rounded	
T24/1	
Input data - rounded	
γ_{60} rounded to 0.0001	0.3501
T_F rounded to 0.1	-48.0
T24/2	
T_x, kelvin	228.705555555556
T24/3	
Input data within range	
T24/4	
Reference fluid 1	EE (68/32)
Reference fluid 2	Ethane
T24/5	
Delta (δ)	0.809699083043
T24/6	
Critical temperature (T_c)	303.956027379569
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.752429742971
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.949826716859
T24/9	
Scaling factor (h_2)	0.902595741301
T24/10	
Tau for fluid at 60°F (τ)	0.050173283141
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	11.892882208216
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	11.673968376914
T24/11	
Interpolating factor (X)	10.770572039296
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.247570257029
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	16.490243357324
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	16.012272020935
T24/13	
C_{TL}	1.374174158511
T24/14	
C_{TL} (rounded)	1.37417

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Example 24/2 – Use Ethane and EP (65/35)

Input Data	
Relative density @ 60°F (γ_{60})	0.399950
Observed temperature, °F (T_F)	24.9500
Computed data – last digit is rounded	
T24/1	
Input data – rounded	
γ_{60} rounded to 0.0001	0.4000
T_F rounded to 0.1	25.0
T24/2	
T_x, kelvin	269.261111111111
T24/3	
Input data within range	
T24/4	
Reference fluid 1 Ethane	
Reference fluid 2 .... EP (65/35)	
T24/5	
Delta (δ)	0.600493975410
T24/6	
Critical temperature (T_c)	322.347999263131
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.835311873276
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.895633154899
T24/9	
Scaling factor (h_2)	1.230484986694
T24/10	
Tau for fluid at 60°F (τ)	0.104366845101
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	13.268022876946
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	11.625034524899
T24/11	
Interpolating factor (X)	13.871545440974
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.164688126724
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	14.572475327916
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	12.816926793350
T24/13	
C_{TL}	1.100764647588
T24/14	
C_{TL} (rounded)	1.10076

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Example 24/3 – Use EP (65/35) and EP (35/65)

Input Data	
Relative density @ 60°F (γ_{60})	0.451530
Observed temperature, °F (T_F)	87.4200
Computed data – last digit is rounded	
T24/1	
Input data – rounded	
γ_{60} rounded to 0.0001	0.4515
T_F rounded to 0.1	87.4
T24/2	
T_x, kelvin	303.927777777778
T24/3	
Input data within range	
T24/4	
Reference fluid 1	EP (65/35)
Reference fluid 2	EP (35/65)
T24/5	
Delta (δ)	0.540652977812
T24/6	
Critical temperature (T_c)	343.828869453095
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.883950723106
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.839678052674
T24/9	
Scaling factor (h_2)	1.103940309258
T24/10	
Tau for fluid at 60°F (τ)	0.160321947326
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	12.739470807395
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	11.668538966703
T24/11	
Interpolating factor (X)	12.815798776833
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.116049276894
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$)	11.880371290411
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$)	10.885682581443
T24/13	
C_{TL}	0.932749411288
T24/14	
C_{TL} (rounded)	0.93275

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Example 24/4 – Use EP (35/65) and Propane

Input Data	
Relative density @ 60°F (γ_{60})	0.490400
Observed temperature, °F (T_F)	184.9700
Computed data – last digit is rounded	
T24/1	
Input data – rounded	
γ_{60} rounded to 0.0001	0.4904
T_F rounded to 0.1	185.0
T24/2	
T_x, kelvin	358.150000000000
T24/3	
Input data within range	
T24/4	
Reference fluid 1	EP (35/65)
Reference fluid 2	Propane
T24/5	
Delta (δ)	0.546310446458
T24/6	
Critical temperature (T_c)	361.922096932649
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.989577599808
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.797700825682
T24/9	
Scaling factor (h_2)	1.033246217331
T24/10	
Tau for fluid at 60°F (τ)	0.202299174318
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	12.309519597134
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	11.272394278161
T24/11	
Interpolating factor (X)	11.938610116810
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.010422400192
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	7.473276954765
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	7.023541210265
T24/13	
C_{TL}	0.615949186930
T24/14	
C_{TL} (rounded)	0.61595

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Example 24/5 – Use Propane and i-Butane

Input Data	
Relative density @ 60°F (γ_{60})	0.540020
Observed temperature, °F (T_F)	155.0400
Computed data – last digit is rounded	
T24/1	
Input data – rounded	
γ_{60} rounded to 0.0001	0.5400
T_F rounded to 0.1	155.0
T24/2	
T_x, kelvin	341.483333333333
T24/3	
Input data within range	
T24/4	
Reference fluid 1	Propane
Reference fluid 2	i-Butane
T24/5	
Delta (δ)	0.590928640551
T24/6	
Critical temperature (T_c)	392.276653345758
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.870516586753
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.735974351502
T24/9	
Scaling factor (h_2)	1.263326064155
T24/10	
Tau for fluid at 60°F (τ)	0.264025648498
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	12.016437691588
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	9.429772887863
T24/11	
Interpolating factor (X)	11.955024717591
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.129483413247
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	10.227566043346
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	8.025028872910
T24/13	
C_{TL}	0.851071799690
T24/14	
C_{TL} (rounded)	0.85107

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Example 24/6 – Use i-Butane and n-Butane

Input Data	
Relative density @ 60°F (γ_{60})	0.569980
Observed temperature, °F (T_F)	3.0330
Computed data – last digit is rounded	
T24/1	
Input data – rounded	
γ_{60} rounded to 0.0001	0.5700
T_F rounded to 0.1	3.0
T24/2	
T_x, kelvin	257.038888888889
T24/3	
Input data within range	
T24/4	
Reference fluid 1	i-Butane
Reference fluid 2	n-Butane
T24/5	
Delta (δ)	0.336760563380
T24/6	
Critical temperature (T_c)	413.679325352113
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.621348163025
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.697896988954
T24/9	
Scaling factor (h_2)	1.012944464538
T24/10	
Tau for fluid at 60°F (τ)	0.302103011046
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	9.757836502218
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	9.883346486657
T24/11	
Interpolating factor (X)	9.841741258063
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.378651836975
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	10.367065629858
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	10.496815949474
T24/13	
C_{TL}	1.062314380669
T24/14	
C_{TL} (rounded)	1.06231

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Example 24/7 – Use n-Butane and i-Pentane

Input Data	
Relative density @ 60°F (γ_{60})	0.599970
Observed temperature, °F (T_F)	110.0400
Computed data – last digit is rounded	
T24/1	
Input data – rounded	
γ_{60} rounded to 0.0001	0.6000
T_F rounded to 0.1	110.0
T24/2	
T_x, kelvin	316.483333333333
T24/3	
Input data within range	
T24/4	
Reference fluid 1	n-Butane
Reference fluid 2	i-Pentane
T24/5	
Delta (δ)	0.395263708352
T24/6	
Critical temperature (T_c)	439.104903630659
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.720746524843
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.657486521258
T24/9	
Scaling factor (h_2)	1.230050265162
T24/10	
Tau for fluid at 60°F (τ)	0.342513478742
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	10.214309417120
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	8.446076234558
T24/11	
Interpolating factor (X)	10.282689503192
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.279253475157
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	9.687510842155
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	8.011335247961
T24/13	
C_{TL}	0.948465346003
T24/14	
C_{TL} (rounded)	0.94847

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Example 24/8 – Use i-Pentane and n-Pentane

Input Data	
Relative density @ 60°F (γ_{60})	0.625020
Observed temperature, °F (T_F)	169.9700
Computed data - last digit is rounded	
T24/1	
Input data - rounded	
γ_{60}, rounded to 0.0001	0.6250
T_F rounded to 0.1	170.0
T24/2	
T_x, kelvin	349.816666666667
T24/3	
Input data within range	
T24/4	
Reference fluid 1	i-Pentane
Reference fluid 2	n-Pentane
T24/5	
Delta (δ)	0.105628600975
T24/6	
Critical temperature (T_c)	461.412839414980
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.758142463288
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.625699007253
T24/9	
Scaling factor (h_2)	1.006900839912
T24/10	
Tau for fluid at 60°F (τ)	0.374300992747
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	8.652500418110
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	8.668052899178
T24/11	
Interpolating factor (X)	8.660400031891
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.241857536712
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	7.734059015744
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	7.744880148272
T24/13	
C_{TL}	0.893815224960
T24/14	
C_{TL} (rounded)	0.89382

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Example 24/9 – Use n-Pentane and i-Hexane

Input Data	
Relative density @ 60°F (γ_{60})	0.640040
Observed temperature, °F (T_F)	-12.0200
Computed data – last digit is rounded	
T24/1	
Input data – rounded	
γ_{60} rounded to 0.0001	0.6400
T_F rounded to 0.1	-12.0
T24/2	
T_x, kelvin	248.705555555556
T24/3	
Input data within range	
T24/4	
Reference fluid 1	n-Pentane
Reference fluid 2	i-Hexane
T24/5	
Delta (δ)	0.342587982997
T24/6	
Critical temperature (T_c)	479.379498717114
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.518807241906
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.602248440595
T24/9	
Scaling factor (h_2)	1.196694721271
T24/10	
Tau for fluid at 60°F (τ)	0.397751559405
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	8.816158414827
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	7.499847998980
T24/11	
Interpolating factor (X)	8.869948165069
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.481192758094
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$)	9.321161815695
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$)	7.929963121410
T24/13	
C_{TL}	1.057304685863
T24/14	
C_{TL} (rounded)	1.05730

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Example 24/10 – Use i-Hexane and n-Hexane

Input Data	
Relative density @ 60°F (γ_{60})	0.660033
Observed temperature, °F (T_F)	177.0450
Computed data - last digit is rounded	
T24/1	
Input data - rounded	
γ_{60} rounded to 0.0001	0.6600
T_F rounded to 0.1	177.0
T24/2	
T_x, kelvin	353.705555555556
T24/3	
Input data within range	
T24/4	
Reference fluid 1	i-Hexane
Reference fluid 2	n-Hexane
T24/5	
Delta (δ)	0.410758300710
T24/6	
Critical temperature (T_c)	501.870052196607
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.704775178370
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.575259580228
T24/9	
Scaling factor (h_2)	1.006395599121
T24/10	
Tau for fluid at 60°F (τ)	0.424740419772
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	7.641170665754
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	7.665708531720
T24/11	
Interpolating factor (X)	7.671217510578
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.295224821630
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	6.925133823039
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	6.945363609083
T24/13	
C_{TL}	0.906185214223
T24/14	
C_{TL} (rounded)	0.90619

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Example 24/11 – Use n-Hexane and n-Heptane

Input Data	
Relative density @ 60°F (γ_{60})	0.670042
Observed temperature, °F (T_F)	181.0300
Computed data – last digit is rounded	
T24/1	
Input data – rounded	
γ_{60} rounded to 0.0001	0.6700
T_F rounded to 0.1	181.0
T24/2	
T_x, kelvin	355.927777777778
T24/3	
Input data within range	
T24/4	
Reference fluid 1	n-Hexane
Reference fluid 2	n-Heptane
T24/5	
Delta (δ)	0.247591240876
T24/6	
Critical temperature (T_c)	515.470992700730
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.690490411328
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.560081090195
T24/9	
Scaling factor (h_2)	1.188010824747
T24/10	
Tau for fluid at 60°F (τ)	0.439918909805
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	7.744857153990
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	6.743069361289
T24/11	
Interpolating factor (X)	7.809053198722
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.309509588672
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	7.030188106398
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	6.111938115029
T24/13	
C_{TL}	0.907404360428
T24/14	
C_{TL} (rounded)	0.90740

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Example 24/12 – Reduced Temperature ($T_{r,x}$) Greater Than 1.0

```
    Input Data
Relative density @ 60°F (γ60) .........     0.350180
Observed temperature, °F (TF).........   195.0250
    Computed data – last digit is rounded
  T24/1
    Input data – rounded
γ60 rounded to 0.0001 .................     0.3502
TF rounded to 0.1......................   195.0
  T24/2
Tx, kelvin.............................   363.705555555556
  T24/3
Input data within range
  T24/4
Reference fluid 1 .....................     EE (68/32)
Reference fluid 2 .....................     Ethane
  T24/5
Delta (δ)..............................     0.812927805760
  T24/6
Critical temperature (Tc).............   303.979338757587
  T24/7
Reduced observed temp. (Tr,x) .........     1.196481172181
Input data is outside the correlation range of the standard
```

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Example 24/13 – Observed Temperature (T_F) < Lower Range Limit

```
    Input Data
Relative density @ 60°F (γ60) .........     0.500000
Observed temperature, °F (TF).........   -50.8500
    Computed data - last digit is rounded
  T24/1
    Input data - rounded
γ60 rounded to 0.0001 .................     0.5000
TF rounded to 0.1......................   -50.9
  T24/2
Tx, kelvin.............................   227.094444444444
  T24/3
Tx is outside the input range of the standard
```

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Example 24/14 – Relative Density @ 60 °F (γ_{60}) < Lower Range Limit

```
    Input Data
Relative density @ 60°F (γ60) .........     0.349940
Observed temperature, °F (TF).........    40.0000
    Computed data - last digit is rounded
  T24/1
    Input data - rounded
γ60 rounded to 0.0001 .................     0.3499
TF rounded to 0.1......................    40.0
  T24/2
Tx, kelvin.............................   277.594444444444
  T24/3
γ60 is outside the input range of the standard
```

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Example 24/15 – Observed Temperature (T_F) > Upper Range Limit

```
    Input Data
Relative density @ 60°F (γ60) .........     0.450000
Observed temperature, °F (TF).........   199.4600
    Computed data - last digit is rounded
  T24/1
    Input data - rounded
γ60 rounded to 0.0001 .................     0.4500
TF rounded to 0.1......................   199.5
  T24/2
Tx, kelvin.............................   366.205555555556
  T24/3
Tx is outside the input range of the standard
```

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Example 24/16 – Relative Density @ 60 °F (γ_{60}) > Upper Range Limit

```
    Input Data
Relative density @ 60°F (γ60) .........      0.688070
Observed temperature, °F (TF).........      0.0000
    Computed data – last digit is rounded
  T24/1
    Input data – rounded
γ60 rounded to 0.0001 .................      0.6881
TF rounded to 0.1......................      0.0
  T24/2
Tx, kelvin.............................   255.372222222222
  T24/3
γ60 is outside the input range of the standard
```

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Example 24/17 – Observed Temperature (T_F) and Relative Density @ 60 °F (γ_{60}) = Upper Range Limit

Input Data	
Relative density @ 60°F (γ_{60})	0.688000
Observed temperature, °F (T_F)	199.4400
Computed data – last digit is rounded	
T24/1	
Input data – rounded	
γ_{60} rounded to 0.0001	0.6880
T_F rounded to 0.1	199.4
T24/2	
T_x, kelvin	366.150000000000
T24/3	
Input data within range	
T24/4	
Reference fluid 1	n-Hexane
Reference fluid 2	n-Heptane
T24/5	
Delta (δ)	0.998373305527
T24/6	
Critical temperature (T_c)	540.096644421272
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.677934224887
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.534544249696
T24/9	
Scaling factor (h_2)	1.188010824747
T24/10	
Tau for fluid at 60°F (τ)	0.465455750304
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	7.876480858049
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	6.859355371549
T24/11	
Interpolating factor (X)	8.148529834765
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.322065775113
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$) ..	7.103375621618
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$) ..	6.176601533604
T24/13	
C_{TL}	0.900466171184
T24/14	
C_{TL} (rounded)	0.90047

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Example 24/18 – Observed Temperature (T_F) and Relative Density @ 60 °F (γ_{60}) = Lower Range Limit

Input Data	
Relative density @ 60°F (γ_{60})	0.350000
Observed temperature, °F (T_F)	-50.8000
Computed data - last digit is rounded	
T24/1	
Input data - rounded	
γ_{60} rounded to 0.0001	0.3500
T_F rounded to 0.1	-50.8
T24/2	
T_x, kelvin	227.150000000000
T24/3	
Input data within range	
T24/4	
Reference fluid 1	EE (68/32)
Reference fluid 2	Ethane
T24/5	
Delta (δ)	0.806470360325
T24/6	
Critical temperature (T_c)	303.932716001550
T24/7	
Reduced observed temp. ($T_{r,x}$)	0.747369361839
T24/8	
Reduced temp. at 60°F ($T_{r,60}$)	0.949899567752
T24/9	
Scaling factor (h_2)	0.902595741301
T24/10	
Tau for fluid at 60°F (τ)	0.050100432248
Sat den fluid 1 at 60°F ($\rho_{60,1}^{sat}$)	11.889940226938
Sat den fluid 2 at 60°F ($\rho_{60,2}^{sat}$)	11.671295077352
T24/11	
Interpolating factor (X)	10.772124448866
T24/12	
Tau for fluid at obs. temp. (τ_x)	0.252630638161
Sat den fluid 1 at obs. temp. ($\rho_{x,1}^{sat}$)	16.573069193167
Sat den fluid 2 at obs. temp. ($\rho_{x,2}^{sat}$)	16.091771523334
T24/13	
C_{TL}	1.381375977418
T24/14	
C_{TL} (rounded)	1.38138

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5.1.2 Implementation Procedure for Table 23E (60 °F Basis)

This section presents the implementation procedure T23 for calculating the relative densities of NGLs and LPGs at a base condition of 60 °F from known temperatures and densities.

In the past, a hydrometer correction option was allowed to correct for the expansion of the glass comprising a hydrometer stem. The hydrometer correction previously took the following form:

Observed densities determined by a glass hydrometer require correction for the effect of temperature on the instrument. Readings from most density meters do not. If the density was determined with a glass hydrometer, then a correction for the expansion or contraction of the glass must be made. Call the rounded observed relative density the uncorrected relative density γ_x^*. Calculate the corrected relative density, γ_x from:

$$\gamma_x = [1 - 0.00001278(T_F - 60) - 0.0000000062(T_F - 60)^2]\gamma_x^*$$

The value of γ_x was not rounded prior to use [10].

Density readings must be corrected for the effect of temperature on the instrument prior to entering the density into the following implementation procedure.

5.1.2.1 Inputs and Outputs

Inputs: Relative density at observed temperature, γ_x
Observed temperature, T_F (°F)

Output: Relative density at 60 °F, γ_{60}

5.1.2.2 Outline of Calculations

The calculations are performed using an extended two-fluid corresponding states equation. Two reference fluids are found that are slightly denser and slightly less dense than the observed fluid by comparing their densities at the observed temperature. Iteration must be performed to determine the value of the fluid's relative density at 60 °F such that when the Temperature Correction Factor is applied, the observed relative density is obtained. The "guessed" value for the fluid's relative density at 60 °F is constrained to lie between the relative densities at 60 °F of these two reference fluids (as upper and lower bounds). As the iterations progress, these upper and lower bounds are "brought together" based upon intermediate calculations.

See Figure 3 for a general flow chart of the calculation procedure.

5.1.2.3 T23 Implementation Procedure

T23/Step Number	Operation/Procedure at that step
T23/1:	Round the relative density γ_x to the nearest 0.0001 and round the observed temperature T_F to the nearest 0.1 °F. Temperature rounding examples follow: –0.05 rounds to –0.1; –0.049 rounds to 0.0, –0.051 rounds to –0.1. Density rounding examples follow: 0.35555 rounds to 0.3556, 0.355549 rounds to 0.3555, 0.40289 rounds to 0.4029.
T23/2:	Convert the rounded observed temperature to units of kelvin, T_x:

$$T_x = \frac{T_F + 459.67}{1.8}$$

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T23/3: Check the values of temperature and relative density to ensure that they are in the proper range. The observed temperature T_x and relative density γ_x must fall within the following ranges:

Temperature between 227.15 K and 366.15 K, inclusive (equivalent to –46 °C to 93 °C, or –50.8 °F to 199.4 °F).
Relative density between 0.2100 and 0.7400 inclusive.

If these values do not fall in these ranges, then the standard does not apply. Flag this result (possibly by returning a –1 for γ_{60}) and exit this procedure.

T23/4: Reference fluids must be chosen to perform the density calculations. As written here, this is done in two separate steps: T23/4 to compute the density for each reference fluid at the observed temperature and T23/5 to determine which two reference fluids are to be used. However, Steps 4 and 5 could be combined into a single step (e.g. using a binary search technique).

The reference fluids' densities are to be calculated at the observed temperature, T_x. Use the reference fluids' parameter values from Table 2. First, use each reference fluid's critical temperature, $T_{c,\,ref}$, to compute its reduced observed temperature, $T_{r,x}$:

$$T_{r,x} = \frac{T_x}{T_{c,\,ref}}$$

If $T_{r,x} \leq 1$, calculate the saturation density for this reference fluid at this reduced temperature $T_{r,x}$. Use the procedure as described in Section 5.1.1.3 Step T24/10. Refer to this calculated density for the reference fluid as $\rho^{sat}_{x,\,ref}$. Repeat this for 60 °F using the reduced temperature $T_{r,60}$:

$$T_{r,60} = \frac{519.67}{1.8\,T_{c,\,ref}}$$

Refer to this calculated density as $\rho^{sat}_{60,\,ref}$. Finally, calculate its relative density at the observation temperature, $\gamma_{x,\,ref}$, as:

$$\gamma_{x,\,ref} = \gamma_{60,\,ref}\left(\frac{\rho^{sat}_{x,\,ref}}{\rho^{sat}_{60,\,ref}}\right)$$

where $\gamma_{60,\,ref}$ is the reference fluid's relative density at 60 °F.

If $T_{r,x} > 1$, this reference fluid will not be a liquid at this observed temperature and no value of $\gamma_{x,\,ref}$ can be calculated. It is suggested that this type of "no value" case be flagged by returning any negative value for $\gamma_{x,\,ref}$, such as the additive inverse of $\gamma_{60,\,ref}$ (by multiplying $\gamma_{60,\,ref}$ by –1).

T23/5: Determine the two adjacent reference fluids to be used for the calculations. Choose the lowest density reference fluid that has a density value greater than γ_x and refer to this fluid using the subscript "2." Also, use the next lowest density reference fluid and refer to this fluid using the subscript "1" (even though this reference fluid may not exist as a liquid at the observation temperature). If γ_x is below that for "EE 68/32" (the least dense reference fluid), then set "EE 68/32" as fluid "1" and "ethane" as fluid "2." If γ_x is above that for "n-heptane" (the most dense reference fluid), then set "n-hexane" as fluid "1" and "n-heptane" as fluid "2."

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T23/6: Initialize the boundaries on the iteration for the observed fluid's 60 °F relative density. For most cases, the observed fluid's 60 °F relative density should be between the two reference fluids "1" and "2," $\gamma_{60,1}$ and $\gamma_{60,2}$.

Initialize the upper boundary for the observed fluid's 60 °F relative density, $\gamma_{60,\,high}$, as:

$$\gamma_{60,\,high} = \gamma_{60,2}$$

and the corresponding relative density at the observed temperature, $\gamma_{x,\,high}$, as:

$$\gamma_{x,\,high} = \gamma_{x,2}$$

However, if the relative density γ_x is greater than the reference fluid "2" relative density at the observed temperature $\gamma_{x,2}$, then no answer exists. If this is the case, then $\gamma_{x,60}$ should be flagged (perhaps by being set to –1) and exit this procedure.

Initialize the lower boundary for the observed fluid's 60 °F relative density, $\gamma_{60,\,low}$, as:

$$\gamma_{60,\,low} = \gamma_{60,1}$$

and the corresponding relative density at the observed temperature, $\gamma_{x,\,low}$, as:

$$\gamma_{x,\,low} = \gamma_{x,1}$$

However, if reference fluid "1" is not a liquid at the observed temperature (i.e. $T_{r,x} > 1$ for the reference fluid), then set the lower boundary convergence 60 °F relative density by the following equation:

$$\gamma_{60,\,low} = \left[\frac{T_x - T_{c,1}}{T_{c,2} - T_{c,1}}\right](\gamma_{60,2} - \gamma_{60,1}) + \gamma_{60,1}$$

This equation was derived from equations in Section 5.1 at a reduced temperature of 1.0.

If $\gamma_{60,\,low}$ is less than 0.3500, then set it equal to 0.3500.

If $\gamma_{60,\,low}$ has been reset using the preceding technique then recalculate the corresponding $\gamma_{x,\,low}$ value. Use the procedure in Section 5.1.1.3 Steps T24/4 through T24/13 to calculate its Temperature Correction Factor, CTL. Skip Step 24/14 to avoid rounding the output CTL. The relative density at the observed temperature will be:

$$\gamma_{x,\,low} = C_{TL} \times \gamma_{60,\,low}$$

At this point, upper and lower convergence boundaries have been set. After one more check, the iterative process to determine a 60 °F relative density γ_{60} can begin. If the observed relative density γ_x is less than the lower limit $\gamma_{x,\,low}$, then no answer exists. If this is the case, then γ_{60} should be flagged (perhaps by being set to –1) and exit this procedure.

T23/7: Calculate an intermediate 60 °F relative density value, $\gamma_{60,\,mid}$. If a value for $\gamma_{60,\,low}$ exists, then calculate $\gamma_{60,\,mid}$ from:

$$\delta = \frac{\gamma_x - \gamma_{x,\,low}}{\gamma_{x,\,high} - \gamma_{x,\,low}}$$

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If δ is less than 0.001 then set it equal to 0.001; if δ is greater than 0.999 then set it equal to 0.999. Calculate the intermediate 60 °F relative density value:

$$\gamma_{60,\,mid} = \gamma_{60,\,low} + \delta(\gamma_{60,\,high} - \gamma_{60,\,low})$$

However, if a value for $\gamma_{x,\,low}$ does not exist, then calculate $\gamma_{60,\,mid}$ from:

$$\gamma_{60,\,mid} = \frac{\gamma_{60,\,high} + \gamma_{60,\,low}}{2}$$

Calculate the Temperature Correction Factor, C_{TL}, using this value of $\gamma_{60,\,mid}$ and T_x, unrounded, and the procedure from Section 5.1.1.3 Steps T24/5 to T24/13. (Do not round this C_{TL} value.) The relative density, $\gamma_{x,\,mid}$ at observed temperature, T_x, will be:

$$\gamma_{x,\,mid} = C_{TL} \times \gamma_{60,\,mid}$$

T23/8: Check for convergence of the 60 °F relative density. The calculations will be considered converged if either occurs:

— If γ_x is between $\gamma_{x,\,low}$ and $\gamma_{x,\,mid}$ and the difference between $\gamma_{60,\,low}$ and $\gamma_{60,\,mid}$ is less than 0.00000001 (10^{-8}).

— If γ_x is between $\gamma_{x,\,high}$ and $\gamma_{x,\,mid}$ and the difference between $\gamma_{60,\,high}$ and $\gamma_{60,\,mid}$ is less than 0.00000001 (10^{-8}).

If convergence has been achieved, set:

$$\gamma_{60} = \gamma_{60,\,mid}$$

and skip to Step T23/12.

T23/9: There are three pairs of relative density values: $(\gamma_{x,\,low}, \gamma_{60,\,low})$, $(\gamma_{x,\,mid}, \gamma_{60,\,mid})$ and $(\gamma_{x,\,high}, \gamma_{60,\,high})$. A quadratic equation can be fit through these three points. This quadratic equation should be a good approximation to the actual relationship between γ_x and γ_{60}. Using the value of the observed relative density γ_x in the quadratic equation should give a very good estimate to γ_{60}.

Calculate the parameters for the quadratic equation by:

$$\alpha = (\gamma_{60,\,high} - \gamma_{60,\,low})$$

$$\beta = \gamma_{x,\,high}^2 - \gamma_{x,\,low}^2$$

$$\phi = \frac{\gamma_{x,\,high} - \gamma_{x,\,low}}{\gamma_{x,\,mid} - \gamma_{x,\,low}}$$

$$A = \frac{\alpha - \phi(\gamma_{60,\,mid} - \gamma_{60,\,low})}{\beta - \phi(\gamma_{x,\,mid}^2 - \gamma_{x,\,low}^2)}$$

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$$B = \frac{\alpha - A\beta}{\gamma_{x,\,high} - \gamma_{x,\,low}}$$

$$C = \gamma_{60,\,low} - B\gamma_{x,\,low} - A\gamma_{x,\,low}^2$$

Using these values of A, B, and C, calculate the associated value $\gamma_{60,\,trial}$ using:

$$\gamma_{60,\,trial} = A\gamma_x^2 + B\gamma_x + C$$

This value of $\gamma_{60,\,trial}$ may have to be adjusted if it goes outside of the range of $\gamma_{60,\,low}$ or $\gamma_{60,\,high}$. If $\gamma_{60,\,trial} < \gamma_{60,\,low}$, then reset the value as:

$$\gamma_{60,\,trial} = \gamma_{60,\,low} + \frac{(\gamma_{60,\,mid} - \gamma_{60,\,low})(\gamma_x - \gamma_{x,\,low})}{(\gamma_{x,\,mid} - \gamma_{x,\,low})}$$

If $\gamma_{60,\,trial} > \gamma_{60,\,high}$ then reset the value as:

$$\gamma_{60,\,trial} = \gamma_{60,\,mid} + \frac{(\gamma_{60,\,high} - \gamma_{60,\,mid})(\gamma_x - \gamma_{x,\,mid})}{(\gamma_{x,\,high} - \gamma_{x,\,mid})}$$

Finally, calculate the Temperature Correction Factor, C_{TL}, using the value of $\gamma_{60,\,trial}$ and the procedure from Section 5.1.1.3 Steps T24/4 to T24/13. Skip Step 24/14 to avoid rounding the output C_{TL}. The relative density at observed temperature, $\gamma_{x,\,trial}$, will be:

$$\gamma_{x,\,trial} = C_{TL} \times \gamma_{60,\,trial}$$

T23/10: Check for convergence of the 60 °F relative density. The calculations will be considered converged if the absolute difference between $\gamma_{x,\,trial}$ and γ_x is less than 0.00000001 (10^{-8}). If converged, set:

$$\gamma_{60} = \gamma_{60,\,trial}$$

and skip to Step T23/12.

T23/11: The calculation has not yet converged, so the iteration boundaries must be updated.

If $\gamma_{x,\,trial} > \gamma_x$ then reset the upper boundaries to:

$$\gamma_{x,\,high} = \gamma_{x,\,trial}$$

$$\gamma_{60,\,high} = \gamma_{60,\,trial}$$

Also, if $\gamma_{x,\,mid} < \gamma_x$ then reset the lower boundaries to:

$$\gamma_{x,\,low} = \gamma_{x,\,mid}$$

$$\gamma_{60,\,low} = \gamma_{60,\,mid}$$

Or if $\gamma_{x,\,trial} < \gamma_x$ then reset the lower boundaries to:

$$\gamma_{x,\,low} = \gamma_{x,\,trial}$$

$$\gamma_{60,\,low} = \gamma_{60,\,trial}$$

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Also, if $\gamma_{x,\,mid} > \gamma_x$ then reset the upper boundaries to:

$$\gamma_{x,\,high} = \gamma_{x,\,mid}$$

$$\gamma_{60,\,high} = \gamma_{60,\,mid}$$

Return to Step T23/7 and continue iterations. Do at most 10 iterations. If 10 iterations are reached, then no solution can be found. Flag this result (possibly by returning a –1 for γ_{60}) and exit this procedure.

NOTE At this time, all known cases have been found to require less than 10 iterations.

T23/12: Round the 60 °F relative density value γ_{60} to the nearest 0.0001. If the value is less than 0.3500 or greater than 0.6880, then the result is outside the scope of this standard. Flag result (possibly by returning a –1 for γ_{60}). Exit this procedure.

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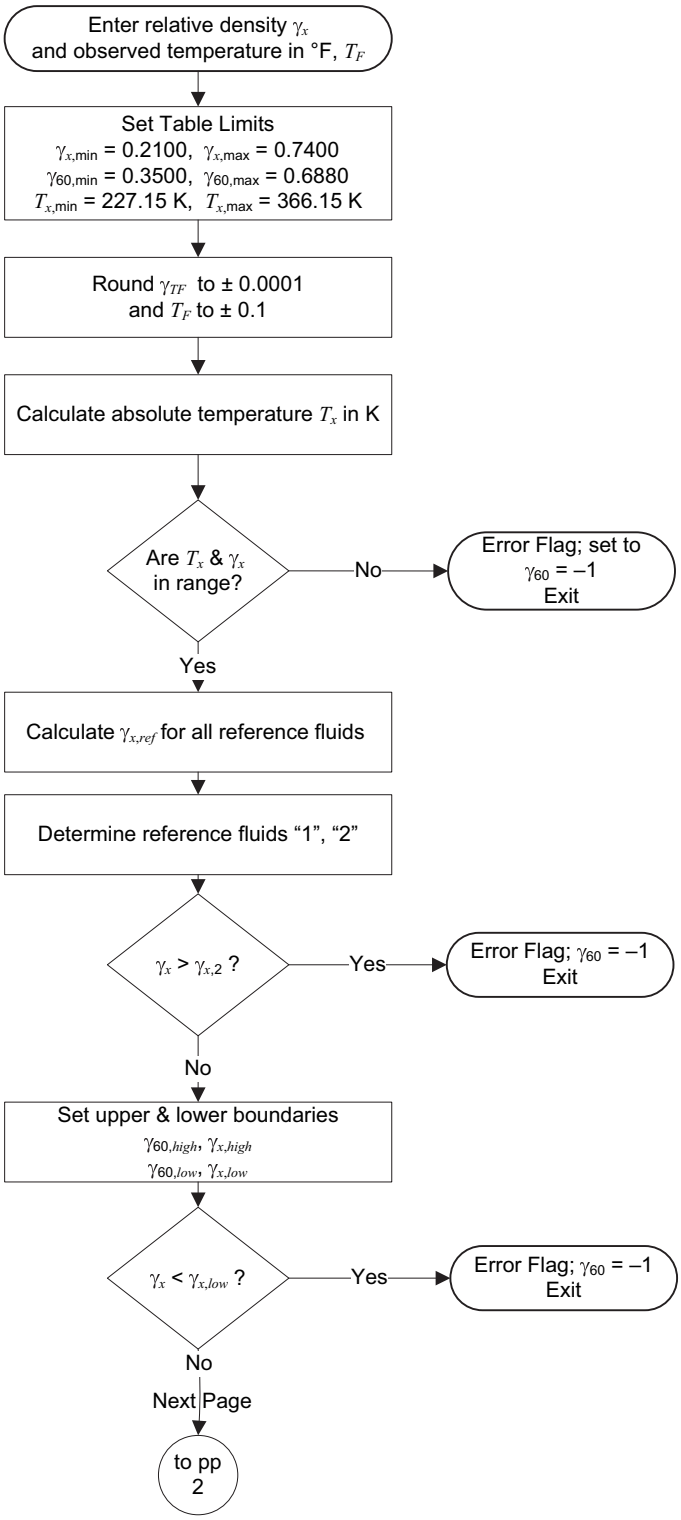


Figure 3—Flow Chart of Implementation Procedure for Table 23E

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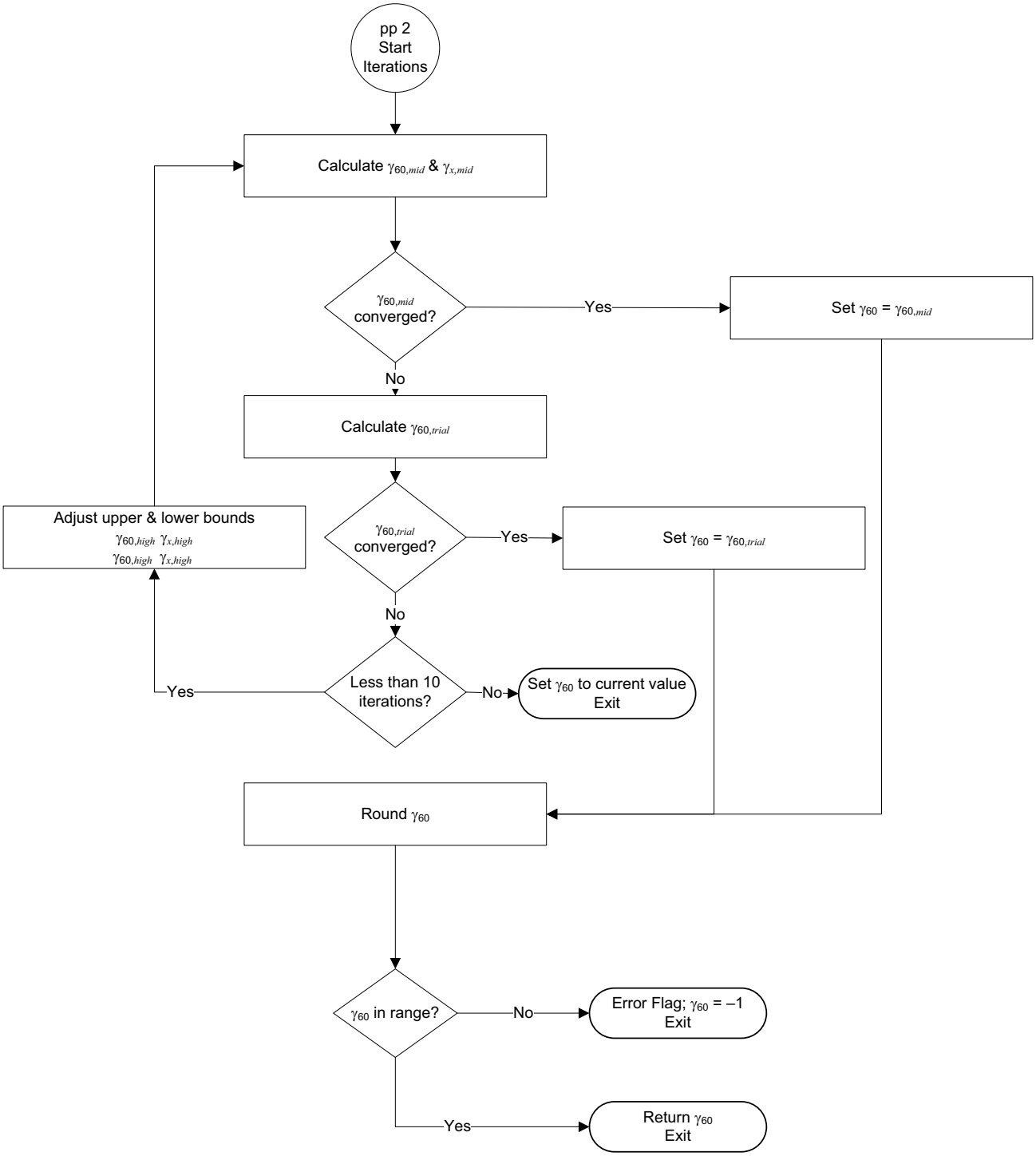


Figure 3—Flow Chart of Implementation Procedure for Table 23E (Continued)

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5.1.2.4 Examples for Section 5.1.2 (Table 23E)

(See Table 2 for properties of the Reference Fluids)

Example 23/1 – Use i-Pentane and n-Pentane

Input Data	
Relative density @ obs. temp. (γ_x) ...	0.67432
Observed temperature, °F (T_F)	-23.33
Computed data – last digit is rounded	
T23/1	
Input data – rounded	
γ_x, observed rel. density	0.6743
T_F, °F	-23.3
T23/2	
T_x, kelvin	242.427777777778
T23/3	
γ_x and T_F are within range, continue	
T23/4	
γ_x for fluid 1	0.668992076725
γ_x for fluid 2	0.674300900334
T23/5	
Reference fluid 1	i-Pentane
Reference fluid 2	n-Pentane
$T_{r,x}$ for fluid 1	0.526513286808
$T_{r,x}$ for fluid 2	0.516188177958
$T_{r,60}$ for fluid 1	0.627021013716
$T_{r,60}$ for fluid 2	0.614724913352
T23/6	
Upper boundary $\gamma_{60,high}$	0.631054000000
Upper boundary $\gamma_{x,high}$	0.674300900334
Lower boundary $\gamma_{60,low}$	0.624285000000
Lower boundary $\gamma_{x,low}$	0.668992076725
Iteration steps	Pass 1
T23/7	
Delta (δ)	0.999000000000
$\gamma_{60,mid}$	0.631047231000
C_{TL}	1.068534241176
$\gamma_{x,mid}$	0.674295574123
T23/8	Continue
T23/9	
Alpha (α)	0.006769000000
Beta (β)	0.007131305470
Phi (ϕ)	1.001004282842
A	-0.784857658731
B	2.329340853270
C	-0.582762216726
$\gamma_{60,Trial}$	0.631052855782
$C_{TL,Trial}$	1.068531730459
$\gamma_{x,Trial}$	0.674300000000
T23/10	Converged
T23/11 not needed, convergence already achieved	
T23/12	
γ_{60} ($\gamma_{60,Trial}$ rounded)	0.6311

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Example 23/2 – Adjust $\gamma_{60,Trial}$, Reset High and Low/High Boundaries

Input Data				
Relative density @ obs. temp. (γ_x) ...	0.24573			
Observed temperature, °F (T_F)	189.98			
Computed data – last digit is rounded				
T23/1				
Input data – rounded				
γ_x, observed rel. density	0.2457			
T_F, °F	190.0			
T23/2				
T_x, kelvin	360.927777777778			
T23/3				
γ_x and T_F are within range, continue				
T23/4				
γ_x for fluid 1	-0.470381000000			
γ_x for fluid 2	0.341646473673			
T23/5				
Reference fluid 1	EP (35/65)			
Reference fluid 2	Propane			
$T_{r,x}$ for fluid 1	1.024024790835			
$T_{r,x}$ for fluid 2	0.976060840981			
$T_{r,60}$ for fluid 1	0.819115801951			
$T_{r,60}$ for fluid 2	0.780749514726			
T23/6				
Upper boundary $\gamma_{60,high}$	0.507025000000			
Upper boundary $\gamma_{x,high}$	0.341646473673			
Lower boundary $\gamma_{60,low}$	0.488296314601			
Lower boundary $\gamma_{x,low}$	0.209990106855			
Iteration steps	Pass 1	Pass 2	Pass 3	Pass 4
T23/7				
Delta (δ)	0.271235596182	0.601796434584	0.126556348248	0.004138210954
$\gamma_{60,mid}$	0.493376200751	0.489664201999	0.488882034911	0.488850690456
C_{TL}	0.587375829009	0.529645485907	0.504021249568	0.502607558267
$\gamma_{x,mid}$	0.289797254929	0.259348434199	0.246406934127	0.245700051887
T23/8	Continue	Continue	Continue	Continue
T23/9				
Alpha (α)	0.018728685399	0.002273006817	0.000895498051	0.000031474704
Beta (β)	0.072626467996	0.028442228403	0.007860987453	0.000349330714
Phi (ϕ)	1.649681388134	1.202204934943	5.820815799273	237.456099384553
A	1.515978266954	1.061284960315	1.166129963841	1.088675802961
B	-0.694014759007	-0.470388528249	-0.529337816619	-0.491403133721
C	0.567184205356	0.540274994825	0.548511356689	0.543866723826
$\gamma_{60,Trial}$	0.488182097917	0.488768703948	0.488850560207	0.488850688195
$\gamma_{60,Trial}$ adjusted				
$\gamma_{60,Trial}$	0.490569321418	not changed	not changed	not changed
$C_{TL,Trial}$	0.549012993292	0.498645735699	0.502601576844	0.502607454450
$\gamma_{x,Trial}$	0.269328931569	0.243722429967	0.245697062401	0.245700000000
T23/10	Continue	Continue	Continue	Converged
T23/11				
Reset boundaries				
$\gamma_{x,high}$	0.269328931569	0.259348434199	0.246406934127	
$\gamma_{60,high}$	0.490569321418	0.489664201999	0.488882034911	
$\gamma_{x,low}$	not changed	0.243722429967	0.245697062401	
$\gamma_{60,low}$	not changed	0.488768703948	0.488850560207	
T23/12				
γ_{60} ($\gamma_{60,Trial}$ rounded)	0.4889			

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