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

MAY 2004
ADDENDUM 1, SEPTEMBER 2007

REAFFIRMED, AUGUST 2012

INTERNATIONAL
Standards Worldwide

American
Petroleum
Institute

Helping You
Get The Job
Done Right.SM

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

Measurement Coordination

MAY 2004
ADDENDUM 1, SEPTEMBER 2007

REAFFIRMED, AUGUST 2012

INTERNATIONAL
Standards Worldwide

American
Petroleum
Institute

Helping You
Get The Job
Done Right.SM

SPECIAL NOTES

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. Sometimes a one-time extension of up to two years will be added to this review cycle. This publication will no longer be in effect five years after its publication date as an operative API standard or, where an extension has been granted, upon republication. Status of the publication can be ascertained from the API Standards department telephone (202) 682-8000. A catalog of API publications, programs and services is published annually and updated biannually by API, and available through Global Engineering Documents, 15 Inverness Way East, M/S C303B, Englewood, CO 80112-5776.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this standard or comments and questions concerning the procedures under which this standard was developed should be directed in writing to the Director of the Standards department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Requests for permission to reproduce or translate all or any part of the material published herein should be addressed to the Director, Business Services.

API standards are published to facilitate the broad availability of proven, sound engineering and operating practices. These standards are not intended to obviate the need for applying sound engineering judgment regarding when and where these standards should be utilized. The formulation and publication of API standards is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

FOREWORD

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to API, Standards department, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

CONTENTS

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 11.1-2004 includes modifications published in September 2007 as Addendum 1. Added text is highlighted in yellow. Deleted text is indicated by strikethrough.

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.

1952 Tables, Density and Volume Correction Tables[1]

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^3	15°C
54	Reduction of Volume to 15°C Against Density at 15°C	kg/m^3	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 know 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.

[1] Tables 53 and 54 were first published in 1953 by IP.

1980 Tables, Density and Volume Correction Tables					
			Commodity Based Table Designation		
Description	Density Units	Base Temp.	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^3	15°C	53A	53B	
Correction of Volume to 15°C Against Density at 15°C	kg/m^3	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.

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) ~~(VCF)~~. 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 (CTL, F_p, 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 ~~(VCF)~~ values consistent with the 1980 Tables.

~~The~~ This Standard provides general procedures for the conversion of input data to generate CTL, F_p, CPL, and CTPL values at the user specified base temperature and pressure (T_b, P_b) ~~a form that is consistent with the computation procedures used to generate VCF values~~. 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

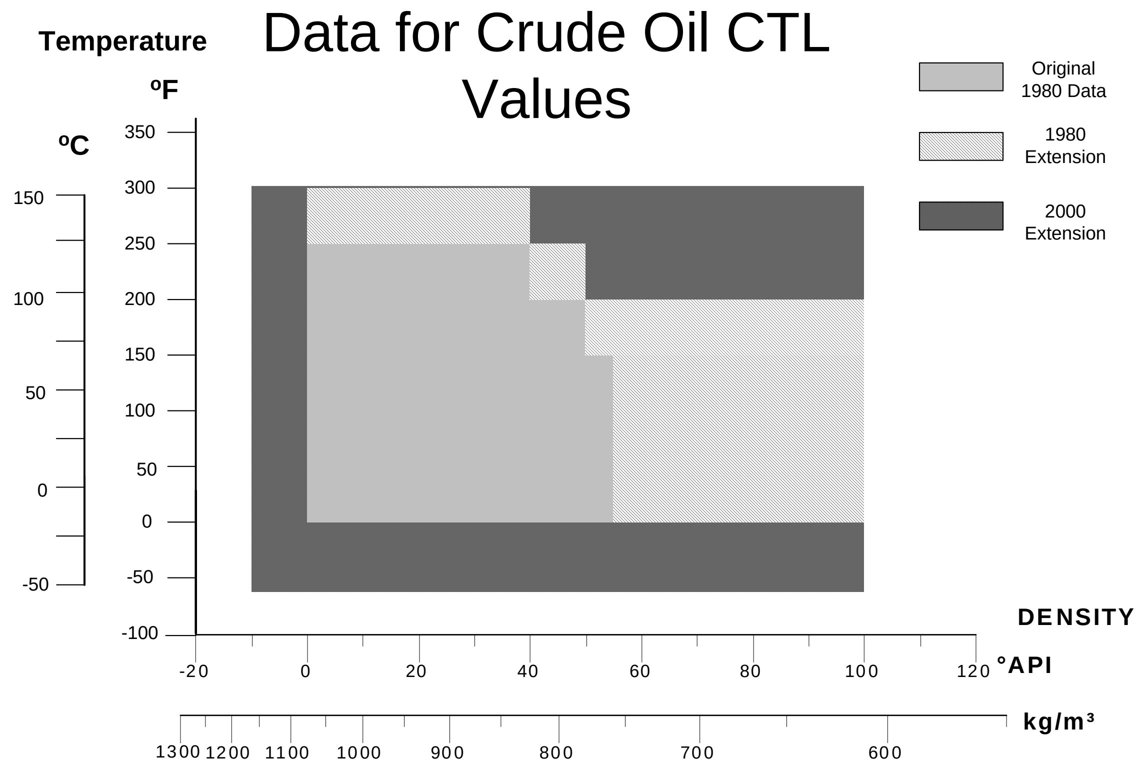
The limits on this Standard are defined in a mixture of terms of customary and metric units. The following table shows the defining limits and their associated units. These values are shown in ***bold italics***. Also shown in the table are the limits converted to their equivalent units (and, in the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

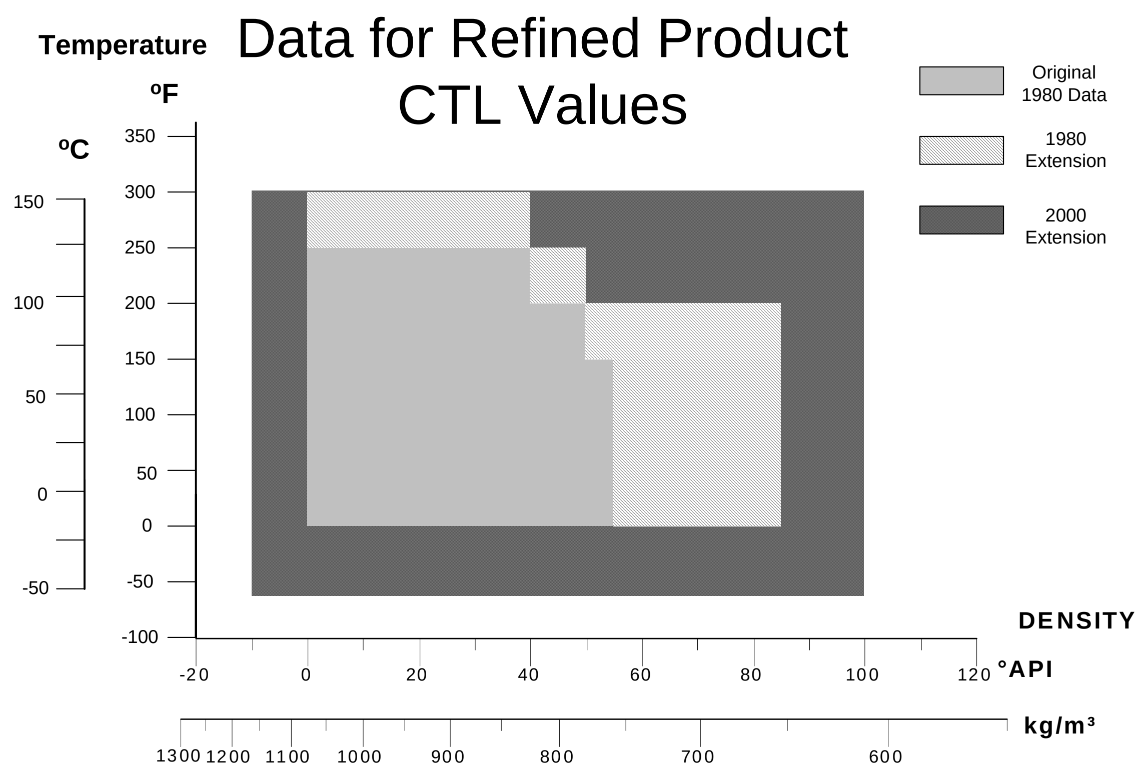
	Crude Oil	Refined Products	Lubricating Oils
Density, kg/m³ @ 60°F	***610.6 to 1163.5***		***800.9 to 1163.5***
Relative Density @ 60°F	0.61120 to 1.16464		0.80168 to 1.1646
API Gravity @ 60°F	100.0 to -10.0		45.0 to -10.0
kg/m³ @ 15°C	611.16 to 1163.79	611.16 to 1163.86	801.25 to 1163.85
kg/m³ @ 20°C	606.12 to 1161.15	606.12 to 1160.62	798.11 to 1160.71
Temperature, °C	***-50.00 to 150.00***		
°F	-58.0 to 302.0		
Pressure, psig	***0 to 1,500***		
kPa (gauge)	0 to 1.034×10^{4}		
bar (gauge)	0 to 103.4		
α_{60}, per °F	***230.0×10^{-6} to 930.0×10^{-6}***		
per °C	414.0×10^{-6} to 1674.0×10^{-6}		

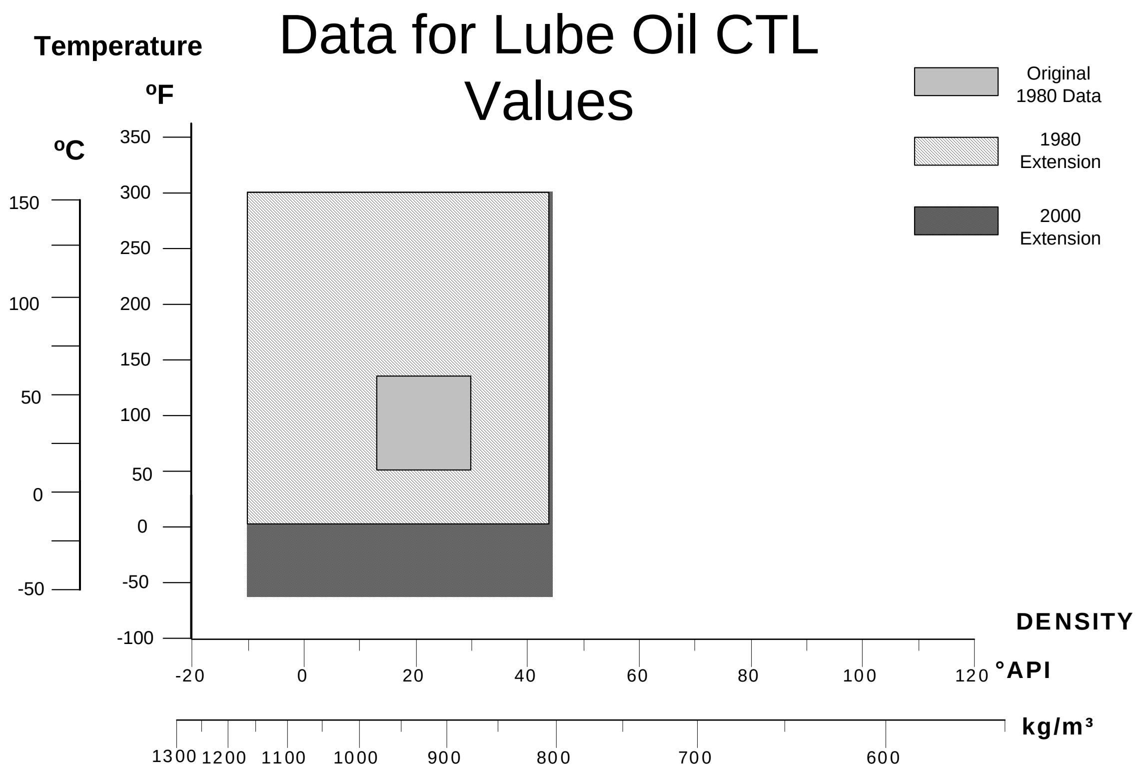
Note that only the precision levels of the defining values shown in this table are correct. The other values showing converted units have been rounded to the significant digits shown; as rounded values, they may numerically fall just outside of the actual limits established by the defining values.

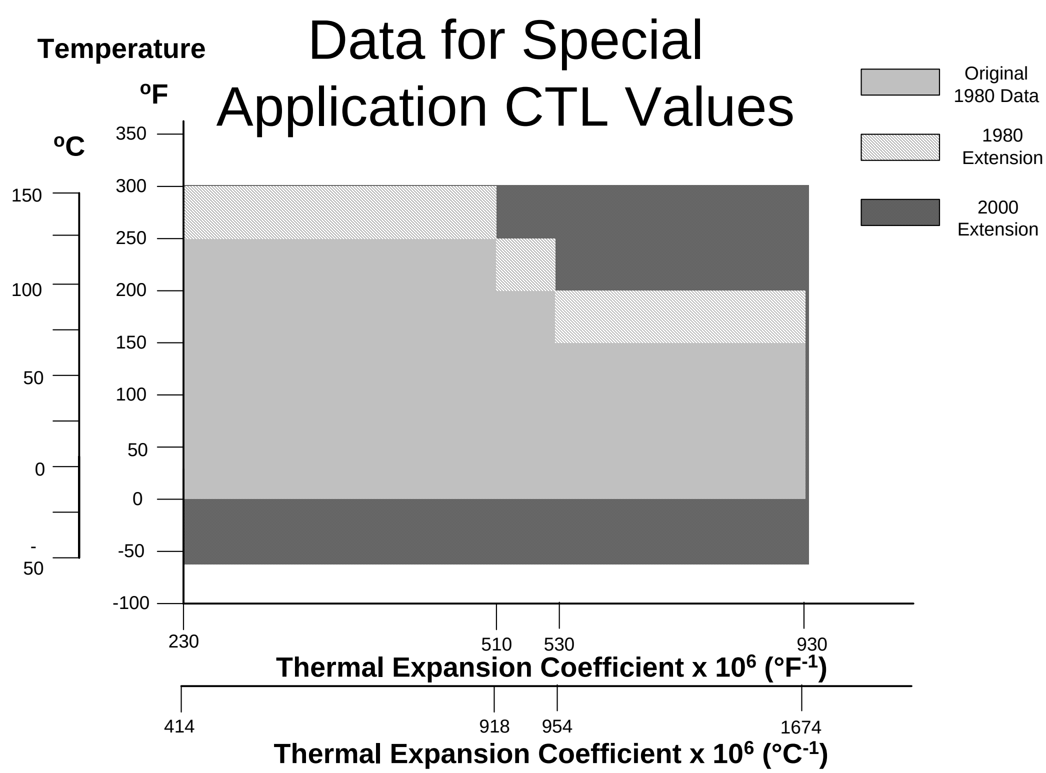
In 1980 the correlation for CTL was chosen so that it would be monotonic with respect to temperature (both the function and its temperature derivative). It also did not have any discontinuities over a very wide range of temperatures and densities. This does not say that the correlation is valid outside 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.

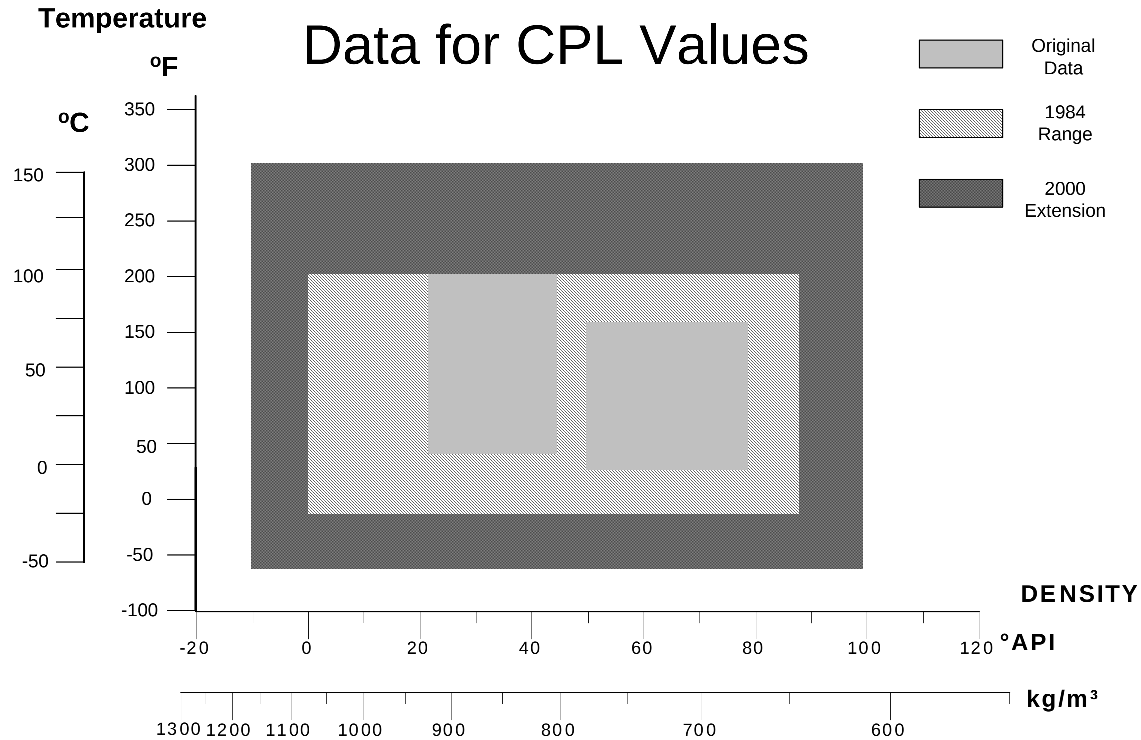
The following figures show the range of the original data, the extensions to give the previous standards, and the current extensions for the Generalized Crude Oils, Generalized Refined Products, Generalized Lube Oils, Special Applications, and the compressibility factors. Computed values in any of these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


Data for Crude Oil CTL Values
Temperature
ºF
ºC
350
300
250
200
150
100
50
0
-50
-100
150
100
50
0
-50
Original 1980 Data
1980 Extension
2000 Extension
DENSITY
-20 0 20 40 60 80 100 120
°API
kg/m³
1300 1200 1100 1000 900 800 700 600


Data for Refined Product CTL Values
Temperature
ºF
ºC
350
300
250
200
150
100
50
0
-50
-100
150
100
50
0
-50
Original 1980 Data
1980 Extension
2000 Extension
DENSITY
-20 0 20 40 60 80 100 120
°API
kg/m³
1300 1200 1100 1000 900 800 700 600


Data for Lube Oil CTL Values
Temperature
ºF
ºC
350
300
250
200
150
100
50
0
-50
-100
150
100
50
0
-50
Original 1980 Data
1980 Extension
2000 Extension
DENSITY
-20
0
20
40
60
80
100
120
°API
kg/m³
1300
1200
1100
1000
900
800
700
600


Data for Special Application CTL Values
Temperature
ºF
ºC
350
300
250
200
150
100
50
0
-50
-100
150
100
50
0
-50
Original 1980 Data
1980 Extension
2000 Extension
230
510
530
930
Thermal Expansion Coefficient x 10^6 (°F^-1)
414
918
954
1674
Thermal Expansion Coefficient x 10^6 (°C^-1)



11.1.2.4 Classification of Liquids

This set of correlations is intended for use with petroleum fluids comprising either crude oils, refined products, or lubricating oils that are single-phase liquids under normal operating conditions. The liquid classifications listed here are typical terms used in the industry, but local nomenclature may vary. The list is illustrative and is not meant to be all-inclusive.

11.1.2.4.1 Crude Oil

A crude oil is considered to conform to the commodity group Generalized Crude Oils if its density falls in the range between approximately -10 to 100 °API. Crude oils that have been stabilized for transportation or storage purposes and whose API gravities lie within that range are considered to be part of the commodity group.

11.1.2.4.2 Refined Products

A refined product is considered to conform to the commodity group of Generalized Refined Products if the fluid falls within one of the refined product groups. The groups are defined as follows:

1. Gasoline: Motor gasoline and unfinished gasoline blending stock with a base density range between approximately 50 °API and 85 °API. This group includes substances with the commercial identification of:
   - premium gasoline
   - gasoline
   - unleaded gasoline
   - motor spirit
   - clear gasoline
   - low lead gas
   - motor gasoline
   - catalyst gas
   - alkylate
   - catalytic cracked gasoline
   - naphtha

- reformulated gasoline
- aviation gasoline

2. Jet Fuels: Jet fuels, kerosene, and Stoddard solvents with a base density range between approximately 37 °API and 50 °API. This group includes substances with the commercial identification of:
   - jet fuel A
   - jet kerosene
   - aviation jet A
   - kerosene
   - aviation turbine fuel
   - Stoddard solvent
   - white kerosene
   - JP-2
   - JP-8

3. Fuel Oils: Diesel oils, heating oils and fuel oils with a base density range between approximately -10 °API and 37 °API. This group includes substances with the commercial identification of:
   - No. 6 fuel oil
   - fuel oil PA
   - low sulfur fuel
   - LT (low temperature) fuel oil
   - fuel oil
   - fuel oils LLS (light low sulfur)
   - No. 2 furnace oil
   - furnace oil
   - auto diesel
   - gas oil
   - No. 2 burner fuel
   - diesel fuel
   - heating fuel
   - premium diesel

Note the product descriptors are generalizations. The commercial specification ranges of some products may place their densities partly within an adjacent class (e.g., a low density diesel may lie in the jet fuel class). In such cases, the product should be allocated to the class appropriate to its density not its descriptor.

11.1.2.4.3 Lubricating Oils

A lubricating oil is considered to conform to the commodity group Generalized Lubricating Oils if it is a base stock derived from crude oil fractions by distillation or asphalt precipitation. For the purpose of this Standard, lubricating oils have initial boiling points greater than 700°F (370°C) and densities in the range between approximately -10 to 45°API.

11.1.2.4.4 Special Applications

Liquids that are assigned the special applications category are generally relatively pure products or homogeneous mixtures with stable (unchanging) chemical composition that are derived from petroleum (or are petroleum-based with minor proportions of other constituents) and have been tested to establish a specific thermal expansion factor for the particular fluid. These tables should be considered for use when:

- The generalized commodity groups' parameters are suspected of not adequately representing the thermal expansion properties of the liquid.

- A precise thermal expansion coefficient can be determined by experiment. A minimum of 10 temperature/density data points is recommended to use this method. See 11.1.5.2 for the procedure to calculate the thermal expansion coefficient from measured density data.

- Buyer and seller agree that, for their purpose, a greater degree of equity can be obtained using factors specifically measured for the liquid involved in the transaction.

11.1.2.5 Application of Tables to Specific Substances

The following are guidelines for the use of the correlations for specific products.

11.1.2.5.1 Waxy Crudes

It is the convention in the petroleum industry to apply the Generalized Crude Oil Tables to waxy crude oils even when they are at temperatures below that at which wax forms as a separate phase. However, the density of the crude oil should be determined at a temperature at which the oil exists as a single liquid phase.

11.1.2.5.2 Natural and Drip Gasolines

Natural gasolines are paraffinic substances and are not actually refined products. These substances should be considered part of the Generalized Crude Oil commodity group provided their density lies in the appropriate range.

Drip gasoline is the paraffinic condensate from gas well production. Drip gasoline is a mixture of natural gas liquids, primarily butanes, pentanes, hexanes, and heptanes. Drip gasoline should also be considered part of the Generalized Crude Oil commodity group provided its density lies in the appropriate range.

Aromatic natural gasoline should be considered part of the Generalized Refined Products commodity group.

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. 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°/60° relative densities of 0.3500 to 0.6880 (272.8 to 74.2°API). The tables in this Standard generally apply to products that do not have to be stored in pressurized containers at normal temperatures.

11.1.2.5.4 LNG

LNG (Liquefied Natural Gas) is predominantly methane, ethane, and propane. LNG is less dense than the liquids covered by this Standard.

11.1.2.5.5 Ethylene and Propylene

API Chapter 11.3.2.1 "Ethylene Density" encompasses the temperature portion of the volume correction factors. API Chapter 11.3.2.2 "Propylene Compressibility" encompasses the temperature portion of the volume correction factors. Use this Standard for the pressure correction portion of the volume correction factors.

11.1.2.5.6 Butadiene

Use ASTM Standard D1550 for the temperature correction portion of the volume factors for butadiene. Use this Standard for the pressure correction portion of the volume correction factors.

11.1.2.5.7 Cyclohexane and Aromatics

Use ASTM Standard D1555 for the temperature correction portion of the volume factors for cyclohexane and aromatic compounds. Use this Standard for the pressure correction portion of the volume correction factors.

11.1.2.5.8 Asphalts and Road Tars

The Asphalt Institute recommends the use of ASTM D4311 for volume correction factors of asphalt and ASTM D633 for volume correction factors of road tar. The API recommends that historical Tables 6 and 7 are also acceptable.

11.1.2.5.9 Reformulated Fuels

API has investigated volume correction factors for reformulated fuels. Included in this study were gasoline feedstocks containing any one of the following oxygenates: MTBE, ETBE, DIPE, and TAME. The addition of minor proportions of ethers to gasolines, up to 2.7 wt% oxygen, such as permitted in many national fuels specifications, does not significantly change the correction factors from the Generalized Refined Products table.

The Special Applications procedure, which requires laboratory testing of a representative sample, was also found satisfactory for all of the gasolines, oxygenates, and mixtures studied.

11.1.2.5.10 MTBE

Methyl tertiary butyl ether (MTBE) is best represented by the Special Applications procedure with a 60°F thermal expansion factor (α_{60}) of 789.0×10^{-6} °F^{-1}.

11.1.2.5.11 JP-4

The NIST database contained four samples of the substance known as JP-4. The open literature contains data on six additional samples. (An independent industrial laboratory under government contract measured these data.) The ten samples encompass a density range at 60°F of 744.3 to 786.5 kg/m³. A study of these ten samples shows that:

- Six samples are best represented as a Generalized Crude Oil. Four samples are best represented as a Generalized Refined Product.
- When the sample is best represented as a Generalized Refined Product, the error in representing it as a Generalized Crude Oil is very small.
- However, when the sample is best represented as a Generalized Crude Oil, the error in representing it as a Generalized Refined Product is significant.

In consideration of these results it is recommended:

- In the general case, represent JP-4 as a Generalized Crude Oil.
- In cases where the buyer and seller agree that a greater degree of precision is desirable, determine the coefficient of thermal expansion of the various blends and use the special application tables.

The above recommendations apply only to JP-4 which is a blend. Other jet fuels such as JP-2 and JP-8 or materials that have densities at 60°F of 787.5 kg/m³ or greater are well represented as a Generalized Refined Product.

11.1.2.5.12 Pure Compounds

Pure paraffinic compounds (C5+) are well represented as Generalized Crude Oils within the range of the correlations. Non-paraffinic pure compounds (C5+) are not well represented as either Generalized Crude Oils or Generalized Refined Products; however, thermal expansion factors can be determined and these pure compounds can be treated as a Special Application.

It is recognized that there are some pure components whose densities put them in the range of this Standard and the standard(s) for light hydrocarbons. The two standards give results that are of comparable accuracy but are slightly different. It is up to the contracting parties to decide which is more appropriate to use.

11.1.2.5.13 Gasohol

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 (α_{60}) of 714.34×10^{-6} °F^{-1}.

11.1.3 Outline of Calculation Procedures

In order to produce identical results in 1980 using the computer technology of that day, the 1980 CTL Tables used an integer mathematical method. This method required a set of complex truncation and rounding routines to generate results that would be consistent using different machines. Since the issuance of the 1980 CTL Tables changes in computer hardware, software, and standardization policies have eased this need. The standard computer processor of the early 2000s supports 64-bit floating-point operations. This Standard is designed to use that technology and simplify the arithmetic associated with the procedure. This Standard reflects the use of floating point mathematical operations where integer creation of decimal numbers is not necessary. However, older computer processor technology, primarily 16-bit chips without math coprocessors (or lower powered technology), may not reproduce the factors exactly to the fifth decimal place, which is the level of precision adopted as a requirement of this revised Standard.

In order to produce exact (to fifth decimal place) factors between two different computers and/or computer software, absolute adherence to the procedure is still required. If the sequence of the procedure is not followed, exact reproduction is unlikely to be achieved. The implementation procedures described herein can, by careful and deliberate application, produce consistent results through the majority of languages and word sizes in present and anticipated future use. Finally, all constants shown must be carried to the exact number of digits as presented and all calculations must be executed using 64-bit calculations as a minimum.

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

The phrases “standard,” “base,” “observed,” and “alternate” conditions are used throughout this Standard.

- The “observed” condition is the temperature and pressure at which the density of a liquid is actually or assumed to have been measured. Calculations can then be performed to correct this observed density to any other temperature and pressure conditions.

- The “standard” or “base” condition is a defined combination of temperature and pressure at which liquid volumes are expressed for purposes of custody transfer, stock accounting, etc. The terms standard and base are used interchangeably. Accepted standard temperatures are 60°F, 15°C and 20°C. Accepted standard pressures are zero gauge pressure (for non-volatile liquids at the standard temperature) or the liquid’s vapor pressure at the standard temperature (for volatile liquids).

- The “alternate” conditions are any other temperature and pressure conditions to which the observed or standard density can be corrected.

The distinction between these conditions may best be shown with an example. Consider a storage tank containing a liquid at an average temperature of 122°F. A sample is withdrawn and the density measured at 85°F. One would like to correct the volume of liquid in the tank to a 60°F standard temperature. In the example, the observed conditions are 85°F and 0 psig since those are the temperature and pressure at which the density is actually measured. The standard or base condition is 60°F and 0 psig. However, since the tank is actually at 122°F and 0 psig, the observed density cannot be directly applied to the tank volume. In this case, the tank’s temperature and pressure of 122°F and 0 psig are considered as alternate conditions.

The situation is similar for measurements made on flowing liquids. Consider a pipeline with a liquid flowing at 70°F and 150 psig at the flow meter. The density of liquid is measured at 80°F and 145 psig at the densimeter. In this example, the observed conditions are 80°F and 145 psig since those are the temperature and pressure at which the density is actually measured. The standard or base condition is 60°F and 0 psig. However, since the flowing liquid is actually at 70°F and 150 psig, the observed density cannot be directly applied to the meter volume. In this case, the meter’s temperature and pressure of 70°F and 150 psig are considered the alternate conditions.

11.1.3.2 Basic Equations

The correction of the density of a liquid from its base condition to an alternate temperature and pressure condition is given in this Standard as a direct calculation performed in a two part process:

1. A thermal correction is applied to the liquid to account for the change from the base temperature to the alternate temperature along its base pressure.

2. A pressure correction is applied to the liquid to account for the change from the base pressure to the alternate pressure at the alternate temperature.

The temperature correction factor is referred to as the CTL (Correction factor for the effect of Temperature on the Liquid) and can be expressed as C_{TL}. The pressure correction factor is referred to as the CPL (Correction factor for the effect of Pressure on the Liquid) and can be expressed as C_{PL}. The product of these correction factors can be referred to as the CTPL (Correction factor for the effects of Temperature and Pressure on the Liquid) and expressed as C_{TPL}; this is the full VCF.

Mathematically, the procedure starts with the density $\rho_T \equiv \rho(T, P_e)$ (and corresponding volume $V_T \equiv V(T, P_e)$) expressed at the base temperature T and base pressure P_e. Corrections are made to obtain the density $\rho(t, P)$ (and corresponding volume $V(t, P)$) at the alternate temperature t and gauge pressure P. The thermal correction to an intermediate density $\rho(t, P_e)$ is done first:

$$C_{TL} \equiv \frac{\rho(t, P_e)}{\rho(T, P_e)} \tag{1}$$

and then the pressure correction to $\rho(t, P)$:

$$C_{PL} \equiv \frac{\rho(t, P)}{\rho(t, P_e)}. \tag{2}$$

Note that the combined correction is simply the product of the first two correction factors since:

$$C_{TPL} \equiv \frac{\rho(t, P)}{\rho(T, P_e)} = \frac{\rho(t, P_e)}{\rho(T, P_e)} \cdot \frac{\rho(t, P)}{\rho(t, P_e)} = C_{TL} \cdot C_{PL}. \tag{3}$$

Volume corrections use the same factors since the volume of a fixed mass is inversely proportional to its density:

$$C_{TL} = \frac{\rho(t, P_e)}{\rho(T, P_e)} = \frac{V(T, P_e)}{V(t, P_e)} \tag{4}$$

$$C_{PL} = \frac{\rho(t, P)}{\rho(t, P_e)} = \frac{V(t, P_e)}{V(t, P)} \tag{5}$$

$$C_{TPL} = \frac{\rho(t, P)}{\rho(T, P_e)} = \frac{V(T, P_e)}{V(t, P)}. \tag{6}$$

The density and volume at temperature t and pressure P can be calculated from the density and volume at base conditions as:

$$\rho(t, P) = C_{TPL} \cdot \rho(T, P_e) \tag{7}$$

$$V(t, P) = \frac{V(T, P_e)}{C_{TPL}}. \tag{8}$$

Densities can be corrected from any observed condition to any other alternate condition by combining the correction factors for each set of conditions. The factors for correcting the observed density $\rho_o = \rho(t_o, P_o)$ to the standard conditions are defined as:

$$C_{TL,o} = \frac{\rho(t_o, P_e)}{\rho(T, P_e)} \tag{9}$$

$$C_{PL,o} = \frac{\rho(t_o, P_o)}{\rho(t_o, P_e)} \tag{10}$$

$$C_{TPL,o} = \frac{\rho(t_o, P_o)}{\rho(T, P_e)} = C_{TL,o} \cdot C_{PL,o} \tag{11}$$

then the correction from $\rho(t_o, P_o)$ to $\rho(t, P)$ can be calculated from:

$$\frac{\rho(t,P)}{\rho(t_o,P_o)} = \frac{\rho(t,P)}{\rho(T,P_e)} \cdot \frac{\rho(T,P_e)}{\rho(t_o,P_o)} = \frac{C_{TPL}}{C_{TPL,o}} = \frac{C_{TL} \cdot C_{PL}}{C_{TL,o} \cdot C_{PL,o}} . \tag{12}$$

The correction for the volume is:

$$\frac{V(t,P)}{V(t_o,P_o)} = \frac{C_{TPL,o}}{C_{TPL}} = \frac{C_{TL,o} \cdot C_{PL,o}}{C_{TL} \cdot C_{PL}} . \tag{13}$$

11.1.3.3 Calculation of CTL and CPL Factors in This Standard

The specific equation forms for the temperature and pressure correction factors used in this Standard are:

$$\begin{aligned} C_{TL} &= \exp\left\{-\alpha_T\left(t-T\right)\left[1+0.8\alpha_T\left(t-T+\delta_T\right)\right]\right\} \\ &= \exp\left\{-\alpha_T \Delta t\left[1+0.8\alpha_T\left(\Delta t+\delta_T\right)\right]\right\} \end{aligned} \tag{14}$$

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

where α_T is the thermal expansion coefficient at the base temperature T, Δt is the difference between the alternate temperature and the base temperature, F_P is the compressibility coefficient, and δ_T is a small base temperature correction value.

In the 1980 Standard, α_T was correlated to the density at a 60°F base temperature and 0 psig pressure, ρ^*, and is denoted as α_{60}. The CTL equation was developed as a correction to 60°F density, so $T = 60$ and $\delta_T = 0$. F_P was correlated to this same base density and the temperature t at which the compression occurs. The forms for these correlations are:

$$\alpha_{60} = \frac{K_0 + K_1\rho^* + K_2\rho^{*2}}{\rho^{*2}} = \frac{K_0}{\rho^{*2}} + \frac{K_1}{\rho^*} + K_2 \tag{16}$$

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

There was one set of coefficients for the F_P compressibility factor (A = -1.99470, B = 0.00013427, C = 793920, D = 2326; based on density in kg/m^3 at 60°F ~~the A, B, C, and D values~~) but several sets of coefficients for the α_{60} thermal expansion coefficient (the K_0, K_1, and K_2 values) depending upon the liquid's classification and density at 60°F.

To recognize differences between the current ITS-90 temperature scale and the IPTS-68 temperature scale in effect when the data for this Standard were measured, this Standard makes small corrections to the temperature t and the base temperature T and a non-zero base temperature correction factor, denoted as δ_{60}, is used. Also, the density used in the correlations, ρ^*, is slightly different from a ρ_{60} measured consistent with ITS-90. See 11.1.5.3 for the procedure to convert ITS-90 temperatures to an IPTS-68 basis, Appendix C for the origin of the δ_{60} correction factor, and 11.1.6.1 for the calculation of ρ^* from ρ_{60}.

Equations (16) and (17) are directly expressed in terms of ρ^*. However, since ρ^* can be directly related to ρ_{60}, then these equations can also be thought of as being a direct function of ρ_{60}, too.

11.1.3.4 Base Pressure in This Standard

For volatile hydrocarbons, the base pressure is the saturation pressure for the liquid (i.e., its "bubble point" pressure). It is generally assumed that if the saturation pressure is less than atmospheric pressure then there is little error in applying the correction at a constant base pressure of 1 atmosphere. For liquids with equilibrium vapor pressure less than atmospheric pressure (0 psig or 14.696 psia) the P_e value used in Equation 15 shall be atmospheric pressure (0 psig or 14.696 psia). ~~The heavier liquids covered by this Standard are fairly non-volatile — the saturation pressure is less than the atmospheric pressure over the entire temperature range of this Standard. It is only the lightest of the liquids covered by this Standard whose vapor pressures may exceed atmospheric pressure at the higher temperatures.~~

~~For simplicity of application, this Standard will neglect any effects of the liquid's saturation pressure exceeding atmospheric pressure. In all equations, this Standard will use~~ ~~$P_e = 0$~~ ~~(gauge) and the CPL equation reduces to:~~

$$\cancel{C_{PL} = \frac{1}{1 - F_P P}} \qquad \cancel{(18)}$$

For liquids with an equilibrium vapor pressure greater than atmospheric, the equilibrium vapor pressure (P_e) should be subtracted from the pressure input values before entering the calculation sequences given in 11.1.5.1, 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.

11.1.3.5 Iteration Scheme to Determine Base Density from Observed Density

Because α_{60} and F_P in Equations (16) and (17) are direct functions of the 60°F density ρ_{60}, the CTL and CPL equations are also direct functions of ρ_{60}. When a given ρ_{60} is used to calculate a corresponding density ρ, then these equations are very convenient to use. However, if an observed density ρ_o is given and the corresponding ρ_{60} is to be calculated, then these equations are not so convenient. Equations (16) and (17) cannot be rearranged so that ρ_{60} can be directly calculated from ρ_o. In this case, the ρ_{60} can only be determined numerically using a process of "iteration." Iteration is a process by which ρ_{60} is repeatedly guessed until the ρ calculated at the observed conditions matches the observed density ρ_o.

The following six steps are a general iterative procedure to calculate ρ_{60} from a given ρ_o:

1. Start the procedure by estimating a value for ρ_{60}.

2. Start an iterative step. Calculate the ρ value at the observed conditions using the current estimate of ρ_{60}:

   - Determine the value of ρ^*_{60} consistent with the current estimate of ρ_{60}.
   - Calculate the α_{60} value using Equation (16) (unless the calculation is for a Special Applications liquid and the α_{60} is a given, constant value). Calculate the CTL using Equation (18).
   - Calculate the F_P value using Equation(17). Calculate the CPL using Equation (18).

- Calculate the ρ value at the observed conditions using Equation (7).

3. Compare the given observed density ρ_o to the calculated density at observed conditions ρ.

4. If the difference between the given observed density ρ_o and the calculated density at observed conditions ρ is acceptably small, then no further iterations need be done. Terminate the iterative process by going to Step 6.

5. If the difference is not acceptably small, then estimate a new ρ_{60} value and continue the iterative process by returning to Step 2. This finishes an iterative step.

6. The final ρ_{60} value is the desired output from this iterative procedure. This finishes the iterative procedure.

The iterative process as described will continue until the convergence criterion of Step 4 is achieved. Sometimes it is practical to establish an upper limit on the number of iterations allowed. When this is added, an additional check is added at the start of Step 2 to stop the calculations if the maximum number of iterations has been exceeded. If so, the iterations are stopped even though convergence has not been achieved. A special error condition is returned to signify non-convergence. The actual form of this error condition is not specified by this standard.

The nature of the iterative process is most significantly defined by how the new value for ρ_{60} is determined in Step 5. The 1980 CTL Tables were created using a "Direct Substitution" method – it was a simple iterative procedure to explain, but was neither powerful nor robust. The Direct Substitution method was prone to converge very slowly (or not at all) for some observed density values, especially those near the boundaries of the sub-groups for the Refined Products. For this revision, there was a need for a powerful iteration procedure; this need was made even greater by the inclusion of the pressure correction term in the procedure. For this reason, a more sophisticated "Newton's Method" is used.

Newton's method defines a specific way to calculate a new ρ_{60} value from the previous value in Step 5 above. The non-linear Equations (16) and (17) are "linearized" about each estimate of the ρ_{60} value. The equations are linearized by taking the derivative of all of these equations with respect to ρ_{60}. This linearized equation can then be directly solved for a value of ρ_{60} that gives the observed density ρ_o. The solution of the linearized equation is used as the next iterative step's estimate for ρ_{60}.

Newton's methods have two important properties: (1) when an estimate is near the actual answer, the method is guaranteed to converge and (2) the convergence of the estimate to the correct answer is very quick. These properties give the power and robustness needed in this Standard.

The derivation of the iteration equations is in Appendix F. The detailed steps to implement the iterative procedure (e.g., how to make the initial estimate, checks to keep values in bounds, convergence tolerances, etc.) are in 11.1.6.2.

11.1.3.6 Calculation of CTL and CPL Factors for Base Temperatures Other Than 60°F

The goal of this Standard is to provide <u>consistent</u> results when performing corrections using either metric or customary units. That is, when one corrects an observed density to the density at alternate conditions of temperature and pressure, the same result should be obtained irrespective of the base conditions used or the units in which they are expressed. For the equations and correlations used in this Standard, the 60°F base condition must always be applied in the calculation procedure, even when input and output data are expressed in the metric system of units.

It was a desire in this revision to modify the equations in 11.1.3.3 to enable direct input of densities at each separate base temperature (60°F, 15°C and 20°C). <u>Unfortunately this proved impossible to achieve while keeping all calculations consistent.</u> Because of this, the 60°F base condition must be incorporated into all of the CTL and CPL calculations used in this Standard. See Appendix C for details.

11.1.3.7 Calculation Types

Based upon the equations used for this Standard, there are three distinct types of calculations when using the 60°F base density. These particular classifications are based upon how the calculations are performed — each calculation type requires the preceding type(s):

Type 1. Starting with the density at the 60°F and 0 psig base condition, correct the density (and volume) to an alternate temperature and pressure condition.

Type 2. Starting with an observed density at its temperature and pressure, correct the density (and volume) back to the 60°F and 0 psig base condition.

Type 3. Starting with an observed density at its temperature and pressure, correct the density (and volume) to an alternate temperature and pressure condition.

A Type 1 calculation is straightforward — starting with the density at 60°F and 0 psig all parameters can be determined and the calculations can proceed in a "feed-forward" manner. No iterations are involved in this type of calculation. A Type 2 calculation is more complicated — this requires a set of Type 1 calculations, iterating upon the value of the 60°F and 0 psig density. A Type 3 calculation is a combination of a Type 2 calculation followed by another Type 1 calculation.

All calculations involving metric base temperatures are Type 3 calculations. The corresponding metric calculation types are:

Type 1M. Starting with the density at the metric base condition, correct the density (and volume) to the alternate temperature and pressure condition. This is a Type 3 calculation — the density at the metric base condition is the "observed density" and the correction is made to the alternate temperature and pressure condition after first calculating the value of density at 60°F and 0 psig.

Type 2M. Starting with an observed density at its temperature and pressure, correct the density (volume) to the metric base condition. This is also a Type 3 calculation — the alternate temperature and pressure condition is now the metric base condition.

Type 3M. Starting with an observed density at its temperature and pressure, correct the density (volume) to the alternate temperature and pressure condition. This description is identical to the non-metric Type 3 calculation description. If the density at the metric base condition is required, however, then an extra Type 1 calculation must be performed.

The pipeline example given previously is an example of a Type 3 calculation. The density at the observed conditions at the densimeter is first corrected to the standard condition of 60°F and 0 psig. The final step is to adjust this standard density to the alternate conditions at the flow meter.

11.1.3.8 Calculating the Thermal Expansion Factor for Special Applications

The correlations for the 60°F thermal expansion factor give results for an "average" liquid of a specific commodity type. However, there may be occasions when one wants to make density measurements on a particular liquid in order to determine its actual α_{60} value. An implementation procedure is presented in 11.1.5.2 to derive ρ_{60} and α_{60} values from a set of density measurements. The following are general guidelines that should be followed before the data analysis is done:

- A minimum of 10 data points is needed to use this method.
- The data measurements should cover the temperature range over which the VCF values are to be used. The range should include 60°F even if a measurement is not made at this temperature.
- The density measurements should be made at such pressures that a pressure correction need not be applied (i.e., the CPL factor is 1 for all of the data points).

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 CTPL is rounded as specified in API *MPMS* Chapter 12. If there is no guidance for a specific application, round to five decimal places. ~~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.

11.1.3.10 Glass Hydrometer Corrections

When a glass hydrometer is used to measure the density of a liquid, special corrections must be made to account for the thermal expansion of the glass when the temperature is different from that at which the hydrometer was calibrated. The 1980 CTL Tables had generalized equations to correct glass hydrometer readings and made these corrections part of the printed odd-numbered Tables. However, the detailed procedures to correct a glass hydrometer reading are beyond the scope of this Standard. The user should refer to the appropriate sections of API *MPMS* Chapter 9 or other appropriate density/hydrometer standards for guidance.

11.1.3.11 International Temperature Scale of 1990, ITS-90

The International Committee for Weights and Measures, CIPM, publishes the international temperature scale. Its purpose is to define procedures by which specified practical thermometers of the required quality can be calibrated in such a way that the values of temperature obtained from them can be precise and reproducible while at the same time closely approximating the corresponding thermodynamic values. The temperature scale provides defined values of temperature for various phenomena (e.g., the triple point of water is defined to be 273.16 K and the freezing point of tin is 505.078 K) and a means to interpolate temperature values in between the fixed points.

See Appendix D for a detailed description of the International Temperature Scale.

Since the international temperature scale is used for the calibration of thermometers, the values of temperature-dependent physical parameters of materials will, in principle, depend on what scale is in force at the time the parameter is measured or referenced. However, since changes between scales are relatively small, this effect will only become noticeable at high levels of precision.

The data collected for the 1980 version of the CTL Standard and used to develop the correlations were based on measurements made with the IPTS-68 temperature scale, in force from 1968 to 1990. However, current temperature measurement devices are calibrated consistent with the ITS-90 temperature scale that superseded IPTS-68 in 1990. -

A subtle effect of the change of temperature scale is that the customary standard temperature, 60°F, has undergone a slight shift. What is 60°F in ITS-90 is an equivalent 60.007°F in IPTS-68. Because of this, any input ρ_{60} values determined today must be corrected to an equivalent IPTS-68 60°F value, ρ^*, before the value can be used in the α_{60} and F_P correlations, Equations (16) and (17), respectively.

11.1.4 Summary and Precision Statement

The changes made to this Standard are primarily oriented to the computer application of the underlying equations. The underlying equations have not been substantially changed. Therefore, that the Precision Statement made for the 1980 CTL Tables and 1981 Compressibility Tables are still valid for this version.

The 1980 CTL Tables were based on density temperature determinations made by the U.S. National Bureau of Standards from 1974 to 1979 under contract to the API on 225 samples of products ranging from heavy fuel oil to gasoline blend components and 124 samples of crude oil that covered a wide range of quality and represented about 45% of the world's crude production and reserves as known during that time period. The thermal expansion properties (volume correction factors) for products (including lube stocks) and crude oils were correlated in separate, generalized tables as a function of temperature and density or API gravity. The predicted precision at the 95% confidence level was:

	CTL precision at 95 % confidence level			
Temperature	100°F	150°F	200°F	250°F
Crudes and Products	±0.05%	±0.15%	±0.25%	±0.35%

A precision statement for the 250°F to 300°F portion of the tables has not been given because it is an extrapolation.

For the 1981 Compressibility Tables, the maximum compressibility factor uncertainty was estimated to be ±6.5% at the 95% confidence level. Hence at worst, one should expect that the real compressibility factor for a given material could be either 6.5% higher or 6.5% lower than the value in the Standard. This statement is only true within the limits of the database. It may not be true for the extrapolated portions of the Standard. To assess the possible uncertainty in the calculated volume at equilibrium pressure using the above database and equation, two approaches were taken. First it was assumed that only the correlation uncertainty in mean compressibility of ±6.5% was significant. With this approach, volumetric uncertainties due to pressure effects should be in the range of 0.02 to 0.10%, depending on operating conditions.

11.1.5 Implementation Procedures — General

The methods needed to calculate the Volume Correction Factors follow in 11.1.5, 11.1.5.5, and 11.1.7. These methods are called Implementation Procedures.

Auxiliary calculations are presented first in 11.1.5:

- Converting the units of input values to those used by the calculation routines.
- Calculating the thermal expansion factor from measured density data.
- Calculating the equivalent IPTS-68 temperature value given an ITS-90 temperature value.
- Rounding the values used in this Standard.

The core calculation methods using the 60°F base temperature are presented in 11.1.5.5:

- Starting with the density at the 60°F base condition, correct the density (and volume) to the alternate temperature and pressure condition. (Type 1 calculation)
- Starting with an observed density at its temperature and pressure, correct the density (and volume) back to the 60°F base condition. (Type 2 calculation)
- Starting with an observed density at its temperature and pressure, correct the density (and volume) to some alternate temperature and pressure condition. (Type 3 calculation)

Calculation methods for temperature bases other than 60°F are presented in 11.1.7. They make use of the non-metric calculation routines.

All calculations shall be performed using at least 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} or smaller. This also means that approximately 16 or more decimal digits are used for all calculations.

The procedures require no rounding of initial, intermediate, and most final values. The only value to be rounded is the combined temperature and pressure volume correction factor, CTPL. However, for practical reasons of presentation, rounding is used when creating tabular representations of the results from these Implementation Procedures.

Examples of the calculations are presented at the end of the sections with the Implementation Procedures. Even though double precision was used for these example calculations only twelve decimal digits are printed here. 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.

11.1.5.1 Method to Convert Units of Temperature, Pressure, Thermal Expansion Factor, and Density-Related Values

Note: For liquids with an equilibrium vapor pressure greater than atmospheric, see 11.1.3.4.

Outline of Calculations

This procedure accepts the density, temperature, and pressure values in units as entered and converts them to the units required by the calculation procedure.

Relative density & API gravity values are *in vacuo*.

Possible Input and Output Values

$t_{\circ C}$	Temperature value (°C)
P_{kPa}	Pressure value (kPa (gauge))
P_{bar}	Pressure value (bar (gauge))
γ_T	Relative density value based upon water at temperature T
γ_{60}	Relative density value based upon water at 60°F
G	API gravity (°API)
$\alpha_{60,\circ C}$	60°F thermal expansion factor (°C^{-1})
ρ	Density value (kg/m³)
t	Temperature value (°F)
P	Pressure value (psig)
α_{60}	60°F thermal expansion factor (°F^{-1})

Calculation Procedure

Step 1: Convert the units of the input variables to those required by the procedure: kg/m³ for density, °F for temperature, psig for pressure, and °F^{-1} for the 60°F thermal expansion factor.

Temperature

If the input temperature variable is in °F units then no processing is required.

If the input temperature variable is in °C units then:

$$t = 1.8 \cdot t_{\circ C} + 32$$

Pressure

If the input pressure variable is in units of psig then no processing is required.

If the input pressure variable is in units of kPa then:

$$P = \frac{P_{kPa}}{6.894757}.$$

If the input pressure variable is in units of bar then:

$$P = \frac{P_{bar}}{0.06894757}.$$

Density

If the input density variable is relative density then:

$$\rho = \gamma_T \cdot \rho_{w,T}$$

where $\rho_{w,T}$ is the density of water consistent with the reference temperature T. The only water density needed in this Standard is for 60°F. The accepted value for the density of water at 60°F is 999.016 kg/m³ (see Appendix D).

If the input density variable is API gravity then:

$$\rho = \frac{141.5}{G+131.5} \cdot \rho_{w,60} = \frac{141.5}{G+131.5} \cdot 999.016$$

If the input density variable is already in units of kg/m³ then no processing is required. However, there are instances in this Standard that the density in units of kg/m³ must be converted back to API gravity or relative density. If the 60°F relative density is required, then:

$$\gamma_{60} = \frac{\rho}{\rho_{w,60}} = \frac{\rho}{999.016}$$

or if the API gravity is required, then:

$$G = \frac{141.5}{\rho/\rho_{w,60}} - 131.5 = \frac{141.5}{\rho/999.016} - 131.5$$

60°F Thermal Expansion Factor

If the input 60°F thermal expansion factor variable is in units of $°F^{-1}$ and the output is also $°F^{-1}$ then no processing is required.

If the input 60°F thermal expansion factor variable is in units of $°C^{-1}$ and the output is also $°C^{-1}$ then no processing is required.

If the input 60°F thermal expansion factor variable is in units of $°C^{-1}$ and the output is $°F^{-1}$ then:

$$\alpha_{60} = \frac{\alpha_{60,°C}}{1.8}.$$

If the input 60°F thermal expansion factor variable is in units of $°F^{-1}$ and the output is $°C^{-1}$ then:

$$\alpha_{60,°C} = 1.8 \cdot \alpha_{60}.$$

Step 2: Exit from this procedure.

11.1.5.2 Method to Calculate Thermal Expansion Factor from Density Measurements

Outline of Calculations

This procedure accepts measured density values and derives values of the density at 60°F (ρ_{60}) and the thermal expansion factor at 60°F (α_{60}). The following are general guidelines for the data analysis:

- A minimum of 10 data points is needed to use this method.
- The data measurements should cover the temperature range over which the VCF values are to be used. The range should span 60°F even if a measurement is not made at this temperature.
- The density measurements should be made at such pressures that a pressure correction need not be applied (i.e., the CPL factor is 1 for all of the data points).

This procedure results in a α_{60} value in units of °F^{-1}. However, if units of °C^{-1} are required then use the procedure in 11.1.5.1 to convert as appropriate.

Input Values

N Number of measured density values

t_i Individual temperature value for which there is a density measurement (°F)

$\rho_{m,i}$ Individual density measurement (kg/m³)

Output Values

α_{60} Thermal expansion factor at 60°F (°F^{-1})

ρ_{60} Density at 60°F (kg/m³)

Intermediate Values

δ_{60} Temperature shift value (a constant, 0.01374979547°F)

t_i^* Shifted individual temperature values (°F)

Δt_i Difference between an individual temperature value and the base temperature (°F).

S_j Summations of the Δt_i and $\rho_{m,i}$ values needed to perform the regression. There are eight different summations needed; each will be identified by their subscript (j).

a_j Coefficients for the cubic equation that will define the thermal expansion coefficient. There are 4 different coefficients; each will be identified by their subscript (j).

$\alpha^{(m)}$ Value of the thermal expansion factor on the m-th iteration (°F^{-1})

$\Delta\alpha^{(m)}$ Change added to the value of $\alpha^{(m)}$ on the m-th iteration to get the value for the next (m+1)-th iteration (°F^{-1})

Calculation Procedure

Step 1: Shift the input temperatures t_i to t_i^* following the procedure in 11.1.5.3.

Step 2: Calculate the differences of the individual temperatures from the base temperature:

$$\Delta t_i = t_i^* - 60.00687490\,.$$

Step 3: Calculate the summations of the Δt_i and $\rho_{m,i}$ values needed to perform the regression. These are:

$$S_\rho = \sum_{i=1}^{N} \ln \rho_{m,i}$$

$$S_{\rho\rho} = \sum_{i=1}^{N} \left(\ln \rho_{m,i}\right)^2$$

$$S_t = \sum_{i=1}^{N} \Delta t_i$$

$$S_{t\rho} = \sum_{i=1}^{N} \Delta t_i \cdot \ln \rho_{m,i}$$

$$S_{tt} = \sum_{i=1}^{N} \left(\Delta t_i\right)^2$$

$$S_{tt\rho} = \sum_{i=1}^{N} \left(\Delta t_i\right)^2 \cdot \ln \rho_{m,i}$$

$$S_{ttt} = \sum_{i=1}^{N} \left(\Delta t_i\right)^3$$

$$S_{tttt} = \sum_{i=1}^{N} \left(\Delta t_i\right)^4$$

Step 4: Calculate the coefficients for the cubic equation that will define the thermal expansion coefficient:

$$a_0 = S_{t\rho} - \frac{S_\rho S_t}{N}$$

$$a_1 = S_{tt} + 1.6\left(S_{tt\rho} + \delta_{60} S_{t\rho}\right) - \frac{S_t^2 + 1.6\left(S_{tt} + \delta_{60} S_t\right) S_\rho}{N}$$

$$a_2 = 2.4\left[S_{ttt} + \delta_{60} S_{tt} - \frac{S_t\left(S_{tt} + \delta_{60} S_t\right)}{N}\right]$$

$$a_3 = 1.28\left[S_{tttt} + \left(2S_{ttt} + \delta_{60} S_{tt}\right)\delta_{60} - \frac{\left(S_{tt} + \delta_{60} S_t\right)^2}{N}\right]$$

Step 5: Initialize the estimate for the thermal expansion factor, $\alpha^{(1)}$:

$$\alpha^{(1)} = \frac{a_0}{\dfrac{S_t^2}{N} - S_{tt}}$$

Initialize iteration counter as $m = 1$ and start iterations.

Step 6: Determine a correction to the current iterative value of $\alpha^{(m)}$:

$$\Delta\alpha^{(m)} = -\frac{a_0 + \left[a_1 + \left(a_2 + a_3\alpha^{(m)}\right)\alpha^{(m)}\right]\alpha^{(m)}}{a_1 + \left(2a_2 + 3a_3\alpha^{(m)}\right)\alpha^{(m)}}$$

Step 7: Update the value for $\alpha^{(m+1)}$:

$$\alpha^{(m+1)} = \alpha^{(m)} + \Delta\alpha^{(m)}$$

Step 8: Go to Step 4 and repeat iteration five times.

Step 9: After the 6th iteration, set the values of α_{60} and ρ_{60}:

$$\alpha_{60} = \alpha^{(6)}$$

$$\rho_{60} = \exp\left\{\frac{S_\rho + \left[S_t + 0.8\left(S_{tt} + \delta_{60}S_t\right)\alpha_{60}\right]\alpha_{60}}{N}\right\}$$

Step 10: Round the values of α_{60} and ρ_{60} to be consistent with 11.1.5.4.

Step 11: Exit from this procedure.

Example

The following table shows experimental data for a specific petroleum fluid. From these data the α_{60} and ρ_{60} values are desired.

°C	kg/m³
14.9	868.21
15.9	867.50
20.2	864.51
25.0	861.19
29.6	857.91
32.9	855.62
35.4	853.82
40.2	850.48
42.0	849.16
44.9	847.15

The following tables show: the original data; the data manipulated to be put into the proper units; intermediate summations and equation coefficients; the iterative results; and the final α_{60} and ρ_{60} values.

Original Data		Manipulated Data			
t_i	$\rho_{m,i}$	t_i	t_i^*	Δt_i	$\ln \rho_{m,i}$
°C	kg/m³	°F	°F	°F	
14.9	868.21	58.82	58.8266	-1.1803	6.76643
15.9	867.50	60.62	60.6270	0.6202	6.76562
20.2	864.51	68.36	68.3690	8.3621	6.76216
25.0	861.19	77.00	77.0113	17.0044	6.75832
29.6	857.91	85.28	85.2934	25.2866	6.75450
32.9	855.62	91.22	91.2350	31.2281	6.75183
35.4	853.82	95.72	95.7362	35.7293	6.74972
40.2	850.48	104.36	104.3785	44.3716	6.74580
42.0	849.16	107.60	107.6194	47.6125	6.74425
44.9	847.15	112.82	112.8408	52.8339	6.74188

Summations	
N	10
$S_\rho = \sum \ln \rho_{m,i}$	67.5405
$S_{\rho\rho} = \sum (\ln \rho_{m,i})^2$	456.173
$S_t = \sum \Delta t_i$	261.868
$S_{t\rho} = \sum \Delta t_i \cdot \ln \rho_{m,i}$	1767.12
$S_{tt} = \sum (\Delta t_i)^2$	10279.26
$S_{tt\rho} = \sum (\Delta t_i)^2 \cdot \ln \rho_{m,i}$	69348.6
$S_{ttt} = \sum (\Delta t_i)^3$	440511
$S_{tttt} = \sum (\Delta t_i)^4$	19885457.5

Coefficients in Equation for α_{60}	
a_0	-1.55568
a_1	3296.87
a_2	411,305
a_3	1.19345E+07

Iteration	$\alpha^{(m)}$	$\Delta\alpha^{(m)}$
1	4.54646E-04	-7.98343E-06
2	4.46663E-04	-7.42106E-09
3	4.46655E-04	-6.40949E-15
4	4.46655E-04	0.000E+00
5	4.46655E-04	0.000E+00
6	4.46655E-04	0.000E+00

The resulting coefficient of thermal expansion (to six digits) is $\alpha_{60} = 446.655 \times 10^{-6}$ °F^{-1} and the calculated density at 60ºF (to six digits) is $\rho_{60} = 867.756$ kg / m³. When rounded consistent with 11.1.5.4 the results are $\alpha_{60} = 446.7 \times 10^{-6}$ °F^{-1} and $\rho_{60} = 867.8$ kg/m³ .

11.1.5.3 Method to Convert Temperature from ITS-90 to IPTS-68 Basis

Outline of Calculations

This procedure converts temperature from ITS-90 to IPTS-68 basis. This correction is necessary because of the change in the standard procedure to calibrate temperature measurement devices. The change in the temperatures between the two scales is small. The equation presented here is from the original paper describing the ITS-90 temperature scale.[2]

Input Values

$t_{F,90}$ Temperature consistent with ITS-90 (°F)

$t_{C,90}$ Temperature consistent with ITS-90 (°C)

Output Values

$t_{F,68}$ Temperature consistent with IPTS-68 (°F)

$t_{C,68}$ Temperature consistent with IPTS-68 (°C)

Intermediate Values

Δ_t Correction to ITS-90 temperature to give IPTS-68 temperature (°C)

τ Scaled temperature value.

Calculation Procedure

Step1: Accept input temperature value, either in units of °F, $t_{F,90}$, or °C, $t_{C,90}$.

Step 2: If input temperature was in units of °F, calculate the temperature in units of °C:

$$t_{C,90} = \frac{t_{F,90} - 32}{1.8}$$

Step 3. Calculate the scaled temperature value:

$$\tau = \frac{t_{C,90}}{630}$$

and use this to calculate the temperature correction:

$$\Delta_t = \Big(a_1 + \Big(a_2 + \Big(a_3 + \Big(a_4 + \Big(a_5 + \Big(a_6 + \big(a_7 + a_8\tau\big)\tau\Big)\tau\Big)\tau\Big)\tau\Big)\tau\Big)\tau\Big)\tau \; .$$

The a_i coefficients are given in the following table.

2 "The International Temperature Scale of 1990, ITS-90," NPL Special Report QU S45, National Physical Laboratory, Teddington, Middlesex, November 1989.

i	a_i
1	-0.148759
2	-0.267408
3	1.080760
4	1.269056
5	-4.089591
6	-1.871251
7	7.438081
8	-3.536296

Step 4. Determine the equivalent IPTS-68 temperature:

$$t_{C,68} = t_{C,90} - \Delta_t$$

If the input temperature was in units of °F, also calculate the equivalent IPTS-68 temperature in customary units:

$$t_{\mathrm{F},68} = 1.8 t_{\mathrm{C},68} + 32$$

Step 5: Exit from this procedure.

11.1.5.4 Rounding of Values

Outline of Calculations

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.

Calculation Procedure

Step 1: The following table shows acceptable units for the input and calculated variables and the increment to which they should be rounded.

Variable Type	Units	Rounding Increment (δ)
Density	°API	0.1
	Relative Density	0.0001
	kg/m^3	0.1
Temperature	°F	0.1
	°C	0.05
Pressure	psig	1
	kPa (gauge)	5
	bar (gauge)	0.05
Thermal Expansion Coefficient (α_{60})	°F^{-1}	0.0000001 (0.1×10^{-6})
	°C^{-1}	0.0000002 (0.2×10^{-6})
CTL		0.00001
Scaled Compressibility Factor (F_P)	psi^{-1}	0.001

	kPa^{-1}	0.0001
	bar^{-1}	0.01
CPL		0.00001
CTPL		0.00001

Step 2: Normalize the input variable.

$$Y = \frac{|X|}{\delta}$$

where X is the value to be rounded, $|X|$ is its absolute value, δ is the rounding increment, and Y is the normalized variable.

Step 3: Find the integer closest to the normalized variable. If the decimal portion of Y is not exactly equal to 0.5 then use the following equation for rounding:

$$I = \text{trunc}(Y + 0.5)$$

where trunc is the truncation function and I is the rounded value for the normalized variable. However, if the decimal portion of Y is exactly equal to 0.5 then use the following equation for rounding:

$$I = \begin{cases} \text{trunc}(Y)+1 & \text{if } \text{trunc}(Y) \text{ is odd} \\ \text{trunc}(Y) & \text{if } \text{trunc}(Y) \text{ is even} \end{cases}.$$

Step 4: Rescale the integer from Step 3:

$$X_{round} = \pm\delta \cdot I$$

where X_{round} is the rounded variable. The sign of the rounded value is chosen to match that of the original value.

Step 5: Exit from this procedure.

Examples

A temperature of 5.34°C is rounded as:

$$Y = \frac{|5.34|}{0.05} = 106.8$$

$$I = \text{trunc}(106.8 + 0.5) = \text{trunc}(107.3) = 107$$

$$X_{round} = +0.05 \cdot 107 = +5.35$$

A temperature of -5.34°C is rounded as:

$$Y = \frac{|-5.34|}{0.05} = 106.8$$

$$I = \text{trunc}(106.8 + 0.5) = \text{trunc}(107.3) = 107$$

$$X_{round} = -0.05 \cdot 107 = -5.35$$

A temperature of 10.05°F should be rounded as follows:

$$Y = \frac{|10.05|}{0.1} = 100.5$$

$$I = \text{trunc}(100.5) = 100 \quad \text{(rounding towards the even integer)}$$

$$X_{round} = +0.1 \cdot 100 = 10.0$$

11.1.5.5 Other Implementation Considerations

- ~~CTPL should be substituted for CTL × CPL, where a standard specifies a serial multiplication of correction factors.~~
- Where a calculation within an existing standard makes use of a CTL factor alone, an equivalent value CTPL is calculated with observed gauge pressure set to zero.
- The discrimination rules for the input parameters should comply with the appropriate Standard (Chapters 12.1 and 12.2) prior to implementation of API *MPMS* Chapter 11.1. Verification data has been completed up to eight decimal places. ~~In this document, the final VCF (CTPL) is rounded to five decimal places. Different rounding precisions may be used to accommodate other standards, however they should not exceed eight decimal places.~~

11.1.6 Implementation Procedures for Customary Units (60°F and 0 psig Base Conditions)

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

Note: For liquids with an equilibrium vapor pressure greater than atmospheric, see 11.1.3.4.

Outline of Calculations

This procedure calculates the Volume Correction Factor (VCF) for correcting from the density at the base conditions (60°F and 0 psig) to alternate temperature and pressure conditions. The parameters used in this procedure depend upon the commodity group to which the liquid belongs. This calculation is done as a two-part process:

1. A thermal correction is applied to the liquid to account for the change from the base temperature (60°F) to the alternate temperature at a constant base pressure.

2. A pressure correction is applied to the liquid to account for the change from the base pressure (0 psig) to the alternate pressure at the alternate temperature.

The procedure has the flexibility of accepting a pre-calculated 60°F thermal expansion factor or calculating one based upon the commodity type of the liquid.

The calculation routine is depicted in Figure 11.1.6.1.A.

The procedure has been written assuming that the input values are all in the proper units (°F, psig, and kg/m³). If they are not in the proper units then apply the procedures in 11.1.5.1 before entering this procedure. The density values calculated by this procedure are in the units of kg/m³. If these units do not match the original input units, then the output densities should be converted to that of the original input value's units using the procedures in 11.1.5.1.

Input Values

Commodity group describing liquid (if α_{60} not input)

α_{60} Pre-calculated 60°F thermal expansion factor (if commodity group not given) (°F^{-1})

ρ_{60} Density at base conditions (60°F and 0 psig) (kg/m³)

t Alternate temperature (°F)

P Alternate pressure (psig)

Optional Input Values

$V_{t,P}$ Volume at alternate conditions (t and P) (any valid set of units, such as barrels, liters, and cubic metres)

Output Values

C_{TL} Volume correction factor due to temperature

C_{PL} Volume correction factor due to pressure

F_P Scaled compressibility factor (psi^{-1})

C_{TPL} Combined volume correction factor due to temperature and pressure

Optional Output Values

ρ Density at alternate conditions (kg/m³)

V_{60} Volume at base conditions (60°F and 0 psig) (same units as $V_{t,P}$)

Intermediate Values

δ_{60} Temperature shift value (a constant, 0.01374979547°F)

t^* Alternate temperature shifted to IPTS-68 basis (°F)

ρ^* Base density shifted to IPTS-68 60°F basis (kg/m³)

Δt Alternate temperature minus the base temperature of 60°F (°F)

α_{60} Thermal expansion factor at 60°F (°F^{-1}) (if not input)

K_0 Coefficient in correlation for α_{60} (kg^2/m^6 °F)

K_1 Coefficient in correlation for α_{60} (kg/m^3 °F)

K_2 Coefficient in correlation for α_{60} (°F^{-1})

A, B Variables used in calculation of ρ^*.

Calculation Procedure

Step1: Unless otherwise directed, check the input values to determine if they are in the range of this Standard. The following are the valid limits.

$$-58.0°\text{F} \le t \le 302.0°\text{F}$$

$$0 \le P \le 1500 \text{ psig}$$

$$\rho_{60,\min} \le \rho_{60} \le \rho_{60,\max} \quad \text{(if commodity type is specified)}$$

$$230.0 \times 10^{-6} \ °\text{F}^{-1} \le \alpha_{60} \le 930.0 \times 10^{-6} \ °\text{F}^{-1} \quad (\text{if } \alpha_{60}\text{, not commodity type, is specified})$$

The following table gives the ρ_{60} limits for the various commodity groups. This check does not have to be done if α_{60}, not the commodity group, is specified.

Commodity Type	$\rho_{60,\min}$	$\rho_{60,\max}$
Crude Oil	610.6 kg/m³	1163.5 kg/m³
Refined Products		
Lubricating Oil	800.9 kg/m³	

If $P < 0$ psig then set $P = 0$ psig and continue with the procedure.

If any of the other conditions are not true then one or more of the input variables is out of range. Set an error condition (such as setting all output values to zero) and exit procedure.

Step 2: Shift the input temperature t to the IPTS-68 basis t^* following the procedure in 11.1.5.3.

Step 3: Shift the input ρ_{60} value to the IPTS-68 basis ρ^*. If a pre-calculated α_{60} value has been input, use:

$$\rho^* = \rho_{60} \cdot \exp[0.5\alpha_{60}\delta_{60}(1 + 0.4\alpha_{60}\delta_{60})]$$

If the commodity group has been specified, then compute the ρ^* value using:

$$\rho^* = \rho_{60}\left\{1 + \frac{\exp\left[A(1+0.8A)\right]-1}{1 + A(1+1.6A)B}\right\}$$

where:

$$A = \frac{\delta_{60}}{2}\left[\left(\frac{K_0}{\rho_{60}} + K_1\right)\frac{1}{\rho_{60}} + K_2\right]$$

$$B = \frac{2K_0 + K_1\rho_{60}}{K_0 + (K_1 + K_2\rho_{60})\rho_{60}}\ .$$

The K_i coefficients used in these equations depend upon the commodity group. The following table gives the coefficients to be used.

		Density Range(kg/m³)	K_0	K_1	K_2
Crude Oil		$610.6 \le \rho_{60} < 1163.5$	341.0957	0.0	0.0
Products	Fuel Oils	$838.3127 \le \rho_{60} \le 1163.5$	103.8720	0.2701	0.0
	Jet Fuels	$787.5195 \le \rho_{60} < 838.3127$	330.3010	0.0	0.0
	Transition Zone	$770.3520 \le \rho_{60} < 787.5195$	1489.0670	0.0	-0.00186840
	Gasolines	$610.6 \le \rho_{60} < 770.3520$	192.4571	0.2438	0.0
Lubricating Oil		$800.9 \le \rho_{60} < 1163.5$	0.0	0.34878	0.0

Step 4: In preparation of calculating the correction factor due to temperature, C_{TL}, determine the coefficient of thermal expansion at the base temperature of 60°F, α_{60}. If a pre-calculated α_{60} value has been input, proceed to Step 5.

If the commodity group has been specified, then compute the α_{60} value using:

$$\alpha_{60} = \left(\frac{K_0}{\rho^*} + K_1 \right) \frac{1}{\rho^*} + K_2$$

The coefficients used in this equation depend upon the commodity group. Use the same coefficients that were used in Step 3.

Step 5: Calculate the difference between the alternate temperature and the base temperature as:

$$\Delta t = t^* - 60.0068749 \; .$$

Use this value to calculate the correction factor due to temperature, C_{TL} :

$$C_{TL} = \exp\left\{ -\alpha_{60} \Delta t \left[1 + 0.8 \alpha_{60} \left(\Delta t + \delta_{60} \right) \right] \right\} \quad \text{where} \quad \delta_{60} = 0.01374979547 \; .$$

Step 6: Calculate the scaled compressibility factor F_P . Use the equation:

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

Step 7: Calculate the correction factor due to pressure, C_{PL} . Use the equation:

$$C_{PL} = \frac{1}{1 - 10^{-5} \cdot F_P \cdot P} \; .$$

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

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

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

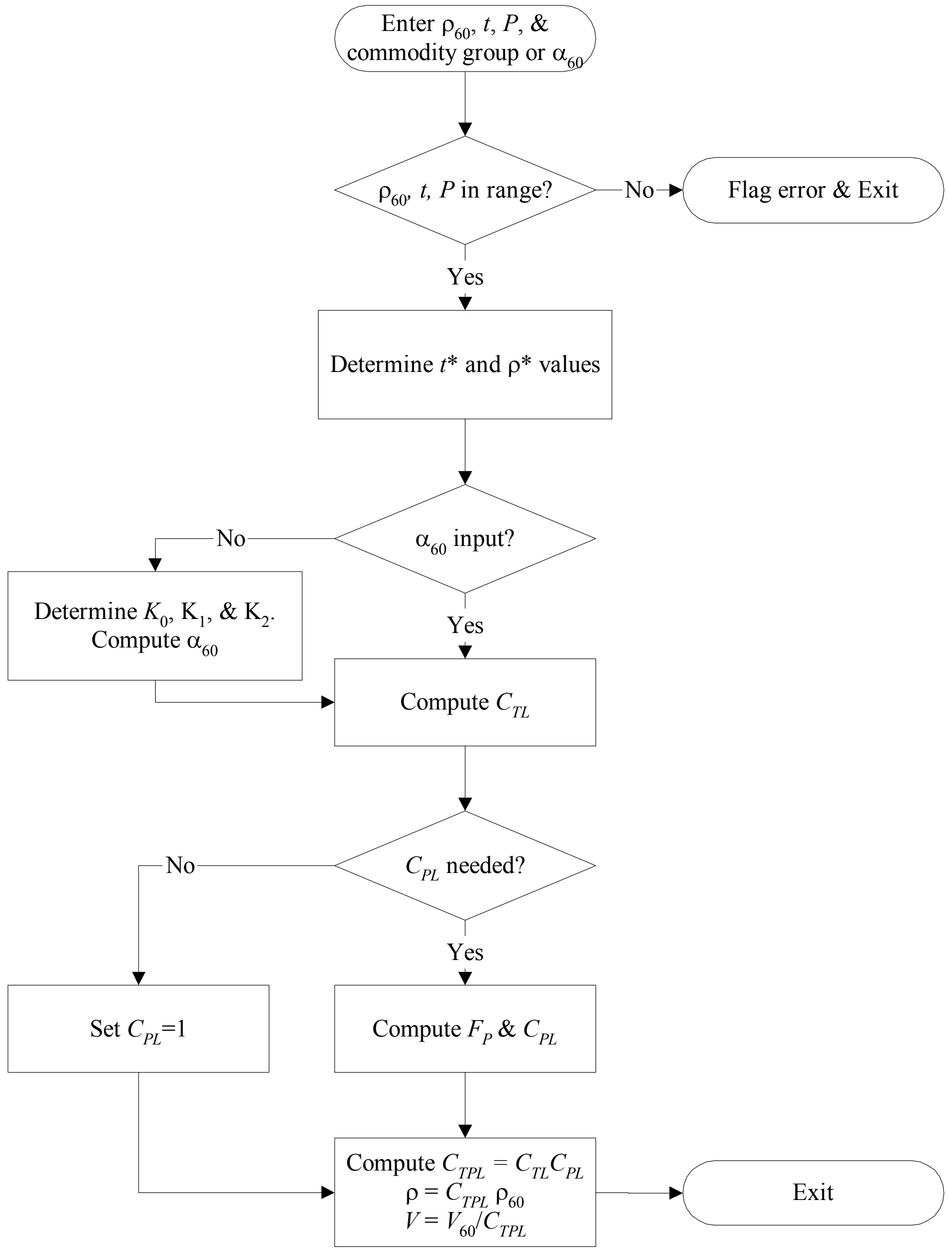
Step 9: Optionally, correct a volume measured at alternate condtions to base conditions and/or correct base density to alternate conditions.:

$$\rho = C_{TL} \cdot C_{PL} \cdot \rho_{60} \; .$$

$$. V_{60} = V_{t,P} * C_{TPL}$$

Step 10: Exit from this procedure.

Figure 11.1.6.1.A Flow Chart Of Procedure Correcting Volume and Density to an Alternate Temperature and Pressure from Base Conditions



Example Calculations

```
        API MPMS 11.1.6.1 Customary Units, Example 1
A volume of a crude oil is measured at observed conditions of temperature and pressure.  The base API is
known.  Calculate the volume at base conditions and correct the base density to an alternate condition.

    Input Data
Commodity .....................   Generalized Crude Oil
t alternate temperature, °F ....   -27.7
P alternate pressure, PSI ......       0
Base API gravity ..............  17.785
Volume at alternate t & P ......  987.99

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  946.918739324112

    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*) ....  -27.712499233089

    Step 3 - Shift Rho60 to IPTS-68 temperature scale
K0 ............................  341.095700000000
K1 ............................    0.000000000000
K2 ............................    0.000000000000
A .............................    0.000002615273
B .............................    2.000000000000
Rho60* ........................  946.921215770785

    Step 4 - Determine coefficient of thermal expansion
Alpha60 .......................    0.000380407044

    Step 5 - Calculate temperature correction factor Ctl
delta t .......................  -87.719374133089
Ctl ...........................    1.033011591958

    Step 6 - Calculate scaled compressibility factor Fp
Fp for psi ....................    0.305779891997

    Step 7 - Calculate pressure correction factor Cpl
Cpl ...........................    1.000000000000

    Step 8 - Calculate the Volume Correction Factor Ctpl
Ctpl ..........................    1.033011591958
Ctpl, rounded .................    1.03301

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

```
         API MPMS 11.1.6.1 Customary Units, Example 2
A volume of a crude oil is measured at observed conditions of temperature and pressure.  The base API is
known.  Calculate the volume at base conditions and correct the base density to an alternate condition.

    Input Data
Commodity .....................   Generalized Crude Oil
t alternate temperature, °F ....  301.93
P alternate pressure, PSI ......    1500
Base API gravity ...............     -10
Volume at alternate t & P ......   285.5

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) .... 1163.463078189300

    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*) ....  301.993163042978

    Step 3 - Shift Rho60 to IPTS-68 temperature scale
K0 ............................  341.095700000000
K1 ............................    0.000000000000
K2 ............................    0.000000000000
A .............................    0.000001732357
B .............................    2.000000000000
Rho60* ........................    1.16346509372e+03

    Step 4 - Determine coefficient of thermal expansion
Alpha60 .......................    0.000251982006

    Step 5 - Calculate temperature correction factor Ctl
delta t .......................  241.986288142978
Ctl ...........................    0.938051116886

    Step 6 - Calculate scaled compressibility factor Fp
Fp for psi ....................    0.427958509999

    Step 7 - Calculate pressure correction factor Cpl
Cpl ...........................    1.006460852301

    Step 8 - Calculate the Volume Correction Factor Ctpl
Ctpl ..........................    0.944111726603
Ctpl, rounded .................    0.94411

    Step 9 - Calculate volume at base conditions
             and density at alternate conditions
Volume at base conditions ......        269.543405
Density at t & P, kg/cu m ......   1098.4391355882
°API at t & P .................     -2.8076041994
```

```
         API MPMS 11.1.6.1 Customary Units, Example 3
A volume of a refined product is measured at observed conditions of temperature and pressure.  The base
API 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 ....  48.04
P alternate pressure, PSI ......   -7.3
  Forcing negative pressure to zero
Base API gravity ..............    19.4
Volume at alternate t & P ......  12002

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  936.784387011266

    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*) ....   48.043878159606

    Step 3 - Shift Rho60 to IPTS-68 temperature scale
  Using fuel oil coefficients:
K0 ............................  103.872000000000
K1 ............................    0.270100000000
K2 ............................    0.000000000000
A .............................    0.000002795957
B .............................    1.291041575770
Rho60* ........................  936.787006219757

    Step 4 - Determine coefficient of thermal expansion
Alpha60 .......................    0.000406689168

    Step 5 - Calculate temperature correction factor Ctl
delta t .......................  -11.962996740394
Ctl ...........................    1.004858068990

    Step 6 - Calculate scaled compressibility factor Fp
Fp for psi ....................    0.384339609206

    Step 7 - Calculate pressure correction factor Cpl
Cpl ...........................    1.000000000000

    Step 8 - Calculate the Volume Correction Factor Ctpl
Ctpl ..........................    1.004858068990
Ctpl, rounded .................    1.00486

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

```
         API MPMS 11.1.6.1 Customary Units, Example 4
A volume of a refined product is measured at observed conditions of temperature and pressure.  The base
relative density 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 ....      85
P alternate pressure, PSI ......   247.3
Base relative density ..........  0.7943
Volume at alternate t & P ......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  793.518408800000

    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*) ....   85.013358222928

    Step 3 - Shift Rho60 to IPTS-68 temperature scale
  Using jet fuel coefficients:
K0 ............................  330.301000000000
K1 ............................    0.000000000000
K2 ............................    0.000000000000
A .............................    0.000003606302
B .............................    2.000000000000
Rho60* ........................  793.521270459968

    Step 4 - Determine coefficient of thermal expansion
Alpha60 .......................    0.000524557068

    Step 5 - Calculate temperature correction factor Ctl
delta t .......................   25.006483322928
Ctl ...........................    0.986832406683

    Step 6 - Calculate scaled compressibility factor Fp
Fp for psi ....................    0.664706197066

    Step 7 - Calculate pressure correction factor Cpl
Cpl ...........................    1.001646525013

    Step 8 - Calculate the Volume Correction Factor Ctpl
Ctpl ..........................    0.988457250925
Ctpl, rounded .................    0.98846

    Step 9 - Calculate volume at base conditions
             and density at alternate conditions
Volume at base conditions ......            988.46
Density at t & P, kg/cu m ......   784.3590249208
Relative density at t & P ......    0.785131594410
```

```
         API MPMS 11.1.6.1 Customary Units, Example 5
A volume of a refined product is measured at observed conditions of temperature and pressure.  The base
API 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 ....    55.9
P alternate pressure, PSI ......     350
Base API gravity ...............  48.0015
Volume at alternate t & P ......   10000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  787.518566697214

    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*) ....   55.905838569594

    Step 3 - Shift Rho60 to IPTS-68 temperature scale
  Using transition zone coefficients:
K0 ............................    1.48906700000e+03
K1 ............................    0.000000000000
K2 ............................   -0.001868400000
A .............................    0.000003661589
B .............................    9.016112546440
Rho60* ........................  787.521450184768

    Step 4 - Determine coefficient of thermal expansion
Alpha60 .......................    0.000532585048

    Step 5 - Calculate temperature correction factor Ctl
delta t .......................   -4.101036330406
Ctl ...........................    1.002182725702

    Step 6 - Calculate scaled compressibility factor Fp
Fp for psi ....................    0.608111538634

    Step 7 - Calculate pressure correction factor Cpl
Cpl ...........................    1.002132930093

    Step 8 - Calculate the Volume Correction Factor Ctpl
Ctpl ..........................    1.004320311396
Ctpl, rounded .................    1.00432

    Step 9 - Calculate volume at base conditions
             and density at alternate conditions
Volume at base conditions ......          10043.2
Density at t & P, kg/cu m ......    790.9208921357
°API at t & P .................     47.2293336231
```

```
         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
kg/m³ 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 ......  1234.5
Base density, kg/cu m ..........   657.3
Volume at alternate t & P ......   14.72

    Computed Data - last digit is rounded for display purposes

    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 Rho60 to IPTS-68 temperature scale
  Using gasoline coefficients:
K0 ............................  192.457100000000
K1 ............................    0.243800000000
K2 ............................    0.000000000000
A .............................    0.000005612455
B .............................    1.545657407721
Rho60* ........................  657.303689061482

    Step 4 - Determine coefficient of thermal expansion
Alpha60 .......................    0.000816362130

    Step 5 - Calculate temperature correction factor Ctl
delta t .......................  -32.707976283241
Ctl ...........................    1.026475833518

    Step 6 - Calculate scaled compressibility factor Fp
Fp for psi ....................    0.993527440282

    Step 7 - Calculate pressure correction factor Cpl
Cpl ..........................    1.012417396817

    Step 8 - Calculate the Volume Correction Factor Ctpl
Ctpl ..........................    1.039221991267
Ctpl, rounded .................    1.03922

    Step 9 - Calculate volume at base conditions
             and density at alternate conditions
Volume at base conditions ......        15.2973184
Density at t & P, kg/cu m ......    683.0806148596
```

```
         API MPMS 11.1.6.1 Customary Units, Example 7
A volume of a specialized liquid is measured at observed conditions of temperature and pressure.  The
base relative density 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 °F ...........   0.000732185
t alternate temperature, °F ....   97.7
P alternate pressure, PSI ......  287.4
Base relative density .......... 1.0537
Volume at alternate t & P ...... 203.85

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) .... 1052.663159200000

    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*) ....   97.716729951690

    Step 3 - Shift Rho60 to IPTS-68 temperature scale

    Step 4 - Determine coefficient of thermal expansion
Using user Alpha ...............    0.000732185000

    Step 5 - Calculate temperature correction factor Ctl
delta t ........................   37.709855051690
Ctl ............................    0.972173795696

    Step 6 - Calculate scaled compressibility factor Fp
Fp for psi .....................    0.346454796729

    Step 7 - Calculate pressure correction factor Cpl
Cpl ............................    1.000996703515

    Step 8 - Calculate the Volume Correction Factor Ctpl
Ctpl ...........................    0.973142764735
Ctpl, rounded ..................    0.97314

    Step 9 - Calculate volume at base conditions
             and density at alternate conditions
Volume at base conditions ......        198.374589
Density at t & P, kg/cu m ......   1024.3915370787
Relative density at t & P ......    1.025400531201
```

```
         API MPMS 11.1.6.1 Customary Units, Example 8
A volume of a lube oil is measured at observed conditions of temperature and pressure.  The base API is
known.  Calculate the volume at base conditions and correct the base density to an alternate condition.

    Input Data
Commodity .....................   Generalized Lube Oil
t alternate temperature, °F ....   129.3
P alternate pressure, PSI ......   138.8
Base API gravity ...............    42.9
Volume at alternate t & P ......   99.98

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  810.554839449541

    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*) ....  129.325201088023

    Step 3 - Shift Rho60 to IPTS-68 temperature scale
K0 ............................    0.000000000000
K1 ............................    0.348780000000
K2 ............................    0.000000000000
A .............................    0.000002958254
B .............................    1.000000000000
Rho60* ........................  810.557237278501

    Step 4 - Determine coefficient of thermal expansion
Alpha60 .......................    0.000430296571

    Step 5 - Calculate temperature correction factor Ctl
delta t .......................   69.318326188023
Ctl ...........................    0.969922293864

    Step 6 - Calculate scaled compressibility factor Fp
Fp for psi ....................    0.732650236105

    Step 7 - Calculate pressure correction factor Cpl
Cpl ...........................    1.001017953704

    Step 8 - Calculate the Volume Correction Factor Ctpl
Ctpl ..........................    0.970909629855
Ctpl, rounded .................    0.97091

    Step 9 - Calculate volume at base conditions
             and density at alternate conditions
Volume at base conditions ......        97.0715818
Density at t & P, kg/cu m ......    786.9754991473
°API at t & P .................     48.1253684558
```

```
        API MPMS 11.1.6.1 Customary Units, Example 9
A volume of a crude oil is measured at observed conditions of temperature and pressure.  The base API is
known.  Calculate the volume at base conditions and correct the base density to an alternate condition.

    Input Data
Commodity .....................   Generalized Crude Oil
t alternate temperature, °F ....  -58.05
P alternate pressure, PSI ......       0
Base API gravity ..............      100
Volume at alternate t & P ......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  610.629650107991

    Step 1 - Check input values for range excursion
Temperature less than -50°C (-58°F) - outside limits of table


        API MPMS 11.1.6.1 Customary Units, Example 10
A volume of a crude oil is measured at observed conditions of temperature and pressure.  The base API is
known.  Calculate the volume at base conditions and correct the base density to an alternate condition.

    Input Data
Commodity .....................   Generalized Crude Oil
t alternate temperature, °F ....  302.05
P alternate pressure, PSI ......       0
Base API gravity ..............      100
Volume at alternate t & P ......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  610.629650107991

    Step 1 - Check input values for range excursion
Temperature greater than 150°C (302°F) - outside limits of table


        API MPMS 11.1.6.1 Customary Units, Example 11
A volume of a crude oil is measured at observed conditions of temperature and pressure.  The base API is
known.  Calculate the volume at base conditions and correct the base density to an alternate condition.

    Input Data
Commodity .....................   Generalized Crude Oil
t alternate temperature, °F ....      92
P alternate pressure, PSI ......    1501
Base API gravity ..............      100
Volume at alternate t & P ......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  610.629650107991

    Step 1 - Check input values for range excursion
Pressure greater than 1500 psi - outside limits of table
```

```
        API MPMS 11.1.6.1 Customary Units, Example 12
A volume of a crude oil is measured at observed conditions of temperature and pressure.  The base API is
known.  Calculate the volume at base conditions and correct the base density to an alternate condition.

    Input Data
Commodity .....................  Generalized Crude Oil
t alternate temperature, °F ....      72
P alternate pressure, PSI ......       0
Base API gravity ..............  100.06
Volume at alternate t & P ......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  610.471428571429

    Step 1 - Check input values for range excursion
Density less than 610.6 kg/cu m - outside limits of table


        API MPMS 11.1.6.1 Customary Units, Example 13
A volume of a refined product is measured at observed conditions of temperature and pressure.  The base
API 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 ....     302
P alternate pressure, PSI ......       0
Base API gravity ..............  -10.08
Volume at alternate t & P ......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) .... 1164.229649151705

    Step 1 - Check input values for range excursion
Density greater than 1163.5 kg/cu m - outside limits of table


        API MPMS 11.1.6.1 Customary Units, Example 14
A volume of a lube oil is measured at observed conditions of temperature and pressure.  The base API is
known.  Calculate the volume at base conditions and correct the base density to an alternate condition.

    Input Data
Commodity .....................  Generalized Lube Oil
t alternate temperature, °F ....       0
P alternate pressure, PSI ......       0
Base API gravity ..............   45.08
Volume at alternate t & P ......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  800.547989579794

    Step 1 - Check input values for range excursion
Density less than 800.9 kg/cu m - outside limits of table
```

```
        API MPMS 11.1.6.1 Customary Units, Example 15
A volume of a crude oil is measured at observed conditions of temperature and pressure.  The base API is
known.  Calculate the volume at base conditions and correct the base density to an alternate condition.

    Input Data
Commodity .....................   Generalized Crude Oil
t alternate temperature, °F ....     200
P alternate pressure, PSI ......       0
Base API gravity ...............     100
Volume at alternate t & P ......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter (Rho60) ....  610.629650107991

    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*) ....  200.043348977974

    Step 3 - Shift Rho60 to IPTS-68 temperature scale
K0 ............................  341.095700000000
K1 ............................    0.000000000000
K2 ............................    0.000000000000
A .............................    0.000006289074
B .............................    2.000000000000
Rho60* ........................  610.633490386188

    Step 4 - Determine coefficient of thermal expansion
Alpha60 .......................    0.000914776512

    Step 5 - Calculate temperature correction factor Ctl
delta t .......................  140.036474077974
Ctl ...........................    0.868288296907

    Step 6 - Calculate scaled compressibility factor Fp
Fp for psi ....................    4.092820997603

    Step 7 - Calculate pressure correction factor Cpl
Cpl ...........................    1.000000000000

    Step 8 - Calculate the Volume Correction Factor Ctpl
Ctpl ..........................    0.868288296907
Ctpl, rounded .................    0.86829

    Step 9 - Calculate volume at base conditions
             and density at alternate conditions
Volume at base conditions ......           868.29
Density at t & P, kg/cu m ......    530.2025789330
°API at t & P .................    135.116515303
```

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

Note: For liquids with an equilibrium vapor pressure greater than atmospheric, see 11.1.3.4.

Outline of Calculations

This procedure calculates the density at the base conditions (60°F and 0 psig) that is consistent with an observed density at its temperature and pressure condition. The procedure has the flexibility of accepting a pre-calculated 60°F thermal expansion factor or calculating one based upon the commodity type of the liquid.

The equations for the temperature and pressure correction factors are direct functions of the base density. In this procedure, however, this base density is unknown. So, the base density must be calculated using iteration. This basic procedure is:

1) Estimate a value for the 60°F density.

2) Calculate the observed density via the procedure outlined in 11.1.6.1.

3) Compare this result with the given observed density.

4) If the calculated observed density is acceptably close to the given observed density, then the iterations are complete.

5) If the calculated and given observed densities are not acceptably close, then the value for the 60°F density is changed and we repeat the process, starting at step 2.

This final iterative value of the 60°F density is the desired output from this procedure.

A Newton's method of iteration procedure is outlined here. The Newton's method is a specific way to determine how the value for the 60°F density is changed in step 5 above. However, this method need not be used to comply with the implementation procedure. Other initial guesses or iterative solution techniques could be used and still be deemed compliant with this Standard provided the process is continued until the calculated and given observed densities are acceptably close— this criterion is Step 4 of this procedure. See 11.1.3.4 and Appendix F for further discussions about this iteration scheme.

Note that when using the Generalized Refined Products group (the B Tables), the sub-group may change depending upon the iterative value of the base density, ρ_{60}. This sub-group switching is automatically performed as part of this iteration procedure. Other iterative procedures may not be able to do this.

The calculation steps are depicted in Figure 11.1.6.2.A.

The procedure has been written assuming that the input values are all in the proper units (°F, psig, and kg/m³). If they are not in the proper units then apply the procedures in 11.1.5.1 before entering this procedure. The density values calculated by this procedure are in the units of kg/m³. If these units do not match the original input units, then the output densities should be converted to that of the original input value's units using the procedures in 11.1.5.1.

Input Values

Commodity group describing liquid (if α_{60} not input)

α_{60} Pre-calculated 60°F thermal expansion factor (if commodity group not given)

ρ_o Observed density (kg/m³)

t_o Temperature at which the observed density was measured (°F)

P_o Pressure at which the observed density was measured (psig)

Optional Input Values

V_o Volume at observed conditions (any valid set of units, such as barrels, liters, and cubic metres)

Output Values

ρ_{60} Density at base conditions (60°F and 0 psig) (kg/m³)

C_{TL} Volume correction factor due to temperature

C_{PL} Volume correction factor due to pressure

F_P Scaled compressibility factor (psi^{-1})

C_{TPL} Combined volume correction factor due to temperature and pressure

Optional Output Values

V_{60} Volume at base conditions (60°F and 0 psig) (same set of units as V)

Intermediate Values

$\rho_{60}^{(m)}$ Value of ρ_{60} on the m-th iteration

$\rho_{60,\max}$ Maximum value allowed for ρ_{60} on any iteration

$\rho_{60,\min}$ Minimum value allowed for ρ_{60} on any iteration

$C_{TL}^{(m)}$ Volume correction factor due to temperature on the m-th iteration

$C_{PL}^{(m)}$ Volume correction factor due to pressure on the m-th iteration

$C_{TPL}^{(m)}$ Value of the combined VCF due to temperature and pressure on the m-th iteration

$F_P^{(m)}$ Scaled compressibility factor on the m-th iteration (psi^{-1})

Δt Temperature difference from the base temperature of 60°F (°F)

$\delta\rho_o^{(m)}$ Deviation between the value of the observed density ρ_o and the estimate of ρ_{60} on the m-th iteration

$\Delta\rho_{60}^{(m)}$ Change applied to the value of $\rho_{60}^{(m)}$ on the m-th iteration to get the value on the next iteration (kg/m³)

$D_\alpha^{(m)}$ Coefficient needed to perform iteration on ρ_{60}

$D_T^{(m)}$ Correction factor due to temperature used in iterative procedure

$D_P^{(m)}$ Correction factor due to pressure used in iterative procedure

$E^{(m)}$ Correction factor due to density used in iterative procedure

Calculation Procedure

Step1: Check the input values to determine if they are in the range of this Standard. The following are the valid limits:

$$-58.0°\text{F} \le t_o \le 302.0°\text{F}$$

$$0 \le P_o \le 1500 \text{ psig}$$

$$\rho_{\min} \le \rho_o \le \rho_{\max} \quad \text{(if commodity type is specified)}$$

$$230.0 \times 10^{-6} \ °\text{F}^{-1} \le \alpha_{60} \le 930.0 \times 10^{-6} \ °\text{F}^{-1} \quad \text{(if } \alpha_{60}\text{, not commodity type, is specified)}$$

The following table gives the largest possible ρ_o limits for the various commodity groups. This check does not have to be done if α_{60}, not the commodity group, is specified. Note that even if a ρ_o value is within these limits it may still not correspond to a valid ρ_{60} value.

Commodity Type	$\rho_{\min}$	$\rho_{\max}$
Crude Oil	470.5 kg/m³	1201.8 kg/m³
Refined Products	470.4 kg/m³	1209.5 kg/m³
Lubricating Oil	714.3 kg/m³	1208.3 kg/m³

If $P_o < 0$ psig then set $P_o = 0$ psig and continue with the procedure.

If any of the input variables are out of range set an error condition (such as setting all output values to zero) and exit procedure.

Step 2: Use the observed density ρ_o as the initial guess for the density at base conditions, $\rho_{60}^{(0)}$

$$\rho_{60}^{(0)} = \rho_o .$$

Limit this initial guess to remain in the range of this Standard. Set:

$$\rho_{60}^{(0)} = \begin{cases} \rho_{60,\min} & \text{if } \rho_o < \rho_{60,\min} \\ \rho_{60,\max} & \text{if } \rho_o > \rho_{60,\max} \end{cases} .$$

The following table gives the ρ_{60} limits for the various commodity groups. This check does not have to be done if α_{60}, not the commodity group, is specified.

<table>
<tr><th>Commodity Type</th><th>$\rho_{60,\min}$</th><th>$\rho_{60,\max}$</th></tr>
<tr><td>Crude Oil</td><td rowspan="2">610.6 kg/m³</td><td rowspan="3">1163.5 kg/m³</td></tr>
<tr><td>Refined Products</td></tr>
<tr><td>Lubricating Oil</td><td>800.9 kg/m³</td></tr>
</table>

Consider the iteration counter to be set at $m = 0$ and start the iterative procedure.

Step 3: Following the procedure in 11.1.6.1, calculate the correction factor due to temperature and pressure, $C_{TPL}^{(m)}$, using the current guess for the density at base conditions, $\rho_{60}^{(m)}$. Do not check the input values for being in the proper range. Do not round the value of $C_{TPL}^{(m)}$. Retain the value of α_{60} as $\alpha_{60}^{(m)}$.

Step 4: Determine if the result of this current estimate for the density at base conditions and the corresponding CTPL reproduces the observed density. If it does then the calculation has converged and the iterations should halt. The estimate is considered as "good enough" if:

$$\left|\delta\rho_o^{(m)}\right| < 0.000001 \text{ kg / m}^3 \quad \text{where} \quad \delta\rho_o^{(m)} \equiv \rho_o - \rho_{60}^{(m)} \cdot C_{TPL}^{(m)} .$$

If this condition is true, go to Step 7.

Step 5: Revise the estimate for the density at base conditions. The general recursion equation is:

$$\rho_{60}^{(m+1)} = \rho_{60}^{(m)} + \Delta\rho_{60}^{(m)} .$$

Newton's iteration method to determine $\Delta\rho_{60}^{(m)}$ is:

$$\Delta\rho_{60}^{(m)} = \frac{E^{(m)}}{1 + D_T^{(m)} + D_P^{(m)}} .$$

where:

$$E^{(m)} = \frac{\rho_o}{C_{TL}^{(m)} C_{PL}^{(m)}} - \rho_{60}^{(m)}$$

$$D_T^{(m)} = D_\alpha^{(m)} \cdot \alpha_{60}^{(m)} \Delta t \left(1 + 1.6\alpha_{60}^{(m)} \Delta t\right) \quad \text{and} \quad \Delta t \equiv t_o - 60$$

$$D_P^{(m)} = -\frac{2C_{PL}^{(m)} P_o F_P^{(m)} \left(7.93920 + 0.02326 t_o\right)}{\rho_{60}^{(m)2}} .$$

The $D_\alpha^{(m)}$ values depend upon the commodity group and are obtained from the following table. If the α_{60} value has been specified as an input value, then $D_\alpha^{(m)} = 0$ (meaning that $D_T^{(m)} = 0$). Note that when dealing with Generalized Refined Products the sub-group could change during the course of the iterations (depending on the current $\rho_{60}^{(m)}$ value) resulting in different $D_\alpha^{(m)}$ values from one iteration to the next.

Commodity Groups (Table)		Density Range(kg/m³)	D_α
Crude Oil (A)		$610.6 \le \rho_{60} < 1163.5$	2.0
Refined Products (B)	Fuel Oils	$838.3127 \le \rho_{60} \le 1163.5$	1.3
	Jet Fuels	$787.5195 \le \rho_{60} < 838.3127$	2.0
	Transition Zone	$770.3520 \le \rho_{60} < 787.5195$	8.5
	Gasolines	$610.6 \le \rho_{60} < 770.3520$	1.5
Lubricating Oil (D)		$800.9 \le \rho_{60} < 1163.5$	1.0
Special Applications (C)		All ρ_{60} values	0.0

There are cases where the Newton's method $\Delta\rho_{60}^{(m)}$ value should not be directly used:

- If the Newton's method gives a value outside of the valid range for this Standard, constrain the $\Delta\rho_{60}^{(m)}$ value to go only to the boundary:

$$\text{If } \rho_{60}^{(m)} + \Delta\rho_{60}^{(m)} < \rho_{60,\min} \text{ then reset } \Delta\rho_{60}^{(m)} = \rho_{60,\min} - \rho_{60}^{(m)}.$$

$$\text{If } \rho_{60}^{(m)} + \Delta\rho_{60}^{(m)} > \rho_{60,\max} \text{ then reset } \Delta\rho_{60}^{(m)} = \rho_{60,\max} - \rho_{60}^{(m)}.$$

Step 6: Increment the iteration counter to $m+1$. If this value for the iteration counter is less than or equal to 15 continue the iterative procedure with Step 3. Otherwise set an error condition for non-convergence (such as setting all output values to zero) and exit procedure.

(Note: If the commodity class is Refined Products with a density near the boundary of a product group, there may be rare instances where convergence may fail due to a mathematical anomaly. In these instances, the resulting density should be within acceptable tolerance after 15 iterations. The density from the last iteration may be used to calculate the CTPL and the result should be flagged with a note that it did not converge.. This resulting CTPL should be within acceptable tolerance.)

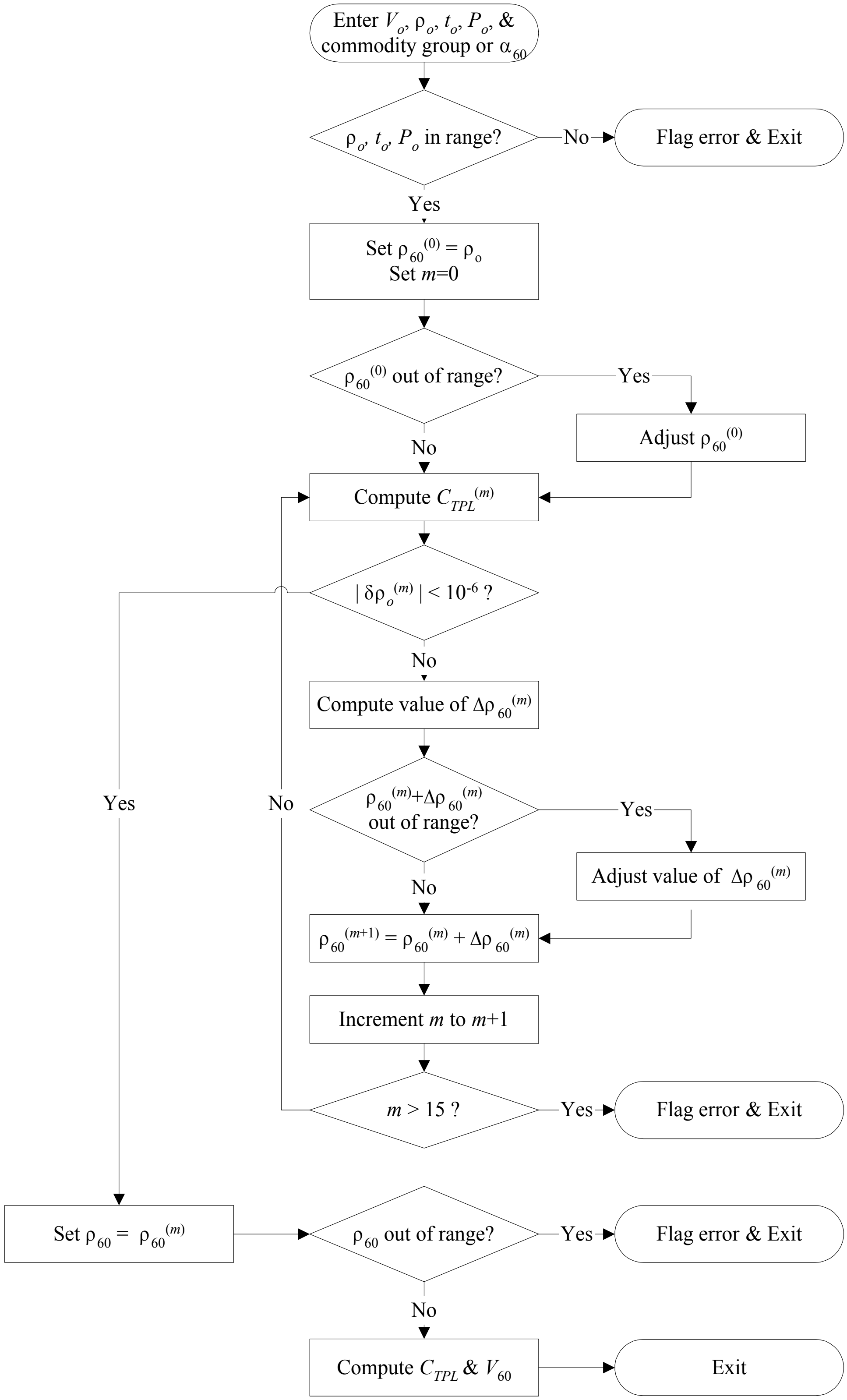
Step 7: After the convergence criterion in Step 4 is met, set the value of ρ_{60} to the last $\rho_{60}^{(m)}$ value and set the value of C_{TPL} to the last $C_{TPL}^{(m)}$ value. Check this ρ_{60} value to determine if it is in the range of this Standard. If $\rho_{60} < \rho_{60,\min}$ or $\rho_{60} > \rho_{60,\max}$ then this ρ_{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.

Step 8: If volume V_o has been input and the temperature and pressure for the density are the same as those for V_o, the volume at base conditions is calculated:

$$V_{60} = V_o \cdot C_{TPL}.$$

Step 9: Exit from this procedure.

Figure 11.1.6.2.A Flow Chart Of Procedure For Correcting Volume and Density from Observed Conditions to Base Conditions



Example Calculations

```
                   Example 1
    Input Data
Commodity .....................   Generalized Crude Oil
t observed temperature, °F .....          80.3
P observed pressure, PSI .......            -5
  Forcing negative pressure(s) to zero
Dens, kg/cu m, observed t & P ..         823.7
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

    Step 1
  All input data within range of procedure

    Step 2
Initial density, kg/cu m .......  823.700000000000

            Iteration(m) ..... 0                  1                  2
    Step 3
Rho60(m) ..........  823.700000000000   832.047700405069   832.048516184234
K0(m) .............  341.095700000000   341.095700000000   341.095700000000
K1(m) .............    0.000000000000     0.000000000000     0.000000000000
K2(m) .............    0.000000000000     0.000000000000     0.000000000000
A(m) ..............    0.000003456244     0.000003387241     0.000003387234
B(m) ..............    2.000000000000     2.000000000000     2.000000000000
Rho60*(m) .........  823.702846901034   832.050518744082   832.051334520484
alpha60(m) ........    0.000502730357     0.000492693523     0.000492692557
Ctl(m) ............    0.989761292256     0.989966291106     0.989966310837
d_alpha(m) ........    2.000000000000     2.000000000000     2.000000000000
Fp(m) .............    0.583649345323     0.567047025149     0.567045450015
Cpl(m) ............    1.000000000000     1.000000000000     1.000000000000
Ctpl(m) ...........    0.989761292256     0.989966291106     0.989966310837
Rho60(m)xCtpl(m) ...  815.266376431390   823.699175993020   823.700000004364

    Step 4
delta Rho60(m) .....    8.433623568610     0.000824006980    -0.000000004364

    Step 5
E(m) ..............    8.520866227639     0.000832358624
Dt(m) .............    0.020744134812     0.020323464473
Dp(m) .............   -0.000000000000    -0.000000000000
delta Rho(m) .......    8.347700405068     0.000815779165
Rho60(m+1) ........  832.047700405069   832.048516184234

    Step 6, iteration(m) ..... 1                  2

    Step 7
  Density at 60°F is within range of procedure
  Output values
Density at 60°F ................  832.048516184234
Ctl ............................    0.989966310837
Fp for psi .....................    0.567045450015
Cpl ............................    1.000000000000
Ctpl ...........................    0.989966310837
Ctpl, rounded ..................    0.98997

    Step 8
Volume at base conditions ......            989.97
```

```
                   Example 2
    Input Data
Commodity ....................   Generalized Crude Oil
t observed temperature, °F .....       -57.95
P observed pressure, PSI .......        113.5
Rel density, observed t & P ....      0.72332
Volume at observed t & P .......       637483

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ...........  722.608253120000

    Step 1
  All input data within range of procedure

    Step 2
Initial density, kg/cu m .......  722.608253120000

            Iteration(m) ..... 0                  1                   2                   3
    Step 3
Rho60(m) ..........  722.608253120000   663.810409807890   663.445091139654   663.445062852402
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) ..............    0.000004490934     0.000005321749     0.000005327611     0.000005327612
B(m) ..............    2.000000000000     2.000000000000     2.000000000000     2.000000000000
Rho60*(m) .........  722.611498295617   663.813942426971   663.448625703918   663.448597416816
alpha60(m) ........    0.000653230582     0.000774075826     0.000774928524     0.000774928590
Ctl(m) ............    1.074992616223     1.088336251578     1.088429734446     1.088429741690
d_alpha(m) ........    2.000000000000     2.000000000000     2.000000000000     2.000000000000
Fp(m) .............    0.476986337657     0.602443036118     0.603436463770     0.603436540820
Cpl(m) ............    1.000541672744     1.000684240711     1.000685369796     1.000685369884
Ctpl(m) ...........    1.075574910423     1.089080935549     1.089175711311     1.089175718656
Rho60(m)xCtpl(m) ...  777.219307120433   722.943262140502   722.608279058022   722.608253120858

    Step 4
delta Rho60(m) .....  -54.611054000433    -0.335009020502    -0.000025938022    -0.000000000858

    Step 5
E(m) ..............  -50.773826603075    -0.307607092887    -0.000023814360
Dt(m) .............   -0.135100362757    -0.155928968285    -0.156071317540
Dp(m) .............   -0.001367511863    -0.002047013691    -0.002052650200
delta Rho(m) .......  -58.797843312110    -0.365318668236    -0.000028287253
Rho60(m+1) ........  663.810409807890   663.445091139654   663.445062852402

    Step 6, iteration(m) ..... 1                  2                   3

    Step 7
  Density at 60°F is within range of procedure
  Output values
Density at 60°F ...............  663.445062852402
Relative density ..............    0.664098535812
Ctl ...........................    1.088429741690
Fp for psi ....................    0.603436540820
Cpl ...........................    1.000685369884
Ctpl ..........................    1.089175718656
Ctpl, rounded .................    1.08918

    Step 8
Volume at base conditions ......      694333.73394
```

```
                   Example 3
    Input Data
Commodity ......................  Generalized Refined Product
t observed temperature, °F .....           68
P observed pressure, PSI .......           11
Rel density, observed t & P ....       0.8665
Volume at observed t & P .......        28.45

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ...........  865.647364000000

    Step 1
  All input data within range of procedure

    Step 2
Initial density, kg/cu m .......  865.647364000000

            Iteration(m) ..... 0                  1                   2
    Step 3
Commodity ..........       fuel oil           fuel oil            fuel oil
Rho60(m) ........... 865.647364000000   868.722758639837   868.722680008428
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     0.000003083760     0.000003083760
B(m) ...............   1.307601778625     1.306846968664     1.306846987915
Rho60*(m) .......... 865.650045852404   868.725437571840   868.725358940506
alpha60(m) .........   0.000450635987     0.000448551701     0.000448551754
Ctl(m) .............   0.996390100819     0.996406815126     0.996406814700
d_alpha(m) .........   1.300000000000     1.300000000000     1.300000000000
Fp(m) ..............   0.489197521374     0.484824153195     0.484824263921
Cpl(m) .............   1.000053814623     1.000053333501     1.000053333513
Ctpl(m) ............   0.996443721177     0.996459956990     0.996459956576
Rho60(m)xCtpl(m) ... 862.568880610988   865.647442710117   865.647363997967

    Step 4
delta Rho60(m) .....   3.078483389012    -0.000078710117     0.000000002033

    Step 5
E(m) ...............   3.089470407196    -0.000078989744
Dt(m) ..............   0.004713647310     0.004691721251
Dp(m) ..............  -0.000136749381    -0.000134568925
delta Rho(m) .......   3.075394639836    -0.000078631409
Rho60(m+1) ......... 868.722758639837   868.722680008428

    Step 6, iteration(m) ..... 1                  2

    Step 7
  Density at 60°F is within range of procedure
  Output values
Density at 60°F ................  868.722680008428
Relative density ...............    0.869578345100
Ctl ............................    0.996406814700
Fp for psi .....................    0.484824263921
Cpl ............................    1.000053333513
Ctpl ...........................    0.996459956576
Ctpl, rounded ..................    0.99646

    Step 8
Volume at base conditions ......        28.349287
```

```
                Example 4
    Input Data
Commodity .....................  Generalized Refined Product
t observed temperature, °F .....          72
P observed pressure, PSI .......         375
API gravity, observed t & P ....        41.4
Volume at observed t & P .......       200.5

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ........... 817.586836321573

    Step 1
  All input data within range of procedure

    Step 2
Initial density, kg/cu m ....... 817.586836321573

            Iteration(m) ..... 0                  1                  2
    Step 3
Commodity ..........      jet fuel           jet fuel           jet fuel
Rho60(m) ........... 817.586836321573   820.670702702861   820.670624131605
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) ...............   0.000003397100     0.000003371617     0.000003371618
B(m) ...............   2.000000000000     2.000000000000     2.000000000000
Rho60*(m) .......... 817.589613739330   820.673469683855   820.673391112864
alpha60(m) .........   0.000494127651     0.000490421047     0.000490421141
Ctl(m) .............   0.994058492860     0.994103138776     0.994103137645
d_alpha(m) .........   2.000000000000     2.000000000000     2.000000000000
Fp(m) ..............   0.578821088788     0.572609812544     0.572609969057
Cpl(m) .............   1.002175300745     1.002151907560     1.002151908149
Ctpl(m) ............   0.996220869040     0.996242356836     0.996242356288
Rho60(m)xCtpl(m) ... 814.497068596135   817.586915046689   817.586836321334

    Step 4
delta Rho60(m) .....   3.089767725439    -0.000078725116     0.000000000239

    Step 5
E(m) ...............   3.101488657244    -0.000079022053
Dt(m) ..............   0.011971573527     0.011880933438
Dp(m) ..............  -0.006257228682    -0.006143505500
delta Rho(m) .......   3.083866381287    -0.000078571256
Rho60(m+1) ......... 820.670702702861   820.670624131605

    Step 6, iteration(m) ..... 1                  2

    Step 7
  Density at 60°F is within range of procedure
  Output values
Density at 60°F ................ 820.670624131605
API gravity ....................  40.750303402271
Ctl ............................   0.994103137645
Fp for psi .....................   0.572609969057
Cpl ............................   1.002151908149
Ctpl ...........................   0.996242356288
Ctpl, rounded ..................   0.99624

    Step 8
Volume at base conditions ......       199.74612
```

Example 5

Input Data

Commodity	Generalized Refined Product
t observed temperature, °F	25.3
P observed pressure, PSI	267
Dens, kg/cu m, observed t & P ..	803.141
Volume at observed t & P	9998.7

Computed Data - last digit is rounded for display purposes

Step 1

All input data within range of procedure

Step 2

Initial density, kg/cu m 803.141000000000

Iteration(m)	0	1	2	3
Step 3				
Commodity	jet fuel	transition	transition	transition
Rho60(m)	803.141000000000	787.517248843019	787.508024225311	787.507922593917
K0(m)	330.301000000000	1.48906700000e+03	1.48906700000e+03	1.48906700000e+03
K1(m)	0.000000000000	0.000000000000	0.000000000000	0.000000000000
K2(m)	0.000000000000	-0.001868400000	-0.001868400000	-0.001868400000
A(m)	0.000003520404	0.000003661644	0.000003662031	0.000003662035
B(m)	2.000000000000	9.016006690076	9.015265799128	9.015257637156
Rho60*(m)	803.143827374024	787.520132369253	787.510908022297	787.510806393886
alpha60(m)	0.000512062812	0.000532593084	0.000532649331	0.000532649951
Ctl(m)	1.017674681289	1.018379066764	1.018380996124	1.018381017381
d_alpha(m)	2.000000000000	8.500000000000	8.500000000000	8.500000000000
Fp(m)	0.512082157017	0.539941779272	0.539959172137	0.539959363768
Cpl(m)	1.001369131317	1.001443725890	1.001443772463	1.001443772976
Ctpl(m)	1.019068011565	1.019849326989	1.019851306563	1.019851328373
Rho60(m)xCtpl(m) ...	818.455301876645	803.148936224643	803.141087435169	803.141000961936
Step 4				
delta Rho60(m)	-15.314301876645	-0.007936224643	-0.000087435169	-0.000000961936
Step 5				
E(m)	-15.027752517833	-0.007781761906	-0.000085733252	
Dt(m)	-0.034526847401	-0.152443296032	-0.152458905024	
Dp(m)	-0.003620114436	-0.003970318835	-0.003970539931	
delta Rho(m)	-15.623751156981	-0.009224617708	-0.000101631394	
Rho60(m+1)	787.517248843019	787.508024225311	787.507922593917	

Step 6, iteration(m) 1 2 3

Step 7

Density at 60°F is within range of procedure

Output values

Density at 60°F	787.507922593917
Ctl	1.018381017381
Fp for psi	0.539959363768
Cpl	1.001443772976
Ctpl	1.019851328373
Ctpl, rounded	1.01985

Step 8

Volume at base conditions 10197.174195

Example 6

Input Data

Commodity	Generalized Refined Product
t observed temperature, °F	139
P observed pressure, PSI	100
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

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	1.48906700000e+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
Fp(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
Fp for psi	0.910923457238
Cpl	1.000911753995
Ctpl	0.949542039808
Ctpl, rounded	0.94954

Step 8

Volume at base conditions 949.54

```
                 Example 7
    Input Data
Commodity ......................  Specialized Liquid
Alpha at 60°F per °F ...........    0.00057634
t observed temperature, °F .....          84.5
P observed pressure, PSI .......           573
Dens, kg/cu m, observed t & P ..         853.7
Volume at observed t & P .......          5000

    Computed Data - last digit is rounded for display purposes

    Step 1
  All input data within range of procedure

    Step 2
Initial density, kg/cu m .......  853.700000000000

            Iteration(m) ..... 0                  1                  2
    Step 3
Rho60(m) ...........  853.700000000000   863.404788404903   863.403098613648
Rho60*(m) ..........  853.703382614631   863.408209472807   863.406519674857
Ctl(m) .............    0.985817857839     0.985817857839     0.985817857839
d_alpha(m) .........    0.000000000000     0.000000000000     0.000000000000
Fp(m) ..............    0.535641758165     0.519613454257     0.519616156675
Cpl(m) .............    1.003078676432     1.002986276388     1.002986291965
Ctpl(m) ............    0.988852872044     0.988761782431     0.988761797787
Rho60(m)xCtpl(m) ...  844.183696864341   853.701657542469   853.700000000354

    Step 4
delta Rho60(m) .....    9.516303135659    -0.001657542469    -0.000000000354

    Step 5
E(m) ...............    9.623578395423    -0.001676382015
Dt(m) ..............    0.000000000000     0.000000000000
Dp(m) ..............   -0.008368035045    -0.007935441615
delta Rho(m) .......    9.704788404903    -0.001689791254
Rho60(m+1) .........  863.404788404903   863.403098613648

    Step 6, iteration(m) ..... 1                  2

    Step 7
  Density at 60°F is within range of procedure
  Output values
Density at 60°F ................  863.403098613648
Ctl ............................    0.985817857839
Fp for psi .....................    0.519616156675
Cpl ............................    1.002986291965
Ctpl ...........................    0.988761797787
Ctpl, rounded ..................    0.98876

    Step 8
Volume at base conditions ......            4943.8
```

```
                   Example 8
    Input Data
Commodity ......................   Generalized Lube Oil
t observed temperature, °F .....          78.7
P observed pressure, PSI .......           128
API gravity, observed t & P ....          23.6
Volume at observed t & P .......          2500

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ...........  911.416918117344

    Step 1
  All input data within range of procedure

    Step 2
Initial density, kg/cu m .......  911.416918117344

            Iteration(m) ..... 0                 1                   2
    Step 3
Rho60(m) ..........  911.416918117344   917.442528695754   917.442430351448
K0(m) .............    0.000000000000     0.000000000000     0.000000000000
K1(m) .............    0.348780000000     0.348780000000     0.348780000000
K2(m) .............    0.000000000000     0.000000000000     0.000000000000
A(m) ..............    0.000002630878     0.000002613599     0.000002613599
B(m) ..............    1.000000000000     1.000000000000     1.000000000000
Rho60*(m) .........  911.419315946068   917.444926524466   917.444828180160
alpha60(m) ........    0.000382677867     0.000380164509     0.000380164550
Ctl(m) ............    0.992826908221     0.992874117241     0.992874116475
d_alpha(m) ........    1.000000000000     1.000000000000     1.000000000000
Fp(m) .............    0.445753246624     0.438941834085     0.438941943315
Cpl(m) ............    1.000570889885     1.000562161396     1.000562161535
Ctpl(m) ...........    0.993393703061     0.993432272740     0.993432272113
Rho60(m)xCtpl(m) ...  905.395827320613   911.417016390699   911.416918117159

    Step 4
delta Rho60(m) .....    6.021090796731    -0.000098273355     0.000000000185

    Step 5
E(m) ..............    6.061132437402    -0.000098923055
Dt(m) .............    0.007238011198     0.007189938664
Dp(m) .............   -0.001342864386    -0.001305020283
delta Rho(m) .......    6.025610578411    -0.000098344306
Rho60(m+1) ........  917.442528695754   917.442430351448

    Step 6, iteration(m) ..... 1                 2

    Step 7
  Density at 60°F is within range of procedure
  Output values
Density at 60°F ................  917.442430351448
API gravity ....................   22.581345404799
Ctl ............................    0.992874116475
Fp for psi .....................    0.438941943315
Cpl ............................    1.000562161535
Ctpl ...........................    0.993432272113
Ctpl, rounded ..................    0.99343

    Step 8
Volume at base conditions ......        2483.575
```

```
                Example 9
    Input Data
Commodity ......................  Generalized Lube Oil
t observed temperature, °F .....         302
P observed pressure, PSI .......     1499.97
API gravity, observed t & P ....          62
Volume at observed t & P .......       989.4

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ........... 730.546583979328

    Step 1
  All input data within range of procedure

    Step 2
Initial density, kg/cu m ....... 730.546583979328

  Note, Rho60 has been limited to the minimum table value in one or more cases.

            Iteration(m) ..... 0                 1                   2
    Step 3
Rho60(m) ........... 800.900000000000   801.061137965076   801.061124838869
K0(m) .............    0.000000000000     0.000000000000     0.000000000000
K1(m) .............    0.348780000000     0.348780000000     0.348780000000
K2(m) .............    0.000000000000     0.000000000000     0.000000000000
A(m) ..............    0.000002993915     0.000002993313     0.000002993313
B(m) ..............    1.000000000000     1.000000000000     1.000000000000
Rho60*(m) .......... 800.902397828986   801.063535794061   801.063522667854
alpha60(m) .........   0.000435483775     0.000435396176     0.000435396183
Ctl(m) ............    0.891989089232     0.892011193142     0.892011191342
d_alpha(m) .........   1.000000000000     1.000000000000     1.000000000000
Fp(m) .............    1.460680703550     1.459310478928     1.459310590459
Cpl(m) ............    1.022400563598     1.022379079982     1.022379081731
Ctpl(m) ...........    0.911970147554     0.911973582978     0.911973582698
Rho60(m)xCtpl(m) ... 730.396891176188   730.546596174628   730.546583979040

    Step 4
delta Rho60(m) .....    0.149692803140    -0.000012195300     0.000000000288

    Step 5
E(m) ..............    0.164142218407    -0.000013372427
Dt(m) .............    0.123157370141     0.123129022550
Dp(m) .............   -0.104513388078    -0.104371150492
delta Rho(m) .......    0.161137965076    -0.000013126207
Rho60(m+1) ......... 801.061137965076   801.061124838869

    Step 6, iteration(m) ..... 1                 2

    Step 7
  Density at 60°F is within range of procedure
  Output values
Density at 60°F ................ 801.061124838869
API gravity ....................  44.966888252047
Ctl ............................   0.892011191342
Fp for psi .....................   1.459310590459
Cpl ............................   1.022379081731
Ctpl ...........................   0.911973582698
Ctpl, rounded ..................   0.91197

    Step 8
Volume at base conditions ......       902.303118
```

```
                   Example 10
    Input Data
Commodity .....................  Generalized Crude Oil
t observed temperature, °F .....        -58.05
P observed pressure, PSI .......             0
API gravity, observed t & P ....        169.16
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ...........  470.168176677975

    Step 1
Observed temperature less than -50°C (-58°F) - outside limits of table
Density less than 470.4 kg/cu m - outside limits of table


                   Example 11
    Input Data
Commodity .....................  Generalized Crude Oil
t observed temperature, °F .....        302.08
P observed pressure, PSI .......       1500.12
API gravity, observed t & P ....        -13.88
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ........... 1201.842917871110

    Step 1
Observed temperature greater than 150°C (302°F) - outside limits of table
Observed pressure greater than 1500 psi - outside limits of table
Density greater than 1201.8 kg/cu m - outside limits of table


                   Example 12
    Input Data
Commodity .....................  Generalized Refined Product
t observed temperature, °F .....        -58.05
P observed pressure, PSI .......             0
Dens, kg/cu m, observed t & P ..        470.17
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

    Step 1
Observed temperature less than -50°C (-58°F) - outside limits of table
Density less than 470.3 kg/cu m - outside limits of table


                   Example 13
    Input Data
Commodity .....................  Generalized Refined Product
t observed temperature, °F .....        302.08
P observed pressure, PSI .......       1500.05
Dens, kg/cu m, observed t & P ..       1209.52
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

    Step 1
Observed temperature greater than 150°C (302°F) - outside limits of table
Observed pressure greater than 1500 psi - outside limits of table
Density greater than 1209.5 kg/cu m - outside limits of table
```

```
                   Example 14
    Input Data
Commodity ......................   Generalized Lube Oil
t observed temperature, °F .....             60
P observed pressure, PSI .......              0
API gravity, observed t & P ....         -14.53
Volume at observed t & P .......           1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ............ 1208.521535436437

    Step 1
Density greater than 1163.5 kg/cu m - outside limits of table


                   Example 15
    Input Data
Commodity ......................   Generalized Lube Oil
t observed temperature, °F .....          72.32
P observed pressure, PSI .......              0
API gravity, observed t & P ....          66.48
Volume at observed t & P .......           1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ............  714.015375290433

    Step 1
Density less than 714.3 kg/cu m - outside limits of table


                   Example 16
    Input Data
Commodity ......................   Generalized Lube Oil
t observed temperature, °F .....         -57.97
P observed pressure, PSI .......          240.7
API gravity, observed t & P ....         -14.51
Volume at observed t & P .......           1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ............ 1208.314932900248

    Step 1
Density greater than 1208.3 kg/cu m - outside limits of tabl
```

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

Note: For liquids with an equilibrium vapor pressure greater than atmospheric, see 11.1.3.4.

Outline of Calculations

This procedure combines those in 11.1.6.2 and 11.1.6.1. First, the density at the base conditions (60°F and 0 psig) consistent with an observed density is calculated. This base density is then corrected to the alternate temperature and pressure conditions.

The procedure has been written assuming that the input values are all in the proper units (°F, psig, and kg/m³). If they are not in the proper units then apply the procedures in 11.1.5.1 before entering this procedure. The density values calculated by this procedure are in the units of kg/m³. If these units do not match the original input units, then the output densities should be converted to that of the original input value's units using the procedures in 11.1.5.1.

Input Values

Commodity group describing liquid (if α_{60} not input)

α_{60} Pre-calculated 60°F thermal expansion factor (if commodity group not given)

ρ_o Observed density (kg/m³)

t_o Temperature at which the observed density was measured (°F)

P_o Pressure at which the observed density was measured (psig)

t Alternate temperature at which density is desired (°F)

P Alternate pressure at which density is desired (psig)

Optional Input Values

V_o Volume at observed conditions (any valid set of units, such as barrels, liters, and cubic metres)

Output Values

ρ Density at alternate conditions t and P (kg/m³)

ρ_{60} Density at base conditions 60°F and 0 psig (kg/m³)

$C_{TL,o}$ Volume correction factor due to temperature between the base and observed temperatures

$C_{PL,o}$ Volume correction factor due to pressure between the base and observed pressures at the observed temperature

$F_{P,o}$ Scaled compressibility factor at the observed temperature (psi^{-1})

$C_{TPL,o}$ Combined volume correction factor due to temperature and pressure between the base and observed conditions

C_{TL} Volume correction factor due to temperature between the base and alternate temperatures

C_{PL} Volume correction factor due to pressure between the base and alternate pressures at the alternate temperature

F_P Scaled compressibility factor at the alternate temperature (psi^{-1})

C_{TPL} Combined volume correction factor due to temperature and pressure between the base and alternate conditions

Optional Output Values

V Volume at alternate conditions t and P (same units as V_o)

V_{60} Volume at base conditions 60°F and 0 psig (same units as V_o)

Calculation Procedure

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

Step 2: With the ρ_{60} value found in Step 1, calculate the corresponding ρ 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_P, C_{PL}, and C_{TPL} in the procedure. Round this value of C_{TPL}.

Step 3: Calculate the volumes at the base conditions:

$$V_{60} = V_o \cdot C_{TPL,o}$$

and at the alternate conditions t and P:

$$V = \frac{V_{60}}{C_{TPL}}.$$

Step 4: Exit from this procedure.

Example Calculations

```
                   Example 1
    Input Data
Commodity .....................   Generalized Crude Oil
t observed temperature, °F .....   80.25
t alternate temperature, °F ....   -57.9
P observed pressure, PSI .......      -5
P alternate pressure, PSI ......       0
  Forcing negative pressure(s) to zero
Rho, observed density ..........   823.7
Volume at observed t & P .......    1000

    Computed Data - last digit is rounded for display purposes

    Step 1

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

Iteration(m)	0	1	2
Rho60(m)	823.700000000000	832.027290281072	832.028099977475
K0(m)	341.095700000000	341.095700000000	341.095700000000
K1(m)	0.000000000000	0.000000000000	0.000000000000
K2(m)	0.000000000000	0.000000000000	0.000000000000
A(m)	0.000003456244	0.000003387407	0.000003387400
B(m)	2.000000000000	2.000000000000	2.000000000000
Rho60*(m)	823.702846901034	832.030108689221	832.030918382881
alpha60(m)	0.000502730357	0.000492717695	0.000492716736
Ctl(m)	0.989786584353	0.989990582976	0.989990602513
d_alpha(m)	2.000000000000	2.000000000000	2.000000000000
Fp(m)	0.583545365081	0.566987343326	0.566985780172
Cpl(m)	1.000000000000	1.000000000000	1.000000000000
Ctpl(m)	0.989786584353	0.989990582976	0.989990602513
Rho60(m)xCtpl(m) ...	815.287209531590	823.699182157009	823.700000004321
delta Rho60(m)	8.412790468410	0.000817842991	-0.000000004321
E(m)	8.499600420336	0.000826111889	
Dt(m)	0.020692222013	0.020273630412	
Dp(m)	-0.000000000000	-0.000000000000	
delta Rho(m)	8.327290281072	0.000809696404	
Rho60(m+1)	832.027290281072	832.028099977475	

```
  Output values
Rho60 ........................  832.028099977475
Ctl,o ........................    0.989990602513
Fp,o .........................    0.566985780172
Cpl,o ........................    1.000000000000
Ctpl,o .......................    0.989990602513
Ctpl,0, rounded ...............    0.98999

    Step 2
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F ........................  -57.900000000000
t corrected to IPTS-68 °F ......  -57.917345475911
A ............................    0.000003387400
B ............................    2.000000000000
Rho60* ........................  832.030918382881
alpha60 .......................    0.000492716736
delta t, °F ................... -117.924220375911
Ctl ..........................    1.056966235844
Fp,psi .........................    0.349850873727
P in psi ......................    0.000000000000
Cpl ..........................    1.000000000000
Ctpl ..........................    1.056966235844
Ctpl, rounded .................    1.05697
Density at t & P, kg/cu m ......  879.425608949795

    Step 3
Volume at base conditions ......          989.99
Volume at alternate t & P ......     936.630178718
```

Example 2

Input Data

Commodity	Generalized Crude Oil
t observed temperature, ˚F	-57.95
t alternate temperature, ˚F	301.95
P observed pressure, PSI	113.5
P alternate pressure, PSI	1342
Rho, observed rel density	0.7233
Volume at observed t & P	9988.7

Computed Data - last digit is rounded for display purposes

Calculation of Intermediate Results

Density kg/cu meter	722.588272800000

Step 1

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

Iteration(m)	0	1	2	3
Rho60(m)	722.588272800000	663.788670139111	663.423300413573	663.423272118035
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)	0.000004491182	0.000005322097	0.000005327961	0.000005327962
B(m)	2.000000000000	2.000000000000	2.000000000000	2.000000000000
Rho60*(m)	722.591518065349	663.792202873887	663.426835093931	663.426806798544
alpha60(m)	0.000653266707	0.000774126529	0.000774979431	0.000774979497
Ctl(m)	1.074996632822	1.088341810579	1.088435315140	1.088435322387
d_alpha(m)	2.000000000000	2.000000000000	2.000000000000	2.000000000000
Fp(m)	0.477019634140	0.602502062133	0.603495823943	0.603495901031
Cpl(m)	1.000541710576	1.000684307797	1.000685437263	1.000685437350
Ctpl(m)	1.075578969868	1.089086571366	1.089181369263	1.089181376610
Rho60(m)xCtpl(m) ...	777.200750096823	722.923326873446	722.588298745482	722.588272800858
delta Rho60(m)	-54.612477296823	-0.335054073446	-0.000025945482	-0.000000000858
E(m)	-50.774958256698	-0.307646868720	-0.000023821085	
Dt(m)	-0.135106783503	-0.155937434550	-0.156079813850	
Dp(m)	-0.001367683008	-0.002047348489	-0.002052987115	
delta Rho(m)	-58.799602660889	-0.365369725538	-0.000028295538	
Rho60(m+1)	663.788670139111	663.423300413573	663.423272118035	

Output values

Rho60	663.423272118035
Ctl,o	1.088435322387
Fp,o	0.603495901031
Cpl,o	1.000685437350
Ctpl,o	1.089181376610
Ctpl,O, rounded	1.08918

Step 2

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

t, ˚F	301.950000000000
t corrected to IPTS-68 ˚F	302.013165895828
A	0.000005327962
B	2.000000000000
Rho60*	663.426806798544
alpha60	0.000774979497
delta t, ˚F	242.006290995828
Ctl	0.805983918837
Fp,psi	4.244916846250
P in psi	1.34200000000e+03
Cpl	1.060408035597
Ctpl	0.854671824096
Ctpl, rounded	0.85467
Density at t & P, kg/cu m	567.009178129011

Step 3

Volume at base conditions	10879.492266
Volume at alternate t & P	12729.4654849

```
                   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
P alternate pressure, PSI ......    534
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

    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
Fp(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
Fp,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
Fp,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 ......       284.4366525
Volume at alternate t & P ......     295.586162551
```

```
                   Example 4
    Input Data
Commodity .....................  Generalized Refined Product
t observed temperature, °F .....  72.04
t alternate temperature, °F ....    -58
P observed pressure, PSI .......    375
P alternate pressure, PSI ......  47.75
Rho, observed API gravity ......   41.4
Volume at observed t & P .......  14.95

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ...........  817.586836321573

    Step 1

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

            Iteration(m) ..... 0                   1                    2
Commodity ..........      jet fuel            jet fuel             jet fuel
Rho60(m) ...........  817.586836321573    820.686613127170     820.686533964218
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) ...............    0.000003397100      0.000003371487       0.000003371487
B(m) ...............    2.000000000000      2.000000000000       2.000000000000
Rho60*(m) ..........  817.589613739330    820.689380054522     820.689300891838
alpha60(m) .........    0.000494127651      0.000490402032       0.000490402127
Ctl(m) .............    0.994038653374      0.994083678416       0.994083677273
d_alpha(m) .........    2.000000000000      2.000000000000       2.000000000000
Fp(m) ..............    0.578904789700      0.572660317953       0.572660475665
Cpl(m) .............    1.002175615991      1.002152097771       1.002152098365
Ctpl(m) ............    0.996201299764      0.996223043685       0.996223043130
Rho60(m)xCtpl(m) ...  814.481069013354    817.586915641051     817.586836321331
delta Rho60(m) .....    3.105767308219     -0.000079319477       0.000000000242
E(m) ...............    3.117610174726     -0.000079620199
Dt(m) ..............    0.012011855055      0.011920440676
Dp(m) ..............   -0.006258741122     -0.006144404888
delta Rho(m) .......    3.099776805597     -0.000079162951
Rho60(m+1) .........  820.686613127170    820.686533964218
  Output values
Rho60 .........................  820.686533964218
Ctl,o .........................    0.994083677273
Fp,o ..........................    0.572660475665
Cpl,o .........................    1.002152098365
Ctpl,o ........................    0.996223043130
Ctpl,O, rounded ...............    0.99622

    Step 2
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F .........................  -58.000000000000
t corrected to IPTS-68 °F .....  -58.017359639581
A .............................    0.000003371487
B .............................    2.000000000000
Rho60* ........................  820.689300891838
alpha60 .......................    0.000490402127
delta t, °F .................... -118.024234539581
Ctl ...........................    1.056751557035
Fp,psi ........................    0.359117236149
P in psi ......................   47.750000000000
Cpl ...........................    1.000171507890
Ctpl ..........................    1.056932798265
Ctpl, rounded .................    1.05693
Density at t & P, kg/cu m .....  867.410514841381

    Step 3
Volume at base conditions ......        14.893489
Volume at alternate t & P ......    14.0912728374
```

```
                   Example 5
    Input Data
Commodity .....................   Generalized Refined Product
t observed temperature, °F .....   35.34
t alternate temperature, °F ....  127.98
P observed pressure, PSI .......   38.4
P alternate pressure, PSI ......  121.8
Rho, observed density ..........  790.53
Volume at observed t & P .......   99998

    Computed Data - last digit is rounded for display purposes

    Step 1

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

            Iteration(m) ..... 0                 1                   2                   3
Commodity ..........       jet fuel          transition          transition          transition
Rho60(m) ...........  790.530000000000    779.954265918190    779.174329912980    779.174880755919
K0(m) ..............  330.301000000000      1.48906700000e+03   1.48906700000e+03   1.48906700000e+03
K1(m) ..............    0.000000000000      0.000000000000      0.000000000000      0.000000000000
K2(m) ..............    0.000000000000     -0.001868400000     -0.001868400000     -0.001868400000
A(m) ...............    0.000003633619      0.000003983317      0.000004017024      0.000004017000
B(m) ...............    2.000000000000      8.449428366970      8.395311744142      8.395349701311
Rho60*(m) ..........  790.532872477731    779.957372634827    779.177459785401    779.178010611977
alpha60(m) .........    0.000528530459      0.000579380687      0.000584283321      0.000584279853
Ctl(m) .............    1.012984460926      1.014228023715      1.014347865394      1.014347780630
d_alpha(m) .........    2.000000000000      8.500000000000      8.500000000000      8.500000000000
Fp(m) ..............    0.555420998123      0.577092033703      0.578759095821      0.578757914964
Cpl(m) .............    1.000213327162      1.000221652460      1.000222292896      1.000222292442
Ctpl(m) ............    1.013200558026      1.014452829851      1.014573347718      1.014573262475
Rho60(m)xCtpl(m) ...  800.965437136296    791.226812215287    790.529508355868    790.530000807356
delta Rho60(m) .....  -10.435437136296     -0.696812215287      0.000491644132     -0.000000807356
E(m) ...............  -10.299478275680     -0.686884786342      0.000484582147
Dt(m) ..............   -0.025523526372     -0.118667770827     -0.119648229356
Dp(m) ..............   -0.000598140833     -0.000638452051     -0.000641579262
delta Rho(m) .......  -10.575734081810     -0.779936005211      0.000550842939
Rho60(m+1) .........  779.954265918190    779.174329912980    779.174880755919
  Output values
Rho60 .........................  779.174880755919
Ctl,o .........................    1.014347780630
Fp,o ..........................    0.578757914964
Cpl,o .........................    1.000222292442
Ctpl,o ........................    1.014573262475
Ctpl,O, rounded ...............    1.01457

    Step 2
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F .........................  127.980000000000
t corrected to IPTS-68 °F ......  128.004847502107
A .............................    0.000004017000
B .............................    8.395349701311
Rho60* ........................  779.178010611977
alpha60 .......................    0.000584279853
delta t, °F ...................   67.997972602107
Ctl ...........................    0.959835974243
Fp,psi ........................    0.835760463789
P in psi ......................  121.800000000000
Cpl ...........................    1.001018993536
Ctpl ..........................    0.960814040896
Ctpl, rounded .................    0.96081
Density at t & P, kg/cu m ......  748.642165743914

    Step 3
Volume at base conditions ......      101454.97086
Volume at alternate t & P ......     105593.167078
```

```
                   Example 6
    Input Data
Commodity ......................  Generalized Refined Product
t observed temperature, °F .....  74.33
t alternate temperature, °F ....    -50
P observed pressure, PSI .......      2
P alternate pressure, PSI ......  -2.33
  Forcing negative pressure(s) to zero
Rho, observed density ..........  602.6
Volume at observed t & P .......  501.7

    Computed Data - last digit is rounded for display purposes

    Step 1

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

  Note, Rho60 has been limited to the minimum table value in one or more cases.

            Iteration(m) ..... 0                   1                   2
Commodity ..........      gasoline            gasoline            gasoline
Rho60(m) ...........  610.600000000000    610.620823885543    610.620806310613
K0(m) ..............  192.457100000000    192.457100000000    192.457100000000
K1(m) ..............    0.243800000000      0.243800000000      0.243800000000
K2(m) ..............    0.000000000000      0.000000000000      0.000000000000
A(m) ...............    0.000006293846      0.000006293511      0.000006293511
B(m) ...............    1.563858906231      1.563850519437      1.563850526515
Rho60*(m) ..........  610.603843016189    610.624666827835    610.624649252968
alpha60(m) .........    0.000915473165      0.000915424342      0.000915424383
Ctl(m) .............    0.986827537721      0.986828242827      0.986828242232
d_alpha(m) .........    1.500000000000      1.500000000000      1.500000000000
Fp(m) ..............    1.837615045698      1.837290064364      1.837290338603
Cpl(m) .............    1.000036753652      1.000036747152      1.000036747157
Ctpl(m) ............    0.986863807236      0.986864505954      0.986864505365
Rho60(m)xCtpl(m) ...  602.579040698547    602.600017689212    602.599999985069
delta Rho60(m) .....    0.020959301453     -0.000017689212      0.000000014931
E(m) ...............    0.021238291747     -0.000017924662
Dt(m) ..............    0.020091138288      0.020090044786
Dp(m) ..............   -0.000190615729     -0.000190569019
delta Rho(m) .......    0.020823885543     -0.000017574930
Rho60(m+1) .........  610.620823885543    610.620806310613
  Output values
Rho60 .........................  610.620806310613
Ctl,o .........................    0.986828242232
Fp,o ..........................    1.837290338603
Cpl,o .........................    1.000036747157
Ctpl,o ........................    0.986864505365
Ctpl,O, rounded ...............    0.98686

    Step 2
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F .........................  -50.000000000000
t corrected to IPTS-68 °F ......  -50.016186329276
A .............................    0.000006293511
B .............................    1.563850526515
Rho60* ........................  610.624649252968
alpha60 .......................    0.000915424383
delta t, °F ................... -110.023061229276
Ctl ...........................    1.097026730683
Fp,psi ........................    0.831793615513
P in psi ......................    0.000000000000
Cpl ...........................    1.000000000000
Ctpl ..........................    1.097026730683
Ctpl, rounded .................    1.09703
Density at t & P, kg/cu m ......  669.867346834158

    Step 3
Volume at base conditions ......        495.107662
Volume at alternate t & P ......     451.316428903
```

```
                Example 7
    Input Data
Commodity ......................  Specialized Liquid
Alpha at 60˚F per ˚F ..........     0.00057634
t observed temperature, ˚F .....   84.5
t alternate temperature, ˚F ....   97.4
P observed pressure, PSI .......    157
P alternate pressure, PSI ......      0
Rho, observed density ..........  853.7
Volume at observed t & P .......  10000

    Computed Data - last digit is rounded for display purposes

    Step 1

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

            Iteration(m) ..... 0                   1                   2
Rho60(m) ...........  853.700000000000    865.279709574172    865.279061018129
Rho60*(m) ..........  853.703382614631    865.283138071074    865.282489512461
Ctl(m) .............    0.985817857839      0.985817857839      0.985817857839
d_alpha(m) .........    0.000000000000      0.000000000000      0.000000000000
Fp(m) ..............    0.535641758165      0.516633299257      0.516634323827
Cpl(m) .............    1.000841665365      1.000811772720      1.000811774331
Ctpl(m) ............    0.986647586587      0.986618117883      0.986618119472
Rho60(m)xCtpl(m) ...  842.301044668997    853.700638502822    853.700000000034
delta Rho60(m) .....   11.398955331003     -0.000638502822     -0.000000000034
E(m) ...............   11.553218683115     -0.000647163082
Dt(m) ..............    0.000000000000      0.000000000000
Dp(m) ..............   -0.002287699090     -0.002147788038
delta Rho(m) .......   11.579709574172     -0.000648556043
Rho60(m+1) .........  865.279709574172    865.279061018129
  Output values
Rho60 ..........................  865.279061018129
Ctl,o ..........................    0.985817857839
Fp,o ...........................    0.516634323827
Cpl,o ..........................    1.000811774331
Ctpl,o .........................    0.986618119472
Ctpl,O, rounded ................    0.98662

    Step 2
  Correcting 60˚F and 0 psi density to alternate conditions:
t, ˚F ..........................   97.400000000000
t corrected to IPTS-68 ˚F ......   97.416649907262
Rho60* .........................  865.282489512461
alpha60 ........................    0.000576340000
delta t, ˚F ....................   37.409775007262
Ctl ............................    0.978305995393
Fp,psi .........................    0.538697628351
P in psi .......................    0.000000000000
Cpl ............................    1.000000000000
Ctpl ...........................    0.978305995393
Ctpl, rounded ..................    0.97831
Density at t & P, kg/cu m ......  846.507693082447

    Step 3
Volume at base conditions ......            9866.2
Volume at alternate t & P ......     10084.9424007
```

```
                Example 8
    Input Data
Commodity ......................  Generalized Lube Oil
t observed temperature, ˚F .....  -57.9
t alternate temperature, ˚F ....    60
P observed pressure, PSI .......   233
P alternate pressure, PSI ......   245
Rho, observed API gravity ......  -14.1
Volume at observed t & P .......  251.2

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ............ 1204.095093696763

    Step 1

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

  Note, Rho60 has been limited to the maximum table value in one or more cases.

            Iteration(m) ..... 0                   1                   2
Rho60(m) ..........    1.16350000000e+03   1.16281780211e+03   1.16281779744e+03
K0(m) .............    0.000000000000      0.000000000000      0.000000000000
K1(m) .............    0.348780000000      0.348780000000      0.348780000000
K2(m) .............    0.000000000000      0.000000000000      0.000000000000
A(m) ..............    0.000002060874      0.000002062083      0.000002062083
B(m) ..............    1.000000000000      1.000000000000      1.000000000000
Rho60*(m) .........    1.16350239783e+03   1.16282019994e+03   1.16282019527e+03
alpha60(m) ........    0.000299767324      0.000299943190      0.000299943191
Ctl(m) ............    1.034947039914      1.034967289554      1.034967289693
d_alpha(m) ........    1.000000000000      1.000000000000      1.000000000000
Fp(m) .............    0.219692735298      0.219818332632      0.219818333493
Cpl(m) ............    1.000512146233      1.000512439174      1.000512439176
Ctpl(m) ...........    1.035477084142      1.035497647337      1.035497647478
Rho60(m)xCtpl(m) ...   1.20477758740e+03   1.20409509837e+03   1.20409509370e+03
delta Rho60(m) .....  -0.682493702536     -0.000004668362     -0.000000000031
E(m) ..............   -0.659110387848     -0.000004508327
Dt(m) .............   -0.033344012152     -0.033362401069
Dp(m) .............   -0.000498813024     -0.000499684129
delta Rho(m) .......  -0.682197891836     -0.000004666339
Rho60(m+1) ........    1.16281780211e+03   1.16281779744e+03
  Output values
Rho60 .........................    1.16281779744e+03
Ctl,o .........................    1.034967289693
Fp,o ..........................    0.219818333493
Cpl,o .........................    1.000512439176
Ctpl,o ........................    1.035497647478
Ctpl,O, rounded ...............    1.03550

    Step 2
  Correcting 60˚F and 0 psi density to alternate conditions:
t, ˚F .........................  60.000000000000
t corrected to IPTS-68 ˚F ......  60.006874897736
A .............................   0.000002062083
B .............................   1.000000000000
Rho60* ........................   1.16282019527e+03
alpha60 .......................   0.000299943191
delta t, ˚F ...................  -0.000000002264
Ctl ...........................   1.000000000001
Fp,psi ........................   0.273551802459
P in psi ...................... 245.000000000000
Cpl ...........................   1.000670651388
Ctpl ..........................   1.000670651389
Ctpl, rounded .................   1.00067
Density at t & P, kg/cu m ......  1.16359764281e+03

    Step 3
Volume at base conditions ......         260.1176
Volume at alternate t & P ......     259.943437897
```

Example 9

Input Data

Commodity	Generalized Lube Oil
t observed temperature, ˚F	302
t alternate temperature, ˚F	98.65
P observed pressure, PSI	1499.97
P alternate pressure, PSI	568.33
Rho, observed API gravity	36.43
Volume at observed t & P	999.6

Computed Data - last digit is rounded for display purposes

Calculation of Intermediate Results

Density kg/cu meter	841.783862323587

Step 1

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

Iteration(m)	0	1	2	3
Rho60(m)	841.783862323587	918.495586362405	917.505574875598	917.505498028854
K0(m)	0.000000000000	0.000000000000	0.000000000000	0.000000000000
K1(m)	0.348780000000	0.348780000000	0.348780000000	0.348780000000
K2(m)	0.000000000000	0.000000000000	0.000000000000	0.000000000000
A(m)	0.000002848507	0.000002610602	0.000002613419	0.000002613420
B(m)	1.000000000000	1.000000000000	1.000000000000	1.000000000000
Rho60*(m)	841.786260152468	918.497984191115	917.507972704310	917.507895857566
alpha60(m)	0.000414333206	0.000379728650	0.000380138386	0.000380138418
Ctl(m)	0.897323171647	0.906037218501	0.905934141267	0.905934133257
d_alpha(m)	1.000000000000	1.000000000000	1.000000000000	1.000000000000
Fp(m)	1.170912452486	0.835056757732	0.838261317711	0.838261567336
Cpl(m)	1.017877320899	1.012684481602	1.012733778595	1.012733782436
Ctpl(m)	0.913364905936	0.917529830931	0.917470106044	0.917470101411
Rho60(m)xCtpl(m) ...	768.855838229786	842.747100065625	841.783937077072	841.783862321888
delta Rho60(m)	72.928024093801	-0.963237742038	-0.000074753485	0.000000001699
E(m)	79.845441421959	-1.049816267075	-0.000081477843	
Dt(m)	0.116354714813	0.105405643037	0.105533972802	
Dp(m)	-0.075504148327	-0.044997474985	-0.045269890050	
delta Rho(m)	76.711724038818	-0.990011486807	-0.000076846744	
Rho60(m+1)	918.495586362405	917.505574875598	917.505498028854	

Output values

Rho60	917.505498028854
Ctl,o	0.905934133257
Fp,o	0.838261567336
Cpl,o	1.012733782436
Ctpl,o	0.917470101411
Ctpl,O, rounded	0.91747

Step 2

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

t, ˚F	98.650000000000
t corrected to IPTS-68 ˚F	98.666983527884
A	0.000002613420
B	1.000000000000
Rho60*	917.507895857566
alpha60	0.000380138418
delta t, ˚F	38.660108627884
Ctl	0.985240961815
Fp,psi	0.464994043354
P in psi	568.330000000000
Cpl	1.002649703018
Ctpl	0.987851557765
Ctpl, rounded	0.98785
Density at t & P, kg/cu m	906.359235485755

Step 3

Volume at base conditions	917.103012
Volume at alternate t & P	928.382863795

```
                   Example 10
    Input Data
Commodity .....................   Generalized Crude Oil
t observed temperature, ˚F .....  -58.05
t alternate temperature, ˚F ....  -58.05
P observed pressure, PSI .......      -5
P alternate pressure, PSI ......      -5
  Forcing negative pressure(s) to zero
Rho, observed API gravity ......  169.16
Volume at observed t & P .......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ...........  470.168176677975
Observed temperature less than -50˚C (-58˚F) - outside limits of table
Alternate temperature less than -50˚C (-58˚F) - outside limits of table
Density less than 470.4 kg/cu m - outside limits of table


                   Example 11
    Input Data
Commodity .....................   Generalized Crude Oil
t observed temperature, ˚F .....  302.08
t alternate temperature, ˚F ....  302.06
P observed pressure, PSI .......  1500.43
P alternate pressure, PSI ......       0
Rho, observed API gravity ......  -13.87
Volume at observed t & P .......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ........... 1201.740746408229
Observed temperature greater than 150˚C (302˚F) - outside limits of table
Alternate temperature greater than 150˚C (302˚F) - outside limits of table
Observed pressure greater than 1500 psi - outside limits of table
```

```
                  Example 12
    Input Data
Commodity .....................  Generalized Crude Oil
t observed temperature, ˚F .....  89.08
t alternate temperature, ˚F ....  97.06
P observed pressure, PSI .......   0.43
P alternate pressure, PSI ......  27.75
Rho, observed API gravity ......   -9.1
Volume at observed t & P .......   1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ............ 1154.908202614379

    Step 1

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

            Iteration(m) ..... 0                    1                    2
Rho60(m) ..........     1.15490820261e+03   1.16345254536e+03   1.16345298090e+03
K0(m) .............   341.095700000000    341.095700000000    341.095700000000
K1(m) .............     0.000000000000      0.000000000000      0.000000000000
K2(m) .............     0.000000000000      0.000000000000      0.000000000000
A(m) ..............     0.000001758116      0.000001732388      0.000001732387
B(m) ..............     2.000000000000      2.000000000000      2.000000000000
Rho60*(m) .........     1.15491023307e+03   1.16345456091e+03   1.16345499645e+03
alpha60(m) ........     0.000255728885      0.000251986568      0.000251986379
Ctl(m) ............     0.992545110373      0.992654436869      0.992654442380
d_alpha(m) ........     2.000000000000      2.000000000000      2.000000000000
Fp(m) .............     0.291666373754      0.288480207162      0.288480047418
Cpl(m) ............     1.000001254167      1.000001240466      1.000001240466
Ctpl(m) ...........     0.992546355190      0.992655668224      0.992655673734
Rho60(m)xCtpl(m) ...    1.14629992708e+03   1.15490776386e+03   1.15490820262e+03
delta Rho60(m) .....    8.608275530558      0.000438752057     -0.000000001698
E(m) ..............     8.672920398676      0.000441998239
Dt(m) .............     0.015050161444      0.014827366651
Dp(m) .............    -0.000001882680     -0.000001834864
delta Rho(m) .......    8.544342747166      0.000435541110
Rho60(m+1) ........     1.16345254536e+03   1.16345298090e+03
  Output values
Rho60 .........................    1.16345298090e+03
Ctl,o .........................    0.992654442380
Fp,o ..........................    0.288480047418
Cpl,o .........................    1.000001240466
Ctpl,o ........................    0.992655673734
Ctpl,O, rounded ...............    0.99266

    Step 2
  Correcting 60˚F and 0 psi density to alternate conditions:
t, ˚F .........................   97.060000000000
t corrected to IPTS-68 ˚F ......   97.076559209491
A .............................    0.000001732387
B .............................    2.000000000000
Rho60* ........................    1.16345499645e+03
alpha60 .......................    0.000251986379
delta t, ˚F ...................   37.069684309491
Ctl ...........................    0.990633258118
Fp,psi ........................    0.292777732234
P in psi ......................   27.750000000000
Cpl ...........................    1.000081252422
Ctpl ..........................    0.990713749470
Ctpl, rounded .................    0.99071
Density at t & P, kg/cu m ......   1.15264886504e+03

    Step 3
Volume at base conditions ......           992.66
Volume at alternate t & P ......     1001.96828537
```

```
                  Example 13
    Input Data
Commodity .....................  Generalized Crude Oil
t observed temperature, °F .....   87.9
t alternate temperature, °F ....  237.8
P observed pressure, PSI ....... 172.34
P alternate pressure, PSI ......      0
Rho, observed API gravity ......  105.3
Volume at observed t & P .......   1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ........... 596.962685810811

    Step 1

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

  Note, Rho60 has been limited to the minimum table value in one or more cases.

            Iteration(m) ..... 0                1
Rho60(m) .......... 610.600000000000   610.603878491534
K0(m) ............. 341.095700000000   341.095700000000
K1(m) .............   0.000000000000     0.000000000000
K2(m) .............   0.000000000000     0.000000000000
A(m) ..............   0.000006289685     0.000006289605
B(m) ..............   2.000000000000     2.000000000000
Rho60*(m) ......... 610.603840464675   610.607718931815
alpha60(m) ........   0.000914865355     0.000914853733
Ctl(m) ............   0.974283340298     0.974283669212
d_alpha(m) ........   2.000000000000     2.000000000000
Fp(m) .............   2.003652617491     2.003584457334
Cpl(m) ............   1.003465060102     1.003464941820
Ctpl(m) ...........   0.977659290629     0.977659505442
Rho60(m)xCtpl(m) ... 596.958762857874   596.962685866784
delta Rho60(m) .....   0.003922952936    -0.000000055974
E(m) ..............   0.004012597204
Dt(m) .............   0.053134326876
Dp(m) .............  -0.018557567083
delta Rho(m) .......   0.003878491534
Rho60(m+1) ......... 610.603878491534
  Output values
Rho60 ......................... 610.603878491534
Ctl,o .........................   0.974283669212
Fp,o ..........................   2.003584457334
Cpl,o .........................   1.003464941820
Ctpl,o ........................   0.977659505442
Ctpl,O, rounded ...............   0.97766

    Step 2
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F ......................... 237.800000000000
t corrected to IPTS-68 °F ...... 237.851832056034
A .............................   0.000006289605
B .............................   2.000000000000
Rho60* ........................ 610.607718931815
alpha60 .......................   0.000914853733
delta t, °F ................... 177.844957156034
Ctl ...........................   0.832034523163
Fp,psi ........................   5.209412010592
P in psi ......................   0.000000000000
Cpl ...........................   1.000000000000
Ctpl ..........................   0.832034523163
Ctpl, rounded .................   0.83203
Density at t & P, kg/cu m ...... 508.043506882197

    Step 3
Volume at base conditions ......           977.66
Volume at alternate t & P ......    1175.02974652
```

```
                   Example 14
    Input Data
Commodity .....................   Generalized Refined Product
t observed temperature, °F .....  -58.05
t alternate temperature, °F ....  -58.05
P observed pressure, PSI .......       0
P alternate pressure, PSI ......       0
Rho, observed density ..........  470.17
Volume at observed t & P .......    1000

    Computed Data - last digit is rounded for display purposes
Observed temperature less than -50°C (-58°F) - outside limits of table
Alternate temperature less than -50°C (-58°F) - outside limits of table
Density less than 470.3 kg/cu m - outside limits of table


                   Example 15
    Input Data
Commodity .....................   Generalized Refined Product
t observed temperature, °F .....  302.08
t alternate temperature, °F ....  302.05
P observed pressure, PSI .......  1500.5
P alternate pressure, PSI ......       0
Rho, observed density ..........  1209.56
Volume at observed t & P .......    1000

    Computed Data - last digit is rounded for display purposes
Observed temperature greater than 150°C (302°F) - outside limits of table
Alternate temperature greater than 150°C (302°F) - outside limits of table
Observed pressure greater than 1500 psi - outside limits of table
Density greater than 1209.5 kg/cu m - outside limits of table
```

```
               Example 16
    Input Data
Commodity .....................   Generalized Lube Oil
t observed temperature, ˚F .....  -58.05
t alternate temperature, ˚F ....  -58.05
P observed pressure, PSI .......       0
P alternate pressure, PSI ......       0
Rho, observed API gravity ......  -10.05
Volume at observed t & P .......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ........... 1163.942066694113
Observed temperature less than -50˚C (-58˚F) - outside limits of table
Alternate temperature less than -50˚C (-58˚F) - outside limits of table


               Example 17
    Input Data
Commodity .....................   Generalized Lube Oil
t observed temperature, ˚F .....  302.05
t alternate temperature, ˚F ....  302.05
P observed pressure, PSI .......  1500.5
P alternate pressure, PSI ......       0
Rho, observed API gravity ......   45.08
Volume at observed t & P .......    1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ...........  800.547989579794
Observed temperature greater than 150˚C (302˚F) - outside limits of table
Alternate temperature greater than 150˚C (302˚F) - outside limits of table
Observed pressure greater than 1500 psi - outside limits of table
```

```
                Example 18
    Input Data
Commodity .....................  Generalized Lube Oil
t observed temperature, °F ..... -57.95
t alternate temperature, °F ....     60
P observed pressure, PSI .......  233.7
P alternate pressure, PSI ...... 245.66
Rho, observed API gravity ...... -14.15
Volume at observed t & P .......   1000

    Computed Data - last digit is rounded for display purposes

  Calculation of Intermediate Results
Density kg/cu meter ........... 1204.608129527056

    Step 1

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

  Note, Rho60 has been limited to the maximum table value in one or more cases.

            Iteration(m) ..... 0                  1                  2
Rho60(m) ..........    1.16350000000e+03   1.16331178872e+03   1.16331178744e+03
K0(m) .............    0.000000000000      0.000000000000      0.000000000000
K1(m) .............    0.348780000000      0.348780000000      0.348780000000
K2(m) .............    0.000000000000      0.000000000000      0.000000000000
A(m) ..............    0.000002060874      0.000002061207      0.000002061207
B(m) ..............    1.000000000000      1.000000000000      1.000000000000
Rho60*(m) .........    1.16350239783e+03   1.16331418655e+03   1.16331418527e+03
alpha60(m) ........    0.000299767324      0.000299815823      0.000299815823
Ctl(m) ............    1.034961676758      1.034967263386      1.034967263424
d_alpha(m) ........    1.000000000000      1.000000000000      1.000000000000
Fp(m) .............    0.219672384586      0.219706997026      0.219706997262
Cpl(m) ............    1.000513638051      1.000513719024      1.000513719024
Ctpl(m) ...........    1.035493272457      1.035498945759      1.035498945797
Rho60(m)xCtpl(m) ...   1.20479642250e+03   1.20460813081e+03   1.20460812953e+03
delta Rho60(m) .....  -0.188292976336     -0.000001282839     -0.000000000009
E(m) ..............   -0.181838918074     -0.000001238861
Dt(m) .............   -0.033357305031     -0.033362378201
Dp(m) .............   -0.000500177750     -0.000500418486
delta Rho(m) .......  -0.188211278184     -0.000001282283
Rho60(m+1) ........    1.16331178872e+03   1.16331178744e+03
  Output values
Rho60 .........................   1.16331178744e+03
Ctl,o .........................   1.034967263424
Fp,o ..........................   0.219706997262
Cpl,o .........................   1.000513719024
Ctpl,o ........................   1.035498945797
Ctpl,O, rounded ...............   1.03550

    Step 2
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F .........................  60.000000000000
t corrected to IPTS-68 °F ......  60.006874897736
A .............................   0.000002061207
B .............................   1.000000000000
Rho60* ........................   1.16331418527e+03
alpha60 .......................   0.000299815823
delta t, °F ...................  -0.000000002264
Ctl ...........................   1.000000000001
Fp,psi ........................   0.273391493229
P in psi ...................... 245.660000000000
Cpl ...........................   1.000672064910
Ctpl ..........................   1.000672064911
Ctpl, rounded .................   1.00067
Density at t & P, kg/cu m ......   1.16409360847e+03

    Step 3
Volume at base conditions ......          1035.5
Volume at alternate t & P ......     1034.8066795
```

11.1.7 Implementation Procedures for Metric Units (15°C or 20°C and 0 kPa Base Conditions)

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

Note: For liquids with an equilibrium vapor pressure greater than atmospheric, see 11.1.3.4.

Outline of Calculations

This procedure calculates the Volume Correction Factor (VCF) given the density at the metric base conditions (15°C or 20°C and 0 kPa (gauge)). The parameters used in this procedure depend upon the commodity group to which the liquid belongs. Because the VCF expressions were developed and expressed in terms of a base density at 60°F, this calculation must be done as a two part process:

1. Calculate the density at 60°F and 0 psig consistent with the metric base density.
2. Calculate the density at the alternate metric temperature and pressure conditions.

The procedure has been written assuming that the input values are all in the proper units (°C, kPa or bar (gauge), and kg/m³). If they are not in the proper units then apply the procedures in 11.1.5.1. The density values calculated by this procedure are in kg/m³.

Input Values

Commodity group describing liquid (if α_{60} not input)

α_{60} Pre-calculated 60°F thermal expansion factor (if commodity group not given)

ρ_T Density at metric base conditions (15°C or 20°C and 0 kPa (gauge)) (kg/m³)

T Base temperature (15°C or 20°C)

t Alternate temperature (°C)

P Alternate pressure (kPa or bar (gauge))

Optional Input Values

$V_{t,P}$ Volume at alternate conditions (t and P) (any valid set of units, such as liters, cubic metres, and barrels)

Output Values

C_{TL} Volume correction factor due to temperature

C_{PL} Volume correction factor due to pressure

F_P Scaled compressibility factor (kPa^{-1} or bar^{-1})

C_{TPL} Combined volume correction factor due to temperature and pressure

Optional Output Values

ρ Density at alternate conditions (kg/m³)

V_T Volume at base conditions (same set of units as $V_{t,P}$)

ρ_{60} Density at 60°F and 0 psig (kg/m³)

Intermediate Values

$T_{\circ F}$ Base temperature T converted to units of °F (°F)

$t_{\circ F}$ Alternate temperature t converted to units of °F (°F)

P_{psi} Alternate pressure P converted to units of psig (psig)

$C_{TL,60}$ CTL value correcting ρ_{60} to ρ_T

C_{TL}^* CTL value correcting ρ_{60} to the alternate temperature

C_{TPL}^* CTPL value correcting ρ_{60} to the alternate temperature and pressure

$F_{P,psi}$ Scaled compressibility factor (psi^{-1})

Calculation Procedure

Step 1: Convert the base temperature, alternate temperature, and alternate pressure into customary units using equations in 11.1.5.1. Call these variables $T_{\circ F}$, $t_{\circ F}$, and P_{psi}.

Step 2: Calculate the correction factors for the density at 60°F, ρ_{60}, corresponding to the metric base density ρ_T value at $T_{\circ F}$ using the procedure in 11.1.6.2. The pressure correction need not be calculated since the metric base pressure (0 kPa (gauge)) is the same as the base pressure in 11.1.6.1 (0 psig). If this procedure returns with an error condition (i.e. fluid outside the limits of this Standard), exit this procedure. Call the CTL associated with this step $C_{TL,60}$.

Step 3: Using this value of ρ_{60}, calculate the density value at the alternate conditions $t_{\circ F}$ and P_{psi} 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_{PL}, C_{TPL}^*, and $F_{P,psi}$.

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.

Modify the scaled compressibility factor for the metric pressure units:

$$F_P = \frac{F_{P,psi}}{6.894757} \quad \text{for kPa}$$

$$F_P = \frac{F_{P,psi}}{0.06894757} \quad \text{for bar}$$

Step 5: Optionally, correct a volume measured at alternate condtions to base conditions and/or correct base density to alternate conditions.:

$$\rho = C_{TL} \bullet C_{PL} \bullet \rho_T$$

$$V_T = V_{t,P} * C_{TPL}$$

Step 6: Exit from this procedure.

Example Calculations

```
        API MPMS 11.1.7.1 Metric Units, Example 1
A volume of a crude oil 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 .....................  Generalized Crude Oil
T base temperature, ˚C .........            15
t alternate temperature, ˚C ....         -32.8
P alternate pressure, bar ......          24.6
Base density, kg/cu m ..........         772.3
Volume at observed t & P .......          9885

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, ˚F ....        -27.04
T base, ˚F .....................            59
P alternate, PSI ..............  356.792849987

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

            Iteration(m) ..... 0                    1
Rho60(m) ..........  772.300000000000    771.858049874826
K0(m) .............  341.095700000000    341.095700000000
K1(m) .............    0.000000000000      0.000000000000
K2(m) .............    0.000000000000      0.000000000000
A(m) ..............    0.000003931610      0.000003936113
B(m) ..............    2.000000000000      2.000000000000
Rho60*(m) .........  772.303036373950    771.861087987332
alpha60(m) ........    0.000571874537      0.000572529607
Ctl,60(m) .........    1.000571924875      1.000572579894
d_alpha(m) ........    2.000000000000      2.000000000000
Rho60(m)xCtl,60(m) .  772.741697581079    772.300000275011
delta Rho60(m) .....   -0.441697581079     -0.000000275011
E(m) ..............   -0.441445107641
Dt(m) .............   -0.001142702545
Dp(m) .............   -0.000000000000
delta Rho(m) .......   -0.441950125174
Rho60(m+1) ........  771.858049874826

Rho60 .........................  771.858049874826
Ctl,60 ........................    1.000572579894

    Step 3 -  Correct 60˚F/0 psi density to alternate conditions:
t, ˚F .........................  -27.040000000000
t corrected to IPTS-68 ˚F ......  -27.052381115706
A .............................    0.000003936113
B .............................    2.000000000000
Rho60* ........................  771.861087987332
alpha60 .......................    0.000572529607
delta t, ˚F ...................  -87.059256015706
Ctl* ..........................    1.049020399586
Fp,psi ........................    0.462386457487
P in psi ......................  356.792849987316
Cpl ...........................    1.001652488031
Ctpl* .........................    1.050753893241

    Step 4 - Modify Ctl and Ctpl for temperature base of 15˚C
Ctl ...........................    1.048420095319
Ctpl ..........................    1.050152596978
Ctpl, rounded .................    1.05015
Fp,bar ........................    6.706348860257

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

```
         API MPMS 11.1.7.1 Metric Units, Example 2
A volume of a crude oil is measured at observed conditions of temperature and pressure.  The base density
at 20˚C is known.  Calculate the volume at base conditions and correct the base density to an alternate
condition.

    Input Data
Commodity ......................  Generalized Crude Oil
T base temperature, ˚C .........            20
t alternate temperature, ˚C ....         -32.8
P alternate pressure, bar ......         24.65
Base density, kg/cu m ..........         772.3
Volume at observed t & P .......        397498

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, ˚F ....        -27.04
T base, ˚F .....................            68
P alternate, PSI ...............  357.518038707

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

            Iteration(m) ..... 0                   1                   2
Rho60(m) ..........  772.300000000000    775.822822685260    775.822887700255
K0(m) .............  341.095700000000    341.095700000000    341.095700000000
K1(m) .............    0.000000000000      0.000000000000      0.000000000000
K2(m) .............    0.000000000000      0.000000000000      0.000000000000
A(m) ..............    0.000003931610      0.000003895986      0.000003895985
B(m) ..............    2.000000000000      2.000000000000      2.000000000000
Rho60*(m) .........  772.303036373950    775.825845271850    775.825910286592
alpha60(m) ........    0.000571874537      0.000566692882      0.000566692787
Ctl,60(m) .........    0.995417583056      0.995459159111      0.995459159873
d_alpha(m) ........    2.000000000000      2.000000000000      2.000000000000
Rho60(m)xCtl,60(m) .  768.760999394329    772.299934689151    772.300000000155
delta Rho60(m) .....    3.539000605671      0.000065310849     -0.000000000155
E(m) ..............    3.555292437978      0.000065608768
Dt(m) .............    0.009216970486      0.009132855760
Dp(m) .............   -0.000000000000     -0.000000000000
delta Rho(m) .......    3.522822685260      0.000065014995
Rho60(m+1) ........  775.822822685260    775.822887700255

Rho60 ..........................  775.822887700255
Ctl,60 .........................    0.995459159873

    Step 3 -  Correct 60˚F/0 psi density to alternate conditions:
t, ˚F ..........................  -27.040000000000
t corrected to IPTS-68 ˚F ......  -27.052381115706
A ..............................    0.000003895985
B ..............................    2.000000000000
Rho60* .........................  775.825910286592
alpha60 ........................    0.000566692787
delta t, ˚F ....................  -87.059256015706
Ctl* ...........................    1.048529743821
Fp,psi .........................    0.456638589390
P in psi .......................  357.518038706803
Cpl ............................    1.001635234957
Ctpl* ..........................    1.050244336311

    Step 4 - Modify Ctl and Ctpl for temperature base of 20˚C
Ctl ............................    1.053312668251
Ctpl ...........................    1.055035081947
Ctpl, rounded ..................    1.05504
Fp,bar .........................    6.622983078151

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

```
         API MPMS 11.1.7.1 Metric Units, Example 3
A volume of a refined product 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 .....................   Generalized Refined Product
T base temperature, °C ........            15
t alternate temperature, °C ....         87.32
P alternate pressure, kPa ......            75
Base density, kg/cu m ..........         865.6
Volume at observed t & P .......         48.75

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, °F ....       189.176
T base, °F .....................            59
P alternate, PSI ...............  10.8778307923

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

            Iteration(m) ..... 0                    1                    2
Commodity ..........      fuel oil             fuel oil             fuel oil
Rho60(m) ...........  865.600000000000     865.209800869528     865.209799447010
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) ...............    0.000003098311       0.000003100138       0.000003100138
B(m) ...............    1.307613432453       1.307709473868       1.307709474219
Rho60*(m) ..........  865.602681897543     865.212483139130     865.212481716614
alpha60(m) .........    0.000450668230       0.000450934024       0.000450934025
Ctl,60(m) ..........    1.000450723728       1.000450989520       1.000450989521
d_alpha(m) .........    1.300000000000       1.300000000000       1.300000000000
Rho60(m)xCtl,60(m) .  865.990146458899     865.600001422325     865.600000000005
delta Rho60(m) .....   -0.390146458899      -0.000001422325      -0.000000000005
E(m) ...............   -0.389970689856      -0.000001421684
Dt(m) ..............   -0.000585446247      -0.000585791280
Dp(m) ..............   -0.000000000000      -0.000000000000
delta Rho(m) .......   -0.390199130472      -0.000001422518
Rho60(m+1) .........  865.209800869528     865.209799447010

Rho60 .........................  865.209799447010
Ctl,60 ........................    1.000450989521

    Step 3 -  Correct 60°F/0 psi density to alternate conditions:
t, °F .........................  189.176000000000
t corrected to IPTS-68 °F ......  189.216725285673
A .............................    0.000003100138
B .............................    1.307709474219
Rho60* ........................  865.212481716614
alpha60 .......................    0.000450934025
delta t, °F ...................  129.209850385673
Ctl* ..........................    0.940840865293
Fp,psi ........................    0.725556454792
P in psi ......................   10.877830792296
Cpl ...........................    1.000078931033
Ctpl* .........................    0.940915126834

    Step 4 - Modify Ctl and Ctpl for temperature base of 15°C
Ctl ...........................    0.940416747194
Ctpl ..........................    0.940490975260
Ctpl, rounded .................    0.94049
Fp,kPa ........................    0.105233071273

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

API MPMS 11.1.7.1 Metric Units, Example 4

A volume of a refined product 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 ......................  Generalized Refined Product
T base temperature, ˚C .........           15
t alternate temperature, ˚C ....        27.37
P alternate pressure, bar ......        17.05
Base density, kg/cu m ..........        793.5
Volume at observed t & P .......        200.2

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, ˚F ....       81.266
T base, ˚F .....................           59
P alternate, PSI ............... 247.289353345

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

            Iteration(m) ..... 0                  1
Commodity ..........      jet fuel           jet fuel
Rho60(m) ........... 793.500000000000   793.083483971112
K0(m) .............. 330.301000000000   330.301000000000
K1(m) ..............   0.000000000000     0.000000000000
K2(m) ..............   0.000000000000     0.000000000000
A(m) ...............   0.000003606470     0.000003610259
B(m) ...............   2.000000000000     2.000000000000
Rho60*(m) .......... 793.502861726357   793.086347200399
alpha60(m) .........   0.000524581407     0.000525132553
Ctl,60(m) ..........   1.000524634773     1.000525185891
d_alpha(m) .........   2.000000000000     2.000000000000
Rho60(m)xCtl,60(m) . 793.916297692263   793.500000227253
delta Rho60(m) .....  -0.416297692263    -0.000000227253
E(m) ...............  -0.416079402540
Dt(m) ..............  -0.001048282220
Dp(m) ..............  -0.000000000000
delta Rho(m) .......  -0.416516028888
Rho60(m+1) ......... 793.083483971112

Rho60 ......................... 793.083483971112
Ctl,60 .........................   1.000525185891

    Step 3 -  Correct 60˚F/0 psi density to alternate conditions:
t, ˚F .........................  81.266000000000
t corrected to IPTS-68 ˚F ......  81.278374938351
A .............................   0.000003610259
B .............................   2.000000000000
Rho60* ........................ 793.086347200399
alpha60 .......................   0.000525132553
delta t, ˚F ...................  21.271500038351
Ctl* ..........................   0.988793028121
Fp,psi ........................   0.656392797417
P in psi ...................... 247.289353344868
Cpl ...........................   1.001625828532
Ctpl* .........................   0.990400636038

    Step 4 - Modify Ctl and Ctpl for temperature base of 15˚C
Ctl ...........................   0.988274000560
Ctpl ..........................   0.989880764627
Ctpl, rounded .................   0.98988
Fp,bar ........................   9.520173044783

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

API MPMS 11.1.7.1 Metric Units, Example 5

A volume of a refined product is measured at observed conditions of temperature and pressure. The base density at 20˚C is known. Calculate the volume at base conditions and correct the base density to an alternate condition.

Input Data

Commodity	Generalized Refined Product
T base temperature, ˚C	20
t alternate temperature, ˚C	-36
P alternate pressure, bar	8.6
Base density, kg/cu m	772.3
Volume at observed t & P	1502.3

Computed Data - last digit is rounded for display purposes

Step 1 - Convert to customary units

t alternate temperature, ˚F	-32.8
T base, ˚F	68
P alternate, PSI	124.732459752

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

Iteration(m)	0	1	2	3
Commodity	transition	transition	transition	transition
Rho60(m)	772.300000000000	776.046081952777	776.056443403059	776.056458538058
K0(m)	1.48906700000e+03	1.48906700000e+03	1.48906700000e+03	1.48906700000e+03
K1(m)	0.000000000000	0.000000000000	0.000000000000	0.000000000000
K2(m)	-0.001868400000	-0.001868400000	-0.001868400000	-0.001868400000
A(m)	0.000004318542	0.000004153240	0.000004152786	0.000004152785
B(m)	7.948794061670	8.185560760776	8.186236842691	8.186237830334
Rho60*(m)	772.303335114335	776.049304966171	776.059666107245	776.059681241792
alpha60(m)	0.000628139366	0.000604096073	0.000604030053	0.000604029957
Ctl,60(m)	0.994966066092	0.995159024472	0.995159554282	0.995159555056
d_alpha(m)	8.500000000000	8.500000000000	8.500000000000	8.500000000000
Rho60(m)xCtl,60(m) .	768.412292842796	772.289261861302	772.299984314832	772.299999977145
delta Rho60(m)	3.887707157204	0.010738138698	0.000015685168	0.000000022855
E(m)	3.907376632928	0.010790374638	0.000015761461	
Dt(m)	0.043056901100	0.041396169845	0.041391611065	
Dp(m)	-0.000000000000	-0.000000000000	-0.000000000000	
delta Rho(m)	3.746081952777	0.010361450282	0.000015134999	
Rho60(m+1)	776.046081952777	776.056443403059	776.056458538058	

Rho60	776.056458538058
Ctl,60	0.995159555056

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

t, ˚F	-32.800000000000
t corrected to IPTS-68 ˚F	-32.813394933532
A	0.000004152785
B	8.186237830334
Rho60*	776.059681241792
alpha60	0.000604029957
delta t, ˚F	-92.820269833532
Ctl*	1.055011702151
Fp,psi	0.445919193636
P in psi	124.732459751663
Cpl	1.000556515516
Ctpl*	1.055598832533

Step 4 - Modify Ctl and Ctpl for temperature base of 20˚C

Ctl	1.060143267269
Ctpl	1.060733253446
Ctpl, rounded	1.06073
Fp,bar	6.467511380549

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

Volume at base conditions	1593.534679
Density, kg/cu m, at t & P	819.201779

```
         API MPMS 11.1.7.1 Metric Units, Example 6
A volume of a refined product 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 .....................  Generalized Refined Product
T base temperature, ˚C .........           15
t alternate temperature, ˚C ....        27.35
P alternate pressure, kPa ......         1235
Base density, kg/cu m ..........        657.3
Volume at observed t & P .......         1000

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, ˚F ....        81.23
T base, ˚F .....................           59
P alternate, PSI ..............  179.121613713

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

            Iteration(m) ..... 0                   1                   2
Commodity ..........      gasoline            gasoline            gasoline
Rho60(m) ...........  657.300000000000    656.763177196090    656.763156816252
K0(m) ..............  192.457100000000    192.457100000000    192.457100000000
K1(m) ..............    0.243800000000      0.243800000000      0.243800000000
K2(m) ..............    0.000000000000      0.000000000000      0.000000000000
A(m) ...............    0.000005612455      0.000005619548      0.000005619548
B(m) ...............    1.545657407721      1.545859957612      1.545859965304
Rho60*(m) ..........  657.303689061482    656.766867902911    656.766847523136
alpha60(m) .........    0.000816362130      0.000817393796      0.000817393835
Ctl,60(m) ..........    1.000816376104      1.000817407544      1.000817407583
d_alpha(m) .........    1.500000000000      1.500000000000      1.500000000000
Rho60(m)xCtl,60(m) .  657.836604013187    657.300020371521    657.300000000770
delta Rho60(m) .....   -0.536604013187     -0.000020371521     -0.000000000770
E(m) ...............   -0.536166299832     -0.000020354883
Dt(m) ..............   -0.001222943721     -0.001224487176
Dp(m) ..............   -0.000000000000     -0.000000000000
delta Rho(m) .......   -0.536822803910     -0.000020379838
Rho60(m+1) .........  656.763177196090    656.763156816252

Rho60 .........................  656.763156816252
Ctl,60 ........................    1.000817407583

    Step 3 -  Correct 60˚F/0 psi density to alternate conditions:
t, ˚F .........................   81.230000000000
t corrected to IPTS-68 ˚F ......   81.242365479576
A .............................    0.000005619548
B .............................    1.545859965304
Rho60* ........................  656.766847523136
alpha60 .......................    0.000817393835
delta t, ˚F ...................   21.235490579576
Ctl* ..........................    0.982555008412
Fp,psi ........................    1.342969568596
P in psi ......................  179.121613713145
Cpl ...........................    1.002411349381
Ctpl* .........................    0.984924291823

    Step 4 - Modify Ctl and Ctpl for temperature base of 15˚C
Ctl ...........................    0.981752516460
Ctpl ..........................    0.984119864783
Ctpl, rounded .................    0.98412
Fp,kPa ........................    0.194781276352

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

```
        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 °F ...........   0.000446759
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 observed t & P .......         47.85

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, °F ....        193.82
T base, °F .....................            59
P alternate, PSI ............... 657.746168574

    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
Fp,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
Fp,bar .........................  41.702651081010

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

```
        API MPMS 11.1.7.1 Metric Units, Example 8
A volume of a crude oil 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 .....................   Generalized Crude Oil
T base temperature, ˚C .........          15
t alternate temperature, ˚C ....     -50.025
P alternate pressure, kPa ......          -5
  Forcing negative pressure to zero
Base density, kg/cu m ..........      610.46
Volume at observed t & P .......        1000

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, ˚F ....     -58.045
T base, ˚F .....................          59
P alternate, PSI ...............           0
Alternate temperature less than -50˚C (-58˚F) - outside limits of table
Density less than 610.6 kg/cu m - outside limits of table


        API MPMS 11.1.7.1 Metric Units, Example 9
A volume of a refined product is measured at observed conditions of temperature and pressure.  The base
density at 20˚C is known.  Calculate the volume at base conditions and correct the base density to an
alternate condition.

    Input Data
Commodity .....................   Generalized Refined Product
T base temperature, ˚C .........          20
t alternate temperature, ˚C ....     150.025
P alternate pressure, kPa ......       10343
Base density, kg/cu m ..........     1163.55
Volume at observed t & P .......        1000

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, ˚F ....     302.045
T base, ˚F .....................          68
P alternate, PSI ............... 1500.12538513
Alternate temperature greater than 150˚C (302˚F) - outside limits of table
Alternate pressure greater than 1500 psi - outside limits of table
Density greater than 1163.5 kg/cu m - outside limits of table
```

```
        API MPMS 11.1.7.1 Metric Units, Example 10
A volume of a lube oil 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 ......................   Generalized Lube Oil
T base temperature, ˚C .........          15
t alternate temperature, ˚C ....       -50.025
P alternate pressure, kPa ......            0
Base density, kg/cu m ..........       800.849
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, ˚F ....       -58.045
T base, ˚F .....................            59
P alternate, PSI ...............             0
Alternate temperature less than -50˚C (-58˚F) - outside limits of table
Density less than 800.9 kg/cu m - outside limits of table


        API MPMS 11.1.7.1 Metric Units, Example 11
A volume of a lube oil is measured at observed conditions of temperature and pressure.  The base density
at 20˚C is known.  Calculate the volume at base conditions and correct the base density to an alternate
condition.

    Input Data
Commodity ......................   Generalized Lube Oil
T base temperature, ˚C .........          20
t alternate temperature, ˚C ....       150.025
P alternate pressure, bar ......        103.43
Base density, kg/cu m ..........       1163.55
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

    Step 1 - Convert to customary units
t alternate temperature, ˚F ....       302.045
T base, ˚F .....................            68
P alternate, PSI ...............  1500.12538513
Alternate temperature greater than 150˚C (302˚F) - outside limits of table
Alternate pressure greater than 1500 psi - outside limits of table
Density greater than 1163.5 kg/cu m - outside limits of tabl
```

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

Note: For liquids with an equilibrium vapor pressure greater than atmospheric, see 11.1.3.4.

Outline of Calculations

This procedure calculates the density at the metric base conditions (15°C or 20°C and 0 kPa (gauge)) that is consistent with an observed density measured at the observed temperature and pressure conditions. Because the VCF expressions were developed and expressed in terms of a base density at 60°F, this calculation must be done as a two part process:

1. Calculate the density at 60°F and 0 psig consistent with the observed density.
2. Calculate the density at the metric base temperature and pressure conditions.

The procedure has been written assuming that the input values are all in the proper units (°C, kPa or bar (gauge), and kg/m³). If they are not in the proper units then apply the procedures in 11.1.5.1. The density values calculated by this procedure are in kg/m³. If these units do not match the original input units, then the calculated density value(s) should be converted to that of the original input value's units using the procedures in 11.1.5.1.

Input Values

Commodity group describing liquid (if α_{60} not input)

α_{60} Pre-calculated 60°F thermal expansion factor (if commodity group not given)

ρ_o Observed density (kg/m³)

T Base temperature (15°C or 20°C)

t_o Temperature at which the observed density was measured (°C)

P_o Pressure at which the observed density was measured (kPa or bar (gauge))

Optional Input Values

V_o Volume at observed conditions (any valid set of units, such as liters, cubic metres, and barrels)

Output Values

ρ_T Density at metric base conditions (15°C or 20°C and 0 kPa (gauge)) (kg/m³)

C_{TL} Volume correction factor due to temperature

C_{PL} Volume correction factor due to pressure

F_P Scaled compressibility factor (kPa^{-1} or bar^{-1})

C_{TPL} Combined volume correction factor due to temperature and pressure

Optional Output Values

V_T Volume at base conditions (same set of units as V)

ρ_{60} Density at 60°F and 0 psig (kg/m³)

Intermediate Values

$T_{\circ F}$ Base temperature T converted to units of °F (°F)

$t_{o,\circ F}$ Temperature t_o converted to units of °F (°F)

$P_{o,psi}$ Pressure P_o converted to units of psig (psig)

$C_{TL,60}$ CTL value correcting ρ_{60} to ρ_T

C^*_{TL} CTL value correcting ρ_{60} to the observed temperature

C^*_{TPL} CTPL value correcting ρ_{60} to the observed temperature and pressure

$F_{P,psi}$ Scaled compressibility factor (psi^{-1})

Calculation Procedure

Step 1: Convert the base temperature, observed temperature, and observed pressure into customary units using equations in 11.1.5.1. Call these variables $T_{\circ F}$, $t_{o,\circ F}$, and $P_{o,psi}$.

Step 2: Calculate the correction factors for the density at 60°F, ρ_{60}, corresponding to the observed density ρ_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}, C_{PL}, C^*_{TPL}, and $F_{P,psi}$.

Step 3: Using this value of ρ_{60}, calculate the associated metric base density value ρ_T at $T_{\circ F}$ using the procedure in 11.1.6.1. The pressure correction need not be calculated since the metric base pressure (0 kPa (gauge)) is the same as the base pressure in 11.1.6.1 (0 psig). Call the CTL associated with this step $C_{TL,60}$.

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.

Modify the scaled compressibility factor for the metric pressure units:

$$F_P = \frac{F_{P,psi}}{6.894757} \quad \text{for kPa}$$

$$F_P = \frac{F_{P,psi}}{0.06894757} \quad \text{for bar.}$$

Step 5: Calculate the volume at the base conditions:

$$V_T = V_o \cdot C_{TPL}.$$

Step 6: Exit from this procedure.

Example Calculations

```
                   Example 1
    Input Data
Commodity ......................  Generalized Refined Product
Base temperature, ˚C ...........            15
t observed temperature, ˚C .....         82.35
P observed pressure, kPa .......         10005
Observed density, kg/cu m ......         721.1
Volume at observed t & P .......         10000

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature ˚F ......        180.23
T base temperature, ˚F .........            59
P observed, pressure, psi ......  1451.10262769

    Step 2
  Correcting observed density to 60˚F & 0 psi reference conditions
          Iteration(m) ..... 0                  1                   2            ...          4
Commodity ..........      gasoline          transition          transition       ...      gasoline
Rho60(m) ...........  721.100000000000   771.024002892933    770.371769059203    ...  770.349118751609
K0(m) ..............  192.457100000000     1.48906700000e+03   1.48906700000e+03 ...  192.457100000000
K1(m) ..............    0.243800000000     0.000000000000      0.000000000000    ...    0.243800000000
K2(m) ..............    0.000000000000    -0.001868400000     -0.001868400000    ...    0.000000000000
A(m) ...............    0.000004868905     0.000004375399      0.000004404570    ...    0.000004405357
B(m) ...............    1.522610196760     7.871492061474      7.832604886721    ...    1.506108826170
Rho60*(m) ..........  721.103510963661   771.027376333242    770.375162118135    ...  770.352512411255
alpha60(m) .........    0.000708209662     0.000636409156      0.000640652189    ...    0.000640784451
Ctl,60(m) ..........    0.913041162555     0.921988714711      0.921460588472    ...    0.921444124669
d_alpha(m) .........    1.500000000000     8.500000000000      8.500000000000    ...    1.500000000000
Fp(m) ..............    1.437164972964     1.072840733926      1.076555996647    ...    1.076685418863
Cpl(m) .............    1.021298922143     1.015814216115      1.015869850080    ...    1.015871788215
Ctpl(m) ............    0.932487955189     0.936569243501      0.936084029866    ...    0.936069090668
Rho60(m)xCtpl,60(m)   672.417064487103   722.117367110801    721.132710075817    ...  721.099999086448
delta Rho60(m) .....   48.682935512897    -1.017367110800     -0.032710075817    ...    0.000000913552
E(m) ...............   52.207575703224    -1.086270041281     -0.034943525125
Dt(m) ..............    0.145122527595     0.730004317792      0.735405759822
Dp(m) ..............   -0.099381547746    -0.064543274367     -0.064880057581
delta Rho(m) .......   49.924002892933    -0.652233833730     -0.020917681828
Rho60(m+1) .........  771.024002892933   770.371769059203    770.350851377375
  Output values
Rho60 ..........................  770.349118751609
Ctl* ...........................    0.921444124669
Fp,psi .........................    1.076685418863
Cpl ............................    1.015871788215
Ctpl* ..........................    0.936069090668

    Step 3
  Correcting 60˚F density to 15˚C base conditions:
t, ˚F ..........................   59.000000000000
t corrected to IPTS-68 ˚F ......   59.006621316269
A ..............................    0.000004405357
B ..............................    1.506108826170
Rho60* .........................  770.352512411255
alpha60 ........................    0.000640784451
delta t, ˚F ....................   -1.000253583731
Ctl ............................    1.000640828053
Fp,psi .........................    0.658572575399
P in psi .......................    0.000000000000
Cpl ............................    1.000000000000
Ctpl ...........................    1.000640828053
Density, kg/cu m, at 15˚C ......  770.842780077632
Ctl,60 .........................    1.000640828053

    Step 4
  Modify Ctl* factor and calculate Ctpl factor for base temperature of 15˚C
Ctl ............................    0.920854015583
Ctpl ...........................    0.935469615495
Ctpl, rounded ..................    0.93547
Fp,kPa .........................    0.156160024039

    Step 5
Volume at base conditions ......            9354.7
```

```
                   Example 2
    Input Data
Commodity ......................  Generalized Crude Oil
Base temperature, ˚C ..........            15
t observed temperature, ˚C .....         26.8
P observed pressure, kPa .......           -5
  Forcing negative pressure to zero
Observed density, kg/cu m ......        823.7
Volume at observed t & P .......         1000

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature ˚F ......        80.24
T base temperature, ˚F .........           59
P observed, pressure, psi ......            0

    Step 2
  Correcting observed density to 60˚F & 0 psi reference conditions
            Iteration(m) ..... 0                   1                   2
Rho60(m) ...........  823.700000000000    832.023208166070    832.024016649536
K0(m) ..............  341.095700000000    341.095700000000    341.095700000000
K1(m) ..............    0.000000000000      0.000000000000      0.000000000000
K2(m) ..............    0.000000000000      0.000000000000      0.000000000000
A(m) ...............    0.000003456244      0.000003387440      0.000003387433
B(m) ...............    2.000000000000      2.000000000000      2.000000000000
Rho60*(m) ..........  823.702846901034    832.026026588046    832.026835068774
alpha60(m) .........    0.000502730357      0.000492722530      0.000492721573
Ctl,60(m) ..........    0.989791642730      0.989995441596      0.989995461094
d_alpha(m) .........    2.000000000000      2.000000000000      2.000000000000
Fp(m) ..............    0.583524571256      0.566975407116      0.566973846350
Cpl(m) .............    1.000000000000      1.000000000000      1.000000000000
Ctpl(m) ............    0.989791642730      0.989995441596      0.989995461094
Rho60(m)xCtpl,60(m)   815.291376116514    823.699183386120    823.700000004313
delta Rho60(m) .....    8.408623883486      0.000816613880     -0.000000004313
E(m) ...............    8.495347425137      0.000824866303
Dt(m) ..............    0.020681839939      0.020263663462
Dp(m) ..............   -0.000000000000     -0.000000000000
delta Rho(m) .......    8.323208166070      0.000808483466
Rho60(m+1) .........  832.023208166070    832.024016649536
  Output values
Rho60 ..........................  832.024016649536
Ctl* ...........................    0.989995461094
Fp,psi .........................    0.566973846350
Cpl ............................    1.000000000000
Ctpl* ..........................    0.989995461094

    Step 3
  Correcting 60˚F density to 15˚C base conditions:
t, ˚F ..........................   59.000000000000
t corrected to IPTS-68 ˚F ......   59.006621316269
A ..............................    0.000003387433
B ..............................    2.000000000000
Rho60* .........................  832.026835068774
alpha60 ........................    0.000492721573
delta t, ˚F ....................   -1.000253583731
Ctl ............................    1.000492776246
Fp,psi .........................    0.526407914039
P in psi .......................    0.000000000000
Cpl ............................    1.000000000000
Ctpl ...........................    1.000492776246
Density, kg/cu m, at 15˚C ......  832.434018321149
Ctl,60 .........................    1.000492776246

    Step 4
  Modify Ctl* factor and calculate Ctpl factor for base temperature of 15˚C
Ctl ............................    0.989507855128
Ctpl ...........................    0.989507855128
Ctpl, rounded ..................    0.98951
Fp,kPa .........................    0.082232607523

    Step 5
Volume at base conditions ......           989.51
```

```
                  Example 3
    Input Data
Commodity ......................  Generalized Crude Oil
Base temperature, °C ...........            15
t observed temperature, °C .....           -50
P observed pressure, kPa .......           115
Observed density, kg/cu m ......         722.6
Volume at observed t & P .......        145902

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature °F ......           -58
T base temperature, °F .........            59
P observed, pressure, psi ......  16.6793405482

    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
Fp(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)xCtpl,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
Fp,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
Fp,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
Fp,kPa .......................    0.087329935201

    Step 5
Volume at base conditions ......      158685.93324
```

```
                   Example 4
    Input Data
Commodity ......................   Generalized Refined Product
Base temperature, °C ...........              15
t observed temperature, °C .....              20
P observed pressure, bar .......           11.25
Observed density, kg/cu m ......           865.6
Volume at observed t & P .......           99873

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature °F ......              68
T base temperature, °F .........              59
P observed, pressure, psi ......  163.167461884

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
            Iteration(m) ..... 0                    1                    2
Commodity .........        fuel oil             fuel oil             fuel oil
Rho60(m) ..........  865.600000000000     868.036205969593     868.036119189528
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) ..............    0.000003098311       0.000003086948       0.000003086948
B(m) ..............    1.307613432453       1.307015151471       1.307015172741
Rho60*(m) .........  865.602681897543     868.038885551754     868.038798771772
alpha60(m) ........    0.000450668230       0.000449015417       0.000449015475
Ctl,60(m) .........    0.996389842254       0.996403096509       0.996403096038
d_alpha(m) ........    1.300000000000       1.300000000000       1.300000000000
Fp(m) .............    0.489265549347       0.485793045037       0.485793167772
Cpl(m) ............    1.000798960006       1.000793284984       1.000793285184
Ctpl(m) ...........    0.997185917889       0.997193528123       0.997193527852
Rho60(m)xCtpl,60(m)  863.164130524430     865.600086769462     865.599999997702
delta Rho60(m) ....    2.435869475570      -0.000086769462       0.000000002298
E(m) ..............    2.442743556515      -0.000087013664
Dt(m) .............    0.004713986507       0.004696599303
Dp(m) .............   -0.002030474931      -0.002004751931
delta Rho(m) ......    2.436205969593      -0.000086780065
Rho60(m+1) ........  868.036205969593     868.036119189528
  Output values
Rho60 ..........................  868.036119189528
Ctl* ...........................    0.996403096038
Fp,psi .........................    0.485793167772
Cpl ............................    1.000793285184
Ctpl* ..........................    0.997193527852

    Step 3
  Correcting 60°F density to 15°C base conditions:
t, °F ..........................   59.000000000000
t corrected to IPTS-68 °F ......   59.006621316269
A ..............................    0.000003086948
B ..............................    1.307015172741
Rho60* .........................  868.038798771772
alpha60 ........................    0.000449015475
delta t, °F ....................   -1.000253583731
Ctl ............................    1.000449070985
Fp,psi .........................    0.471908186296
P in psi .......................    0.000000000000
Cpl ............................    1.000000000000
Ctpl ...........................    1.000449070985
Density, kg/cu m, at 15°C ......  868.425929024799
Ctl,60 .........................    1.000449070985

    Step 4
  Modify Ctl* factor and calculate Ctpl factor for base temperature of 15°C
Ctl ............................    0.995955841168
Ctpl ...........................    0.996745918181
Ctpl, rounded ..................    0.99675
Fp,bar .........................    7.045834505444

    Step 5
Volume at base conditions ......       99548.41275
```

```
                Example 5
    Input Data
Commodity ......................   Generalized Refined Product
Base temperature, °C ...........             15
t observed temperature, °C .....          22.25
P observed pressure, kPa .......         2587.3
Observed density, kg/cu m ......         817.59
Volume at observed t & P .......         400.15

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature °F ......          72.05
T base temperature, °F .........             59
P observed, pressure, psi ......  375.256154785

    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) ...........  817.590000000000    820.692548571452    820.692469224813
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) ...............    0.000003397074      0.000003371438      0.000003371438
B(m) ...............    2.000000000000      2.000000000000      2.000000000000
Rho60*(m) ..........  817.592777407010    820.695315478794    820.695236132422
alpha60(m) .........    0.000494123827      0.000490394939      0.000490395034
Ctl,60(m) ..........    0.994033739721      0.994078841829      0.994078840682
d_alpha(m) .........    2.000000000000      2.000000000000      2.000000000000
Fp(m) ..............    0.578919272217      0.572669043746      0.572669201827
Cpl(m) .............    1.002177159928      1.002153603876      1.002153604472
Ctpl(m) ............    0.996197910146      0.996219693875      0.996219693318
Rho60(m)xCtpl,60(m)   814.481449356498    817.590079503693    817.589999999757
delta Rho60(m) .....    3.108550643502     -0.000079503693      0.000000000243
E(m) ...............    3.120414740728     -0.000079805382
Dt(m) ..............    0.012021831912      0.011930259927
Dp(m) ..............   -0.006263285716     -0.006148764741
delta Rho(m) .......    3.102548571452     -0.000079346639
Rho60(m+1) .........  820.692548571452    820.692469224813
  Output values
Rho60 ..........................  820.692469224813
Ctl* ...........................    0.994078840682
Fp,psi .........................    0.572669201827
Cpl ............................    1.002153604472
Ctpl* ..........................    0.996219693318

    Step 3
  Correcting 60°F density to 15°C base conditions:
t, °F ..........................   59.000000000000
t corrected to IPTS-68 °F ......   59.006621316269
A ..............................    0.000003371438
B ..............................    2.000000000000
Rho60* .........................  820.695236132422
alpha60 ........................    0.000490395034
delta t, °F ....................   -1.000253583731
Ctl ............................    1.000490449780
Fp,psi .........................    0.546468815042
P in psi .......................    0.000000000000
Cpl ............................    1.000000000000
Ctpl ...........................    1.000490449780
Density, kg/cu m, at 15°C ......  821.094977665680
Ctl,60 .........................    1.000490449780

    Step 4
  Modify Ctl* factor and calculate Ctpl factor for base temperature of 15°C
Ctl ............................    0.993591533933
Ctpl ...........................    0.995731337103
Ctpl, rounded ..................    0.99573
Fp,kPa .........................    0.083058649032

    Step 5
Volume at base conditions ......       398.4413595
```

```
                 Example 6
    Input Data
Commodity ......................  Generalized Refined Product
Base temperature, °C ...........              15
t observed temperature, °C .....            1.85
P observed pressure, kPa .......            1835
Observed density, kg/cu m ......           798.9
Volume at observed t & P .......          1998.7

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature °F ......           35.33
T base temperature, °F .........              59
P observed, pressure, psi ......  266.144260052

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
            Iteration(m) ..... 0                    1                   2                   3
Commodity ..........       jet fuel           transition          transition          transition
Rho60(m) ...........  798.900000000000    787.400070634008    787.384039337631    787.383920775576
K0(m) ..............  330.301000000000      1.48906700000e+03   1.48906700000e+03   1.48906700000e+03
K1(m) ..............    0.000000000000      0.000000000000      0.000000000000      0.000000000000
K2(m) ..............    0.000000000000     -0.001868400000     -0.001868400000     -0.001868400000
A(m) ...............    0.000003557880      0.000003666557      0.000003667230      0.000003667235
B(m) ...............    2.000000000000      9.006605007576      9.005320384922      9.005310885749
Rho60*(m) ..........  798.902842383204    787.402957599810    787.386926774049    787.386808215474
alpha60(m) .........    0.000517513825      0.000533307729      0.000533405525      0.000533406248
Ctl,60(m) ..........    1.012720045074      1.013106625035      1.013109018441      1.013109036142
d_alpha(m) .........    2.000000000000      8.500000000000      8.500000000000      8.500000000000
Fp(m) ..............    0.539405165049      0.561636550375      0.561668867244      0.561669106263
Cpl(m) .............    1.001437659784      1.001497001104      1.001497087371      1.001497088009
Ctpl(m) ............    1.014175991955      1.014623246771      1.014625731158      1.014625749532
Rho60(m)xCtpl,60(m)   810.225199972732    798.914416174111    798.900106615004    798.900000786490
delta Rho60(m) .....  -11.325199972732     -0.014416174111     -0.000106615004     -0.000000786490
E(m) ...............  -11.166898114894     -0.014208401155     -0.000105078159
Dt(m) ..............   -0.025012538589     -0.109477820520     -0.109497464438
Dp(m) ..............   -0.003946878508     -0.004230714297     -0.004231130387
delta Rho(m) .......  -11.499929365992     -0.016031296377     -0.000118562055
Rho60(m+1) .........  787.400070634008    787.384039337631    787.383920775576
  Output values
Rho60 ..........................  787.383920775576
Ctl* ...........................    1.013109036142
Fp,psi .........................    0.561669106263
Cpl ............................    1.001497088009
Ctpl* ..........................    1.014625749532

    Step 3
  Correcting 60°F density to 15°C base conditions:
t, °F ..........................  59.000000000000
t corrected to IPTS-68 °F ......  59.006621316269
A ..............................   0.000003667235
B ..............................   9.005310885749
Rho60* .........................  787.386808215474
alpha60 ........................   0.000533406248
delta t, °F ....................  -1.000253583731
Ctl ............................   1.000533459147
Fp,psi .........................   0.615797119674
P in psi .......................   0.000000000000
Cpl ............................   1.000000000000
Ctpl ...........................   1.000533459147
Density, kg/cu m, at 15°C ......  787.803957930685
Ctl,60 .........................   1.000533459147

    Step 4
  Modify Ctl* factor and calculate Ctpl factor for base temperature of 15°C
Ctl ............................   1.012568872015
Ctpl ...........................   1.014084776732
Ctpl, rounded ..................   1.01408
Fp,kPa .........................   0.081463219989

    Step 5
Volume at base conditions ......       2026.841696
```

Example 7

Input Data

Commodity	Generalized Refined Product
Base temperature, ˚C	15
t observed temperature, ˚C	5.47
P observed pressure, kPa	1710
Observed density, kg/cu m	779.6
Volume at observed t & P	89987

Computed Data - last digit is rounded for display purposes

Step 1

Convert to customary units

t observed temperature ˚F	41.846
T base temperature, ˚F	59
P observed, pressure, psi	248.014542064

Step 2

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

Iteration(m)	0	1	2	3
Commodity	transition	gasoline	gasoline	gasoline
Rho60(m)	779.600000000000	769.400165598634	769.471459445302	769.471465004491
K0(m)	1.48906700000e+03	192.457100000000	192.457100000000	192.457100000000
K1(m)	0.000000000000	0.243800000000	0.243800000000	0.243800000000
K2(m)	-0.001868400000	0.000000000000	0.000000000000	0.000000000000
A(m)	0.000003998615	0.000004413544	0.000004412928	0.000004412927
B(m)	8.424754338437	1.506416929692	1.506393769168	1.506393767363
Rho60*(m)	779.603117231299	769.403561376653	769.474855063988	769.474860623165
alpha60(m)	0.000581605759	0.000641975247	0.000641885648	0.000641885641
Ctl,60(m)	1.010526957658	1.011615628566	1.011614013345	1.011614013219
d_alpha(m)	8.500000000000	1.500000000000	1.500000000000	1.500000000000
Fp(m)	0.592937732948	0.616603375978	0.616431384264	0.616431370856
Cpl(m)	1.001472737569	1.001531608276	1.001531180404	1.001531180371
Ctpl(m)	1.012015198674	1.013165027434	1.013162976899	1.013162976739
Rho60(m)xCtpl,60(m)	788.967048886192	779.529339886637	779.599994490212	779.599999999564
delta Rho60(m)	-9.367048886192	0.070660113363	0.000005509788	0.000000000436
E(m)	-9.255838151904	0.069741958565	0.000005438205	
Dt(m)	-0.088230857221	-0.017155646821	-0.017153297920	
Dp(m)	-0.004319297253	-0.004611843291	-0.004609700597	
delta Rho(m)	-10.199834401366	0.071293846668	0.000005559189	
Rho60(m+1)	769.400165598634	769.471459445302	769.471465004491	

Output values

Rho60	769.471465004491
Ctl*	1.011614013219
Fp,psi	0.616431370856
Cpl	1.001531180371
Ctpl*	1.013162976739

Step 3

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

t, ˚F	59.000000000000
t corrected to IPTS-68 ˚F	59.006621316269
A	0.000004412927
B	1.506393767363
Rho60*	769.474860623165
alpha60	0.000641885641
delta t, ˚F	-1.000253583731
Ctl	1.000641929113
Fp,psi	0.660935428188
P in psi	0.000000000000
Cpl	1.000000000000
Ctpl	1.000641929113
Density, kg/cu m, at 15˚C	769.965411139556
Ctl,60	1.000641929113

Step 4

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

Ctl	1.010965045324
Ctpl	1.012513015157
Ctpl, rounded	1.01251
Fp,kPa	0.089405815297

Step 5

Volume at base conditions	91112.73737

```
                   Example 8
    Input Data
Commodity ......................  Specialized Liquid
Base temperature, ˚C ...........              15
Alpha at 60˚F per ˚F ...........       0.0005763
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 ......          84.524
T base temperature, ˚F .........              59
P observed, pressure, psi ......   57.2899088394

    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
Fp(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
Fp,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
Fp,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
Fp,kPa ........................    0.074832551126

    Step 5
Volume at base conditions ......       8378.286189
```

```
                   Example 9
    Input Data
Commodity ......................  Generalized Lube Oil
Base temperature, °C ..........            15
t observed temperature, °C .....        -49.97
P observed pressure, bar .......          31.1
Observed density, kg/cu m ......        1204.6
Volume at observed t & P .......           100

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature °F ......       -57.946
T base temperature, °F .........            59
P observed, pressure, psi ......  451.067383521

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
  Note, Rho60 has been limited to the maximum table value in one or more cases.

            Iteration(m) ..... 0                    1                    2
Rho60(m) ..........    1.16350000000e+03   1.16272940734e+03   1.16272940184e+03
K0(m) .............    0.000000000000      0.000000000000      0.000000000000
K1(m) .............    0.348780000000      0.348780000000      0.348780000000
K2(m) .............    0.000000000000      0.000000000000      0.000000000000
A(m) ..............    0.000002060874      0.000002062240      0.000002062240
B(m) ..............    1.000000000000      1.000000000000      1.000000000000
Rho60*(m) .........    1.16350239783e+03   1.16273180517e+03   1.16273179967e+03
alpha60(m) ........    0.000299767324      0.000299965993      0.000299965994
Ctl,60(m) .........    1.034960505816      1.034983389675      1.034983389839
d_alpha(m) ........    1.000000000000      1.000000000000      1.000000000000
Fp(m) .............    0.219674012573      0.219815870301      0.219815871316
Cpl(m) ............    1.000991860633      1.000992501778      1.000992501782
Ctpl(m) ...........    1.035987042399      1.036010612529      1.036010612698
Rho60(m)xCtpl,60(m)    1.20537092383e+03   1.20460000551e+03   1.20460000000e+03
delta Rho60(m) .....  -0.770923831696     -0.000005508255     -0.000000000037
E(m) ..............   -0.744144279942     -0.000005316794
Dt(m) .............   -0.033356241627     -0.033377021810
Dp(m) .............   -0.000965881756     -0.000967787625
delta Rho(m) .......  -0.770592656165     -0.000005505893
Rho60(m+1) .........   1.16272940734e+03   1.16272940184e+03
  Output values
Rho60 .........................    1.16272940184e+03
Ctl* ..........................    1.034983389839
Fp,psi ........................    0.219815871316
Cpl ...........................    1.000992501782
Ctpl* .........................    1.036010612698

    Step 3
  Correcting 60°F density to 15°C base conditions:
t, °F .........................   59.000000000000
t corrected to IPTS-68 °F ......   59.006621316269
A .............................    0.000002062240
B .............................    1.000000000000
Rho60* ........................    1.16273179967e+03
alpha60 .......................    0.000299965994
delta t, °F ...................   -1.000253583731
Ctl ...........................    1.000300016026
Fp,psi ........................    0.273073437320
P in psi ......................    0.000000000000
Cpl ...........................    1.000000000000
Ctpl ..........................    1.000300016026
Density, kg/cu m, at 15°C ...... 1163.078239292499
Ctl,60 ........................    1.000300016026

    Step 4
  Modify Ctl* factor and calculate Ctpl factor for base temperature of 15°C
Ctl ...........................    1.034672971366
Ctpl ..........................    1.035699886134
Ctpl, rounded .................    1.03570
Fp,bar ........................    3.188159804848

    Step 5
Volume at base conditions ......            103.57
```

```
                   Example 10
    Input Data
Commodity ......................  Generalized Lube Oil
Base temperature, °C ..........              15
t observed temperature, °C .....            150
P observed pressure, kPa .......            100
Observed density, kg/cu m ......          734.3
Volume at observed t & P .......         987.37

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature °F ......            302
T base temperature, °F .........             59
P observed, pressure, psi ......  14.5037743897

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
  Note, Rho60 has been limited to the minimum table value in one or more cases.

            Iteration(m) ..... 0                    1                    2
Rho60(m) ..........  800.900000000000    820.631387494658    820.630280570930
K0(m) .............    0.000000000000      0.000000000000      0.000000000000
K1(m) .............    0.348780000000      0.348780000000      0.348780000000
K2(m) .............    0.000000000000      0.000000000000      0.000000000000
A(m) ..............    0.000002993915      0.000002921929      0.000002921933
B(m) ..............    1.000000000000      1.000000000000      1.000000000000
Rho60*(m) .........  800.902397828986    820.633785323592    820.632678399864
alpha60(m) ........    0.000435483775      0.000425012967      0.000425013540
Ctl,60(m) .........    0.891989089232      0.894630496606      0.894630352025
d_alpha(m) ........    1.000000000000      1.000000000000      1.000000000000
Fp(m) .............    1.460680703550      1.307424930168      1.307432768085
Cpl(m) ............    1.000211898725      1.000189661927      1.000189663064
Ctpl(m) ...........    0.892178100583      0.894800173950      0.894800030358
Rho60(m)xCtpl,60(m)  714.545440757119    734.301108279052    734.299999967969
delta Rho60(m) .....  19.754559242881     -0.001108279052      0.000000032031
E(m) ..............   22.141945907400     -0.001238577153
Dt(m) .............    0.123157370141      0.119779166844
Dp(m) .............   -0.000988647166     -0.000842856189
delta Rho(m) .......  19.731387494658     -0.001106923728
Rho60(m+1) ........  820.631387494658    820.630280570930
  Output values
Rho60 .........................  820.630280570930
Ctl* ..........................    0.894630352025
Fp,psi ........................    1.307432768085
Cpl ...........................    1.000189663064
Ctpl* .........................    0.894800030358

    Step 3
  Correcting 60°F density to 15°C base conditions:
t, °F .........................   59.000000000000
t corrected to IPTS-68 °F ......   59.006621316269
A .............................    0.000002921933
B .............................    1.000000000000
Rho60* ........................  820.632678399864
alpha60 .......................    0.000425013540
delta t, °F ...................   -1.000253583731
Ctl ...........................    1.000425069038
Fp,psi ........................    0.546584015650
P in psi ......................    0.000000000000
Cpl ...........................    1.000000000000
Ctpl ..........................    1.000425069038
Density, kg/cu m, at 15°C ......  820.979105094945
Ctl,60 ........................    1.000425069038

    Step 4
  Modify Ctl* factor and calculate Ctpl factor for base temperature of 15°C
Ctl ...........................    0.894250233938
Ctpl ..........................    0.894419840177
Ctpl, rounded .................    0.89442
Fp,kPa ........................    0.189627098980

    Step 5
Volume at base conditions ......       883.1234754
```

```
                   Example 11
    Input Data
Commodity .....................   Generalized Crude Oil
Base temperature, ˚C ..........            15
t observed temperature, ˚C .....        -50.05
P observed pressure, kPa .......             0
Observed density, kg/cu m ......        470.27
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature ˚F ......        -58.09
T base temperature, ˚F .........            59
P observed, pressure, psi ......             0
Observed temperature less than -50°C (-58˚F) - outside limits of table
Density less than 470.4 kg/cu m - outside limits of table


                   Example 12
    Input Data
Commodity .....................   Generalized Crude Oil
Base temperature, ˚C ..........            15
t observed temperature, ˚C .....        150.03
P observed pressure, bar .......       103.425
Observed density, kg/cu m ......       1201.85
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature ˚F ......       302.054
T base temperature, ˚F .........            59
P observed, pressure, psi ......  1500.05286626
Observed temperature greater than 150˚C (302˚F) - outside limits of table
Observed pressure greater than 1500 psi - outside limits of table
Density greater than 1201.8 kg/cu m - outside limits of table


                   Example 13
    Input Data
Commodity .....................   Generalized Refined Product
Base temperature, ˚C ..........            15
t observed temperature, ˚C .....        -50.05
P observed pressure, kPa .......             0
Observed density, kg/cu m ......        470.17
Volume at observed t & P .......          1000

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature ˚F ......        -58.09
T base temperature, ˚F .........            59
P observed, pressure, psi ......             0
Observed temperature less than -50°C (-58˚F) - outside limits of table
Density less than 470.3 kg/cu m - outside limits of table
```

```
                   Example 14
    Input Data
Commodity ......................   Generalized Refined Product
Base temperature, ˚C ...........             15
t observed temperature, ˚C .....         150.02
P observed pressure, kPa .......        10342.5
Observed density, kg/cu m ......        1209.56
Volume at observed t & P .......           1000

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature ˚F ......        302.036
T base temperature, ˚F .........             59
P observed, pressure, psi ......  1500.05286626
Observed temperature greater than 150˚C (302˚F) - outside limits of table
Observed pressure greater than 1500 psi - outside limits of table
Density greater than 1209.5 kg/cu m - outside limits of table


                   Example 15
    Input Data
Commodity ......................   Generalized Lube Oil
Base temperature, ˚C ...........             15
t observed temperature, ˚C .....          15.56
P observed pressure, kPa .......        10342.5
Observed density, kg/cu m ......        1208.52
Volume at observed t & P .......           1000

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature ˚F ......         60.008
T base temperature, ˚F .........             59
P observed, pressure, psi ......  1500.05286626
Observed pressure greater than 1500 psi - outside limits of table
Density greater than 1208.3 kg/cu m - outside limits of table


                   Example 16
    Input Data
Commodity ......................   Generalized Lube Oil
Base temperature, ˚C ...........             15
t observed temperature, ˚C .....          22.42
P observed pressure, kPa .......              0
Observed density, kg/cu m ......        714.245
Volume at observed t & P .......           1000

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
t observed temperature ˚F ......         72.356
T base temperature, ˚F .........             59
P observed, pressure, psi ......              0
Density less than 714.3 kg/cu m - outside limits of table
```

Example 17

Input Data

Commodity	Generalized Lube Oil
Base temperature, ˚C	15
t observed temperature, ˚C	0.42
P observed pressure, kPa	0
Observed density, kg/cu m	723.45
Volume at observed t & P	1000

Computed Data - last digit is rounded for display purposes

Step 1

Convert to customary units

t observed temperature ˚F	32.756
T base temperature, ˚F	59
P observed, pressure, psi	0

Step 2

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

Note, Rho60 has been limited to the minimum table value in one or more cases.

Iteration(m)	0	1	2	...	14
Rho60(m)	800.900000000000	800.900000000000	800.900000000000	...	800.900000000000
K0(m)	0.000000000000	0.000000000000	0.000000000000	...	0.000000000000
K1(m)	0.348780000000	0.348780000000	0.348780000000	...	0.348780000000
K2(m)	0.000000000000	0.000000000000	0.000000000000	...	0.000000000000
A(m)	0.000002993915	0.000002993915	0.000002993915	...	0.000002993915
B(m)	1.000000000000	1.000000000000	1.000000000000	...	1.000000000000
Rho60*(m)	800.902397828986	800.902397828986	800.902397828986	...	800.902397828986
alpha60(m)	0.000435483775	0.000435483775	0.000435483775	...	0.000435483775
Ctl,60(m)	1.011823984996	1.011823984996	1.011823984996	...	1.011823984996
d_alpha(m)	1.000000000000	1.000000000000	1.000000000000	...	1.000000000000
Fp(m)	0.530563546266	0.530563546266	0.530563546266	...	0.530563546266
Cpl(m)	1.000000000000	1.000000000000	1.000000000000	...	1.000000000000
Ctpl(m)	1.011823984996	1.011823984996	1.011823984996	...	1.011823984996
Rho60(m)xCtpl,60(m)	810.369829583667	810.369829583667	810.369829583667	...	810.369829583667
delta Rho60(m)	-86.919829583667	-86.919829583667	-86.919829583667	...	-86.919829583667
E(m)	-85.904100784852	-85.904100784852	-85.904100784852	...	-85.904100784852
Dt(m)	-0.011639100638	-0.011639100638	-0.011639100638	...	-0.011639100638
Dp(m)	-0.000000000000	-0.000000000000	-0.000000000000	...	-0.000000000000
delta Rho(m)	0.000000000000	0.000000000000	0.000000000000	...	0.000000000000
Rho60(m+1)	800.900000000000	800.900000000000	800.900000000000	...	800.900000000000

Convergence not achieved after 15 iterations, solution not found.

Density is outside limits of procedur

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

Note: For liquids with an equilibrium vapor pressure greater than atmospheric, see 11.1.3.4.

Outline of Calculations

This procedure combines those in 11.1.6.2 and 11.1.6.1. The density at conditions of 60°F and 0 psig that is consistent with the observed density is first calculated. This density is then corrected to the alternate temperature and pressure conditions. The corresponding density at the metric base temperature (15°C or 20°C) is also calculated.

The procedure has been written assuming that the input values are all in the proper units (°C, kPa or bar (gauge), and kg/m³). If they are not in the proper units then apply the procedures in 11.1.5.1. The density values calculated by this procedure are in kg/m³.

Input Values

Commodity group describing liquid (if α_{60} not input)

α_{60}	Pre-calculated 60°F thermal expansion factor (if commodity group not given)
V_o	Volume at observed conditions (any valid set of units, such as liters, cubic metres, and barrels)
ρ_o	Observed density (kg/m³)
t_o	Temperature at which the observed density was measured (°C)
P_o	Pressure at which the observed density was measured (kPa or bar (gauge))
t	Alternate temperature at which density is desired (°C)
P	Alternate pressure at which density is desired (kPa or bar (gauge))
T	Base temperature (15°C or 20°C)

Output Values

ρ	Density at alternate conditions t and P (kg/m³)
ρ_T	Density at base temperature conditions T and 0 psig (kg/m³)
$C_{TL,o}$	Volume correction factor due to temperature between the base and observed temperatures
$C_{PL,o}$	Volume correction factor due to pressure between the base and observed pressures at the observed temperature
$F_{P,o}$	Scaled compressibility factor at the observed temperature (kPa^{-1} or bar^{-1})
$C_{TPL,o}$	Combined volume correction factor due to temperature and pressure between the base and observed conditions
C_{TL}	Volume correction factor due to temperature between the base and alternate temperatures
C_{PL}	Volume correction factor due to pressure between the base and alternate pressures at the alternate temperature
F_P	Scaled compressibility factor at the alternate temperature (kPa^{-1} or bar^{-1})

C_{TPL} Combined volume correction factor due to temperature and pressure between the base and alternate conditions

Optional Output Values

V Volume at alternate conditions t and P (same units as V_o)

V_T Volume at base conditions (same set of units as V)

ρ_{60} Density at 60°F and 0 psig (kg/m³)

Intermediate Values

$T_{\circ F}$ Base temperature T converted to units of °F (°F)

$t_{o,\circ F}$ Density measurement temperature t_o converted to units of °F (°F)

$P_{o,psi}$ Density measurement pressure P_o converted to units of psig (psig)

$t_{\circ F}$ Alternate temperature t converted to units of °F (°F)

P_{psi} Alternate pressure P converted to units of psig (psig)

$C_{TL,60}$ CTL value correcting ρ_{60} to ρ_T

$C^*_{TL,o}$ CTL value correcting ρ_{60} to the observed temperature

$C^*_{TPL,o}$ CTPL value correcting ρ_{60} to the observed temperature and pressure

$F_{P,o,psi}$ Scaled compressibility factor at observed temperature (psi^{-1})

C^*_{TL} CTL value correcting ρ_{60} to the alternate temperature

C^*_{TPL} CTPL value correcting ρ_{60} to the alternate temperature and pressure

$F_{P,psi}$ Scaled compressibility factor at alternate temperature (psi^{-1})

Calculation Procedure

Step 1: Convert the base temperature, density measurement temperature and pressure, and alternate temperature and pressure into customary units using equations in 11.1.5.1. Call these variables $T_{\circ F}$, $t_{o,\circ F}$, $P_{o,psi}$, $t_{\circ F}$, and P_{psi}.

Step 2: Calculate the density at 60°F, ρ_{60}, corresponding to the observed density ρ_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 $F_{P,o,psi}$.

Step 3: Using this value of ρ_{60} from Step 2, calculate the correction factors for the density ρ 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 $F_{P,psi}$.

Step 4: Using the value of ρ_{60} from Step 2, calculate the associated metric base density value ρ_T at $T_{\circ F}$ using the procedure in 11.1.6.1. The pressure correction need not be calculated since the metric base pressure (0 kPa (gauge)) is the same as the base pressure in 11.1.6.1 (0 psig). Call the CTL associated with this step $C_{TL,60}$.

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

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

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

and the combined temperature and pressure correction factors are:

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

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

Round these values of $C_{TPL,o}$ and C_{TPL} consistent with 11.1.5.4.

Modify the scaled compressibility factor for the metric pressure units:

$$\left.\begin{aligned} F_{P,o} &= \frac{F_{P,o,psi}}{6.894757} \\ F_P &= \frac{F_{P,psi}}{6.894757} \end{aligned}\right\} \text{ for kPa}$$

$$\left.\begin{aligned} F_{P,o} &= \frac{F_{P,o,psi}}{0.06894757} \\ F_P &= \frac{F_{P,psi}}{0.06894757} \end{aligned}\right\} \text{ for bar}$$

Step 6: Calculate the volumes at the base conditions:

$$V_T = V_o \cdot C_{TPL,o}$$

and at the alternate conditions t and P:

$$V = \frac{V_T}{C_{TPL}}$$

Step 7: Exit from this procedure.

Example Calculations

```
                   Example 1
    Input Data
Commodity ......................  Generalized Crude Oil
t observed, °C ................          26.82
P observed pressure, kPa .......            -5
Base temperature, °C ..........             15
t alternate temp, °C ..........             90
P alternate pressure, kPa ......             0
  Forcing negative pressure(s) to zero
Observed density, kg/cu m ......       823.687
Volume at observed t & P .......       1247.65

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
T base, °F ....................             59
t observed, °F ................         80.276
t alternate temperature, °F ....           194
P observed pressure, PSI .......             0
P alternate pressure, PSI ......             0

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
            Iteration(m) ..... 0                  1                    2
Rho60(m) ........... 823.687000000000   832.025033300798   832.025846221517
K0(m) ............. 341.095700000000   341.095700000000   341.095700000000
K1(m) .............   0.000000000000     0.000000000000     0.000000000000
K2(m) .............   0.000000000000     0.000000000000     0.000000000000
A(m) ..............   0.000003456353     0.000003387425     0.000003387418
B(m) ..............   2.000000000000     2.000000000000     2.000000000000
Rho60*(m) .......... 823.689846945966   832.027851716592   832.028664634558
alpha60(m) .........   0.000502746226     0.000492720369     0.000492719406
Ctl,60(m) ..........   0.989773108757     0.989977640002     0.989977659642
d_alpha(m) .........   2.000000000000     2.000000000000     2.000000000000
Fp(m) .............   0.583626059244     0.567043227602     0.567041657958
Cpl(m) ............   1.000000000000     1.000000000000     1.000000000000
Ctpl(m) ...........   0.989773108757     0.989977640002     0.989977659642
Rho60(m)xCtpl,60(m)  815.263242632906   823.686178889619   823.687000004344
delta Rho60(m) .....   8.423757367094     0.000821110381    -0.000000004344
E(m) ..............   8.510796355814     0.000829423158
Dt(m) .............   0.020719880670     0.020300182163
Dp(m) .............  -0.000000000000    -0.000000000000
delta Rho(m) .......   8.338033300798     0.000812920720
Rho60(m+1) ......... 832.025033300798   832.025846221517
  Output values
Rho60 .........................  832.025846221517
Ctl,o .........................    0.989977659642
Fp,o,psi ......................    0.567041657958
Cpl,o .........................    1.000000000000
Ctpl,o ........................    0.989977659642

    Step 3
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F .........................  194.000000000000
t corrected to IPTS-68 °F ......  194.041903907457
A .............................    0.000003387418
B .............................    2.000000000000
Rho60* ........................  832.028664634558
alpha60 .......................    0.000492719406
delta t, °F ...................  134.035029007457
Ctl* ..........................    0.932831011404
Fp,psi ........................    0.843798579721
P in psi ......................    0.000000000000
Cpl ...........................    1.000000000000
Ctpl* .........................    0.932831011404
Density at t & P, kg/cu m ......  776.139511645102

    Step 4
  Correcting 60°F density to 15°C base conditions:
t, °F .........................   59.000000000000
t corrected to IPTS-68 °F ......   59.006621316269
A .............................    0.000003387418
B .............................    2.000000000000
Rho60* ........................  832.028664634558
alpha60 .......................    0.000492719406
delta t, °F ...................   -1.000253583731
Ctl ...........................    1.000492774079
Fp,psi ........................    0.526404800069
```

```
P in psi ......................   0.000000000000
Cpl ...........................   1.000000000000
Ctpl ..........................   1.000492774079
Density, kg/cu m, at 15°C/0 kPa  832.435846991832
Ctl,60 ........................   1.000492774079

    Step 5
  Modify Ctl* factor and calculate the Ctpl factor for 15°C base conditions:
Ctl,o .........................   0.989490064587
Ctl ...........................   0.932371562866
Ctpl,o ........................   0.989490064587
Ctpl,o, rounded ...............   0.98949
Ctpl ..........................   0.932371562866
Ctpl, rounded .................   0.93237
Fp,o,kPa ......................   0.082242442766
Fp,kPa ........................   0.122382642306

    Step 6
Volume at base conditions ......  1234.537198500
Volume at alternate conditions .  1324.085071914
```

```
                   Example 2
    Input Data
Commodity ......................  Generalized Crude Oil
t observed, °C .................           -40
P observed pressure, bar .......          2.15
Base temperature, °C ...........            15
t alternate temp, °C ...........            90
P alternate pressure, bar ......         24.35
Observed density, kg/cu m ......         758.7
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
t observed, °F .................           -40
t alternate temperature, °F ....           194
P observed pressure, PSI .......  31.1831149379
P alternate pressure, PSI ......   353.16690639

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
            Iteration(m) ..... 0                  1                   2                   3
Rho60(m) ..........  758.700000000000    711.913889867543    711.744703424067    711.744696439390
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) ..............    0.000004073825      0.000004626873      0.000004629073      0.000004629073
B(m) ..............    2.000000000000      2.000000000000      2.000000000000      2.000000000000
Rho60*(m) .........  758.703090801856    711.917183791842    711.747998131348    711.747991146704
alpha60(m) ........    0.000592560281      0.000673003454      0.000673323444      0.000673323457
Ctl,60(m) .........    1.058083142973      1.065762254490      1.065792691351      1.065792692608
d_alpha(m) ........    2.000000000000      2.000000000000      2.000000000000      2.000000000000
Fp(m) .............    0.457240895647      0.539420913206      0.539775688302      0.539775702959
Cpl(m) ............    1.000142602287      1.000168236542      1.000168347209      1.000168347214
Ctpl(m) ...........    1.058234028049      1.065941554646      1.065972114576      1.065972115838
Rho60(m)xCtpl,60(m)  802.882157080785    758.858598539479    758.700006547377    758.700000000175
delta Rho60(m) ..... -44.182157080785     -0.158598539478     -0.000006547377     -0.000000000175
E(m) .............. -41.750837631105     -0.148787275238     -0.000006142165
Dt(m) .............   -0.107275970307     -0.120106813994     -0.120157026013
Dp(m) .............   -0.000347264176     -0.000465306440     -0.000465833907
delta Rho(m) ....... -46.786110132457     -0.169186443476     -0.000006984677
Rho60(m+1) ........  711.913889867543    711.744703424067    711.744696439390
  Output values
Rho60 ........................  711.744696439390
Ctl,o ........................    1.065792692608
Fp,o,psi .....................    0.539775702959
Cpl,o ........................    1.000168347214
Ctpl,o .......................    1.065972115838

    Step 3
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F ........................  194.000000000000
t corrected to IPTS-68 °F ......  194.041903907457
A ............................    0.000004629073
B ............................    2.000000000000
Rho60* .......................  711.747991146704
alpha60 ......................    0.000673323457
delta t, °F ..................  134.035029007457
Ctl* .........................    0.907768859462
Fp,psi .......................    1.631503749170
P in psi .....................  353.166906389884
Cpl ..........................    1.005795323575
Ctpl* ........................    0.913029673734
Density at t & P, kg/cu m ......  649.844027971673

    Step 4
  Correcting 60°F density to 15°C base conditions:
t, °F ........................   59.000000000000
t corrected to IPTS-68 °F ......   59.006621316269
A ............................    0.000004629073
B ............................    2.000000000000
Rho60* .......................  711.747991146704
alpha60 ......................    0.000673323457
delta t, °F ..................   -1.000253583731
Ctl ..........................    1.000673362920
Fp,psi .......................    0.861873048137
P in psi .....................    0.000000000000
Cpl ..........................    1.000000000000
Ctpl .........................    1.000673362920
Density, kg/cu m, at 15°C/0 bar   712.223958926801
```

```
Ctl,60 .........................   1.000673362920

    Step 5
  Modify Ctl* factor and calculate the Ctpl factor for 15°C base conditions:
Ctl,o ..........................   1.065075510252
Ctl ............................   0.907158012893
Ctpl,o .........................   1.065254812747
Ctpl,o, rounded ................   1.06525
Ctpl ...........................   0.912415287111
Ctpl, rounded ..................   0.91242
Fp,o,bar .......................   7.828785016773
Fp,bar .........................  23.662962293959

    Step 6
Volume at base conditions ......   1065.250000000
Volume at alternate conditions .   1167.499616405
```

```
                   Example 3
    Input Data
Commodity .......................  Generalized Crude Oil
t observed, °C .................         26.82
P observed pressure, kPa .......            -5
Base temperature, °C ...........            20
t alternate temp, °C ...........         68.45
P alternate pressure, kPa ......             0
  Forcing negative pressure(s) to zero
Observed density, kg/cu m ......       823.687
Volume at observed t & P .......        243.85

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
T base, °F .....................            68
t observed, °F .................        80.276
t alternate temperature, °F ....        155.21
P observed pressure, PSI .......             0
P alternate pressure, PSI ......             0

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
            Iteration(m) ..... 0                   1                   2
Rho60(m) ........... 823.687000000000    832.025033300798    832.025846221517
K0(m) .............. 341.095700000000    341.095700000000    341.095700000000
K1(m) ..............   0.000000000000      0.000000000000      0.000000000000
K2(m) ..............   0.000000000000      0.000000000000      0.000000000000
A(m) ...............   0.000003456353      0.000003387425      0.000003387418
B(m) ...............   2.000000000000      2.000000000000      2.000000000000
Rho60*(m) .......... 823.689846945966    832.027851716592    832.028664634558
alpha60(m) .........   0.000502746226      0.000492720369      0.000492719406
Ctl,60(m) ..........   0.989773108757      0.989977640002      0.989977659642
d_alpha(m) .........   2.000000000000      2.000000000000      2.000000000000
Fp(m) ..............   0.583626059244      0.567043227602      0.567041657958
Cpl(m) .............   1.000000000000      1.000000000000      1.000000000000
Ctpl(m) ............   0.989773108757      0.989977640002      0.989977659642
Rho60(m)xCtpl,60(m)  815.263242632906    823.686178889619    823.687000004344
delta Rho60(m) .....   8.423757367094      0.000821110381     -0.000000004344
E(m) ...............   8.510796355814      0.000829423158
Dt(m) ..............   0.020719880670      0.020300182163
Dp(m) ..............  -0.000000000000     -0.000000000000
delta Rho(m) .......   8.338033300798      0.000812920720
Rho60(m+1) ......... 832.025033300798    832.025846221517
  Output values
Rho60 .........................  832.025846221517
Ctl,o .........................    0.989977659642
Fp,o,psi ......................    0.567041657958
Cpl,o .........................    1.000000000000
Ctpl,o ........................    0.989977659642

    Step 3
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F .........................  155.210000000000
t corrected to IPTS-68 °F ......  155.242076384128
A .............................    0.000003387418
B .............................    2.000000000000
Rho60* ........................  832.028664634558
alpha60 .......................    0.000492719406
delta t, °F ...................   95.235201484128
Ctl* ..........................    0.952480168160
Fp,psi ........................    0.736816285394
P in psi ......................    0.000000000000
Cpl ...........................    1.000000000000
Ctpl* .........................    0.952480168160
Density at t & P, kg/cu m ......  792.488117922186

    Step 4
  Correcting 60°F density to 20°C base conditions:
t, °F .........................   68.000000000000
t corrected to IPTS-68 °F ......   68.008921288340
A .............................    0.000003387418
B .............................    2.000000000000
Rho60* ........................  832.028664634558
alpha60 .......................    0.000492719406
delta t, °F ...................    8.002046388340
Ctl ...........................    0.996052590368
Fp,psi ........................    0.543226596368
P in psi ......................    0.000000000000
Cpl ...........................    1.000000000000
Ctpl ..........................    0.996052590368
```

```
Density, kg/cu m, at 20°C/0 kPa   828.741499381895
Ctl,60 .........................    0.996052590368

    Step 5
  Modify Ctl* factor and calculate the Ctpl factor for 20°C base conditions:
Ctl,o ..........................    0.993900994000
Ctl ............................    0.956254897955
Ctpl,o .........................    0.993900994000
Ctpl,o, rounded ................    0.99390
Ctpl ...........................    0.956254897955
Ctpl, rounded ..................    0.95625
Fp,o,kPa .......................    0.082242442766
Fp,kPa .........................    0.106866171700

    Step 6
Volume at base conditions ......    242.362515000
Volume at alternate conditions .    253.450996078
```

```
                   Example 4
    Input Data
Commodity ......................  Generalized Refined Product
t observed, °C ................        22.25
P observed pressure, kPa .......        2585
Base temperature, °C ..........           15
t alternate temp, °C ..........       102.35
P alternate pressure, kPa ......        3505
Observed density, kg/cu m ......      817.55
Volume at observed t & P .......      9987.5

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
T base, °F .....................          59
t observed, °F ................        72.05
t alternate temperature, °F ....      216.23
P observed pressure, PSI ....... 374.922567974
P alternate pressure, PSI ......  508.35729236

    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
Fp(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
Fp,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
Fp,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
Fp,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
Fp,o,kPa ......................     0.083069734480
Fp,kPa ........................     0.139369604520

    Step 6
Volume at base conditions ......    9944.853375000
Volume at alternate conditions .   10740.162400778
```

```
                 Example 5
    Input Data
Commodity ......................  Generalized Refined Product
t observed, °C ................          1.85
P observed pressure, kPa .......         1835
Base temperature, °C ..........            20
t alternate temp, °C ..........         45.95
P alternate pressure, kPa ......        10342
Observed density, kg/cu m ......          799
Volume at observed t & P .......        15.85

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
T base, °F .....................            68
t observed, °F .................         35.33
t alternate temperature, °F ....        114.71
P observed pressure, PSI ....... 266.144260052
P alternate pressure, PSI ...... 1499.98034739

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
          Iteration(m) ..... 0                  1                    2                    3
Commodity ..........     jet fuel          transition           transition           transition
Rho60(m) ...........  799.000000000000   787.501672522079    787.495993941460    787.495951332206
K0(m) ..............  330.301000000000     1.48906700000e+03   1.48906700000e+03   1.48906700000e+03
K1(m) ..............    0.000000000000     0.000000000000      0.000000000000      0.000000000000
K2(m) ..............    0.000000000000    -0.001868400000     -0.001868400000     -0.001868400000
A(m) ...............    0.000003556989     0.000003662297      0.000003662535      0.000003662537
B(m) ...............    2.000000000000     9.014755727047      9.014299762272      9.014296341125
Rho60*(m) ..........  799.002842027463   787.504556505496    787.498878091552    787.498835483549
alpha60(m) .........    0.000517384293     0.000532688062      0.000532722689      0.000532722949
Ctl,60(m) ..........    1.012716874189     1.013091459604      1.013092307056      1.013092313415
d_alpha(m) .........    2.000000000000     8.500000000000      8.500000000000      8.500000000000
Fp(m) ..............    0.539219872095     0.561431824168      0.561443262359      0.561443348187
Cpl(m) .............    1.001437165218     1.001496454604      1.001496485138      1.001496485367
Ctpl(m) ............    1.014172315657     1.014607504983      1.014608384637      1.014608391238
Rho60(m)xCtpl,60(m)   810.323680209578   799.005107127664    799.000038321080    799.000000287288
delta Rho60(m) .....  -11.323680209578    -0.005107127664     -0.000038321080     -0.000000287288
E(m) ...............  -11.165440068483    -0.005033599337     -0.000037769331
Dt(m) ..............   -0.025006408584    -0.109353347057     -0.109360302838
Dp(m) ..............   -0.003944533201    -0.004228078613     -0.004228225860
delta Rho(m) .......  -11.498327477921    -0.005678580620     -0.000042609254
Rho60(m+1) .........  787.501672522079   787.495993941460    787.495951332206
  Output values
Rho60 ......................... 787.495951332206
Ctl,o .........................   1.013092313415
Fp,o,psi ......................   0.561443348187
Cpl,o .........................   1.001496485367
Ctpl,o ........................   1.014608391238

    Step 3
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F ......................... 114.710000000000
t corrected to IPTS-68 °F ...... 114.731286608945
A .............................   0.000003662537
B .............................   9.014296341125
Rho60* ........................ 787.498835483549
alpha60 .......................   0.000532722949
delta t, °F ...................  54.724411708945
Ctl* ..........................   0.970607576134
Fp,psi ........................   0.764313263012
P in psi ......................   1.49998034739e+03
Cpl ...........................   1.011597508944
Ctpl* .........................   0.981864206179
Density at t & P, kg/cu m ...... 773.214087124006

    Step 4
  Correcting 60°F density to 20°C base conditions:
t, °F .........................  68.000000000000
t corrected to IPTS-68 °F ......  68.008921288340
A .............................   0.000003662537
B .............................   9.014296341125
Rho60* ........................ 787.498835483549
alpha60 .......................   0.000532722949
delta t, °F ...................   8.002046388340
Ctl ...........................   0.995731698796
Fp,psi ........................   0.637442285063
P in psi ......................   0.000000000000
Cpl ...........................   1.000000000000
Ctpl ..........................   0.995731698796
```

```
Density, kg/cu m, at 20°C/0 kPa   784.134681415189
Ctl,60 ........................     0.995731698796

    Step 5
  Modify Ctl* factor and calculate the Ctpl factor for 20°C base conditions:
Ctl,o .........................     1.017435032590
Ctl ...........................     0.974768180331
Ctpl,o ........................     1.018957609228
Ctpl,o, rounded ...............     1.01896
Ctpl ..........................     0.986073063021
Ctpl, rounded .................     0.98607
Fp,o,kPa ......................     0.081430476547
Fp,kPa ........................     0.110854271298

    Step 6
Volume at base conditions ......     16.150516000
Volume at alternate conditions .     16.378670885
```

```
                Example 6
    Input Data
Commodity ......................  Generalized Refined Product
t observed, °C ................          5.45
P observed pressure, kPa .......         1708
Base temperature, °C ..........            15
t alternate temp, °C ..........        -44.95
P alternate pressure, kPa ......          348
Observed density, kg/cu m ......        779.6
Volume at observed t & P .......        201.5

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
T base, °F .....................            59
t observed, °F ................         41.81
t alternate temperature, °F ....       -48.91
P observed pressure, PSI .......  247.724466577
P alternate pressure, PSI ......  50.4731348763

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
            Iteration(m) ..... 0                    1                    2                    3
Commodity ..........       transition           gasoline             gasoline             gasoline
Rho60(m) ..........   779.600000000000    769.382460404541    769.455200805984    769.455206492347
K0(m) .............     1.48906700000e+03 192.457100000000    192.457100000000    192.457100000000
K1(m) .............     0.000000000000      0.243800000000      0.243800000000      0.243800000000
K2(m) .............    -0.001868400000      0.000000000000      0.000000000000      0.000000000000
A(m) ..............     0.000003998615      0.000004413697      0.000004413068      0.000004413068
B(m) ..............     8.424754338437      1.506422681731      1.506399050765      1.506399048917
Rho60*(m) .........   779.603117231299    769.385856222133    769.458596461004    769.458602147354
alpha60(m) ........     0.000581605759      0.000641997502      0.000641906079      0.000641906072
Ctl,60(m) .........     1.010547763402      1.011638979603      1.011637328270      1.011637328141
d_alpha(m) ........     8.500000000000      1.500000000000      1.500000000000      1.500000000000
Fp(m) .............     0.592853161339      0.616555878641      0.616380416094      0.616380402381
Cpl(m) ............     1.001470802414      1.001529696158      1.001529260164      1.001529260130
Ctpl(m) ...........     1.012034079492      1.013186479863      1.013184384936      1.013184384772
Rho60(m)xCtpl,60(m)   788.981768372203    779.527906725858    779.599994364210    779.599999999553
delta Rho60(m) .....   -9.381768372203      0.072093274142      0.000005635790      0.000000000447
E(m) ..............    -9.270209929007      0.071154990295      0.000005562452
Dt(m) .............    -0.088402809484     -0.017189603867     -0.017187202601
Dp(m) .............    -0.004313216483     -0.004605864910     -0.004603681605
delta Rho(m) .......  -10.217539595459      0.072740401443      0.000005686363
Rho60(m+1) ........   769.382460404541    769.455200805984    769.455206492347
  Output values
Rho60 .........................  769.455206492347
Ctl,o .........................    1.011637328141
Fp,o,psi ......................    0.616380402381
Cpl,o .........................    1.001529260130
Ctpl,o ........................    1.013184384772

    Step 3
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F .........................  -48.910000000000
t corrected to IPTS-68 °F ......  -48.926020214553
A .............................    0.000004413068
B .............................    1.506399048917
Rho60* ........................  769.458602147354
alpha60 .......................    0.000641906072
delta t, °F ................... -108.932895114553
Ctl* ..........................    1.068241256966
Fp,psi ........................    0.426326280590
P in psi ......................   50.473134876255
Cpl ...........................    1.000215226551
Ctpl* .........................    1.068471170847
Density at t & P, kg/cu m ......  822.140705395444

    Step 4
  Correcting 60°F density to 15°C base conditions:
t, °F .........................   59.000000000000
t corrected to IPTS-68 °F ......   59.006621316269
A .............................    0.000004413068
B .............................    1.506399048917
Rho60* ........................  769.458602147354
alpha60 .......................    0.000641906072
delta t, °F ...................   -1.000253583731
Ctl ...........................    1.000641949542
Fp,psi ........................    0.660979356291
P in psi ......................    0.000000000000
Cpl ...........................    1.000000000000
Ctpl ..........................    1.000641949542
```

```
Density, kg/cu m, at 15°C/0 kPa   769.949157909619
Ctl,60 ........................    1.000641949542

    Step 5
  Modify Ctl* factor and calculate the Ctpl factor for 15°C base conditions:
Ctl,o .........................    1.010988324649
Ctl ...........................    1.067555939919
Ctpl,o ........................    1.012534388785
Ctpl,o, rounded ...............    1.01253
Ctpl ..........................    1.067785706302
Ctpl, rounded .................    1.06779
Fp,o,kPa ......................    0.089398422944
Fp,kPa ........................    0.061833401901

    Step 6
Volume at base conditions ......    204.024795000
Volume at alternate conditions .    191.072022589
```

```
                 Example 7
    Input Data
Commodity ......................   Specialized Liquid
Alpha at 60°F per °F ...........     0.00057634
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
t observed, °F .................          84.56
t alternate temperature, °F ....         131.09
P observed pressure, PSI .......  57.2899088394
P alternate pressure, PSI ......  943.470524052

    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
Fp(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
Fp,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
Fp,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
Fp,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
Ctpl,o, rounded ...............    0.98551
Ctpl ..........................    0.963457306095
```

```
Ctpl, rounded ..................   0.96346
Fp,o,kPa .......................   0.074836882253
Fp,kPa .........................   0.087007330735

    Step 6
Volume at base conditions ......    985.510000000
Volume at alternate conditions .   1022.886264090
```

```
                   Example 8
    Input Data
Commodity ......................  Generalized Lube Oil
t observed, °C ................        -49.95
P observed pressure, bar .......         31.1
Base temperature, °C ..........            15
t alternate temp, °C ..........         67.65
P alternate pressure, bar ......        13.65
Observed density, kg/cu m ......      1204.65
Volume at observed t & P .......       200.04

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
T base, °F ....................            59
t observed, °F ................        -57.91
t alternate temperature, °F ....       153.77
P observed pressure, PSI ....... 451.067383521
P alternate pressure, PSI ......  197.97652042

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
  Note, Rho60 has been limited to the maximum table value in one or more cases.

            Iteration(m) ..... 0                   1                    2
Rho60(m) ...........    1.16350000000e+03   1.16279157433e+03   1.16279156929e+03
K0(m) ..............    0.000000000000      0.000000000000      0.000000000000
K1(m) ..............    0.348780000000      0.348780000000      0.348780000000
K2(m) ..............    0.000000000000      0.000000000000      0.000000000000
A(m) ...............    0.000002060874      0.000002062130      0.000002062130
B(m) ...............    1.000000000000      1.000000000000      1.000000000000
Rho60*(m) ..........    1.16350239783e+03   1.16279397216e+03   1.16279396712e+03
alpha60(m) .........    0.000299767324      0.000299949955      0.000299949957
Ctl,60(m) ..........    1.034949967296      1.034970997658      1.034970997807
d_alpha(m) .........    1.000000000000      1.000000000000      1.000000000000
Fp(m) ..............    0.219688665005      0.219819089881      0.219819090810
Cpl(m) .............    1.000991926857      1.000992516329      1.000992516333
Ctpl(m) ............    1.035976561965      1.035998223273      1.035998223427
Rho60(m)xCtpl,60(m)     1.20535872985e+03   1.20465000504e+03   1.20465000000e+03
delta Rho60(m) .....   -0.708729845881     -0.000005041899     -0.000000000034
E(m) ...............   -0.684117645033     -0.000004866707
Dt(m) ..............   -0.033346670785     -0.033365768499
Dp(m) ..............   -0.000966068958     -0.000967821268
delta Rho(m) .......   -0.708425670699     -0.000005039739
Rho60(m+1) .........    1.16279157433e+03   1.16279156929e+03
  Output values
Rho60 .........................   1.16279156929e+03
Ctl,o .........................   1.034970997807
Fp,o,psi ......................   0.219819090810
Cpl,o .........................   1.000992516333
Ctpl,o ........................   1.035998223427

    Step 3
  Correcting 60°F and 0 psi density to alternate conditions:
t, °F ......................... 153.770000000000
t corrected to IPTS-68 °F ...... 153.801698849288
A .............................   0.000002062130
B .............................   1.000000000000
Rho60* ........................   1.16279396712e+03
alpha60 .......................   0.000299949957
delta t, °F ...................  93.794823949288
Ctl* ..........................   0.971642779704
Fp,psi ........................   0.325535400898
P in psi ...................... 197.976520419791
Cpl ...........................   1.000644899286
Ctpl* .........................   0.972269391439
Density at t & P, kg/cu m ......   1.13054665144e+03

    Step 4
  Correcting 60°F density to 15°C base conditions:
t, °F .........................  59.000000000000
t corrected to IPTS-68 °F ......  59.006621316269
A .............................   0.000002062130
B .............................   1.000000000000
Rho60* ........................   1.16279396712e+03
alpha60 .......................   0.000299949957
delta t, °F ...................  -1.000253583731
Ctl ...........................   1.000299999987
Fp,psi ........................   0.273053327335
P in psi ......................   0.000000000000
Cpl ...........................   1.000000000000
```

```
Ctpl ...........................   1.000299999987
Density, kg/cu m, at 15°C/0 bar  1163.140406745777
Ctl,60 .........................   1.000299999987

    Step 5
  Modify Ctl* factor and calculate the Ctpl factor for 15°C base conditions:
Ctl,o ..........................   1.034660599640
Ctl ............................   0.971351374304
Ctpl,o .........................   1.035687517185
Ctpl,o, rounded ................   1.03569
Ctpl ...........................   0.971977798112
Ctpl, rounded ..................   0.97198
Fp,o,bar .......................   3.188206499661
Fp,bar .........................   4.721492010499

    Step 6
Volume at base conditions ......    207.179427600
Volume at alternate conditions .    213.151945102
```

```
                Example 9
    Input Data
Commodity ......................  Generalized Lube Oil
t observed, °C .................          35.8
P observed pressure, kPa .......           140
Base temperature, °C ...........            20
t alternate temp, °C ...........           150
P alternate pressure, kPa ......         10340
Observed density, kg/cu m ......        734.29
Volume at observed t & P .......         12501

    Computed Data - last digit is rounded for display purposes

    Step 1
  Convert to customary units
T base, °F .....................            68
t observed, °F .................         96.44
t alternate temperature, °F ....           302
P observed pressure, PSI .......  20.3052841456
P alternate pressure, PSI ......  1499.6902719

    Step 2
  Correcting observed density to 60°F & 0 psi reference conditions
  Note, Rho60 has been limited to the minimum table value in one or more cases.
```

Iteration(m)	0	1	2	...	14
Rho60(m)	800.900000000000	800.900000000000	800.900000000000	...	800.900000000000
K0(m)	0.000000000000	0.000000000000	0.000000000000	...	0.000000000000
K1(m)	0.348780000000	0.348780000000	0.348780000000	...	0.348780000000
K2(m)	0.000000000000	0.000000000000	0.000000000000	...	0.000000000000
A(m)	0.000002993915	0.000002993915	0.000002993915	...	0.000002993915
B(m)	1.000000000000	1.000000000000	1.000000000000	...	1.000000000000
Rho60*(m)	800.902397828986	800.902397828986	800.902397828986	...	800.902397828986
alpha60(m)	0.000435483775	0.000435483775	0.000435483775	...	0.000435483775
Ctl,60(m)	0.984053694045	0.984053694045	0.984053694045	...	0.984053694045
d_alpha(m)	1.000000000000	1.000000000000	1.000000000000	...	1.000000000000
Fp(m)	0.674169679903	0.674169679903	0.674169679903	...	0.674169679903
Cpl(m)	1.000136910811	1.000136910811	1.000136910811	...	1.000136910811
Ctpl(m)	0.984188421635	0.984188421635	0.984188421635	...	0.984188421635
Rho60(m)xCtpl,60(m)	788.236506887413	788.236506887413	788.236506887413	...	788.236506887413
delta Rho60(m)	-53.946506887413	-53.946506887413	-53.946506887413	...	-53.946506887413
E(m)	-54.813189935518	-54.813189935518	-54.813189935518	...	-54.813189935518
Dt(m)	0.016271950498	0.016271950498	0.016271950498	...	0.016271950498
Dp(m)	-0.000434671401	-0.000434671401	-0.000434671401	...	-0.000434671401
delta Rho(m)	0.000000000000	0.000000000000	0.000000000000	...	0.000000000000
Rho60(m+1)	800.900000000000	800.900000000000	800.900000000000	...	800.900000000000

```
  Convergence not achieved after 15 iterations, solution not found.
  Density is outside limits of procedure
```

```
                   Example 10
    Input Data
Commodity ......................  Generalized Crude Oil
t observed, °C .................       -50.05
P observed pressure, kPa .......            0
Base temperature, °C ...........           15
t alternate temp, °C ...........       -50.05
P alternate pressure, kPa ......            0
Observed density, kg/cu m ......       470.27
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
t observed, °F .................       -58.09
t alternate temperature, °F ....       -58.09
P observed pressure, PSI .......            0
P alternate pressure, PSI ......            0
Observed temperature less than -50°C (-58°F) - outside limits of table
Alternate temperature less than -50°C (-58°F) - outside limits of table
Density less than 470.4 kg/cu m - outside limits of table


                   Example 11
    Input Data
Commodity ......................  Generalized Crude Oil
t observed, °C .................       150.03
P observed pressure, bar .......      103.425
Base temperature, °C ...........           15
t alternate temp, °C ...........       150.03
P alternate pressure, bar ......      103.425
Observed density, kg/cu m ......      1201.85
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
t observed, °F .................      302.054
t alternate temperature, °F ....      302.054
P observed pressure, PSI .......  1500.05286626
P alternate pressure, PSI ......  1500.05286626
Observed temperature greater than 150°C (302°F) - outside limits of table
Alternate temperature greater than 150°C (302°F) - outside limits of table
Observed pressure greater than 1500 psi - outside limits of table
Alternate pressure greater than 1500 psi - outside limits of table
Density greater than 1201.8 kg/cu m - outside limits of table
```

```
                   Example 12
    Input Data
Commodity ......................  Generalized Refined Product
t observed, ˚C ................        150.02
P observed pressure, kPa .......      10342.5
Base temperature, ˚C ..........            15
t alternate temp, ˚C ..........        150.02
P alternate pressure, kPa ......      10342.5
Observed density, kg/cu m ......      1209.56
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
t observed, ˚F ................       302.036
t alternate temperature, ˚F ....      302.036
P observed pressure, PSI .......  1500.05286626
P alternate pressure, PSI ......  1500.05286626
Observed temperature greater than 150˚C (302˚F) - outside limits of table
Alternate temperature greater than 150˚C (302˚F) - outside limits of table
Observed pressure greater than 1500 psi - outside limits of table
Alternate pressure greater than 1500 psi - outside limits of table
Density greater than 1209.5 kg/cu m - outside limits of table


                   Example 13
    Input Data
Commodity ......................  Generalized Lube Oil
t observed, ˚C ................         25.56
P observed pressure, kPa .......      10342.5
Base temperature, ˚C ..........            15
t alternate temp, ˚C ..........         36.85
P alternate pressure, kPa ......            0
Observed density, kg/cu m ......      1208.52
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
t observed, ˚F ................        78.008
t alternate temperature, ˚F ....        98.33
P observed pressure, PSI .......  1500.05286626
P alternate pressure, PSI ......            0
Observed pressure greater than 1500 psi - outside limits of table
Density greater than 1208.3 kg/cu m - outside limits of tabl
```

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

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. Therefore, this Standard is intended to be used in its algorithmic form. However, this section provides procedures for generating correction factors in tabular format that can be printed for convenience. The format of these tables is that of the historical Petroleum Measurement Tables.

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 equivalent of 1980 temperature correction tables can be generated by setting the pressure to the base value (one atmosphere). The equivalent of the pressure correction tables can be generated by printing the compressibility factor at the base pressure.

The following table shows the tabular format of the temperature correction and compressibility factor tables for which generation instructions will be given. Any deviation from the set of units and pressure value will give a custom table that will not have an official designation.

Petroleum Measurement Tables

Table Description	Table Designations	Base Temperature	Input Value	Pressure Value & Units	Output & Units
API Gravity Correction to 60°F	5A, 5B, 5D	60°F	Observed °API	0 psig	Base °API
Correction of Volume to 60°F Against API Gravity at 60°F	6A, 6B, 6C, 6D	60°F	Base °API	0 psig	CTL
Correction of Observed Specific Gravity to Specific Gravity 60/60°F	23A, 23B	60°F	Observed Relative Density	0 psig	Base Relative Density
Correction of Volume to 60°F Against Specific Gravity 60/60°F	24A, 24B, 24C	60°F	Base Relative Density	0 psig	CTL
Correction of Observed Density to Density at 15°C	53A, 53B, 53D	15°C	Observed kg/m^3	0 kPa (gauge)	Base Density (kg/m^3)
Correction of Volume to 15°C Against Density at 15°C	54A, 54B, 54C, 54D	15°C	Base kg/m^3	0 kPa (gauge)	CTL
Correction of Observed Density to Density at 20°C	59A, 59B, 59D	20°C	Observed kg/m^3	0 kPa (gauge)	Base Density (kg/m^3)
Correction of Volume to 20°C Against Density at 20°C	60A, 60B, 60C, 60D	20°C	Base kg/m^3	0 kPa (gauge)	CTL
Compressibility Factors for Hydrocarbons Related to API Gravity and Metering Temperature	1984 Ch. 11.2.1	60°F	Base °API	0 psig	F_P (psi^{-1})
Compressibility Factors for Hydrocarbons Related to Density and Metering Temperature	1984 Ch. 11.2.1M	15°C	Base kg/m^3	0 kPa (gauge)	F_P (kPa^{-1})

These table representations of this Standard's algorithm are to be generated with rounded input and be represented with rounded output. The procedure to round the values is given in 11.1.5.4.

Unlike previous editions of the VCF tables there are no provisions to correct density measurements with a glass hydrometer. It is essential that only corrected hydrometer values be used in conjunction with these tables. Glass hydrometer values should be corrected consistent with directions from the hydrometer manufacturer and appropriate glass hydrometer standard. The odd-numbered 1980 Tables all included a hydrometer correction. Because of this, the odd-numbered tables generated by the algorithm in this Standard will not be identical to the corresponding odd-numbered 1980 Tables. Appendix A includes a discussion of the hydrometer corrections used in the 1980 CTL Tables.

11.1.8.1 Instructions to Generate Table 5A — API Gravity Correction to 60°F for Generalized Crude Oils

Input Variables: Observed API gravity and temperature. Pressure set to 0 psig.

Output Variables: API gravity at 60°F.

Step 1: Hold pressure value at 0 psig.

Step 2: Increment observed API gravity value by 0.1°API in range of –13.4° to 168.9°API. Ensure that the observed API gravity value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment observed temperature by 0.1°F in range of –58.0° to 302.0°F. Ensure that the observed temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from API gravity to kg/m³ using procedure in 11.1.5.1.

Step 5: Determine the base density using procedure in 11.1.6.2 & specifying commodity group "A."

Step 6: Convert the density units from kg/m³ back to API gravity using procedure in 11.1.5.1. Round the value of this API gravity consistent with instructions in 11.1.5.4.

Step 7: Increment the value of the API gravity or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of API gravity and temperature have been calculated.

Table 5A. Correction of Observed API Gravity to API Gravity at 60°F (Crude Oils)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 psig

	Observed API Gravity							
°F	65.0	65.1	65.2	65.3	65.4	65.5	65.6	°F
	Corresponding Density at 60°F & 0 psig, °API							
135.0	56.0	56.1	56.2	56.3	56.4	56.5	56.6	135.0
135.1	56.0	56.1	56.2	56.3	56.4	56.5	56.6	135.1
135.2	56.0	56.1	56.2	56.3	56.4	56.5	56.5	135.2
135.3	56.0	56.1	56.2	56.3	56.4	56.4	56.5	135.3
135.4	56.0	56.1	56.2	56.3	56.3	56.4	56.5	135.4
135.5	56.0	56.1	56.2	56.2	56.3	56.4	56.5	135.5
135.6	56.0	56.1	56.1	56.2	56.3	56.4	56.5	135.6
135.7	56.0	56.1	56.1	56.2	56.3	56.4	56.5	135.7
135.8	56.0	56.0	56.1	56.2	56.3	56.4	56.5	135.8
135.9	55.9	56.0	56.1	56.2	56.3	56.4	56.5	135.9
136.0	55.9	56.0	56.1	56.2	56.3	56.4	56.5	136.0
136.1	55.9	56.0	56.1	56.2	56.3	56.4	56.4	136.1
136.2	55.9	56.0	56.1	56.2	56.3	56.3	56.4	136.2
136.3	55.9	56.0	56.1	56.2	56.2	56.3	56.4	136.3
136.4	55.9	56.0	56.1	56.1	56.2	56.3	56.4	136.4
136.5	55.9	56.0	56.1	56.1	56.2	56.3	56.4	136.5
136.6	55.9	56.0	56.0	56.1	56.2	56.3	56.4	136.6
136.7	55.9	55.9	56.0	56.1	56.2	56.3	56.4	136.7
136.8	55.8	55.9	56.0	56.1	56.2	56.3	56.4	136.8
136.9	55.8	55.9	56.0	56.1	56.2	56.3	56.4	136.9
137.0	55.8	55.9	56.0	56.1	56.2	56.3	56.3	137.0
137.1	55.8	55.9	56.0	56.1	56.2	56.2	56.3	137.1
137.2	55.8	55.9	56.0	56.1	56.1	56.2	56.3	137.2
137.3	55.8	55.9	56.0	56.0	56.1	56.2	56.3	137.3
137.4	55.8	55.9	56.0	56.0	56.1	56.2	56.3	137.4
137.5	55.8	55.9	55.9	56.0	56.1	56.2	56.3	137.5
137.6	55.8	55.8	55.9	56.0	56.1	56.2	56.3	137.6
137.7	55.7	55.8	55.9	56.0	56.1	56.2	56.3	137.7
137.8	55.7	55.8	55.9	56.0	56.1	56.2	56.3	137.8
137.9	55.7	55.8	55.9	56.0	56.1	56.2	56.2	137.9
138.0	55.7	55.8	55.9	56.0	56.1	56.1	56.2	138.0
138.1	55.7	55.8	55.9	56.0	56.0	56.1	56.2	138.1
138.2	55.7	55.8	55.9	56.0	56.0	56.1	56.2	138.2
138.3	55.7	55.8	55.9	55.9	56.0	56.1	56.2	138.3
138.4	55.7	55.8	55.8	55.9	56.0	56.1	56.2	138.4
138.5	55.7	55.7	55.8	55.9	56.0	56.1	56.2	138.5
138.6	55.6	55.7	55.8	55.9	56.0	56.1	56.2	138.6
138.7	55.6	55.7	55.8	55.9	56.0	56.1	56.2	138.7
138.8	55.6	55.7	55.8	55.9	56.0	56.1	56.1	138.8
138.9	55.6	55.7	55.8	55.9	56.0	56.0	56.1	138.9
139.0	55.6	55.7	55.8	55.9	55.9	56.0	56.1	139.0
139.1	55.6	55.7	55.8	55.9	55.9	56.0	56.1	139.1
139.2	55.6	55.7	55.8	55.8	55.9	56.0	56.1	139.2
139.3	55.6	55.7	55.7	55.8	55.9	56.0	56.1	139.3
139.4	55.6	55.6	55.7	55.8	55.9	56.0	56.1	139.4
139.5	55.5	55.6	55.7	55.8	55.9	56.0	56.1	139.5
139.6	55.5	55.6	55.7	55.8	55.9	56.0	56.1	139.6
139.7	55.5	55.6	55.7	55.8	55.9	56.0	56.0	139.7
139.8	55.5	55.6	55.7	55.8	55.9	55.9	56.0	139.8
139.9	55.5	55.6	55.7	55.8	55.8	55.9	56.0	139.9
140.0	55.5	55.6	55.7	55.8	55.8	55.9	56.0	140.0

11.1.8.2 Instructions to Generate Table 5B — API Gravity Correction to 60°F for Generalized Products

Input Variables: Observed API gravity and temperature. Pressure set to 0 psig.

Output Variables: API gravity at 60°F.

Step 1: Hold pressure value at 0 psig.

Step 2: Increment observed API gravity value by 0.1°API in range of –14.2° to 168.9°API. Ensure that the observed API gravity value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment observed temperature by 0.1°F in range of –58.0° to 302.0°F. Ensure that the observed temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from API gravity to kg/m³ using procedure in 11.1.5.1.

Step 5: Determine the base density using procedure in 11.1.6.2 & specifying commodity group "B."

Step 6: Convert the density units from kg/m³ back to API gravity using procedure in 11.1.5.1. Round the value of this API gravity consistent with instructions in 11.1.5.4.

Step 7: Increment the value of the API gravity or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of API gravity and temperature have been calculated.

Table 5B. Correction of Observed API Gravity to API Gravity at 60°F (Refined Products)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 psig

	Observed API Gravity							
°F	65.0	65.1	65.2	65.3	65.4	65.5	65.6	°F
	Corresponding Density at 60°F & 0 psig, °API							
135.0	55.2	55.3	55.4	55.4	55.5	55.6	55.7	135.0
135.1	55.2	55.3	55.3	55.4	55.5	55.6	55.7	135.1
135.2	55.2	55.2	55.3	55.4	55.5	55.6	55.7	135.2
135.3	55.1	55.2	55.3	55.4	55.5	55.6	55.7	135.3
135.4	55.1	55.2	55.3	55.4	55.5	55.6	55.7	135.4
135.5	55.1	55.2	55.3	55.4	55.5	55.6	55.6	135.5
135.6	55.1	55.2	55.3	55.4	55.5	55.5	55.6	135.6
135.7	55.1	55.2	55.3	55.4	55.4	55.5	55.6	135.7
135.8	55.1	55.2	55.3	55.3	55.4	55.5	55.6	135.8
135.9	55.1	55.2	55.2	55.3	55.4	55.5	55.6	135.9
136.0	55.1	55.1	55.2	55.3	55.4	55.5	55.6	136.0
136.1	55.0	55.1	55.2	55.3	55.4	55.5	55.6	136.1
136.2	55.0	55.1	55.2	55.3	55.4	55.5	55.6	136.2
136.3	55.0	55.1	55.2	55.3	55.4	55.5	55.5	136.3
136.4	55.0	55.1	55.2	55.3	55.4	55.4	55.5	136.4
136.5	55.0	55.1	55.2	55.3	55.3	55.4	55.5	136.5
136.6	55.0	55.1	55.2	55.2	55.3	55.4	55.5	136.6
136.7	55.0	55.1	55.1	55.2	55.3	55.4	55.5	136.7
136.8	55.0	55.0	55.1	55.2	55.3	55.4	55.5	136.8
136.9	54.9	55.0	55.1	55.2	55.3	55.4	55.5	136.9
137.0	54.9	55.0	55.1	55.2	55.3	55.4	55.5	137.0
137.1	54.9	55.0	55.1	55.2	55.3	55.4	55.4	137.1
137.2	54.9	55.0	55.1	55.2	55.3	55.3	55.4	137.2
137.3	54.9	55.0	55.1	55.2	55.2	55.3	55.4	137.3
137.4	54.9	55.0	55.1	55.1	55.2	55.3	55.4	137.4
137.5	54.9	55.0	55.0	55.1	55.2	55.3	55.4	137.5
137.6	54.9	54.9	55.0	55.1	55.2	55.3	55.4	137.6
137.7	54.8	54.9	55.0	55.1	55.2	55.3	55.4	137.7
137.8	54.8	54.9	55.0	55.1	55.2	55.3	55.4	137.8
137.9	54.8	54.9	55.0	55.1	55.2	55.3	55.3	137.9
138.0	54.8	54.9	55.0	55.1	55.2	55.2	55.3	138.0
138.1	54.8	54.9	55.0	55.1	55.1	55.2	55.3	138.1
138.2	54.8	54.9	55.0	55.0	55.1	55.2	55.3	138.2
138.3	54.8	54.9	54.9	55.0	55.1	55.2	55.3	138.3
138.4	54.8	54.8	54.9	55.0	55.1	55.2	55.3	138.4
138.5	54.7	54.8	54.9	55.0	55.1	55.2	55.3	138.5
138.6	54.7	54.8	54.9	55.0	55.1	55.2	55.3	138.6
138.7	54.7	54.8	54.9	55.0	55.1	55.2	55.2	138.7
138.8	54.7	54.8	54.9	55.0	55.1	55.2	55.2	138.8
138.9	54.7	54.8	54.9	55.0	55.1	55.1	55.2	138.9
139.0	54.7	54.8	54.9	55.0	55.0	55.1	55.2	139.0
139.1	54.7	54.8	54.9	54.9	55.0	55.1	55.2	139.1
139.2	54.7	54.8	54.8	54.9	55.0	55.1	55.2	139.2
139.3	54.7	54.7	54.8	54.9	55.0	55.1	55.2	139.3
139.4	54.6	54.7	54.8	54.9	55.0	55.1	55.2	139.4
139.5	54.6	54.7	54.8	54.9	55.0	55.1	55.2	139.5
139.6	54.6	54.7	54.8	54.9	55.0	55.1	55.1	139.6
139.7	54.6	54.7	54.8	54.9	55.0	55.0	55.1	139.7
139.8	54.6	54.7	54.8	54.9	54.9	55.0	55.1	139.8
139.9	54.6	54.7	54.8	54.8	54.9	55.0	55.1	139.9
140.0	54.6	54.7	54.7	54.8	54.9	55.0	55.1	140.0

11.1.8.3 Instructions to Generate Table 5D — API Gravity Correction to 60°F for Generalized Lubricating Oils

Input Variables: Observed API gravity and temperature. Pressure set to 0 psig.

Output Variables: API gravity at 60°F.

Step 1: Hold pressure value at 0 psig.

Step 2: Increment observed API gravity value by 0.1°API in range of –14.1° to 66.3°API. Ensure that the observed API gravity value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment observed temperature by 0.1°F in range of –58.0° to 302.0°F. Ensure that the observed temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from API gravity to kg/m³ using procedure in 11.1.5.1.

Step 5: Determine the base density using procedure in 11.1.6.2 & specifying commodity group "D."

Step 6: Convert the density units from kg/m³ back to API gravity using procedure in 11.1.5.1. Round the value of this API gravity consistent with instructions in 11.1.5.4.

Step 7: Increment the value of the API gravity or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of API gravity and temperature have been calculated.

Table 5D. Correction of Observed API Gravity to API Gravity at 60°F (Lube Oils)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 psig

	Observed API Gravity							
°F	0.0	0.1	0.2	0.3	0.4	0.5	0.6	°F
	Corresponding Density at 60°F & 0 psig, °API							
135.0	-3.1	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.0
135.1	-3.1	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.1
135.2	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.2
135.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.3
135.4	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.4
135.5	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.5
135.6	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.6
135.7	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.7
135.8	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.8
135.9	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	135.9
136.0	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	136.0
136.1	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	136.1
136.2	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	136.2
136.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	136.3
136.4	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	136.4
136.5	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	136.5
136.6	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	136.6
136.7	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	136.7
136.8	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.6	136.8
136.9	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	-2.7	136.9
137.0	-3.2	-3.1	-3.0	-2.9	-2.8	-2.8	-2.7	137.0
137.1	-3.2	-3.1	-3.0	-2.9	-2.9	-2.8	-2.7	137.1
137.2	-3.2	-3.1	-3.0	-3.0	-2.9	-2.8	-2.7	137.2
137.3	-3.2	-3.1	-3.0	-3.0	-2.9	-2.8	-2.7	137.3
137.4	-3.2	-3.1	-3.1	-3.0	-2.9	-2.8	-2.7	137.4
137.5	-3.2	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	137.5
137.6	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	137.6
137.7	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	137.7
137.8	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	137.8
137.9	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	137.9
138.0	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.0
138.1	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.1
138.2	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.2
138.3	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.3
138.4	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.4
138.5	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.5
138.6	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.6
138.7	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.7
138.8	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.8
138.9	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	138.9
139.0	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	139.0
139.1	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	139.1
139.2	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.7	139.2
139.3	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	-2.8	139.3
139.4	-3.3	-3.2	-3.1	-3.0	-2.9	-2.9	-2.8	139.4
139.5	-3.3	-3.2	-3.1	-3.0	-3.0	-2.9	-2.8	139.5
139.6	-3.3	-3.2	-3.1	-3.0	-3.0	-2.9	-2.8	139.6
139.7	-3.3	-3.2	-3.1	-3.1	-3.0	-2.9	-2.8	139.7
139.8	-3.3	-3.2	-3.2	-3.1	-3.0	-2.9	-2.8	139.8
139.9	-3.3	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	139.9
140.0	-3.4	-3.3	-3.2	-3.1	-3.0	-2.9	-2.8	140.0

11.1.8.4 Instructions to Generate Tables 6A and 6B — Correction of Volume to 60°F Against API Gravity at 60°F for Generalized Crude Oils and Products

Input Variables: Base API gravity and temperature. Pressure set to 0 psig.

Output Variables: CTL at input temperature.

Step 1: Hold pressure value at 0 psig.

Step 2: Increment base API gravity value by 0.1°API in range of –10.0° to 100.0°API. Ensure that the base API gravity value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.1°F in range of –58.0° to 302.0°F. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from API gravity to kg/m³ using procedure in 11.1.5.1.

Step 5: Determine the CTL value using procedure in 11.1.6.1 & specifying commodity group "A" or "B" as appropriate. Round the CTL value consistent with instructions in 11.1.5.4.

Step 6: Increment the value of the API gravity or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of API gravity and temperature have been calculated.

Table 6A. Volume Correction Factor Due to Temperature Against API Gravity at 60°F (Crude Oils)

Alternate Pressure is 0 psig

Base API Gravity

Volume Correction for the Effect of Temperature on Liquid (CTL) to 60°F

°F	95.0	95.1	95.2	95.3	95.4	95.5	95.6	°F
120.0	0.94671	0.94666	0.94661	0.94656	0.94652	0.94647	0.94642	120.0
120.1	0.94662	0.94657	0.94652	0.94647	0.94643	0.94638	0.94633	120.1
120.2	0.94653	0.94648	0.94643	0.94638	0.94634	0.94629	0.94624	120.2
120.3	0.94644	0.94639	0.94634	0.94629	0.94625	0.94620	0.94615	120.3
120.4	0.94635	0.94630	0.94625	0.94620	0.94616	0.94611	0.94606	120.4
120.5	0.94626	0.94621	0.94616	0.94611	0.94607	0.94602	0.94597	120.5
120.6	0.94617	0.94612	0.94607	0.94602	0.94598	0.94593	0.94588	120.6
120.7	0.94608	0.94603	0.94598	0.94593	0.94588	0.94584	0.94579	120.7
120.8	0.94599	0.94594	0.94589	0.94584	0.94579	0.94575	0.94570	120.8
120.9	0.94590	0.94585	0.94580	0.94575	0.94570	0.94566	0.94561	120.9
121.0	0.94581	0.94576	0.94571	0.94566	0.94561	0.94557	0.94552	121.0
121.1	0.94572	0.94567	0.94562	0.94557	0.94552	0.94548	0.94543	121.1
121.2	0.94563	0.94558	0.94553	0.94548	0.94543	0.94539	0.94534	121.2
121.3	0.94554	0.94549	0.94544	0.94539	0.94534	0.94529	0.94525	121.3
121.4	0.94545	0.94540	0.94535	0.94530	0.94525	0.94520	0.94516	121.4
121.5	0.94536	0.94531	0.94526	0.94521	0.94516	0.94511	0.94507	121.5
121.6	0.94527	0.94522	0.94517	0.94512	0.94507	0.94502	0.94497	121.6
121.7	0.94518	0.94513	0.94508	0.94503	0.94498	0.94493	0.94488	121.7
121.8	0.94509	0.94504	0.94499	0.94494	0.94489	0.94484	0.94479	121.8
121.9	0.94500	0.94495	0.94490	0.94485	0.94480	0.94475	0.94470	121.9
122.0	0.94491	0.94486	0.94481	0.94476	0.94471	0.94466	0.94461	122.0
122.1	0.94482	0.94477	0.94472	0.94467	0.94462	0.94457	0.94452	122.1
122.2	0.94473	0.94468	0.94463	0.94458	0.94453	0.94448	0.94443	122.2
122.3	0.94464	0.94459	0.94454	0.94449	0.94444	0.94439	0.94434	122.3
122.4	0.94455	0.94450	0.94445	0.94440	0.94435	0.94430	0.94425	122.4
122.5	0.94446	0.94441	0.94436	0.94431	0.94426	0.94421	0.94416	122.5
122.6	0.94437	0.94432	0.94427	0.94422	0.94417	0.94412	0.94407	122.6
122.7	0.94428	0.94423	0.94418	0.94413	0.94408	0.94403	0.94398	122.7
122.8	0.94419	0.94414	0.94409	0.94404	0.94399	0.94394	0.94389	122.8
122.9	0.94410	0.94405	0.94400	0.94395	0.94390	0.94385	0.94380	122.9
123.0	0.94401	0.94396	0.94391	0.94386	0.94381	0.94376	0.94371	123.0
123.1	0.94392	0.94387	0.94382	0.94377	0.94372	0.94367	0.94362	123.1
123.2	0.94383	0.94378	0.94373	0.94368	0.94363	0.94358	0.94353	123.2
123.3	0.94374	0.94369	0.94364	0.94359	0.94354	0.94349	0.94344	123.3
123.4	0.94365	0.94360	0.94355	0.94350	0.94345	0.94340	0.94335	123.4
123.5	0.94356	0.94351	0.94346	0.94341	0.94336	0.94331	0.94326	123.5
123.6	0.94347	0.94342	0.94337	0.94332	0.94327	0.94322	0.94317	123.6
123.7	0.94338	0.94333	0.94328	0.94323	0.94318	0.94313	0.94307	123.7
123.8	0.94329	0.94324	0.94319	0.94314	0.94309	0.94304	0.94298	123.8
123.9	0.94320	0.94315	0.94310	0.94305	0.94300	0.94294	0.94289	123.9
124.0	0.94311	0.94306	0.94301	0.94296	0.94291	0.94285	0.94280	124.0
124.1	0.94302	0.94297	0.94292	0.94287	0.94281	0.94276	0.94271	124.1
124.2	0.94293	0.94288	0.94283	0.94278	0.94272	0.94267	0.94262	124.2
124.3	0.94284	0.94279	0.94274	0.94269	0.94263	0.94258	0.94253	124.3
124.4	0.94275	0.94270	0.94265	0.94260	0.94254	0.94249	0.94244	124.4
124.5	0.94266	0.94261	0.94256	0.94250	0.94245	0.94240	0.94235	124.5
124.6	0.94257	0.94252	0.94247	0.94241	0.94236	0.94231	0.94226	124.6
124.7	0.94248	0.94243	0.94238	0.94232	0.94227	0.94222	0.94217	124.7
124.8	0.94239	0.94234	0.94229	0.94223	0.94218	0.94213	0.94208	124.8
124.9	0.94230	0.94225	0.94220	0.94214	0.94209	0.94204	0.94199	124.9
125.0	0.94221	0.94216	0.94211	0.94205	0.94200	0.94195	0.94190	125.0

Table 6B. Volume Correction Factor Due to Temperature Against API Gravity at 60°F (Refined Products)

Alternate Pressure is 0 psig

Base API Gravity

Volume Correction for the Effect of Temperature on Liquid (CTL) to 60°F

°F	95.0	95.1	95.2	95.3	95.4	95.5	95.6	°F
120.0	0.94615	0.94611	0.94608	0.94604	0.94600	0.94596	0.94593	120.0
120.1	0.94606	0.94602	0.94598	0.94595	0.94591	0.94587	0.94583	120.1
120.2	0.94597	0.94593	0.94589	0.94586	0.94582	0.94578	0.94574	120.2
120.3	0.94588	0.94584	0.94580	0.94576	0.94573	0.94569	0.94565	120.3
120.4	0.94579	0.94575	0.94571	0.94567	0.94564	0.94560	0.94556	120.4
120.5	0.94570	0.94566	0.94562	0.94558	0.94554	0.94551	0.94547	120.5
120.6	0.94561	0.94557	0.94553	0.94549	0.94545	0.94542	0.94538	120.6
120.7	0.94551	0.94548	0.94544	0.94540	0.94536	0.94532	0.94529	120.7
120.8	0.94542	0.94539	0.94535	0.94531	0.94527	0.94523	0.94520	120.8
120.9	0.94533	0.94529	0.94526	0.94522	0.94518	0.94514	0.94510	120.9
121.0	0.94524	0.94520	0.94517	0.94513	0.94509	0.94505	0.94501	121.0
121.1	0.94515	0.94511	0.94507	0.94504	0.94500	0.94496	0.94492	121.1
121.2	0.94506	0.94502	0.94498	0.94495	0.94491	0.94487	0.94483	121.2
121.3	0.94497	0.94493	0.94489	0.94485	0.94482	0.94478	0.94474	121.3
121.4	0.94488	0.94484	0.94480	0.94476	0.94472	0.94469	0.94465	121.4
121.5	0.94479	0.94475	0.94471	0.94467	0.94463	0.94460	0.94456	121.5
121.6	0.94470	0.94466	0.94462	0.94458	0.94454	0.94450	0.94447	121.6
121.7	0.94461	0.94457	0.94453	0.94449	0.94445	0.94441	0.94437	121.7
121.8	0.94451	0.94448	0.94444	0.94440	0.94436	0.94432	0.94428	121.8
121.9	0.94442	0.94439	0.94435	0.94431	0.94427	0.94423	0.94419	121.9
122.0	0.94433	0.94429	0.94426	0.94422	0.94418	0.94414	0.94410	122.0
122.1	0.94424	0.94420	0.94416	0.94413	0.94409	0.94405	0.94401	122.1
122.2	0.94415	0.94411	0.94407	0.94403	0.94400	0.94396	0.94392	122.2
122.3	0.94406	0.94402	0.94398	0.94394	0.94390	0.94387	0.94383	122.3
122.4	0.94397	0.94393	0.94389	0.94385	0.94381	0.94377	0.94373	122.4
122.5	0.94388	0.94384	0.94380	0.94376	0.94372	0.94368	0.94364	122.5
122.6	0.94379	0.94375	0.94371	0.94367	0.94363	0.94359	0.94355	122.6
122.7	0.94370	0.94366	0.94362	0.94358	0.94354	0.94350	0.94346	122.7
122.8	0.94361	0.94357	0.94353	0.94349	0.94345	0.94341	0.94337	122.8
122.9	0.94351	0.94348	0.94344	0.94340	0.94336	0.94332	0.94328	122.9
123.0	0.94342	0.94338	0.94334	0.94331	0.94327	0.94323	0.94319	123.0
123.1	0.94333	0.94329	0.94325	0.94321	0.94317	0.94314	0.94310	123.1
123.2	0.94324	0.94320	0.94316	0.94312	0.94308	0.94304	0.94300	123.2
123.3	0.94315	0.94311	0.94307	0.94303	0.94299	0.94295	0.94291	123.3
123.4	0.94306	0.94302	0.94298	0.94294	0.94290	0.94286	0.94282	123.4
123.5	0.94297	0.94293	0.94289	0.94285	0.94281	0.94277	0.94273	123.5
123.6	0.94288	0.94284	0.94280	0.94276	0.94272	0.94268	0.94264	123.6
123.7	0.94279	0.94275	0.94271	0.94267	0.94263	0.94259	0.94255	123.7
123.8	0.94270	0.94266	0.94262	0.94258	0.94254	0.94250	0.94246	123.8
123.9	0.94261	0.94257	0.94253	0.94249	0.94245	0.94241	0.94237	123.9
124.0	0.94251	0.94247	0.94243	0.94239	0.94235	0.94231	0.94227	124.0
124.1	0.94242	0.94238	0.94234	0.94230	0.94226	0.94222	0.94218	124.1
124.2	0.94233	0.94229	0.94225	0.94221	0.94217	0.94213	0.94209	124.2
124.3	0.94224	0.94220	0.94216	0.94212	0.94208	0.94204	0.94200	124.3
124.4	0.94215	0.94211	0.94207	0.94203	0.94199	0.94195	0.94191	124.4
124.5	0.94206	0.94202	0.94198	0.94194	0.94190	0.94186	0.94182	124.5
124.6	0.94197	0.94193	0.94189	0.94185	0.94181	0.94177	0.94173	124.6
124.7	0.94188	0.94184	0.94180	0.94176	0.94172	0.94167	0.94163	124.7
124.8	0.94179	0.94175	0.94171	0.94166	0.94162	0.94158	0.94154	124.8
124.9	0.94170	0.94165	0.94161	0.94157	0.94153	0.94149	0.94145	124.9
125.0	0.94160	0.94156	0.94152	0.94148	0.94144	0.94140	0.94136	125.0

11.1.8.5 Instructions to Generate Tables 6D — Correction of Volume to 60°F Against API Gravity at 60°F for for Generalized Lubricating Oils

Input Variables: Base API gravity and temperature. Pressure set to 0 psig.

Output Variables: CTL at input temperature.

Step 1: Hold pressure value at 0 psig.

Step 2: Increment base API gravity value by 0.1°API in range of –10.0° to 45.0°API. Ensure that the base API gravity value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.1°F in range of –58.0° to 302.0°F. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from API gravity to kg/m^3 using procedure in 11.1.5.1.

Step 5: Determine the CTL value using procedure in 11.1.6.1 & specifying commodity group "D." Round the CTL value consistent with instructions in 11.1.5.4.

Step 6: Increment the value of the API gravity or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of API gravity and temperature have been calculated.

Table 6D. Volume Correction Factor Due to Temperature Against API Gravity at 60°F (Lube Oils)

Alternate Pressure is 0 psig

	Base API Gravity							
°F	35.0	35.1	35.2	35.3	35.4	35.5	35.6	°F
	Volume Correction for the Effect of Temperature on Liquid (CTL) to 60°F							
120.0	0.97517	0.97516	0.97514	0.97513	0.97511	0.97510	0.97508	120.0
120.1	0.97513	0.97512	0.97510	0.97509	0.97507	0.97506	0.97504	120.1
120.2	0.97509	0.97507	0.97506	0.97504	0.97503	0.97501	0.97500	120.2
120.3	0.97505	0.97503	0.97502	0.97500	0.97499	0.97497	0.97496	120.3
120.4	0.97501	0.97499	0.97498	0.97496	0.97495	0.97493	0.97491	120.4
120.5	0.97496	0.97495	0.97493	0.97492	0.97490	0.97489	0.97487	120.5
120.6	0.97492	0.97491	0.97489	0.97488	0.97486	0.97485	0.97483	120.6
120.7	0.97488	0.97487	0.97485	0.97484	0.97482	0.97480	0.97479	120.7
120.8	0.97484	0.97482	0.97481	0.97479	0.97478	0.97476	0.97475	120.8
120.9	0.97480	0.97478	0.97477	0.97475	0.97474	0.97472	0.97471	120.9
121.0	0.97476	0.97474	0.97473	0.97471	0.97469	0.97468	0.97466	121.0
121.1	0.97471	0.97470	0.97468	0.97467	0.97465	0.97464	0.97462	121.1
121.2	0.97467	0.97466	0.97464	0.97463	0.97461	0.97460	0.97458	121.2
121.3	0.97463	0.97462	0.97460	0.97458	0.97457	0.97455	0.97454	121.3
121.4	0.97459	0.97457	0.97456	0.97454	0.97453	0.97451	0.97450	121.4
121.5	0.97455	0.97453	0.97452	0.97450	0.97449	0.97447	0.97445	121.5
121.6	0.97451	0.97449	0.97447	0.97446	0.97444	0.97443	0.97441	121.6
121.7	0.97446	0.97445	0.97443	0.97442	0.97440	0.97439	0.97437	121.7
121.8	0.97442	0.97441	0.97439	0.97438	0.97436	0.97434	0.97433	121.8
121.9	0.97438	0.97437	0.97435	0.97433	0.97432	0.97430	0.97429	121.9
122.0	0.97434	0.97432	0.97431	0.97429	0.97428	0.97426	0.97425	122.0
122.1	0.97430	0.97428	0.97427	0.97425	0.97424	0.97422	0.97420	122.1
122.2	0.97426	0.97424	0.97422	0.97421	0.97419	0.97418	0.97416	122.2
122.3	0.97421	0.97420	0.97418	0.97417	0.97415	0.97414	0.97412	122.3
122.4	0.97417	0.97416	0.97414	0.97413	0.97411	0.97409	0.97408	122.4
122.5	0.97413	0.97411	0.97410	0.97408	0.97407	0.97405	0.97404	122.5
122.6	0.97409	0.97407	0.97406	0.97404	0.97403	0.97401	0.97399	122.6
122.7	0.97405	0.97403	0.97402	0.97400	0.97398	0.97397	0.97395	122.7
122.8	0.97401	0.97399	0.97397	0.97396	0.97394	0.97393	0.97391	122.8
122.9	0.97396	0.97395	0.97393	0.97392	0.97390	0.97389	0.97387	122.9
123.0	0.97392	0.97391	0.97389	0.97387	0.97386	0.97384	0.97383	123.0
123.1	0.97388	0.97386	0.97385	0.97383	0.97382	0.97380	0.97379	123.1
123.2	0.97384	0.97382	0.97381	0.97379	0.97378	0.97376	0.97374	123.2
123.3	0.97380	0.97378	0.97377	0.97375	0.97373	0.97372	0.97370	123.3
123.4	0.97376	0.97374	0.97372	0.97371	0.97369	0.97368	0.97366	123.4
123.5	0.97371	0.97370	0.97368	0.97367	0.97365	0.97363	0.97362	123.5
123.6	0.97367	0.97366	0.97364	0.97362	0.97361	0.97359	0.97358	123.6
123.7	0.97363	0.97361	0.97360	0.97358	0.97357	0.97355	0.97353	123.7
123.8	0.97359	0.97357	0.97356	0.97354	0.97352	0.97351	0.97349	123.8
123.9	0.97355	0.97353	0.97352	0.97350	0.97348	0.97347	0.97345	123.9
124.0	0.97351	0.97349	0.97347	0.97346	0.97344	0.97343	0.97341	124.0
124.1	0.97346	0.97345	0.97343	0.97342	0.97340	0.97338	0.97337	124.1
124.2	0.97342	0.97341	0.97339	0.97337	0.97336	0.97334	0.97333	124.2
124.3	0.97338	0.97336	0.97335	0.97333	0.97332	0.97330	0.97328	124.3
124.4	0.97334	0.97332	0.97331	0.97329	0.97327	0.97326	0.97324	124.4
124.5	0.97330	0.97328	0.97326	0.97325	0.97323	0.97322	0.97320	124.5
124.6	0.97326	0.97324	0.97322	0.97321	0.97319	0.97317	0.97316	124.6
124.7	0.97321	0.97320	0.97318	0.97317	0.97315	0.97313	0.97312	124.7
124.8	0.97317	0.97316	0.97314	0.97312	0.97311	0.97309	0.97307	124.8
124.9	0.97313	0.97311	0.97310	0.97308	0.97307	0.97305	0.97303	124.9
125.0	0.97309	0.97307	0.97306	0.97304	0.97302	0.97301	0.97299	125.0

11.1.8.6 Instructions to Generate Table 23A — Correction of Observed Specific Gravity to Specific Gravity 60/60°F for Generalized Crude Oils

Input Variables: Observed relative density and temperature. Pressure set to 0 psig.

Output Variables: Relative density (60/60°F).

Step 1: Hold pressure value at 0 psig.

Step 2: Increment observed relative density value by 0.0001 in range of 0.4710 to 1.1989. Ensure that the observed relative density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment observed temperature by 0.1°F in range of –58.0° to 302.0°F. Ensure that the observed temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from relative density to kg/m³ using procedure in 11.1.5.1.

Step 5: Determine the base density using procedure in 11.1.6.2 & specifying commodity group “A.”

Step 6: Convert the density units from kg/m³ back to relative density (60/60°F) using procedure in 11.1.5.1. Round the value of this relative density consistent with instructions in 11.1.5.4.

Step7: Increment the value of the relative density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of relative density and temperature have been calculated.

Table 23A. Correction of Observed Relative Density to Base Relative Density (60/60°F) (Crude Oils)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 psig

	Observed Relative Density (60/60)							
°F	0.8270	0.8271	0.8272	0.8273	0.8274	0.8275	0.8276	°F
	Corresponding Density at 60°F & 0 psig, Relative Density (60/60)							
90.0	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	90.0
90.1	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	90.1
90.2	0.8394	0.8395	0.8395	0.8396	0.8397	0.8398	0.8399	90.2
90.3	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	0.8400	90.3
90.4	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	0.8400	90.4
90.5	0.8395	0.8396	0.8397	0.8398	0.8399	0.8400	0.8401	90.5
90.6	0.8395	0.8396	0.8397	0.8398	0.8399	0.8400	0.8401	90.6
90.7	0.8396	0.8397	0.8398	0.8399	0.8399	0.8400	0.8401	90.7
90.8	0.8396	0.8397	0.8398	0.8399	0.8400	0.8401	0.8402	90.8
90.9	0.8396	0.8397	0.8398	0.8399	0.8400	0.8401	0.8402	90.9
91.0	0.8397	0.8398	0.8399	0.8400	0.8401	0.8402	0.8403	91.0
91.1	0.8397	0.8398	0.8399	0.8400	0.8401	0.8402	0.8403	91.1
91.2	0.8398	0.8399	0.8400	0.8401	0.8402	0.8402	0.8403	91.2
91.3	0.8398	0.8399	0.8400	0.8401	0.8402	0.8403	0.8404	91.3
91.4	0.8398	0.8399	0.8400	0.8401	0.8402	0.8403	0.8404	91.4
91.5	0.8399	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	91.5
91.6	0.8399	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	91.6
91.7	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	0.8405	91.7
91.8	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	0.8406	91.8
91.9	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	0.8406	91.9
92.0	0.8401	0.8402	0.8403	0.8404	0.8405	0.8406	0.8407	92.0
92.1	0.8401	0.8402	0.8403	0.8404	0.8405	0.8406	0.8407	92.1
92.2	0.8402	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	92.2
92.3	0.8402	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	92.3
92.4	0.8402	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	92.4
92.5	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	92.5
92.6	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	92.6
92.7	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	92.7
92.8	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	92.8
92.9	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	92.9
93.0	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	93.0
93.1	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	93.1
93.2	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	93.2
93.3	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	93.3
93.4	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	93.4
93.5	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	93.5
93.6	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	93.6
93.7	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	0.8414	93.7
93.8	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	0.8414	93.8
93.9	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	0.8414	93.9
94.0	0.8409	0.8410	0.8411	0.8412	0.8413	0.8414	0.8415	94.0
94.1	0.8409	0.8410	0.8411	0.8412	0.8413	0.8414	0.8415	94.1
94.2	0.8410	0.8411	0.8412	0.8413	0.8414	0.8415	0.8416	94.2
94.3	0.8410	0.8411	0.8412	0.8413	0.8414	0.8415	0.8416	94.3
94.4	0.8410	0.8411	0.8412	0.8413	0.8414	0.8415	0.8416	94.4
94.5	0.8411	0.8412	0.8413	0.8414	0.8415	0.8416	0.8417	94.5
94.6	0.8411	0.8412	0.8413	0.8414	0.8415	0.8416	0.8417	94.6
94.7	0.8412	0.8413	0.8414	0.8415	0.8416	0.8417	0.8418	94.7
94.8	0.8412	0.8413	0.8414	0.8415	0.8416	0.8417	0.8418	94.8
94.9	0.8413	0.8413	0.8414	0.8415	0.8416	0.8417	0.8418	94.9
95.0	0.8413	0.8414	0.8415	0.8416	0.8417	0.8418	0.8419	95.0

11.1.8.7 Instructions to Generate Table 23B — Correction of Observed Specific Gravity to Specific Gravity 60/60°F for Generalized Products

Input Variables: Observed relative density and temperature. Pressure set to 0 psig.

Output Variables: Relative density (60/60°F).

Step 1: Hold pressure value at 0 psig.

Step 2: Increment observed relative density value by 0.0001 in range of 0.4709 to 1.2065. Ensure that the observed relative density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment observed temperature by 0.1°F in range of –58.0° to 302.0°F. Ensure that the observed temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from relative density to kg/m³ using procedure in 11.1.5.1.

Step 5: Determine the base density using procedure in 11.1.6.2 & specifying commodity group "B."

Step 6: Convert the density units from kg/m³ back to relative density (60/60°F) using procedure in 11.1.5.1. Round the value of this relative density consistent with instructions in 11.1.5.4.

Step7: Increment the value of the relative density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of relative density and temperature have been calculated.

Table 23B. Correction of Observed Relative Density to Base Relative Density (60/60°F) (Refined Products)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 psig

	Observed Relative Density (60/60)							
°F	0.8270	0.8271	0.8272	0.8273	0.8274	0.8275	0.8276	°F
	Corresponding Density at 60°F & 0 psig, Relative Density (60/60)							
90.0	0.8389	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	90.0
90.1	0.8389	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	90.1
90.2	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	90.2
90.3	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	90.3
90.4	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	90.4
90.5	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	90.5
90.6	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	90.6
90.7	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	90.7
90.8	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	90.8
90.9	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	90.9
91.0	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	91.0
91.1	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	91.1
91.2	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	0.8400	91.2
91.3	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	0.8400	91.3
91.4	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	0.8400	91.4
91.5	0.8395	0.8396	0.8397	0.8398	0.8399	0.8400	0.8401	91.5
91.6	0.8395	0.8396	0.8397	0.8398	0.8399	0.8400	0.8401	91.6
91.7	0.8396	0.8397	0.8398	0.8399	0.8400	0.8401	0.8402	91.7
91.8	0.8396	0.8397	0.8398	0.8399	0.8400	0.8401	0.8402	91.8
91.9	0.8396	0.8397	0.8398	0.8399	0.8400	0.8401	0.8402	91.9
92.0	0.8397	0.8398	0.8399	0.8400	0.8401	0.8402	0.8403	92.0
92.1	0.8397	0.8398	0.8399	0.8400	0.8401	0.8402	0.8403	92.1
92.2	0.8398	0.8399	0.8400	0.8401	0.8402	0.8403	0.8404	92.2
92.3	0.8398	0.8399	0.8400	0.8401	0.8402	0.8403	0.8404	92.3
92.4	0.8398	0.8399	0.8400	0.8401	0.8402	0.8403	0.8404	92.4
92.5	0.8399	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	92.5
92.6	0.8399	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	92.6
92.7	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	0.8406	92.7
92.8	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	0.8406	92.8
92.9	0.8400	0.8401	0.8402	0.8403	0.8404	0.8405	0.8406	92.9
93.0	0.8401	0.8402	0.8403	0.8404	0.8405	0.8406	0.8407	93.0
93.1	0.8401	0.8402	0.8403	0.8404	0.8405	0.8406	0.8407	93.1
93.2	0.8402	0.8403	0.8404	0.8405	0.8405	0.8406	0.8407	93.2
93.3	0.8402	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	93.3
93.4	0.8402	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	93.4
93.5	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	93.5
93.6	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	93.6
93.7	0.8403	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	93.7
93.8	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	93.8
93.9	0.8404	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	93.9
94.0	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	94.0
94.1	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	94.1
94.2	0.8405	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	94.2
94.3	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	94.3
94.4	0.8406	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	94.4
94.5	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	94.5
94.6	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	94.6
94.7	0.8407	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	94.7
94.8	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	0.8414	94.8
94.9	0.8408	0.8409	0.8410	0.8411	0.8412	0.8413	0.8414	94.9
95.0	0.8409	0.8410	0.8411	0.8412	0.8413	0.8414	0.8415	95.0

11.1.8.8 Instructions to Generate Table 23D — Correction of Observed Specific Gravity to Specific Gravity 60/60°F for Generalized Lubricating Oils

Input Variables: Observed relative density and temperature. Pressure set to 0 psig.

Output Variables: Relative density (60/60°F).

Step 1: Hold pressure value at 0 psig.

Step 2: Increment observed relative density value by 0.0001 in range of 0.7151 to 1.2053. Ensure that the observed relative density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment observed temperature by 0.1°F in range of –58.0° to 302.0°F. Ensure that the observed temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from relative density to kg/m³ using procedure in 11.1.5.1.

Step 5: Determine the base density using procedure in 11.1.6.2 & specifying commodity group "AD."

Step 6: Convert the density units from kg/m³ back to relative density (60/60°F) using procedure in 11.1.5.1. Round the value of this relative density consistent with instructions in 11.1.5.4.

Step7: Increment the value of the relative density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of relative density and temperature have been calculated.

Table 23D. Correction of Observed Relative Density to Base Relative Density (60/60°F) (Lube Oils)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 psig

°F	0.8270	0.8271	0.8272	0.8273	0.8274	0.8275	0.8276	°F
	Corresponding Density at 60°F & 0 psig, Relative Density (60/60)							
90.0	0.8375	0.8376	0.8377	0.8378	0.8379	0.8380	0.8381	90.0
90.1	0.8375	0.8376	0.8377	0.8378	0.8379	0.8380	0.8381	90.1
90.2	0.8376	0.8377	0.8378	0.8379	0.8380	0.8381	0.8382	90.2
90.3	0.8376	0.8377	0.8378	0.8379	0.8380	0.8381	0.8382	90.3
90.4	0.8377	0.8378	0.8379	0.8380	0.8381	0.8382	0.8383	90.4
90.5	0.8377	0.8378	0.8379	0.8380	0.8381	0.8382	0.8383	90.5
90.6	0.8377	0.8378	0.8379	0.8380	0.8381	0.8382	0.8383	90.6
90.7	0.8378	0.8379	0.8380	0.8381	0.8382	0.8383	0.8384	90.7
90.8	0.8378	0.8379	0.8380	0.8381	0.8382	0.8383	0.8384	90.8
90.9	0.8378	0.8379	0.8380	0.8381	0.8382	0.8383	0.8384	90.9
91.0	0.8379	0.8380	0.8381	0.8382	0.8383	0.8384	0.8385	91.0
91.1	0.8379	0.8380	0.8381	0.8382	0.8383	0.8384	0.8385	91.1
91.2	0.8379	0.8380	0.8381	0.8382	0.8383	0.8384	0.8385	91.2
91.3	0.8380	0.8381	0.8382	0.8383	0.8384	0.8385	0.8386	91.3
91.4	0.8380	0.8381	0.8382	0.8383	0.8384	0.8385	0.8386	91.4
91.5	0.8380	0.8381	0.8382	0.8383	0.8384	0.8385	0.8386	91.5
91.6	0.8381	0.8382	0.8383	0.8384	0.8385	0.8386	0.8387	91.6
91.7	0.8381	0.8382	0.8383	0.8384	0.8385	0.8386	0.8387	91.7
91.8	0.8381	0.8382	0.8383	0.8384	0.8385	0.8386	0.8387	91.8
91.9	0.8382	0.8383	0.8384	0.8385	0.8386	0.8387	0.8388	91.9
92.0	0.8382	0.8383	0.8384	0.8385	0.8386	0.8387	0.8388	92.0
92.1	0.8383	0.8384	0.8385	0.8386	0.8387	0.8388	0.8389	92.1
92.2	0.8383	0.8384	0.8385	0.8386	0.8387	0.8388	0.8389	92.2
92.3	0.8383	0.8384	0.8385	0.8386	0.8387	0.8388	0.8389	92.3
92.4	0.8384	0.8385	0.8386	0.8387	0.8388	0.8389	0.8390	92.4
92.5	0.8384	0.8385	0.8386	0.8387	0.8388	0.8389	0.8390	92.5
92.6	0.8384	0.8385	0.8386	0.8387	0.8388	0.8389	0.8390	92.6
92.7	0.8385	0.8386	0.8387	0.8388	0.8389	0.8390	0.8391	92.7
92.8	0.8385	0.8386	0.8387	0.8388	0.8389	0.8390	0.8391	92.8
92.9	0.8385	0.8386	0.8387	0.8388	0.8389	0.8390	0.8391	92.9
93.0	0.8386	0.8387	0.8388	0.8389	0.8390	0.8391	0.8392	93.0
93.1	0.8386	0.8387	0.8388	0.8389	0.8390	0.8391	0.8392	93.1
93.2	0.8386	0.8387	0.8388	0.8389	0.8390	0.8391	0.8392	93.2
93.3	0.8387	0.8388	0.8389	0.8390	0.8391	0.8392	0.8393	93.3
93.4	0.8387	0.8388	0.8389	0.8390	0.8391	0.8392	0.8393	93.4
93.5	0.8387	0.8388	0.8389	0.8390	0.8391	0.8392	0.8393	93.5
93.6	0.8388	0.8389	0.8390	0.8391	0.8392	0.8393	0.8394	93.6
93.7	0.8388	0.8389	0.8390	0.8391	0.8392	0.8393	0.8394	93.7
93.8	0.8389	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	93.8
93.9	0.8389	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	93.9
94.0	0.8389	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	94.0
94.1	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	94.1
94.2	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	94.2
94.3	0.8390	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	94.3
94.4	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	94.4
94.5	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	94.5
94.6	0.8391	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	94.6
94.7	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	94.7
94.8	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	94.8
94.9	0.8392	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	94.9
95.0	0.8393	0.8394	0.8395	0.8396	0.8397	0.8398	0.8399	95.0

11.1.8.9 Instructions to Generate Tables 24A and 24B — Correction of Volume to 60°F Against Specific Gravity 60/60°F for Generalized Crude Oils and Products

Input Variables: Base relative density (60/60°F) and temperature. Pressure set to 0 psig.

Output Variables: CTL at input temperature.

Step 1: Hold pressure value at 0 psig.

Step 2: Increment relative density (60/60°F) value by 0.0001 in range of 0.6113 to 1.1646. Ensure that the base relative density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.1°F in range of –58.0° to 302°F. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from relative density to kg/m³ using procedure in 11.1.5.1.

Step 5: Determine the CTL value using procedure in 11.1.6.1 & specifying commodity group "A" or "B" as appropriate. Round the CTL value consistent with instructions in 11.1.5.4.

Step 6: Increment the value of the relative density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of relative density and temperature have been calculated.

Table 24A. Volume Correction Factor Due to Temperature Against Relative Density at 60°F (Crude Oils)

Alternate Pressure is 0 psig

Base Relative Density (60/60)

Volume Correction for the Effect of Temperature on Liquid (CTL) to 60°F

°F	0.9250	0.9251	0.9252	0.9253	0.9254	0.9255	0.9256	°F
105.0	0.98193	0.98193	0.98194	0.98194	0.98194	0.98195	0.98195	105.0
105.1	0.98189	0.98189	0.98189	0.98190	0.98190	0.98191	0.98191	105.1
105.2	0.98185	0.98185	0.98185	0.98186	0.98186	0.98187	0.98187	105.2
105.3	0.98181	0.98181	0.98181	0.98182	0.98182	0.98183	0.98183	105.3
105.4	0.98177	0.98177	0.98177	0.98178	0.98178	0.98179	0.98179	105.4
105.5	0.98173	0.98173	0.98173	0.98174	0.98174	0.98175	0.98175	105.5
105.6	0.98169	0.98169	0.98169	0.98170	0.98170	0.98171	0.98171	105.6
105.7	0.98164	0.98165	0.98165	0.98166	0.98166	0.98166	0.98167	105.7
105.8	0.98160	0.98161	0.98161	0.98162	0.98162	0.98162	0.98163	105.8
105.9	0.98156	0.98157	0.98157	0.98158	0.98158	0.98158	0.98159	105.9
106.0	0.98152	0.98153	0.98153	0.98154	0.98154	0.98154	0.98155	106.0
106.1	0.98148	0.98149	0.98149	0.98150	0.98150	0.98150	0.98151	106.1
106.2	0.98144	0.98145	0.98145	0.98146	0.98146	0.98146	0.98147	106.2
106.3	0.98140	0.98141	0.98141	0.98141	0.98142	0.98142	0.98143	106.3
106.4	0.98136	0.98137	0.98137	0.98137	0.98138	0.98138	0.98139	106.4
106.5	0.98132	0.98133	0.98133	0.98133	0.98134	0.98134	0.98135	106.5
106.6	0.98128	0.98129	0.98129	0.98129	0.98130	0.98130	0.98131	106.6
106.7	0.98124	0.98125	0.98125	0.98125	0.98126	0.98126	0.98127	106.7
106.8	0.98120	0.98120	0.98121	0.98121	0.98122	0.98122	0.98123	106.8
106.9	0.98116	0.98116	0.98117	0.98117	0.98118	0.98118	0.98118	106.9
107.0	0.98112	0.98112	0.98113	0.98113	0.98114	0.98114	0.98114	107.0
107.1	0.98108	0.98108	0.98109	0.98109	0.98110	0.98110	0.98110	107.1
107.2	0.98104	0.98104	0.98105	0.98105	0.98106	0.98106	0.98106	107.2
107.3	0.98100	0.98100	0.98101	0.98101	0.98102	0.98102	0.98102	107.3
107.4	0.98096	0.98096	0.98097	0.98097	0.98097	0.98098	0.98098	107.4
107.5	0.98092	0.98092	0.98093	0.98093	0.98093	0.98094	0.98094	107.5
107.6	0.98088	0.98088	0.98089	0.98089	0.98089	0.98090	0.98090	107.6
107.7	0.98084	0.98084	0.98085	0.98085	0.98085	0.98086	0.98086	107.7
107.8	0.98080	0.98080	0.98081	0.98081	0.98081	0.98082	0.98082	107.8
107.9	0.98076	0.98076	0.98076	0.98077	0.98077	0.98078	0.98078	107.9
108.0	0.98072	0.98072	0.98072	0.98073	0.98073	0.98074	0.98074	108.0
108.1	0.98068	0.98068	0.98068	0.98069	0.98069	0.98070	0.98070	108.1
108.2	0.98064	0.98064	0.98064	0.98065	0.98065	0.98066	0.98066	108.2
108.3	0.98059	0.98060	0.98060	0.98061	0.98061	0.98062	0.98062	108.3
108.4	0.98055	0.98056	0.98056	0.98057	0.98057	0.98058	0.98058	108.4
108.5	0.98051	0.98052	0.98052	0.98053	0.98053	0.98054	0.98054	108.5
108.6	0.98047	0.98048	0.98048	0.98049	0.98049	0.98050	0.98050	108.6
108.7	0.98043	0.98044	0.98044	0.98045	0.98045	0.98045	0.98046	108.7
108.8	0.98039	0.98040	0.98040	0.98041	0.98041	0.98041	0.98042	108.8
108.9	0.98035	0.98036	0.98036	0.98037	0.98037	0.98037	0.98038	108.9
109.0	0.98031	0.98032	0.98032	0.98033	0.98033	0.98033	0.98034	109.0
109.1	0.98027	0.98028	0.98028	0.98028	0.98029	0.98029	0.98030	109.1
109.2	0.98023	0.98024	0.98024	0.98024	0.98025	0.98025	0.98026	109.2
109.3	0.98019	0.98020	0.98020	0.98020	0.98021	0.98021	0.98022	109.3
109.4	0.98015	0.98015	0.98016	0.98016	0.98017	0.98017	0.98018	109.4
109.5	0.98011	0.98011	0.98012	0.98012	0.98013	0.98013	0.98014	109.5
109.6	0.98007	0.98007	0.98008	0.98008	0.98009	0.98009	0.98010	109.6
109.7	0.98003	0.98003	0.98004	0.98004	0.98005	0.98005	0.98006	109.7
109.8	0.97999	0.97999	0.98000	0.98000	0.98001	0.98001	0.98002	109.8
109.9	0.97995	0.97995	0.97996	0.97996	0.97997	0.97997	0.97997	109.9
110.0	0.97991	0.97991	0.97992	0.97992	0.97993	0.97993	0.97993	110.0

Table 24B. Volume Correction Factor Due to Temperature Against Relative Density at 60°F (Refined Products)

Alternate Pressure is 0 psig

Base Relative Density (60/60)

Volume Correction for the Effect of Temperature on Liquid (CTL) to 60°F

°F	0.9250	0.9251	0.9252	0.9253	0.9254	0.9255	0.9256	°F
105.0	0.98127	0.98127	0.98127	0.98128	0.98128	0.98128	0.98128	105.0
105.1	0.98123	0.98123	0.98123	0.98123	0.98124	0.98124	0.98124	105.1
105.2	0.98118	0.98119	0.98119	0.98119	0.98120	0.98120	0.98120	105.2
105.3	0.98114	0.98115	0.98115	0.98115	0.98115	0.98116	0.98116	105.3
105.4	0.98110	0.98110	0.98111	0.98111	0.98111	0.98111	0.98112	105.4
105.5	0.98106	0.98106	0.98106	0.98107	0.98107	0.98107	0.98108	105.5
105.6	0.98102	0.98102	0.98102	0.98103	0.98103	0.98103	0.98103	105.6
105.7	0.98098	0.98098	0.98098	0.98098	0.98099	0.98099	0.98099	105.7
105.8	0.98093	0.98094	0.98094	0.98094	0.98094	0.98095	0.98095	105.8
105.9	0.98089	0.98089	0.98090	0.98090	0.98090	0.98091	0.98091	105.9
106.0	0.98085	0.98085	0.98086	0.98086	0.98086	0.98086	0.98087	106.0
106.1	0.98081	0.98081	0.98081	0.98082	0.98082	0.98082	0.98082	106.1
106.2	0.98077	0.98077	0.98077	0.98077	0.98078	0.98078	0.98078	106.2
106.3	0.98072	0.98073	0.98073	0.98073	0.98074	0.98074	0.98074	106.3
106.4	0.98068	0.98069	0.98069	0.98069	0.98069	0.98070	0.98070	106.4
106.5	0.98064	0.98064	0.98065	0.98065	0.98065	0.98065	0.98066	106.5
106.6	0.98060	0.98060	0.98060	0.98061	0.98061	0.98061	0.98062	106.6
106.7	0.98056	0.98056	0.98056	0.98057	0.98057	0.98057	0.98057	106.7
106.8	0.98052	0.98052	0.98052	0.98052	0.98053	0.98053	0.98053	106.8
106.9	0.98047	0.98048	0.98048	0.98048	0.98048	0.98049	0.98049	106.9
107.0	0.98043	0.98043	0.98044	0.98044	0.98044	0.98045	0.98045	107.0
107.1	0.98039	0.98039	0.98040	0.98040	0.98040	0.98040	0.98041	107.1
107.2	0.98035	0.98035	0.98035	0.98036	0.98036	0.98036	0.98036	107.2
107.3	0.98031	0.98031	0.98031	0.98031	0.98032	0.98032	0.98032	107.3
107.4	0.98026	0.98027	0.98027	0.98027	0.98028	0.98028	0.98028	107.4
107.5	0.98022	0.98022	0.98023	0.98023	0.98023	0.98024	0.98024	107.5
107.6	0.98018	0.98018	0.98019	0.98019	0.98019	0.98019	0.98020	107.6
107.7	0.98014	0.98014	0.98014	0.98015	0.98015	0.98015	0.98016	107.7
107.8	0.98010	0.98010	0.98010	0.98010	0.98011	0.98011	0.98011	107.8
107.9	0.98005	0.98006	0.98006	0.98006	0.98007	0.98007	0.98007	107.9
108.0	0.98001	0.98002	0.98002	0.98002	0.98002	0.98003	0.98003	108.0
108.1	0.97997	0.97997	0.97998	0.97998	0.97998	0.97999	0.97999	108.1
108.2	0.97993	0.97993	0.97993	0.97994	0.97994	0.97994	0.97995	108.2
108.3	0.97989	0.97989	0.97989	0.97990	0.97990	0.97990	0.97990	108.3
108.4	0.97985	0.97985	0.97985	0.97985	0.97986	0.97986	0.97986	108.4
108.5	0.97980	0.97981	0.97981	0.97981	0.97981	0.97982	0.97982	108.5
108.6	0.97976	0.97976	0.97977	0.97977	0.97977	0.97978	0.97978	108.6
108.7	0.97972	0.97972	0.97973	0.97973	0.97973	0.97973	0.97974	108.7
108.8	0.97968	0.97968	0.97968	0.97969	0.97969	0.97969	0.97969	108.8
108.9	0.97964	0.97964	0.97964	0.97964	0.97965	0.97965	0.97965	108.9
109.0	0.97959	0.97960	0.97960	0.97960	0.97961	0.97961	0.97961	109.0
109.1	0.97955	0.97956	0.97956	0.97956	0.97956	0.97957	0.97957	109.1
109.2	0.97951	0.97951	0.97952	0.97952	0.97952	0.97952	0.97953	109.2
109.3	0.97947	0.97947	0.97947	0.97948	0.97948	0.97948	0.97949	109.3
109.4	0.97943	0.97943	0.97943	0.97944	0.97944	0.97944	0.97944	109.4
109.5	0.97938	0.97939	0.97939	0.97939	0.97940	0.97940	0.97940	109.5
109.6	0.97934	0.97935	0.97935	0.97935	0.97935	0.97936	0.97936	109.6
109.7	0.97930	0.97930	0.97931	0.97931	0.97931	0.97932	0.97932	109.7
109.8	0.97926	0.97926	0.97926	0.97927	0.97927	0.97927	0.97928	109.8
109.9	0.97922	0.97922	0.97922	0.97923	0.97923	0.97923	0.97923	109.9
110.0	0.97918	0.97918	0.97918	0.97918	0.97919	0.97919	0.97919	110.0

11.1.8.10 Instructions to Generate Table 24D — Correction of Volume to 60°F Against Specific Gravity 60/60°F for Generalized Lubricating Oils

Input Variables: Base relative density (60/60°F) and temperature. Pressure set to 0 psig.

Output Variables: CTL at input temperature.

Step 1: Hold pressure value at 0 psig.

Step 2: Increment relative density (60/60°F) value by 0.0001 in range of 0.8017 to 1.1646. Ensure that the base relative density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.1°F in range of –58.0° to 302°F. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Convert density units from relative density to kg/m³ using procedure in 11.1.5.1.

Step 5: Determine the CTL value using procedure in 11.1.6.1 & specifying commodity group "A" or "BD" as appropriate. Round the CTL value consistent with instructions in 11.1.5.4.

Step 6: Increment the value of the relative density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of relative density and temperature have been calculated.

Table 24D. Volume Correction Factor Due to Temperature Against Relative Density at 60°F (lube Oils)

Alternate Pressure is 0 psig

Base Relative Density (60/60)

Volume Correction for the Effect of Temperature on Liquid (CTL) to 60°F

°F	0.9250	0.9251	0.9252	0.9253	0.9254	0.9255	0.9256	°F
105.0	0.98293	0.98293	0.98293	0.98293	0.98294	0.98294	0.98294	105.0
105.1	0.98289	0.98289	0.98289	0.98290	0.98290	0.98290	0.98290	105.1
105.2	0.98285	0.98285	0.98286	0.98286	0.98286	0.98286	0.98286	105.2
105.3	0.98281	0.98282	0.98282	0.98282	0.98282	0.98282	0.98282	105.3
105.4	0.98278	0.98278	0.98278	0.98278	0.98278	0.98278	0.98279	105.4
105.5	0.98274	0.98274	0.98274	0.98274	0.98274	0.98275	0.98275	105.5
105.6	0.98270	0.98270	0.98270	0.98270	0.98271	0.98271	0.98271	105.6
105.7	0.98266	0.98266	0.98266	0.98267	0.98267	0.98267	0.98267	105.7
105.8	0.98262	0.98262	0.98263	0.98263	0.98263	0.98263	0.98263	105.8
105.9	0.98258	0.98259	0.98259	0.98259	0.98259	0.98259	0.98260	105.9
106.0	0.98255	0.98255	0.98255	0.98255	0.98255	0.98256	0.98256	106.0
106.1	0.98251	0.98251	0.98251	0.98251	0.98252	0.98252	0.98252	106.1
106.2	0.98247	0.98247	0.98247	0.98248	0.98248	0.98248	0.98248	106.2
106.3	0.98243	0.98243	0.98244	0.98244	0.98244	0.98244	0.98244	106.3
106.4	0.98239	0.98240	0.98240	0.98240	0.98240	0.98240	0.98241	106.4
106.5	0.98236	0.98236	0.98236	0.98236	0.98236	0.98237	0.98237	106.5
106.6	0.98232	0.98232	0.98232	0.98232	0.98233	0.98233	0.98233	106.6
106.7	0.98228	0.98228	0.98228	0.98229	0.98229	0.98229	0.98229	106.7
106.8	0.98224	0.98224	0.98225	0.98225	0.98225	0.98225	0.98225	106.8
106.9	0.98220	0.98221	0.98221	0.98221	0.98221	0.98221	0.98221	106.9
107.0	0.98217	0.98217	0.98217	0.98217	0.98217	0.98217	0.98218	107.0
107.1	0.98213	0.98213	0.98213	0.98213	0.98213	0.98214	0.98214	107.1
107.2	0.98209	0.98209	0.98209	0.98209	0.98210	0.98210	0.98210	107.2
107.3	0.98205	0.98205	0.98205	0.98206	0.98206	0.98206	0.98206	107.3
107.4	0.98201	0.98201	0.98202	0.98202	0.98202	0.98202	0.98202	107.4
107.5	0.98197	0.98198	0.98198	0.98198	0.98198	0.98198	0.98199	107.5
107.6	0.98194	0.98194	0.98194	0.98194	0.98194	0.98195	0.98195	107.6
107.7	0.98190	0.98190	0.98190	0.98190	0.98191	0.98191	0.98191	107.7
107.8	0.98186	0.98186	0.98186	0.98187	0.98187	0.98187	0.98187	107.8
107.9	0.98182	0.98182	0.98183	0.98183	0.98183	0.98183	0.98183	107.9
108.0	0.98178	0.98179	0.98179	0.98179	0.98179	0.98179	0.98180	108.0
108.1	0.98175	0.98175	0.98175	0.98175	0.98175	0.98176	0.98176	108.1
108.2	0.98171	0.98171	0.98171	0.98171	0.98172	0.98172	0.98172	108.2
108.3	0.98167	0.98167	0.98167	0.98168	0.98168	0.98168	0.98168	108.3
108.4	0.98163	0.98163	0.98164	0.98164	0.98164	0.98164	0.98164	108.4
108.5	0.98159	0.98160	0.98160	0.98160	0.98160	0.98160	0.98161	108.5
108.6	0.98155	0.98156	0.98156	0.98156	0.98156	0.98156	0.98157	108.6
108.7	0.98152	0.98152	0.98152	0.98152	0.98152	0.98153	0.98153	108.7
108.8	0.98148	0.98148	0.98148	0.98148	0.98149	0.98149	0.98149	108.8
108.9	0.98144	0.98144	0.98144	0.98145	0.98145	0.98145	0.98145	108.9
109.0	0.98140	0.98140	0.98141	0.98141	0.98141	0.98141	0.98141	109.0
109.1	0.98136	0.98137	0.98137	0.98137	0.98137	0.98137	0.98138	109.1
109.2	0.98133	0.98133	0.98133	0.98133	0.98133	0.98134	0.98134	109.2
109.3	0.98129	0.98129	0.98129	0.98129	0.98130	0.98130	0.98130	109.3
109.4	0.98125	0.98125	0.98125	0.98126	0.98126	0.98126	0.98126	109.4
109.5	0.98121	0.98121	0.98122	0.98122	0.98122	0.98122	0.98122	109.5
109.6	0.98117	0.98118	0.98118	0.98118	0.98118	0.98118	0.98119	109.6
109.7	0.98114	0.98114	0.98114	0.98114	0.98114	0.98115	0.98115	109.7
109.8	0.98110	0.98110	0.98110	0.98110	0.98111	0.98111	0.98111	109.8
109.9	0.98106	0.98106	0.98106	0.98107	0.98107	0.98107	0.98107	109.9
110.0	0.98102	0.98102	0.98102	0.98103	0.98103	0.98103	0.98103	110.0

11.1.8.11 Instructions to Generate Table 53A — Correction of Observed Density to Density at 15°C for Generalized Crude Oils

Input Variables: Observed density and temperature. Pressure set to 0 kPa.

Output Variables: Base density at 15°C and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa.

Step 2: Increment density value by 0.1 kg/m³ in range of 470.6 to 1197.7 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the base density using procedure in 11.1.7.2 & specifying commodity group "A." Round the resulting density value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 53A. Correction of Observed Density to 15°C Base Density (Crude Oils)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 kPa (gauge)

°C	827.0	827.1	827.2	827.3	827.4	827.5	827.6	°C
	Corresponding Density at 15°C & 0 kPa (gauge), kg/m³							
35.00	841.7	841.8	841.9	842.0	842.1	842.2	842.3	35.00
35.05	841.7	841.8	841.9	842.0	842.1	842.2	842.3	35.05
35.10	841.7	841.8	841.9	842.0	842.1	842.2	842.3	35.10
35.15	841.8	841.9	842.0	842.1	842.2	842.3	842.4	35.15
35.20	841.8	841.9	842.0	842.1	842.2	842.3	842.4	35.20
35.25	841.9	841.9	842.0	842.1	842.2	842.3	842.4	35.25
35.30	841.9	842.0	842.1	842.2	842.3	842.4	842.5	35.30
35.35	841.9	842.0	842.1	842.2	842.3	842.4	842.5	35.35
35.40	842.0	842.1	842.2	842.3	842.4	842.5	842.5	35.40
35.45	842.0	842.1	842.2	842.3	842.4	842.5	842.6	35.45
35.50	842.0	842.1	842.2	842.3	842.4	842.5	842.6	35.50
35.55	842.1	842.2	842.3	842.4	842.5	842.6	842.7	35.55
35.60	842.1	842.2	842.3	842.4	842.5	842.6	842.7	35.60
35.65	842.1	842.2	842.3	842.4	842.5	842.6	842.7	35.65
35.70	842.2	842.3	842.4	842.5	842.6	842.7	842.8	35.70
35.75	842.2	842.3	842.4	842.5	842.6	842.7	842.8	35.75
35.80	842.2	842.3	842.4	842.5	842.6	842.7	842.8	35.80
35.85	842.3	842.4	842.5	842.6	842.7	842.8	842.9	35.85
35.90	842.3	842.4	842.5	842.6	842.7	842.8	842.9	35.90
35.95	842.4	842.5	842.6	842.7	842.7	842.8	842.9	35.95
36.00	842.4	842.5	842.6	842.7	842.8	842.9	843.0	36.00
36.05	842.4	842.5	842.6	842.7	842.8	842.9	843.0	36.05
36.10	842.5	842.6	842.7	842.8	842.9	843.0	843.1	36.10
36.15	842.5	842.6	842.7	842.8	842.9	843.0	843.1	36.15
36.20	842.5	842.6	842.7	842.8	842.9	843.0	843.1	36.20
36.25	842.6	842.7	842.8	842.9	843.0	843.1	843.2	36.25
36.30	842.6	842.7	842.8	842.9	843.0	843.1	843.2	36.30
36.35	842.6	842.7	842.8	842.9	843.0	843.1	843.2	36.35
36.40	842.7	842.8	842.9	843.0	843.1	843.2	843.3	36.40
36.45	842.7	842.8	842.9	843.0	843.1	843.2	843.3	36.45
36.50	842.8	842.9	843.0	843.0	843.1	843.2	843.3	36.50
36.55	842.8	842.9	843.0	843.1	843.2	843.3	843.4	36.55
36.60	842.8	842.9	843.0	843.1	843.2	843.3	843.4	36.60
36.65	842.9	843.0	843.1	843.2	843.3	843.4	843.5	36.65
36.70	842.9	843.0	843.1	843.2	843.3	843.4	843.5	36.70
36.75	842.9	843.0	843.1	843.2	843.3	843.4	843.5	36.75
36.80	843.0	843.1	843.2	843.3	843.4	843.5	843.6	36.80
36.85	843.0	843.1	843.2	843.3	843.4	843.5	843.6	36.85
36.90	843.0	843.1	843.2	843.3	843.4	843.5	843.6	36.90
36.95	843.1	843.2	843.3	843.4	843.5	843.6	843.7	36.95
37.00	843.1	843.2	843.3	843.4	843.5	843.6	843.7	37.00
37.05	843.2	843.3	843.3	843.4	843.5	843.6	843.7	37.05
37.10	843.2	843.3	843.4	843.5	843.6	843.7	843.8	37.10
37.15	843.2	843.3	843.4	843.5	843.6	843.7	843.8	37.15
37.20	843.3	843.4	843.5	843.6	843.7	843.8	843.8	37.20
37.25	843.3	843.4	843.5	843.6	843.7	843.8	843.9	37.25
37.30	843.3	843.4	843.5	843.6	843.7	843.8	843.9	37.30
37.35	843.4	843.5	843.6	843.7	843.8	843.9	844.0	37.35
37.40	843.4	843.5	843.6	843.7	843.8	843.9	844.0	37.40
37.45	843.4	843.5	843.6	843.7	843.8	843.9	844.0	37.45
37.50	843.5	843.6	843.7	843.8	843.9	844.0	844.1	37.50

11.1.8.12 Instructions to Generate Table 53B — Correction of Observed Density to Density at 15°C for Generalized Products

Input Variables: Observed density and temperature. Pressure set to 0 kPa.

Output Variables: Base density at 15°C and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa.

Step 2: Increment density value by 0.1 kg/m³ in range of 470.5 to 1205.4 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the base density using procedure in 11.1.7.2 & specifying commodity group "B." Round the resulting density value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 53B. Correction of Observed Density to 15°C Base Density (Refined Products)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 kPa (gauge)

Observed Density (kg/m³)

Corresponding Density at 15°C & 0 kPa (gauge), kg/m³

°C	827.0	827.1	827.2	827.3	827.4	827.5	827.6	°C
35.00	841.2	841.3	841.4	841.5	841.6	841.7	841.8	35.00
35.05	841.3	841.4	841.5	841.6	841.7	841.8	841.9	35.05
35.10	841.3	841.4	841.5	841.6	841.7	841.8	841.9	35.10
35.15	841.3	841.4	841.5	841.6	841.7	841.8	841.9	35.15
35.20	841.4	841.5	841.6	841.7	841.8	841.9	842.0	35.20
35.25	841.4	841.5	841.6	841.7	841.8	841.9	842.0	35.25
35.30	841.5	841.6	841.7	841.8	841.9	842.0	842.1	35.30
35.35	841.5	841.6	841.7	841.8	841.9	842.0	842.1	35.35
35.40	841.5	841.6	841.7	841.8	841.9	842.0	842.1	35.40
35.45	841.6	841.7	841.8	841.9	842.0	842.1	842.2	35.45
35.50	841.6	841.7	841.8	841.9	842.0	842.1	842.2	35.50
35.55	841.6	841.7	841.8	841.9	842.0	842.1	842.2	35.55
35.60	841.7	841.8	841.9	842.0	842.1	842.2	842.3	35.60
35.65	841.7	841.8	841.9	842.0	842.1	842.2	842.3	35.65
35.70	841.7	841.8	841.9	842.0	842.1	842.2	842.3	35.70
35.75	841.8	841.9	842.0	842.1	842.2	842.3	842.4	35.75
35.80	841.8	841.9	842.0	842.1	842.2	842.3	842.4	35.80
35.85	841.8	841.9	842.0	842.1	842.2	842.3	842.4	35.85
35.90	841.9	842.0	842.1	842.2	842.3	842.4	842.5	35.90
35.95	841.9	842.0	842.1	842.2	842.3	842.4	842.5	35.95
36.00	842.0	842.1	842.2	842.2	842.3	842.4	842.5	36.00
36.05	842.0	842.1	842.2	842.3	842.4	842.5	842.6	36.05
36.10	842.0	842.1	842.2	842.3	842.4	842.5	842.6	36.10
36.15	842.1	842.2	842.3	842.4	842.5	842.6	842.7	36.15
36.20	842.1	842.2	842.3	842.4	842.5	842.6	842.7	36.20
36.25	842.1	842.2	842.3	842.4	842.5	842.6	842.7	36.25
36.30	842.2	842.3	842.4	842.5	842.6	842.7	842.8	36.30
36.35	842.2	842.3	842.4	842.5	842.6	842.7	842.8	36.35
36.40	842.2	842.3	842.4	842.5	842.6	842.7	842.8	36.40
36.45	842.3	842.4	842.5	842.6	842.7	842.8	842.9	36.45
36.50	842.3	842.4	842.5	842.6	842.7	842.8	842.9	36.50
36.55	842.3	842.4	842.5	842.6	842.7	842.8	842.9	36.55
36.60	842.4	842.5	842.6	842.7	842.8	842.9	843.0	36.60
36.65	842.4	842.5	842.6	842.7	842.8	842.9	843.0	36.65
36.70	842.4	842.5	842.6	842.7	842.8	842.9	843.0	36.70
36.75	842.5	842.6	842.7	842.8	842.9	843.0	843.1	36.75
36.80	842.5	842.6	842.7	842.8	842.9	843.0	843.1	36.80
36.85	842.6	842.7	842.8	842.9	843.0	843.1	843.2	36.85
36.90	842.6	842.7	842.8	842.9	843.0	843.1	843.2	36.90
36.95	842.6	842.7	842.8	842.9	843.0	843.1	843.2	36.95
37.00	842.7	842.8	842.9	843.0	843.1	843.2	843.3	37.00
37.05	842.7	842.8	842.9	843.0	843.1	843.2	843.3	37.05
37.10	842.7	842.8	842.9	843.0	843.1	843.2	843.3	37.10
37.15	842.8	842.9	843.0	843.1	843.2	843.3	843.4	37.15
37.20	842.8	842.9	843.0	843.1	843.2	843.3	843.4	37.20
37.25	842.8	842.9	843.0	843.1	843.2	843.3	843.4	37.25
37.30	842.9	843.0	843.1	843.2	843.3	843.4	843.5	37.30
37.35	842.9	843.0	843.1	843.2	843.3	843.4	843.5	37.35
37.40	842.9	843.0	843.1	843.2	843.3	843.4	843.5	37.40
37.45	843.0	843.1	843.2	843.3	843.4	843.5	843.6	37.45
37.50	843.0	843.1	843.2	843.3	843.4	843.5	843.6	37.50

11.1.8.13 Instructions to Generate Table 53D — Correction of Observed Density to Density at 15°C for Generalized Lubricating Oils

Input Variables: Observed density and temperature. Pressure set to 0 kPa.

Output Variables: Base density at 15°C and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa.

Step 2: Increment density value by 0.1 kg/m³ in range of 714.5 to 1204.1 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the base density using procedure in 11.1.7.2 & specifying commodity group "D." Round the resulting density value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 53D. Correction of Observed Density to 15°C Base Density (Lube Oils)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 kPa (gauge)

°C	Observed Density (kg/m³) 827.0	827.1	827.2	827.3	827.4	827.5	827.6	°C
	Corresponding Density at 15°C & 0 kPa (gauge), kg/m³							
35.00	839.6	839.7	839.8	839.9	840.0	840.1	840.2	35.00
35.05	839.6	839.7	839.8	839.9	840.0	840.1	840.2	35.05
35.10	839.7	839.8	839.9	840.0	840.1	840.2	840.3	35.10
35.15	839.7	839.8	839.9	840.0	840.1	840.2	840.3	35.15
35.20	839.7	839.8	839.9	840.0	840.1	840.2	840.3	35.20
35.25	839.8	839.9	840.0	840.1	840.2	840.3	840.4	35.25
35.30	839.8	839.9	840.0	840.1	840.2	840.3	840.4	35.30
35.35	839.8	839.9	840.0	840.1	840.2	840.3	840.4	35.35
35.40	839.9	840.0	840.1	840.2	840.3	840.4	840.5	35.40
35.45	839.9	840.0	840.1	840.2	840.3	840.4	840.5	35.45
35.50	839.9	840.0	840.1	840.2	840.3	840.4	840.5	35.50
35.55	840.0	840.1	840.2	840.3	840.4	840.5	840.6	35.55
35.60	840.0	840.1	840.2	840.3	840.4	840.5	840.6	35.60
35.65	840.0	840.1	840.2	840.3	840.4	840.5	840.6	35.65
35.70	840.1	840.2	840.3	840.4	840.5	840.6	840.7	35.70
35.75	840.1	840.2	840.3	840.4	840.5	840.6	840.7	35.75
35.80	840.1	840.2	840.3	840.4	840.5	840.6	840.7	35.80
35.85	840.1	840.2	840.3	840.4	840.5	840.6	840.7	35.85
35.90	840.2	840.3	840.4	840.5	840.6	840.7	840.8	35.90
35.95	840.2	840.3	840.4	840.5	840.6	840.7	840.8	35.95
36.00	840.2	840.3	840.4	840.5	840.6	840.7	840.8	36.00
36.05	840.3	840.4	840.5	840.6	840.7	840.8	840.9	36.05
36.10	840.3	840.4	840.5	840.6	840.7	840.8	840.9	36.10
36.15	840.3	840.4	840.5	840.6	840.7	840.8	840.9	36.15
36.20	840.4	840.5	840.6	840.7	840.8	840.9	841.0	36.20
36.25	840.4	840.5	840.6	840.7	840.8	840.9	841.0	36.25
36.30	840.4	840.5	840.6	840.7	840.8	840.9	841.0	36.30
36.35	840.5	840.6	840.7	840.8	840.9	841.0	841.1	36.35
36.40	840.5	840.6	840.7	840.8	840.9	841.0	841.1	36.40
36.45	840.5	840.6	840.7	840.8	840.9	841.0	841.1	36.45
36.50	840.6	840.7	840.8	840.9	841.0	841.1	841.2	36.50
36.55	840.6	840.7	840.8	840.9	841.0	841.1	841.2	36.55
36.60	840.6	840.7	840.8	840.9	841.0	841.1	841.2	36.60
36.65	840.7	840.8	840.9	841.0	841.1	841.2	841.3	36.65
36.70	840.7	840.8	840.9	841.0	841.1	841.2	841.3	36.70
36.75	840.7	840.8	840.9	841.0	841.1	841.2	841.3	36.75
36.80	840.8	840.9	841.0	841.1	841.2	841.3	841.4	36.80
36.85	840.8	840.9	841.0	841.1	841.2	841.3	841.4	36.85
36.90	840.8	840.9	841.0	841.1	841.2	841.3	841.4	36.90
36.95	840.8	840.9	841.0	841.1	841.2	841.3	841.4	36.95
37.00	840.9	841.0	841.1	841.2	841.3	841.4	841.5	37.00
37.05	840.9	841.0	841.1	841.2	841.3	841.4	841.5	37.05
37.10	840.9	841.0	841.1	841.2	841.3	841.4	841.5	37.10
37.15	841.0	841.1	841.2	841.3	841.4	841.5	841.6	37.15
37.20	841.0	841.1	841.2	841.3	841.4	841.5	841.6	37.20
37.25	841.0	841.1	841.2	841.3	841.4	841.5	841.6	37.25
37.30	841.1	841.2	841.3	841.4	841.5	841.6	841.7	37.30
37.35	841.1	841.2	841.3	841.4	841.5	841.6	841.7	37.35
37.40	841.1	841.2	841.3	841.4	841.5	841.6	841.7	37.40
37.45	841.2	841.3	841.4	841.5	841.6	841.7	841.8	37.45
37.50	841.2	841.3	841.4	841.5	841.6	841.7	841.8	37.50

11.1.8.14 Instructions to Generate Tables 54A — Correction of Volume to 15°C Against Density at 15°C for Generalized Crude Oils

Input Variables: Base density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa (gauge).

Step 2: Increment density value by 0.1 kg/m³ in range of 611.2 to 1163.7 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL using procedure in 11.1.7.1 & specifying commodity group "A." Round the value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 54A. Volume Correction Factor Due to Temperature Against 15°C Base Density (Crude Oils)

Alternate Pressure is 0 kPa (gauge)

Base Density (kg/m³)

Volume Correction for the Effect of Temperature on Liquid (CTL) to 15°C

°C	925.0	925.1	925.2	925.3	925.4	925.5	925.6	°C
40.00	0.98196	0.98196	0.98197	0.98197	0.98198	0.98198	0.98198	40.00
40.05	0.98192	0.98193	0.98193	0.98194	0.98194	0.98194	0.98195	40.05
40.10	0.98189	0.98189	0.98190	0.98190	0.98190	0.98191	0.98191	40.10
40.15	0.98185	0.98186	0.98186	0.98186	0.98187	0.98187	0.98187	40.15
40.20	0.98181	0.98182	0.98182	0.98183	0.98183	0.98183	0.98184	40.20
40.25	0.98178	0.98178	0.98179	0.98179	0.98179	0.98180	0.98180	40.25
40.30	0.98174	0.98175	0.98175	0.98175	0.98176	0.98176	0.98177	40.30
40.35	0.98171	0.98171	0.98171	0.98172	0.98172	0.98173	0.98173	40.35
40.40	0.98167	0.98167	0.98168	0.98168	0.98169	0.98169	0.98169	40.40
40.45	0.98163	0.98164	0.98164	0.98165	0.98165	0.98165	0.98166	40.45
40.50	0.98160	0.98160	0.98161	0.98161	0.98161	0.98162	0.98162	40.50
40.55	0.98156	0.98156	0.98157	0.98157	0.98158	0.98158	0.98159	40.55
40.60	0.98152	0.98153	0.98153	0.98154	0.98154	0.98154	0.98155	40.60
40.65	0.98149	0.98149	0.98150	0.98150	0.98150	0.98151	0.98151	40.65
40.70	0.98145	0.98146	0.98146	0.98146	0.98147	0.98147	0.98148	40.70
40.75	0.98142	0.98142	0.98142	0.98143	0.98143	0.98144	0.98144	40.75
40.80	0.98138	0.98138	0.98139	0.98139	0.98140	0.98140	0.98140	40.80
40.85	0.98134	0.98135	0.98135	0.98136	0.98136	0.98136	0.98137	40.85
40.90	0.98131	0.98131	0.98132	0.98132	0.98132	0.98133	0.98133	40.90
40.95	0.98127	0.98127	0.98128	0.98128	0.98129	0.98129	0.98130	40.95
41.00	0.98123	0.98124	0.98124	0.98125	0.98125	0.98125	0.98126	41.00
41.05	0.98120	0.98120	0.98121	0.98121	0.98121	0.98122	0.98122	41.05
41.10	0.98116	0.98117	0.98117	0.98117	0.98118	0.98118	0.98119	41.10
41.15	0.98113	0.98113	0.98113	0.98114	0.98114	0.98115	0.98115	41.15
41.20	0.98109	0.98109	0.98110	0.98110	0.98111	0.98111	0.98111	41.20
41.25	0.98105	0.98106	0.98106	0.98107	0.98107	0.98107	0.98108	41.25
41.30	0.98102	0.98102	0.98103	0.98103	0.98103	0.98104	0.98104	41.30
41.35	0.98098	0.98098	0.98099	0.98099	0.98100	0.98100	0.98101	41.35
41.40	0.98094	0.98095	0.98095	0.98096	0.98096	0.98097	0.98097	41.40
41.45	0.98091	0.98091	0.98092	0.98092	0.98092	0.98093	0.98093	41.45
41.50	0.98087	0.98088	0.98088	0.98088	0.98089	0.98089	0.98090	41.50
41.55	0.98084	0.98084	0.98084	0.98085	0.98085	0.98086	0.98086	41.55
41.60	0.98080	0.98080	0.98081	0.98081	0.98082	0.98082	0.98082	41.60
41.65	0.98076	0.98077	0.98077	0.98078	0.98078	0.98078	0.98079	41.65
41.70	0.98073	0.98073	0.98074	0.98074	0.98074	0.98075	0.98075	41.70
41.75	0.98069	0.98069	0.98070	0.98070	0.98071	0.98071	0.98072	41.75
41.80	0.98065	0.98066	0.98066	0.98067	0.98067	0.98068	0.98068	41.80
41.85	0.98062	0.98062	0.98063	0.98063	0.98063	0.98064	0.98064	41.85
41.90	0.98058	0.98059	0.98059	0.98059	0.98060	0.98060	0.98061	41.90
41.95	0.98055	0.98055	0.98055	0.98056	0.98056	0.98057	0.98057	41.95
42.00	0.98051	0.98051	0.98052	0.98052	0.98053	0.98053	0.98053	42.00
42.05	0.98047	0.98048	0.98048	0.98049	0.98049	0.98049	0.98050	42.05
42.10	0.98044	0.98044	0.98044	0.98045	0.98045	0.98046	0.98046	42.10
42.15	0.98040	0.98040	0.98041	0.98041	0.98042	0.98042	0.98043	42.15
42.20	0.98036	0.98037	0.98037	0.98038	0.98038	0.98039	0.98039	42.20
42.25	0.98033	0.98033	0.98034	0.98034	0.98034	0.98035	0.98035	42.25
42.30	0.98029	0.98030	0.98030	0.98030	0.98031	0.98031	0.98032	42.30
42.35	0.98025	0.98026	0.98026	0.98027	0.98027	0.98028	0.98028	42.35
42.40	0.98022	0.98022	0.98023	0.98023	0.98024	0.98024	0.98024	42.40
42.45	0.98018	0.98019	0.98019	0.98020	0.98020	0.98020	0.98021	42.45
42.50	0.98015	0.98015	0.98015	0.98016	0.98016	0.98017	0.98017	42.50

11.1.8.15 Instructions to Generate Tables 54B — Correction of Volume to 15°C Against Density at 15°C for Generalized Products

Input Variables: Base density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa (gauge).

Step 2: Increment density value by 0.1 kg/m³ in range of 611.2 to 1163.8 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL using procedure in 11.1.7.1 & specifying commodity group "B." Round the value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 54B. Volume Correction Factor Due to Temperature Against 15°C Base Density (Refined Products)

Alternate Pressure is 0 kPa (gauge)

Base Density (kg/m³)

Volume Correction for the Effect of Temperature on Liquid (CTL) to 15°C

°C	925.0	925.1	925.2	925.3	925.4	925.5	925.6	°C
40.00	0.98129	0.98130	0.98130	0.98130	0.98130	0.98131	0.98131	40.00
40.05	0.98126	0.98126	0.98126	0.98126	0.98127	0.98127	0.98127	40.05
40.10	0.98122	0.98122	0.98122	0.98123	0.98123	0.98123	0.98124	40.10
40.15	0.98118	0.98118	0.98119	0.98119	0.98119	0.98119	0.98120	40.15
40.20	0.98114	0.98115	0.98115	0.98115	0.98115	0.98116	0.98116	40.20
40.25	0.98111	0.98111	0.98111	0.98111	0.98112	0.98112	0.98112	40.25
40.30	0.98107	0.98107	0.98107	0.98108	0.98108	0.98108	0.98108	40.30
40.35	0.98103	0.98103	0.98104	0.98104	0.98104	0.98104	0.98105	40.35
40.40	0.98099	0.98100	0.98100	0.98100	0.98100	0.98101	0.98101	40.40
40.45	0.98096	0.98096	0.98096	0.98096	0.98097	0.98097	0.98097	40.45
40.50	0.98092	0.98092	0.98092	0.98093	0.98093	0.98093	0.98093	40.50
40.55	0.98088	0.98088	0.98089	0.98089	0.98089	0.98089	0.98090	40.55
40.60	0.98084	0.98085	0.98085	0.98085	0.98085	0.98086	0.98086	40.60
40.65	0.98081	0.98081	0.98081	0.98081	0.98082	0.98082	0.98082	40.65
40.70	0.98077	0.98077	0.98077	0.98078	0.98078	0.98078	0.98078	40.70
40.75	0.98073	0.98073	0.98074	0.98074	0.98074	0.98074	0.98075	40.75
40.80	0.98069	0.98070	0.98070	0.98070	0.98070	0.98071	0.98071	40.80
40.85	0.98066	0.98066	0.98066	0.98066	0.98067	0.98067	0.98067	40.85
40.90	0.98062	0.98062	0.98062	0.98063	0.98063	0.98063	0.98063	40.90
40.95	0.98058	0.98058	0.98059	0.98059	0.98059	0.98059	0.98060	40.95
41.00	0.98054	0.98054	0.98055	0.98055	0.98055	0.98056	0.98056	41.00
41.05	0.98050	0.98051	0.98051	0.98051	0.98052	0.98052	0.98052	41.05
41.10	0.98047	0.98047	0.98047	0.98048	0.98048	0.98048	0.98048	41.10
41.15	0.98043	0.98043	0.98043	0.98044	0.98044	0.98044	0.98045	41.15
41.20	0.98039	0.98039	0.98040	0.98040	0.98040	0.98041	0.98041	41.20
41.25	0.98035	0.98036	0.98036	0.98036	0.98037	0.98037	0.98037	41.25
41.30	0.98032	0.98032	0.98032	0.98032	0.98033	0.98033	0.98033	41.30
41.35	0.98028	0.98028	0.98028	0.98029	0.98029	0.98029	0.98030	41.35
41.40	0.98024	0.98024	0.98025	0.98025	0.98025	0.98026	0.98026	41.40
41.45	0.98020	0.98021	0.98021	0.98021	0.98021	0.98022	0.98022	41.45
41.50	0.98017	0.98017	0.98017	0.98017	0.98018	0.98018	0.98018	41.50
41.55	0.98013	0.98013	0.98013	0.98014	0.98014	0.98014	0.98015	41.55
41.60	0.98009	0.98009	0.98010	0.98010	0.98010	0.98010	0.98011	41.60
41.65	0.98005	0.98006	0.98006	0.98006	0.98006	0.98007	0.98007	41.65
41.70	0.98002	0.98002	0.98002	0.98002	0.98003	0.98003	0.98003	41.70
41.75	0.97998	0.97998	0.97998	0.97999	0.97999	0.97999	0.97999	41.75
41.80	0.97994	0.97994	0.97995	0.97995	0.97995	0.97995	0.97996	41.80
41.85	0.97990	0.97991	0.97991	0.97991	0.97991	0.97992	0.97992	41.85
41.90	0.97986	0.97987	0.97987	0.97987	0.97988	0.97988	0.97988	41.90
41.95	0.97983	0.97983	0.97983	0.97984	0.97984	0.97984	0.97984	41.95
42.00	0.97979	0.97979	0.97980	0.97980	0.97980	0.97980	0.97981	42.00
42.05	0.97975	0.97975	0.97976	0.97976	0.97976	0.97977	0.97977	42.05
42.10	0.97971	0.97972	0.97972	0.97972	0.97973	0.97973	0.97973	42.10
42.15	0.97968	0.97968	0.97968	0.97969	0.97969	0.97969	0.97969	42.15
42.20	0.97964	0.97964	0.97964	0.97965	0.97965	0.97965	0.97966	42.20
42.25	0.97960	0.97960	0.97961	0.97961	0.97961	0.97962	0.97962	42.25
42.30	0.97956	0.97957	0.97957	0.97957	0.97958	0.97958	0.97958	42.30
42.35	0.97953	0.97953	0.97953	0.97953	0.97954	0.97954	0.97954	42.35
42.40	0.97949	0.97949	0.97949	0.97950	0.97950	0.97950	0.97951	42.40
42.45	0.97945	0.97945	0.97946	0.97946	0.97946	0.97947	0.97947	42.45
42.50	0.97941	0.97942	0.97942	0.97942	0.97942	0.97943	0.97943	42.50

11.1.8.16 Instructions to Generate Tables 54D — Correction of Volume to 15°C Against Density at 15°C for Generalized Lubricating Oils

Input Variables: Base density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa (gauge).

Step 2: Increment density value by 0.1 kg/m³ in range of 801.3 to 1163.8 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL using procedure in 11.1.7.1 & specifying commodity group "D." Round the value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 54D. Volume Correction Factor Due to Temperature Against 15°C Base Density (Lube Oils)

Alternate Pressure is 0 kPa (gauge)

Base Density (kg/m³)

Volume Correction for the Effect of Temperature on Liquid (CTL) to 15°C

°C	925.0	925.1	925.2	925.3	925.4	925.5	925.6	°C
40.00	0.98295	0.98295	0.98295	0.98295	0.98296	0.98296	0.98296	40.00
40.05	0.98291	0.98292	0.98292	0.98292	0.98292	0.98292	0.98293	40.05
40.10	0.98288	0.98288	0.98288	0.98289	0.98289	0.98289	0.98289	40.10
40.15	0.98285	0.98285	0.98285	0.98285	0.98285	0.98285	0.98286	40.15
40.20	0.98281	0.98281	0.98281	0.98282	0.98282	0.98282	0.98282	40.20
40.25	0.98278	0.98278	0.98278	0.98278	0.98278	0.98279	0.98279	40.25
40.30	0.98274	0.98274	0.98275	0.98275	0.98275	0.98275	0.98275	40.30
40.35	0.98271	0.98271	0.98271	0.98271	0.98272	0.98272	0.98272	40.35
40.40	0.98267	0.98268	0.98268	0.98268	0.98268	0.98268	0.98269	40.40
40.45	0.98264	0.98264	0.98264	0.98265	0.98265	0.98265	0.98265	40.45
40.50	0.98261	0.98261	0.98261	0.98261	0.98261	0.98261	0.98262	40.50
40.55	0.98257	0.98257	0.98257	0.98258	0.98258	0.98258	0.98258	40.55
40.60	0.98254	0.98254	0.98254	0.98254	0.98254	0.98255	0.98255	40.60
40.65	0.98250	0.98250	0.98251	0.98251	0.98251	0.98251	0.98251	40.65
40.70	0.98247	0.98247	0.98247	0.98247	0.98248	0.98248	0.98248	40.70
40.75	0.98243	0.98244	0.98244	0.98244	0.98244	0.98244	0.98245	40.75
40.80	0.98240	0.98240	0.98240	0.98241	0.98241	0.98241	0.98241	40.80
40.85	0.98237	0.98237	0.98237	0.98237	0.98237	0.98238	0.98238	40.85
40.90	0.98233	0.98233	0.98234	0.98234	0.98234	0.98234	0.98234	40.90
40.95	0.98230	0.98230	0.98230	0.98230	0.98230	0.98231	0.98231	40.95
41.00	0.98226	0.98226	0.98227	0.98227	0.98227	0.98227	0.98227	41.00
41.05	0.98223	0.98223	0.98223	0.98223	0.98224	0.98224	0.98224	41.05
41.10	0.98219	0.98220	0.98220	0.98220	0.98220	0.98220	0.98221	41.10
41.15	0.98216	0.98216	0.98216	0.98217	0.98217	0.98217	0.98217	41.15
41.20	0.98213	0.98213	0.98213	0.98213	0.98213	0.98214	0.98214	41.20
41.25	0.98209	0.98209	0.98210	0.98210	0.98210	0.98210	0.98210	41.25
41.30	0.98206	0.98206	0.98206	0.98206	0.98206	0.98207	0.98207	41.30
41.35	0.98202	0.98202	0.98203	0.98203	0.98203	0.98203	0.98203	41.35
41.40	0.98199	0.98199	0.98199	0.98199	0.98200	0.98200	0.98200	41.40
41.45	0.98195	0.98196	0.98196	0.98196	0.98196	0.98196	0.98197	41.45
41.50	0.98192	0.98192	0.98192	0.98193	0.98193	0.98193	0.98193	41.50
41.55	0.98189	0.98189	0.98189	0.98189	0.98189	0.98190	0.98190	41.55
41.60	0.98185	0.98185	0.98186	0.98186	0.98186	0.98186	0.98186	41.60
41.65	0.98182	0.98182	0.98182	0.98182	0.98182	0.98183	0.98183	41.65
41.70	0.98178	0.98178	0.98179	0.98179	0.98179	0.98179	0.98179	41.70
41.75	0.98175	0.98175	0.98175	0.98175	0.98176	0.98176	0.98176	41.75
41.80	0.98171	0.98172	0.98172	0.98172	0.98172	0.98172	0.98173	41.80
41.85	0.98168	0.98168	0.98168	0.98169	0.98169	0.98169	0.98169	41.85
41.90	0.98165	0.98165	0.98165	0.98165	0.98165	0.98166	0.98166	41.90
41.95	0.98161	0.98161	0.98162	0.98162	0.98162	0.98162	0.98162	41.95
42.00	0.98158	0.98158	0.98158	0.98158	0.98159	0.98159	0.98159	42.00
42.05	0.98154	0.98154	0.98155	0.98155	0.98155	0.98155	0.98155	42.05
42.10	0.98151	0.98151	0.98151	0.98151	0.98152	0.98152	0.98152	42.10
42.15	0.98147	0.98148	0.98148	0.98148	0.98148	0.98148	0.98149	42.15
42.20	0.98144	0.98144	0.98144	0.98145	0.98145	0.98145	0.98145	42.20
42.25	0.98141	0.98141	0.98141	0.98141	0.98141	0.98142	0.98142	42.25
42.30	0.98137	0.98137	0.98138	0.98138	0.98138	0.98138	0.98138	42.30
42.35	0.98134	0.98134	0.98134	0.98134	0.98135	0.98135	0.98135	42.35
42.40	0.98130	0.98130	0.98131	0.98131	0.98131	0.98131	0.98131	42.40
42.45	0.98127	0.98127	0.98127	0.98127	0.98128	0.98128	0.98128	42.45
42.50	0.98123	0.98124	0.98124	0.98124	0.98124	0.98124	0.98125	42.50

11.1.8.17 Instructions to Generate Tables 59A — Correction of Observed Density to Density at 20°C for Generalized Crude Oils

Input Variables: Base density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa (gauge).

Step 2: Increment density value by 0.1 kg/m³ in range of 470.6 to 1197.7 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL using procedure in 11.1.7.2 & specifying commodity group "A." Round the value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 59A. Correction of Observed Density to 20°C Base Density (Crude Oils)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 kPa (gauge)

°C	Observed Density (kg/m³) 827.0	827.1	827.2	827.3	827.4	827.5	827.6	°C
	Corresponding Density at 20°C & 0 kPa (gauge), kg/m³							
35.00	838.0	838.1	838.2	838.3	838.4	838.5	838.6	35.00
35.05	838.1	838.2	838.2	838.3	838.4	838.5	838.6	35.05
35.10	838.1	838.2	838.3	838.4	838.5	838.6	838.7	35.10
35.15	838.1	838.2	838.3	838.4	838.5	838.6	838.7	35.15
35.20	838.2	838.3	838.4	838.5	838.6	838.7	838.8	35.20
35.25	838.2	838.3	838.4	838.5	838.6	838.7	838.8	35.25
35.30	838.2	838.3	838.4	838.5	838.6	838.7	838.8	35.30
35.35	838.3	838.4	838.5	838.6	838.7	838.8	838.9	35.35
35.40	838.3	838.4	838.5	838.6	838.7	838.8	838.9	35.40
35.45	838.3	838.4	838.5	838.6	838.7	838.8	838.9	35.45
35.50	838.4	838.5	838.6	838.7	838.8	838.9	839.0	35.50
35.55	838.4	838.5	838.6	838.7	838.8	838.9	839.0	35.55
35.60	838.5	838.6	838.6	838.7	838.8	838.9	839.0	35.60
35.65	838.5	838.6	838.7	838.8	838.9	839.0	839.1	35.65
35.70	838.5	838.6	838.7	838.8	838.9	839.0	839.1	35.70
35.75	838.6	838.7	838.8	838.9	839.0	839.1	839.2	35.75
35.80	838.6	838.7	838.8	838.9	839.0	839.1	839.2	35.80
35.85	838.6	838.7	838.8	838.9	839.0	839.1	839.2	35.85
35.90	838.7	838.8	838.9	839.0	839.1	839.2	839.3	35.90
35.95	838.7	838.8	838.9	839.0	839.1	839.2	839.3	35.95
36.00	838.7	838.8	838.9	839.0	839.1	839.2	839.3	36.00
36.05	838.8	838.9	839.0	839.1	839.2	839.3	839.4	36.05
36.10	838.8	838.9	839.0	839.1	839.2	839.3	839.4	36.10
36.15	838.9	839.0	839.0	839.1	839.2	839.3	839.4	36.15
36.20	838.9	839.0	839.1	839.2	839.3	839.4	839.5	36.20
36.25	838.9	839.0	839.1	839.2	839.3	839.4	839.5	36.25
36.30	839.0	839.1	839.2	839.3	839.4	839.5	839.6	36.30
36.35	839.0	839.1	839.2	839.3	839.4	839.5	839.6	36.35
36.40	839.0	839.1	839.2	839.3	839.4	839.5	839.6	36.40
36.45	839.1	839.2	839.3	839.4	839.5	839.6	839.7	36.45
36.50	839.1	839.2	839.3	839.4	839.5	839.6	839.7	36.50
36.55	839.1	839.2	839.3	839.4	839.5	839.6	839.7	36.55
36.60	839.2	839.3	839.4	839.5	839.6	839.7	839.8	36.60
36.65	839.2	839.3	839.4	839.5	839.6	839.7	839.8	36.65
36.70	839.3	839.3	839.4	839.5	839.6	839.7	839.8	36.70
36.75	839.3	839.4	839.5	839.6	839.7	839.8	839.9	36.75
36.80	839.3	839.4	839.5	839.6	839.7	839.8	839.9	36.80
36.85	839.4	839.5	839.6	839.7	839.8	839.9	840.0	36.85
36.90	839.4	839.5	839.6	839.7	839.8	839.9	840.0	36.90
36.95	839.4	839.5	839.6	839.7	839.8	839.9	840.0	36.95
37.00	839.5	839.6	839.7	839.8	839.9	840.0	840.1	37.00
37.05	839.5	839.6	839.7	839.8	839.9	840.0	840.1	37.05
37.10	839.5	839.6	839.7	839.8	839.9	840.0	840.1	37.10
37.15	839.6	839.7	839.8	839.9	840.0	840.1	840.2	37.15
37.20	839.6	839.7	839.8	839.9	840.0	840.1	840.2	37.20
37.25	839.7	839.7	839.8	839.9	840.0	840.1	840.2	37.25
37.30	839.7	839.8	839.9	840.0	840.1	840.2	840.3	37.30
37.35	839.7	839.8	839.9	840.0	840.1	840.2	840.3	37.35
37.40	839.8	839.9	840.0	840.1	840.2	840.3	840.3	37.40
37.45	839.8	839.9	840.0	840.1	840.2	840.3	840.4	37.45
37.50	839.8	839.9	840.0	840.1	840.2	840.3	840.4	37.50

11.1.8.18 Instructions to Generate Tables 59B — Correction of Observed Density to Density at 20°C for Generalized Products

Input Variables: Base density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa (gauge).

Step 2: Increment density value by 0.1 kg/m³ in range of 470.5 to 1205.4 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL using procedure in 11.1.7.2 & specifying commodity group "B." Round the value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 59B. Correction of Observed Density to 20°C Base Density (Refined Products)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 kPa (gauge)

Observed Density (kg/m³)

Corresponding Density at 20°C & 0 kPa (gauge), kg/m³

°C	827.0	827.1	827.2	827.3	827.4	827.5	827.6	°C
35.00	837.7	837.8	837.9	838.0	838.1	838.2	838.3	35.00
35.05	837.7	837.8	837.9	838.0	838.1	838.2	838.3	35.05
35.10	837.8	837.9	838.0	838.1	838.2	838.3	838.4	35.10
35.15	837.8	837.9	838.0	838.1	838.2	838.3	838.4	35.15
35.20	837.8	837.9	838.0	838.1	838.2	838.3	838.4	35.20
35.25	837.9	838.0	838.1	838.2	838.3	838.4	838.5	35.25
35.30	837.9	838.0	838.1	838.2	838.3	838.4	838.5	35.30
35.35	837.9	838.0	838.1	838.2	838.3	838.4	838.5	35.35
35.40	838.0	838.1	838.2	838.3	838.4	838.5	838.6	35.40
35.45	838.0	838.1	838.2	838.3	838.4	838.5	838.6	35.45
35.50	838.0	838.1	838.2	838.3	838.4	838.5	838.6	35.50
35.55	838.1	838.2	838.3	838.4	838.5	838.6	838.7	35.55
35.60	838.1	838.2	838.3	838.4	838.5	838.6	838.7	35.60
35.65	838.2	838.3	838.4	838.5	838.6	838.7	838.8	35.65
35.70	838.2	838.3	838.4	838.5	838.6	838.7	838.8	35.70
35.75	838.2	838.3	838.4	838.5	838.6	838.7	838.8	35.75
35.80	838.3	838.4	838.5	838.6	838.7	838.8	838.9	35.80
35.85	838.3	838.4	838.5	838.6	838.7	838.8	838.9	35.85
35.90	838.3	838.4	838.5	838.6	838.7	838.8	838.9	35.90
35.95	838.4	838.5	838.6	838.7	838.8	838.9	839.0	35.95
36.00	838.4	838.5	838.6	838.7	838.8	838.9	839.0	36.00
36.05	838.4	838.5	838.6	838.7	838.8	838.9	839.0	36.05
36.10	838.5	838.6	838.7	838.8	838.9	839.0	839.1	36.10
36.15	838.5	838.6	838.7	838.8	838.9	839.0	839.1	36.15
36.20	838.5	838.6	838.7	838.8	838.9	839.0	839.1	36.20
36.25	838.6	838.7	838.8	838.9	839.0	839.1	839.2	36.25
36.30	838.6	838.7	838.8	838.9	839.0	839.1	839.2	36.30
36.35	838.7	838.8	838.9	839.0	839.1	839.2	839.3	36.35
36.40	838.7	838.8	838.9	839.0	839.1	839.2	839.3	36.40
36.45	838.7	838.8	838.9	839.0	839.1	839.2	839.3	36.45
36.50	838.8	838.9	839.0	839.1	839.2	839.3	839.4	36.50
36.55	838.8	838.9	839.0	839.1	839.2	839.3	839.4	36.55
36.60	838.8	838.9	839.0	839.1	839.2	839.3	839.4	36.60
36.65	838.9	839.0	839.1	839.2	839.3	839.4	839.5	36.65
36.70	838.9	839.0	839.1	839.2	839.3	839.4	839.5	36.70
36.75	838.9	839.0	839.1	839.2	839.3	839.4	839.5	36.75
36.80	839.0	839.1	839.2	839.3	839.4	839.5	839.6	36.80
36.85	839.0	839.1	839.2	839.3	839.4	839.5	839.6	36.85
36.90	839.0	839.1	839.2	839.3	839.4	839.5	839.6	36.90
36.95	839.1	839.2	839.3	839.4	839.5	839.6	839.7	36.95
37.00	839.1	839.2	839.3	839.4	839.5	839.6	839.7	37.00
37.05	839.2	839.3	839.4	839.5	839.6	839.7	839.8	37.05
37.10	839.2	839.3	839.4	839.5	839.6	839.7	839.8	37.10
37.15	839.2	839.3	839.4	839.5	839.6	839.7	839.8	37.15
37.20	839.3	839.4	839.5	839.6	839.7	839.8	839.9	37.20
37.25	839.3	839.4	839.5	839.6	839.7	839.8	839.9	37.25
37.30	839.3	839.4	839.5	839.6	839.7	839.8	839.9	37.30
37.35	839.4	839.5	839.6	839.7	839.8	839.9	840.0	37.35
37.40	839.4	839.5	839.6	839.7	839.8	839.9	840.0	37.40
37.45	839.4	839.5	839.6	839.7	839.8	839.9	840.0	37.45
37.50	839.5	839.6	839.7	839.8	839.9	840.0	840.1	37.50

11.1.8.19 Instructions to Generate Tables 59D — Correction of Observed Density to Density at 20°C for Generalized Lubricating Oils

Input Variables: Base density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa (gauge).

Step 2: Increment density value by 0.1 kg/m³ in range of 714.5 to 1204.1 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL using procedure in 11.1.7.2 & specifying commodity group "D." Round the value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 59D. Correction of Observed Density to 20°C Base Density (Lube Oils)
If hydrometer used to determine density, apply glass correction before entering table

Observed Pressure is 0 kPa (gauge)

	Observed Density (kg/m³)							
°C	827.0	827.1	827.2	827.3	827.4	827.5	827.6	°C
	Corresponding Density at 20°C & 0 kPa (gauge), kg/m³							
35.00	836.5	836.6	836.7	836.8	836.9	837.0	837.1	35.00
35.05	836.5	836.6	836.7	836.8	836.9	837.0	837.1	35.05
35.10	836.5	836.6	836.7	836.8	836.9	837.0	837.1	35.10
35.15	836.6	836.7	836.8	836.9	837.0	837.1	837.2	35.15
35.20	836.6	836.7	836.8	836.9	837.0	837.1	837.2	35.20
35.25	836.6	836.7	836.8	836.9	837.0	837.1	837.2	35.25
35.30	836.7	836.8	836.9	837.0	837.1	837.2	837.3	35.30
35.35	836.7	836.8	836.9	837.0	837.1	837.2	837.3	35.35
35.40	836.7	836.8	836.9	837.0	837.1	837.2	837.3	35.40
35.45	836.8	836.9	837.0	837.1	837.2	837.3	837.4	35.45
35.50	836.8	836.9	837.0	837.1	837.2	837.3	837.4	35.50
35.55	836.8	836.9	837.0	837.1	837.2	837.3	837.4	35.55
35.60	836.8	836.9	837.0	837.1	837.2	837.3	837.4	35.60
35.65	836.9	837.0	837.1	837.2	837.3	837.4	837.5	35.65
35.70	836.9	837.0	837.1	837.2	837.3	837.4	837.5	35.70
35.75	836.9	837.0	837.1	837.2	837.3	837.4	837.5	35.75
35.80	837.0	837.1	837.2	837.3	837.4	837.5	837.6	35.80
35.85	837.0	837.1	837.2	837.3	837.4	837.5	837.6	35.85
35.90	837.0	837.1	837.2	837.3	837.4	837.5	837.6	35.90
35.95	837.1	837.2	837.3	837.4	837.5	837.6	837.7	35.95
36.00	837.1	837.2	837.3	837.4	837.5	837.6	837.7	36.00
36.05	837.1	837.2	837.3	837.4	837.5	837.6	837.7	36.05
36.10	837.2	837.3	837.4	837.5	837.6	837.7	837.8	36.10
36.15	837.2	837.3	837.4	837.5	837.6	837.7	837.8	36.15
36.20	837.2	837.3	837.4	837.5	837.6	837.7	837.8	36.20
36.25	837.3	837.4	837.5	837.6	837.7	837.8	837.9	36.25
36.30	837.3	837.4	837.5	837.6	837.7	837.8	837.9	36.30
36.35	837.3	837.4	837.5	837.6	837.7	837.8	837.9	36.35
36.40	837.4	837.5	837.6	837.7	837.8	837.9	838.0	36.40
36.45	837.4	837.5	837.6	837.7	837.8	837.9	838.0	36.45
36.50	837.4	837.5	837.6	837.7	837.8	837.9	838.0	36.50
36.55	837.5	837.6	837.7	837.8	837.9	838.0	838.1	36.55
36.60	837.5	837.6	837.7	837.8	837.9	838.0	838.1	36.60
36.65	837.5	837.6	837.7	837.8	837.9	838.0	838.1	36.65
36.70	837.5	837.6	837.7	837.8	837.9	838.0	838.1	36.70
36.75	837.6	837.7	837.8	837.9	838.0	838.1	838.2	36.75
36.80	837.6	837.7	837.8	837.9	838.0	838.1	838.2	36.80
36.85	837.6	837.7	837.8	837.9	838.0	838.1	838.2	36.85
36.90	837.7	837.8	837.9	838.0	838.1	838.2	838.3	36.90
36.95	837.7	837.8	837.9	838.0	838.1	838.2	838.3	36.95
37.00	837.7	837.8	837.9	838.0	838.1	838.2	838.3	37.00
37.05	837.8	837.9	838.0	838.1	838.2	838.3	838.4	37.05
37.10	837.8	837.9	838.0	838.1	838.2	838.3	838.4	37.10
37.15	837.8	837.9	838.0	838.1	838.2	838.3	838.4	37.15
37.20	837.9	838.0	838.1	838.2	838.3	838.4	838.5	37.20
37.25	837.9	838.0	838.1	838.2	838.3	838.4	838.5	37.25
37.30	837.9	838.0	838.1	838.2	838.3	838.4	838.5	37.30
37.35	838.0	838.1	838.2	838.3	838.4	838.5	838.6	37.35
37.40	838.0	838.1	838.2	838.3	838.4	838.5	838.6	37.40
37.45	838.0	838.1	838.2	838.3	838.4	838.5	838.6	37.45
37.50	838.1	838.2	838.3	838.4	838.5	838.6	838.7	37.50

11.1.8.20 Instructions to Generate Table 60A — Correction of Volume to 20°C Against Density at 20°C for Generalized Crude Oils

Input Variables: Base density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa (gauge).

Step 2: Increment density value by 0.1 kg/m³ in range of 606.2 to 1161.1 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL using procedure in 11.1.7.1 & specifying commodity group "A." Round the value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 60A. Volume Correction Factor Due to Temperature Against 20°C Base Density (Crude Oils)

Alternate Pressure is 0 kPa (gauge)

Base Density (kg/m³)

Volume Correction for the Effect of Temperature on Liquid (CTL) to 20°C

°C	925.0	925.1	925.2	925.3	925.4	925.5	925.6	°C
40.00	0.98561	0.98561	0.98561	0.98561	0.98562	0.98562	0.98562	40.00
40.05	0.98557	0.98557	0.98558	0.98558	0.98558	0.98558	0.98559	40.05
40.10	0.98553	0.98554	0.98554	0.98554	0.98555	0.98555	0.98555	40.10
40.15	0.98550	0.98550	0.98550	0.98551	0.98551	0.98551	0.98552	40.15
40.20	0.98546	0.98546	0.98547	0.98547	0.98547	0.98548	0.98548	40.20
40.25	0.98542	0.98543	0.98543	0.98543	0.98544	0.98544	0.98544	40.25
40.30	0.98539	0.98539	0.98539	0.98540	0.98540	0.98540	0.98541	40.30
40.35	0.98535	0.98536	0.98536	0.98536	0.98537	0.98537	0.98537	40.35
40.40	0.98532	0.98532	0.98532	0.98533	0.98533	0.98533	0.98534	40.40
40.45	0.98528	0.98528	0.98529	0.98529	0.98529	0.98530	0.98530	40.45
40.50	0.98524	0.98525	0.98525	0.98525	0.98526	0.98526	0.98526	40.50
40.55	0.98521	0.98521	0.98521	0.98522	0.98522	0.98522	0.98523	40.55
40.60	0.98517	0.98517	0.98518	0.98518	0.98518	0.98519	0.98519	40.60
40.65	0.98514	0.98514	0.98514	0.98515	0.98515	0.98515	0.98515	40.65
40.70	0.98510	0.98510	0.98511	0.98511	0.98511	0.98512	0.98512	40.70
40.75	0.98506	0.98507	0.98507	0.98507	0.98508	0.98508	0.98508	40.75
40.80	0.98503	0.98503	0.98503	0.98504	0.98504	0.98504	0.98505	40.80
40.85	0.98499	0.98499	0.98500	0.98500	0.98500	0.98501	0.98501	40.85
40.90	0.98495	0.98496	0.98496	0.98496	0.98497	0.98497	0.98497	40.90
40.95	0.98492	0.98492	0.98493	0.98493	0.98493	0.98494	0.98494	40.95
41.00	0.98488	0.98489	0.98489	0.98489	0.98490	0.98490	0.98490	41.00
41.05	0.98485	0.98485	0.98485	0.98486	0.98486	0.98486	0.98487	41.05
41.10	0.98481	0.98481	0.98482	0.98482	0.98482	0.98483	0.98483	41.10
41.15	0.98477	0.98478	0.98478	0.98478	0.98479	0.98479	0.98479	41.15
41.20	0.98474	0.98474	0.98474	0.98475	0.98475	0.98475	0.98476	41.20
41.25	0.98470	0.98471	0.98471	0.98471	0.98472	0.98472	0.98472	41.25
41.30	0.98467	0.98467	0.98467	0.98468	0.98468	0.98468	0.98469	41.30
41.35	0.98463	0.98463	0.98464	0.98464	0.98464	0.98465	0.98465	41.35
41.40	0.98459	0.98460	0.98460	0.98460	0.98461	0.98461	0.98461	41.40
41.45	0.98456	0.98456	0.98456	0.98457	0.98457	0.98457	0.98458	41.45
41.50	0.98452	0.98452	0.98453	0.98453	0.98453	0.98454	0.98454	41.50
41.55	0.98448	0.98449	0.98449	0.98450	0.98450	0.98450	0.98451	41.55
41.60	0.98445	0.98445	0.98446	0.98446	0.98446	0.98447	0.98447	41.60
41.65	0.98441	0.98442	0.98442	0.98442	0.98443	0.98443	0.98443	41.65
41.70	0.98438	0.98438	0.98438	0.98439	0.98439	0.98439	0.98440	41.70
41.75	0.98434	0.98434	0.98435	0.98435	0.98435	0.98436	0.98436	41.75
41.80	0.98430	0.98431	0.98431	0.98431	0.98432	0.98432	0.98432	41.80
41.85	0.98427	0.98427	0.98427	0.98428	0.98428	0.98429	0.98429	41.85
41.90	0.98423	0.98424	0.98424	0.98424	0.98425	0.98425	0.98425	41.90
41.95	0.98420	0.98420	0.98420	0.98421	0.98421	0.98421	0.98422	41.95
42.00	0.98416	0.98416	0.98417	0.98417	0.98417	0.98418	0.98418	42.00
42.05	0.98412	0.98413	0.98413	0.98413	0.98414	0.98414	0.98414	42.05
42.10	0.98409	0.98409	0.98409	0.98410	0.98410	0.98410	0.98411	42.10
42.15	0.98405	0.98405	0.98406	0.98406	0.98406	0.98407	0.98407	42.15
42.20	0.98401	0.98402	0.98402	0.98403	0.98403	0.98403	0.98404	42.20
42.25	0.98398	0.98398	0.98399	0.98399	0.98399	0.98400	0.98400	42.25
42.30	0.98394	0.98395	0.98395	0.98395	0.98396	0.98396	0.98396	42.30
42.35	0.98391	0.98391	0.98391	0.98392	0.98392	0.98392	0.98393	42.35
42.40	0.98387	0.98387	0.98388	0.98388	0.98388	0.98389	0.98389	42.40
42.45	0.98383	0.98384	0.98384	0.98384	0.98385	0.98385	0.98386	42.45
42.50	0.98380	0.98380	0.98381	0.98381	0.98381	0.98382	0.98382	42.50

11.1.8.21 Instructions to Generate Table 60B — Correction of Volume to 20°C Against Density at 20°C for Generalized Products

Input Variables: Base density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa (gauge).

Step 2: Increment density value by 0.1 kg/m³ in range of 606.2 to 1160.6 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL using procedure in 11.1.7.1 & specifying commodity group “B.” Round the value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 60B. Volume Correction Factor Due to Temperature Against 20°C Base Density (Refined Products)

Alternate Pressure is 0 kPa (gauge)

Base Density (kg/m³)

Volume Correction for the Effect of Temperature on Liquid (CTL) to 20°C

°C	925.0	925.1	925.2	925.3	925.4	925.5	925.6	°C
40.00	0.98504	0.98504	0.98504	0.98504	0.98504	0.98505	0.98505	40.00
40.05	0.98500	0.98500	0.98500	0.98501	0.98501	0.98501	0.98501	40.05
40.10	0.98496	0.98496	0.98497	0.98497	0.98497	0.98497	0.98497	40.10
40.15	0.98492	0.98493	0.98493	0.98493	0.98493	0.98493	0.98494	40.15
40.20	0.98489	0.98489	0.98489	0.98489	0.98489	0.98490	0.98490	40.20
40.25	0.98485	0.98485	0.98485	0.98485	0.98486	0.98486	0.98486	40.25
40.30	0.98481	0.98481	0.98482	0.98482	0.98482	0.98482	0.98482	40.30
40.35	0.98477	0.98478	0.98478	0.98478	0.98478	0.98478	0.98479	40.35
40.40	0.98474	0.98474	0.98474	0.98474	0.98474	0.98475	0.98475	40.40
40.45	0.98470	0.98470	0.98470	0.98470	0.98471	0.98471	0.98471	40.45
40.50	0.98466	0.98466	0.98467	0.98467	0.98467	0.98467	0.98467	40.50
40.55	0.98462	0.98463	0.98463	0.98463	0.98463	0.98463	0.98464	40.55
40.60	0.98459	0.98459	0.98459	0.98459	0.98459	0.98460	0.98460	40.60
40.65	0.98455	0.98455	0.98455	0.98455	0.98456	0.98456	0.98456	40.65
40.70	0.98451	0.98451	0.98451	0.98452	0.98452	0.98452	0.98452	40.70
40.75	0.98447	0.98448	0.98448	0.98448	0.98448	0.98448	0.98449	40.75
40.80	0.98444	0.98444	0.98444	0.98444	0.98444	0.98445	0.98445	40.80
40.85	0.98440	0.98440	0.98440	0.98440	0.98441	0.98441	0.98441	40.85
40.90	0.98436	0.98436	0.98436	0.98437	0.98437	0.98437	0.98437	40.90
40.95	0.98432	0.98432	0.98433	0.98433	0.98433	0.98433	0.98434	40.95
41.00	0.98428	0.98429	0.98429	0.98429	0.98429	0.98430	0.98430	41.00
41.05	0.98425	0.98425	0.98425	0.98425	0.98426	0.98426	0.98426	41.05
41.10	0.98421	0.98421	0.98421	0.98422	0.98422	0.98422	0.98422	41.10
41.15	0.98417	0.98417	0.98418	0.98418	0.98418	0.98418	0.98419	41.15
41.20	0.98413	0.98414	0.98414	0.98414	0.98414	0.98415	0.98415	41.20
41.25	0.98410	0.98410	0.98410	0.98410	0.98411	0.98411	0.98411	41.25
41.30	0.98406	0.98406	0.98406	0.98407	0.98407	0.98407	0.98407	41.30
41.35	0.98402	0.98402	0.98403	0.98403	0.98403	0.98403	0.98404	41.35
41.40	0.98398	0.98399	0.98399	0.98399	0.98399	0.98400	0.98400	41.40
41.45	0.98395	0.98395	0.98395	0.98395	0.98396	0.98396	0.98396	41.45
41.50	0.98391	0.98391	0.98391	0.98392	0.98392	0.98392	0.98392	41.50
41.55	0.98387	0.98387	0.98388	0.98388	0.98388	0.98388	0.98389	41.55
41.60	0.98383	0.98384	0.98384	0.98384	0.98384	0.98385	0.98385	41.60
41.65	0.98380	0.98380	0.98380	0.98380	0.98381	0.98381	0.98381	41.65
41.70	0.98376	0.98376	0.98376	0.98377	0.98377	0.98377	0.98377	41.70
41.75	0.98372	0.98372	0.98373	0.98373	0.98373	0.98373	0.98373	41.75
41.80	0.98368	0.98369	0.98369	0.98369	0.98369	0.98370	0.98370	41.80
41.85	0.98365	0.98365	0.98365	0.98365	0.98366	0.98366	0.98366	41.85
41.90	0.98361	0.98361	0.98361	0.98362	0.98362	0.98362	0.98362	41.90
41.95	0.98357	0.98357	0.98358	0.98358	0.98358	0.98358	0.98358	41.95
42.00	0.98353	0.98354	0.98354	0.98354	0.98354	0.98354	0.98355	42.00
42.05	0.98350	0.98350	0.98350	0.98350	0.98351	0.98351	0.98351	42.05
42.10	0.98346	0.98346	0.98346	0.98347	0.98347	0.98347	0.98347	42.10
42.15	0.98342	0.98342	0.98343	0.98343	0.98343	0.98343	0.98343	42.15
42.20	0.98338	0.98339	0.98339	0.98339	0.98339	0.98339	0.98340	42.20
42.25	0.98335	0.98335	0.98335	0.98335	0.98335	0.98336	0.98336	42.25
42.30	0.98331	0.98331	0.98331	0.98331	0.98332	0.98332	0.98332	42.30
42.35	0.98327	0.98327	0.98327	0.98328	0.98328	0.98328	0.98328	42.35
42.40	0.98323	0.98323	0.98324	0.98324	0.98324	0.98324	0.98325	42.40
42.45	0.98319	0.98320	0.98320	0.98320	0.98320	0.98321	0.98321	42.45
42.50	0.98316	0.98316	0.98316	0.98316	0.98317	0.98317	0.98317	42.50

11.1.8.22 Instructions to Generate Table 60D — Correction of Volume to 20°C Against Density at 20°C for Generalized Lubricating Oils

Input Variables: Base density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature and 0 kPa (gauge).

Step 1: Hold pressure value at 0 kPa (gauge).

Step 2: Increment density value by 0.1 kg/m³ in range of 798.2 to 1160.7 kg/m³. Ensure that the density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL using procedure in 11.1.7.1 & specifying commodity group "D." Round the value for display consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

Table 60D. Volume Correction Factor Due to Temperature Against 20°C Base Density (Lube Oils)

Alternate Pressure is 0 kPa (gauge)

Base Density (kg/m³)

Volume Correction for the Effect of Temperature on Liquid (CTL) to 20°C

°C	925.0	925.1	925.2	925.3	925.4	925.5	925.6	°C
40.00	0.98635	0.98635	0.98635	0.98635	0.98635	0.98635	0.98635	40.00
40.05	0.98631	0.98631	0.98631	0.98632	0.98632	0.98632	0.98632	40.05
40.10	0.98628	0.98628	0.98628	0.98628	0.98628	0.98628	0.98629	40.10
40.15	0.98624	0.98624	0.98625	0.98625	0.98625	0.98625	0.98625	40.15
40.20	0.98621	0.98621	0.98621	0.98621	0.98621	0.98622	0.98622	40.20
40.25	0.98617	0.98618	0.98618	0.98618	0.98618	0.98618	0.98618	40.25
40.30	0.98614	0.98614	0.98614	0.98614	0.98615	0.98615	0.98615	40.30
40.35	0.98611	0.98611	0.98611	0.98611	0.98611	0.98611	0.98611	40.35
40.40	0.98607	0.98607	0.98607	0.98608	0.98608	0.98608	0.98608	40.40
40.45	0.98604	0.98604	0.98604	0.98604	0.98604	0.98604	0.98605	40.45
40.50	0.98600	0.98600	0.98601	0.98601	0.98601	0.98601	0.98601	40.50
40.55	0.98597	0.98597	0.98597	0.98597	0.98597	0.98598	0.98598	40.55
40.60	0.98593	0.98594	0.98594	0.98594	0.98594	0.98594	0.98594	40.60
40.65	0.98590	0.98590	0.98590	0.98590	0.98591	0.98591	0.98591	40.65
40.70	0.98587	0.98587	0.98587	0.98587	0.98587	0.98587	0.98587	40.70
40.75	0.98583	0.98583	0.98583	0.98584	0.98584	0.98584	0.98584	40.75
40.80	0.98580	0.98580	0.98580	0.98580	0.98580	0.98580	0.98581	40.80
40.85	0.98576	0.98576	0.98577	0.98577	0.98577	0.98577	0.98577	40.85
40.90	0.98573	0.98573	0.98573	0.98573	0.98573	0.98574	0.98574	40.90
40.95	0.98569	0.98570	0.98570	0.98570	0.98570	0.98570	0.98570	40.95
41.00	0.98566	0.98566	0.98566	0.98566	0.98567	0.98567	0.98567	41.00
41.05	0.98563	0.98563	0.98563	0.98563	0.98563	0.98563	0.98564	41.05
41.10	0.98559	0.98559	0.98559	0.98560	0.98560	0.98560	0.98560	41.10
41.15	0.98556	0.98556	0.98556	0.98556	0.98556	0.98557	0.98557	41.15
41.20	0.98552	0.98552	0.98553	0.98553	0.98553	0.98553	0.98553	41.20
41.25	0.98549	0.98549	0.98549	0.98549	0.98549	0.98550	0.98550	41.25
41.30	0.98545	0.98546	0.98546	0.98546	0.98546	0.98546	0.98546	41.30
41.35	0.98542	0.98542	0.98542	0.98542	0.98543	0.98543	0.98543	41.35
41.40	0.98539	0.98539	0.98539	0.98539	0.98539	0.98539	0.98540	41.40
41.45	0.98535	0.98535	0.98535	0.98536	0.98536	0.98536	0.98536	41.45
41.50	0.98532	0.98532	0.98532	0.98532	0.98532	0.98533	0.98533	41.50
41.55	0.98528	0.98528	0.98529	0.98529	0.98529	0.98529	0.98529	41.55
41.60	0.98525	0.98525	0.98525	0.98525	0.98526	0.98526	0.98526	41.60
41.65	0.98521	0.98522	0.98522	0.98522	0.98522	0.98522	0.98522	41.65
41.70	0.98518	0.98518	0.98518	0.98518	0.98519	0.98519	0.98519	41.70
41.75	0.98515	0.98515	0.98515	0.98515	0.98515	0.98515	0.98516	41.75
41.80	0.98511	0.98511	0.98511	0.98512	0.98512	0.98512	0.98512	41.80
41.85	0.98508	0.98508	0.98508	0.98508	0.98508	0.98509	0.98509	41.85
41.90	0.98504	0.98504	0.98505	0.98505	0.98505	0.98505	0.98505	41.90
41.95	0.98501	0.98501	0.98501	0.98501	0.98502	0.98502	0.98502	41.95
42.00	0.98497	0.98498	0.98498	0.98498	0.98498	0.98498	0.98498	42.00
42.05	0.98494	0.98494	0.98494	0.98495	0.98495	0.98495	0.98495	42.05
42.10	0.98491	0.98491	0.98491	0.98491	0.98491	0.98491	0.98492	42.10
42.15	0.98487	0.98487	0.98487	0.98488	0.98488	0.98488	0.98488	42.15
42.20	0.98484	0.98484	0.98484	0.98484	0.98484	0.98485	0.98485	42.20
42.25	0.98480	0.98480	0.98481	0.98481	0.98481	0.98481	0.98481	42.25
42.30	0.98477	0.98477	0.98477	0.98477	0.98478	0.98478	0.98478	42.30
42.35	0.98473	0.98474	0.98474	0.98474	0.98474	0.98474	0.98474	42.35
42.40	0.98470	0.98470	0.98470	0.98471	0.98471	0.98471	0.98471	42.40
42.45	0.98467	0.98467	0.98467	0.98467	0.98467	0.98467	0.98468	42.45
42.50	0.98463	0.98463	0.98463	0.98464	0.98464	0.98464	0.98464	42.50

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

Input Variables: 60°F thermal expansion factor and temperature. Pressure set to 0 psig.

Output Variables: CTL at input temperature.

Step 1: Hold pressure at 0 psig.

Step 2: Increment 60°F thermal expansion coefficient by 0.1×10^{-6} $°F^{-1}$ in range of 230.0×10^{-6} to 930.0×10^{-6} $°F^{-1}$. Ensure that the value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.1°F in range of –58.0° to 302.0°F. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL values using the procedure in 11.1.6.1 & specifying the special applications group "C." Round the CTL value consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the thermal expansion coefficient or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of thermal expansion factor and temperature have been calculated.

Table 6C. Volume Correction Factor Due to Temperature for Individual and Special Applications

Alternate Pressure is 0 psig

Base alpha-60, 1/°F

Volume Correction for the Effect of Temperature on Liquid (CTL) to 60°F

°F	0.0004700	0.0004701	0.0004702	0.0004703	0.0004704	0.0004705	0.0004706	°F
90.0	0.98584	0.98584	0.98583	0.98583	0.98583	0.98582	0.98582	90.0
90.1	0.98579	0.98579	0.98578	0.98578	0.98578	0.98578	0.98577	90.1
90.2	0.98574	0.98574	0.98574	0.98573	0.98573	0.98573	0.98573	90.2
90.3	0.98570	0.98569	0.98569	0.98569	0.98568	0.98568	0.98568	90.3
90.4	0.98565	0.98565	0.98564	0.98564	0.98564	0.98563	0.98563	90.4
90.5	0.98560	0.98560	0.98560	0.98559	0.98559	0.98559	0.98558	90.5
90.6	0.98555	0.98555	0.98555	0.98554	0.98554	0.98554	0.98554	90.6
90.7	0.98551	0.98550	0.98550	0.98550	0.98549	0.98549	0.98549	90.7
90.8	0.98546	0.98546	0.98545	0.98545	0.98545	0.98544	0.98544	90.8
90.9	0.98541	0.98541	0.98541	0.98540	0.98540	0.98540	0.98539	90.9
91.0	0.98536	0.98536	0.98536	0.98535	0.98535	0.98535	0.98535	91.0
91.1	0.98532	0.98531	0.98531	0.98531	0.98530	0.98530	0.98530	91.1
91.2	0.98527	0.98527	0.98526	0.98526	0.98526	0.98525	0.98525	91.2
91.3	0.98522	0.98522	0.98522	0.98521	0.98521	0.98521	0.98520	91.3
91.4	0.98517	0.98517	0.98517	0.98517	0.98516	0.98516	0.98516	91.4
91.5	0.98513	0.98512	0.98512	0.98512	0.98511	0.98511	0.98511	91.5
91.6	0.98508	0.98508	0.98507	0.98507	0.98507	0.98506	0.98506	91.6
91.7	0.98503	0.98503	0.98503	0.98502	0.98502	0.98502	0.98501	91.7
91.8	0.98499	0.98498	0.98498	0.98498	0.98497	0.98497	0.98497	91.8
91.9	0.98494	0.98493	0.98493	0.98493	0.98492	0.98492	0.98492	91.9
92.0	0.98489	0.98489	0.98488	0.98488	0.98488	0.98487	0.98487	92.0
92.1	0.98484	0.98484	0.98484	0.98483	0.98483	0.98483	0.98482	92.1
92.2	0.98480	0.98479	0.98479	0.98479	0.98478	0.98478	0.98478	92.2
92.3	0.98475	0.98474	0.98474	0.98474	0.98473	0.98473	0.98473	92.3
92.4	0.98470	0.98470	0.98469	0.98469	0.98469	0.98468	0.98468	92.4
92.5	0.98465	0.98465	0.98465	0.98464	0.98464	0.98464	0.98463	92.5
92.6	0.98461	0.98460	0.98460	0.98460	0.98459	0.98459	0.98459	92.6
92.7	0.98456	0.98456	0.98455	0.98455	0.98455	0.98454	0.98454	92.7
92.8	0.98451	0.98451	0.98450	0.98450	0.98450	0.98449	0.98449	92.8
92.9	0.98446	0.98446	0.98446	0.98445	0.98445	0.98445	0.98444	92.9
93.0	0.98442	0.98441	0.98441	0.98441	0.98440	0.98440	0.98440	93.0
93.1	0.98437	0.98437	0.98436	0.98436	0.98436	0.98435	0.98435	93.1
93.2	0.98432	0.98432	0.98431	0.98431	0.98431	0.98430	0.98430	93.2
93.3	0.98427	0.98427	0.98427	0.98426	0.98426	0.98426	0.98425	93.3
93.4	0.98423	0.98422	0.98422	0.98422	0.98421	0.98421	0.98421	93.4
93.5	0.98418	0.98418	0.98417	0.98417	0.98417	0.98416	0.98416	93.5
93.6	0.98413	0.98413	0.98412	0.98412	0.98412	0.98411	0.98411	93.6
93.7	0.98408	0.98408	0.98408	0.98407	0.98407	0.98407	0.98406	93.7
93.8	0.98404	0.98403	0.98403	0.98403	0.98402	0.98402	0.98402	93.8
93.9	0.98399	0.98399	0.98398	0.98398	0.98398	0.98397	0.98397	93.9
94.0	0.98394	0.98394	0.98393	0.98393	0.98393	0.98392	0.98392	94.0
94.1	0.98389	0.98389	0.98389	0.98388	0.98388	0.98388	0.98387	94.1
94.2	0.98385	0.98384	0.98384	0.98384	0.98383	0.98383	0.98383	94.2
94.3	0.98380	0.98380	0.98379	0.98379	0.98379	0.98378	0.98378	94.3
94.4	0.98375	0.98375	0.98374	0.98374	0.98374	0.98373	0.98373	94.4
94.5	0.98370	0.98370	0.98370	0.98369	0.98369	0.98369	0.98368	94.5
94.6	0.98366	0.98365	0.98365	0.98365	0.98364	0.98364	0.98364	94.6
94.7	0.98361	0.98361	0.98360	0.98360	0.98360	0.98359	0.98359	94.7
94.8	0.98356	0.98356	0.98356	0.98355	0.98355	0.98354	0.98354	94.8
94.9	0.98351	0.98351	0.98351	0.98350	0.98350	0.98350	0.98349	94.9
95.0	0.98347	0.98346	0.98346	0.98346	0.98345	0.98345	0.98345	95.0

Table 24C. Volume Correction Factor Due to Temperature to 60°F for Individual and Special Applications

Alternate Pressure is 0 psig

Base alpha-60, 1/°F

Volume Correction for the Effect of Temperature on Liquid (CTL) to 60°F

°F	0.0004700	0.0004701	0.0004702	0.0004703	0.0004704	0.0004705	0.0004706	°F
90.0	0.98584	0.98584	0.98583	0.98583	0.98583	0.98582	0.98582	90.0
90.1	0.98579	0.98579	0.98578	0.98578	0.98578	0.98578	0.98577	90.1
90.2	0.98574	0.98574	0.98574	0.98573	0.98573	0.98573	0.98573	90.2
90.3	0.98570	0.98569	0.98569	0.98569	0.98568	0.98568	0.98568	90.3
90.4	0.98565	0.98565	0.98564	0.98564	0.98564	0.98563	0.98563	90.4
90.5	0.98560	0.98560	0.98560	0.98559	0.98559	0.98559	0.98558	90.5
90.6	0.98555	0.98555	0.98555	0.98554	0.98554	0.98554	0.98554	90.6
90.7	0.98551	0.98550	0.98550	0.98550	0.98549	0.98549	0.98549	90.7
90.8	0.98546	0.98546	0.98545	0.98545	0.98545	0.98544	0.98544	90.8
90.9	0.98541	0.98541	0.98541	0.98540	0.98540	0.98540	0.98539	90.9
91.0	0.98536	0.98536	0.98536	0.98535	0.98535	0.98535	0.98535	91.0
91.1	0.98532	0.98531	0.98531	0.98531	0.98530	0.98530	0.98530	91.1
91.2	0.98527	0.98527	0.98526	0.98526	0.98526	0.98525	0.98525	91.2
91.3	0.98522	0.98522	0.98522	0.98521	0.98521	0.98521	0.98520	91.3
91.4	0.98517	0.98517	0.98517	0.98517	0.98516	0.98516	0.98516	91.4
91.5	0.98513	0.98512	0.98512	0.98512	0.98511	0.98511	0.98511	91.5
91.6	0.98508	0.98508	0.98507	0.98507	0.98507	0.98506	0.98506	91.6
91.7	0.98503	0.98503	0.98503	0.98502	0.98502	0.98502	0.98501	91.7
91.8	0.98499	0.98498	0.98498	0.98498	0.98497	0.98497	0.98497	91.8
91.9	0.98494	0.98493	0.98493	0.98493	0.98492	0.98492	0.98492	91.9
92.0	0.98489	0.98489	0.98488	0.98488	0.98488	0.98487	0.98487	92.0
92.1	0.98484	0.98484	0.98484	0.98483	0.98483	0.98483	0.98482	92.1
92.2	0.98480	0.98479	0.98479	0.98479	0.98478	0.98478	0.98478	92.2
92.3	0.98475	0.98474	0.98474	0.98474	0.98473	0.98473	0.98473	92.3
92.4	0.98470	0.98470	0.98469	0.98469	0.98469	0.98468	0.98468	92.4
92.5	0.98465	0.98465	0.98465	0.98464	0.98464	0.98464	0.98463	92.5
92.6	0.98461	0.98460	0.98460	0.98460	0.98459	0.98459	0.98459	92.6
92.7	0.98456	0.98456	0.98455	0.98455	0.98455	0.98454	0.98454	92.7
92.8	0.98451	0.98451	0.98450	0.98450	0.98450	0.98449	0.98449	92.8
92.9	0.98446	0.98446	0.98446	0.98445	0.98445	0.98445	0.98444	92.9
93.0	0.98442	0.98441	0.98441	0.98441	0.98440	0.98440	0.98440	93.0
93.1	0.98437	0.98437	0.98436	0.98436	0.98436	0.98435	0.98435	93.1
93.2	0.98432	0.98432	0.98431	0.98431	0.98431	0.98430	0.98430	93.2
93.3	0.98427	0.98427	0.98427	0.98426	0.98426	0.98426	0.98425	93.3
93.4	0.98423	0.98422	0.98422	0.98422	0.98421	0.98421	0.98421	93.4
93.5	0.98418	0.98418	0.98417	0.98417	0.98417	0.98416	0.98416	93.5
93.6	0.98413	0.98413	0.98412	0.98412	0.98412	0.98411	0.98411	93.6
93.7	0.98408	0.98408	0.98408	0.98407	0.98407	0.98407	0.98406	93.7
93.8	0.98404	0.98403	0.98403	0.98403	0.98402	0.98402	0.98402	93.8
93.9	0.98399	0.98399	0.98398	0.98398	0.98398	0.98397	0.98397	93.9
94.0	0.98394	0.98394	0.98393	0.98393	0.98393	0.98392	0.98392	94.0
94.1	0.98389	0.98389	0.98389	0.98388	0.98388	0.98388	0.98387	94.1
94.2	0.98385	0.98384	0.98384	0.98384	0.98383	0.98383	0.98383	94.2
94.3	0.98380	0.98380	0.98379	0.98379	0.98379	0.98378	0.98378	94.3
94.4	0.98375	0.98375	0.98374	0.98374	0.98374	0.98373	0.98373	94.4
94.5	0.98370	0.98370	0.98370	0.98369	0.98369	0.98369	0.98368	94.5
94.6	0.98366	0.98365	0.98365	0.98365	0.98364	0.98364	0.98364	94.6
94.7	0.98361	0.98361	0.98360	0.98360	0.98360	0.98359	0.98359	94.7
94.8	0.98356	0.98356	0.98356	0.98355	0.98355	0.98354	0.98354	94.8
94.9	0.98351	0.98351	0.98351	0.98350	0.98350	0.98350	0.98349	94.9
95.0	0.98347	0.98346	0.98346	0.98346	0.98345	0.98345	0.98345	95.0

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

Input Variables: 60°F thermal expansion coefficient and temperature. Pressure set to 0 kPa (gauge).

Output Variables: CTL at input temperature.

Step 1: Hold pressure at 0 kPa (gauge).

Step 2: Increment 60°F thermal expansion coefficient by 0.2×10^{-6} °C^{-1} in range of 414.0×10^{-6} to 1674×10^{-6} °C^{-1}. Ensure that the value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°F in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the CTL values using the procedure in 11.1.7.1 & specifying the special applications group "C." Round the CTL value consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the thermal expansion coefficient or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of thermal expansion factor and temperature have been calculated.

Table 54C. Volume Correction Factor Due to Temperature to 15°C for Individual and Special Applications

Alternate Pressure is 0 kPa (gauge)

Base alpha-60, 1/°C

Volume Correction for the Effect of Temperature on Liquid (CTL) to 15°C

°C	0.0009000	0.0009002	0.0009004	0.0009006	0.0009008	0.0009010	0.0009012	°C
35.00	0.98192	0.98191	0.98191	0.98190	0.98190	0.98190	0.98189	35.00
35.05	0.98187	0.98187	0.98186	0.98186	0.98185	0.98185	0.98185	35.05
35.10	0.98182	0.98182	0.98182	0.98182	0.98181	0.98181	0.98180	35.10
35.15	0.98178	0.98178	0.98177	0.98177	0.98176	0.98176	0.98176	35.15
35.20	0.98173	0.98173	0.98173	0.98172	0.98172	0.98171	0.98171	35.20
35.25	0.98169	0.98168	0.98168	0.98168	0.98167	0.98167	0.98166	35.25
35.30	0.98164	0.98164	0.98163	0.98163	0.98163	0.98162	0.98162	35.30
35.35	0.98160	0.98159	0.98159	0.98159	0.98158	0.98158	0.98157	35.35
35.40	0.98155	0.98155	0.98154	0.98154	0.98154	0.98153	0.98153	35.40
35.45	0.98151	0.98150	0.98150	0.98149	0.98149	0.98149	0.98148	35.45
35.50	0.98146	0.98146	0.98145	0.98145	0.98144	0.98144	0.98144	35.50
35.55	0.98142	0.98141	0.98141	0.98140	0.98140	0.98140	0.98139	35.55
35.60	0.98137	0.98137	0.98136	0.98136	0.98135	0.98135	0.98135	35.60
35.65	0.98133	0.98132	0.98132	0.98131	0.98131	0.98130	0.98130	35.65
35.70	0.98128	0.98128	0.98127	0.98127	0.98126	0.98126	0.98125	35.70
35.75	0.98123	0.98123	0.98123	0.98122	0.98122	0.98121	0.98121	35.75
35.80	0.98119	0.98118	0.98118	0.98118	0.98117	0.98117	0.98116	35.80
35.85	0.98114	0.98114	0.98113	0.98113	0.98113	0.98112	0.98112	35.85
35.90	0.98110	0.98109	0.98109	0.98109	0.98108	0.98108	0.98107	35.90
35.95	0.98105	0.98105	0.98104	0.98104	0.98104	0.98103	0.98103	35.95
36.00	0.98101	0.98100	0.98100	0.98099	0.98099	0.98099	0.98098	36.00
36.05	0.98096	0.98096	0.98095	0.98095	0.98094	0.98094	0.98094	36.05
36.10	0.98092	0.98091	0.98091	0.98090	0.98090	0.98089	0.98089	36.10
36.15	0.98087	0.98087	0.98086	0.98086	0.98085	0.98085	0.98084	36.15
36.20	0.98083	0.98082	0.98082	0.98081	0.98081	0.98080	0.98080	36.20
36.25	0.98078	0.98078	0.98077	0.98077	0.98076	0.98076	0.98075	36.25
36.30	0.98073	0.98073	0.98073	0.98072	0.98072	0.98071	0.98071	36.30
36.35	0.98069	0.98068	0.98068	0.98068	0.98067	0.98067	0.98066	36.35
36.40	0.98064	0.98064	0.98063	0.98063	0.98063	0.98062	0.98062	36.40
36.45	0.98060	0.98059	0.98059	0.98058	0.98058	0.98058	0.98057	36.45
36.50	0.98055	0.98055	0.98054	0.98054	0.98053	0.98053	0.98053	36.50
36.55	0.98051	0.98050	0.98050	0.98049	0.98049	0.98049	0.98048	36.55
36.60	0.98046	0.98046	0.98045	0.98045	0.98044	0.98044	0.98044	36.60
36.65	0.98042	0.98041	0.98041	0.98040	0.98040	0.98039	0.98039	36.65
36.70	0.98037	0.98037	0.98036	0.98036	0.98035	0.98035	0.98034	36.70
36.75	0.98032	0.98032	0.98032	0.98031	0.98031	0.98030	0.98030	36.75
36.80	0.98028	0.98027	0.98027	0.98027	0.98026	0.98026	0.98025	36.80
36.85	0.98023	0.98023	0.98023	0.98022	0.98022	0.98021	0.98021	36.85
36.90	0.98019	0.98018	0.98018	0.98018	0.98017	0.98017	0.98016	36.90
36.95	0.98014	0.98014	0.98013	0.98013	0.98013	0.98012	0.98012	36.95
37.00	0.98010	0.98009	0.98009	0.98008	0.98008	0.98008	0.98007	37.00
37.05	0.98005	0.98005	0.98004	0.98004	0.98003	0.98003	0.98003	37.05
37.10	0.98001	0.98000	0.98000	0.97999	0.97999	0.97998	0.97998	37.10
37.15	0.97996	0.97996	0.97995	0.97995	0.97994	0.97994	0.97993	37.15
37.20	0.97992	0.97991	0.97991	0.97990	0.97990	0.97989	0.97989	37.20
37.25	0.97987	0.97987	0.97986	0.97986	0.97985	0.97985	0.97984	37.25
37.30	0.97982	0.97982	0.97982	0.97981	0.97981	0.97980	0.97980	37.30
37.35	0.97978	0.97977	0.97977	0.97977	0.97976	0.97976	0.97975	37.35
37.40	0.97973	0.97973	0.97972	0.97972	0.97972	0.97971	0.97971	37.40
37.45	0.97969	0.97968	0.97968	0.97967	0.97967	0.97967	0.97966	37.45
37.50	0.97964	0.97964	0.97963	0.97963	0.97962	0.97962	0.97962	37.50

Table 60C. Volume Correction Factor Due to Temperature to 20°C for Individual and Special Applications

Alternate Pressure is 0 kPa (gauge)

Base alpha-60, 1/°C

Volume Correction for the Effect of Temperature on Liquid (CTL) to 20°C

°C	0.0009000	0.0009002	0.0009004	0.0009006	0.0009008	0.0009010	0.0009012	°C
35.00	0.98636	0.98635	0.98635	0.98635	0.98635	0.98634	0.98634	35.00
35.05	0.98631	0.98631	0.98631	0.98630	0.98630	0.98630	0.98629	35.05
35.10	0.98627	0.98626	0.98626	0.98626	0.98625	0.98625	0.98625	35.10
35.15	0.98622	0.98622	0.98621	0.98621	0.98621	0.98621	0.98620	35.15
35.20	0.98618	0.98617	0.98617	0.98617	0.98616	0.98616	0.98616	35.20
35.25	0.98613	0.98613	0.98612	0.98612	0.98612	0.98611	0.98611	35.25
35.30	0.98608	0.98608	0.98608	0.98607	0.98607	0.98607	0.98607	35.30
35.35	0.98604	0.98604	0.98603	0.98603	0.98603	0.98602	0.98602	35.35
35.40	0.98599	0.98599	0.98599	0.98598	0.98598	0.98598	0.98597	35.40
35.45	0.98595	0.98594	0.98594	0.98594	0.98593	0.98593	0.98593	35.45
35.50	0.98590	0.98590	0.98590	0.98589	0.98589	0.98589	0.98588	35.50
35.55	0.98586	0.98585	0.98585	0.98585	0.98584	0.98584	0.98584	35.55
35.60	0.98581	0.98581	0.98580	0.98580	0.98580	0.98579	0.98579	35.60
35.65	0.98576	0.98576	0.98576	0.98575	0.98575	0.98575	0.98575	35.65
35.70	0.98572	0.98572	0.98571	0.98571	0.98571	0.98570	0.98570	35.70
35.75	0.98567	0.98567	0.98567	0.98566	0.98566	0.98566	0.98565	35.75
35.80	0.98563	0.98562	0.98562	0.98562	0.98561	0.98561	0.98561	35.80
35.85	0.98558	0.98558	0.98558	0.98557	0.98557	0.98557	0.98556	35.85
35.90	0.98554	0.98553	0.98553	0.98553	0.98552	0.98552	0.98552	35.90
35.95	0.98549	0.98549	0.98548	0.98548	0.98548	0.98547	0.98547	35.95
36.00	0.98544	0.98544	0.98544	0.98544	0.98543	0.98543	0.98543	36.00
36.05	0.98540	0.98540	0.98539	0.98539	0.98539	0.98538	0.98538	36.05
36.10	0.98535	0.98535	0.98535	0.98534	0.98534	0.98534	0.98533	36.10
36.15	0.98531	0.98530	0.98530	0.98530	0.98529	0.98529	0.98529	36.15
36.20	0.98526	0.98526	0.98526	0.98525	0.98525	0.98525	0.98524	36.20
36.25	0.98522	0.98521	0.98521	0.98521	0.98520	0.98520	0.98520	36.25
36.30	0.98517	0.98517	0.98516	0.98516	0.98516	0.98515	0.98515	36.30
36.35	0.98513	0.98512	0.98512	0.98512	0.98511	0.98511	0.98511	36.35
36.40	0.98508	0.98508	0.98507	0.98507	0.98507	0.98506	0.98506	36.40
36.45	0.98503	0.98503	0.98503	0.98502	0.98502	0.98502	0.98501	36.45
36.50	0.98499	0.98498	0.98498	0.98498	0.98497	0.98497	0.98497	36.50
36.55	0.98494	0.98494	0.98494	0.98493	0.98493	0.98493	0.98492	36.55
36.60	0.98490	0.98489	0.98489	0.98489	0.98488	0.98488	0.98488	36.60
36.65	0.98485	0.98485	0.98484	0.98484	0.98484	0.98483	0.98483	36.65
36.70	0.98481	0.98480	0.98480	0.98480	0.98479	0.98479	0.98479	36.70
36.75	0.98476	0.98476	0.98475	0.98475	0.98475	0.98474	0.98474	36.75
36.80	0.98471	0.98471	0.98471	0.98470	0.98470	0.98470	0.98469	36.80
36.85	0.98467	0.98467	0.98466	0.98466	0.98465	0.98465	0.98465	36.85
36.90	0.98462	0.98462	0.98462	0.98461	0.98461	0.98461	0.98460	36.90
36.95	0.98458	0.98457	0.98457	0.98457	0.98456	0.98456	0.98456	36.95
37.00	0.98453	0.98453	0.98452	0.98452	0.98452	0.98451	0.98451	37.00
37.05	0.98449	0.98448	0.98448	0.98448	0.98447	0.98447	0.98446	37.05
37.10	0.98444	0.98444	0.98443	0.98443	0.98443	0.98442	0.98442	37.10
37.15	0.98439	0.98439	0.98439	0.98438	0.98438	0.98438	0.98437	37.15
37.20	0.98435	0.98435	0.98434	0.98434	0.98433	0.98433	0.98433	37.20
37.25	0.98430	0.98430	0.98430	0.98429	0.98429	0.98429	0.98428	37.25
37.30	0.98426	0.98425	0.98425	0.98425	0.98424	0.98424	0.98424	37.30
37.35	0.98421	0.98421	0.98420	0.98420	0.98420	0.98419	0.98419	37.35
37.40	0.98417	0.98416	0.98416	0.98416	0.98415	0.98415	0.98414	37.40
37.45	0.98412	0.98412	0.98411	0.98411	0.98411	0.98410	0.98410	37.45
37.50	0.98407	0.98407	0.98407	0.98406	0.98406	0.98406	0.98405	37.50

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

Input Variables: Base API gravity and temperature. Pressure set to 0 psig.

Output Variables: Fp at input temperature.

Step 1: Hold pressure at 0 psig.

Step 2: Increment base API gravity value by 0.1°API in range of –10.0° to 100.0°API. Ensure that the observed API gravity value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.1°C in range of –58.0° to 302.0°F. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the Fp values using the procedure in 11.1.6.1. Any commodity group can be specified. Round the Fp value consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the thermal expansion factor or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of API gravity and temperature have been calculated.

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

Alternate Pressure is 0 psig

Base API Gravity

Scaled Compressibility Factor (Fp), 1/psig

°F	65.0	65.1	65.2	65.3	65.4	65.5	65.6	°F
135.0	1.179	1.181	1.184	1.186	1.189	1.192	1.194	135.0
135.1	1.179	1.182	1.184	1.187	1.190	1.192	1.195	135.1
135.2	1.180	1.182	1.185	1.187	1.190	1.193	1.195	135.2
135.3	1.180	1.183	1.185	1.188	1.191	1.193	1.196	135.3
135.4	1.181	1.183	1.186	1.189	1.191	1.194	1.196	135.4
135.5	1.181	1.184	1.187	1.189	1.192	1.194	1.197	135.5
135.6	1.182	1.184	1.187	1.190	1.192	1.195	1.197	135.6
135.7	1.182	1.185	1.188	1.190	1.193	1.195	1.198	135.7
135.8	1.183	1.186	1.188	1.191	1.193	1.196	1.199	135.8
135.9	1.184	1.186	1.189	1.191	1.194	1.197	1.199	135.9
136.0	1.184	1.187	1.189	1.192	1.194	1.197	1.200	136.0
136.1	1.185	1.187	1.190	1.192	1.195	1.198	1.200	136.1
136.2	1.185	1.188	1.190	1.193	1.196	1.198	1.201	136.2
136.3	1.186	1.188	1.191	1.194	1.196	1.199	1.201	136.3
136.4	1.186	1.189	1.191	1.194	1.197	1.199	1.202	136.4
136.5	1.187	1.189	1.192	1.195	1.197	1.200	1.203	136.5
136.6	1.187	1.190	1.193	1.195	1.198	1.200	1.203	136.6
136.7	1.188	1.191	1.193	1.196	1.198	1.201	1.204	136.7
136.8	1.188	1.191	1.194	1.196	1.199	1.202	1.204	136.8
136.9	1.189	1.192	1.194	1.197	1.199	1.202	1.205	136.9
137.0	1.190	1.192	1.195	1.197	1.200	1.203	1.205	137.0
137.1	1.190	1.193	1.195	1.198	1.201	1.203	1.206	137.1
137.2	1.191	1.193	1.196	1.199	1.201	1.204	1.206	137.2
137.3	1.191	1.194	1.196	1.199	1.202	1.204	1.207	137.3
137.4	1.192	1.194	1.197	1.200	1.202	1.205	1.208	137.4
137.5	1.192	1.195	1.198	1.200	1.203	1.205	1.208	137.5
137.6	1.193	1.196	1.198	1.201	1.203	1.206	1.209	137.6
137.7	1.193	1.196	1.199	1.201	1.204	1.207	1.209	137.7
137.8	1.194	1.197	1.199	1.202	1.205	1.207	1.210	137.8
137.9	1.195	1.197	1.200	1.202	1.205	1.208	1.210	137.9
138.0	1.195	1.198	1.200	1.203	1.206	1.208	1.211	138.0
138.1	1.196	1.198	1.201	1.204	1.206	1.209	1.212	138.1
138.2	1.196	1.199	1.201	1.204	1.207	1.209	1.212	138.2
138.3	1.197	1.199	1.202	1.205	1.207	1.210	1.213	138.3
138.4	1.197	1.200	1.203	1.205	1.208	1.211	1.213	138.4
138.5	1.198	1.201	1.203	1.206	1.208	1.211	1.214	138.5
138.6	1.198	1.201	1.204	1.206	1.209	1.212	1.214	138.6
138.7	1.199	1.202	1.204	1.207	1.210	1.212	1.215	138.7
138.8	1.200	1.202	1.205	1.207	1.210	1.213	1.215	138.8
138.9	1.200	1.203	1.205	1.208	1.211	1.213	1.216	138.9
139.0	1.201	1.203	1.206	1.209	1.211	1.214	1.217	139.0
139.1	1.201	1.204	1.207	1.209	1.212	1.214	1.217	139.1
139.2	1.202	1.204	1.207	1.210	1.212	1.215	1.218	139.2
139.3	1.202	1.205	1.208	1.210	1.213	1.216	1.218	139.3
139.4	1.203	1.206	1.208	1.211	1.214	1.216	1.219	139.4
139.5	1.203	1.206	1.209	1.211	1.214	1.217	1.219	139.5
139.6	1.204	1.207	1.209	1.212	1.215	1.217	1.220	139.6
139.7	1.205	1.207	1.210	1.213	1.215	1.218	1.221	139.7
139.8	1.205	1.208	1.210	1.213	1.216	1.218	1.221	139.8
139.9	1.206	1.208	1.211	1.214	1.216	1.219	1.222	139.9
140.0	1.206	1.209	1.212	1.214	1.217	1.220	1.222	140.0

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

Input Variables: Base 15°C density and temperature. Pressure set to 0 kPa (gauge).

Output Variables: Fp at input temperature.

Step 1: Hold pressure at 0 kPa (gauge).

Step 2: Increment base density value by 0.1 kg/m³ in range 611.2 to 1163.7 kg/m³. Ensure that the base density value remains rounded consistent with instructions in 11.1.5.4.

Step 3: Increment temperature by 0.05°C in range of –50.00° to 150.00°C. Ensure that the temperature value remains rounded consistent with instructions in 11.1.5.4.

Step 4: Determine the Fp values using the procedure in 11.1.7.1. Specify the commodity type "A." Round the Fp value consistent with instructions in 11.1.5.4.

Step 5: Increment the value of the base density or temperature and return to Step 2 or 3 as appropriate. Continue until all combinations of density and temperature have been calculated.

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

Alternate Pressure is 0 kPa (gauge)

°C	Base Density (kg/m³) 827.0	827.1	827.2	827.3	827.4	827.5	827.6	°C
	Scaled Compressibility Factor (Fp), 1/kPa (gauge)							
35.00	0.0883	0.0882	0.0882	0.0882	0.0882	0.0881	0.0881	35.00
35.05	0.0883	0.0883	0.0882	0.0882	0.0882	0.0881	0.0881	35.05
35.10	0.0883	0.0883	0.0883	0.0882	0.0882	0.0882	0.0881	35.10
35.15	0.0884	0.0883	0.0883	0.0883	0.0882	0.0882	0.0882	35.15
35.20	0.0884	0.0884	0.0883	0.0883	0.0883	0.0882	0.0882	35.20
35.25	0.0884	0.0884	0.0884	0.0883	0.0883	0.0883	0.0882	35.25
35.30	0.0884	0.0884	0.0884	0.0884	0.0883	0.0883	0.0883	35.30
35.35	0.0885	0.0884	0.0884	0.0884	0.0883	0.0883	0.0883	35.35
35.40	0.0885	0.0885	0.0884	0.0884	0.0884	0.0883	0.0883	35.40
35.45	0.0885	0.0885	0.0885	0.0884	0.0884	0.0884	0.0883	35.45
35.50	0.0886	0.0885	0.0885	0.0885	0.0884	0.0884	0.0884	35.50
35.55	0.0886	0.0886	0.0885	0.0885	0.0885	0.0884	0.0884	35.55
35.60	0.0886	0.0886	0.0886	0.0885	0.0885	0.0885	0.0884	35.60
35.65	0.0886	0.0886	0.0886	0.0885	0.0885	0.0885	0.0885	35.65
35.70	0.0887	0.0886	0.0886	0.0886	0.0885	0.0885	0.0885	35.70
35.75	0.0887	0.0887	0.0886	0.0886	0.0886	0.0885	0.0885	35.75
35.80	0.0887	0.0887	0.0887	0.0886	0.0886	0.0886	0.0885	35.80
35.85	0.0888	0.0887	0.0887	0.0887	0.0886	0.0886	0.0886	35.85
35.90	0.0888	0.0888	0.0887	0.0887	0.0887	0.0886	0.0886	35.90
35.95	0.0888	0.0888	0.0887	0.0887	0.0887	0.0887	0.0886	35.95
36.00	0.0888	0.0888	0.0888	0.0887	0.0887	0.0887	0.0887	36.00
36.05	0.0889	0.0888	0.0888	0.0888	0.0887	0.0887	0.0887	36.05
36.10	0.0889	0.0889	0.0888	0.0888	0.0888	0.0887	0.0887	36.10
36.15	0.0889	0.0889	0.0889	0.0888	0.0888	0.0888	0.0887	36.15
36.20	0.0890	0.0889	0.0889	0.0889	0.0888	0.0888	0.0888	36.20
36.25	0.0890	0.0890	0.0889	0.0889	0.0889	0.0888	0.0888	36.25
36.30	0.0890	0.0890	0.0889	0.0889	0.0889	0.0889	0.0888	36.30
36.35	0.0890	0.0890	0.0890	0.0889	0.0889	0.0889	0.0888	36.35
36.40	0.0891	0.0890	0.0890	0.0890	0.0889	0.0889	0.0889	36.40
36.45	0.0891	0.0891	0.0890	0.0890	0.0890	0.0889	0.0889	36.45
36.50	0.0891	0.0891	0.0891	0.0890	0.0890	0.0890	0.0889	36.50
36.55	0.0892	0.0891	0.0891	0.0891	0.0890	0.0890	0.0890	36.55
36.60	0.0892	0.0892	0.0891	0.0891	0.0891	0.0890	0.0890	36.60
36.65	0.0892	0.0892	0.0891	0.0891	0.0891	0.0890	0.0890	36.65
36.70	0.0892	0.0892	0.0892	0.0891	0.0891	0.0891	0.0890	36.70
36.75	0.0893	0.0892	0.0892	0.0892	0.0891	0.0891	0.0891	36.75
36.80	0.0893	0.0893	0.0892	0.0892	0.0892	0.0891	0.0891	36.80
36.85	0.0893	0.0893	0.0893	0.0892	0.0892	0.0892	0.0891	36.85
36.90	0.0894	0.0893	0.0893	0.0893	0.0892	0.0892	0.0892	36.90
36.95	0.0894	0.0893	0.0893	0.0893	0.0893	0.0892	0.0892	36.95
37.00	0.0894	0.0894	0.0893	0.0893	0.0893	0.0892	0.0892	37.00
37.05	0.0894	0.0894	0.0894	0.0893	0.0893	0.0893	0.0892	37.05
37.10	0.0895	0.0894	0.0894	0.0894	0.0893	0.0893	0.0893	37.10
37.15	0.0895	0.0895	0.0894	0.0894	0.0894	0.0893	0.0893	37.15
37.20	0.0895	0.0895	0.0895	0.0894	0.0894	0.0894	0.0893	37.20
37.25	0.0896	0.0895	0.0895	0.0895	0.0894	0.0894	0.0894	37.25
37.30	0.0896	0.0895	0.0895	0.0895	0.0895	0.0894	0.0894	37.30
37.35	0.0896	0.0896	0.0895	0.0895	0.0895	0.0894	0.0894	37.35
37.40	0.0896	0.0896	0.0896	0.0895	0.0895	0.0895	0.0894	37.40
37.45	0.0897	0.0896	0.0896	0.0896	0.0895	0.0895	0.0895	37.45
37.50	0.0897	0.0897	0.0896	0.0896	0.0896	0.0895	0.0895	37.50

Appendix A — History & Development of the 1980 Petroleum Measurement Tables

A.1 Background

For the purpose of custody transfer of bulk petroleum oils and products, bulk volumes and contractual densities are stated at a specified standard or base temperature. 60°F is used as the base temperature within the United States and producing countries dealing with the United States. However, 15°C and 20°C are standard bases in many nations around the world. Volumes metered at temperatures other than base value are corrected to the base value by factors developed and tabulated in the Petroleum Measurement Tables.

The first joint tables for customary and metric units were developed in the late 1940s as described by Hall et al. (1975). Much of the data were based on the crude and fraction data published by Bearce and Peffer (1916). These tables were published in 1952 as the result of close cooperation between the Institute of Petroleum (London), the Committee D-2 on Petroleum Products and Lubricants of the American Society for Testing Materials, and the American Petroleum Institute.

In 1972 Downer and Inkley demonstrated that the previously published tables were not satisfactorily applicable to many crude oils of current economic importance. The API and the National Bureau of Standards (NBS) initiated a cooperative venture, funded by the API, to create a data base of density measurements on both crude oils and refined products. This joint venture was initiated in 1974 and its intent was to provide the solid scientific base for the development of more accurate, consequently more equitable, measurement tables.

The completion of this five-year, $500,000 project in March 1979 opened the way for modernizing the tables. The sequence of events leading up to the publication of these tables is summarized in Table A-1. Using the NBS density data and taking advantage of publications of outstanding technical authorities, a Joint API-ASTM Subcommittee on Physical Properties produced the 1980 edition of the Petroleum Measurement Tables in close cooperation with the Institute of Petroleum. The results of this project are described in the open literature by Hankinson et al. (1979) and Hankinson et al. (1980).

Table A-2 gives a capsule picture of the issues that concerned the committee in producing the final version of its work.

A.2 Experimental Project

In the 1974 to 1979 program, API member companies provided the NBS with 463 samples; 211 of crude oils, the remainder of refined products. The list of samples represented 66.8 percent of the world crude production and 68.1 percent of the estimated reserves for 1974. The criteria for the selection of crude sample sources were (1) production for 1974, (2) estimated reserves for that year, and (3) countries wishing to contribute samples of national origin which did not fit the first two categories. Refined products were obtained primarily from API member companies. Each company was requested to submit at least three samples, preferably of those products having the highest refining volume. Refineries outside of the United States provided approximately 30 percent of the refined products samples.

A detailed description of the experimental technique and preliminary, unconfirmed results were released by the NBS principal investigator, J. R. Whetstone, in September 1978. Based on statistical studies performed by the Physical Properties Working Group and because of the group's recommendations, Whetstone checked approximately 30 percent of the original data and made significant modifications to the data base. In March 1979, Whetstone released the finalized data base to the API. Excluding samples on which fewer than three experimental measurements were reported, and certain duplicates, the final data base consisted of 349 samples distributed as shown in Table A-3. The data base contains temperature density data only and does not reflect viscosity, molecular weight, UOPK, or any additional characterization parameter. There were 25 samples for which fewer than three points of data were reported and 14 samples which were replicated for equipment calibration. The points in these two groups were eliminated from the data base, are not contained in Table A-3, and were not used in the correlation effort.

A.3 Fluid Groups

The original NBS data were screened for consistency and to obtain a preliminary indication of the existence of more than a single population. The screening was performed by the use of linear equations and large machine generated plots (see Table A-4).

The samples included in the data base were identified by source and class of substance (crude oil, jet fuel, kerosene, motor gasoline, fuel oil and lube oil). These classifications were used as a guide to statistical examination of the data base to determine if it contained identifiable, statistically different populations. It was found that there were five major identifiable groups of substances that had significantly different relationships between the coefficient of thermal expansion and density. The differences between each of these unusual groups and the rest of the data were all statistically significant. These deviations were attributed to differences in composition, aromaticity, density range, or other anomalies. These major and minor categories are identified in Table A-3.

A.4 Separate Representation Needed for Crude and Product Classes

Figure A-1 shows that the coefficient of thermal expansion of crude oil and the classes of products (gasolines, jet fuels, fuel oils, and lube oils) follow separate curves as a function of inverse density squared. This fact forces different representations to be used for each class in each of the new petroleum measurement tables. A more detailed breakdown of the product classifications is as follows:

Gasoline	$50 \le °API \le 85$
Jet fuels	$37 \le °API \le 50$
Fuel oils	$0 \le °API \le 37$
Lubricating oils	$0 \le °API \le 45$

It is worth emphasizing that meticulous care went into establishing, by both visual and mathematical analysis, the need for five populations of data, the crude and four product groups indicated. As stressed by William E. Deming, as early as 1939, "without a homogeneous population, a statistician's calculations by themselves, are an illusion, if not a delusion."

The most significant impact of this portion of the study was to demonstrate conclusively that the wide range of commercially important materials represented by the data base could not be adequately described by two dimensional tables, such as the previously published Tables 5 and 6 in the Petroleum Measurement Tables. The basic accuracy of this quality data would be destroyed and bias would be introduced by an attempt to characterize the five categories as a single group. This loss of accuracy and the introduction of bias is not defensible if the tables are to be equitable to all table users.

A.5 Correlation Development

The fundamental definition for the coefficient of thermal expansion is:

$$\alpha = \frac{1}{V}\frac{dV}{dt} \tag{A.1}$$

where: α = coefficient of thermal expansion
V = volume at any temperature.

The final form of the equation relating volume correction factors to easily obtainable measurements depends upon the integration of this definition. The integration, in turn, depends upon the assumptions made and the sequence in the derivation at which the assumptions are invoked.

A number of forms were proposed and studied by the working group. Three types of equations were eliminated from consideration:

1. forms with finite discontinuities in the equation or the derivative between temperatures of 0°F and 300°F.

2. equations containing complicated transcendental functions not suitable for general use on mini and microcomputers.

3. equations containing high order powers inside an exponential or other limitations prohibiting the use of single precision nonlinear analysis.

From this type of elimination, an exponential equation emerged containing a second order term which exhibited the most desirable characteristics in terms of accuracy, simplicity, and curve shape. The working group accepted this exponential equation for use in the final correlation.

The equation was derived using:

$$\alpha = \alpha_T + \beta \Delta t \tag{A.2}$$

where:

$\alpha_T = \alpha$ at the base temperature
β = a function of α and is independent of temperature.

Hence from Equations (A.1) and (A.2):

$$\frac{1}{V}\frac{dV}{dt} = \alpha_T + \beta \Delta t \tag{A.3}$$

$$\Delta t = t - T$$

Which can be rearranged and integrated between t and T to give:

$$\ln \frac{V}{V_T} = \alpha_T \Delta t + \frac{\beta}{2} \Delta t^2 \tag{A.4}$$

A study of the NBS data demonstrated that:

$$\beta = k\,\alpha_T^2 \tag{A.5}$$

where:

k = a temperature independent constant.

These equations were statistically validated by computer studies of the NBS data base. The precise value of k was selected from a consideration of (1) the computer studies, (2) the theoretical curvature of density with temperature, and (3) high temperature literature data on crudes, petroleum fractions, and C_6 through C_{32} alkanes. These literature data were obtained from the work of Jessup (1929) and Orwall and Flory (1967). The value of k best expressing these criteria is 1.6.

Thus, Equation (A.5) becomes:

$$\mathrm{VCF} = \frac{V_T}{V} = \frac{\rho}{\rho_T} = \exp\left[-\alpha_T \Delta t \left(1 + 0.8\alpha_T \Delta t\right)\right] \tag{A.6}$$

where:

t = any temperature
T = base temperature.

Equation (A.6) is valid for a particular fluid of known α_T.

It was determined that the coefficients of thermal expansion at the base temperature for each group are related to the densities at the base temperature by:

$$\alpha_T = \frac{K_0 + K_1 \rho_T}{\rho_T^2} \quad \text{(A.7)}$$

A.6 Parameter Determination and Results

The values of K_0 and K_1 were established for each major group from a simultaneous nonlinear regression of all data points within that group to Equations (A.6) and (A.7). In this case the parameters were K_0 and K_1 for the group and the vector of 60°F densities for each sample. See Column C of Table A-5.

The data were also reduced a set at a time by the use of Equation (A.6). In this case the parameters were the α_T and ρ_T for each sample. It is apparent that the use of two parameters for fitting a three or four point sample introduces a maximum bias because of the over specification of the degrees of freedom. These results are shown in Column A, Table A-5. The α_T and ρ_T pairs obtained from this procedure were, as the third method, fit to Equation (A.7) to determine the values of K_0 and K_1. See Column B of Table A-5.

The results and accuracy indicators are presented in Tables A-5 and A-6. Percent standard deviation given in the table is defined by:

$$\sigma = \sqrt{\frac{1}{n_p - 1} \sum_{i=1}^{n_o} \left[\frac{\rho_i - \rho_c}{\rho_i} \right]^2} \times 100 \quad \text{(A.8)}$$

where:

σ = percent standard deviation
ρ_i = experimental density
ρ_c = calculated density
n_p = number of points
n_o = total number of observations in a group.

An examination of Table A-5 shows that there is a significant increase in standard deviation between the data fit a set at a time (Column A) and the data fit simultaneously (Column C). This occurred for two major reasons:

1. By the act of grouping, which was necessary to produce a reasonable number of tables, sample differences such as composition, aromaticity, and density differences were averaged out. This effect could be reduced by the inclusion of some technique to characterize the aromaticity as described previously.

2. The reduction of the error in small data sets well below the experimental scatter of the data by fitting a set at a time. At this time there is insufficient information available to ascertain the distribution of the standard deviation between these two factors.

Table A-5 further shows that the simultaneous or global fit of all data in a group is significantly better than the attempt to generalize the pairs resulting from the set at a time regression. This is because of the scatter about Equation (A.7) caused by the "overfitting" of the small data sets. The global fit (Column C) gives equal weight to each data point while the generalization technique (Column B) gives equal weight to each data set, hence the global fit is a less biased, more equitable representation of the entire data base. The results from the global fit (see Table A-6) were used in the preparation of the tables.

A complete set of results including the percent standard deviation, the maximum percent error, the density at 60°F, and the coefficient of thermal expansion are presented for each sample in the 1980 printed tables.

Equation (A.6) presents the volume correction factor (VCF) as a function of the thermal expansion coefficient and density, both evaluated at the reference temperature. In that basic form, the equation is independent of any specific group and equally applicable to all groups. The equation is reliable over the temperature range of 0°F to 250°F and an API range of 0° to 100°. Equation (A.7) relates thermal expansion coefficient and density to a specific group through the constants K_0 and K_1 for each group.

A.7 Development of 1980 Tables

Because of the growing importance of computers and their increasing influence on the metering effort, it was decided that the actual API Standard would consist of computer procedures. Subroutines were developed following these procedures so that identical answers were obtained regardless of the word size (within the limits of the word size conventions of the major hardware vendors) used by the hardware.

There were three common sets of tables in current use. These were in terms of °API (TABLES 5 and 6), relative density (TABLES 23 and 24), and density in kg/m³ (TABLES 53 and 54). In order to maximize accuracy and maintain convenience of use, three separate tables were required to replace each existing table. For example, for TABLE 6 there were: TABLE 6A Generalized Crude Oils, TABLE 6B Generalized Products, and TABLE 6C Volume Correction Factors for Individual and Special Applications. Equivalent tables were developed for the other two sets in the appropriate units. See Table A-7. The temperature ranges of the tables and the limits are shown in Table A-8.

The crude oil and products tables retained the format of the previously published tables. Volume correction factors or densities were tabulated as functions of temperature. These were computed from Equations (A.6) and (A.7) with the appropriate values for K_0 and K_1. Each products table was computed in three sections:

1. Fuel oils group equation from an API of 0° to an API of 37°.

2. Jet fuel group equation from an API of 37° to an API of 50°.

3. Gasoline group equation from an API of 50° to an API of 85°.

This is shown graphically in Figure A-2. TABLE 6A for crude oils covered a range from 0° to 100°API.

TABLES C, the Special Applications Tables, presented tabular entries of volume correction factor against thermal expansion coefficient and temperature. Each TABLE C was computed from Equation (A.6) and thus was independent of the group or substance. TABLE C could be used with any valid method of obtaining the thermal expansion coefficient for a given fluid as long as a statistically significant number of points were obtained. A minimum of ten such points was recommended. An appendix (see Volumes III, VI, and IB) to the published TABLES C presented values of the thermal expansion coefficient along with the base density for each of the NBS samples. In addition, values of the constants K_0 and K_1, were given for each major group. The existence of this table and its primary subroutine allowed the use of measured data for previously unstudied fluids to be easily incorporated into the procedure. High precision density data obtained from the laboratory for a fluid of interest could be reduced by Equation (A.1) to obtain α_T and ρ_T. TABLES C could then be entered with the α_T so determined.

TABLES C, when used with a minimum of ten data points, allowed one to extract the highest degree of accuracy from the data base. TABLES C introduced a high degree of flexibility into the procedure by allowing new data to be incorporated into the Standard. It was suggested that TABLES C be used when:

1. TABLES A and B did not adequately represent the thermal expansion properties of the fluids of interest; and

2. Precise thermal expansion coefficients could be obtained directly or indirectly by experiment (As an example, high precision density data may be used to compute the coefficient.); and

3. If buyers and sellers agree that, for their use, a greater degree of equity could be obtained.

The lubricating oil samples were not fit satisfactorily by the new product tables. The API database consisted of 17 lube samples with 107 points over a density range of 861 to 940 kg/m^3 and temperature range of 40° to 136°F. However, one of the samples had to be eliminated as unsuitable. Altogether the database did not contain a sufficient number of samples to develop a definitive equation. A request for further data for these specific sample types was made to the API by the Working Group. Two more sets of high quality data were made available. A combined database was formed consisting of 32 samples with 156 points covering a density range of 860 to 940 kg/m^3 over a temperature range of 52° to 176°F. The resultant database was regressed using the same techniques as the original work. In 1981, the D Tables for Lubricating Oils became the first extension to the Standard.

A.8 Summary and Precision Statement

The 1980 tables gave factors for converting petroleum volumes observed at temperatures other than the base temperature to corresponding volumes at the base temperature for values of API gravity in the range 0° to 100°. The tables were based on density temperature determinations made by the U.S. National Bureau of Standards from 1974 to 1979 under contract to the API on 225 samples of products ranging from heavy fuel oil to gasoline blend components and 124 samples of crude oil that cover a wide range of quality and represent about 45 percent of the world's crude production and reserves as known during that time period. The thermal expansion properties (volume correction factors) for products (including lube stocks) and crude oils were correlated in separate, generalized tables as a function of temperature and density or API gravity. The predicted precision at the 95 percent confidence level was:

	VCF precision at 95 % confidence level			
Temperature	100°F	150°F	200°F	250°F
Crudes and Products	±0.05%	±0.15%	±0.25%	±0.35%

A precision statement for the 250°F to 300°F portion of the tables was not given because it is an extrapolation.

Independent Test of the Correlation

In order to obtain an independent test of the revised tables, an oil of commercial importance which was not included in the NBS data set was studied. The steps of this study are described below.

1. An oil sample of Prudhoe Bay crude oil was supplied by SOHIO.
2. The experimental work was performed by Dr. James W.Gall of Phillips Petroleum Company.
   a. The sample was chilled to 50°F, settled and the upper portion siphoned off. This step removed any wax that formed at 50°F and the assorted solids in the original sample.
   b. The oil densities were measured on a Mettler/ Paar high precision densitometer. The instrument was calibrated with both water and nitrogen at each temperature and pressure for which the oil density was measured. The calibration was confirmed using pentane.
3. The experimental results were tested against the new correlation by:
   a. The constants for the thermal expansion coefficients equation were fixed at the generalized values for crude oil.

$$K_0 = 341.0957$$
$$K_1 = 0.0$$

b. Weighting factors of unity were applied to the first five points of data since they are in the NBS data set temperature range. Weighting factors of 0.0001 were applied to the remaining four points. This step insured that the single parameter, the 60°F density, was not influenced by the data in the extrapolation region of the model.

c. A nonlinear regression routine was used to fit the data to the TABLE 6 model and determine the missing parameter, the 60°F density.

The results are shown in Table A-9. The first five points of data were fit to a 0.0277 percent standard deviation; all points exhibit a 0.0365 percent standard deviation. These deviations are well within the 95 percent confidence limits given in the precision statement of the model and validate both the basic model and the temperature extrapolation.

A.9 Comparison of the Pre-1980 and 1980 Tables

The goal of the 1980 tables working group was to develop the revised tables based on the most recent data, not to be influenced by comparisons with the 1952 table. However, after the developmental effort was completed, a limited number of such comparisons were made for instructional purposes.

Figure A-3 shows the comparison of the volume correction factors of the 1952 and 1980 tables relative to the experimental data on the Prudhoe Bay crude. Table A-10 presents a representative sample of a comparison made between the NBS data and the 1952 TABLE 6.

Hydrometer Corrections

The hardcopy version of TABLES 5, 23, and 53 include the appropriate stem correction for the thermal expansion of a glass hydrometer. These corrections are given by:

TABLES 5 and 23

$$\mathrm{HYC} = 1.0 - 0.00001278(t-60) - 0.0000000062(t-60)^2$$

$$t = {}^\circ\mathrm{F}$$

TABLE 53

$$\mathrm{HYC} = 1.0 - 0.000023(t-15) - 0.00000002(t-15)^2$$

$$t = {}^\circ\mathrm{C}$$

TABLE 59

$$t = {}^\circ\mathrm{C}$$

The subroutines for these tables contain an override switch allowing the user to omit the correction. Such an override capability is necessary if the observed densities or gravities are obtained from an absolute densitometer rather than a temperature dependent hydrometer.

A.10 Density & Relative Density

The term "weight in air" is that weight which a quantity of fluid appears to have when weighed in air against commercial weights which have been standardized so that each will have a mass (weight in vacuo) equal to the nominal mass associated with it. The term "weight in vacuo" refers to the true mass of a fluid.

It should be noted that pure fluid densities as reported in the literature and which are used for the calibration of densitometers are based on "weight in vacuo." Hence, the densitometer readings obtained from such calibrations are also "in vacuo" values. The densities referred to in the 1980 Tables are all "in vacuo" values. Following the convention specified in 15.2.4.8 of API Publication 2564, Second Edition, and with the concurrence of the Institute of Petroleum, the term "specific gravity" was discontinued. It was replaced with the term "relative density." Relative density is a relationship defined by the ratios of the volume of fluid to the volume of water where both volumes are "in vacuo" values determined at identical temperatures.

A.11 References

Bearce, H. W. and E. L. Peffer, "Technology Papers of the National Bureau of Standards-Density and Thermal Expansion of American Petroleum Oils," p. 125-154, GPO, Washington, D.C., 1916.

Deming, William E., *Theory of Sampling*, John Wiley and Co., N.Y., N.Y., 1960.

Downer, L. and F. A. Inkley, *Oil and Gas Journal*, Vol. 10, No. 25, p. 52-55, June 19, 1972.

Hall, A. H., J. A. Simpson, and J. R. Whetstone, "Investigation of Densities and Thermal Expansion Coefficients Applicable to Petroleum Measurement," SP 7 World Petroleum Congress, Tokyo, 1975.

Jessup, R.S., *Journal of Research of the National Bureau of Standards*, P. 985-1011, 1929.

Orwall, R. A., and P. J. Flory, *Journal of American Chemical Society*, 89:26, Dec. 1967.

Hankinson, R. W., R. G. Segers, T. Krolikowski Buck, and F. P. Gielzecki, *Oil and Gas Journal*, Vol. 77, No. 52, p. 66-70, Dec. 24, 1979.

Hankinson, R. W., R. G. Segers, T. Krolikowski Buck, and F. P. Gielzecki, *Proceedings of the 59th Annual Gas Processors Association Convention*, Houston, Texas, March 1980.

Table A-1 - API Thermal Volumetric Correction Factor Study

- Downer and Inkley presented problem in 1972.
- API sponsored five year NBS project to reaffirm TABLES 5 and 6.
- NBS produced density-temperature data for industry supplied samples.
- NBS submitted data to API in September 1978 with revisions in March 1980
- Preliminary results by NBS showed data did not confirm TABLES 5 and 6.
- API COSM Physical Properties Working Group expanded October 1978.
- Recommendations to API in March 1979.
- API ballot on new tables issued

  COSM, MARCH 1979-UNANIMOUS APPROVAL

  COPM, AUGUST 1979-UNANIMOUS APPROVAL

  IP, SEPTEMBER 1979-UNANIMOUS APPROVAL

Table A-2 - Issues Addressed by API Working Group

- How should NBS data be screened for consistency?
- Do the samples represent more than one statistical population?
- What is the best equation for relating volume correction factor to temperature for a single population?
- How should the density of a substance at base temperature be related to thermal expansion coefficients for a population of substances?
- What is the best technique for extrapolating beyond 140°F, the limit of the NBS data?
- How many tables should be published to replace the present tables?
- What should be their limits, increments, and format?
- How can universal computer code be best developed?

Table A-3 API/NBS Data Base

Category	Number of Samples	Number of Observations	Density Range kg/m³	Temperature Range °F
Crude oil	124	600	770 - 990	40 - 133
Finished and unfinished gasolines	76	436	657 - 770	39 - 111
Jet fuels, kerosines, solvents	44	351	785 - 825	39 - 125
Fuel oils, heating oils, diesel oils	76	617	812 - 1075	39 - 136
Lubricating oils	17	107	861 - 940	40 - 136
Miscellaneous				
Lube	2	13	927 - 972	50 - 127
Reformate, naphtha, etc.	6	43	664 - 823	39 - 129
JP-4	4	21	736 - 763	41 - 104
TOTALS	349	2278		

Table A-4 - Preliminary Study of NBS Data

Computer Generated Plots of Deviations in Densities from Linear Equations:

- Screening of NBS Data for Anomalies

    Large differences over small temperature ranges.

    Same bias for points from several samples run on same day.

    Bias in points run several months apart on same sample.

- Visual Analysis of Total Population

    Trends in deviations indicated if a sample was above, at, or below average, i.e. to identify sub-groups in population.

    Distinguish between data anomalies and trends.

- Communicate Results

    Data anomalies communicated to NBS (and others) who immediately recognized the problems.

Results

5 populations, 1 crude and 4 product groups indicated.

NBS revised data on nearly 30 percent of samples.

Table A-5 - Comparison of Correlation Results

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

			Tabular Entries in Percent Standard Deviation				
			A	B	C	From Method C	
Group	n_s	n_p	Set at a Time	Generalization of A	Global Fit	K_0	K_1
Crude oils	124	690	.0152	.0371	.0253	341.0957	0.0
Gasoline and naphthas	76	436	.0109	.0304	.0266	192.4571	0.2438
Jet fuels and kerosines	44	351	.0105	.0237	.0174	330.3010	0.0
Diesels, heating oils and fuel oils	76	617	.0094	.0262	.0180	103.8720	0.2701
Lubricating oils	17	107	.0067	.0274	.0197	144.0427[3]	0.1896[4]
TOTAL	337	2201					

Note: Alpha in reciprocal °F. Rho in kg/m³.

Table A-6 - Results of Global Regression of NBS Data to Final Equations

Group	Number of Points	Percent Standard Deviation
Crude oils	690	.0253
Gasolines	436	.0266
Jet fuels	351	.0174
Fuel oils	617	.0180
Lubricating oils	107	.0197

Table A-7 – 1980 Table Development

Tables

- Three separate tables.

  TABLE A Generalized Crude Oils (0-100° API)

  TABLE B Generalized Products (0-85° API)

  TABLE C VCF for Individual and Special Applications

- Temperature and °API in 0.5 increments.

---

[3] In Table A-5, the K_0 and K_1 values for lubricating oils differ from those used in the published D Tables. This arises because further samples were submitted later to give a total data base of 32 samples and 156 points. Regression analysis of the revised database resulted in values for lubricating oils of K_0 = 0.0, K_1 = 0.34878.

- Printout to five significant digits.
- Interpolation not to be used.
- Appendix to TABLE C contains ρ_T and α_T for each individual sample.

Table A-8 – 1980 Table Development

TABLE A		TABLE B	
°API	°F	°API	°F
0-40	0-300	0-40	0-300
40-50	0-250	40-50	0-250
50-100	0-200	50-85	0-200

Table A-9-Prudhoe Bay Oil Density (P = 24.8 psia)

Temperature		Density, kg/m³		
°C	°F	Experimental	Calculated	Percent Error
10.13	50.234	897.36	896.931	-.0477
20.04	68.072	889.92	890.012	.0225
29.96	85.928	883.00	883.272	.0309
39.89	103.802	876.36	876.389	.0033
50.08	122.144	869.373	869.291	-.0088
60.20	140.360	862.530	862.225	.0353
70.13	158.231	855.671	855.262	.00478
80.00	175.00	848.742	848.710	.00379
89.72	193.496	842.032	841.459	.0680

Summary	Average Absolute Percent Error	Average Percent Standard Deviation
lst 5 points	.02264	.0277
All points	.03759	.0365

ρ_{60} = 893.207 kg/m³

Table A-10-Average Error in the 1952 Table 6

	Percent Over Actual at 60°F		
Fluid	90°F	120°F	150°F
Crude oils			
20°API	0.01	0.04	0.09
30°API	0.07	0.16	0.26
40°API	0.09	0.21	0.32
Products			
20°API	0.06	0.14	0.25
40°API	0.04	0.11	0.18
60°API	0.19	0.41	0.62

Figure A-1 — Coefficients of Expansion for Five Statistically Homogeneous Groups

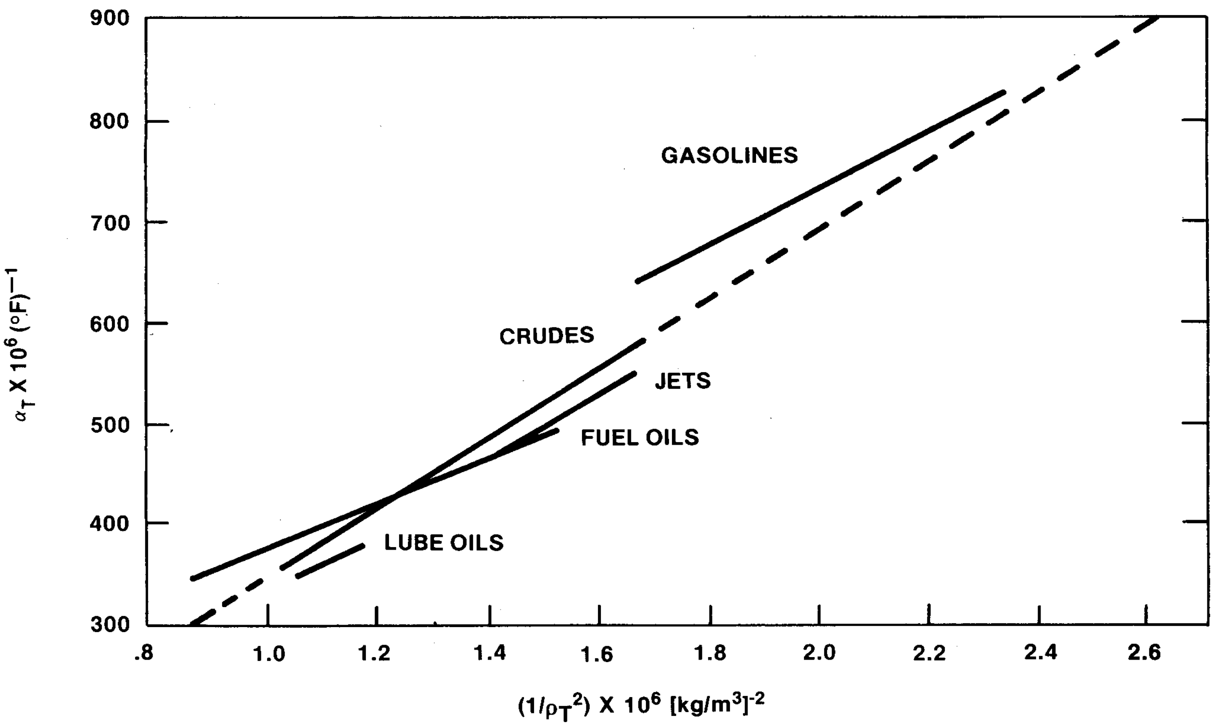


Figure A-2 — 1980 Products Tables (TABLES B)

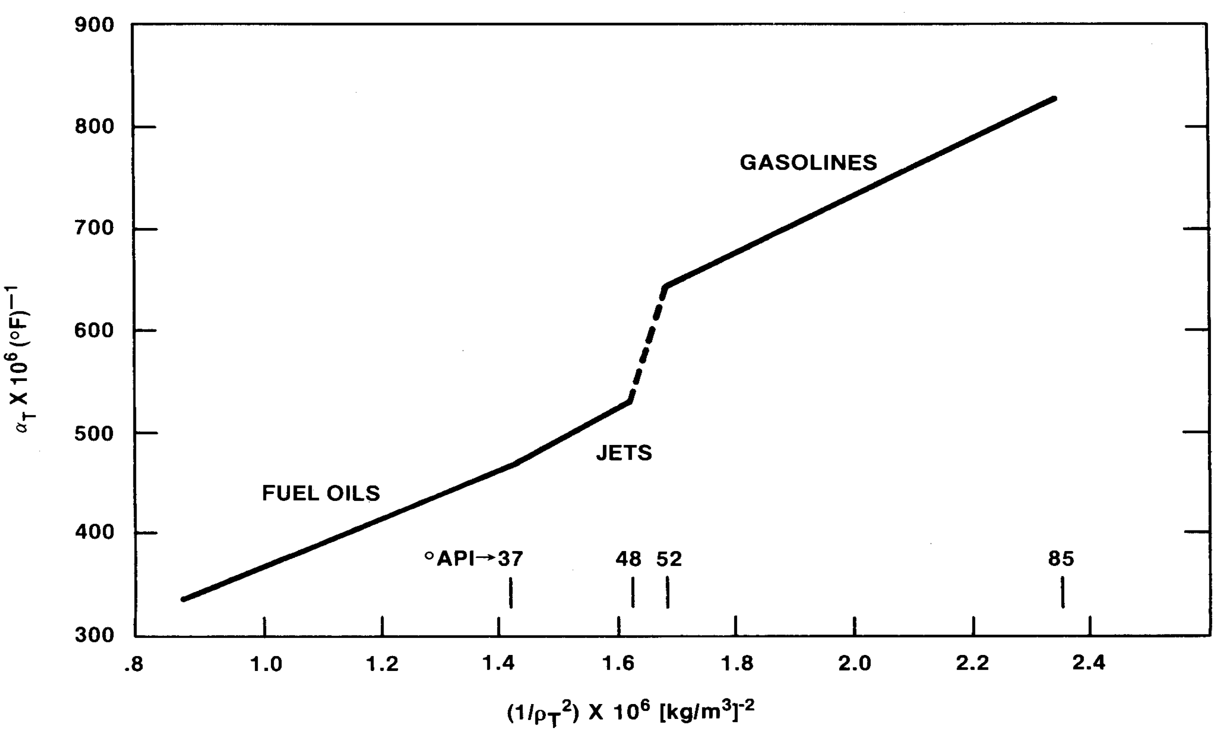
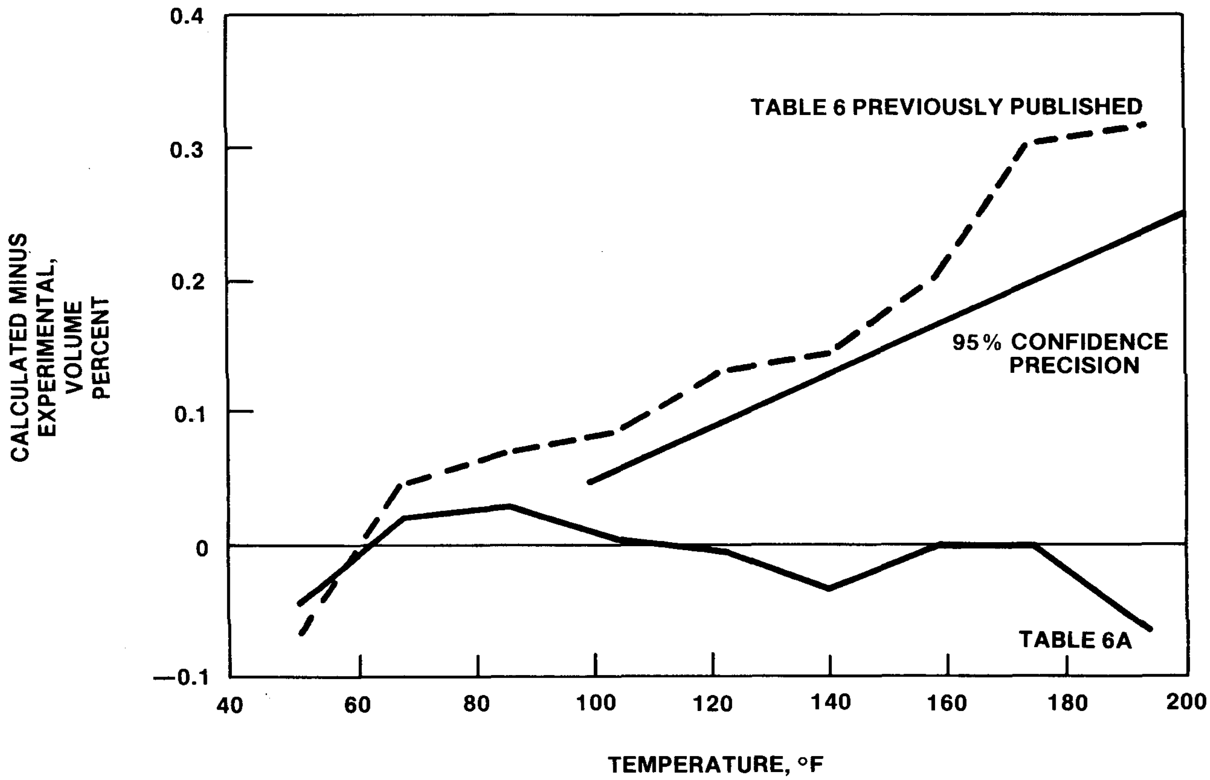


Figure A-3 — Prudhoe Bay Crude August 1979 Data



Appendix B — History & Development of the 1981 Hydrocarbon Compressibility Factors

The compressibility standard (API Standard 1101, Appendix B, Table II) for hydrocarbons in the 0-90° 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. Also, Standard 1101 was developed without the aid of a mathematical model.

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, though. This standard 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.

The database for this standard was obtained from Jessup, Downer and Gardiner, and Downer. It consisted of seven crude oils, five gasolines, and seven middle distillate-gas oils. The lubricating oil data from these sources were not included. Modeling results showed that lubricating oils are a different population than crude oils and other refined products. Their inclusion multiplies the compressibility correlation uncertainty by a factor of two. However, lubricating oils are not normally metered under pressure and do not require the use of this standard.

The limits of the experimental data are 20 to 76°API (934 to 681 kg/m³), 32 to 302°F (0 to 150°C), and 0 to 711 psig (0 to 4902 kPa (gauge)). As a result of a Committee on Static Petroleum Measurement (COSM) and Committee on Petroleum Measurement (COPM) survey, the actual limits of the standard are broader: 0 to 90°API (1074 to 638 kg/m³), –20 to 200°F (–30 to 90°C), and 0 to 1500 psig (0 to 10300 kPa (gauge)). Hence, certain portions of the standard represent extrapolated results. In these extrapolated regions, the uncertainty analysis may not be valid.

B.1 Basic Mathematical Model & Uncertainty Analysis

The basic mathematical model, used to develop this Standard, relates the compressibility factor exponentially to temperature and the square of molecular volume. Its form is:

$$F = \exp\left(A + B \cdot T + \frac{C}{\rho_{60}^2} + \frac{D \cdot T}{\rho_{60}^2} \right) \tag{B.1}$$

where: F = compressibility factor
T = temperature
ρ_{60} = density at 60°F.

(It is assumed that $1/\rho_{60}$ is proportional to molecular volume.)

Here, compressibility is the result of the interaction of two molecular volumes and temperature. Equation (B.1) is consistent with the development of the thermal expansion of hydrocarbons. The use of higher powers of T and ρ_{60} did not yield further significant minimization of compressibility factor uncertainty.

Using the above equation and database, maximum compressibility factor uncertainty is ±6.5% at the 95% confidence level. Hence at worst, one should expect that the real compressibility factor for a given material could be either 6.5% higher or 6.5% lower than the value in the Standard. This statement is only true within the limits of the database. It may not be true for the extrapolated portions of the Standard.

To assess the possible uncertainty in the calculated volume at equilibrium pressure using the above database and equation, two approaches were taken. First it was assumed that only the correlation uncertainty in mean compressibility of ±6.5% was significant. With this approach, volumetric uncertainties should be in the range of 0.02 to 0.10%, depending on operating conditions. These uncertainties are in agreement with the maximum error of 0.10% recommended by a COSM and CIPM survey.

The first volumetric uncertainty analysis assumes that mean compressibility is not a function of pressure. For low pressures, this assumption is adequate. For higher pressures, mean compressibility will decrease with increasing pressure. At what pressure this effect becomes significant for the materials of this Standard is not definitely known. However, analysis of the Jessup data indicates that mean compressibility could possibly decrease by about 0.005% per psi (0.00073% per kPa) with increasing pressure. Incorporating both the compressibility correlation uncertainty and potential pressure uncertainty yields volumetric uncertainties in the range of 0.03 to 0.21%. Hence, the use of this Standard with operating pressures greater than the experimental limit of 711 psig (4902 kPa (gauge)) could double the uncertainty in calculated volume over the uncertainty based on available data.

B.2 References

Jacobsen, E. W., Ambrosius, E. E. Dashiell, J. W. , and Crawford, C. L., "Second Progress Report on Study of Existing Data on Compressibility of Liquid Hydrocarbons," Report of the Central Committee on Pipe-Line Transportation, Vol. 2 (IV), p. 39-45, American Petroleum Institute, Washington, D.C., 1945.

Jessep, R. S., "Compressibility and Thermal Expansion of Petroleum Oils in the Range 0° to 300°C," *Bureau of Standards Journal of Research*, Vol. 5, July to December 1930, p. 985-1039, National Bureau of Standards, Washington, D.C.

Downer, L., and Gardiner, K. E. S., "Bulk Oil Measurement Compressibility Measurements on Crude Oils Deviations from API Standard 1101," BP Research Report No. 20 587/M (8 pages), October 28, 1970.

Downer, L., "Bulk Oil Measurement Compressibility Data on Crude Oils and Petroleum Products Viewed as a Basis for Revised International Tables (API Standard 1101 Tables)," BP Research Report No. 20 639 (21 pages), January 17, 1972.

Appendix C — Development of Modified C_{TL} Equations for Base Temperatures Other Than 60° F

C.1 Introduction

During the development of this revision of Chapter 11.1, it became apparent that there was a need to examine the equations used to calculate the C_{TL} and allow for a base temperature other than 60°F for the following reasons:

- The existing routines for base temperatures of 60°F, 15°C and 20°C did not always produce consistent results when VCFs were calculated to five, instead of four, decimal places.
- The recognition of the differences between the IPTS-68 and ITS-90 temperature scales admits a slight difference in the definition of 60°F.

An attempt was made to devise a new, direct routine for the calculation of C_{TL} values for any base temperature other than 60°F (on an IPTS-68 basis). The objective was that the outputs using any base temperature should be consistent with those using the procedure for 60°F base temperature, i.e. equivalent inputs should produce equivalent outputs using either procedure.

This Appendix examines the feasibility of developing such a routine.

C.2 Changing Temperature Bases

There are three base temperatures in common use worldwide: 60°F, 15°C, and 20°C. When this Standard was being updated, there was a desire to directly use the metric densities and temperature units in the C_{TL} expression (Equation C.1) in such a way that consistent results would be obtained no matter the base temperature or units. It will be shown here that because of the ρ_{60} (density at 60°F where 60°F is expressed on the IPTS-1968 temperature scale) used in equation (C.2) this set of C_{TL} expressions cannot be mathematically manipulated to directly use different base temperatures and still give consistent results. However, if a very accurate equation can be developed that directly gives ρ_{60} given a density at some other base temperature, then this procedure can be used.

Changing to metric units and a metric base temperature requires the following:

- Change the units of temperature and the thermal expansion coefficient used in Equations (C.1), and (C.2). Shifting the temperature values to an IPTS-68 basis and adding unit conversion parameters can easily do this.. This is discussed in subsection C.6 and in Appendix D.
- Change Equation (C.1) to use a base temperature other than 60°F. It can be shown that adding an extra term can correctly modify the equation to use any base temperature. When this is done, though, the same α_{60} value is still used for the C_{TL}.

Even with these two changes, there is still the matter that the α_{60} correlation directly uses ρ_{60} values. For the metric base temperatures, the desire is the use the 15°C or 20°C base density (ρ_{15} or ρ_{20}) without the ρ_{60} value. This requires more than just scaling the coefficients in Equation (C.2). There is no direct mathematical translation to replace ρ_{60} with these ρ_{15} or ρ_{20} values. One way to eliminate the need for ρ_{60} is to re-correlate the α_{60} expression to use the ρ_{15} or ρ_{20} values. However, modifying the coefficients would introduce inconsistencies with the coefficients used for the non-metric methods based upon the 60°F standard. For this reason, this approach was rejected for the metric base temperatures.

The procedure that was developed for the metric tables requires firstly a calculation of the ρ_{60} value, using an iterative approach as described in Appendix F.

The following sections describes the steps necessary to convert the C_{TL} equations based upon the 1980 Standard to equations that are capable of using any base temperature.

C.3 Consistency of Results

One of the goals of this Standard is to provide consistent results when performing corrections using either metric or customary units. That is, when one corrects an observed density to the density at alternate conditions of temperature and pressure, the same result should be obtained irrespective of the base conditions used or the units in which they are expressed. The procedures adopted in this Standard ensure that consistency of results is always achieved.

For example, let us assume that we have a volume of oil with an observed density of 750.0 kg/m³ at 212°F (100°C) and 1 atm. We would like to correct this volume and density to 248°F (120°C) and 1 atm. We would like the corrected density and volume to be exactly the same whether we do the calculations in customary units using a 60°F standard density or metric units using a 15°C or 20°C standard density. Obviously, the C_{TL} values will be different since they account for corrections to the standard density. But the final resulting corrected density and volume must be the same.

Any modified C_{TL} equation developed for metric temperatures had to produce results consistent with those given by the customary unit tables.

C.4 Original Equations

The original equation for the temperature correction factors contained in the 1980 Standard is:

$$C_{TL} = \frac{\rho}{\rho_{60}} = \exp\left\{-\alpha_{60}\left(t-60\right)\left[1+0.8\alpha_{60}\left(t-60\right)\right]\right\} = \exp\left[-\alpha_{60}\Delta t\left(1+0.8\alpha_{60}\Delta t\right)\right] \quad \text{(C.1)}$$

where C_{TL} is the correction factor for the temperature of the liquid, t is the alternate temperature (°F), ρ is the density at the alternate temperature (kg/m³), ρ_{60} is the density at the base temperature of 60°F (kg/m³), α_{60} is the thermal expansion coefficient at the base temperature of 60°F (°F^{-1}), and Δt is the difference between the alternate temperature and the base temperature.

In the 1980 Standard, α_{60} was correlated to the ρ_{60} density by means of the equation:

$$\alpha_{60} = \frac{K_0 + K_1\rho_{60} + K_2\rho_{60}^2}{\rho_{60}^2} = \frac{K_0}{\rho_{60}^2} + \frac{K_1}{\rho_{60}} + K_2 \quad \text{(C.2)}$$

There are several sets of coefficients for the α_{60} thermal expansion coefficient (the K_0, K_1, and K_2 values) depending upon the liquid's commodity type classification and 60°F density.

The data used in the development of these equations were determined using instruments calibrated according to the IPTS-68 temperature scale.

C.5 Mathematical Conversion from Customary to Metric Temperature Units

For the metric tables, it is preferred to maintain the C_{TL} equation in the form:

$$C_{TL} = \frac{\rho}{\rho_T} = \exp\left\{-\alpha_T\left(t-T\right)\left[1+0.8\alpha_T\left(t-T\right)\right]\right\} \quad \text{(C.3)}$$

where t and T are in °C, T is the new base temperature and all calculations are directly based upon its value and the associated values of the density and thermal expansion coefficient at this temperature. The conversion of this equation is dependant on three main items:

C.5.1 Conversion of Temperatures

Note that, for simplicity, temperatures discussed in this section are expressed on the IPTS-68 temperature scale. The manipulations required to change from the IPTS-68 scale to the ITS-90 scale are described in C.6 and Appendix D.

The first change to the C_{TL} equation to use metric base conditions is to change the temperature units, from °F to °C. This is the easy part to accomplish. The temperature change for (t-T), Δt, only occurs as the product $\alpha_{60}\Delta t$ and this is dimensionless. The units of α_{60} are the reciprocal of the units of temperature, $°F^{-1}$. So, if we change the units of Δt to °C and the units of α_{60} to $°C^{-1}$, then nothing need be done to the C_{TL} equation. However, if we keep the units of α_{60} as $°F^{-1}$, then we need to use a term $C_T\alpha_{60}\Delta t$ where C_T takes care of any inconsistency of units between Δt and α_{60}. This value will be:

$$C_T = \frac{9}{5}°F°C^{-1} \quad \text{However, when } \alpha_{60} \text{ is expressed in } °C^{-1} \text{ then } C_T = 1°C°C^{-1} = 1 \tag{C.4}$$

The actual value of C_T is chosen to make the $C_T\alpha_{60}\Delta t$ term dimensionless. With this consideration, the C_{TL} equation form provisionally becomes:

$$C_{TL} = \exp\{-C_T\alpha_{60}\Delta t[1 + 0.8C_T\alpha_{60}\Delta t]\}. \tag{C.5}$$

where Δt=(t-15.555556).

C.5.2 Shift of Base Temperature Value

The second change is to directly use the metric base temperature T, not 60°F (IPTS-68). This goes beyond simply changing the units. We would like to directly use an expression using the new base temperature in the same general form of:

$$\frac{\rho}{\rho_T} = \exp\{-C_T\alpha_T(t-T)[A_T + B_T C_T \alpha_T (t-T)]\} \tag{C.6}$$

where the constants $\mathcal{A}_T$ and $\mathcal{B}_T$ may be different from the 1.0 and 0.8 used in the 60°F version of the CTL equation. For a <u>consistent</u> C_{TL} correlation, the new set of coefficients $\mathcal{A}_T$ and $\mathcal{B}_T$ must be related to the old constants of 1.0 and 0.8. Keeping units of °F for t and T temporarily the equation develops as follows:

$$\frac{\rho}{\rho_T} = \frac{\rho/\rho_{60}}{\rho_T/\rho_{60}} = \frac{\exp\{-\alpha_{60}(t-60)[1+0.8\alpha_{60}(t-60)]\}}{\exp\{-\alpha_{60}(T-60)[1+0.8\alpha_{60}(T-60)]\}}$$

$$\frac{\rho}{\rho_T}\exp\{-\alpha_{60}(t-T)[1+0.8\alpha_{60}\{(t-T)+2(T-60)\}]\} \tag{C.7}$$

This shows that we cannot use the customary unit form of the equation when we actually change the value of the base temperature because it now includes the $2(T-60)$ term. However, this is a very small modification to the general equation form. So, a version of the general equation that can be used with a change in the base temperature is (t, T and δ_T are in °C):

$$C_{TL} = \frac{\rho}{\rho_T} = \exp\{-C_T\alpha_{60}(t-T)[1+0.8C_T\alpha_{60}(t-T+\delta_T)]\} \tag{C.8}$$

where $\delta_T \equiv 2(T - T_{60})$ and T_{60} is 60°F (IPTS-68) in °C. This form is invariant with changes of base temperature and units on base temperature. Notice that no matter what base temperature is used, it is the 60°F (IPTS-68) values of 1.0, 0.8, and α_{60} that are required in (C.8).

C.5.3 Calculation of the 60°F Thermal Expansion Factor

The third required change involves how the α_{60} term is calculated. The equation form is Equation (C.2). The K_0, K_1, and K_2 coefficients have been developed to be used with the base density at 60°F, ρ_{60}. However, when we change the temperature base, even though we still need α_{60}, we will no longer be having ρ_{60} at T_{60}, but rather ρ_T at T (in °C). The mathematical manipulation to use ρ_T instead of ρ_{60} (here, with no change of units) is:

$$\alpha_{60} = \frac{K_0 \dfrac{\rho_T^2}{\rho_{60}^2}}{\rho_T^2} + \frac{K_1 \dfrac{\rho_T}{\rho_{60}}}{\rho_T} + K_2 = \frac{K_{0,T}}{\rho_T^2} + \frac{K_{1,T}}{\rho_T} + K_2 \quad \text{(C.9)}$$

where the modified coefficients $K_{0,T}$ and $K_{1,T}$ are related to the original coefficients K_0 and K_1 by the ratios $(\rho_T / \rho_{60})^2$ and (ρ_T / ρ_{60}), respectively. There is no simple (ρ_T / ρ_{60}) relationship to convert the K_0 and K_1 constants to corresponding $K_{0,T}$ and $K_{1,T}$ constants. Substituting the metric base temperature T and the original base temperature T_{60} into equation C.8:

$$\frac{\rho_T}{\rho_{60}} = \exp\{-C_T\alpha_{60}(T-T_{60})[1+0.8C_T\alpha_{60}(T-T_{60}+\delta_T)]\} = \exp\left\{-C_T\alpha_{60}\frac{\delta_T}{2}[1+0.8C_T\alpha_{60}\frac{3}{2}\delta_T]\right\} \quad \text{(C.10)}$$

so now the correlation for α_{60} in terms of ρ_T is:

$$\alpha_{60} = K_0 \frac{\exp\{-C_T\alpha_{60}\delta_T[1+0.8C_T\alpha_{60}\frac{3}{2}\delta_T]\}}{\rho_T^2} + K_1 \frac{\exp\{-C_T\alpha_{60}\frac{\delta_T}{2}[1+0.8C_T\alpha_{60}\frac{3}{2}\delta_T]\}}{\rho_T} + K_2 \,. \quad \text{(C.11)}$$

This is a non-linear expression in α_{60} so it cannot be solved explicitly for any arbitrary value of ρ_T at T. Also, by virtue of how α_{60} is calculated from ρ_{60}, the ratio (ρ_T / ρ_{60}) is not constant for any range of ρ_{60}. So, if K_0 and K_1 are constants then the corresponding $K_{0,T}$ and $K_{1,T}$ are not.

While the $K_{0,T}$ and $K_{1,T}$ values might be recorrelated as constants using ρ_T, this Standard would then have a new correlation for the metric base temperatures that could not be guaranteed to be consistent with the C_{TL} expression for customary units.

Therefore, it is not feasible to develop an equation for metric temperature bases in the form of equation C.11 that can be solved. The solution adopted for metric base temperatures in the revision of this Standard is to first compute densities at 60°F, in accordance with the data base developed for the 1980 Tables, using an iterative approach as described in Appendix F

C.6 Conversion to ITS-90 Temperature Scale

The manipulations shown above do not include corrections needed to change from the IPTS-68 temperature scale to the ITS-90 temperature scale. Implementation of the ITS-90 temperature scale posed problems of a shift in the base temperature similar to those discussed for metric base temperatures. When converting the 60°F equations for use with the ITS-90 temperature scale, the base temperature is no longer the original IPTS-68 60°F but a slightly different value, t_{60}, approximately 60.007°F. The shift factor required for use in the equation form of (C.8) will be:

$$\delta_{60} \equiv 2(t_{60} - 60) = 0.01374979547 \,. \quad \text{(C.12)}$$

Because the temperature shift is so small, iterative equations can be applied in a very simple manner to get a ρ_{60} that is consistent with IPTS-68, given a ρ_{60} consistent with ITS-90. This means that the α_{60} value can easily be calculated and the equations for the shifted base temperature used in this Standard.

For computations involving the customary base temperature of 60°F, the procedure that has been adopted is to shift the input temperature and the input ρ_{60}, if given, to an IPTS-68 basis. If ρ_{60} is not given, a value is calculated using an iterative procedure and this is then shifted to an IPTS-68 basis. The calculation of C_{TL} involves IPTS-68 values of ρ_{60}, while Δt is the temperature differential expressed on the IPTS-68 scale.

For metric base temperatures, all relevant temperatures (base, observed and alternate) are first converted from °C to °F, where both units are expressed on the temperature scale ITS-90. If given, the ρ_T value (where T is the metric base temperature) is used to calculate ρ_{60} (ITS-90). The procedure then follows that described above for the 60°F system, with temperatures and base density shifted to IPTS-68.

Since the procedures for the customary and metric base systems utilize the same routines, they deliver identical results when starting from equivalent input values.

Appendix D — International Temperature Scale of 1990, ITS-90

Changes to the International Temperature Scale Since 1980

The International Committee for Weights and Measures, CIPM, publishes the international temperature scale. Its purpose is to define procedures by which specified practical thermometers of the required quality can be calibrated in such a way that the values of temperature obtained from them can be precise and reproducible while at the same time closely approximating the corresponding thermodynamic values. Small amendments to the temperature scale are introduced from time to time by CIPM to improve precision and reproducibility and provide better continuity between sections of the scale.

Since the international temperature scale is used for the calibration of thermometers, the values of temperature-dependent physical parameters of materials will, in principle, depend on what scale is in force at the time the parameter is measured or referenced. However, since changes between scales are relatively small, this effect will only become noticeable at high levels of precision.

When the 1980 Petroleum Measurement Tables were prepared, the temperature scale in effect was the International Practical Temperature Scale of 1968 (IPTS-68). The International Temperature Scale of 1990 (ITS-90) superseded this in 1990.

When the 1980 Petroleum Measurement Tables were prepared, the temperature scale in effect was the International Practical Temperature Scale of 1968 (IPTS-68). The International Temperature Scale of 1990 (ITS-90) superseded this in 1990. The developers of ITS-90 fitted the differences between the ITS-90 and IPTS-68 temperature scales to an 8th order polynomial of the form:

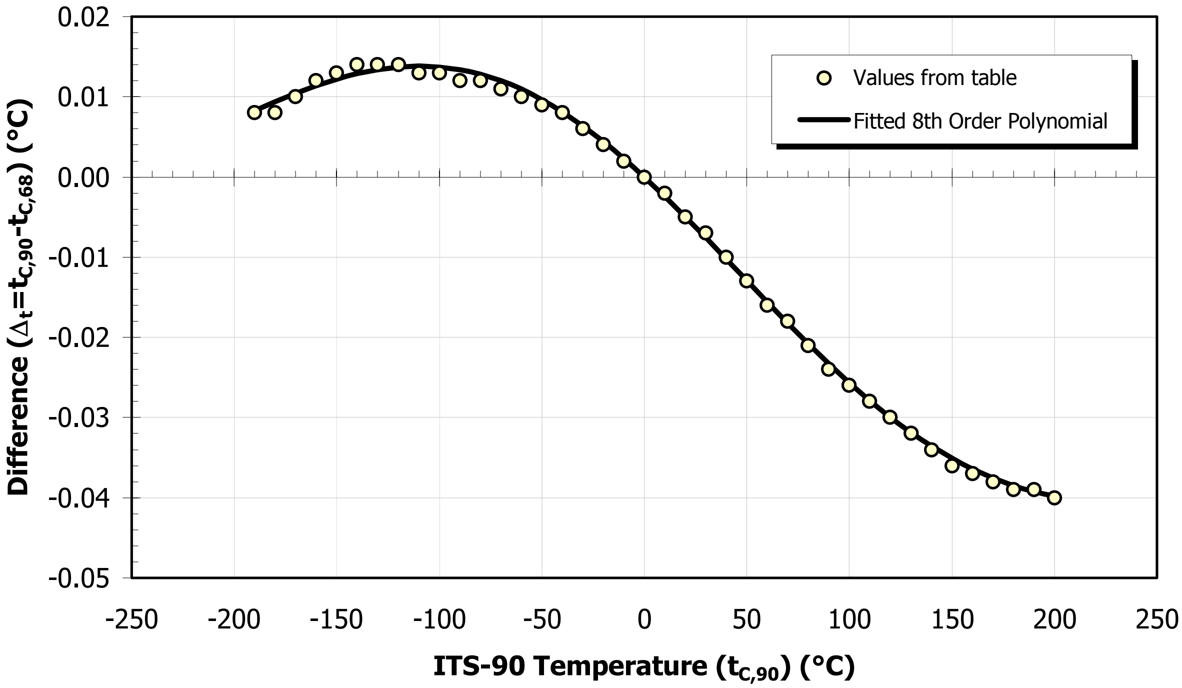
$$\Delta_t = t_{C,90} - t_{C,68} \equiv \sum_{i=1}^{8} a_i \left(\frac{t_{C,90}}{630} \right)^i \qquad \text{(D.1)}$$

Note that this polynomial is useful over the range of -200°C to 630°C.

where Δ_t is the difference between the equivalent temperatures in the ITS-90 and IPTS-68 temperature scales, $t_{C,90}$ is the temperature in the ITS-90 temperature scale, $t_{C,68}$ is the equivalent temperature in the IPTS-68 temperature scale, and the a_i values are constant coefficients given in the following table.

i	a_i	i	a_i
1	-0.148759	5	-4.089591
2	-0.267408	6	-1.871251
3	1.080760	7	7.438081
4	1.269056	8	-3.536296

The following figure shows the magnitude of the differences between the ITS-90 and equivalent IPTS-68 temperature values in the range of this Standard. Over this temperature range, the differences in the two temperature scales are no larger than 0.04°C (0.07°F).



Impact on the Petroleum Measurement Tables

The principal physical parameter contained in the Petroleum Measurement Tables that is affected by the change from IPTS-68 to ITS-90 is density and the related properties of relative density and API gravity.

Values of the density of a substance are a function of its temperature. For petroleum hydrocarbons, the Petroleum Measurement Tables are based on average relationships between density and temperature according to broad classifications of products. The precision of the VCF values, which represent the change of density with temperature, is to 5 decimal places.

The changes due to ITS-90 give differences at high temperatures of no more than ±0.00003. Even though this is well within the inherent accuracy of the correlations, because this would be noticeable, it was decided to fully incorporate procedures to account for differences between ITS-90and IPTS-68. Converting the input ITS-90 temperatures to equivalent IPTS-68 values before making any calculations in 11.1.6.1 did this.

One other subtle effect of the temperature scale correction is that the customary standard temperature, 60°F, has undergone a slight shift. What is 60°F in ITS-90 is an equivalent 60.00687490°F in IPTS-68. Because of this, any input 60°F standard density values must be corrected to an equivalent IPTS-68 60°F value, before the value can be used in the α_{60} and F_P correlations.

60°F Water Density

Another parameter in the Tables that is affected by the change of temperature scale is the density of water at 60°F, which affects the relative density and API gravity. While density is a simple physical property (the mass of a substances divided by its volume at a specified temperature), calculations of relative density and API gravity relate to the density of water as well as the density of the hydrocarbon. Since pure water is a defined substance, it has different density values on IPTS-68 and ITS-90 dependent on the temperature of the measurement. In addition, a new, more accurate equation of state has been adopted for giving water densities. The value at 60°F (ITS-90) has been re-defined as 999.016 kg/m³ for air-free water, based on new laboratory work by Patterson & Morris

(*Metrologia*, 1994, 31, 277-288). The value used in the 1980 Tables was 999.012 kg/m³ (0.999012 g/ml) based on earlier laboratory work and applying IPTS-68.

The water density value of 999.016 kg/m³ at 60°F has been adopted for use in any conversion between density and relative density or API gravity.

Appendix E — Development of Thermal Expansion Regression Equations

The correlations for the 60°F thermal expansion factor give results for an "average" liquid of a specific commodity type. However, there may be occasions when one wants to make density measurements on a particular liquid in order to determine its actual α_{60} value. The following is a development of the equations given in 11.1.5.2 as the procedure to determine the thermal expansion factor from a set of measured density data.

The ρ_{60} and α_{60} values must be determined from a set of density measurements using non-linear regression. In general, this would involve doing a two-variable minimization process. However, because of the form of the equations used to relate density to the thermal expansion factor, the process can be simplified to the solution of a single 3rd order polynomial.

The goal of this regression is to determine ρ_{60} and α_{60} values so that some measure of the difference between the measured density values and values estimated from the CTL equation is minimized. Mathematically, we can express the function that represents this difference using the least squares criteria:

$$\mathcal{F} \equiv \frac{1}{2}\sum_{i=1}^{N}\left(\ln \rho_{m,i} - \ln \rho_{\iota}\right)^2 \tag{E.1}$$

where there are N measured density values, $\rho_{m,i}$ is the i-th measured density value, and ρ_i is the estimate of the density using the corresponding temperature of the i-th measurement. The function $\mathcal{F}$ is the "objective" function, the sum of the squared residuals. (All subsequent summations will not show the limits on the summation, but they remain 1 to N.) This objective function has the following features:

- Since all terms are squared, each term in $\mathcal{F}$ is positive. Negative errors will add to and not cancel out positive errors.
- If this objective function is at an unconstrained minimum, then the 1st derivatives with respect to each variable will be zero and all of the 2nd partial derivatives will be positive.

The equation relating density and temperature is:

$$\rho = \rho_{60}\exp\left\{-\alpha_{60}\Delta t\left[1 + 0.8\alpha_{60}\left(\Delta t + \delta_{60}\right)\right]\right\} \tag{E.2}$$

where ρ is the density at 0 psig and any valid temperature, ρ_{60} is the density at the base temperature 60°F, α_{60} is the 60°F thermal expansion coefficient , Δt is the difference between the alternate temperature and the 60°F base temperature, and δ_{60} is the base temperature shift factor (0.01374979547°F). The temperatures used to calculate Δt must be adjusted using the procedure in 11.1.5.3 and the value for the base temperature should also be shifted consistent with 11.1.5.3, 60.0068749°F. Using Equation (E.2) the objective function can be expressed as:

$$\begin{aligned}\mathcal{F} &= \frac{1}{2}\sum\left\{\ln \rho_{m,i} - \ln \rho_{60} + \alpha_{60}\Delta t_i\left[1 + 0.8\alpha_{60}\left(\Delta t_i + \delta_T\right)\right]\right\}^2 \\ &= \frac{1}{2}\sum\left(\ln \rho_{m,i} - \ln \rho_{60} + \alpha_{60}\Delta t + 0.8\alpha_{60}^2\left(\Delta t_i\right)\left(\Delta t_i + \delta_T\right)\right)^2\end{aligned} . \tag{E.3}$$

This expression can be fully expanded to:

$$\begin{aligned}\mathcal{F} &= \frac{1}{2}\sum\left(\ln\rho_{m,i}\right)^2 - \ln\rho_{60}\sum\ln\rho_{m,i} + \frac{1}{2}\left(\ln\rho_{60}\right)^2 N + \alpha_{60}\sum\Delta t_i\cdot\ln\rho_{m,i} \\ &+0.8\alpha_{60}^2\delta_{60}\sum\Delta t_i\cdot\ln\rho_{m,i} - \alpha_{60}\ln\rho_{60}\sum\Delta t_i - 0.8\alpha_{60}^2\delta_{60}\ln\rho_{60}\sum\Delta t_i \\ &+\frac{1}{2}\alpha_{60}^2\sum\left(\Delta t_i\right)^2 + 0.8\alpha_{60}^3\delta_{60}\sum\left(\Delta t_i\right)^2 + 0.32\alpha_{60}^4\delta_{60}^2\sum\left(\Delta t_i\right)^2 + 0.8\alpha_{60}^2\sum\left(\Delta t_i\right)^2\cdot\ln\rho_{m,i} \\ &-0.8\alpha_{60}^2\ln\rho_{60}\sum\left(\Delta t_i\right)^2 + 0.8\alpha_{60}^3\sum\left(\Delta t_i\right)^3 + 0.64\alpha_{60}^4\delta_{60}\sum\left(\Delta t_i\right)^3 + 0.32\alpha_{60}^4\sum\left(\Delta t_i\right)^4\end{aligned} \tag{E.4}$$

The various summations in Equation (E.4) need only be calculated once and then be treated as constants when adjusting the ρ_{60} and α_{60} values. Equation (E.4) can be restated as:

$$\begin{aligned}\mathcal{F} &= \frac{1}{2}S_{\rho\rho} - \ln\rho_{60}S_\rho + \frac{1}{2}\left(\ln\rho_{60}\right)^2 N + \alpha_{60}S_{t\rho} \\ &+0.8\alpha_{60}^2\delta_{60}S_{t\rho} - \alpha_{60}\ln\rho_{60}S_t - 0.8\alpha_{60}^2\delta_{60}\ln\rho_{60}S_t \\ &+\frac{1}{2}\alpha_{60}^2S_{tt} + 0.8\alpha_{60}^3\delta_{60}S_{tt} + 0.32\alpha_{60}^4\delta_{60}^2S_{tt} + 0.8\alpha_{60}^2S_{tt\rho} \\ &-0.8\alpha_{60}^2\ln\rho_{60}S_{tt} + 0.8\alpha_{60}^3S_{ttt} + 0.64\alpha_{60}^4\delta_{60}S_{ttt} + 0.32\alpha_{60}^4S_{tttt}\end{aligned} \tag{E.5}$$

with the following definitions of the variables to represent the summations:

$$S_\rho \equiv \sum\ln\rho_{m,i} \tag{E.6}$$

$$S_{\rho\rho} \equiv \sum\left(\ln\rho_{m,i}\right)^2 \tag{E.7}$$

$$S_t \equiv \sum\Delta t_i \tag{E.8}$$

$$S_{t\rho} \equiv \sum\Delta t_i\cdot\ln\rho_{m,i} \tag{E.9}$$

$$S_{tt} \equiv \sum\left(\Delta t_i\right)^2 \tag{E.10}$$

$$S_{tt\rho} \equiv \sum\left(\Delta t_i\right)^2\cdot\ln\rho_{m,i} \tag{E.11}$$

$$S_{ttt} \equiv \sum\left(\Delta t_i\right)^3 \tag{E.12}$$

$$S_{tttt} \equiv \sum\left(\Delta t_i\right)^4 \tag{E.13}$$

In the data fitting process, the two adjustable variables are ρ_{60} and α_{60}. An unconstrained minimum will be at an extremum point, i.e., a point where each 1st derivative with respect to a variable is zero. The 1st derivatives for these variables are:

$$\begin{aligned}\left(\frac{\partial\mathcal{F}}{\partial\rho_{60}}\right)_{\alpha_{60}} &= -\frac{S_\rho}{\rho_{60}} + \frac{\ln\rho_{60}}{\rho_{60}}N - \frac{\alpha_{60}}{\rho_{60}}S_t - \frac{0.8\alpha_{60}^2\delta_{60}}{\rho_{60}}S_t - \frac{0.8\alpha_{60}^2}{\rho_{60}}S_{tt} \\ &= \frac{1}{\rho_{60}}\left(-S_\rho + \ln\rho_{60}N - \alpha_{60}S_t - 0.8\alpha_{60}^2\delta_{60}S_t - 0.8\alpha_{60}^2S_{tt}\right)\end{aligned} \tag{E.14}$$

and:

$$\left(\frac{\partial \mathcal{F}}{\partial \alpha_{60}}\right)_{\rho_{60}} = S_{t\rho} + 1.6\alpha_{60}\delta_{60}S_{t\rho} - \ln\rho_{60}S_t - 1.6\alpha_{60}\delta_{60}\ln\rho_{60}S_t + \alpha_{60}S_{tt}$$
$$+2.4\alpha_{60}^2\delta_{60}S_{tt} + 1.28\alpha_{60}^3\delta_{60}^2S_{tt} + 1.6\alpha_{60}S_{tt\rho} - 1.6\alpha_{60}\ln\rho_{60}S_{tt} \tag{E.15}$$
$$+2.4\alpha_{60}^2S_{ttt} + 2.56\alpha_{60}^3\delta_{60}S_{ttt} + 1.28\alpha_{60}^3S_{tttt}$$

Denote the values of the two adjustable variables at the extremum point as ρ^* and α^*. These values are solutions to the two simultaneous equations resulting when setting the 1st derivatives equal to zero:

$$0 = -S_\rho + \ln\rho^* N - \alpha^* S_t - 0.8\left(S_{tt} + \delta_{60}S_t\right)\alpha^{*2} \tag{E.16}$$

and:

$$0 = S_{t\rho} + 1.6\alpha^*\delta_{60}S_{t\rho} - \ln\rho^* S_t - 1.6\alpha^*\delta_{60}\ln\rho^* S_t + \alpha^* S_{tt}$$
$$+2.4\alpha^{*2}\delta_{60}S_{tt} + 1.28\alpha^{*3}\delta_{60}^2S_{tt} + 1.6\alpha^* S_{tt\rho} - 1.6\alpha^*\ln\rho^* S_{tt} \tag{E.17}$$
$$+2.4\alpha^{*2}S_{ttt} + 2.56\alpha^{*3}\delta_{60}S_{ttt} + 1.28\alpha^{*3}S_{tttt}$$

Both equations are non-linear with respect to α^* but the first equation gives a direct relationship between the optimal values of ρ^* and α^*:

$$\ln\rho^* = \frac{S_\rho}{N} + \frac{S_t}{N}\alpha^* + \frac{0.8\left(S_{tt} + \delta_{60}S_t\right)}{N}\alpha^{*2} \tag{E.18}$$

This can be substituted into Equation (E.17) to give a single non-linear equation in α_{60}^*:

$$0 = \left[S_{t\rho} - \frac{S_tS_\rho}{N}\right] + \left[S_{tt} + 1.6\left(S_{tt\rho} + \delta_{60}S_{t\rho}\right) - \frac{S_t^2 + 1.6\left(S_{tt} + \delta_{60}S_t\right)S_\rho}{N}\right]\alpha_{60}^*$$
$$+2.4\left[S_{ttt} + \delta_{60}S_{tt} - \frac{S_t\left(S_{tt} + \delta_{60}S_t\right)}{N}\right]\alpha_{60}^{*2} \tag{E.19}$$
$$+1.28\left[S_{tttt} + \left(2S_{ttt} + \delta_{60}S_{tt}\right)\delta_{60} - \frac{\left(S_{tt} + \delta_{60}S_t\right)^2}{N}\right]\alpha_{60}^{*3}$$

Notice that (E.19) is just a 3rd order polynomial equation in α_{60}^*:

$$0 = a_0 + a_1\alpha_{60}^* + a_2\alpha_{60}^{*2} + a_3\alpha_{60}^{*3} \tag{E.20}$$

with the coefficients defined from:

$$a_0 \equiv S_{t\rho} - \frac{S_\rho S_t}{N} \tag{E.21}$$

$$a_1 \equiv S_{tt} + 1.6\left(S_{tt\rho} + \delta_{60}S_{t\rho}\right) - \frac{S_t^2 + 1.6\left(S_{tt} + \delta_{60}S_t\right)S_\rho}{N} \tag{E.22}$$

$$a_2 \equiv 2.4\left[S_{ttt} + \delta_{60}S_{tt} - \frac{S_t\left(S_{tt} + \delta_{60}S_t\right)}{N}\right] \tag{E.23}$$

$$a_3 \equiv 1.28\left[S_{tttt} + \left(2S_{ttt} + \delta_{60}S_{tt}\right)\delta_{60} - \frac{\left(S_{tt} + \delta_{60}S_t\right)^2}{N}\right]. \qquad \text{(E.24)}$$

The equation leading to α^* is a cubic and there is a procedure to determine its roots analytically. However, this procedure is fairly complex. Sometimes it is simpler to use a numerical method (such as Newton's method) to determine the numerical values of the roots. A Newton's iteration method with the following steps is used in 11.1.5.2:

1. Initialize the value for α^*. The result from a linear regression of $\ln\rho_m$ vs. Δt with $\delta_{60} \approx 0$ is used as the initial guess:

$$\alpha^* = \frac{NS_{t\rho} - S_t S_\rho}{NS_{tt} - S_t^2} = -\frac{a_0}{S_{tt} - \dfrac{S_t^2}{N}}$$

2. Determine the "residual" for this guess:

$$f = a_0 + a_1\alpha^* + a_2\alpha^{*2} + a_3\alpha^{*3}$$

3. Determine the derivative of the residual for this guess:

$$f' = a_1 + 2a_2\alpha^* + 3a_3\alpha^{*2}$$

4. Determine a correction to this guess:

$$\Delta\alpha^* = -\frac{f}{f'}$$

5. Update the value for α^*:

$$\alpha^* \leftarrow \alpha^* + \Delta\alpha^*$$

6. Return to step 2 until some convergence criteria is achieved. Some convergence criteria are small values of the residual, small values of the update value, and/or a set number of iterations.

Since the equation leading to α^* is a cubic, it is guaranteed to always have at least one real root, but may have two or three. Because the coefficients are generated from expressions that involve sums and differences of (mostly) positive summations, we cannot tell *a priori* the signs of the coefficients and how many positive real roots we will have. From geometric considerations, we will have the following:

- The objective function surface should be a quartic function in the plane of the $\ln\rho^*$ value(s) and a quadratic in the plane of the α^* values. Both of these should be concave down.
- If there are multiple roots to the cubic equation giving the α^* value, two of the roots should be associated with local minima & the third with a local maximum. The root associated with the local maximum should lie between the two roots associated with the local minima.

Appendix F — Development of Iteration Equations

The basic iteration scheme to determine the 60°F base density ρ_{60} from the observed density ρ_o is outlined in 11.1.3.5. It is pointed out that a Newton's method defines a specific way to calculate a new ρ_{60} estimate from the previous estimate. In this appendix the actual equations used for the Newton's methods will be developed.

In the following equations variables that may change from one iterative step to the next will be denoted with a superscript '(m)' where the m denotes the m-th iterative step. For example, the value of ρ_{60} used on the first iterative step will be $\rho_{60}^{(1)}$, the value used on the second iterative step will be $\rho_{60}^{(2)}$, and so on.

Newton's Method

Newton's method gives a procedure for finding a numerical value for the zero of a function, i.e., for a function $f(x)$ finding a specific value of X such that $f(X)=0$. The function $f(x)$ is approximated as a straight-line about a point x_0; this approximate equation can then be solved for X. Using a little bit of calculus, the function $f(x)$ can be exactly expanded as a Taylor series polynomial:

$$\begin{aligned} f(x) &= f(x_0)+(x-x_0)\left.\frac{df}{dx}\right|_{x=x_0}+\frac{1}{2}(x-x_0)^2\left.\frac{d^2f}{dx^2}\right|_{x=x_0}+\cdots+\frac{1}{n!}(x-x_0)^n\left.\frac{d^nf}{dx^n}\right|_{x=x_0}+\cdots \\ &= f(x_0)+(x-x_0)f'(x_0)+\frac{1}{2}(x-x_0)^2 f''(x_0)+\cdots+\frac{1}{n!}(x-x_0)^n f^{(n)}(x_0)+\cdots \end{aligned} \tag{F.1}$$

where the derivatives are evaluated at the point $x=x_0$. The approximate straight-line equation is obtained by dropping all terms after the first derivative:

$$f(x)\approx f(x_0)+(x-x_0)f'(x_0). \tag{F.2}$$

Remembering that X is defined as the point where the function's value is zero, we can solve this approximate equation for X:

$$f(X)=0=f(x_0)+(X-x_0)f'(x_0) \quad\Rightarrow\quad X=x_0-\frac{f(x_0)}{f'(x_0)}. \tag{F.3}$$

If we expand the function about each iterative value then $x^{(m)}$ plays the role of x_0 and the next iteration's value $x^{(m+1)}$ plays the role of X. The recursion formula becomes:

$$x^{(m+1)}=x^{(m)}-\frac{f(x^{(m)})}{f'(x^{(m)})}. \tag{F.4}$$

Two notation changes can be made: the function and derivative values may be denoted with the iteration's superscript ($f^{(m)}$ and $f'^{(m)}$ instead of $f(x^{(m)})$ and $f'(x^{(m)})$) and the ratio of the function to its derivative can be referred to as the step change, $\Delta x^{(m)}$. So, this recursion formula can also be expressed as:

$$x^{(m+1)}=x^{(m)}+\Delta x^{(m)} \quad \text{where} \quad \Delta x^{(m)}\equiv-\frac{f^{(m)}}{f'^{(m)}}. \tag{F.5}$$

Derivation of This Standard's Newton's Method Equations

The Newton's method iteration procedure to find ρ_{60} given an observed ρ is:

$$\rho_{60}^{(m+1)}=\rho_{60}^{(m)}+\Delta\rho_{60}^{(m)} \tag{F.6}$$

where the step change $\Delta\rho_{60}^{(m)}$ is calculated from:

$$\Delta\rho_{60}^{(m)} = \frac{E^{(m)}}{1 + D_T^{(m)} + D_P^{(m)}} \qquad \text{(F.7)}$$

$$E^{(m)} = \frac{\rho}{C_{TPL}^{(m)}} - \rho_{60}^{(m)} = \frac{\rho}{C_{TL}^{(m)} \cdot C_{PL}^{(m)}} - \rho_{60}^{(m)} \qquad \text{(F.8)}$$

$$D_T^{(m)} = D_\alpha^{(m)} \alpha_{60}^{(m)} \Delta t \left[1 + 1.6\alpha_{60}^{(m)} \left(\Delta t + \delta_T\right)\right] \qquad \text{(F.9)}$$

$$D_P^{(m)} = -\frac{2C_{PL}^{(m)} PF_P^{(m)} (7.93920 + 0.02326t)}{\rho_{60}^{(m)2}} \qquad \text{(F.10)}$$

These recursion equations can be developed by starting with the residual function:

$$f(\rho_{60}) = C_{TPL} \cdot \rho_{60} - \rho = C_{TL} \cdot C_{PL} \cdot \rho_{60} - \rho \qquad \text{(F.11)}$$

(where $f(\rho_{60}) = 0$ corresponds to the solution). The Newton's method recursion equation will come from:

$$\rho_{60}^{(m+1)} = \rho_{60}^{(m)} - \frac{f\left(\rho_{60}^{(m)}\right)}{f'\left(\rho_{60}^{(m)}\right)} \qquad \text{(F.12)}$$

where:

$$f'(\rho_{60}) = \frac{df}{d\rho_{60}} = C_{PL} \cdot \rho_{60} \cdot \frac{dC_{TL}}{d\rho_{60}} + C_{TL} \cdot \rho_{60} \cdot \frac{dC_{PL}}{d\rho_{60}} + C_{TL} \cdot C_{PL} . \qquad \text{(F.13)}$$

Using this definition for the residual function and its derivative, the iteration scheme can be expressed as:

$$\rho_{60}^{(m+1)} = \rho_{60}^{(m)} - \frac{C_{TL}^{(m)} C_{PL}^{(m)} \rho_{60}^{(m)} - \rho}{C_{TL}^{(m)} C_{PL}^{(m)} + C_{PL}^{(m)} \rho_{60}^{(m)} \left[\frac{dC_{TL}}{d\rho_{60}}\right]^{(m)} + C_{TL}^{(m)} \rho_{60}^{(m)} \left[\frac{dC_{PL}}{d\rho_{60}}\right]^{(m)}} . \qquad \text{(F.14)}$$

We can change the appearance by dividing the numerator and denominator by $C_{TL}^{(m)} C_{PL}^{(m)}$ and factoring out a –1 from the numerator (changing the order of the subtraction):

$$\rho_{60}^{(m+1)} = \rho_{60}^{(m)} + \frac{\dfrac{\rho}{C_{TL}^{(m)} C_{PL}^{(m)}} - \rho_{60}^{(m)}}{1 + \dfrac{\rho_{60}^{(m)}}{C_{TL}^{(m)}} \left[\dfrac{dC_{TL}}{d\rho_{60}}\right]^{(m)} + \dfrac{\rho_{60}^{(m)}}{C_{PL}^{(m)}} \left[\dfrac{dC_{PL}}{d\rho_{60}}\right]^{(m)}} . \qquad \text{(F.15)}$$

We can simplify the looks of equation (F.15) by defining two derivative terms:

$$D_T^{(m)} \equiv \frac{\rho_{60}^{(m)}}{C_{TL}^{(m)}} \left[\frac{dC_{TL}}{d\rho_{60}}\right]^{(m)} \qquad \text{(F.16)}$$

$$D_P^{(m)} \equiv \frac{\rho_{60}^{(m)}}{C_{PL}^{(m)}} \left[\frac{dC_{PL}}{d\rho_{60}}\right]^{(m)} \qquad \text{(F.17)}$$

So:

$$\rho_{60}^{(m+1)} = \rho_{60}^{(m)} + \frac{\dfrac{\rho}{C_{TL}^{(m)} C_{PL}^{(m)}} - \rho_{60}^{(m)}}{1 + D_T^{(m)} + D_P^{(m)}} = \rho_{60}^{(m)} + \frac{E^{(m)}}{1 + D_T^{(m)} + D_P^{(m)}}. \tag{F.18}$$

The various derivatives can be determined from the basic equations. Neglecting any differences between the ITS-90 and IPTS-68 temperature scale densities (i.e.., $d\rho_{60} / d\rho^* \approx 1$), the CTL expressions:

$$C_{TL} = \exp\left\{-\alpha_{60}\Delta t\left[1 + 0.8\alpha_{60}\left(\Delta t + \delta_T\right)\right]\right\} \tag{F.19}$$

$$\alpha_{60} = \frac{K_0 + K_1\rho^* + K_2\rho^{*2}}{\rho^{*2}} = \frac{K_0}{\rho^{*2}} + \frac{K_1}{\rho^*} + K_2 \tag{F.20}$$

give the derivatives:

$$\frac{dC_{TL}}{d\rho_{60}} = -C_{TL}\left\{\Delta t\left[1 + 1.6\alpha_{60}\left(\Delta t + \delta_T\right)\right]\right\}\alpha'_{60} \tag{F.21}$$

$$\alpha'_{60} = \frac{d\alpha_{60}}{d\rho_{60}} \approx \frac{d\alpha_{60}}{d\rho^*} = -\frac{2K_0}{\rho^{*3}} - \frac{K_1}{\rho^{*2}} = -\frac{2K_0 + K_1\rho^*}{\rho^{*3}} \approx -\frac{2K_0 + K_1\rho_{60}}{\rho_{60}^3} \tag{F.22}$$

so $D_T^{(m)}$ is:

$$D_T^{(m)} = \frac{\rho_{60}^{(m)}}{C_{TL}^{(m)}}\left[\frac{dC_{TL}}{d\rho_{60}}\right]^{(m)} = -\rho_{60}^{(m)}\Delta t\left[1 + 1.6\alpha_{60}^{(m)}\left(\Delta t + \delta_T\right)\right]\alpha_{60}'^{(m)}. \tag{F.23}$$

The CPL expressions:

$$C_{PL} = \frac{1}{1 - 10^{-5} F_P P} \tag{F.24}$$

$$F_P = \exp\left(-1.9947 + 0.000134270t + \frac{793920 + 2326t}{\rho^*}\right) \tag{F.25}$$

give the derivatives:

$$\frac{dC_{PL}}{d\rho_{60}} = 10^{-5} C_{PL}^2 P F'_P \tag{F.26}$$

$$F'_P = \frac{dF_P}{d\rho_{60}} \approx \frac{dF_P}{d\rho^*} = -2F_P\left(\frac{793920 + 2326t}{\rho^{*3}}\right) \approx -2F_P\left(\frac{793920 + 2326t}{\rho_{60}^3}\right) \tag{F.27}$$

so $D_P^{(m)}$ is:

$$D_P^{(m)} = \frac{\rho_{60}^{(m)}}{C_{PL}^{(m)}}\left[\frac{dC_{PL}}{d\rho_{60}}\right]^{(m)} = -2 \cdot 10^{-5} C_{PL}^{(m)} P F_P^{(m)}\left(\frac{793920 + 2326t}{\rho_{60}^{(m)2}}\right). \tag{F.28}$$

Note that the derivative terms do not have to be extremely accurate since they only establish the magnitude of the change from one iteration to the next. If they values are off, usually one extra iteration is needed to achieve convergence. That is why we can interchange the ρ_{60} and ρ_{60}^* values in these derivative terms.

Simplification of the Temperature Derivative Term

Let's go back to the $D_T^{(m)}$ term in Equation (F.23). The α_{60} derivative could be replaced with Equation (F.24), but a manipulation can be made simplify the calculation. Equation (F.23) can be modified to:

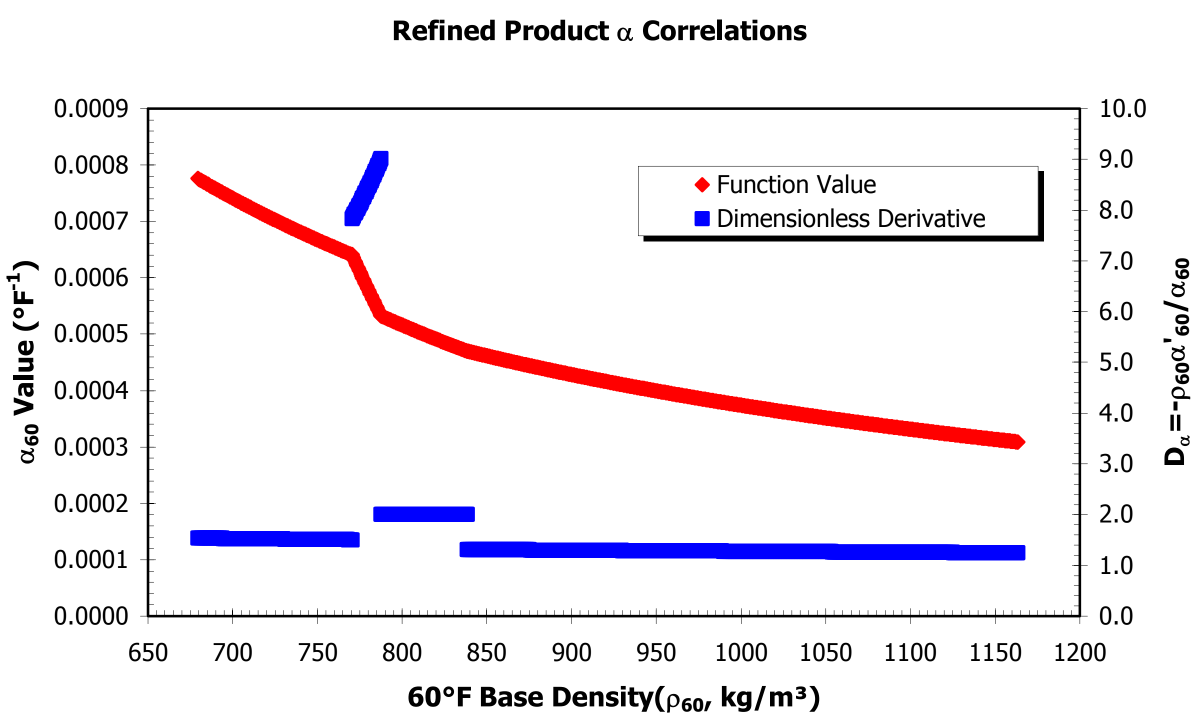
$$D_T = -\rho_{60}\Delta t\left[1+1.6\alpha_{60}^{(m)}\left(\Delta t+\delta_T\right)\right]\left[\alpha'_{60}\right] = \alpha_{60}^{(m)}\Delta t\left[1+1.6\alpha_{60}^{(m)}\left(\Delta t+\delta_T\right)\right]\left[-\frac{\alpha'_{60}}{\alpha_{60}/\rho_{60}}\right]^{(m)}$$

$$D_T = \alpha_{60}^{(m)}\Delta t\left[1+1.6\alpha_{60}^{(m)}\left(\Delta t+\delta_T\right)\right]\left[-\frac{\alpha'_{60}}{\alpha_{60}/\rho_{60}}\right]^{(m)} = \alpha_{60}^{(m)}\Delta t\left(1+1.6\alpha_{60}^{(m)}\Delta t\right)\left[D_\alpha^{(m)}\right] \tag{F.29}$$

where the term in the square brackets is the dimensionless α_{60} derivative and is designated as D_α. The expression for D_α is:

$$D_\alpha = \frac{2K_0 + K_1\rho^*}{K_0 + K_1\rho^* + K_2\rho^{*2}} \approx \frac{2K_0 + K_1\rho_{60}}{K_0 + K_1\rho_{60} + K_2\rho_{60}^2} \tag{F.30}$$

This definition is convenient because of the nature of D_α for the Equation (F.20) for α_{60}. Depending upon the values of K_0, K_1, and K_2, the D_α values are constant or are nearly constant. For example, for the Generalized Crude Oils, $K_1 = K_2 = 0$, so $D_\alpha = 2$ for all ρ_{60} values. Similarly, for the Generalized Lubricating Oils, $K_0 = K_2 = 0$, so $D_\alpha = 1$ for all ρ_{60} values. For nearly all of the commodity groups the D_α values are or are nearly constant, but different, values. The only exception is the Transition Zone ($770.3554 \le \rho_{60} < 787.5224$) where there is a significant change in the value (see the following figure) – however, a constant value of 8.5 does not significantly harm the convergence properties of the iteration equation.



Using the approximate constant D_α values for the different commodity groups, the D_T term becomes:

$$D_T^{(m)} = D_\alpha^{(m)} \alpha_{60}^{(m)} \Delta t \left[1 + 1.6 \alpha_{60}^{(m)} \left(\Delta t + \delta_T \right) \right]. \tag{F.30}$$

This equation shows D_α changing with the iterations; however, as long as the commodity group does not change during the iterations, this would actually be a constant.

The following table shows the appropriate D_α to use for the various commodity groups.

	Density Range(kg/m³)	D_α
Crude Oil	$610.6 \le \rho_{60} < 1163.5$	2.0
Fuel Oils	$838.3154 \le \rho_{60} \le 1163.5$	1.3
Jet Fuels	$787.5224 \le \rho_{60} < 838.3154$	2.0
Transition Zone	$770.3554 \le \rho_{60} < 787.5224$	8.5
Gasolines	$610.6 \le \rho_{60} < 770.3554$	1.5
Lubricating Oil	$800.9 \le \rho_{60} < 1163.5$	1.0
Special Applications	All ρ_{60} values	0.0

Special Applications – "C" Tables

What happens to the iteration equations if the α_{60} value is not calculated from the correlations but instead is pre-calculated and specified? The need for iteration is reduced. In fact, if no pressure correction is applied, the need for iteration could be eliminated entirely.

Equation (F.29) gives the D_T factor in the recursion formula. If the α_{60} value is specified then it does not change with the ρ_{60} values and $\alpha'_{60} = 0$, leading to $D_\alpha = 0$ and $D_T^{(m)} = 0$. This simplifies the recursion formula Equation (F.18) to:

$$\rho_{60}^{(m+1)} = \rho_{60}^{(m)} + \frac{E^{(m)}}{1 + D_P^{(m)}}. \tag{F.31}$$

When a pressure correction is applied iterations will be needed since the $D_P^{(m)}$ term is not necessarily zero. However, if no pressure correction is applied, then the ρ_{60} value could be directly calculated, or, keeping the iteration procedure, only one iteration need be done. When no pressure correction is applied, $C_{PL} = 1$, and $D_P^{(m)} = 0$, leading to:

$$\rho_{60}^{(m+1)} = \rho_{60}^{(m)} + E^{(m)} = \rho_{60}^{(m)} + \frac{\rho}{C_{TL}} - \rho_{60}^{(m)} \quad \Rightarrow \quad \rho_{60}^{(m+1)} = \frac{\rho}{C_{TL}}. \tag{F.32}$$

When α_{60} is specified, C_{TL} is not a function of ρ_{60} and will not change from one iteration to the next. For <u>any</u> ρ_{60} estimate, only one Newton step is necessary to find the correct value of ρ_{60}.

Use of Iteration Equations to Shift 60°F Standard Density

The Newton's Method equations developed here have been used to develop the equation in 11.1.6.1 to shift ρ_{60} to ρ^* for subsequent use in the equations to calculate α_{60} and F_P. This was easy to accomplish since the temperature difference between ρ^* is very small. When done as an iterative procedure, only one iteration is ever needed. Since only a single iteration is needed, the specific starting values can be put into the iteration equations and it can be recast as a single equation to shift the ρ_{60} value to ρ^*.

The shift equation can be most easily developed using the equations based upon the IPTS-68 60°F value being the standard temperature and the ITS-90 60°F value (to be denoted as t_{60}) as the alternate temperature. The initial estimate to the IPTS-68 60°F density, ρ^*, will be the given ITS-90 60°F density, ρ_{60}. Starting with (F.18):

$$\rho^* = \rho_{60} + \frac{\dfrac{\rho_{60}}{C_{TL}^{(0)}} - \rho_{60}}{1 + D_T^{(0)}} = \rho_{60}\left\{1 + \frac{\dfrac{1}{C_{TL}^{(0)}} - 1}{1 + D_T^{(0)}}\right\}. \quad \text{(F.33)}$$

Since the IPTS-68 60°F value is being used as the standard temperature (F.19) becomes:

$$C_{TL}^{(0)} = \exp\left\{-\alpha_{60}^{(0)}\Delta t\left[1 + 0.8\alpha_{60}^{(0)}\Delta t\right]\right\} = \exp\left\{-\alpha_{60}^{(0)}\left(t_{60} - 60\right)\left[1 + 0.8\alpha_{60}^{(0)}\left(t_{60} - 60\right)\right]\right\} \quad \text{(F.34)}$$

where $\alpha_{60}^{(0)}$ is calculated using ρ_{60} in (F.20):

$$\alpha_{60}^{(0)} = \frac{K_0 + K_1\rho_{60} + K_2\rho_{60}^2}{\rho_{60}^2} = \frac{K_0}{\rho_{60}^2} + \frac{K_1}{\rho_{60}} + K_2 \quad \text{(F.35)}$$

$D_T^{(0)}$ is calculated using ρ_{60} in (F.9):

$$D_T^{(0)} = D_\alpha^{(0)}\alpha_{60}^{(0)}\left(T_{60} - 60\right)\left[1 + 1.6\alpha_{60}^{(0)}\left(T_{60} - 60\right)\right] \quad \text{(F.36)}$$

and $D_\alpha^{(0)}$ is calculated using ρ_{60} in (F.30):

$$D_\alpha^{(0)} = \frac{2K_0 + K_1\rho_{60}}{K_0 + K_1\rho_{60} + K_2\rho_{60}^2} \quad \text{(F.37)}$$

The temperature difference $\left(t_{60} - 60\right)$ is based upon the IPTS-68 values for temperature and is used to define the value of δ_{60}; specifically, it is $½\delta_{60}$. Combining this with (F.34), (F.36), and (F.37) changes (F.33) to:

$$\rho^* = \rho_{60}\left\{1 + \frac{\exp\left[0.5\alpha_{60}^{(0)}\delta_{60}\left(1 + 0.4\alpha_{60}^{(0)}\delta_{60}\right)\right] - 1}{1 + 0.5\alpha_{60}^{(0)}\delta_{60}\left(1 + 0.8\alpha_{60}^{(0)}\delta_{60}\right)\left(\dfrac{2K_0 + K_1\rho_{60}}{K_0 + K_1\rho_{60} + K_2\rho_{60}^2}\right)}\right\}. \quad \text{(F.38)}$$

Finally, making the following symbolic substitutions:

$$A \equiv 0.5\alpha_{60}^{(0)}\delta_{60} = \frac{\delta_{60}}{2}\left[\left(\frac{K_0}{\rho_{60}} + K_1\right)\frac{1}{\rho_{60}} + K_2\right] \quad \text{(F.39)}$$

$$B \equiv \frac{2K_0 + K_1\rho_{60}}{K_0 + \left(K_1 + K_2\rho_{60}\right)\rho_{60}} \quad \text{(F.40)}$$

the form for the final shift equation has been developed:

$$\rho^* = \rho_{60}\left\{1 + \frac{\exp\left[A\left(1 + 0.8A\right)\right] - 1}{1 + A\left(1 + 1.6A\right)B}\right\}. \quad \text{(F.41)}$$

8/07

1220 L Street, NW
Washington, DC 20005-4070
USA

202.682.8000

Additional copies are available through IHS

Phone Orders: 1-800-854-7179 (Toll-free in the U.S. and Canada)
303-397-7956 (Local and International)
Fax Orders: 303-397-2740
Online Orders: global.ihs.com

Information about API Publications, Programs and Services
is available on the web at **www.api.org**

Product No. H11013