Manual of Petroleum Measurement Standards Chapter 11—Physical Properties Data

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

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

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Chapter 11 — Physical Properties Data

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

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

11.1.0 Implementation Guidelines

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

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

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

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

11.1.1 Introduction & History

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

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

11.1.1.1 Early Temperature and Pressure Correction Tables

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

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

11.1.1.2 1952 Temperature Correction Tables

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

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

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.

Summary of Changes in Addendum 1:

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

Summary of Changes in Addendum 2:

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

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

11.1.1.6 Customary Temperature & Pressure Correction Tables

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

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

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

11.1.2 Purpose

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

11.1.2.1 Significance

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

11.1.2.2 Scope

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

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

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