

Volume Correction Factor Calculation Development in American Petroleum Institute

Presented at 2012 API Asia Conference and Expo

March 6-8, 2012

Ken Mei
Chevron Energy Technology Company
Richmond, CA USA

OUTLINE

- **Introduction**
- **1952 Tables – History and Basis**
- **1980 Petroleum Measurement Table – What and Why**
- **“New” 2004 API /ASTM/EI Volume Correction Factor (VCF) Standard – What Is New?**
- **Other New Standards – NGL, LPG, Ethanol VCF, and others**
- **Summary**

INTRODUCTION

Crude oil and petroleum products are typically sold based on fluid properties at Reference (“base”) conditions of temperature and pressure.

- US Customary Units: 60 °F and 0 PSIG (1 ATM)
- SI Units: 15 °C and 101.325 kPa (0 PSIG)
- Other Metric Units: 20 °C and 0 PSIG

However, usually the temperature and pressure at which these fluid properties are measured are not at these Reference Conditions.

INTRODUCTION

- **Volume correction factor involves two steps:**
 - Converting observed density to standard (reference) density, and
 - Converting observed volume to standard volume.

- **The VCF must be developed to allow the conversion.**

1952 TABLE – HISTORY AND BASIS

- The work may be traced back to almost a century ago when the scientists and engineers began looking into the thermal expansion coefficient of crude oil and products.
- The work involved density testing of various, commercially available oil samples and developing detailed calculations to correct for temperature and pressure of the fluid being measured.

1952 TABLE – HISTORY AND BASIS

■ 1916

- The US National Bureau of Standards published a Technologic Paper 77-1916 “Density and Thermal Expansion of American Petroleum Oils”. Data from the testing by Bearce and Peffer were used. Based on this study, two tables were published:
 - ▶ Circular 57-1916 “United States Standard Tables for Petroleum Oils (which uses Baume unit) and
 - ▶ Circular 154-1924 “Petroleum Oil Tables” (which uses API gravity unit).*

* Circular 154 was approved by the American Petroleum Institute (API) and the US Bureau of Mines as well as the National Bureau of Standards.

1952 TABLE – HISTORY AND BASIS

■ 1917 to 1935

NBS published two reports:

- NBS RP244-1930 - Thermal Expansion of Petroleum Oils in the range 0 degrees Centigrade to 300 degrees Centigrade, and
- NBS RP393-1931 - Thermal Expansion of Gasolines from 0 degrees Centigrade to 30 degrees Centigrade.

■ 1936

- US NBS published Circular 410, entitled “National Standard Petroleum Oil Tables”.
- The tables were approved by the API, US Bureau of Mines and the American Society for Testing and Materials (ASTM) as well as NBS.

1952 TABLE – HISTORY AND BASIS

■ 1937 to 1945

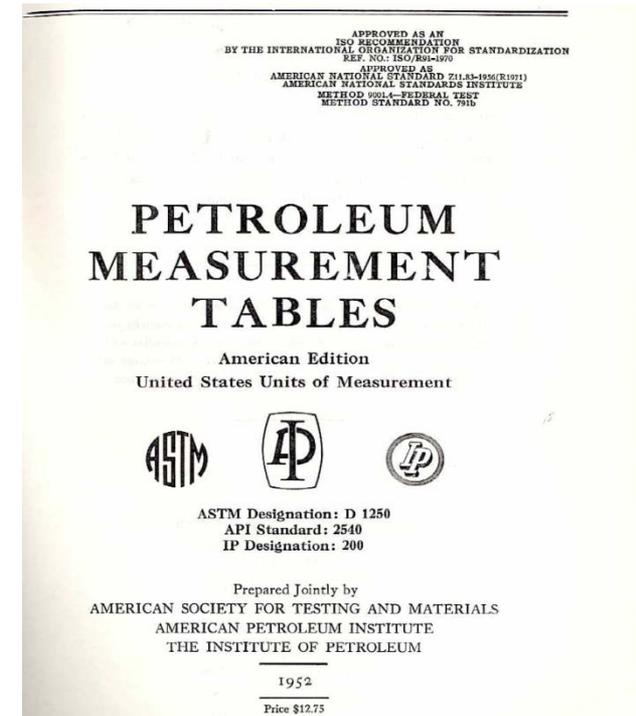
- In 1941, the Institute of Petroleum (IP) published a report entitled “Expansion of Crude Petroleum, Petroleum Products and Allied Substances.”
- The report compared a common factor calculated for approximately 200 oil samples in addition to those considered in NBS Technologic Paper 77 (1916).
- It was not a laboratory work, but was an important contribution in affirming the data base of Circular 410.
- Following this report, Tables for Measurement of Oil was published by the IP in 1945.

1952 TABLE – HISTORY AND BASIS

■ 1946 to 1956

ASTM and IP joined to develop a set of tables generally applicable to all major petroleum liquids.

- These are the *1952 Petroleum Measurement Tables*. The printed tables are published jointly by the ASTM and the IP, and are commonly referred to as the *1952 Tables*, or "*Blue Book Tables*."
- Tables are based primarily on the volumetric data for crudes and fractions developed and published in 1916.
- Most of the samples used are primarily from US domestic production in the 1916 data.
- In 1965, API adopted these *1952 Tables*.



1980 PETROLEUM MEASUREMENT TABLE – WHAT AND WHY

■ 1972

- An experimental program was carried out to measure the thermal expansion coefficient of crude oils and finished products having a wide range of densities.
- Key findings:
 - ▶ The 1952 Petroleum Measurement Tables were satisfactory for finished products
 - ▶ New tables were needed specifically for crude oils.
 - ▶ Data originally supplied by NBS has not been reviewed for 55 years and that during that time there have been **new and different crudes and products and improved techniques for testing them.**

1980 PETROLEUM MEASUREMENT TABLE – WHAT AND WHY

■ 1974 - 1980

- A major data collection and analysis effort by subject matter experts from many companies in API to provide the NBS 463 samples: 211 of crude oil, the remainder of refined products (252).
- The criteria for the selection of crude sample sources were:
 - (1) production for 1974,
 - (2) estimated reserves, and
 - (3) countries wishing to contribute samples of national origin which did not fit the first two categories.
- The list represents 66.8% of the worldwide production and 68.1% of the estimated reserved in 1974.

1980 PETROLEUM MEASUREMENT TABLE – WHAT AND WHY

1980 Tables was published with better data base and data handling than 1952 Tables.

- Better Data Base - The new data base is considered several orders of magnitude more representative of modern crudes, and more crude and product types - when compared to the limited amount of data on primarily US domestic crude and products collected in 1915 and the late 1920's, which formed the basis of the 1952 Tables.
- Better Data Handling - In addition, the equations representing the 1980 Tables correlate the NBS data to within the limits of experimental scatter. Therefore, confidence in both the data and the model is justified. Methodology and quality of data handling reduce the uncertainty from the 1952 Tables.

1980 PETROLEUM MEASUREMENT TABLE – WHAT AND WHY

■ ~1980

- 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.
- Statistical studies were also carried out to check the data.
- After the publication of the Tables, API Committee on Petroleum Measurement (COPM) transitioned out of the supporting the 1952 historical tables. These tables have been archived.
- Measurement equipment and system vendors often do not include the 1952 Tables in the standard calculation software.

■ 1992

- ISO adopted the standard in ISO-91, which points to the 1980 API Tables.

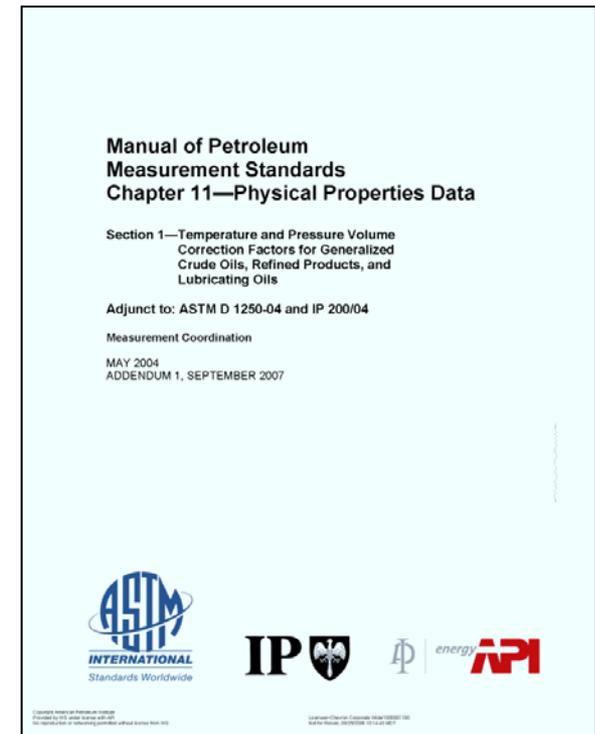
“NEW” 2004 VOLUME CORRECTION FACTOR STANDARD – WHAT IS NEW

■ 2004

- API published the volume correction factor calculation in the Manual of Petroleum Measurement Standards (MPMS), designated as Chapter 11.1 “Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils” after 4+ years of work.
- The standard is a joint publication with ASTM (D1250 Adjunct-04) and EI (IP 200 Adjunct -04).
- After the publication, API Committee on Petroleum Measurement transitioned out of the 1980 tables.

■ 2007

- Addendum published to harmonize rounding in the meter and tank calculations as specified in API MPMS Chapter 12.



“NEW” 2004 VOLUME CORRECTION FACTOR STANDARD – WHAT IS NEW

■ What is New in the Standard?

- There is no printed table for the correction factor in the 2004 version. The standard is published as :
 - ▶ a CD-ROM, and
 - ▶ a fully functional computer program that will do the calculation, with a text description included as an Adobe PDF document.
- The 2004 standard changed implementation procedures to reflect modern computer technology. It changed the convergence method with complex technique but still allows flow computers to perform online calculations.

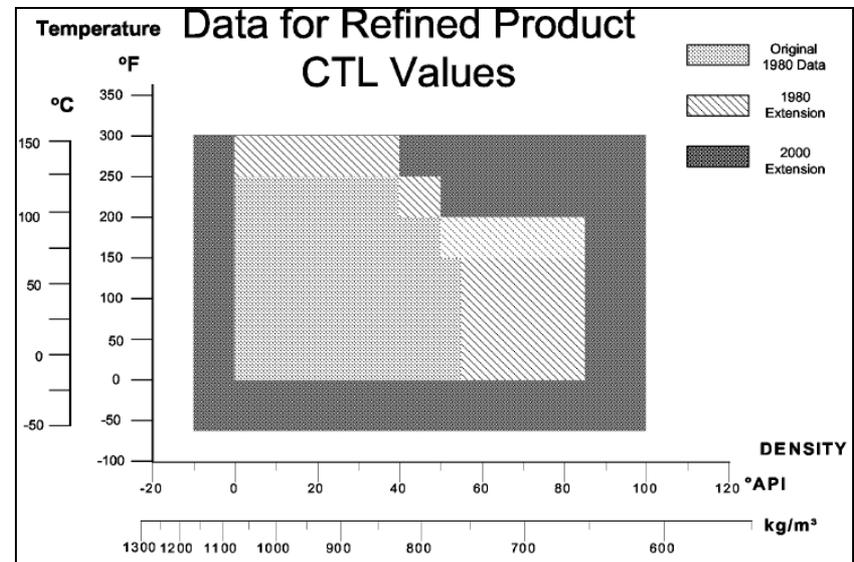
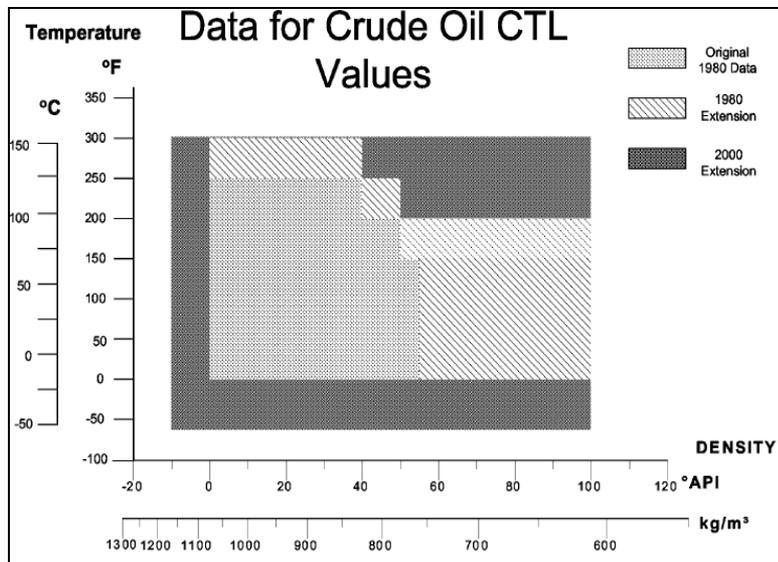
“NEW” 2004 VOLUME CORRECTION FACTOR STANDARD – WHAT IS NEW

■ What is New in the Standard?

- Eliminated the archaic rounding and truncation of intermediate calculated values. When using U.S. Customary Units, the density (in API Gravity) and the temperature (in Fahrenheit) are based on 0.1 degree.
- Incorporated the 1988 IP Tables (59ABD, 60 ABD), which are technically equivalent to ISO 91-2 using 20 °C as the reference temperature.
- Incorporated the IP documentation of the lubricants tables (D Tables) missing from the 1980 Standard.
- Un-rounded Ctl and Cpl. The final value of the correction of temperature and pressure on liquid (Ctpl) follows requirements in API standards for dynamic and static calculations (Ch. 12), otherwise rounded to five (5) significant figures (X.XXXXX).

■ **What is New in the Standard?**

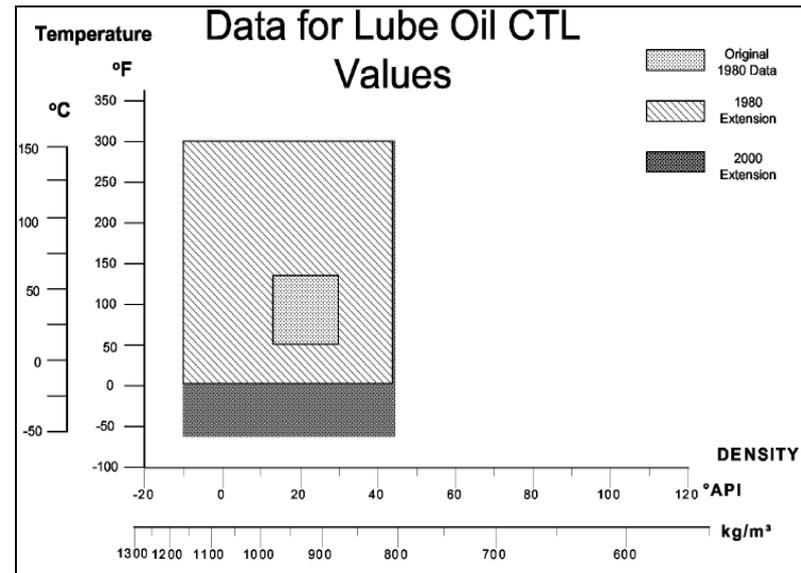
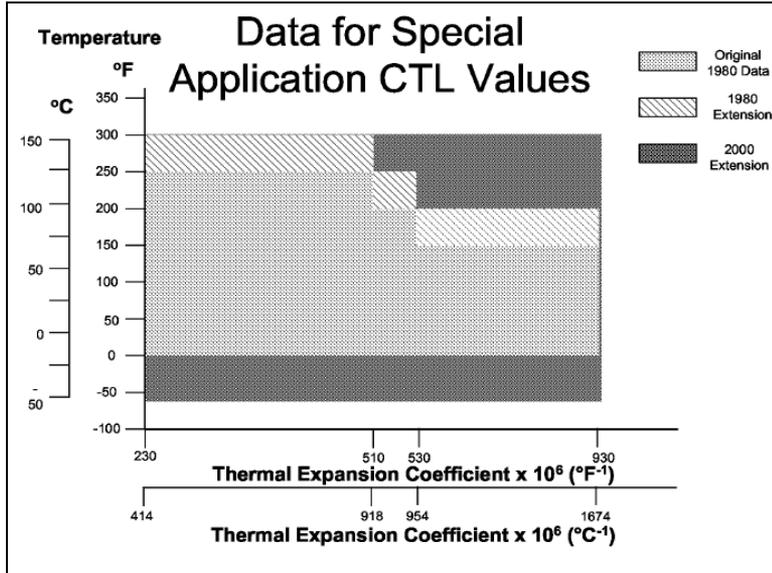
2004 API standard **expands the temperature range** to $-58\text{ }^{\circ}\text{F}$ to $302\text{ }^{\circ}\text{F}$ ($-50\text{ }^{\circ}\text{C}$ to $150\text{ }^{\circ}\text{C}$) for all Tables (A, B, C, D), and expands the density range to $-10\text{ }^{\circ}\text{API}$ to $100\text{ }^{\circ}\text{API}$ for ABC tables, for example:



Content contains Copyright material courtesy of API

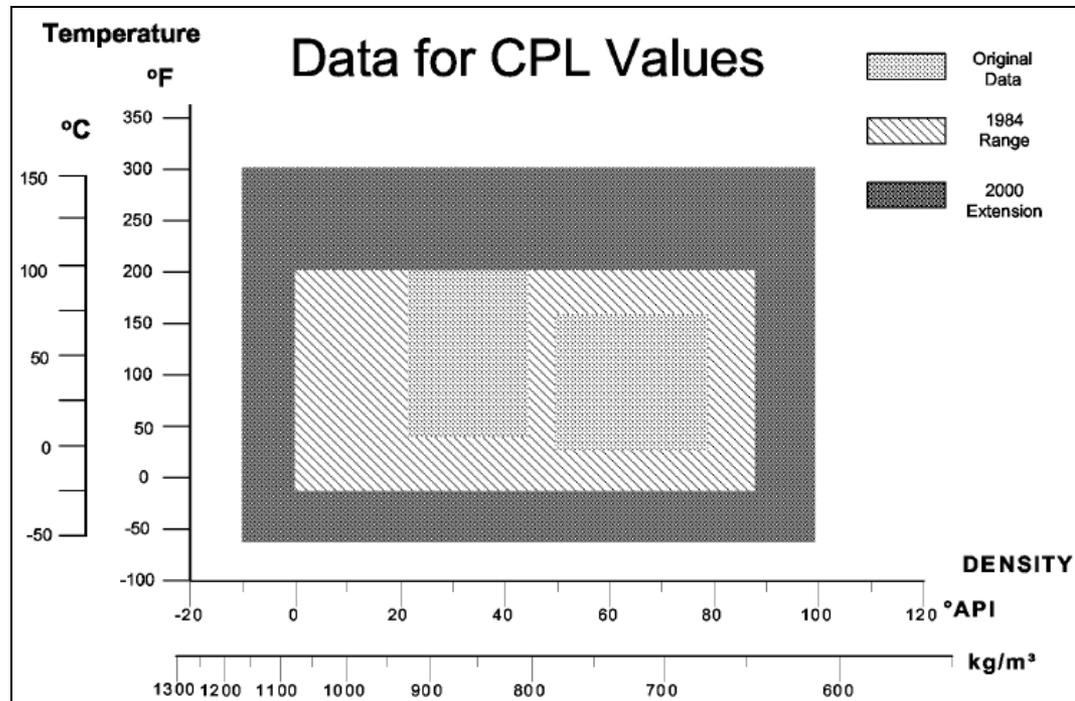
■ What is New in the Standard?

... Expands the temperature range to $-58\text{ }^{\circ}\text{F}$ to $302\text{ }^{\circ}\text{F}$ ($-50\text{ }^{\circ}\text{C}$ to $150\text{ }^{\circ}\text{C}$) for all Tables. Density range of D tables remains $-10\text{ }^{\circ}\text{API}$ to $45\text{ }^{\circ}\text{API}$.



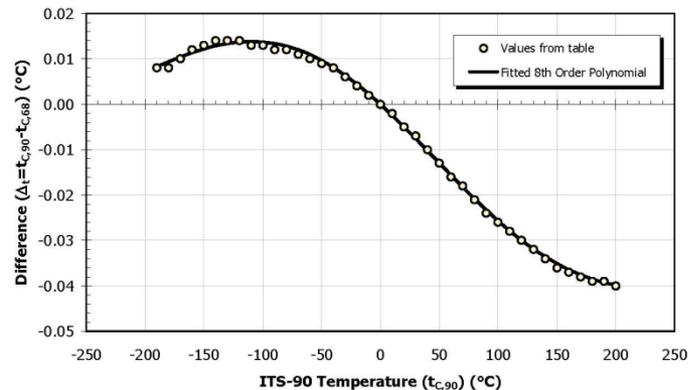
■ **What is New in the Standard?**

The limit of Correction for the effect of Pressure on Liquid (CPL) calculation in 2004 API VCF standard is 0 – 1 500 psig **over the extended temperature limits.**



What is New in the Standard?

- Converted the input ITS-90 temperature to equivalent IPTS-68 in the calculations. 60 °F in ITS-90 is an equivalent 60.00687490 °F in IPTS-68. Change of temperature scale gives differences at high temperature of no more than ± 0.00003 .



Content contains copyrighted material courtesy of API

- The value of water density at 60°F used in the 1980 Tables was 999.012 kg/m³ based on earlier laboratory work and applying IPTS-68. The water density value in 2004 standard is 999.016 kg/m³ at 60°F, based on new laboratory work and using ITS-90 has been adopted for use in any conversion between density and relative density or API gravity.

“NEW” 2004 VOLUME CORRECTION FACTOR STANDARD – WHAT IS NEW

■ What is New in the Standard?

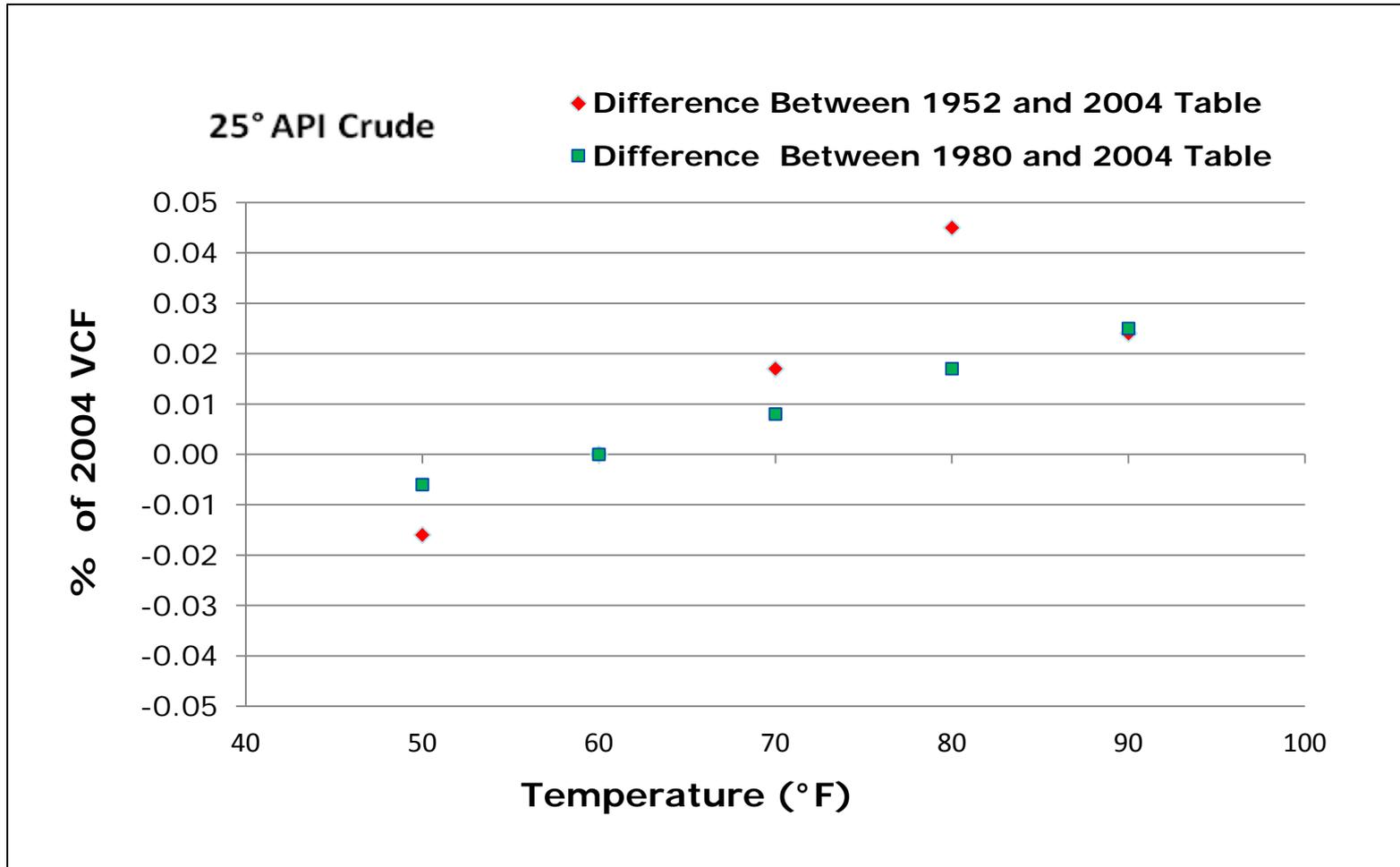
- Extended API MPMS Chapter 11.2.1 temperature and density ranges to match the new VCF tables.
 - ▶ Note: API MPMS Chapter 11.2.1 has been withdrawn, because API MPMS Chapter 11.1 (2004) covers the calculations.
- Allows the use of other base temperatures other than 60 °F and 20 °C. Such as 25 °C in some countries.
- Allows combined pressure correction (previously API MPMS Ch 11.2.1) and temperature correction into one procedure (to prepare for a need to use real-time density measurement made under pressure for VCF calculation). The combined pressure and temperature implementation procedure is now included in API MPMS Chapter 11.1 (2004), not a printed table.

“NEW” 2004 VOLUME CORRECTION FACTOR STANDARD – WHAT IS NEW

■ What is New in the Standard?

- Eliminated the hydrometer glass thermal expansion correction. The correction is handled outside the calculation. Density meter, if used, does not require this correction.
- Extensive comparisons have been made of the volume correction factors by several oil companies (including Chevron), indicated that when operating well within the boundaries of the 1980 version, most of the final values calculated by the two versions were the same, or nearly the same.
- The differences were on the order of 0.0001 and are due to errors of the original 1980 version when rounded to 4 decimal places.

Comparison of 2004 Table and 1952, 1980 Table – for 24 API crude oil



“NEW” 2004 VOLUME CORRECTION FACTOR STANDARD – WHAT IS NEW

■ Recommended Timeline in API Ch 11.1 (2004) for Implementation

- To avoid disruption in the industry, API "recommended that the standards be utilized on all new applications no later than two years after the publication date." Due to delay of release of the software, API re-set the implementation date to January 1, 2007.
- Grandfather clause "If an existing application complies with the Previous Standard(s) then it shall be considered in compliance with this Revised Standard." Application is defined as the "point where the calculation is applied."
- This Grandfather clause is expected to be removed in the upcoming revision by API COPM.

“NEW” 2004 VOLUME CORRECTION FACTOR STANDARD – WHAT IS NEW

■ Third-party Inspection Companies

- International Federation of Inspection Agencies (IFIA) Americas Committee (AC)
 - ▶ Asked that the 2004 API Chapter 11.1 be implemented after December 31, 2006 and applied “to all vessel and barge shipments, including imports and exports involving discharges into and loadings from storage tank facilities, refineries ...and transfers..” regulated by US Customs.
 - ▶ In 12/2006, the US Customs wrote to IFIA AC “...It is our opinion that the petroleum industry and those who measure and test petroleum had sufficient time to become acquainted and familiar with the new Chapter 11.1 of the MPMS. gaugers and accredited laboratories must begin using the new MPMS Chapter 11.1 on January 1, 2007...” for these transactions.
- Other countries – follow 2004 API standards as per contract

Ethanol and Gasoline/Ethanol Blend VCF Calculations

■ Denatured Fuel Ethanol (API MPMS, Ch 11.3.3)

- Previous methods include: using B table with an API gravity of 51.5, or $VCF = 1.0378 - 0.0006301 \times t$ where t =temperature in °F.
- API Ch 11.3.3 (2011) recommends:

For volume or density correction from observed temperature to 60°F, API MPMS Chapter 11.1 shall be used for ethanol denatured with 2% to 5% by volume of either natural gasoline or gasoline.

Such denatured ethanol is considered to be a “special application,” formerly known as Table 54C (or Table 6C) with an alpha coefficient of 0.001085/°C (or 0.000603/°F).

■ Gasoline/Ethanol Blend (API MPMS, Ch 11.3.4)

Laboratory test completed. API Ch 11.3.4 work to complete, and publication of the standard in 2012.

Other Recently Published API Physical Properties Data Tables

API MPMS, Chapter 11— Physical Properties Data

(1) **Section 2**, Part 4—Temperature Correction for the Volume of NGL and LPG* - Tables 23E, 24E, 53E, 54E, 59E, and 60E)

Replaces the 1953 historical tables and other tables

(2) **Section 5**—Density/Weight/Volume Intra-conversion**

Part 1—Conversions of API Gravity at 60 °F

Part 2—Conversions for Relative Density (60/60 °F)

Part 3—Conversions for Absolute Density at 15 °C

They replace previous API/ASTM/IP conversion tables

* ASTM Technical Publication [Stock No. PETROLTBL-TP27], GPA Technical Publication TP-27

** API standard is Adjunct to ASTM D1250-08 and IP 200/08

SUMMARY

- Our industry devoted a very large amount of resources to jointly develop and improve the volume correction factor calculation in the 1970s, and then in 2000s.
- With globalization of oil industry, and harmonization of the petroleum measurement standards by the major standard development organizations, the 2004 API/ASTM VCF Standard is being implemented in more and more companies.
- The 1952 Table and the 1980 Standard have become “historical” and they are not supported by API
- Use of 2009 NGL/LPG VCF standards and 2011 Ethanol VCF standard are recommended, as they supersede previous standards.

Q&A