Manual of Petroleum Measurement Standards Chapter 11.3.3

Miscellaneous Hydrocarbon Product Properties—Denatured Ethanol Density and Volume Correction Factors

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Contents

Introduction

Volume Correction Factors (VCFs) are used to correct observed liquid volumes at specific operating conditions to equivalent volumes at a standard temperature condition. The American Petroleum Institute provides procedures for calculating VCFs for Generalized Crude oils, Refined Products, Lubricating Oils, and Special Applications. These procedures are presented in API *MPMS* Ch. 11.1–2004/Adjunct to ASTM D1250-08/IP 200/08. The API has not previously addressed ethanol, considered a Special Application, in *MPMS* Ch. 11.1, so industry has used a variety of privately developed tables for both denatured 99+ % and denatured 95 % to 99 % fuel ethanol VCFs. (Denaturant requirements vary by country and if this standard is being used outside the United States, refer to the local jurisdiction for denaturant requirements.) The most commonly used table has been that of a large ethanol supplier, and it appears that U.S. Customs and Border Protection (CBP) and the Environmental Protection Agency (EPA) have adopted a variant of this table. The API, through a consortium of its member companies and in cooperation with the Renewable Fuels Association (RFA), commissioned an independent laboratory to take density measurements at various temperatures of pure (99.038 % by volume) ethanol and representative denatured fuel ethanols. The density data were obtained utilizing the best available commercial instrumentation and was then used to develop the VCFs provided in this standard.

Miscellaneous Hydrocarbon Product Properties—Denatured Ethanol Density and Volume Correction Factors

1 Scope

1.1 General

This standard covers density and volume correction factors for denatured fuel ethanol. The actual standard consists of the explicit implementation procedures set forth in this document. Sample tables and other examples created from a computerized version of this implementation procedure are presented as examples only and do not represent the standard.

1.2 Limits of Application

This standard is applicable at any operating temperature to bulk (e.g. tank trucks, tank cargos, barges) denatured 95 % to 99 % fuel ethanol containing D4806 allowed denaturants (natural gasoline, gasoline blend stocks, and unleaded gasoline) and denatured, 99+ % fuel ethanol containing less than 1 % denaturant. This standard does not apply to undenatured ethanol of any purity.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *MPMS* Ch. 11.1–2004, *Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils* (includes Addendum dated September 2007).

API *MPMS* Ch. 12.1.1–2012, *Calculation of Static Petroleum Quantities—Upright Cylindrical Tanks and Marine Vessels*.

3 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1
absolute density
RHO
The mass of a substance per unit of volume at a specified temperature and pressure.

3.2
alpha α
A product-specific thermal coefficient of expansion used in the API *MPMS* Ch. 11.1 equations for VCFs (Annex A).

3.3
denaturants
Materials added to ethanol under a formula approved by a regulatory agency to make it unsuitable for beverage use.

3.4
denatured 95 % to 99 % fuel ethanol
Fuel ethanol denatured with natural gasoline, gasoline blendstocks, or regular gasoline in accordance with US federal regulations.

3.5
denatured 99+ % fuel ethanol
Fuel ethanol denatured with less than 1 % federally approved denaturants in accordance with US federal regulations.

3.6
denatured fuel ethanol
Fuel ethanol made unfit for beverage use by the addition of denaturants allowed by D4806 for automotive spark-ignition engine fuel under formula(s) approved by the applicable regulatory agency to prevent the imposition of beverage alcohol tax.

3.7
ethanol
Ethyl alcohol, the chemical C_2H_5OH.

3.8
fuel ethanol
A grade of undenatured ethanol with other components common to its production (including small amounts of water) that do not affect the use of the product as a component for automotive spark ignition engine fuels.

3.9
gasoline
A volatile mixture of liquid hydrocarbons, generally containing small amounts of additives, suitable for use as a fuel in spark-ignition internal combustion engines.

3.10
gross observed volume
GOV
The total volume of all petroleum or chemical liquids and sediment and water, excluding free water, at observed temperature and pressure.

3.11
gross standard volume
GSV
The GOV gross observed volume corrected by the appropriate factors from the observed temperature and pressure to the specified reference conditions.

3.12
gross volume
GV
The actual volume at flowing temperature and pressure.

3.13
natural gasoline
A natural gas liquid with a vapor pressure intermediate between condensate and liquefied petroleum gas. This liquid hydrocarbon mixture is recovered at normal pressure and temperature and is much more volatile and unstable than commercial gasoline.

3.14
net standard volume
NSV
The gross standard volume (GSV) corrected to exclude non-merchantable components such as sediment and water (S&W).

3.15
volume correction factor
VCF
The ratio of the density of a liquid at a given temperature and pressure to its density at a reference temperature and pressure.

4 Implementation Procedures

4.1 Denatured 99+ % Fuel Ethanol

For volume or density correction from observed temperature to 60 °F, the implementation procedure given in API *MPMS* Ch. 11.1-2004 shall be used for denatured 99 % fuel ethanol. Denatured 99+ % fuel ethanol is considered to be a "special application" (formerly known as Table 6C or Table 54C) with an alpha coefficient of 0.000599 °F or 0.001078 °C (Annex A).

EXAMPLE

A container is determined to have a GOV of 10,000 gallons of denatured 99+ % fuel ethanol at an observed temperature of 85 °F. What is the volume at 60 °F?

API *MPMS* Ch. 11.1-2004, Section 11.1.6.1, returns a VCF of 0.98496 for inputs of 85 °F and an alpha of 0.000599 °F. From API *MPMS* Ch. 12.1.1:

$$\begin{aligned} \mathrm{GSV} &= \mathrm{GOV} \times \mathrm{VCF} \\ &= 10{,}000 \text{ gal} \times 0.98496 = 9850 \text{ gal} \end{aligned}$$

EXAMPLE

A container is determined to have a GOV of 10,000 liters of denatured 99+ % fuel ethanol at an observed temperature of 30 °C. What is the volume at 15 °C?

API *MPMS* Ch. 11.1-2004, Section 11.1.7.1, returns a VCF of 0.98377 for inputs of 30 °C and an alpha of 0.001078 °C. From API *MPMS* Ch. 12.1.1:

$$\begin{aligned} \mathrm{GSV} &= \mathrm{GOV} \times \mathrm{VCF} \\ &= 10{,}000 \text{ liters} \times 0.98377 = 9838 \text{ liters} \end{aligned}$$

EXAMPLE

The density of denatured 99+ % fuel ethanol is determined to be 6.6322 lb/gal at 60 °F. What is the density at 85 °F?

When a product changes temperature, its weight remains unchanged while its volume either expands or contracts. API *MPMS* Ch. 11.1-2004, Section 11.1.6.1, returns a VCF of 0.98496 for inputs of 85 °F and an alpha of 0.000599 °F. From the definition of VCF:

$$RHO^{85} = RHO^{60} \times \mathrm{VCF} = 6.6322 \text{ lb/gal} \times 0.98496 = 6.5325 \text{ lb/gal}$$

EXAMPLE

The density of denatured 99+ % fuel ethanol is determined to be 793.51 kg/m^3 at 15 °C. What is the density at 30 °C?

When a product changes temperature, its weight remains unchanged while its volume either expands or contracts. API *MPMS* Ch. 11.1-2004, Section 11.1.7.1, returns a VCF of 0.98377 for inputs of 30 °C and an alpha of 0.001078 °C. From the definition of VCF:

$$RHO^{30} = RHO^{15} \times \text{VCF} = 793.51\ \text{kg/m}^3 \times 0.98377 = 780.63\ \text{kg/m}^3$$

EXAMPLE

The density of denatured 99+ % fuel ethanol is determined to be 6.5325 lb/gal at 85 °F. What is the density at 60 °F?

When a product changes temperature, its weight remains unchanged while its volume either expands or contracts. API *MPMS* Ch. 11.1-2004, Section 11.1.6.1, returns a VCF of 0.98496 for inputs of 85 °F and an alpha of 0.000599 °F. From the definition of VCF:

$$RHO^{60} = RHO^{85} / \text{VCF} = 6.5325\ \text{lb/gal} / 0.98496 = 6.6322\ \text{lb/gal}$$

EXAMPLE

The density of denatured 99+ % fuel ethanol is determined to be 780.63 kg/m^3 at 30 °C. What is the density at 15 °C?

When a product changes temperature, its weight remains unchanged while its volume either expands or contracts. API *MPMS* Ch. 11.1-2004, Section 11.1.7.1, returns a VCF of 0.98377 for inputs of 30 °C and an alpha of 0.001078 °C. From the definition of VCF:

$$RHO^{15} = RHO^{30} / \text{VCF} = 780.63\ \text{kg/m}^3 / 0.98377 = 793.51\ \text{kg/m}^3$$

4.2 Denatured 95 % to 99 % Fuel Ethanol

For volume or density correction from observed temperature to 60 °F, the implementation procedure given in API *MPMS* Ch. 11.1-2004 shall be used for ethanol denatured with 1 % to 5 % by volume of either natural gasoline or gasoline (Annex B). Such denatured ethanol is considered to be a “special application” (formerly known as Table 6C or Table 54C) with an alpha coefficient of 0.000603 °F or 0.001085 °C (Annex C). For more information on denaturant choice, see Annex B. For more information on the applicability of these alpha coefficients to other denaturants, see Annex C and Annex D.

EXAMPLE

A container is determined to have a GOV of 10,000 gallons of denatured 95 % to 99 % fuel ethanol at an observed temperature of 85 °F. What is the volume at 60 °F?

API *MPMS* Ch. 11.1-2004, Section 11.1.6.1, returns a VCF of 0.98485 for inputs of 85 °F and an alpha of 0.000603 °F.

$$\begin{aligned} \text{GSV} &= \text{GOV} \times \text{VCF} \\ &= 10{,}000\ \text{gal} \times 0.98485 = 9849\ \text{gal} \end{aligned}$$

EXAMPLE

A container is determined to have a GOV of 10,000 liters of denatured 95 % to 99 % fuel ethanol at an observed temperature of 30 °C. What is the volume at 15 °C?

API *MPMS* Ch. 11.1-2004, Section 11.1.7.1, returns a VCF of 0.98366 for inputs of 30 °C and an alpha of 0.001085 °C.

$$\begin{aligned} GSV &= GOV \times VCF \\ &= 10{,}000 \text{ liters} \times 0.98366 = 9837 \text{ liters} \end{aligned}$$

EXAMPLE

The density of denatured 95 % to 99 % fuel ethanol is determined to be 6.6183 lb/gal at 60 °F. What is the density at 85 °F?

When a product changes temperature, its weight remains unchanged while its volume either expands or contracts. API *MPMS* Ch. 11.1-2004, Section 11.1.6.1, returns a VCF of 0.98485 for inputs of 85 °F and an alpha of 0.000603 °F. From the definition of VCF:

$$RHO^{85F} = RHO^{60F} \times \text{VCF} = 6.6183 \text{ lb/gal} \times 0.98485 = 6.5180 \text{ lb/gal}$$

EXAMPLE

The density of denatured 95 % to 99 % fuel ethanol is determined to be 793.05 kg/m^3 at 15 °C. What is the density at 30 °C?

When a product changes temperature, its weight remains unchanged while its volume either expands or contracts. API *MPMS* Ch. 11.1-2004, Section 11.1.7.1, returns a VCF of 0.98366 for inputs of 30 °C and an alpha of 0.001085 °C. From the definition of VCF:

$$RHO^{30C} = RHO^{15C} \times \text{VCF} = 793.05 \text{ kg/m}^3 \times 0.98366 = 780.09 \text{ kg/m}^3$$

EXAMPLE

The density of denatured 95 % to 99 % fuel ethanol is determined to be 6.5180 lb/gal at 85 °F. What is the density at 60 °F?

When a product changes temperature, its weight remains unchanged while its volume either expands or contracts. API *MPMS* Ch. 11.1-2004, Section 11.1.6.1, returns a VCF of 0.98485 for inputs of 85 °F and an alpha of 0.000603 °F. From the definition of VCF:

$$RHO^{60F} = RHO^{85F} / \text{VCF} = 6.5180 \text{ lb/gal} / 0.98485 = 6.6183 \text{ lb/gal}$$

EXAMPLE

The density of denatured 95 % to 99 % fuel ethanol is determined to be 780.09 kg/m^3 at 30 °C. What is the density at 15 °C?

When a product changes temperature, its weight remains unchanged while its volume either expands or contracts. API *MPMS* Ch. 11.1-2004, Section 11.1.7.1, returns a VCF of 0.98366 for inputs of 30 °C and an alpha of 0.001085 °C. From the definition of VCF:

$$RHO^{15C} = RHO^{30C} / \text{VCF} = 780.09 \text{ kg/m}^3 / 0.98366 = 793.005 \text{kg/m}^3$$

5 Rounding

5.1 Data Level

API *MPMS* Ch. 12 governs all rounding. As API *MPMS* Ch. 12.1.1-2012 states, rounding is influenced by the source of the data. For example, if a container's capacity tables are in whole gallons then all subsequent gallon values should be recorded accordingly. In those cases where there are no other limiting factors (i.e. specific direction by API *MPMS* Ch. 12 for ethanols), the operator should be guided by Table 1, which is intended for application to bulk liquid quantities. Other considerations may apply for smaller quantities; e.g. while Table 1 recommends the calculated weight of a bulk cargo (say a barge of asphalt) be rounded to whole pounds or kilograms, a user may wish to calculate the weight of a barrel of product to two or three decimal places. The significant digits in Table 1 provide consistency within this standard and may differ slightly from API *MPMS* Ch. 12.1.1-2012 Table 1.

5.2 Rounding of Numbers

Chain calculations should be performed without rounding or truncation. When a calculation result is to be rounded to a specific number of decimals, it shall always be rounded off in one step to the number of figures to be recorded and not rounded in two or more successive steps. When the figure to the right of the last place to be retained is less than five, the figure in the last place retained should be unchanged. When figure to the right of the last place to be retained is five to nine, the figure in the last place should be increased by one. This procedure is also described in ASTM E29.

Table 1—Significant Digits for Bulk Quantities[a]

Units	No. of Decimals
Liters	**x,xxx,xxx**.0
Gallons	**x,xxx,xxx**.0
Barrels	**xxx,xxx**.xx
Cubic meter	**xxx,xxx**.xxx
Pounds	**xxx**.0
Kilograms	**xxx**.0
Short tons	**xxx,xxx**.xxxx
Long tons	**xxx,xxx**.xxxx
Metric tons	**xxx,xxx**.xxxx
API Gravity @ 60 °F	**xxx**.xx
Density g/cm^3	**x**.xxxxx
Density lbs/gal	**x**.xxxxx
Density kg/m^3	**xxxx**.xx
Relative density	**x**.xxxxx
Temperature °F	**xxx**.x
Temperature °C	**xxx**.x5
VCF	**x**.xxxxx

[a] Densities and relative density are presented with 6 significant figures to reflect values obtainable with modern high precision instrumentation.

Annex A
(informative)

Ethanol VCF Table Historical Information

A.1 Overview

Section A.2 is background information and illustrates some historic approaches for determining VCF for fuel ethanol. These approaches are presented for the users information only. Section A.3 discusses the approach presented in this standard, based on recent laboratory testing and API *MPMS* Chapter 11.1. In addition, there is some discussion on comparing alpha values for the past methods against the methods presented in this standard.

A.2 Historical Ethanol VCFs

In 2007, U.S. Customs and Border Protection provided the industry with a directive specifying the VCF table to be used pure (99+ %) ethanol cargos subject to their control (see Figure A.1).

This VCF table is essentially the same as (but not identical to) other private industry tables in common use before the directive. In API standards, the term “alpha” refers to the product specific coefficient of thermal expansion, α, in the formula:

$$\text{VCF} = \frac{V_{60}}{V_t} = e^{-\alpha \Delta t\,[1 + 0.8\,\alpha\,\Delta t]}$$

where

V_{60} is the volume at 60 °F reference temperature;

V_t is the volume at temperature, t °F;

α is the coefficient of expansion in reciprocal °F units;

Δt $= t - 60$ °F.

The EPA provides a table based on the formula for fuel ethanol in 40 *CFR* 80.1126 (http://www.access.gpo.gov/nara/cfr/waisidx_10/40cfr80_10.html):

$$\text{VCF} = 1.0378 - 0.0006301 \times \text{temperature in °F}$$

These tables should not be confused with Gauging Manual Table 7 (27 *CFR* 30.67) used by the Alcohol and Tobacco Tax and Trade Bureau (TTB), which applies to “spirituous liquors” (drinking alcohol). This table (1913) is of limited utility to the petroleum industry as it covers 18 °F to 100 °F in 2 °F increments and provides three decimal VCFs (http://www.ttb.gov/foia/gauging_manual_toc.shtml#27:1.0.1.1.25.5.507.7).

The OIML (International Organization of Legal Metrology) International Alcoholometric Tables (OIML R 22) provide temperature/density data for water/ethanol mixtures, including 100 % ethanol (http://www.oiml.org/publications/).

Prior to publishing this standard, industry practice for cargoes not under CBP control was to use the Refined Product table of API *MPMS* Ch. 11.1 (formerly known as Table 6B) with a fixed reference gravity of 51.5 °API for all ethanols.

U.S. Department of Homeland Security
Washington, DC 20229

U.S. Customs and Border Protection

AUG 14 2007

Mr. Arthur Kay
SGS Control Services, Inc.

Dear Mr. Kay:

We recently received an e-mail from you requesting guidance about the usage of various alcohol correction factor tables for determining the volume of imported alcohol for U.S. Customs and Border Protection (CBP) purposes. Specifically, you asked about the following volume correction tables: Renewable Fuels Association (RFA) volume correction table, IRS Table 7, and Table C." The following is our guidance to you.

Usage of the RFA table is not acceptable for CBP purposes due to the lack of sufficient decimal place accuracy for large volume shipments. For the measurement of the quantity of bulk ethanol of 99.0 percent or greater purity for CBP purposes, the American Petroleum Institute (API) developed ASTM D 1250-04 standard shall be used. Ethanol of this purity is considered to be a "Special Application" within the standard. The ethanol alpha coefficient of 0.00063/degree F shall be used.

For ethanol of other purities a Thermal Expansion Factor alpha (60F) that has been obtained by following the "Special Application" process as described above and the API-MPMS Chapter 11.1.3.8 "Calculating the Thermal Expansion Factor for Special Applications" and Chapter 11.1.5.2 "Method to Calculate Thermal Expansion Factor from Density Measurements" shall be used.

Please contact Mr. Donald Cousins of my staff at (202) 344-1295 if you have questions regarding this matter.

Sincerely,

Donald A. Cousins

for Ira S. Reese
Executive Director
Laboratories and Scientific Services

Figure A.1—U.S. Customs and Border Protection Directive on 99+ % Ethanol VCF

A.3 New VCF Development

An independent laboratory measured the density of ethanol (0.103 % water by weight, 0.062 % by volume) at different temperatures. The data were input into the API *MPMS* Ch. 11.1–2004 applet to calculate Table 6C expansion coefficients (alphas). The data and the applet output are displayed in Figure A.2 (densities in kg/m^3).

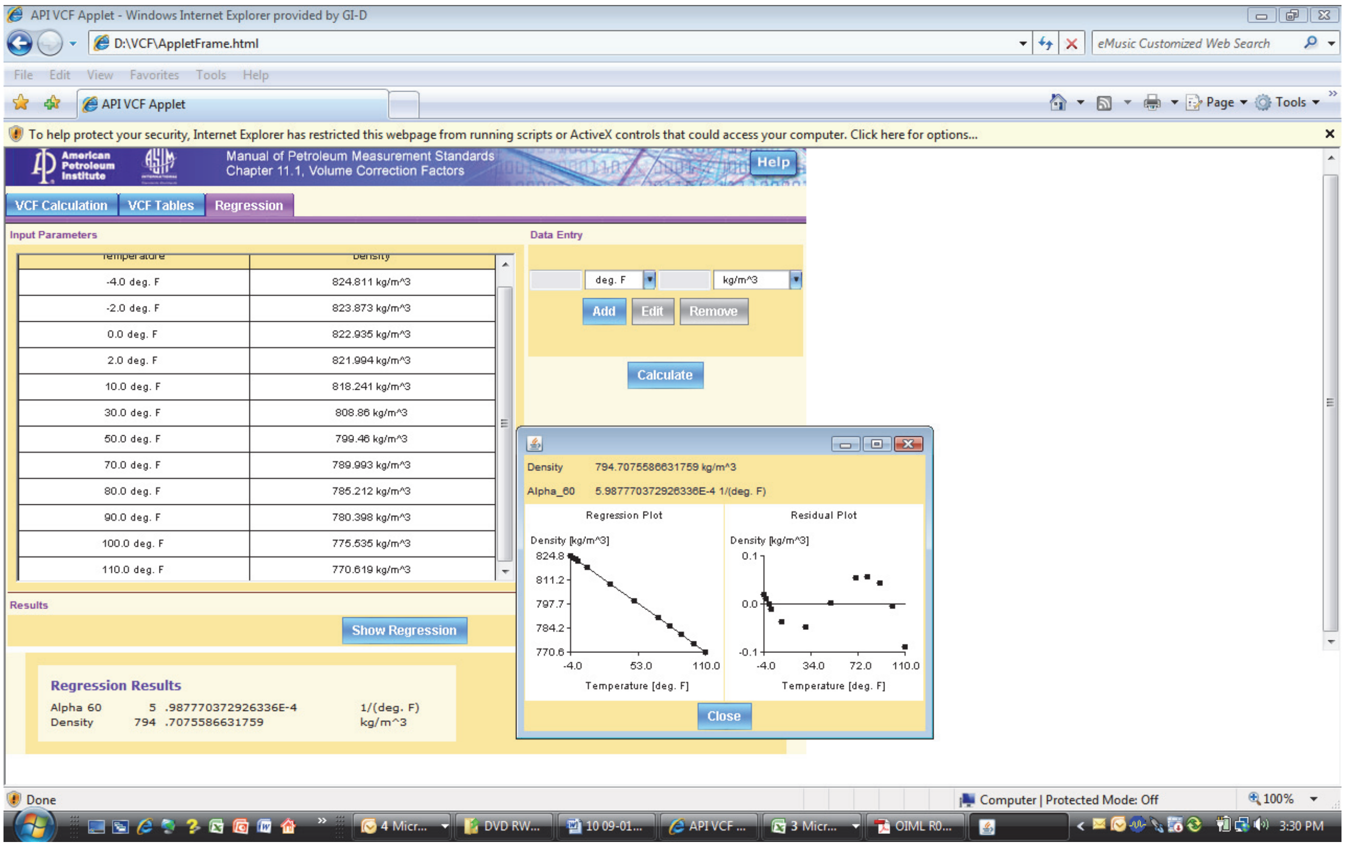

Figure A.2—Data and the Applet Output Results

As a check, the OIML 100 % ethanol densities were also input into the API *MPMS* Ch. 11.1-2004 applet to calculate the Table 6C expansion coefficients (alphas). The alpha obtained, 0.0005989186, agrees with the above independent laboratory results of 0.000598777 when both are rounded to six decimal places. Both sets of data show that an alpha of 0.000599 °F is more representative of 99+ % ethanol than the 0.000630 °F used by CBP at the time of the original publication of this standard (2011).

Table 6B (API *MPMS* Ch. 11.1-2004) with a reference gravity of 50.47 °API most closely matches the above Table 6C for 99+ % ethanol, with a difference of less than ±0.001 % (1 in 100,000 volume units) or less at any given operating temperature.

The same independent laboratory measured the densities of denatured 95 % to 99 % fuel ethanol at different temperatures. This data was also input into the Annex C, API *MPMS* Ch. 11.1–2004 applet to calculate Table 6C expansion coefficients (alphas). The results show that an average alpha of 0.000603 is more representative of fuel ethanol than the EPA equation in 40 *CFR* 80.1126 (see Annex C).

Annex B
(informative)

U.S. Regulation of Alcohol for Fuel Use

The following information is presented for informational purposes. Each user is responsible for ensuring they are in compliance with applicable regulations.

The Alcohol & Tobacco Newsletter (Vol. 1, Issue 11, Dec 2000, (http://www.ttb.gov/public_info/aandtnews.shtml) explains how alcohol for fuel use is regulated.

The *CFR (Code of Federal Regulations)* governing fuel alcohol, at the time of publication of this standard, is 27 *CFR* 19.1005 (http://www.access.gpo.gov/nara/cfr/waisidx_10/27cfr19_10.html).

The *CFR*, at the time of publication of this standard, governing completely denatured alcohol preparation at a distilled spirits plant for fuel use is 27 *CFR* 21, F*ormulas For Denatured Alcohol and Rum* (http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=0975262d55d2a2ea01409cbbd50a37f4&rgn=div5&view=text&node=27:1.0.1.1.17&idno=27). As can be seen, there are several formulations that may be used as an automotive fuel, but only Formula No. 20 is in common use at this time.

The TTB (Alcohol and Tobacco Tax and Trade Bureau) also allows other denaturants for fuel alcohol in addition to those specified in 27 *CFR* 21 and 27 *CFR* 19 (see *Authorized Materials for Rendering Spirits Unfit for Beverage Use*, http://www.ttb.gov/industrial/alcohol_fuel.shtml, Other Alcohol, Alcohol Fuel).

ASTM D4806 has specific limitations on which denaturants can be used for denatured fuel ethanol. Section 5.1 states "The only denaturants allowed for denatured fuel ethanol defined by this specification are natural gasoline, gasoline blendstocks or unleaded gasoline."

Annex C
(Informative)

Denatured Ethanol Density Study

As part of an industry ethanol/gasoline blend density study for an API *MPMS* standard on ethanol/gasoline blend density and volume correction factors (API *MPMS* Ch. 11.3.4-to be published), the following denatured feedstocks were provided by the Renewable Fuels Association:

— FS1: 2 % natural gasoline by volume to 98 % fuel ethanol

— FS2: 5 % natural gasoline by volume to 95 % fuel ethanol

— FS3: 2 % gasoline by volume to 98 % fuel ethanol

— FS4: 5 % gasoline by volume to 95 % fuel ethanol

Only gasoline and natural gasoline denaturants were evaluated for this standard. The densities and special application (formerly Table 6C) alphas of these preparations were very similar, suggesting that denaturants of similar composition should have similar properties. For example, the alphas of this standard will apply to denatured fuel ethanol containing ASTM D4806-09 allowed denaturants (natural gasoline, gasoline blendstocks, and unleaded gasoline). However, caution should be exercised before extending this standard to other denaturants; verification via density measurements is recommended.

Densities were taken at different temperatures and pressures (see Table C.1).

Densities were taken at elevated pressure to assess the effect of operating (blender) pressure on density. The first run was at 64 psig, the rest at 50 psig. The density increase was on the order of 0.01 % to 0.02 %, so pressure correction is not considered necessary. The 0 psig data is displayed in (Figure C.1).

The densities of the denatured ethanol feed stocks FS1 and FS4, although not identical, are so similar that they can barely be seen separately on this graph. The data were run through the API MPMS Ch. 11.1-2004 Applet to calculate Table 6C expansion coefficients (alphas). The results are:

	60 °F kg/m^3	**alpha (x10^{-6})**
FS1	793.50	601.5
FS2	789.39	606.5
FS3	794.95	600.5
FS4	792.98	603.5

The residual plot showed all actual data points to be within $\pm$0.1 kg/m^3 or $\pm$0.013 % of their corresponding calculated values (except for the 110 °F density), as shown in Figure C.2 for FS4. The data could be regressed through any commercially available program to obtain an equation that has a tighter fit (smaller residuals), but using Table 6C of API *MPMS* Ch. 11.1-2004 is more consistent with existing API practice.

As stated above, FS1 and FS3 are 2 % denaturant by volume.

There is little difference between the denatured ethanol feed stock densities, only 5.552 kg/m^3 at 60 °F or 0.70 %, thus their 6C alphas are also very close. As shown below, the spread of their resulting Table 6C VCFs over normal handling temperatures is 0.04 % to –0.03 %. The average, 0.000603 °F (0.001085 °C), adequately represents the four feedstocks and the VCF would deviate at most by $\pm$0.02 %.

Table C.1—Denatured Ethanol Feedstock Densities

	FS1			FS2			FS3			FS4			
°F	Kg/m^3 (0 psig)	Kg/m^3 (64 psig)	Press Diff.	Kg/m^3 (0 psig)	Kg/m^3 (50 psig)	Press Diff.	Kg/m^3 (0 psig)	Kg/m^3 (50 psig)	Press Diff.	Kg/m^3 (0 psig)	Kg/m^3 (50 psig)	Press Diff.	°F
-4	823.722	823.820	0.01 %	819.635	819.716	0.01 %	825.131	825.207	0.01 %	823.227	823.305	0.01 %	-4
-2	822.777	822.880	0.01 %	818.690	818.772	0.01 %	824.188	824.266	0.01 %	822.287	822.366	0.01 %	-2
0	821.836	821.942	0.01 %	817.741	817.759	0.00 %	823.246	823.329	0.01 %	821.347	821.429	0.01 %	0
2	820.898	821.007	0.01 %	816.863	816.950	0.01 %	822.306	822.388	0.01 %	820.408	820.490	0.01 %	2
10	817.145	817.260	0.01 %	813.101	813.193	0.01 %	818.552	818.641	0.01 %	816.648	816.738	0.01 %	10
30	807.764	807.900	0.02 %	803.687	803.798	0.01 %	809.169	809.274	0.01 %	807.247	807.355	0.01 %	30
50	798.341	798.500	0.02 %	794.233	794.360	0.02 %	799.747	799.868	0.02 %	797.803	797.928	0.02 %	50
70	788.833	789.017	0.02 %	784.692	784.838	0.02 %	790.240	790.382	0.02 %	788.270	788.411	0.02 %	70
80	784.030	784.227	0.03 %	779.861	780.019	0.02 %	785.436	785.587	0.02 %	783.448	783.602	0.02 %	80
90	779.186	779.398	0.03 %	774.997	775.168	0.02 %	780.594	780.755	0.02 %	778.587	778.755	0.02 %	90
100	774.290	774.516	0.03 %	770.077	770.259	0.02 %	775.701	775.876	0.02 %	773.674	773.851	0.02 %	100
110	769.336	769.577	0.03 %	765.095	765.289	0.03 %	770.744	770.930	0.02 %	768.702	768.892	0.02 %	110
calc 60 °F	793.50	793.70	0.03 %	789.39	789.53	0.02 %	794.95	795.08	0.02 %	792.98	793.11	0.02 %	calc 60 °F
alpha	601.54	599.88	-0.28 %	606.53	604.88	-0.27 %	600.48	599.20	-0.21 %	603.54	602.20	-0.22 %	alpha

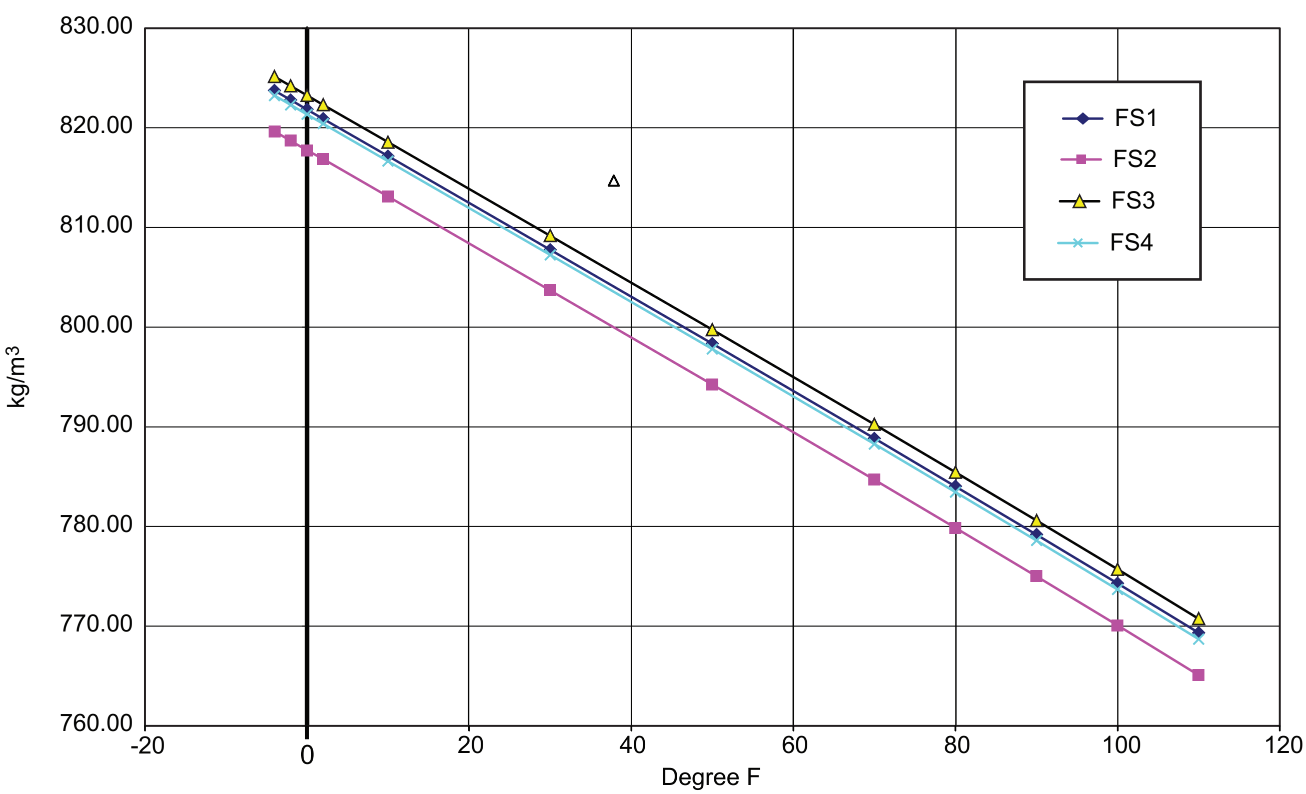

Figure C.1—Denatured Ethanol Feedstock Densities (0 psig)

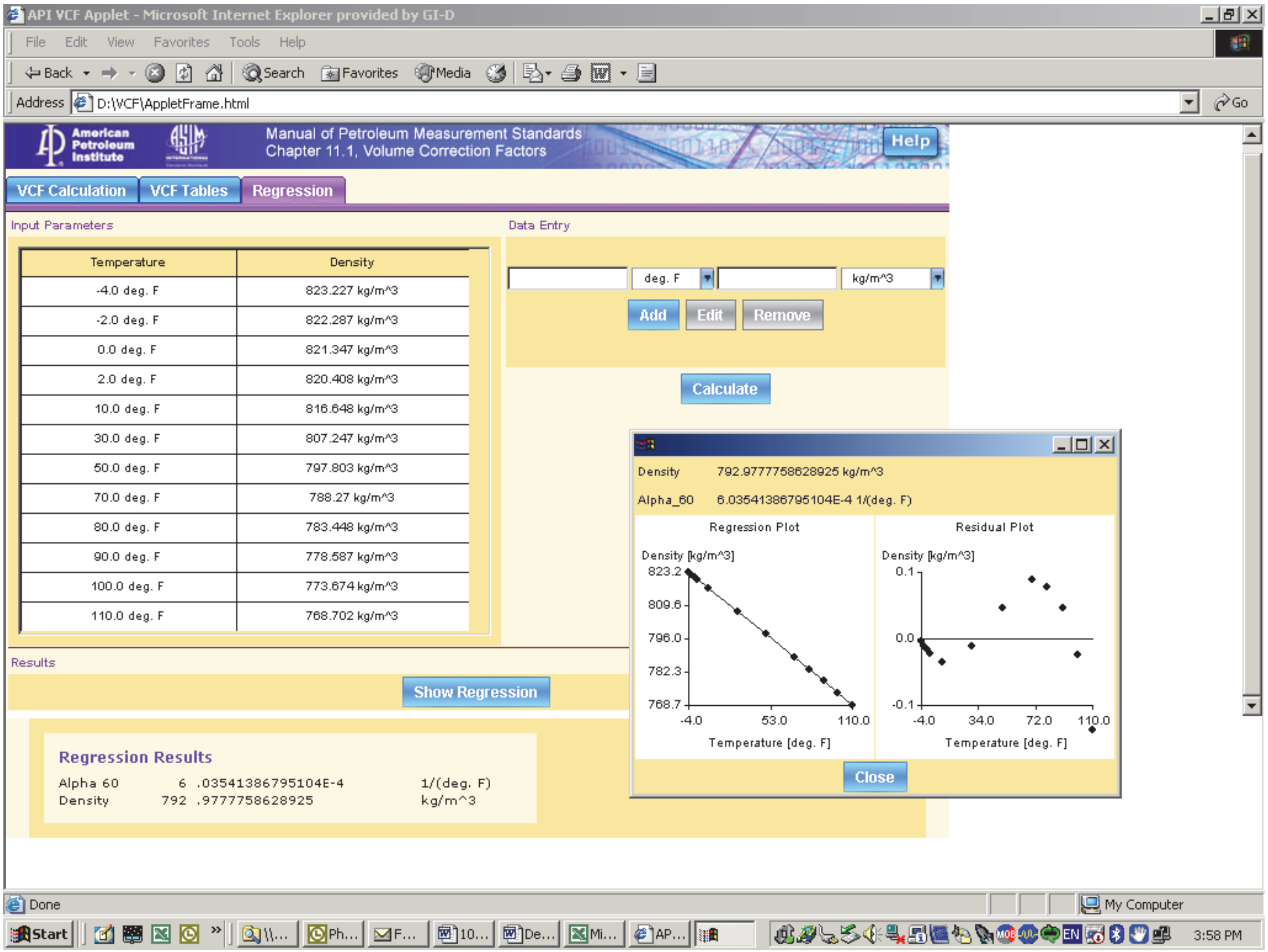

Figure C.2—FS4 Data and the Applet Output Results

Table C.2—Table 6C VCF values

°F	$600.5 \cdot 10^{-6}$	$606.5 \cdot 10^{-6}$	% diff
0	1.03562	1.03597	0.04
10	1.02974	1.03004	0.03
20	1.02384	1.02408	0.02
30	1.01792	1.01810	0.02
40	1.01197	1.01209	0.01
50	1.00600	1.00606	0.01
60	1.00000	1.00000	0.00
70	0.99398	0.99392	-0.01
80	0.98794	0.98782	-0.01
90	0.98189	0.98170	-0.02
100	0.97581	0.97557	-0.02
110	0.96971	0.96941	-0.03

Previous industry practice included the use of the Refined Product table (formerly known as Table 6B) for all ethanols. Table 6B with a reference gravity of 50.61 °API most closely matches the above Table 6C, with a difference of less than 0.001 % (1 in 100,000 volume units) at any given operating temperature.

Annex D
(informative)

Ethanol/Water Mixtures

Densities from OIML R 22, Table 2 (Density as a Function of Temperature and of Alcoholic Strength by Volume), were also input into the API *MPMS* Ch. 11.1-2004 applet to calculate the Table 6C alphas for various ethanol/water mixtures. The results in Table D.1 show that the alphas decrease with increasing water content.

Table D.1—API Applet Regression of Portions of OIML Table II

% Volume Ethanol	alpha		% Volume Ethanol	alpha
0.0	0.000122		70.0	0.000510
5.0	0.000129		80.0	0.000541
10.0	0.000144		90.0	0.000573
20.0	0.000187		95.0	0.000584
30.0	0.000283		96.0	0.000586
40.0	0.000370		97.0	0.000588
50.0	0.000436		98.0	0.000590
60.0	0.000477		99.0	0.000593
			99.9	0.000599

As can be seen, a 95 % ethanol/water solution has an alpha of 0.000584 versus 0.000603 for 95 % ethanol/gasoline. This alpha difference produces a VCF difference (and hence a volume difference) of -0.11 % at 0 °F to 0.12 % at 120 °F.

Preliminary data from the industry ethanol/gasoline blend density study (to be published as API *MPMS* Ch. 11.3.4) show increasing alphas (above 0.000603) as gasoline content increases. Although the above values could be applied to ethanol/water mixtures with very low levels of other denaturants (e.g. part per million levels of brucine), these are not petroleum products and were never intended to be covered by this standard.

Bibliography

For undated references, the latest edition of the referenced document (including any amendments) applies. For dated references, only the edition cited applies.

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[3] API RP 1626-2010, *Storing and Handling Ethanol and Gasoline-Ethanol Blends at Distribution Terminals and Service Stations*.

[4] Alcohol and Tobacco Tax and Trade Bureau (TTB) publication [1], *Authorized Materials for Rendering Spirits Unfit for Beverage Use*.

[5] The *Alcohol and Tobacco Newsletter*, Dec 2000.

[6] 27 *CFR* 19.1005 [2], *Alcohol, Tobacco and Firearms, Distilled spirits plants, Authorized materials*

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[10] International Organization of Legal Metrology [3], *International Recommendation No. 22, International Alcoholic Tables*, 1973 (OIML R 22).

[1] Alcohol and Tobacco Tax and Trade Bureau (TTB), 1310 G Street, NW, Box 12, Washington, DC 20005, http://www.ttb.gov.
[2] The *Code of Federal Regulations* is available from the U.S. Government Printing Office, Washington, DC 20402, www.gpo.gov.
[3] International Organization of Legal Metrology, 11, rue Turgot, F-75009 Paris, France, http://www.oiml.org.

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