

Manual of Petroleum Measurement Standards Chapter 11.3.4

Miscellaneous Hydrocarbon Product Properties— Denatured Ethanol and Gasoline Component Blend Densities and Volume Correction Factors

FIRST EDITION, MAY 2019



AMERICAN PETROLEUM INSTITUTE

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.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

Classified areas may vary depending on the location, conditions, equipment, and substances involved in any given situation. Users of this publication should consult with the appropriate authorities having jurisdiction.

Users of this publication should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained therein.

The scenarios in this standard are merely examples for illustration purposes only. They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

Users of instructions should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

Where applicable, authorities having jurisdiction should be consulted.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to ensure 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 authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications 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.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Copyright © 2019 American Petroleum Institute

Foreword

This edition of *API Manual of Petroleum Measurement Standards (MPMS) Chapter 11.3.4* supersedes Section 11.1.2.5.13 Gasohol, of [API MPMS Chapter 11.1-2004](#).

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.

The verbal forms used to express the provisions in this standard are as follows:

- the term “shall” denotes a minimum requirement in order to conform to the standard;
- the term “should” denotes a recommendation or that which is advised but not required in order to conform to the standard;
- the term “may” is used to express permission or a provision that is optional;
- the term “can” is used to express possibility or capability.

Informative elements—As used in a standard, “informative” denotes elements that identify the document, introduce its content, and explain its background, development, and its relationship with other documents or provide additional information intended to assist the understanding or use of the document.

Normative elements—As used in a standard, “normative” denotes elements that describe the scope of the document and that set out provisions that are required to implement the standard.

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 publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Contents

	Page
1 Scope	1
1.1 General	1
1.2 Range of Applicability	1
2 Blends of Gasoline and Denatured Ethanol (BGE) Normative References	1
3 Terms and Definitions	2
4 Symbols and Abbreviations	2
4.1 Coefficients	2
4.2 Concentrations	3
4.3 Density	3
4.4 Volume	3
4.5 Temperature and Pressure	3
4.6 Subscripts	3
5 Implementation Procedures	3
5.1 Blends of Gasoline and Denatured Ethanol (BGE) Volume and Density Correction	3
5.2 Application of API MPMS Chapter 11.1	6
5.3 Correction to Other Standard Conditions	7
5.4 Rounding	8
6 Calculation of Blending Scenarios	8
6.1 Definition of Scenario Inputs and Targets	8
6.2 Scenario 1—Calculation of BGE V60 and Density from Blending Volumes and Densities	9
6.3 Scenario 2—BGE and Denatured Ethanol Measured, BOB Volume Unmeasured	12
6.4 Scenario 3—Calculation of BOB Volume and BOB and BGE Densities, Ethanol and BGE Volumes Measured	16
6.5 Scenario 4—Calculation of BGE Volume at Base Conditions with Minimal Information	22
7 Precision Statement	24
Annex A (informative) Calculation of α_{60} for Input to BGE CTPL—Worked Examples	26
Annex B (informative) Calculation of Excess Volume Fraction—Worked Examples	29
Annex C (informative) Calculation of Scenarios—Worked Examples	38
Annex E (informative) Measurement Field Descriptions for API MPMS Chapter 11.3.4	47
Bibliography	51

Figures

E.1 Sequential Metering	48
E.2 Ratio Metering	48
E.3 Side Stream Metering	49
E.4 Hybrid Ratio Metering	49
E.5 Hybrid Side Stream Metering	50
E.6 Scenario 4	50

Tables

1 Excess Volume Fraction Equation Parameters	6
2 Available and Target Scenario Parameters	9

Contents

	Page
3 Scenario 1 Output Values	12
4 Scenario 2 Output Values	15
5 Scenario 2 Example Iteration Results	16
6 Scenario 3 Output Values	21
7 Scenario 3 Example Iteration Results	21
8 Scenario 4 Available Input Values	22
9 Scenario 4 Example Iteration Results	24
10 Scenario Uncertainties	25
A.1 Calculation of α_{60} for Input to BGE CTPL—Worked Examples	26
B.1 Excess Volume Fraction—Worked Examples	29
C.1 Independent Input Values for Scenarios 1, 2, and 3	39
C.2 Calculated Inputs for Scenarios 2 and 3.	41
C.3 Calculated Outputs for Scenario 1 Examples	42
C.4 Calculated Outputs for Scenario 2 Examples	43
C.5 Calculated Outputs for Scenario 3 Examples	44
C.6 Scenario 4 Examples for a Constant 1000 m ³ BGE Observed Volume.	45
D.1 Convergence for Cases With and Without Acceleration	46
E.1 Scenario Calculation Inputs and Outputs	47

Introduction

This standard addresses how to calculate volume correction factors for blends of denatured ethanol and gasoline. Previously, the API Standard, [API MPMS Chapter 11.1](#), *Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils*, 2004 addressed these blends by recommending a thermal coefficient of expansion in Section 11.1.2.5.13 and using the “Special Applications Category” in the [Chapter 11.1](#) standard. After considerable laboratory work of actual blending denatured ethanol and gasoline, new equations were derived and are presented in this standard, along with examples with different blending scenarios. See API TR 2580 ^[1] for more information on the laboratory work and background.

Miscellaneous Hydrocarbon Product Properties—Denatured Ethanol and Gasoline Component Blend Densities and Volume Correction Factors

Implementation Guidelines

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 standard be utilized on all 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.

1 Scope

1.1 General

This standard covers density and volume correction factors for blends of denatured ethanol and gasoline blend components ranging from 0 % to 95 % denatured ethanol based upon calculation methods defined in [API MPMS Chapter 11.1](#) and [Chapter 11.3.3](#). Calculation of blends and denatured ethanol containing more than 95 % ethanol should use the calculation procedures within [API MPMS Chapter 11.3.3](#).

The standard consists of correlations and algorithms for estimating the blend volume change at base conditions and for calculating volume correction factors of denatured ethanol and gasoline component blends. This standard also provides the algorithms to estimate certain blend properties in blending situations where some of the required parameters are not measured.

1.2 Range of Applicability

This standard is applicable to blends containing denatured ethanol and gasoline blend components with 15.5 °C (60 °F) densities ranging from 680 to 800 kg/m³ (45.2 to 76.4 °API) containing between 0 % and 95 % by volume denatured ethanol over the temperature range of –40 °C to 50 °C (–40 °F to 122 °F) and pressure range of 0 to 10.34 MPa gage (0 to 1508 psig).

2 Blends of Gasoline and Denatured Ethanol (BGE) 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 applies (including any addenda/errata).

[API Manual of Petroleum Measurement Standards \(MPMS\) Chapter 11.1](#), *Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils*, May 2004, including Addendum 1, September 2007

[API MPMS Chapter 11.2.1](#), *Compressibility Factors for Hydrocarbons: 0–90 Degrees API Gravity and 638–1074 Kilograms per Cubic Metre Ranges*

[API MPMS Chapter 11.3.3](#), *Miscellaneous Hydrocarbon Product Properties—Denatured Ethanol Density and Volume Correction Factors*, Third Edition, January 2019

[API MPMS Chapter 15](#), *Guidelines for the Use of the International System of Units in the Petroleum and Allied Industries*, Third Edition

3 Terms and Definitions

3.1

blends of gasoline and ethanol (BGE)

A blend of gasoline and denatured ethanol blend components ranging from 0 % to 95 % denatured ethanol.

3.2

blend volume percent (BVP)

The concentration of ethanol in the mixture based on the ratio of the volume of denatured ethanol to the total observed volume of the mixture adjusted to base conditions times 100, expressed as a percentage.

NOTE It is bounded by 0 % and 100 %.

3.3

blendstock for oxygenate blending (BOB)

A refined product component consisting of unfinished gasoline to which denatured ethanol will be added to make a finished motor fuel.

3.4

excess alpha

The incremental increase in the thermal expansion coefficient of the mixed liquid that exceeds the coefficient calculated from a volume proportional addition of the component alphas.

3.5

excess volume fraction

The incremental volume growth generated by mixing denatured ethanol and BOB. The excess volume is expressed as a fractional volume divided by the sum of the component volume so it is dimensionless. It is bounded by 0 and 1.

3.6

ideal fraction ethanol

Concentration of ethanol in the mixture expressed as the volume of denatured ethanol divided by the volume of a simple addition of the component volumes at base conditions. As a volume divided by volume measure, it is dimensionless. It is bounded by 0 and 1.

3.7

nominal ethanol content

The labeled denatured ethanol content of an ethanol-blended fuel. The actual ethanol content may vary from the nominal value due to labeling conventions and blending constraints.

4 Symbols and Abbreviations

BGE blend of gasoline and denatured ethanol

4.1 Coefficients

α_{60}	thermal expansion factor at 60 °F (°F ⁻¹)
$\alpha_{60\epsilon}$	excess alpha at 60 °F (°F ⁻¹)
a_j	coefficients for the cubic equation that defines the thermal expansion coefficient, α_{60} . There are four different coefficients; each will be identified by their subscript (j).
$a_{s1}, a_{s2}, a_{s3}, a_{s4}$	coefficients used in the API MPMS Chapter 11.2.1 procedure to determine the scaled compressibility factor, F_s . Subscripts modified from MPMS Chapter 11.2.1 to avoid confusion with the thermal expansion coefficient coefficients.
A, A_{HC}, B, n, Z	coefficients used in the excess volume fraction equation

C_{TPL}	combined volume correction factor due to temperature and pressure
F_S	scaled compressibility factor (psi ⁻¹)
y	fit parameter for the equation (dimensionless)

4.2 Concentrations

$\Phi_{ethanol}$	ideal fraction ethanol (dimensionless, volume)
$V_{\%ethanol}$	blend percent denatured ethanol (volume %)

4.3 Density

ρ	density value (kg/m ³)
ρ_{60}	density at base conditions (60 °F and 0 psig) (kg/m ³)
$\rho_{t,p}$	density at alternate conditions (kg/m ³)

4.4 Volume

$V_{Observed}$	volume at flowing conditions (m ³)
V_{60}	volume at base conditions (60 °F and 0 psig)
$V_{t,P}$	volume at specified conditions (t and P)
V_E	excess volume fraction (dimensionless)

4.5 Temperature and Pressure

P	pressure value (psig)
T	temperature value (°F)

4.6 Subscripts

Subscripts may be added to any symbol to clarify the component to which a property is associated, to distinguish it from a similar property from a different calculation, or to specify an iteration number. In some cases, a comma may be used in a subscript to separate parts for greater visual distinction without further significance.

BOB	blendstock for oxygenate blending properties
C_{TPL}	calculated using thermal expansion correlations
ethanol	denatured ethanol properties
BGE	properties of blends of denatured ethanol and gasoline
i	referring to the value of a specific iteration
mass	calculated using mass balance
observed	values measured at field conditions without adjustment to base conditions

5 Implementation Procedures

5.1 Blends of Gasoline and Denatured Ethanol (BGE) Volume and Density Correction

5.1.1 Background

Experimental and field experience has demonstrated that blending denatured ethanol into gasoline blending stocks results in a mixture that exhibits apparent volume growth over that simple addition of the blended volumes. The

mixture also shows an incremental increase in the coefficient of thermal expansion over that expected by volume proportional addition of the blend stock coefficients.

API gathered a series of laboratory density measurements at various temperatures, pressures, and concentrations for four BOB samples, four denatured ethanol samples, and the 16 possible combinations thereof. The laboratory results were evaluated to filter out outliers and procedural artifacts, and the remaining dataset of 1662 samples were used in regression studies. The studies determined the functions and parameters that best fit the “excess functions”. Combining the excess functions with the previously documented [API MPMS Chapter 11.1](#) functions extends the range of [API MPMS Chapter 11.1](#) to blends of gasoline and denatured ethanol blends.

5.1.2 Source of Excess Thermal Expansion and Excess Volume

When BOB and denatured ethanol are mixed, the two fluids are infinitely soluble in each other and form a single liquid phase. The fluids are chemically different in that BOB is a hydrocarbon mixture consisting primarily of non-polar and aromatic molecules and ethanol is polar. This difference leads to the fluids’ molecules interacting at a molecular level.

A simple construct that explains the observed effects on physical properties, is that the ethanol molecules interfere with the densest alignment of the BOB nonpolar molecules leading to a decrease in expected density or the creation of “excess volume”.

The same interaction causes the thermal expansion coefficient (α_{60}) for the mixture to be larger than the coefficient expected for a hydrocarbon fluid of that density or for a volumetric average of the coefficients of the BOB and ethanol components.

5.1.3 Units of Measure

For this standard, the approach was to develop functions and procedures that extend the functionality of existing API standards to cover ethanol-blended fuels. The primary standard for temperature and pressure adjustment to base conditions is [API MPMS Chapter 11.1](#). [API MPMS Chapter 11.1](#) accepts inputs and generates outputs in many units of measure, but all calculations go through an internal conversion to customary units for use in legacy correlations.

It is intended for the algorithms in this standard to be incorporated into [API MPMS Chapter 11.1](#) calculation engines. Therefore, all the calculations in this standard are based on the same units as used in the [API MPMS Chapter 11.1](#) legacy correlations. This is primarily manifested in the exclusive use of degrees Fahrenheit (°F) for temperature and kilograms per meter cubed (kg/m³) for density.

Volumes in the calculations shall use meters cubed (m³). This is necessary because several equations multiply density (kg/m³) by volume (m³), and require consistent units of measure.

5.1.4 Functions Specific to Blends of Gasoline and Ethanol (BGE)

5.1.4.1 General

The functions in this section are necessary components of the functions required to calculate excess volume fraction and excess α_{60} .

5.1.4.2 Ideal Fraction Ethanol

Ideal fraction ethanol, $\varphi_{ethanol}$, is the fraction of the mixture that would be ethanol assuming ideal mixing without excess volume effects. It is used in some of the calculations because it does not require knowledge of the volume expansion caused by the ethanol. It is calculated using Equation (1).

$$\varphi_{ethanol} = \frac{V_{60, ethanol}}{V_{60, ethanol} + V_{60, BOB}} \quad (1)$$

where

$V_{60, ethanol}$ and $V_{60, BOB}$ are the volumes at base conditions of denatured ethanol and BOB respectively.

5.1.4.3 Blend Volume Percent

For some regulatory and commercial purposes, the concentration of denatured ethanol is stated on a volumetric percent basis referenced to the total volume of BGE at base conditions. Since BGE blends demonstrate an excess volume fraction, the ideal volume fraction ethanol, $\varphi_{ethanol}$, and the blend volume percent, $V_{\%ethanol}$ differs numerically from $\varphi_{ethanol}$ by the excess volume fraction term in the denominator and by a factor of 100. Equation (2) shows that $V_{\%ethanol}$ can be related to the component and blend volumes by:

$$V_{\%ethanol} = \frac{V_{60, ethanol}}{V_{60, BGE}} \times 100 = \frac{V_{60, ethanol}}{(V_{60, ethanol} + V_{60, BOB})(1 + V_{\varepsilon})} \times 100 \quad (2)$$

where

V_{ε} is the excess volume fraction

5.1.4.4 BGE α_{60} for use in API MPMS Chapter 11.1

The thermal expansion coefficient at 60 °F (α_{60}) of BGE is calculated as the volume proportional alphas of the BOB and denatured ethanol blend stocks and an additional component, the excess alpha ($\alpha_{60\varepsilon}$).

The alpha of BOB is computed from the generalized refined product commodity group procedures in Section 11.1.6.1 of [API MPMS Chapter 11.1-2004](#) or the fluid-specific procedures in Section 11.1.5.2 of [API MPMS Chapter 11.1-2004](#), which are not repeated in detail here. [API MPMS Chapter 11.3.3](#) sets a value of 0.000603 °F⁻¹ at 60 °F for the α_{60} of denatured ethanol.

The α_{60} of a BGE shall be calculated by first calculating the excess alpha as shown in Equation (3):

$$\alpha_{60\varepsilon} = 1.8 \cdot \varphi_{ethanol} \cdot (1 - \varphi_{ethanol}) \cdot e^{(-7.5308 - 5.3886 \cdot \varphi_{ethanol} + 5.9914 \cdot \varphi_{ethanol}^2 - 2.9577 \cdot \varphi_{ethanol}^3)} \quad (3)$$

Followed by calculating the proportional contributions of denatured ethanol, BOB, and the excess alpha as shown in Equation (4).

$$\alpha_{60, BGE} = (1 - \varphi_{ethanol}) \times \alpha_{60, BOB} + \varphi_{ethanol} \times \alpha_{60, ethanol} + \alpha_{60\varepsilon} \quad (4)$$

where

$\alpha_{60\varepsilon}$ is the additional alpha to be added to the alpha proportionately contributed by the BOB and denatured ethanol components;

$\varphi_{ethanol}$ is the ideal volume fraction denatured ethanol;

e is Euler's number, 2.718281828...;

$\alpha_{60, ethanol}$ is 0.000603 °F⁻¹.

When using a user-input α_{60} of the procedure of Section 11.1.6.1 of [API MPMS Chapter 11.1-2004](#), definition of the density is not required. A table of worked examples of the α_{60} for BGE of different denatured ethanol concentrations and BOB densities is shown in Annex A.

5.1.4.5 Excess Volume Fraction

The calculation of excess volume fraction involves two equations to calculate a fitting parameter and the excess volume fraction equation. In Equation (5), the dimensionless fitting parameter y is:

$$y = \frac{\varphi_{ethanol} \times Z}{1 + \varphi_{ethanol} \times (Z - 1)} \quad (5)$$

where

$\varphi_{ethanol}$ is the volume fraction of denatured ethanol;

Z is a fit parameter shown in Table 1.

In Equation (6), the excess volume fraction V_e is calculated as:

$$V_e = \max(0, y(1 - y)(A + A_{HC}\rho_{60, BOB} + By^n)) \quad (6)$$

where

V_e is the fraction of the sum of the component volumes not accounted for by simple addition;

A, A_{HC}, B, n are fit parameters shown in Table 1;

$\rho_{60, BOB}$ is the BOB density at 60 °F.

If the excess volume fraction function returns a negative value, set the value to zero. Some combinations of high ethanol (> 95%) and high BOB density (> 785 kg/m³) can lead to a negative calculated value due to limitations of the fitted equation. Since these are commercially non-existent cases, the simplicity of Equation (6) is preferred over eliminating the artifacts.

Table 1—Excess Volume Fraction Equation Parameters

Fit Parameter	Value
A	8.624574
A_{HC}	-0.010160136
B	-0.73742
n	5.411871
Z	2.00855

The user shall note that the required density input to calculate the $\alpha_{60\epsilon}$ calculation is the BOB density, not the BGE density. A table of worked examples on Excess Volume Fraction can be found in Annex B.

5.2 Application of API MPMS Chapter 11.1

5.2.1 Pressure Correction of Denatured Ethanol to Base Conditions

Denatured ethanol can be corrected to base conditions of 60 °F, 0 psig using the method of [API MPMS Chapter 11.2.1](#) with a coefficient, F_s , derived from literature data for the thermodynamic properties of ethanol. The multiplier 10^{-5} in the equation is to scale the result to the same basis as the hydrocarbon, F_s , used in [API MPMS Chapter 11.1-2004](#), Section 11.1.6.1. In Equation (7), the scaled compressibility factor for ethanol, $F_{s, ethanol}$ is calculated as:

$$F_{s, ethanol} = (a_{s1} \times t^2 + a_{s2} \times t + a_{s3}) \times 10^{-5} \quad (7)$$

where

t is temperature in degrees Fahrenheit;

$F_{s, ethanol}$ is scaled compressibility factor, psi^{-1} ;

a_{s1} is 3.98002E-6;

a_{s2} is 1.92284E-3;

a_{s3} is 563.134E-3.

There is insufficient data at this time to justify a modified equation for the pressure correction for BGE.

5.2.2 Temperature and Pressure Correction of Blends of Gasoline and Ethanol (BGE) to Base Conditions

BGE of any concentration shall be corrected to base conditions using the method of [API MPMS Chapter 11.1](#) (and [API MPMS Chapter 11.2.1](#)). BGE shall not use the Generalized Refined Product Commodity group approach, but rather use a user-supplied alpha as calculated in Section 5.1.4.4 of this standard. In the situation where the user does not have the fluid-specific α_{60} for the BOB, the user may use the generic refined product equation in [API MPMS Chapter 11.1](#) to calculate the BOB α_{60} , then apply that α_{60} in the equation in Section 5.1.4 of this standard. The α_{60} from Section 5.1.4 of this standard shall be used in the [API MPMS Chapter 11.1](#) C_{TPL} calculation.

Pressure correction shall be done using the procedure in [API MPMS Chapter 11.1](#) or [API MPMS Chapter 11.2.1](#), entering the procedure with the volume proportional F_s from Equation (8).

$$F_s = \varphi_{ethanol} \times F_{s, ethanol} + (1 - \varphi_{ethanol}) \times F_{s, BOB} \quad (8)$$

where

F_s is the BGE scaled compressibility factor (psi^{-1});

$F_{s, ethanol}$ is the ethanol scaled compressibility factor (psi^{-1}) as calculated in 5.2.1;

$F_{s, BOB}$ is the BOB scaled compressibility factor (psi^{-1}) as calculated per [API MPMS Chapter 11.1](#).

5.3 Correction to Other Standard Conditions

The implementation procedure for correcting a volume from an observed temperature to another standard temperature (e.g. 15 °C or 20 °C) is a three-step process. Calculations shall be carried at full machine precision.

STEP 1 Calculate the C_{TPL} from observed conditions to 60 °F base conditions using the equations in 5.1 to determine the input parameters for Section 11.1.6.2 of [API MPMS Chapter 11.1-2004](#).

STEP 2 Calculate the C_{TPL} from the standard conditions to 60 °F (15.556 °C) using the same input parameters and methods.

STEP 3 Multiply the observed volume times the C_{TPL} (observed to 60) divided by the C_{TPL} (other standard to 60) as described in Equation (9).

$$V_{\text{Alternative Base}} = V_{\text{observed}} \frac{C_{TPL \text{ Obs to } 60^\circ\text{F}}}{C_{TPL \text{ Standard Conditions to } 60^\circ\text{F}}} \quad (9)$$

Density can also be corrected in Step 3 with the formula as shown in Equation (10).

$$\rho_{\text{Alternative Base}} = \rho_{60} \times C_{\text{TPL Alternative Base to } 60^{\circ}\text{F}} \quad (10)$$

Following this procedure, an observed volume of 99.926 m³ of BGE at 57 °F, 30 psig, 781 kg/m³ BOB, 0.492 ideal fraction ethanol as described in Scenario 1 Example, would be converted to alternate base temperatures:

15 °C Base Temperature

$$V_{15^{\circ}\text{C}} = V_{57^{\circ}\text{F}, 30 \text{ psig}} \times \frac{C_{\text{TPL } 57,30 \text{ to } 60^{\circ}\text{F}}}{C_{\text{TPL } 15^{\circ}\text{C to } 60^{\circ}\text{F}}} = 99.926 \text{ m}^3 \times \frac{1.0021125}{1.0006388} = 100.073 \text{ m}^3$$

$$\rho_{15^{\circ}\text{C}} = \rho_{60} \times C_{\text{TPL } 15^{\circ}\text{C to } 60^{\circ}\text{F}} = 783.368 \frac{\text{kg}}{\text{m}^3} \times 1.0006388 = 779.358 \frac{\text{kg}}{\text{m}^3}$$

20 °C Base Temperature

$$V_{20^{\circ}\text{C}} = V_{57^{\circ}\text{F}, 30 \text{ psig}} \times \frac{C_{\text{TPL } 57,30 \text{ to } 60^{\circ}\text{F}}}{C_{\text{TPL } 20^{\circ}\text{C to } 60^{\circ}\text{F}}} = 99.926 \times \frac{1.0021125}{0.994881} = 100.652 \text{ m}^3$$

$$\rho_{20^{\circ}\text{C}} = \rho_{60} \times C_{\text{TPL } 20^{\circ}\text{C to } 60^{\circ}\text{F}} = 783.368 \frac{\text{kg}}{\text{m}^3} \times 0.994881 = 779.358 \frac{\text{kg}}{\text{m}^3}$$

5.4 Rounding

The implementation procedures shall be performed with no rounding or truncation of input, intermediate, or output values. Rounding of values is a topic addressed by other API standards. Within this standard, any apparent rounding in printed or tabulated values is solely for editorial convenience. Calculations within the examples were performed using full machine precision.

6 Calculation of Blending Scenarios

6.1 Definition of Scenario Inputs and Targets

In each of the scenarios, a hypothetical blending scenario requires calculation of the V_{60} of the BGE with varying levels of information. Each of the scenarios is shown in Table 2. The parameters are classified into either “available” which is known and used in the calculation, “find” which is the objective of the calculation, and “–” which only designates that it is neither an objective nor required for the calculation.

In the example calculations, the metered cubed (m³) unit of volume measurement is indicated. Only one unit of volume measurement shall be used within the calculations. If another unit of volume measurement is required as an input or output, the user shall convert the input value to m³ using the methods of [API MPMS Chapter 15](#) prior to entering these calculations.

Each example shown in this section is based on the same input values and has the same expected outputs, except each scenario is constrained by a different set of unknowns in the inputs. For additional worked examples, see Annex C.

The following scenarios are merely examples for illustration purposes only. They are not considered exclusive or exhaustive in nature. API makes no warranties, express, or implied for reliance on or any omissions from the information contained in this document.

Table 2—Available and Target Scenario Parameters

	Input Value Scenarios 1, 2, and 3 Examples	Units	Scenario 1	Scenario 2	Scenario 3	Scenario 4 (Example Input Values)
V_{BOB}	50.603	m ³	Available	Find	Find	—
$T_{Observed,BOB}$	53.0	°F	Available	Available	Available	—
$P_{Observed,BOB}$	36.0	psig	Available	Available	Available	—
$\rho_{60,BOB}$	781.000	kg/m ³	Available	Available	Find	—
$V_{60,BOB}$	—	m ³	Find	Find	Find	—
Nominal Ethanol Content	—	—	—	—	—	Available (10 %)
$V_{observed,ethanol}$	49.644	m ³	Available	Available	Available	—
$T_{observed,ethanol}$	76.0	°F	Available	Available	Available	—
$P_{observed,ethanol}$	54.0	psig	Available	Available	Available	—
$\rho_{60,ethanol}$	788.000	kg/m ³	Available	Available	Available	Available (778.0)
$V_{60,ethanol}$	—	m ³	Find	Find	Find	—
$V_{observed,BGE}$	99.926	m ³	—	Available	Available	Available (99.613)
$T_{observed,ethanol}$	57.0	°F	Available	Available	Available	Available (53.0)
$P_{observed,BGE}$	30.0	psig	Available	Available	Available	Available (75.0)
$\rho_{60,BGE}$	—	kg/m ³	Find	Find	Find	Available (753.0)
$\rho_{observed,BGE}$	785.023	kg/m ³	Find	—	Available	—
$V_{60,BGE}$	—	m ³	Find	Find	Find	Find

6.2 Scenario 1—Calculation of BGE V_{60} and Density from Blending Volumes and Densities

6.2.1 Overview

In this scenario, the volumetric flow and density of the BOB and denatured ethanol streams are known. The density and V_{60} of the BGE can be calculated directly without iteration. If needed, the flowing density of the BGE can also be directly calculated.

6.2.2 Calculation Method

If the flowing density of the BGE is measured, the C_{TPL} shall be calculated from the ρ_{60} used to correct the flowing density to base conditions. If the flowing density is not measured, the BOB and denatured ethanol properties may be used to calculate a $\rho_{60,BGE}$.

Following the generic formula for each step is a worked example using the inputs listed in Table 2.

STEP 1 Calculate ethanol C_{TPL}

Using the α_{60} for denatured ethanol (95 %–99 % purity) and the F_s for ethanol from [API MPMS Chapter 11.3.3](#), calculate the C_{TPL} to correct the denatured ethanol volume from observed to base conditions.

$$C_{TPL \text{ ethanol}} = 0.990713$$

STEP 2 Determine $V_{60,ethanol}$

Using the C_{TPL} from Step 1, adjust the ethanol volume to base conditions.

$$V_{60, ethanol} = C_{TPL, ethanol} * V_{ethanol}$$

$$V_{60, ethanol} = 0.990713 * 49.644 m^3 = 49.183 m^3$$

STEP 3 Calculate C_{TPL} for BOB

Using the calculation procedure in [API MPMS Chapter 11.1](#) for either the specified α_{60} or the Generalized Method, calculate the C_{TPL} to correct the V_{BOB} to base conditions.

$$C_{TPL, BOB} = 1.004229 \text{ (using the Generalized Refined Products Method)}$$

STEP 4 Determine $V_{60,BOB}$

Convert the BOB volume to base conditions

$$V_{60, BOB} = C_{TPL} * V_{BOB}$$

$$V_{60, BOB} = 1.004229 * 50.603 m^3 = 50.817 m^3$$

STEP 5 Calculate ideal ethanol fraction

Use the formula from 5.1.4.2

$$\Phi_{ethanol} = \frac{V_{60, ethanol}}{V_{60, ethanol} + V_{60, BOB}}$$

$$\Phi_{ethanol} = \frac{49.183 m^3}{49.183 m^3 + 50.817 m^3} = 0.492$$

STEP 6 Calculate excess volume

Using 5.1.4.5:

$$y = \frac{\Phi_{ethanol} * Z}{1 + \Phi_{ethanol} * (Z - 1)}$$

Then continuing to calculate excess volume:

$$V_{\epsilon} = y(1 - y)(A + A_{HCP_{60, BOB}} + By^n)$$

$$y = \frac{0.492 * Z}{1 + 0.492 * (Z - 1)}$$

$$V_{\epsilon} = 0.001372$$

where

$\Phi_{ethanol}$ is the ideal volume fraction of denatured ethanol from Step 5;

Z, A, A_{HC}, B, n are fit parameters from Table 1.

STEP 7 Calculate C_{TPL} for BGE

Calculate α_{60} for the BGE using the algorithm in Section 5.1.4.4 of this standard, and for the F_s for the BGE use the algorithm described in 5.2.2 of this standard, then to calculate the C_{TPL} use the [Chapter 11.1](#) methods.

$$C_{TPL, BGE} = 1.002112$$

STEP 8 Calculate $V_{60, BGE}$ from C_{TPL}

Correct the observed BGE volume to base conditions

$$V_{60, BGE} = C_{TPL, bge} * V_{observed}$$

$$V_{60, BGE} = 1.002112 * 99.926 m^3 = 100.137 m^3$$

STEP 9 Calculate blend volume percent ethanol

Using the V_{60} values from Step 2 and Step 8, calculate the blend volume percent ethanol.

$$V_{\%ethanol} = \frac{V_{60, ethanol}}{V_{60, BGE}} = \frac{49.183 m^3}{100.137 m^3} 100 = 49.116 \%$$

STEP 10 Calculate BGE ρ_{60}

BGE density shall be calculated in either of two ways in this procedure:

- 1) If the flowing density is measured, use the C_{TPL} calculated in Step 7 to adjust the measured density to base conditions, or
- 2) If the density is unknown, use the following equations to calculate the ρ_{60} .

BGE density is expected to be the volumetrically proportional combination of the BOB and ethanol densities, adjusted for the excess volume increase in BGE volume.

$$\rho_{60, BGE} = \frac{\left(1 - \frac{V_{\%ethanol}}{100} * (1 + V_e)\right) * \rho_{60, BOB} + \left(\frac{V_{\%ethanol}}{100} * (1 + V_e)\right) * \rho_{60, ethanol}}{1 + V_e}$$

$$\rho_{60, BGE} = \frac{\left(1 - \frac{49.116}{100} * (1 + 0.001372)\right) * 781.0 + \left(\frac{49.116}{100} * (1 + 0.001372)\right) * 788.0}{1 + 0.001372}$$

$$\rho_{60, BGE} = 783.368 \frac{kg}{m^3}$$

STEP 11 Calculate BGE flowing density

If useful, calculate the BGE flowing density using C_{TPL} calculated in Step 7:

$$\rho_{observed, BGE} = C_{TPL, BGE} * \rho_{60, BGE} = 785.023 \frac{kg}{m^3}$$

After output results

The results to be reported for this scenario are:

Table 3—Scenario 1 Output Values

Output Value	From Step	Value
$V_{60,ethanol}$	2	49.183 m ³
$V_{60,BOB}$	4	50.817 m ³
$V_{60,BGE}$	8	100.137 m ³
$V_{\%ethanol}$	9	49.116 %
$\rho_{60,BGE}$	10	783.368 kg/m ³

All results are output without rounding.

6.3 Scenario 2—BGE and Denatured Ethanol Measured, BOB Volume Unmeasured

6.3.1 Overview

In this scenario, the BGE and denatured ethanol flowing volumes are measured, but the BOB volume is not available. It is assumed that the BOB density is available from laboratory data, such as the Certificate of the Analysis. This case is similar to the previous scenario but adds another unknown.

6.3.2 Calculation Method

The calculation approach to solving this scenario is to assume a V_{60} for BOB, which enables the calculation of the V_{60} and ρ_{60} of the BGE using their mixing and thermal expansion properties. The BGE properties are then used to find the BOB V_{60} by mass balance. The mass balance solution is substituted back into the BGE calculations iteratively until the V_{60} , BOB changes less than the specified tolerance within an iteration.

STEP 1 Calculate ethanol C_{TPL}

Using the α_{60} for denatured ethanol (95 %–99 % purity) and the F_s for ethanol from [API MPMS Chapter 11.3.3](#), calculate the C_{TPL} to correct the denatured ethanol volume from observed to base conditions.

$$C_{TPL, ethanol} = 0.990713$$

STEP 2 Determine $V_{60,ethanol}$

Using the C_{TPL} from Step 1

$$V_{60, ethanol} = C_{TPL, ethanol} * V_{ethanol}$$

$$V_{60, ethanol} = 0.990713 * 49.644 m^3 = 49.183 m^3$$

STEP 3 Make first estimate for $V_{60,BOB}$ (first step of iterative sequence)

The following steps form an iterative loop. The equations are shown for the iterations use the subscript “i”; the worked example calculations within each step are only for the first iteration and show the specific subscript “1”.

For the second and subsequent iterations use the value of $V_{60,BOB}$ from Step 10 of the previous iteration.