Calculation of Gross Heating Value, Relative Density, Compressibility and Theoretical Hydrocarbon Liquid Content for Natural Gas Mixtures for Custody Transfer

GPA Standard 2172–09

API Manual of Petroleum Measurement Standards Chapter 14.5

THIRD EDITION, JANUARY 2009

REAFFIRMED, FEBRUARY 2014

ADOPTED AS TENTATIVE STANDARD, 1972
REVISED AND ADOPTED AS STANDARD, 1976
REVISED 1984, 1986, 1996, 2009

GAS PROCESSORS ASSOCIATION
6526 EAST 60TH STREET
TULSA, OKLAHOMA 74145

AMERICAN PETROLEUM INSTITUTE
1220 L STREET, NW
WASHINGTON, DC 20005

Calculation of Gross Heating Value, Relative Density, Compressibility and Theoretical Hydrocarbon Liquid Content for Natural Gas Mixtures for Custody Transfer

GPA Standard 2172–09

API Manual of Petroleum Measurement Standards Chapter 14.5

THIRD EDITION, JANUARY 2009

REAFFIRMED, FEBRUARY 2014

ADOPTED AS TENTATIVE STANDARD, 1972
REVISED AND ADOPTED AS STANDARD, 1976
REVISED 1984, 1986, 1996, 2009

GAS PROCESSORS ASSOCIATION
6526 EAST 60TH STREET
TULSA, OKLAHOMA 74145

AMERICAN PETROLEUM INSTITUTE
1220 L STREET, NW
WASHINGTON, DC 20005

API 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.

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

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict. API makes no warranties, express or implied for reliance on or any omissions from the information or equations contained in this document. The examples given in this document are for illustration purposes only. They are not to be considered exclusive or exhaustive in nature.

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.

GPA Disclaimer

GPA publications necessarily address problems of a general nature and may be used by anyone desiring to do so. Every effort has been made by GPA to assure accuracy and reliability of the information contained in its publications. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed. It is not the intent of GPA to assume the duties of employers, manufacturers, or suppliers to warn and properly train employees, or others exposed, concerning health and safety risks or precautions.

GPA makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict, or for any infringement of letters of patent regarding apparatus, equipment, or method so covered.

Foreword

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.

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, 1220 L Street, N.W., Washington, D.C. 20005. Requests for permission to reproduce or translate all or any part of the material published herein should 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 and updated quarterly by API, 1220 L Street, N.W., Washington, D.C. 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, D.C. 20005, standards@api.org.

Contents

Tables

Introduction

This standard supersedes previous editions of GPA Standard 2172/API *MPMS* Chapter 14.5, *Calculation of Gross Heating Value, Specific Gravity and Compressibility Factor for Natural Gas Mixtures from Compositional Analysis* and it incorporates and supersedes GPA Reference Bulletin 181, *Tentative Reference Bulletin Heating Value as a Basis for Custody Transfer of Natural Gas*. This standard also supersedes the GPM calculations in GPA Standard 2261, *Analysis for Natural Gas and Similar Gaseous Mixtures by Gas Chromatography* and GPA Standard 2286, *Tentative Method of Extended Analysis for Natural Gas and Similar Gaseous Mixtures by Temperature Programmed Gas Chromatography* as well as Table IV of GPA Standard 2261.

This standard is for the use of those involved in custody transfer of natural gas. Unless fixed by statute, it is the responsibility of the parties to contracts to agree on procedures for determining volumes, heating values and standard conditions for custody transfer.

This standard is similar to ISO 6976, *Natural gas—Calculation of calorific values, density, relative density and Wobbe index from composition*, and to AGA Report No. 5, *Natural Gas Energy Measurement*.

Calculation of Gross Heating Value, Relative Density, Compressibility and Theoretical Hydrocarbon Liquid Content for Natural Gas Mixtures for Custody Transfer

1 Scope

This standard presents procedures for calculating, at base conditions from composition, the following properties of natural gas mixtures: gross heating value, relative density (real and ideal), compressibility factor and theoretical hydrocarbon liquid content which in the U.S. is typically expressed as GPM, the abbreviation for gallons of liquid per thousand cubic feet of gas.

Rigorous calculation of the effect of water upon these calculations is complicated. Because this document relates primarily to custody transfer, the water effect included is an acceptable contractual calculation. Annex A of this standard contains a detailed investigation of the effect of water and detailed derivations of the equations presented in the standard.

2 Normative References

The following documents contain provisions, which through reference in this text constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 14.1, *Collecting and Handling of Natural Gas Samples for Custody Transfer*

AGA Report No. 5 [1], *Fuel Gas Energy Metering*

AGA Report No. 8, *Compressibility Factor of Natural Gas and Related Hydrocarbon Gases*

GPA Standard 2145 [2], *Table of Physical Properties for Hydrocarbons and Other Compounds of Interest to the Natural Gas Industry*

GPA Standard 2166, *Obtaining Natural Gas Samples for Analysis by Gas Chromatography*

GPA Standard 2261, *Analysis for Natural Gas and Similar Gaseous Mixtures by Gas Chromatography*

GPA Standard 2286, *Tentative Method of Extended Analysis for Natural Gas and Similar Gaseous Mixtures by Temperature Programmed Gas Chromatography*

GPA Standard 2377, *Test for Hydrogen Sulfide and Carbon Dioxide in Natural Gas Using Length of Stain Tubes*

GPA Standard 8173, *Method for Converting Mass of Natural Gas Liquids and Vapors to Equivalent Liquid Volumes*

GPA TP-17, *Table of Physical Properties of Hydrocarbons for Extended Analysis of Natural Gases*

IGT Research Bulletin No. 8 [3], *Equilibrium Moisture Content of Natural Gases*

3 Terms and Definitions

For purposes of this standard, the following terms and definitions apply.

3.1
adjusted heating value

The quantity Hv^{id} / Z (adjusted heating value) is energy transferred as heat per real gas volume. When multiplied by the

---

[1] American Gas Association, 400 N. Capitol St., N.W., Suite 450, Washington, D.C. 20001, www.aga.org.

[2] Gas Processors Association, 6526 E. 60th Street, Tulsa, Oklahoma 74145, www.gasprocessors.com.

[3] Institute of Gas Technology, 1700 S. Mount Prospect Road Des Plaines, Illinois 60018, www.gastechnology.org.

real gas volume, it gives the energy transferred as heat from combustion in an ideal gas reaction per volume of the fuel as a real gas.

3.2

as-delivered

A condition for water vapor entrained in the gas. The term “as-delivered” can reference “saturated gas at flowing conditions” (see 3.13) or “partially saturated gas” (see 3.9).

3.3

base conditions

Base conditions are certain pressure and temperature conditions selected for a specific purpose such as defined by state and federal laws and regulations or to meet the needs of contracting parties. Common base pressures in the U.S. include 14.65 psia, 14.73 psia, and 15.025 psia. The base temperature in the U.S. is usually 60 °F.

3.4

Btu

The Btu (British thermal unit) is a measurement unit for a quantity of energy transferred as heat.

3.5

compressibility factor

The compressibility factor is the ratio of the actual volume of a given mass of gas to its volume calculated from the ideal gas law using given conditions of temperature and pressure.

3.6

dry gas

Dry gas contains no water, however, for practical purposes, contracting parties often define “dry” to include small quantities of water. In the U.S., dry gas is typically specified to not exceed 7 lb of water per million standard cubic feet (MMSCF) of gas.

3.7

gross heating value

higher heating value

HHV

The gross heating value, Hv^{id}, is the amount of energy transferred as heat per mole, unit mass or unit volume from the complete, ideal combustion of the gas with oxygen at a base temperature in which all water formed by the reaction condenses to liquid. As explained in Annex A, this is a hypothetical state, but it is acceptable for custody transfer. Reporting the gross heating value on a volumetric rather than a mass or molar basis requires a base pressure along with a base temperature. Spectator water does not contribute to the gross heating value.

3.8

ideal gas

An ideal gas is a hypothetical gas which would follow the characteristic equation $PV = nRT$ under all conditions.

3.9

partially saturated gas

Partially saturated gas contains some quantity of water vapor less than that present under saturated conditions, but more than dry, normally expressed in mass of water per unit volume of delivered gas at defined conditions. The water content for partially saturated gas typically is the quantity measured using a chilled mirror, moisture analyzer or other device commonly accepted in the industry. In the U.S., partially saturated gas normally is expressed as pounds of water per MMSCF of delivered gas.

3.10

real gas

A real gas is one that does not obey the ideal gas law. Instead its behavior follows the expression: $PV = ZnRT$ where Z is the compressibility factor, and Z usually does not equal 1.0. For an ideal gas, Z always equals 1.0.

3.11

relative density

Relative density is the ratio of the mass density of the gas at the measurement temperature and pressure to the mass density of dry air (the assumed composition of air appears in Table A.1) at the same temperature and pressure. In the hypothetical ideal gas state, the relative density becomes the molar mass ratio.

3.12

saturated gas at base conditions

Saturated gas at base conditions contains the equilibrium amount of water vapor at base pressure and temperature. In the U.S., the quantity normally is expressed as pounds of water per MMSCF of delivered gas.

3.13

saturated gas at flowing conditions

Saturated gas at flowing conditions contains the equilibrium amount of water vapor at flowing pressure and temperature and is normally calculated by means of an algorithm. In the U.S., the quantity normally is expressed as pounds of water per MMSCF of delivered gas.

3.14

spectator water

Spectator water is water carried by the gas or air that feeds the combustion reaction. Spectator water does not contribute to the gross heating value.

3.15

theoretical hydrocarbon liquid content

The theoretical hydrocarbon liquid content is the amount of liquid theoretically condensable per unit volume of gas at base conditions. In the U.S., the term GPM (gallons of liquid hydrocarbon per thousand cubic feet of gas) is used.

3.16

wet gas

Gas that contains water, however, for practical purposes contracting parties often define wet as greater than 7 lb of water per million standard cubic feet of gas, i.e. gas that is either partially or completely water saturated.

4 Symbols and Abbreviated Terms

a	(subscript) property of air
b	(subscript) base condition
b_i	summation factors from GPA 2145
B_{ij}	second virial coefficient
Btu	British thermal unit. 1 Btu ≈ 1055.056 J (Btu_{IT})
Btu/lbm	Btu per pound mass. 1 Btu/lbm = 2.326 J g^{-1} (exact)
d	mass density
ε	excess air
ft^3	cubic foot. 1 ft^3 ≈ 0.0283168 m^3
G	relative density
GPM	gallons per thousand cubic feet (mcf) at base conditions
h	humidity
Hv	gross heating value
i	(subscript) i^{th} component
j	(subscript) i^{th} component
id	(superscript) an ideal gas property

lbm	pound mass. 1 lbm = 453.59237 g (exact)
LC	theoretical hydrocarbon liquid content (which can be expressed as gallons per thousand cubic feet, GPM)
M	molar mass
MMBtu	million Btu
MMSCF	million standard cubic feet
N	total number of components
NGL	natural gas liquids
n	number of moles
P	pressure
P_w^{sat}	vapor pressure of water at the base temperature
R	universal gas constant[4] = 8.314472 J mol^{-1} K^{-1}
	= 10.7316 psia ft^3 (lbmol ˚R)$^{-1}$
T	temperature
V	volume
x	mole fraction
x_w	mole fraction of water
Z	compressibility factor, the ratio of real gas volume to the ideal gas volume

5 Background

5.1 Heating Value

Heating value reported on a unit volume basis is energy transferred in an ideal gas reaction per volume of ideal gas fuel. When divided by Z, the heating value provides the energy transferred in an ideal gas reaction per volume of real gas fuel. The water content is on a basis of dry, saturated at base conditions, or “as delivered” (actual condition of gas may be partially saturated or saturated at flowing conditions). The heating value used in most calculations is the gross heating value represented as energy per unit of real gas volume, which is defined in this standard as the adjusted heating value.

The adjusted heating value determines the ideal energy content of a real gas volume. This heating value, when multiplied by the real volumetric flow rate produces the ideal energy flow rate.

5.2 Relative Density

For a gas, the relative density may be reported on an ideal basis or a real basis. The first step in the relative density calculation is to calculate the relative density for the gas on its ideal basis. Because all real gases deviate from the ideal gas law, the relative density of a gas must be adjusted by the compressibility factor. Industry practice may use the relative density value in calculations. It is important for the user to understand the subsequent calculations and provide either real or ideal relative densities as required.

5.3 Compressibility Factor

The compressibility factor calculations in this standard apply to pressures near atmospheric (such as those calculated and reported for gas analyses). Ideally, the compressibility calculation method used in the heating value calculation would be the same as that used in the volume calculation. Volume calculation standards currently require use of the latest version of AGA Report No. 8 to determine the compressibility factor.

---

[4] GPA Standard 2145-09, use latest revision.

5.4 Theoretical Hydrocarbon Liquid Content

The theoretical hydrocarbon liquid content is the amount of liquid hydrocarbon by component that theoretically could be condensed from a gas. In the U.S., this is commonly termed gallons of a particular hydrocarbon liquid per thousand cubic feet of natural gas at the analysis conditions (abbreviated GPM).

The gas portion of the volume ratio of gas to liquid reported in GPA 2145 is on an ideal basis, so the calculated value has the same basis. The ideal theoretical hydrocarbon liquid content must be corrected for compressibility factor to be on a real volume basis. For example, in the U.S., dividing GPM by Z results in gallons of a component per thousand cubic feet of real gas, which can then be applied consistently to a real volume of natural gas.

6 Summary of Method

From the composition of a natural gas sample, it is possible to calculate the gross heating value, relative density, compressibility factor and theoretical hydrocarbon liquid content for the sample.

The gas sample should be collected according to the latest version of GPA 2166, API *MPMS* Ch. 14.1 or other acceptable methods. To ensure accuracy of this method, the gas sample must be representative of the gas under consideration.

The sample analysis for hydrocarbons and inerts including helium and oxygen should conform to the latest version of GPA 2261, or other technically acceptable methods that meet or exceed GPA standards for repeatability and reproducibility. Hydrogen sulfide concentration should be determined in accordance with GPA 2377 or other industry standard method. Water content should be determined by a physical test or calculated according to the assumptions in this Standard or by other means as agreed to by the parties involved.

Component properties used in the calculations for gross heating value, relative density, compressibility factor and theoretical hydrocarbon liquid content appear in the latest edition of GPA 2145 and similar industry publications.

When analyzing a sample for composition, it is essential to include all components with mole fractions greater than or equal to 0.0001 in the analysis or within the detectable limits of the analyzing equipment, such as is covered by GPA 2261 or GPA 2286. A threshold of 0.00001 mole fraction or less may be used to identify trace constituents. The results of the compositional analysis should be expressed to the same precision. Some routine analyses ignore constituents such as water, helium, hydrogen sulfide and oxygen. This practice reduces the accuracy of the calculated results if one or more of these constituents are present. Note that hydrogen sulfide, when present as a contaminant that must be removed from the natural gas stream before final use, usually is assigned no heating value. Water vapor is treated similarly.

7 Equations for Custody Transfer Calculations

7.1 Gross Heating Value (Volumetric Basis)

The gross heating value as a function of composition is:

$$Hv^{id}(\mathrm{dry}) = x_1 Hv_1^{id} + x_2 Hv_2^{id} + \cdots + x_N Hv_N^{id} = \sum_{i=1}^{N} x_i Hv_i^{id} \tag{1}$$

$$Hv^{id}(\mathrm{wet}) = (1 - x_w)\, Hv^{id}(\mathrm{dry}) \tag{2}$$

where

Hv^{id} is the gross heating value per unit volume at base temperature and pressure;

Hv_i^{id}	is the Hv^{id} of i^{th} component;
^{id}	is the (superscript) denotation of an ideal gas property;
dry	is the dry gas;
wet	is the gas containing water;
x_i	is the mole fraction of i^{th} component;
N	is the total number of components (excluding water);
x_w	is the mole fraction of water in the gas.

This standard assumes that the composition from the gas chromatograph is reported without water vapor (dry*)*, which is the usual case. Annex A illustrates procedures for compositions that include water. For saturated gas at base conditions the mole fraction of water in the gas is approximately:

$$x_w = P_w^{\text{sat}} / P_b \tag{3}$$

where

P_w^{sat}	is the vapor pressure of water at the base temperature; and
P_b	is the base pressure.

Table 1 provides the (1 – x_w) multiplier resulting from Equation (3) for some common base pressures used in the United States with a base temperature of 60 °F where the vapor pressure of water [5] is 0.25640 psia.

Table 1—U.S. Multipliers

P_b (psia)	$1-x_w$
14.65	0.9825
14.696	0.9826
14.73	0.9826
15.025	0.9829

Table 2 presents (1 – x_w) for some common base temperatures used outside the United States at a base pressure of 101.325 kPa.

Table 2—Temperature Multipliers

T_b (°C)	$1-x_w$
0	0.9940
15	0.9832
20	0.9769
25	0.9687

For saturated gas at other than base conditions, the mole fraction of water in the gas should be calculated using the methodology in IGT Bulletin No. 8 or another appropriate industry standard. For partially saturated wet gas, the mole percentage of water in the gas must be determined by an actual measurement or its mole percentage may be defined or assumed by statute or contract.

7.2 Relative Density

The relative density for a real gas is:

$$G = d / d_a = \left(MPT_aZ_a\right) / \left(M_aP_aTZ\right) \tag{4}$$

---

[5] Wagner, W. and Pruss, A., "The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use," *J. Phys. Chem. Ref. Data*, 31(2):387 – 535, 2002.

if $T = T_a$ and $P = P_a$ then

$$G = \left(M / M_a\right)\left(Z_a / Z\right) = G^{id}\left(Z_a / Z\right) \tag{5}$$

where

G is the relative density;
d is the mass density;
M is the molar mass;
P is the pressure;
T is the temperature;
Z is the compressibility factor;
$_a$ is the (subscript) denotes a property of air.

Calculation from composition uses:

$$G^{id} = x_1 G_1^{id} + x_2 G_2^{id} + \cdots + x_N G_N^{id}$$

$$= \sum_{i=1}^{N} x_i G_i^{id} \tag{6}$$

G^{id} is the desired result because relative density is a means to determine the molar mass ratio. G^{id} is independent of base pressure, however G varies with base pressure because Z_a and Z are functions of base pressure.

7.3 Compressibility Factor

There are a number of methods to calculate compressibility. This section discusses two of the methods.

At base conditions (near atmospheric pressure), a simple expression that provides the compressibility (real gas) factor within experimental error for natural gas mixtures is:

$$Z = 1 - P_b \left[\sum_{i=1}^{N} x_i b_i\right]^2 \tag{7}$$

where the b_i are the summation factors as defined in the latest revision of GPA 2145.

An alternative rigorous procedure, uses:

$$Z = 1 + BP_b \tag{8}$$

in which:

$$B = \sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j B_{ij} \tag{9}$$

where

x_i is the first compound mole fraction;
x_j is the second compound mole fraction;
B_{ij} is the second virial coefficient, refer to Table 3.

Example B.11 illustrates this rigorous method and has been adapted so that the C_6+ fraction uses the nC_6 second virial coefficient.

The latest version of AGA Report No. 8 is required for compressibility determination in applications such as flow calculations for gas measurement.

7.4 Theoretical Hydrocarbon Liquid Content

Plant settlement, accounting and allocation calculations often rely upon the theoretical component liquid volumes for each hydrocarbon component contained in a natural gas stream. These theoretical component volumes result from multiplying the volume of natural gas by the theoretical hydrocarbon liquid content determined from a representative gas sample. In U.S. customary units, liquid volumes are gallons and gas volumes are thousands of cubic feet (MCF) yielding the expression GPM or gallons per thousand cubic feet for this property.

The theoretical hydrocarbon liquid content may require adjustment for contractual pressure base conditions (P_b) that are not the same as the standard pressure associated with the physical properties.

$$LC_i^{id} = x_i \times K_{\text{units}} \times \frac{1}{(V_{\text{gas},id} / V_{\text{liquid}})_i} \times \frac{P_b}{P_{\text{std}}} \quad (10)$$

where

LC is the theoretical hydrocarbon liquid content;
x is the mole fraction;
K_{units} is the unit conversion;
V is the volume;
P_b is the base pressure;
P_{std} is the standard pressure at which the ideal gas volume per liquid volume is reported;
$_i$ is the (subscript) denotes a property of component i.

The calculation of component liquid volume equivalent expressed as gallons per thousand ideal standard cubic feet (GPM$_i$) of natural gas from composition is

$$LC_i^{id} = x_i \times 1000 \times \frac{1}{(\text{ft}^3_{\text{gas},id} / \text{gal}_{\text{liquid}})_i} \times \frac{P_b}{14.696} \quad (11)$$

where

LC is the theoretical hydrocarbon liquid content;
x is the mole fraction;
$(\text{ft}^3_{\text{gas},id} / \text{gal}_{\text{liquid}})$ is the volume of ideal gas in cubic feet per gallon of liquid from GPA 2145;
P_b is the base pressure in psia; and
$_i$ is the (subscript) denotes a property of component i.

The volume of ideal gas per unit volume of liquid for the heaviest hydrocarbon component grouping is recommended to be established by extended analysis of the sample or another method as discussed in Section 9. See Example B.10 for a typical calculation of a C_6+ GPM from C_6s, C_7s and C_8s.

Because the gas portion of the gas/liquid volume ratio is on an ideal basis, the calculated theoretical hydrocarbon liquid content has the same basis. Dividing LC by Z results in a quantity of a liquid component per real unit volume of gas, which can then be consistently applied to a real volume of natural gas. For calculation of theoretical component liquid volumes from real gas volumes the ideal theoretical hydrocarbon liquid content shall be corrected for compressibility.

$$LC_i = \frac{LC_i^{id}}{Z} \quad (12)$$

Where theoretical hydrocarbon liquid content has units of GPM, commonly used in the U.S., the GPM shall be corrected for compressibility.

$$\mathrm{GPM}_i = \frac{\mathrm{GPM}_i^{id}}{Z} \tag{13}$$

Where the gas analysis is reported without water vapor (dry) and the measured volume is water saturated at either base or delivery conditions, the theoretical hydrocarbon liquid content quantity must be corrected for the water content since the LC (GPM) factors were calculated on a dry basis.

Table 3—Second Virial Coefficients

First compound	Second compound	Second Virial Coefficient B_{ij}, 10^3 $psia^{-1}$ at 60 °F
Hydrogen	Hydrogen	0.041
Hydrogen	Helium	0.046
Hydrogen	Nitrogen	0.035
Hydrogen	Oxygen	0.032
Hydrogen	Hydrogen Sulfide	0.002
Hydrogen	Carbon Dioxide	–0.066
Hydrogen	Methane	0.022
Hydrogen	Ethane	0.032
Hydrogen	Propane	0.016
Hydrogen	I–Butane	0.000
Hydrogen	N–Butane	0.026
Hydrogen	I–Pentane	0.069
Hydrogen	N–Pentane	–0.012
Hydrogen	C_6+ (as nC_6)	–0.010
Helium	Helium	0.034
Helium	Nitrogen	0.060
Helium	Oxygen	0.063
Helium	Hydrogen Sulfide	0.043
Helium	Carbon Dioxide	0.051
Helium	Methane	0.070
Helium	Ethane	0.057
Helium	Propane	0.098
Helium	I-Butane	0.075
Helium	N-Butane	0.128
Helium	I-Pentane	0.075
Helium	N-Pentane	0.075
Helium	C_6+ (as nC_6)	0.080
Nitrogen	Nitrogen	–0.019
Nitrogen	Oxygen	–0.037
Nitrogen	Hydrogen Sulfide	–0.135
Nitrogen	Carbon Dioxide	–0.144
Nitrogen	Methane	–0.060
Nitrogen	Ethane	–0.152
Nitrogen	Propane	–0.237
Nitrogen	I-Butane	–0.213
Nitrogen	N-Butane	–0.250
Nitrogen	I-Pentane	–0.326
Nitrogen	N-Pentane	–0.280
Nitrogen	C_6+ (as nC_6)	–0.373
Oxygen	Oxygen	–0.053
Oxygen	Hydrogen Sulfide	–0.161
Oxygen	Carbon Dioxide	–0.118
Oxygen	Methane	–0.052
Oxygen	Ethane	–0.124
Oxygen	Propane	–0.201
Oxygen	I-Butane	–0.270
Oxygen	N-Butane	–0.293
Oxygen	I-Pentane	–0.391
Oxygen	N-Pentane	–0.474
Oxygen	C_6+ (as nC_6)	–0.508
Hydrogen Sulfide	Hydrogen Sulfide	–0.641
Hydrogen Sulfide	Carbon Dioxide	–0.416
Hydrogen Sulfide	Methane	–0.241
Hydrogen Sulfide	Ethane	–0.445
Hydrogen Sulfide	Propane	–0.842
Hydrogen Sulfide	I-Butane	–1.112
Hydrogen Sulfide	N-Butane	–1.152
Hydrogen Sulfide	I-Pentane	–1.436
Hydrogen Sulfide	N-Pentane	–1.476
Hydrogen Sulfide	C_6+ (as nC_6)	–1.876
Carbon Dioxide	Carbon Dioxide	–0.388
Carbon Dioxide	Methane	–0.181
Carbon Dioxide	Ethane	–0.385
Carbon Dioxide	Propane	–0.618
Carbon Dioxide	I-Butane	–0.819
Carbon Dioxide	N-Butane	–0.862
Carbon Dioxide	I-Pentane	–1.063
Carbon Dioxide	N-Pentane	–1.091
Carbon Dioxide	C_6+ (as nC_6)	–1.379
Methane	Methane	–0.135
Methane	Ethane	–0.281
Methane	Propane	–0.425
Methane	I-Butane	–0.457
Methane	N-Butane	–0.560
Methane	I-Pentane	–0.632
Methane	N-Pentane	–0.675
Methane	C_6+ (as nC_6)	–0.793
Ethane	Ethane	–0.569
Ethane	Propane	–0.833
Ethane	I-Butane	–1.005
Ethane	N-Butane	–1.106
Ethane	I-Pentane	–1.293
Ethane	N-Pentane	–1.379
Ethane	C_6+ (as nC_6)	–1.652
Propane	Propane	–1.183
Propane	I-Butane	–1.522
Propane	N-Butane	–1.666
Propane	I-Pentane	–1.953
Propane	N-Pentane	–2.068
Propane	C_6+ (as nC_6)	–2.542
I-Butane	I-Butane	–2.097
I-Butane	N-Butane	–1.982
I-Butane	I-Pentane	–2.556
I-Butane	N-Pentane	–2.614
I-Butane	C_6+ (as nC_6)	–3.317
N-Butane	N-Butane	–2.289
N-Butane	I-Pentane	–2.671
N-Butane	N-Pentane	–2.915
N-Butane	C_6+ (as nC_6)	–3.404
I-Pentane	I-Pentane	–3.375
I-Pentane	N-Pentane	–3.504
I-Pentane	C_6+ (as nC_6)	–4.452
N-Pentane	N-Pentane	–3.978
N-Pentane	C_6+ (as nC_6)	–4.739
C_6+ (as nC_6)	C_6+ (as nC_6)	–6.434

8 Example Calculations

Refer to Annex B for the following example calculations.

Table B.1	Calculation of gas properties at 60 °F and 14.696 psia for a dry gas.
Table B.2	Calculation of gas properties at 60 °F and 14.65 psia for a dry gas.
Table B.3	Calculation of gas properties at 60 °F and 14.696 psia for a water saturated gas.
Table B.4	Calculation of gas properties at typical base conditions of 60 °F and 14.65 psia for a water saturated gas.
Table B.5	Calculation of gas properties at 60 °F and 14.696 psia for a water saturated gas at flowing conditions of 76 °F and 28 psia.
Table B.6	Calculation of gas properties at 60 °F and 14.65 psia for a water saturated gas at flowing conditions of 76 °F and 28 psia.
Table B.7	Calculation of gas properties at 60 °F and 14.696 psia for a measured and partially water saturated gas.
Table B.8	Calculation of gas properties at 60 °F and 14.65 psia for a measured and partially water saturated gas.
Table B.9	Calculation of gas properties at 15 °C and 101.325 kPa for a water saturated gas.
Table B.10	Calculation for determining the C_6+ gas properties using two commonly used methods.
Table B.11	Calculation for compressibility using the rigorous procedure.

In the examples, the component heating values, relative densities and GPMs are corrected for compressibility. The summation of ideal component values, such as ideal heating value, relative density and GPM, are not reported in the examples because their application beyond the use as intermediate steps in the analysis calculation can lead to misapplication and subsequent errors.

The calculations in the following examples use the physical properties for the components from GPA 2145-09.

9 Application Notes and Cautions

All calculations shall use the physical properties from the latest version of GPA 2145. If a component in the calculation is not present in GPA 2145, refer to GPA TP-17 for its properties.

A typical natural gas analysis determines the individual quantity of components lighter than hexanes, and groups the hexanes and heavier components into a single quantity. Characterization of the physical constants for hexanes and heavier components, commonly referred to as C_6+, should use the most representative data available for the sample. Similar methodology can be used to group on a different component such as heptanes and heavier (C_7+). This characterization may be:

- based upon the composition of the C_6+ fraction determined in an extended chromatographic analysis performed in accordance with GPA 2286 or other equivalent method; (preferred method);
- generalized through an engineering evaluation; and
- as agreed upon among parties involved.

Table B.10 in Annex B provides example calculations for two commonly used characterizations.

While some chromatographs may detect water vapor in the analysis, there is no practical way to quantify the amount of water vapor. Other chromatographs may not be capable of detecting water vapor. The analysis report should include the method used to determine the water vapor content and calculation parameters, if applicable.

Be aware that excluding water vapor from the analysis of a wet gas stream causes inaccuracy in the relative density, compressibility at base conditions and LC (GPM).

Total energy results from multiplying a volume of gas by the heating value per unit volume, both being at the same conditions of pressure, temperature and water content. The base temperature and the base pressure must be the same for both the gas volume and the heating value. When the flowing stream is water saturated, the total energy delivered can be determined by compensating for water vapor in the analysis and subsequent heating value or by volumetrically quantifying the water vapor in the flowing stream, but not both. For example, a gas volume containing water vapor (wet volume) must be multiplied by a wet heating value. If the gas volume is compensated by mathematically removing the water vapor, then the dry heating value must be used to calculate total energy delivered. While it is technically consistent to apply one or the other, this document only addresses water in the analysis calculations.

The prediction of water vapor content at flowing pressure and temperature assumes the gas is water saturated. If the flowing stream conditions are downstream of a compressor where heat of compression is added to the flowing stream, the user must determine whether the stream is, in fact, water saturated. Heater-treaters, separators, piping and other equipment conditions can also affect the water vapor content in the flowing stream causing it to be water saturated, partially water saturated or water saturated with condensed water.

It is recognized that parties may enter into a contractual agreement different from this standard.

10 Precision and Uncertainty

The properties reported in this document derive from experimental measurements that, in general, are accurate to no better than 1 part in 1000. The extra digits that appear in the examples alleviate problems associated with round-off and internal consistency, but they are not significant.

Annex A
(informative)

Details of Calculation Methods and Treatment of Water

A.1 General

Custody transfer of natural gas utilizes a simple pricing equation which states that the cost of gas is the rate of energy released upon combustion multiplied by the price of gas per energy unit multiplied by the time or accounting period. The rate of energy released upon combustion is the product of the heating value of the gas and the flowrate of the gas. The flowrate of the gas requires knowledge of the compressibility factor and the relative density of the gas. All three custody transfer properties of heating value, compressibility factor, and relative density can be calculated from the composition given pure component property tables such as those published in GPA 2145.

This annex presents equations to calculate from composition the custody transfer properties of natural gas. The equations for calculating the properties of dry natural gas are well known, but this annex also presents an account of the effects of water contained in the gas and in the air used to burn the gas.

A.2 Equation Development

The heating value of a natural gas is the absolute value of its enthalpy of combustion in an ideal combustion reaction. The heating value is, therefore, an ideal gas property that can be calculated unambiguously from tables of pure component values and it has no pressure dependence.

An ideal combustion reaction with fuel and air in the ideal gas state and the possibility of water in the fuel and air is:

$$\begin{aligned}
&C_\alpha H_\beta S_\gamma(id)+(\alpha+\beta/4+\gamma)(1+\varepsilon)\mathrm{O_2}(id)+0.04383(\alpha+\beta/4+\gamma)(1+\varepsilon)Ar(id)\\
&+\left[0.00162(\alpha+\beta/4+\gamma)(1+\varepsilon)+x_c/(1-x_N-x_C)\right]\mathrm{CO_2}(id)\\
&+\left[3.727873(\alpha+\beta/4+\gamma)(1+\varepsilon)+x_N/(1-x_N-x_C)\right]\mathrm{N_2}(id)+\left(n_w^g+n_w^a\right)\mathrm{H_2O}(id)\\
&=\left[\alpha+0.00162(\alpha+\beta/4+\gamma)(1+\varepsilon)+x_c/(1-x_N-x_C)\right]\mathrm{CO_2}(id)\\
&+n_w^v\mathrm{H_2O}(id)+n_w^1\mathrm{H_2O}(1)+\gamma\mathrm{SO_2}(id)\\
&+\left[3.72873(\alpha+\beta/4+\gamma)(1+\varepsilon)+x_N/(1-x_n-x_c)\right]\mathrm{N_2}(id)\\
&+0.04383(\alpha+\beta/4+\gamma)(1+\varepsilon)Ar(id)+(\alpha+\beta/4+\gamma)\varepsilon\mathrm{O_2}(id)
\end{aligned} \qquad \text{(A.1)}$$

where

id	denotes the ideal gas state;
α , β , and γ	are the stoichiometric coefficients,
ε	is the fraction of excess air, the composition of air is assumed to be that of Table A.1;
n_w^g	are the moles of water contained in the gas;
n_w^a	are the moles of water contained in the air;
n_w^v	are the moles of water contained in the product gas mixture;
n_w^ℓ	are the moles of water that actually condense;
x_C	is the mole fraction of $\mathrm{CO_2}$ in the gas;
x_N	is the mole fraction of $\mathrm{N_2}$ in the gas.

If air has been injected into the gas, it is assumed that the effect is accounted for in the excess fraction ε. Fuel gas mixtures would have non-integer values of α, β, and γ.

It is customary to define hypothetical reference states for the water formed by the reaction denoted by Equation (A.1) (as opposed to "spectator" water that enters the reaction carried by the gas, n_w^g, and air, n_w^a, and does not contribute to the combustion reaction). If we assume that the water formed in the reaction remains in the ideal gas state, the heating value is termed "net." If we assume that the water formed in the reaction condenses totally to the liquid state, the heating value is termed "gross." Both net and gross states are hypothetical and not realized in practice. The gross heating value is greater than the net heating value by the ideal enthalpy of vaporization for water:

$$\text{Heating value (gross)} - \text{Heating value (net)} = H_w(id) - H_w(\ell) \tag{A.2}$$

where

H is the enthalpy;
ℓ is the liquid state;
w is the water.

The quantity $H_w(id) - H_w(\ell)$ is the ideal enthalpy of vaporization for water.

It is possible to calculate a real gas heating value rather than using a hypothetical state, but the calculations are tedious, the numerical values are negligibly different and the mathematical simplicity of the defining equation is lost. It is customary in the gas industry to use gross heating value for most calculations, so for the remainder of this annex the term "heating value" refers to the gross value.

Heating value is measured on a mass or molar basis and converted to the ideal gas state for reporting. Thus, at any given temperature the heating value is:

$$Hn^{id} = \sum_{i=1}^{N} x_i Hn_i^{id} \tag{A.3}$$

$$Hm^{id} = \sum_{i=1}^{N} x_i M_i Hm_i^{id} / \sum_{i=1}^{N} x_i M_i \tag{A.4}$$

where

Hn^{id} is the heating value in energy per mole;
x_i is the mole fraction;
N is the number of components in the mixture;
Hm^{id} is the heating value in energy per mass;
M is the molar mass.

Clearly, Hm^{id} multiplied by the molar mass (with units of mass per mole) gives Hn^{id}. Both Hn^{id} and Hm^{id} are independent of pressure, but both are functions of temperature and composition.

The natural gas industry uses heating value with dimensions of energy per volume in its calculations. These dimensions result from multiplying Hn^{id} or Hm^{id} by density or mass density of the ideal gas respectively:

$$Hv^{id} = (P/RT)Hn^{id} = (MP/RT)Hm^{id} = \sum_{i=1}^{N} x_i Hv_i^{id} \tag{A.5}$$

where

Hv^{id} is the heating value in energy per volume;
P is absolute pressure;
T is absolute temperature and R is the gas constant.

Hv^{id} depends upon temperature, composition and pressure. GPA 2145 contains values for Hv^{id} at 60 ˚F and 14.696 psia. These values are only valid at the specified T and P. Conversion to another pressure is simply a matter of multiplying by the ratio of the new P and 14.696 psia:

$$Hv^{id} = Hv^{id}{}_{\text{(GPA 2145)}}\left[\frac{P}{14.696}\right] \tag{A.6}$$

When using Equation (A.6), $Hv^{id}{}_{\text{(GPA 2145)}}$ should be calculated using the values from GPA 2145 in Equation (A.5). The correct result is obtained when making the pressure base adjustment after summing the component heating values, using a calculation method with sufficient numerical precision, such as is found in typical spreadsheet software.

Conversion to another temperature is more complicated. Heating value data exist at 25 ˚C based upon the reaction:

$$C_\alpha H_\beta S_\gamma\left(id\right)+\left(\alpha+\beta/4+\gamma\right)\mathrm{O}_2\left(id\right)=\alpha\mathrm{CO}_2\left(id\right)+\left(\beta/2\right)\mathrm{H}_2\mathrm{O}\left(1\right)+\gamma\mathrm{SO}_2\left(id\right) \tag{A.7}$$

The experiments use pure oxygen and are corrected to stoichiometric proportions. It is necessary to correct the sensible heat effects to arrive at a different temperature:

$$Hn^{id}\left(T\right)=Hn^{id}\left(25\right)+\int_{25}^{T}\left[\sum_{rr}C_P^{id}-\sum_{r}C_P^{id}\right]dT \tag{A.8}$$

where

$$\sum_{rr}C_p^{id}=\alpha C_{p,CO_2}^{id}+\left(\beta/2\right)C_{p,H_2O}^{id}+\gamma C_{p,SO_2}^{id} \tag{A.9}$$

$$\sum_{r}C_p^{id}=C_{p,C\alpha H_\beta S_\gamma}^{id}+\left(\alpha+\beta/4+\gamma\right)C_{p,O_2}^{id} \tag{A.10}$$

and C_p^{id} is the ideal specific heat at constant pressure, r denotes reactants and rr denotes products.

The cost of gas comes from the simple accounting equation:

$$c=\dot{Q}^{id}p^{id}\Delta t \tag{A.11}$$

where

c is the cost;

$\dot{Q}^{id}$ is the ideal rate of energy transfer;

p^{id} is the price of gas per ideal energy unit;

Δt is the accounting period.

Using real gas rate of energy transfer merely requires a price of gas per real energy unit which would differ from that in Equation (A.11) in exact proportion to the ratio of $\dot{Q}$ and $\dot{Q}^{id}$:

$$\dot{Q}^{id}p^{id}=\dot{Q}p \tag{A.12}$$

$\dot{Q}^{id}$ results from multiplication of heating value by gas flowrate:

$$\dot{Q}^{id}=\dot{n}Hn^{id}=\dot{m}Hm^{id}=\dot{V}^{id}Hv^{id} \tag{A.13}$$

where

$\dot{n}$, $\dot{m}$ and $\dot{V}^{id}$ are the molar, mass and ideal gas flowrates, respectively.

Gas industry practice dictates use of real gas volumetric flowrate (most flowmeters, such as orifices, provide naturally the mass flowrate which, if used, would eliminate the need for pressure and temperature base corrections). Thus, it is necessary to convert the real gas flowrate into an ideal gas flowrate to use in Equation (A.13), by:

$$\dot{V} = \dot{V}^{id} Z \tag{A.14}$$

where Z is the compressibility factor (which is defined as the ratio of real gas volume to ideal gas volume). Now the energy flowrate becomes:

$$\dot{Q}^{id} = \left(\dot{V} / Z\right) Hv^{id} \tag{A.15}$$

The factor *1/*Z in Equation (A.15) rigorously converts the real gas flowrate into an ideal gas flowrate. It does not convert heating value into a real gas property. Often calorimeter and chromatograph manufacturers report the value of Hv^{id} / Z as output. This is a convenience for the user allowing immediate multiplication by $\dot{V}$ and thus satisfying Equation (A.15).

The truncated virial equation of state satisfactorily represents Z at pressures near ambient by:

$$Z = 1 + BP / RT \tag{A.16}$$

where B is the second virial coefficient which is a function only of temperature and composition.

$$B = \sum_{i=1}^{N} \sum_{j=1}^{N} x_i x_j B_{ij} \tag{A.17}$$

An approximation for B that is computationally simple is:

$$-B / RT = \left[\sum_{i=1}^{N} x_i b_i \right]^2 \tag{A.18}$$

where the b_i are "summation factors" which equal:

$$b_i = \sqrt{\frac{-B_i}{RT}} \tag{A.19}$$

GPA 2145 lists values for b_i .

Another property required to evaluate flowrate is the molar mass of the gas. The gas industry obtains this value from measurements of the gas relative density, which is the mass density of gas divided by the mass density of air:

$$G = d / d_a = MPT_a Z_a / M_a P_a TZ \tag{A.20}$$

where

d	is mass density;
subscript a	refers to air.

If the P and T of gas and air are identical (as recommended for measurement):

$$G = \left(M / M_a\right)\left(Z_a / Z\right) = G^{id} Z_a / Z \tag{A.21}$$

where

G^{id} is the ideal relative density which equals the molar mass ratio of gas to air.

The molar mass of air for the assumed composition is 28.9625 g mol^{-1}. G^{id} is a simple function of composition:

$$G^{id} = \sum_{t=i}^{N} x_1 G_i^{id} \tag{A.22}$$

GPA 2145 lists values for G^{id}.

A.3 Accounting for Water

If the gas contains (or is assumed to contain) water but the compositional analysis is on a dry basis, it is necessary to adjust the mole fractions to account for the fact that water has displaced some gas, thus lowering the heating value.

For gas containing water at or near base conditions the simplified approach that follows may be used. If gas contains water at other than base conditions, the saturated water content of the gas should be calculated using the methodology in IGT Bulletin 8. For partially saturated gas, the mole fraction of water in the gas must be determined by an actual measurement, or may be defined or assumed by statue or contract.

The remainder of this section deals with gas containing water at or near base conditions.

Under these conditions the mole fraction of water in the gas results from the definition of relative humidity:

$$x_w = h^g P_w^\sigma / P = n_w / (1 + n_w) \tag{A.23}$$

(based upon one mole of the fuel $C_\alpha H_\beta S_\gamma$) where

h^g is the relative humidity of the gas;

P_w^σ is the vapor pressure of water;

n_w denotes moles of water.

For saturated gas h^g is unity. Rearranging Equation (A.23) gives the moles of water:

$$n_w = x_w / (1 - x_w) \tag{A.24}$$

The corrected mole fractions then become:

$$x_i\left(\text{cor}\right) = x_i\left[\frac{1}{1+n_w}\right] = x_i\left[\frac{1}{1+x_w/\left(1-x_w\right)}\right] = \left(1-x_w\right)x_i \tag{A.25}$$

and the heating value becomes

$$Hv^{id} = \left(1-x_w\right)\sum_{i=1}^{N} x_i^{\text{dry}} Hv_i^{id} \tag{A.26}$$

where water is not included in the N components of the summation.

It is necessary to remove the effect of water because, although water has a heating value, it is only a condensation effect. Water carried by wet gas (spectator water) does not actually condense. Only water formed in the reaction contributes to heating value.

Accounting for water in the above manner is sufficient for defined custody transfer conditions, but when trying to model actual situations the question becomes much more complicated. It is obvious that all of the reaction water actually cannot condense because in a situation in which both gas and air are dry some of the reaction water saturates the product gases and the remainder condenses. It is possible to account for these effects in a general manner. To do so, it is necessary to calculate n_w^g, n_w^a, n_w^v, and n_w^ℓ.

$$\begin{aligned} &n_w^g / \left[1 + \left(x_N + x_C\right) / \left(1 - x_N - x_C\right) + n_w^g\right] = h^g P_w^\sigma / P \\ &n_w^g = \left(h^g P_w^\sigma / P\right) / \left[\left(1 - x_N - x_C\right)\left(1 - h^g P_w^\sigma / P\right)\right] \end{aligned} \tag{A.27}$$

$$\begin{aligned} &n_w^a / \left[4.77418\left(\alpha + \beta / 4 + \gamma\right)\left(1 + \varepsilon\right) + n_w^a\right] = h^a P_w^\sigma / P \\ &n_w^a = 4.77418\left(\alpha + \beta / 4 + \gamma\right)\left(1 + \varepsilon\right)\left(h^a P_w^\sigma / P\right) / \left(1 - h^a P_w^\sigma / P\right) \end{aligned} \tag{A.28}$$

$$\begin{aligned} &n_w^v / \Big\{\alpha + \gamma + \left(x_n + x_c\right) / \left(1 - x_n - x_c\right) + \left(\alpha + \beta / 4 + \gamma\right)\Big[0.00162\left(1 + \varepsilon\right) \\ &+ 3.72873\left(1 + \varepsilon\right) + 0.04383\left(1 + \varepsilon\right) + \varepsilon\Big] + n_w^v\Big\} = P_w^\sigma / P \\ &n_w^v = \Big\{\alpha + \gamma + \left(x_n + x_c\right) / \left(1 - x_n - x_c\right) + \left(\alpha + \beta / 4 + \gamma\right)\Big[0.00162\left(1 + \varepsilon\right) \\ &+ 3.72873\left(1 + \varepsilon\right) + 0.04383\left(1 + \varepsilon\right) + \varepsilon\Big]\Big\}\left(P_w^\sigma / P\right) / \left(1 - P_w^\sigma / P\right) \end{aligned} \tag{A.29}$$

$$n_w^\ell = \beta / 2 + n_w^g + n_w^a - n_w^v \tag{A.30}$$

where

h_a is the relative humidity of the air.

Equation (A.27) and Equation (A.28) are reformulations of Equation (A.23) to reflect inlet conditions. Equation (A.29) reflects Equation (A.23) for the saturated product gas (it must be saturated before any water can condense). Equation (A.30) is a water balance: $\beta / 2$ are the moles of water formed by the reaction, $n_w^g + n_w^a$ are the moles of spectator water which enter with the gas and air, n_w^v are the moles of water which saturate the product gas and n_w^ℓ are the moles of water which condense. Therefore, the complete correction for the effect of water on heating value is:

$$\begin{aligned} Hv^{id} = {} & Hv^{id}[\text{Equation (26)}] + \Big\{\left(h^g P_w^\sigma / P\right) / \left(1 - x_n - x_c\right)\left(1 - h^g P_w^\sigma / P\right) \\ & + 4.77418\left(\alpha + \beta / 4 + \gamma\right)\left(1 + \varepsilon\right)\left(h^a P_w^\sigma / P\right) / \left(1 - h^a P_w^\sigma / P\right) \\ & - \left[\alpha + \gamma + \left(x_n - x_c\right) / \left(1 - x_n - x_c\right) + \left(\alpha + \beta / 4 + \gamma\right)\left(3.77418 + 4.77418\varepsilon\right)\right] \\ & \times \left(P_w^\sigma / P\right) / \left(1 - P_w^\sigma / P\right)\Big\} Hv_w^{id} \end{aligned} \tag{A.31}$$

Depending upon the relative humidities of the gas and air, the observed heating value can be greater or smaller than that calculated using Equation (A.26). A humidity of air exists for each gas above which Hv^{id} is greater than that calculated by Equation (A.26). That critical value depends upon the gas composition, the humidity of the gas and the amount of excess air. For pure, dry methane with no excess air h_a = 0.79345.

A.4 Real Gas Properties

In principal, we have enough information to convert the heating value to a real gas property (it is not necessary to do so for relative density because the molar mass ratio, G^{id} , is the desired property). However, flow calculations would require heating value for a real gas at base conditions. This is simply a matter of evaluating the integral:

$$Hn - Hn^{id} = \int_{O}^{P} \left\{ \left[\left(\frac{\partial H}{\partial P} \right)_T \right]_{r'} - \left[\left(\frac{\partial H}{\partial P} \right)_T \right]_{r} \right\} dP \qquad \text{(A.32)}$$

where

$$\left(\frac{\partial H}{\partial P} \right)_T = V - T \left(\frac{\partial V}{\partial T} \right)_P = B - T\frac{dB}{dT} = 2RT^2 b \frac{dB}{dT} \qquad \text{(A.33)}$$

and V is the molar volume. The temperature dependence of b must be defined, but in the custody transfer region it is easy to do so. The products and reactants again correspond to Equation (A.7).

While more rigorous calculations are possible to convert the heating value into a real gas property, it serves no custody transfer purpose to do so. Over the range of contract base conditions in this standard, the influence of pressure on enthalpy departure is negligible. No adjustments are provided or recommended.

The heating value is defined in a hypothetical state. It is not possible, at base conditions, to have all the water formed in the reaction be either all gas or all liquid; some of the water formed is in each state. Thus, if the definition is of a hypothetical state, using a hypothetical real gas state rather than an ideal gas state adds nothing but complexity.

Table A.1—Assumed Composition of Air

Component	**Mole Fraction, x_i**	**Molar Mass, M**	$x_i \cdot M$
Nitrogen	0.78102	28.0134	21.87903
Oxygen	0.20946	31.9988	6.70247
Argon	0.00916	39.948	0.365924
Carbon dioxide	0.00033	44.0095	0.014523
Neon	0.0000182	20.1797	0.000367
Helium	0.0000052	4.0026	0.000021
Methane	0.0000015	16.0425	0.000024
Krypton	0.0000011	83.798	0.000092
Hydrogen	0.0000005	2.01588	0.000001
Nitrous oxide	0.0000003	44.0128	0.000013
Carbon monoxide	0.0000002	28.0101	0.000006
Xenon	0.0000001	131.293	0.000013
AIR			**28.9625**

The molar mass of air is given by GPA 2145 as 28.9625 and is consistent with ISO 6976-95 and AGA Report 5, 2008. Individual components in air may change over time based on empirical data but the molar mass of air, calculated from Table A.1, will remain constant within this document for the purposes of, but not limited to, the calculation of gas relative density. For information on individual components, refer to the appropriate component data table. Refer to AGA Report 5, 2008, Table 7.17.1.

Annex B
(informative)

Calculation of Gas Properties

The examples used in this annex are merely examples for illustration purposes only (each company should develop its own approach). They are not to be considered exclusive or exhaustive in nature. API/GPA make no warranties, express or implied for reliance on or any omissions from the information contained in this document.

B.1—Calculation of Gas Properties at 60 °F and 14.696 psia for a Dry Gas

Mole			$Hv_{i,id}$ at 14.696 psia	14.696	= base pressure				ft^3 ideal gas/gal liquid	GPM at
Percent		x_i		$G_{i,id}$	b_i	$x_i*Hv_{i,id}$	$x_i*G_{i,id}$	x_i*b_i	14.696	14.696
0.000	H_20	0.00000	0.00	0.62202	0.06510	0.00	0.00000	0.00000	175.620	0.000
0.030	Helium	0.00030	0.00	0.13820	0.00000	0.00	0.00004	0.00000	98.693	0.003
0.000	H_2S	0.00000	637.10	1.17670	0.02390	0.00	0.00000	0.00000	74.160	0.000
2.020	CO_2	0.02020	0.00	1.51950	0.01950	0.00	0.03069	0.00039	58.746	0.345
0.320	N_2	0.00320	0.00	0.96720	0.00442	0.00	0.00310	0.00001	91.128	0.035
0.000	O_2	0.00000	0.00	1.10480	0.00720	0.00	0.00000	0.00000	112.950	0.000
83.020	C_1	0.83020	1010.00	0.55390	0.01160	838.50	0.45985	0.00963	59.138	14.084
7.450	C_2	0.07450	1769.70	1.03820	0.02380	131.84	0.07735	0.00177	37.488	1.994
4.390	C_3	0.04390	2516.10	1.52250	0.03470	110.46	0.06684	0.00152	36.391	1.210
0.830	IC_4	0.00830	3251.90	2.00680	0.04410	26.99	0.01666	0.00037	30.637	0.272
1.080	NC_4	0.01080	3262.30	2.00680	0.04700	35.23	0.02167	0.00051	31.801	0.341
0.310	IC_5	0.00310	4000.90	2.49110	0.05760	12.40	0.00772	0.00018	27.414	0.113
0.250	NC_5	0.00250	4008.70	2.49110	0.06060	10.02	0.00623	0.00015	27.658	0.091
0.300	C_6+	0.00300	5129.22	3.21755	0.08637	15.39	0.00965	0.00026	22.975	0.131
100.00	Summation	1.00000				1180.8	0.6998	0.01480		18.618

Property	Value	Comments
Z (dry gas)	0.9968	1 – [Pressure Base * (Summation of x_i * b_i)^2]
Z (dry air)	0.9996	1 – [Pressure Base *(b_i of air)^2] where b_i of air = .00537
G (dry gas, dry air)	0.7018	G_{id} (dry gas) * Z (dry air) / Z (dry gas)
$Hv_{i,id}$ / Z (dry gas, dry air)	1184.6	$Hv_{i,id}$ (dry gas dry air) / Z (dry gas) @ 14.696

NOTES	$Hv_{i,id}$ for H_20 is taken as 0 because "spectator water" makes no contribution to heating value.
	Hexane plus (C_6+) values are arbitrary values assuming a 60 % n-Hexane, 30 % n-Heptane, and 10 % n-Octane split.
	Division of $Hv_{i,id}$ by Z does not give a real heating value but rather an ideal gas heating value per real cubic foot.
	Decimals beyond 1 part in 1000 are not significant and are carried only to alleviate round-off error.

This example uses physical properties from GPA 2145-09. Use properties from the current version of GPA 2145.

B.2—Calculation of Gas Properties at 60 °F and 14.65 Psia for a Dry Gas

				14.65	= base pressure					GPM at
Mole Percent		x_i	$Hv_{i,id}$ at 14.696 psia	$G_{i,id}$	b_i	x_i*$Hv_{i,id}$	x_i* $G_{i,id}$	x_i*b_i	ft^3 ideal gas/gal liquid	14.65
0.000	H_20	0.00000	0.00	0.62202	0.06510	0.00	0.00000	0.00000	175.620	0.000
0.030	Helium	0.00030	0.00	0.13820	0.00000	0.00	0.00004	0.00000	98.693	0.003
0.000	H_2S	0.00000	637.10	1.17670	0.02390	0.00	0.00000	0.00000	74.160	0.000
2.020	CO_2	0.02020	0.00	1.51950	0.01950	0.00	0.03069	0.00039	58.746	0.344
0.320	N_2	0.00320	0.00	0.96720	0.00442	0.00	0.00310	0.00001	91.128	0.035
0.000	O_2	0.00000	0.00	1.10480	0.00720	0.00	0.00000	0.00000	112.950	0.000
83.020	C_1	0.83020	1010.00	0.55390	0.01160	838.50	0.45985	0.00963	59.138	14.039
7.450	C_2	0.07450	1769.70	1.03820	0.02380	131.84	0.07735	0.00177	37.488	1.987
4.390	C_3	0.04390	2516.10	1.52250	0.03470	110.46	0.06684	0.00152	36.391	1.206
0.830	IC_4	0.00830	3251.90	2.00680	0.04410	26.99	0.01666	0.00037	30.637	0.271
1.080	NC_4	0.01080	3262.30	2.00680	0.04700	35.23	0.02167	0.00051	31.801	0.340
0.310	IC_5	0.00310	4000.90	2.49110	0.05760	12.40	0.00772	0.00018	27.414	0.113
0.250	NC_5	0.00250	4008.70	2.49110	0.06060	10.02	0.00623	0.00015	27.658	0.090
0.300	C_6+	0.00300	5129.22	3.21755	0.08637	15.39	0.00965	0.00026	22.975	0.131
100.00	Summation	1.00000				1180.8	0.6998	0.01480		18.560

Property	Value	Comments
Z (dry gas)	0.99679	1 – [Pressure Base * (Summation of x_i * b_i)^2]
Z (dry air)	0.9996	1 – [Pressure Base *(b_i of air)^2] where b_i of air = .00537
G (dry gas, dry air)	0.7018	G_{id} (dry gas) * Z (dry air) / Z (dry gas)
Hv_{id}/ Z (dry gas, dry air)	1184.6	Hv_{id} (dry gas dry air) / Z (dry gas) @ 14.696
Hv_{id}/ Z @ 14.65	1180.9	(Hv_{id} (dry gas dry air) / Z)*(14.65/14.696)

NOTES	Hv_{id} for H_20 is taken as 0 because "spectator water" makes no contribution to heating value.
	Values of $Hv_{i,id}$ at 14.65 are calculated as (Hv_{id} at 14.696 * 14.65 / 14.696).
	Hexane Plus (C_6+) properties for B_i, ft^3 ideal gas/gal liquid, $G_{id,}$ and Hv_{id} are arbitrarily derived values based on a 60 % n-Hexane, 30 % n-Heptane, and 10 % n-Octane split.
	Method shown for Z calculation is the "alternate approximate method", the "rigorous method" or the AGA-8 method may also be used.
	Division of Hv_{id} by Z does not give a real heating value but rather an ideal gas heating value per real cubic foot.
	Decimals beyond 1 part in 1000 are not significant and are carried only to alleviate round-off error.

This example uses physical properties from GPA 2145-09. Use properties from the current version of GPA 2145.

B.3—Calculation of Gas Properties at 60 °F and 14.696 psia for a Water Saturated Gas

Mole Percent		Dry Basis	Wet Basis	$Hv_{i,id}$ at 14.696 psia	14.696	= base pressure				Ft^3 ideal gas/gal liquid	GPM at
		x_i	x_{iw}		$G_{i,id}$	b_i	$x_i*Hv_{i,id}$	$x_i*G_{i,id}$	x_i*b_i	14.696 psia	14.696
0.000	$H_2$0	0.00000	0.01744	0.00	0.62202	0.06510	0.0	0.01085	0.00114	175.620	0.100
0.030	Helium	0.00030	0.00029	0.00	0.13820	0.00000	0.0	0.00004	0.00000	98.693	0.003
0.000	H_2S	0.00000	0.00000	637.10	1.17670	0.02390	0.0	0.00000	0.00000	74.160	0.000
2.020	CO_2	0.02020	0.01985	0.00	1.51950	0.01950	0.0	0.03016	0.00039	58.746	0.339
0.320	N_2	0.00320	0.00314	0.00	0.96720	0.00442	0.0	0.00304	0.00001	91.128	0.035
0.000	O_2	0.00000	0.00000	0.00	1.10480	0.00720	0.0	0.00000	0.00000	112.950	0.000
83.020	C_1	0.83020	0.81572	1010.00	0.55390	0.01160	823.9	0.45183	0.00946	59.138	13.843
7.450	C_2	0.07450	0.07320	1769.70	1.03820	0.02380	129.5	0.07600	0.00174	37.488	1.960
4.390	C_3	0.04390	0.04313	2516.10	1.52250	0.03470	108.5	0.06567	0.00150	36.391	1.190
0.830	IC_4	0.00830	0.00816	3251.90	2.00680	0.04410	26.5	0.01637	0.00036	30.637	0.267
1.080	NC_4	0.01080	0.01061	3262.30	2.00680	0.04700	34.6	0.02130	0.00050	31.801	0.335
0.310	IC_5	0.00310	0.00305	4000.90	2.49110	0.05760	12.2	0.00759	0.00018	27.414	0.112
0.250	NC_5	0.00250	0.00246	4008.70	2.49110	0.06060	9.8	0.00612	0.00015	27.658	0.089
0.300	C_6+	0.00300	0.00295	5129.22	3.21755	0.08637	15.1	0.00948	0.00025	22.975	0.129
100.00	Summation	1.00000	1.00000				1160.2	0.6984	0.01568		18.401

Property	Value	Comments
Mole Fraction Water	0.01744	Vapor pressure of water at 60 °F / Pressure Base where vapor pressure of water at 60 °F is 0.25640 psia
Z (sat gas)	0.9964	1 – Pressure Base * (Summation of x_{iw} * b_i)^2
Z (dry air)	0.9996	1 – Pressure Base * (b_i of air)^2 where b_i of air = 0.00537
G (sat gas dry air)	0.7007	G_{id} (sat gas) * Z (dry air) / Z (sat gas)
Hv_{id}/ Z (sat gas dry air)	1164.4	Hv_{id} (sat gas dry air) / Z (sat gas)

Notes:	Wet mole fractions are dry mole fractions * (1 – mole fraction water).
	Although CO_2 has a carbon atom its a=0 because it is not part of the fuel formula CaHbSc.
	Although $H_2$0 has two hydrogen atoms its b=0 because it is not part of the fuel formula CaHbSc.
	Hv_{id} for $H_2$0 is taken as 0 as "spectator water" makes no contribution to heating value.
	Values of Hv_{id} at 14.65 are calculated as $Hv_{i,id}$ at 14.696 * 14.65 / 14.696.
	Hexane Plus (C_6+) properties for b_i, Ft^3 ideal gas/gal liquid, $G_{id,}$ and Hv_{id} are arbitrarily derived values based on a 60 % n-Hexane, 30 % n-Heptane, and 10 % n-Octane split.
	Z calculation is calculated using the simplified method [Equation (7)]. The rigorous method or the AGA-8 method may be used instead.
	Division of Hv_{id} by Z does not give a real heating value but rather an ideal gas heating value per real cubic foot.
	Decimals beyond 1 part in 1000 are not significant and are carried only to alleviate round-off error.

This example uses physical properties from GPA 2145-09. Use properties from the current version of GPA 2145.

B.4—Calculation of Gas Properties at Typical Base Conditions of 60 °F and 14.65 psia for a Water Saturated Gas

		Dry Basis	Wet Basis	$Hv_{i,id}$ at 14.696 psia	14.65	= base pressure				ft^3 ideal gas/gal liquid	GPM at
Mole Percent		x_i	x_{iw}		$G_{i,id}$	b_i	$x_i*Hv_{i,id}$	$x_i*G_{i,id}$	x_i*b_i	14.696 psia	14.65
0.000	H_20	0.00000	0.01750	0.00	0.62202	0.06510	0.0	0.01089	0.00114	175.620	0.100
0.030	Helium	0.00030	0.00029	0.00	0.13820	0.00000	0.0	0.00004	0.00000	98.693	0.003
0.000	H_2S	0.00000	0.00000	637.10	1.17670	0.02390	0.0	0.00000	0.00000	74.160	0.000
2.020	CO_2	0.02020	0.01985	0.00	1.51950	0.01950	0.0	0.03016	0.00039	58.746	0.338
0.320	N_2	0.00320	0.00314	0.00	0.96720	0.00442	0.0	0.00304	0.00001	91.128	0.035
0.000	O_2	0.00000	0.00000	0.00	1.10480	0.00720	0.0	0.00000	0.00000	112.950	0.000
83.020	C_1	0.83020	0.81567	1010.00	0.55390	0.01160	823.8	0.45180	0.00946	59.138	13.799
7.450	C_2	0.07450	0.07320	1769.70	1.03820	0.02380	129.5	0.07599	0.00174	37.488	1.953
4.390	C_3	0.04390	0.04313	2516.10	1.52250	0.03470	108.5	0.06567	0.00150	36.391	1.186
0.830	IC_4	0.00830	0.00815	3251.90	2.00680	0.04410	26.5	0.01636	0.00036	30.637	0.266
1.080	NC_4	0.01080	0.01061	3262.30	2.00680	0.04700	34.6	0.02129	0.00050	31.801	0.334
0.310	IC_5	0.00310	0.00305	4000.90	2.49110	0.05760	12.2	0.00759	0.00018	27.414	0.111
0.250	NC_5	0.00250	0.00246	4008.70	2.49110	0.06060	9.8	0.00612	0.00015	27.658	0.089
0.300	C_6+	0.00300	0.00295	5129.22	3.21755	0.08637	15.1	0.00948	0.00025	22.975	0.128
100.00	Summation	1.00000	1.00000				1160.2	0.6984	0.01568		18.342

Property	Value	Comments
Mole Fraction Water	0.01750	Vapor pressure of water at 60 °F / Pressure Base where vapor pressure of water at 60 °F is 0.25640 psia
Z (sat gas)	0.9964	1 – Pressure Base * (Summation of x_{iw} * b_i)^2
Z (dry air)	0.9996	1 – Pressure Base * (b_i of air)^2 where b_i of air = 0.00537
G (sat gas dry air)	0.7007	G_{id} (sat gas) * Z (dry air) / Z (sat gas)
Hv_{id}/ Z (sat gas dry air)	1164.4	Hv_{id} (sat gas dry air) / Z (sat gas)
Hv_{id}/ Z @ 14.65	1160.7	Hv_{id} (sat gas dry air) / Z (sat gas)/(14.65/14.696)

NOTES	Wet mole fractions are dry mole fractions * (1 – mole fraction water).
	Although CO_2 has a carbon atom its a=0 because it is not part of the fuel formula CaHbSc.
	Although H_20 has two hydrogen atoms its b=0 because it is not part of the fuel formula CaHbSc.
	Hv_{id} for H_20 is taken as 0 as "spectator water" makes no contribution to heating value.
	Values of $Hv_{i,id}$ at 14.65 are calculated as $Hv_{i,id}$ at 14.696 * 14.65 / 14.696.
	Hexane Plus (C_6+) properties for b_i, ft^3 ideal gas/gal liquid, $G_{id,}$ and Hv_{id} are arbitrarily derived values based on a 60 % n-Hexane, 30 % n-Heptane, and 10 % n-Octane split.
	Z calculation is calculated using the simplified method [Equation (7)]. The rigorous method or the AGA-8 method may be used instead.
	Division of Hv_{id} by Z does not give a real heating value but rather an ideal gas heating value per real cubic foot.
	Decimals beyond 1 part in 1000 are not significant and are carried only to alleviate round-off error.

This example uses physical properties from GPA 2145-09. Use properties from the current version of GPA 2145.

B.5—Calculation of Gas Properties at 60 °F and 14.696 psia for a Water Saturated Gas at Flowing Conditions of 76 °F and 28 psia

Mole Percent		Dry Basis x_i	Wet Basis x_{iw}	$Hv_{i,id}$ at 14.696 psia	14.696 $G_{i,id}$	= base pressure b_i	$x_{iw}*Hv_{i,id}$	$x_{iw}*G_{i,id}$	$x_{iw}*b_i$	Ft^3 ideal gas/gal liquid 14.696 psia	GPM at 14.696
0.000	H_20	0.00000	0.01618	0.00	0.62202	0.06510	0.000	0.0101	0.00105	175.620	0.092
0.030	Helium	0.00030	0.00030	0.00	0.13820	0.00000	0.000	0.0000	0.00000	98.693	0.003
0.000	H_2S	0.00000	0.00000	637.10	1.17670	0.02390	0.000	0.0000	0.00000	74.160	0.000
2.020	CO_2	0.02020	0.01987	0.00	1.51950	0.01950	0.000	0.0302	0.00039	58.746	0.340
0.320	N_2	0.00320	0.00315	0.00	0.96720	0.00442	0.000	0.0030	0.00001	91.128	0.035
0.000	O_2	0.00000	0.00000	0.00	1.10480	0.00720	0.000	0.0000	0.00000	112.950	0.000
83.020	C_1	0.83020	0.81676	1010.00	0.55390	0.01160	824.932	0.4524	0.00947	59.138	13.861
7.450	C_2	0.07450	0.07329	1769.70	1.03820	0.02380	129.709	0.0761	0.00174	37.488	1.962
4.390	C_3	0.04390	0.04319	2516.10	1.52250	0.03470	108.669	0.0658	0.00150	36.391	1.191
0.830	IC_4	0.00830	0.00817	3251.90	2.00680	0.04410	26.554	0.0164	0.00036	30.637	0.267
1.080	NC_4	0.01080	0.01063	3262.30	2.00680	0.04700	34.663	0.0213	0.00050	31.801	0.335
0.310	IC_5	0.00310	0.00305	4000.90	2.49110	0.05760	12.202	0.0076	0.00018	27.414	0.112
0.250	NC_5	0.00250	0.00246	4008.70	2.49110	0.06060	9.860	0.0061	0.00015	27.658	0.089
0.300	C_6+	0.00300	0.00295	5129.22	3.21755	0.08637	15.139	0.0095	0.00025	22.975	0.129
100.00	Sum	1.00000	1.00000				1161.73	0.6985	0.01561		18.416

Property	Values @ P&T	Comments
Z (dry gas)	0.9968	From example in Table 2
Saturation Temperature	76.0	°F
Saturation Pressure	28.0	psia
lb Water / MMCF	768.3	(Corrected A value / Saturation Pressure) + Corrected B value
Mole Fraction Water	0.01618	(lb Water / MMCF) * R * (459.67 + Tbase) / (Mwater * Pbase * 1,000,000)
Z (sat gas)	0.9964	1 – Pressure Base * (Summation of x_{iw} * b_i)^2
Z (dry air)	0.9996	1 – Pressure Base * (b_i of air)^2 where $_{bi}$ of air = 0.00537
G (sat gas dry air)	0.7007	G_{id} (sat gas) * Z (dry air) / Z (sat gas)
Hv_{id}/ Z (sat gas dry air)	1165.9	Hv_{id} (sat gas dry air) / Z (sat gas)

NOTES	
	Wet mole fractions are dry mole fractions * (1 – mole fraction water).
	Although CO_2 has a carbon atom its a=0 because it is not part of the fuel formula CaHbSc.
	Although H_20 has two hydrogen atoms its b=0 because it is not part of the fuel formula CaHbSc.
	Hv_{id} for H_20 is taken as 0 as "spectator water" makes no contribution to heating value.
	Values of $Hv_{i,id}$ at 14.65 are calculated as $Hv_{i,id}$ at 14.696 * 14.65 / 14.696.
	Hexane Plus (C_6+) properties for B_i, ft^3 ideal gas/gal liquid, G_{id}, and Hv_{id} are are arbitrarily derived values based on a 60 % n Hexane, 30 % n-Heptane, and 10 % n-Octane split.
	Method shown for Z calculation is the "alternate approximate method", the "rigorous method" or the AGA-8 method may also be used.
	Division of Hv_{id} by Z does not give a real heating value but rather an ideal gas heating value per real cubic foot.
	Decimals beyond 1 part in 1000 are not significant and are carried only to alleviate round-off error.
	As an alternate to looking up Base A and B values from Table B of IGT Report 8 the following equations may be used.
	they provide a close approximation (maximum error 1 % high average error 0.25 % high) over the temperature range –40 °F to 340 °F.
	Temperature used in the correlation must be the saturation temperature in R.

This example uses physical properties from GPA 2145-09. Use properties from the current version of GPA 2145.

B.6—Calculation of Gas Properties at 60 °F and 14.65 psia for a Water Saturated Gas at Flowing Conditions of 76 °F and 28 psia

Mole Percent		Dry Basis x_i	Wet Basis x_{iw}	$Hv_{i,id}$ at 14.696 psia	14.65 $G_{i,id}$	= base pressure b_i	$x_{iw}*Hv_{i,id}$	$x_{iw}*G_{i,id}$	$x_{iw}*b_i$	ft³ ideal gas/gal liquid 14.696 psia	GPM at 14.65
0.000	H_20	0.00000	0.01623	0.00	0.62202	0.06510	0.000	0.0101	0.00106	175.620	0.092
0.030	Helium	0.00030	0.00030	0.00	0.13820	0.00000	0.000	0.0000	0.00000	98.693	0.003
0.000	H_2S	0.00000	0.00000	637.10	1.17670	0.02390	0.000	0.0000	0.00000	74.160	0.000
2.020	CO_2	0.02020	0.01987	0.00	1.51950	0.01950	0.000	0.0302	0.00039	58.746	0.338
0.320	N_2	0.00320	0.00315	0.00	0.96720	0.00442	0.000	0.0030	0.00001	91.128	0.035
0.000	O_2	0.00000	0.00000	0.00	1.10480	0.00720	0.000	0.0000	0.00000	112.950	0.000
83.020	C_1	0.83020	0.81672	1010.00	0.55390	0.01160	824.890	0.4524	0.00947	59.138	13.817
7.450	C_2	0.07450	0.07329	1769.70	1.03820	0.02380	129.702	0.0761	0.00174	37.488	1.956
4.390	C_3	0.04390	0.04319	2516.10	1.52250	0.03470	108.664	0.0658	0.00150	36.391	1.187
0.830	IC_4	0.00830	0.00817	3251.90	2.00680	0.04410	26.553	0.0164	0.00036	30.637	0.267
1.080	NC_4	0.01080	0.01062	3262.30	2.00680	0.04700	34.661	0.0213	0.00050	31.801	0.334
0.310	IC_5	0.00310	0.00305	4000.90	2.49110	0.05760	12.201	0.0076	0.00018	27.414	0.111
0.250	NC_5	0.00250	0.00246	4008.70	2.49110	0.06060	9.859	0.0061	0.00015	27.658	0.089
0.300	C_6+	0.00300	0.00295	5129.22	3.21755	0.08637	15.138	0.0095	0.00025	22.975	0.129
100.00	Summation	1.00000	1.00000				1161.7	0.6985	0.01561		18.358

Property	Values @ P & T	Comments
Z (dry gas)	0.9968	From example in Table 2
Saturation Temperature	76.0	°F
Saturation Pressure	28.0	Psia
lb Water / MMCF	768.3	(Corrected A value / Saturation Pressure) + Corrected B value
Mole Fraction Water	0.01623	(lb Water / MMCF) * R * (459.67 + T_{base}) / (M_{water} * P_{base} * 1,000,000)
Z (sat gas)	0.9964	1 – Pressure Base * (Summation of x_{iw} * b_i)^2
Z (dry air)	0.9996	1 – Pressure Base * (b_i of air)^2 where b_i of air = 0.00537
G (sat gas dry air)	0.7007	G_{id} (sat gas) * Z (dry air) / Z (sat gas)
Hv_{id}/ Z (sat gas dry air)	1165.8	Hv_{id} (sat gas dry air) / Z (sat gas)
Hv_{id}/ Z at 14.65	1162.2	Hv_{id} (sat gas dry air) / Z (sat gas)/(14.65/14.696)

NOTES	Wet mole fractions are dry mole fractions * (1 – mole fraction water).
	Although CO_2 has a carbon atom its a=0 because it is not part of the fuel formula CaHbSc.
	Although H_20 has two hydrogen atoms its b=0 because it is not part of the fuel formula CaHbSc.
	Hv_{id} for H_20 is taken as 0 as "spectator water" makes no contribution to heating value.
	Values of $Hv_{i,id}$ at 14.65 are calculated as $Hv_{i,id}$ at 14.696 * 14.65 / 14.696.
	Hexane Plus (C_6+) properties for B_i, ft³ ideal gas/gal liquid, G_{id}, and Hv_{id} are arbitrarily derived values based on a 60 % n-Hexane, 30 % n-Heptane, and 10 % n-Octane split.
	Method shown for Z calculation is the "alternate approximate method", the "rigorous method" or the AGA-8 method may also be used.
	Division of Hv_{id} by Z does not give a real heating value but rather an ideal gas heating value per real cubic foot.
	Decimals beyond 1 part in 1000 are not significant and are carried only to alleviate round-off error.
	As an alternate to looking up Base A and B values from Table B of IGT Report 8 the following equations may be used.
	They provide a close approximation (maximum error 1 % high average error .25 % high) over the temperature range –40 °F to 340 °F.
	Temperature used in the correlation must be the saturation temperature in °R.

This example uses physical properties from GPA 2145-09. Use properties from the current version of GPA 2145.

B.7—Calculation of Gas Properties at 60 °F and 14.696 psia for a Measured and Partially Water Saturated Gas

		Dry Basis	Wet Basis	$Hv_{i,id}$ at 14.696 psia	14.696	= base pressure				ft³ ideal gas/gal liquid	GPM at
Mole Percent		x_i	x_{iw}		$G_{i,id}$	b_i	$x_{iw}*Hv_{i,id}$	$x_{iw}*G_{i,id}$	$x_{iw}*b_i$	14.696 psia	14.696
0.000	$H_2$0	0.00000	0.01618	0.00	0.62202	0.06510	0.00	0.0101	0.00105	175.620	0.092
0.030	Helium	0.00030	0.00030	0.00	0.13820	0.00000	0.00	0.0000	0.00000	98.693	0.003
0.000	H_2S	0.00000	0.00000	637.10	1.17670	0.02390	0.00	0.0000	0.00000	74.160	0.000
2.020	CO_2	0.02020	0.01987	0.00	1.51950	0.01950	0.00	0.0302	0.00039	58.746	0.340
0.320	N_2	0.00320	0.00315	0.00	0.96720	0.00442	0.00	0.0030	0.00001	91.128	0.035
0.000	O_2	0.00000	0.00000	0.00	1.10480	0.00720	0.00	0.0000	0.00000	112.950	0.000
83.020	C_1	0.83020	0.81677	1010.00	0.55390	0.01160	824.94	0.4524	0.00947	59.138	13.861
7.450	C_2	0.07450	0.07329	1769.70	1.03820	0.02380	129.71	0.0761	0.00174	37.488	1.962
4.390	C_3	0.04390	0.04319	2516.10	1.52250	0.03470	108.67	0.0658	0.00150	36.391	1.191
0.830	IC_4	0.00830	0.00817	3251.90	2.00680	0.04410	26.55	0.0164	0.00036	30.637	0.267
1.080	NC_4	0.01080	0.01063	3262.30	2.00680	0.04700	34.66	0.0213	0.00050	31.801	0.335
0.310	IC_5	0.00310	0.00305	4000.90	2.49110	0.05760	12.20	0.0076	0.00018	27.414	0.112
0.250	NC_5	0.00250	0.00246	4008.70	2.49110	0.06060	9.86	0.0061	0.00015	27.658	0.089
0.300	C_6+	0.00300	0.00295	5129.22	3.21755	0.08637	15.14	0.0095	0.00025	22.975	0.129
100.00	Summation	1.00000	1.00000				1161.7	0.6985	0.01561		18.416

Property	Value	Comments
lb Water per MMCF	768	Pounds of water per MMCF as measured by test
Mole Fraction Water	0.01618	Molar quantity of water vapor converting pounds of water MMCF to Mole Fraction
Z (sat gas)	0.9964	1 – Pressure Base * (Summation of x_{iw} * b_i)^2
Z (dry air)	0.9996	1 – Pressure Base * (b_i of air)^2 where b_i of air = 0.00537
G (sat gas dry air)	0.7008	G_{id} (sat gas) * Z (dry air) / Z (sat gas)
Hv_{id} (sat gas dry air)	1165.9	Hv_{id} (sat gas dry air) / Z (sat gas)

NOTES	Wet mole fractions are dry mole fractions * (1 – mole fraction water).
	Although CO_2 has a carbon atom its a=0 because it is not part of the fuel formula CaHbSc.
	Although $H_2$0 has two hydrogen atoms its b=0 because it is not part of the fuel formula CaHbSc.
	Hv_{id} for $H_2$0 is taken as 0 as "spectator water" makes no contribution to heating value.
	Values of $Hv_{i,id}$ at 14.65 are calculated as $Hv_{i,id}$ at 14.696 * 14.65 / 14.696.
	Hexane Plus (C_6+) properties for B_i, ft³ ideal gas/gal liquid, $G_{id,}$ and Hv_{id} are arbitrarily derived values based on a 60 % n-Hexane, 30 % n-Heptane, and 10 % n-Octane split.
	Z calculation is calculated using the simplified method [Equation (7)]. The rigorous method or the AGA-8 method may be used instead.
	Division of Hv_{id} by Z does not give a real heating value but rather an ideal gas heating value per real cubic foot.
	Decimals beyond 1 part in 1000 are not significant and are carried only to alleviate round-off error.

This example uses physical properties from GPA 2145-09. Use properties from the current version of GPA 2145.

B.8—Calculation of Gas Properties at 60 °F and 14.65 psia for a Measured and Partially Water Saturated Gas

Mole Percent		Dry Basis x_i	Wet Basis x_{iw}	$Hv_{i,id}$ at 14.696 psia	14.65 $G_{i,id}$	= base pressure b_i	$x_{iw}*Hv_{i,id}$	$x_{iw}*G_{i,id}$	$x_{iw}*b_i$	ft^3 ideal gas/gal liquid 14.696 psia	GPM at 14.65
0.000	H_20	0.00000	0.01623	0.00	0.62202	0.06510	0.00	0.0101	0.00106	175.620	0.092
0.030	Helium	0.00030	0.00030	0.00	0.13820	0.00000	0.00	0.0000	0.00000	98.693	0.003
0.000	H_2S	0.00000	0.00000	637.10	1.17670	0.02390	0.00	0.0000	0.00000	74.160	0.000
2.020	CO_2	0.02020	0.01987	0.00	1.51950	0.01950	0.00	0.0302	0.00039	58.746	0.338
0.320	N_2	0.00320	0.00315	0.00	0.96720	0.00442	0.00	0.0030	0.00001	91.128	0.035
0.000	O_2	0.00000	0.00000	0.00	1.10480	0.00720	0.00	0.0000	0.00000	112.950	0.000
83.020	C_1	0.83020	0.81673	1010.00	0.55390	0.01160	824.89	0.4524	0.00947	59.138	13.817
7.450	C_2	0.07450	0.07329	1769.70	1.03820	0.02380	129.70	0.0761	0.00174	37.488	1.956
4.390	C_3	0.04390	0.04319	2516.10	1.52250	0.03470	108.66	0.0658	0.00150	36.391	1.187
0.830	IC_4	0.00830	0.00817	3251.90	2.00680	0.04410	26.55	0.0164	0.00036	30.637	0.267
1.080	NC_4	0.01080	0.01062	3262.30	2.00680	0.04700	34.66	0.0213	0.00050	31.801	0.334
0.310	IC_5	0.00310	0.00305	4000.90	2.49110	0.05760	12.20	0.0076	0.00018	27.414	0.111
0.250	NC_5	0.00250	0.00246	4008.70	2.49110	0.06060	9.86	0.0061	0.00015	27.658	0.089
0.300	C_6+	0.00300	0.00295	5129.22	3.21755	0.08637	15.14	0.0095	0.00025	22.975	0.129
100.00	Summation	1.00000	1.00000				1161.7	0.6985	0.01561		18.358

Property	Value	Comments
lb Water per MMCF	768	Pounds of water per MMCF as measured by test
Mole Fraction Water	0.01623	Molar quantity of water vapor converting pounds of water MMCF to Mole Fraction
Z (sat gas)	0.9964	1 – Pressure Base * (Summation of $x_{iw} * b_i$)^2
Z (dry air)	0.9996	1 – Pressure Base * (b_i of air)^2 where b_i of air = 0.00537
G (sat gas dry air)	0.7007	G_{id} (sat gas) * Z (dry air) / Z (sat gas)
Hv_{id} (sat gas dry air)	1165.8	Hv_{id} (sat gas dry air) / Z (sat gas)
Hv_{id}/Z (sat gas dry air)	1162.2	Hv_{id} (sat gas dry air) / Z (sat gas)/(14.65/14.696)

NOTES	Wet mole fractions are dry mole fractions * (1 – mole fraction water).
	Although CO_2 has a carbon atom its a=0 because it is not part of the fuel formula CaHbSc.
	Although H_20 has two hydrogen atoms its b=0 because it is not part of the fuel formula CaHbSc.
	Hv_{id} for H_20 is taken as 0 as "spectator water" makes no contribution to heating value.
	Values of $Hv_{i,id}$ at 14.65 are calculated as $Hv_{i,id}$ at 14.696 * 14.65 / 14.696.
	Hexane Plus (C_6+) properties for B_i, ft^3 ideal gas/gal liquid, $G_{id,}$ and Hv_{id} are arbitrarily derived values based on a 60 % n-Hexane, 30 % n-Heptane, and 10 % n-Octane split.
	Z calculation is calculated using the simplified method [Equation (7)]. The rigorous method or the AGA-8 method may be used instead.
	Division of Hv_{id} by Z does not give a real heating value but rather an ideal gas heating value per real cubic foot.
	Decimals beyond 1 part in 1000 are not significant and are carried only to alleviate round-off error.

This example uses physical properties from GPA 2145-09. Use properties from the current version of GPA 2145.

B.9—Calculation of Gas Properties at 15 °C and 101.325 kPa for a Water Saturated Gas

		Dry Basis	Wet Basis	$Hv_{i,id}$ at 101.325 kPa	101.325	= base pressure				Ratio, ideal gas / liquid	*LC*, m^3 liquid / 1000 m^3 gas
Mole Percent		x_i	x_{iw}		$G_{i,id}$	b_i	$x_i*Hv_{i,id}$	$x_i*G_{i,id}$	x_i*b_i	101.325 kPa	101.325 kPa
0.000	H_20	0.00000	0.01683	0.000	0.62202	0.02495	0.000	0.01047	0.00042	1311.300	0.013
0.030	Helium	0.00030	0.00029	0.000	0.13820	0.00000	0.000	0.00004	0.00000	736.900	0.000
0.000	H_2S	0.00000	0.00000	23.784	1.17670	0.00913	0.000	0.00000	0.00000	554.600	0.000
2.020	CO_2	0.02020	0.01986	0.000	1.51950	0.00745	0.000	0.03018	0.00015	441.200	0.045
0.320	N_2	0.00320	0.00315	0.000	0.96720	0.00170	0.000	0.00304	0.00001	680.400	0.005
0.000	O_2	0.00000	0.00000	0.000	1.10480	0.00275	0.000	0.00000	0.00000	843.300	0.000
83.020	C_1	0.83020	0.81622	37.706	0.55390	0.00442	30.777	0.45211	0.00361	442.170	1.853
7.450	C_2	0.07450	0.07325	66.066	1.03820	0.00910	4.839	0.07604	0.00067	281.400	0.261
4.390	C_3	0.04390	0.04316	93.934	1.52250	0.01320	4.054	0.06571	0.00057	272.130	0.159
0.830	IC_4	0.00830	0.00816	121.400	2.00680	0.01680	0.991	0.01638	0.00014	229.020	0.036
1.080	NC_4	0.01080	0.01062	121.790	2.00680	0.01790	1.293	0.02131	0.00019	237.680	0.045
0.310	IC_5	0.00310	0.00305	149.360	2.49110	0.02200	0.455	0.00759	0.00007	204.850	0.015
0.250	NC_5	0.00250	0.00246	149.650	2.49110	0.02320	0.368	0.00612	0.00006	206.670	0.012
0.300	C_6+	0.00300	0.00295	191.485	3.21755	0.03299	0.565	0.00949	0.00010	171.660	0.017
100.00	Summation	1.00000	1.00000				43.342	0.6985	0.00597		2.461

Property	Value	Comments
Mole Fraction Water	0.01683	Vapor pressure of water at 15 °C / Pressure Base where vapor pressure of water at 15 °C is 1.7058 kPa
Z (sat gas)	0.9964	1 – Pressure Base * (Summation of $x_{iw} * b_i$)^2
Z (dry air)	0.9996	1 – Pressure Base * (b_i of air)^2 where b_i of air = 0.00206
G (sat gas dry air)	0.7007	G_{id} (sat gas) * Z (dry air) / Z (sat gas)
Hv_{id}/Z (sat gas dry air)	43.498	Hv_{id} (sat gas dry air) / Z (sat gas)

NOTES	Wet mole fractions are dry mole fractions * (1 – mole fraction water).
	Although CO_2 has a carbon atom it's a = 0 because it is not part of the fuel formula CaHbSc.
	Although H_20 has two hydrogen atoms its b = 0 because it is not part of the fuel formula CaHbSc.
	Hv_{id} for H_20 is taken as 0 as "spectator water" makes no contribution to heating value.
	Hexane Plus (C_6+) properties for B_i, ft^3 ideal gas/gal liquid, G_{id}, and Hv_{id} are arbitrarily derived values based on a 60 % n-Hexane, 30 % n-Heptane, and 10 % n-Octane split.
	Z calculation is calculated using the simplified method [Equation(7)]. The rigorous method or the AGA-8 method may be used instead.
	Division of Hv_{id} by Z does not give a real heating value but rather an ideal gas heating value per real cubic foot.
	Decimals beyond 1 part in 1000 are not significant and are carried only to alleviate round-off error.

This example uses physical properties from GPA 2145-09. Use properties from the current version of GPA 2145.

B.10—Calculation for Determining the C_6+ Gas Properties Using Two Commonly Used Methods

Example assuming Hexane Plus (C_6+) properties are based on a 60 % n-Hexane, 30 % n-Heptane, and 10 % n-Octane split.

	a	b	c	d	e	f	g	h	i
				(a * c)	**(gas)**			**(gas)**	**Summation**
Mole calculations	**Mole %**	**M**	***b***	**Z Factor**	**Rel. Den.**	ft^3/**gal**	**gal/** ft^3	**Btu/ft^3**	**Factor**
n-hexane	0.6	86.1754	0.0776	0.0466	2.9754		0.0410	4755.9	0.0776
n-heptane	0.3	100.2019	0.0951	0.0285	3.4597		0.0460	5502.6	0.0951
n-octane	0.1	114.2285	0.1128	0.0113	3.944		0.0511	6249.0	0.1128
Hexanes Plus	Totals	**93.1887**	**0.0864**	**0.0864**	**3.2176**	22.975	**0.0435**	**5129.2**	**0.0864**

To calculate ft^3/Gal you must first convert mole % to liquid volume %.
LV Fract = Mole % / ft^3 per gal
LV % = LV Fraction / Sum of LV Fraction

	l	M	N	O	j	K
Liquid calculations	ft^3 ideal gas/gal liquid	(a / l) LV Frac	(m / sum of m) LVol %	(l * n) ft^3 ideal gas	**Btu/gal as an Ideal Gas**	**Btu/gal** j * n
n-hexane	24.38	0.0246	0.57	13.78	115950	65560.0953
n-heptane	21.73	0.0138	0.32	6.89	119570	37925.8246
n-octane	19.57	0.0051	0.12	2.30	122290	14356.5932
Hexanes Plus		**0.0435**		22.975		**117,843**

Hexanes Plus	Btu/Gal = Btu/ft^3 * ft^3/gal	**117,843**
	Btu/Gas = Btu/ ft^3 / gal/ ft^3	**117,843**
	ft^3/gal = 1/gal/ ft^3	**22.975**

Example assuming Hexane Plus (C_6+) properties are based on a 47 % n-Hexane, 36 % n-Heptane, and 17 % n-Octane split.

	a	b	c	d	e	f	g	h	i
				(a * c)	**(gas)**			**(gas)**	**Summation**
Mole calculations	**Mole %**	**M**	***b***	***Z* Factor**	**Rel. Den.**	ft^3/**gal**	**gal/** ft^3	**Btu/** ft^3	**Factor**
n-hexane	0.47	86.1754	0.0776	0.0365	2.9754		0.0410	4755.9	0.0776
n-heptane	0.36	100.2019	0.0951	0.0342	3.4597		0.0460	5502.6	0.0951
n-octane	0.17	114.2285	0.1128	0.0192	3.944		0.0511	6249.0	0.1128
Hexanes Plus	Totals	**95.9940**	**0.0899**	**0.0899**	**3.3144**	22.975	**0.0445**	**5278.5**	**0.0899**

To calculate ft^3/gal you must first convert mole % to liquid volume %.
LV Fract = Mole % / ft^3 per gal
LV % = LV Fraction / Sum of LV Fraction

	l	m	n	o	j	k
Liquid calculations	ft^3 ideal gas/gal liquid	(a / l) LV Frac	(m / sum of m) LVol %	(l * n) ft^3 ideal gas	**Btu/gal as an Ideal Gas**	**Btu/Gal** j * n
n-hexane	24.38	0.0193	0.43	10.55	115950	50195.4626
n-heptane	21.73	0.0166	0.37	8.08	119570	44483.0498
n-octane	19.57	0.0087	0.20	3.82	122290	23854.9545
Hexanes Plus		**0.0445**		22.456		**118,533**

Hexanes Plus	Btu/gal = Btu/ ft^3 * ft^3/gal	**118,534**
	Btu/gas = Btu/ ft^3 / gal/ ft^3	**118,534**
	ft^3/gal = 1/Gal/ ft^3	**22.456**

B.11—Calculation for Compressibility Using the Rigorous Procedure

Pressure Base	**14.65**	psia
	Mole %	
Hydrogen	0.000	
Helium	0.030	
Nitrogen	0.320	
Oxygen	0.000	
Hydrogen Sulfide	0.000	
Carbon Dioxide	2.020	
Methane	83.020	
Ethane	7.450	
Propane	4.390	
I-Butane	0.830	
N-Butane	1.080	
I-Pentane	0.310	
N-Pentane	0.250	
C_6+	0.300	
Total	100.000	

Z = 0.99682 = 1 + (PressureBase * Sum of ($x_i * x_j * B_{ij}$) / 1000)

First compound	Second compound	Second Virial Coefficient B_{ij}, 10^3 psia^{-1} at 60 °F	$x_i * x_j * B_{ij}$
Hydrogen	Hydrogen	0.04100	0.000000000000000
Hydrogen	Helium	0.04600	0.000000000000000
Hydrogen	Nitrogen	0.03500	0.000000000000000
Hydrogen	Oxygen	0.03200	0.000000000000000
Hydrogen	Hydrogen Sulfide	0.00200	0.000000000000000
Hydrogen	Carbon Dioxide	–0.06600	0.000000000000000
Hydrogen	Methane	0.02200	0.000000000000000
Hydrogen	Ethane	0.03200	0.000000000000000
Hydrogen	Propane	0.01600	0.000000000000000
Hydrogen	I-Butane	0.00000	0.000000000000000
Hydrogen	N-Butane	0.02600	0.000000000000000
Hydrogen	I-Pentane	0.06900	0.000000000000000
Hydrogen	N-Pentane	–0.01200	0.000000000000000
Hydrogen	C_6+ (n-C_6)	–0.01000	0.000000000000000
Helium	Helium	0.03400	0.000000003060000
Helium	Nitrogen	0.06000	0.000000115200000
Helium	Oxygen	0.06300	0.000000000000000
Helium	Hydrogen Sulfide	0.04300	0.000000000000000
Helium	Carbon Dioxide	0.05100	0.000000618120000
Helium	Methane	0.07000	0.000034868400000
Helium	Ethane	0.05700	0.000002547900000
Helium	Propane	0.09800	0.000002581320000
Helium	I-Butane	0.07500	0.000000373500000
Helium	N-Butane	0.12800	0.000000829440000
Helium	I-Pentane	0.07500	0.000000139500000
Helium	N-Pentane	0.07500	0.000000112500000
Helium	C_6+ (n-C_6)	0.08000	0.000000144000000
Nitrogen	Nitrogen	–0.01900	–0.000000194560000
Nitrogen	Oxygen	–0.03700	0.000000000000000
Nitrogen	Hydrogen Sulfide	–0.13500	0.000000000000000
Nitrogen	Carbon Dioxide	–0.14400	–0.000018616320000
Nitrogen	Methane	–0.06000	–0.000318796800000
Nitrogen	Ethane	–0.15200	–0.000072473600000
Nitrogen	Propane	–0.23700	–0.000066587520000
Nitrogen	I-Butane	–0.21300	–0.000011314560000
Nitrogen	N-Butane	–0.25000	–0.000017280000000
Nitrogen	I-Pentane	–0.32600	–0.000006467840000
Nitrogen	N-Pentane	–0.28000	–0.000004480000000
Nitrogen	C_6+ (n-C_6)	–0.37300	–0.000007161600000

Oxygen	Oxygen	–0.05300	0.000000000000000
Oxygen	Hydrogen Sulfide	–0.16100	0.000000000000000
Oxygen	Carbon Dioxide	–0.11800	0.000000000000000
Oxygen	Methane	–0.05200	0.000000000000000
Oxygen	Ethane	–0.12400	0.000000000000000
Oxygen	Propane	–0.20100	0.000000000000000
Oxygen	I-Butane	–0.27000	0.000000000000000
Oxygen	N-Butane	–0.29300	0.000000000000000
Oxygen	I-Pentane	–0.39100	0.000000000000000
Oxygen	N-Pentane	–0.47400	0.000000000000000
Oxygen	C_6+ (n-C_6)	–0.50800	0.000000000000000
Hydrogen Sulfide	Hydrogen Sulfide	–0.64100	0.000000000000000
Hydrogen Sulfide	Carbon Dioxide	–0.41600	0.000000000000000
Hydrogen Sulfide	Methane	–0.24100	0.000000000000000
Hydrogen Sulfide	Ethane	–0.44500	0.000000000000000
Hydrogen Sulfide	Propane	–0.84200	0.000000000000000
Hydrogen Sulfide	I-Butane	–1.11200	0.000000000000000
Hydrogen Sulfide	N-Butane	–1.15200	0.000000000000000
Hydrogen Sulfide	I-Pentane	–1.43600	0.000000000000000
Hydrogen Sulfide	N-Pentane	–1.47600	0.000000000000000
Hydrogen Sulfide	C_6+ (n-C_6)	–1.87600	0.000000000000000
Carbon Dioxide	Carbon Dioxide	–0.38800	–0.000158319520000
Carbon Dioxide	Methane	–0.18100	–0.006070754480000
Carbon Dioxide	Ethane	–0.38500	–0.001158773000000
Carbon Dioxide	Propane	–0.61800	–0.001096060080000
Carbon Dioxide	I-Butane	–0.81900	–0.000274627080000
Carbon Dioxide	N-Butane	–0.86200	–0.000376107840000
Carbon Dioxide	I-Pentane	–1.06300	–0.000133130120000
Carbon Dioxide	N-Pentane	–1.09100	–0.000110191000000
Carbon Dioxide	C_6+ (n-C_6)	–1.37900	–0.000167134800000
Methane	Methane	–0.13500	–0.093046325400000
Methane	Ethane	–0.28100	–0.034759643800000
Methane	Propane	–0.42500	–0.030978913000000
Methane	I-Butane	–0.45700	–0.006298063240000
Methane	N-Butane	–0.56000	–0.010042099200000
Methane	I-Pentane	–0.63200	–0.003253055680000
Methane	N-Pentane	–0.67500	–0.002801925000000
Methane	C_6+ (n-C_6)	–0.79300	–0.003950091600000
Ethane	Ethane	–0.56900	–0.003158092250000
Ethane	Propane	–0.83300	–0.005448736300000
Ethane	I-Butane	–1.00500	–0.001242883500000
Ethane	N-Butane	–1.10600	–0.001779775200000
Ethane	I-Pentane	–1.29300	–0.000597236700000
Ethane	N-Pentane	–1.37900	–0.000513677500000
Ethane	C_6+ (n-C_6)	–1.65200	–0.000738444000000
Propane	Propane	–1.18300	–0.002279889430000
Propane	I-Butane	–1.52200	–0.001109142280000
Propane	N-Butane	–1.66600	–0.001579767840000
Propane	I-Pentane	–1.95300	–0.000531567540000
Propane	N-Pentane	–2.06800	–0.000453926000000
Propane	C_6+ (n-C_6)	–2.54200	–0.000669562800000
I-Butane	I-Butane	–2.09700	–0.000144462330000
I-Butane	N-Butane	–1.98200	–0.000355332960000
I-Butane	I-Pentane	–2.55600	–0.000131531760000
I-Butane	N-Pentane	–2.61400	–0.000108481000000
I-Butane	C_6+ (n-C_6)	–3.31700	–0.000165186600000
N-Butane	N-Butane	–2.28900	–0.000266988960000
N-Butane	I-Pentane	–2.67100	–0.000178850160000
N-Butane	N-Pentane	–2.91500	–0.000157410000000
N-Butane	C_6+ (n-C_6)	–3.40400	–0.000220579200000
I-Pentane	I-Pentane	–3.37500	–0.000032433750000
I-Pentane	N-Pentane	–3.50400	–0.000054312000000
I-Pentane	C_6+ (n-C_6)	–4.45200	–0.000082807200000

N-Pentane	N-Pentane	–3.97800	–0.000024862500000
N-Pentane	C_6+ (n-C_6)	–4.73900	–0.000071085000000
C_6+ (n-C_6)	C_6+ (n-C_6)	–6.43400	–0.000057906000000
	Total B_{ij}		–0.217311185460000

NOTES

C_6+ virial coefficient values are for n-C_6.

Virial coefficient values are from *Orifice Metering of Natural Gas* AGA Report No. 3, 1985.

Annex C

(informative)

Water Content Example Calculations

The examples used in this annex are merely examples for illustration purposes only (each company should develop its own approach). They are not to be considered exclusive or exhaustive in nature. API/GPA make no warranties, express or implied for reliance on or any omissions from the information contained in this document.

C.1 Dry and Water Saturated Conditions (Non-rigorous)

To convert from dry to water saturated at base conditions or from water saturated at base conditions to dry basis using the law of partial pressures.

$$\text{fraction water vapor} = \frac{\text{partial pressure water}}{\text{total pressure}} \tag{C.1}$$

The partial pressure of water equals its vapor pressure, which at 60 °F is 0.25640 psia [6]. Thus,

$$\text{fraction water vapor}_{60°F} = \frac{0.25640}{P} = F_{wv} \tag{C.2}$$

where

P is the pressure, absolute;
F_{wv} is the water vapor fraction.

To convert from dry to water saturated determine the fraction of gas other than water vapor, the dry gas fraction, by subtracting F_{wv} from unity. At base pressure and 60 °F this is:

$$\text{fraction gas}_{60°F} = 1 - F_{wv} \tag{C.3}$$

To convert from water saturated to dry at base pressure and 60 °F, multiply by the reciprocal of the fraction of gas other than water vapor, fraction gas $_{60\ °F}$.

$$\text{Convert saturated to dry} = \frac{1}{1 - F_{wv}} \tag{C.4}$$

The total pressure at base conditions is the base pressure. Conversion factors for common base pressures appear in the Table C.1.

Table C.1—Conversion Factors

Base pressure in psia	**14.65**	**14.696**	**14.73**	**15.025**
Dry to water saturated	0.9825	0.9826	0.9826	0.9829
Water saturated to dry	1.0178	1.0178	1.0177	1.0174

---

[6] Wagner, W. and Pruss, A., "The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use", *J. Phys. Chem. Ref. Data*, 31(2):387 – 535, 2002

EXAMPLE—Convert Water Saturated Heating Value to Dry

For example, convert a 1015 Btu/scf water saturated heating value at 14.73 psia and 60 °F to dry at the same base conditions. The water saturated to dry conversion value from Table C.1 at 14.73 psia base pressure is 1.0177. Therefore the calculation is:

$$\text{Dry Heating Value} = \text{Water Saturated Heating Value} \times \text{Conversion Factor}$$

thus:

$$\text{Dry Heating Value} = 1015 \times 1.0177 = 1033.0 \text{ Btu/scf at } 14.73 \text{ psia and } 60\ ^{\circ}\text{F}$$

EXAMPLE—Convert Dry Heating Value to Water Saturated

To convert a 1033 Btu/scf dry at 14.73 psia and 60 °F heating value to water saturated at the same base conditions requires a similar procedure. The dry to water saturated conversion value from Table C.1 at 14.73 psia base pressure is 0.9826. Therefore the calculation is:

$$\text{Water Saturated Heating Value} = \text{Dry Heating Value} \times \text{Conversion Factor}$$

thus:

$$\text{Water Saturated Value} = 1033 \times 0.9826 = 1015.0 \text{ Btu/scf at } 14.73 \text{ psia and } 60^{\circ}\text{F}$$

C.2 Dry to Partially Water Saturated (non-rigorous)

The water content in a natural gas stream may be obtained by determining the dew point using a suitable tester, such as the chilled mirror device (Bureau of Mines dew point tester), then converting the dew point to a water vapor content to appropriate units such as lb/MMSCF using industry accepted methods, such as those in the dehydration section of the Gas Processors Suppliers Association (GPSA) *Engineering Data Book* or tables such as those published by the International School of Hydrocarbon Measurement.

Acceptable test instruments are available that display the mass of water vapor per unit volume of gas directly using an indicating or recording meter. The test instruments should be carefully calibrated and used with caution if the gas being measured may contain substances known to interfere with water vapor content measurement.

To calculate the volume of vapor occupied by water at the measured water content in lb/MMCF:

$$M_{\text{water}} = 18.0153 \text{ lb }_{(\text{GPA } 2145)} = 1 \text{ Mol Water}$$

$$1 \text{ Mol Ideal Gas} = V = \frac{RT}{P}$$

where

M_{water} is the molar mass (molecular weight) of water;
R is 10.7316 psia ft^3 (lbmol °R)$^{-1}$;
T is 60 °F = 519.67 °R;
V is the volume in ft^3 at pressure and temperature;
P is the pressure, absolute.

Table C.2—Mole Volume of Water Vapor at 60 °F

Pressure, psia	14.65	14.696	14.73	15.025
Volume, ft^3	380.675	379.484	378.608	371.174

Volume Water Vapor

$$V_{wv} = \frac{\text{Measured Water Content}}{M_{\text{water}}} \times \text{Mol Volume} \tag{C.5}$$

C.2.1 Volume Ratio of Dry to Partially Saturated Gas

Where the dry volume is large relative to the amount of water vapor such as is usually the case for water content measured in pounds per million cubic feet of gas, the ratio of dry to partially saturated gas can be calculated as:

$$V_{\text{ratio}} = \frac{1,000,000}{1,000,000 \pm V_{wv}} \tag{C.6}$$

NOTE In Equation (C.6), use plus ($+V_{wv}$) for dry to partially saturated and use minus ($-V_{wv}$) for partially saturated to dry.

EXAMPLE—Convert Dry Heating Value to Partially Saturated

As an example, correct a dry heating value of 1050 Btu/ft^3 at 14.73 psia and 60 °F for the effect of 30 lb of water per MMCF of gas.

$$V_{wv} = \frac{30}{18.0153} \times 378.608 = 630.5 \text{ ft}^3$$

$$V_{\text{ratio}} = \frac{1,000,000}{(1,000,000 + 630.5)} = 0.9994$$

$$Hv_{\text{partially sat}} = Hv_{\text{dry}} \times V_{\text{ratio}} = 1050 \times 0.9994 = 1049.3 \text{ Btu} / \text{ft}^3$$

EXAMPLE—Convert Partially Saturated Heating Value to Dry

As an example, a gas has a heating value of 1075 Btu/ft^3 @ 15.025 psia and 60 °F when it contains 35 lb of water per MMCF. Determine the heating value of the same gas containing no water.

$$V_{wv} = \frac{35}{18.0153} X \; 371.174 = 721.1 \text{ ft}^3$$

$$V_{\text{ratio}} = \frac{1,000,000}{(1,000,000 - 721.1)} = 1.0007$$

$$Hv_{\text{dry}} = Hv_{\text{partially sat}} \times V_{\text{ratio}} = 1075 \times 1.0007 = 1075.8 \text{ Btu} / \text{ft}^3$$

C.3 Water Content Correlation—IGT RB 8

The water vapor content Equation (C.7) is based on the IGT RB 8. This further references seventeen other works. As presented in IGT RB 8, the fundamental equation for W is:

$$W = \frac{A}{P_f} + B \tag{C.7}$$

where

W is the water vapor content (lb water / MMSCF gas at 14.7 psia and 60 °F);
P_f is the flowing pressure, psia;
A and B are the variables contained within IGT RB 8 Tables as function of T_f;
T_f is the flowing temperature, °F.

Since the IGT RB 8, Table B values of constants A and B are non-linear a simple table look up is not appropriate as linear interpolation between table entries would result in error. Therefore, non-linear equations that replicate the table and interpolate between the table entries are used to solve for A and B. These equations and their constants are:

$$A = e^{(K1 - (K2 / (T_f + K3)))} \tag{C.8}$$

$$B = e^{(K4 - (K5 / (T_f + K6)))} \tag{C.9}$$

where

e is the Naperian constant;
$K1$ is 25.36794227;
$K2$ is 7170.42747964;
$K3$ is 389.5293906;
$K4$ is 15.97666211;
$K5$ is 7737.37631961;
$K6$ is 483.28778105;
T_f is the water dew point temperature, °F.

Table C.3, Values of Constants A and B, from IGT RB 8 is reproduced in Table C.3.

Table C.3—Values of Constants A and B

Base conditions = 14.7 psia and 60 °F

To correct A and B to other base conditions, multiply each by:

$$(P_b/14.7)\,[519.6/(459.6 + T_b)]\,(0.998/z_b)$$

°F	A	B	°F	A	B	°F	A	B	°F	A	B
–40	131	0.22	42	6240	3.54	124	89700	25.8	206	619000	115
–38	147	0.24	44	6740	3.74	126	94700	26.9	208	644000	119
–36	165	0.26	46	7280	3.96	128	100000	28.0	210	671000	122
–34	184	0.28	48	7850	4.18	130	106000	29.1	212	698000	126
–32	206	0.30	50	8460	4.42	132	111000	30.3	214	725000	130
–30	230	0.33	52	9110	4.66	134	117000	31.6	216	754000	134
–28	256	0.36	54	9800	4.92	136	124000	32.9	218	785000	139
–26	285	0.39	56	10500	5.19	138	130000	34.2	220	816000	143
–24	317	0.42	58	11300	5.48	140	137000	35.6	222	848000	148
–22	352	0.45	60	12200	5.77	142	144000	37.0	224	881000	152
–20	390	0.48	62	13100	6.08	144	152000	38.5	226	915000	157
–18	434	0.52	64	14000	6.41	146	160000	40.0	228	950000	162
–16	479	0.56	66	15000	6.74	148	168000	41.6	230	987000	166
–14	530	0.60	68	16100	7.10	150	177000	43.2	232	1020000	171
–12	586	0.64	70	17200	7.47	152	186000	44.9	234	1060000	177
–10	648	0.69	72	18500	7.85	154	195000	46.6	236	1100000	182
–8	714	0.74	74	19700	8.25	156	205000	48.4	238	1140000	187
–6	786	0.79	76	21100	8.67	158	215000	50.2	240	1190000	192
–4	866	0.85	78	22500	9.11	160	225000	52.1	242	1230000	198
–2	950	0.91	80	24100	9.57	162	236000	54.1	244	1270000	204
0	1050	0.97	82	25700	10.0	164	248000	56.1	246	1320000	210
2	1150	1.04	84	27400	10.5	166	259000	58.2	248	1370000	216
4	1260	1.11	86	29200	11.1	168	272000	60.3	250	1420000	222
6	1380	1.19	88	31100	11.6	170	285000	62.5	252	1470000	229
8	1510	1.27	90	33200	12.2	172	298000	64.8	254	1520000	235
10	1650	1.35	92	35300	12.7	174	312000	67.1	256	1570000	242
12	1810	1.44	94	37500	13.3	176	326000	69.5	258	1630000	248
14	1970	1.54	96	39900	14.0	178	341000	72.0	260	1680000	255
16	2150	1.64	98	42400	14.6	180	357000	74.5	280	2340000	333
18	2350	1.74	100	45100	15.3	182	372000	77.2	300	3180000	430
20	2560	1.85	102	47900	16.0	184	390000	79.9	320	4260000	548
22	2780	1.97	104	50800	16.7	186	407000	82.7	340	5610000	692
24	3030	2.09	106	53900	17.5	188	425000	85.5	360	7270000	869
26	3290	2.22	108	57100	18.3	190	443000	88.4	380	9300000	1090
28	3570	2.36	110	60500	19.1	192	463000	91.4	400	11700000	1360
30	3880	2.50	112	64100	20.0	194	483000	94.5	420	14700000	1700
32	4210	2.65	114	67900	20.9	196	504000	97.7	440	18100000	2130
34	4560	2.81	116	71800	21.8	198	525000	101	460	22200000	2550
36	4940	2.98	118	76000	22.7	200	547000	104			
38	5350	3.16	120	80400	23.7	202	570000	108			
40	5780	3.34	122	84900	24.7	204	594000	111			

Annex D

(informative)

Calculation of NGL Energy Content from Volume

The examples used in this annex are merely examples for illustration purposes only (each company should develop its own approach). They are not to be considered exclusive or exhaustive in nature. API/GPA make no warranties, express or implied for reliance on or any omissions from the information contained in this document.

D.1 Scope

This method includes procedures to convert natural gas liquid (NGL) volumes to energy units (such as Btu) to meet the need for system balances, plant shrinkage calculations or a situation that requires a consistency in energy units between natural gas and the liquids extracted as a result of processing. The NGL volumes may be expressed in mass, liquid volume or equivalent vapor volumes. Equivalent vapor volumes calculated from liquid volumes using GPA volume factors may be converted directly to Btu using GPA component heating values. Vapor volumes measured by conventional methods and corrected for deviation from ideal gas behavior must use a corrected Btu factor for accuracy. NGL volumes measured by conventional methods and expressed as liquid volume shall be converted to component volume or mass in accordance with GPA 8173.

D.2 Procedure

Given either component mass, component liquid volume or component gas volume, convert the quantity to energy using the appropriate physical constant from the latest version of GPA 2145. Component mass, component liquid volumes and component gas volumes should be determined according to the latest version of GPA 8173.

D.2.1 Mass

$$Q_i = m_i \times Hm_i \tag{D.1}$$

where

Q is the energy;
m is the mass;
Hm is the component heating value represented as energy per unit mass, fuel as an ideal gas; and
$_i$ is the (subscript) component i.

An example calculation follows to illustrate the determination of component and total energy in MMBtu (million Btu) for component mass from an NGL quantity of 29,604,847 lb.

D.2.2 Liquid Volume

$$Q_i = LV_i \times Hl_i \tag{D.2}$$

where

Q is the energy;
LV is the liquid volume;
Hl is the component heating value represented as energy per unit liquid volume, fuel as an ideal gas; and
$_i$ is the (subscript) component i.

An example calculation follows to illustrate the determination of component and total energy in MMBtu (million Btu) for component volume from an NGL quantity of 7,432,671 gal.

Table D.1—Calculate Energy Content from Liquid Mass

Component	Mass (lb)	GPA 2145 Btu/lbm, fuel as ideal gas [7]	Energy (MMBtu)
Carbon Dioxide	760,845	0	0
Methane	5,921	23,892	141
Ethane	9,754,797	22,334	217,864
Propane	7,836,403	21,654	169,689
i-Butane	2,871,670	21,232	60,971
n- Butane	2,569,701	21,300	54,735
i-Pentane	1,204,917	21,044	25,356
n-Pentane	716,437	21,085	15,106
Hexane Plus [8]	3,884,156	20,839	80,942
Total	29,604,847		624,805

Table D.2—Calculate Energy Content from Liquid Volume

Component	Volume (gallons)	GPA 2145 Btu/gal, fuel as ideal gas [7]	Energy (MMBtu)
Carbon Dioxide	111,017	0	0
Methane	2,368	59,729	141
Ethane	3,282,675	66,340	217,773
Propane	1,852,534	91,563	169,624
i-Butane	611,853	99,630	60,959
n- Butane	527,703	103,740	54,744
i-Pentane	231,386	109,680	25,378
n-Pentane	136,158	110,870	15,096
Hexane Plus [8]	676,977	119,570	80,946
	7,432,671		624,661

D.2.3 Gas Volume

$$Q_i = GV_i \times Hv_i \tag{D.3}$$

where

Q is the energy;
GV is the gas volume;
Hv is the component heating value represented as energy per unit gas volume, fuel as an ideal gas;
i is the (subscript) component i.

An example calculation follows to illustrate the determination of component and total energy in MMBtu (million Btu) for component volume from an equivalent gas volume of 257,594 MCF (thousand cubic feet) at 14.696 psia and 60 °F.

---

[7] GPA 2145-09, use latest version.

[8] This example uses the heating value for normal heptane for hexanes plus. Use the results of an extended analysis, engineering evaluation or other method.

Table D.3—Calculate Energy Content from Equivalent Gas Volume

Component	**Volume** (MCF @ 14.696 psia)	**GPA 2145 Btu/ft^3, fuel as ideal gas** [7]	**Energy** (MMBtu)
Carbon Dioxide	6,561	0.0	0
Methane	140	1010.0	141
Ethane	123,110	1769.7	217,868
Propane	67,440	2516.1	169,686
i-Butane	18,750	3251.9	60,973
n- Butane	16,778	3263.3	54,752
i-Pentane	6,338	4000.9	25,358
n-Pentane	3,768	4008.7	15,105
Hexane Plus [8]	14,710	5502.6	80,943
	257,594		624,815

Annex E
(informative)

Determination of Gas Energy Content per Unit Mass

Table E.1—Calculations for Btu per Pound for Water Saturated Gas at Base Conditions

Mole Percent		Dry Basis Mole Fraction x_i	Wet Basis Mole Fraction x_{iw}	Molecular Weight GPA 2145-09 M	Dry Basis Molecular Weight $x_i * M$	Wet Basis Molecular Weight $x_{iw} * M$	Dry Basis Weight Fraction $x_i / \Sigma x$	Wet Basis Weight Fraction $x_{iw} / \Sigma x$	Btu / lb.-Mass GPA 2145-09 H_v-mass	Dry Basis Hv (mass) Wt Fraction$_i$ * Btu/lb	Wet Basis Hv (mass) Wt Fraction$_i$ * Btu/lb
0.000	**H_2O**	0.00000	0.01744	18.0153	0.000	0.314	0.00000	0.01553	0	0	0
0.030	**Helium**	0.00030	0.00029	4.0026	0.001	0.001	0.00006	0.00006	0	0	0
0.000	**H_2S**	0.00000	0.00000	34.0809	0.000	0.000	0.00000	0.00000	0	0	0
2.020	**CO_2**	0.02020	0.01985	44.0095	0.889	0.873	0.04386	0.04318	0	0	0
0.320	**N_2**	0.00320	0.00314	28.0134	0.090	0.088	0.00442	0.00435	0	0	0
0.000	**O_2**	0.00000	0.00000	31.9988	0.000	0.000	0.00000	0.00000	0	0	0
83.020	**C_1**	0.83020	0.81572	16.0425	13.318	13.086	0.65712	0.64691	23,892	15,700	15,456
7.450	**C_2**	0.07450	0.07320	30.0690	2.240	2.201	0.11053	0.10881	22,334	2,468	2,430
4.390	**C_3**	0.04390	0.04313	44.0956	1.936	1.902	0.09551	0.09403	21,654	2,068	2,036
0.830	**IC_4**	0.00830	0.00816	58.1222	0.482	0.474	0.02380	0.02343	21,232	505	498
1.080	**NC_4**	0.01080	0.01061	58.1222	0.628	0.617	0.03097	0.03049	21,300	660	649
0.310	**IC_5**	0.00310	0.00305	72.1488	0.224	0.220	0.01104	0.01086	21,044	232	229
0.250	**NC_5**	0.00250	0.00246	72.1488	0.180	0.177	0.00890	0.00876	21,085	188	185
0.300	**C_6+ (**NOTE 1)	0.00300	0.00295	93.1887	0.280	0.275	0.01379	0.01358	20,894	288	284
100.000	Summation	1.00000	1.00000		20.269	20.229	1.00000	1.00000		22,110	21,766

NOTE 1 Molecular weight of C_6+ is an arbitrary value derived from a 60-30-10 nC_6-nC7-nC8 split.
NOTE 2 Mass and energy are not pressure dependent. Do not adjust the sample Btu/lbm for pressure base.

energy API®

2009 Publications Order Form

Effective January 1, 2009.
API Members receive a 30% discount where applicable.
The member discount does not apply to purchases made for the purpose of resale or for incorporation into commercial products, training courses, workshops, or other commercial enterprises.

Available through IHS:

Phone Orders:	**1-800-854-7179**	(Toll-free in the U.S. and Canada)
	303-397-7956	(Local and International)
Fax Orders:	**303-397-2740**	
Online Orders:	**global.ihs.com**	

Date: ____________________

☐ **API Member** (Check if Yes)

Invoice To (☐ Check here if same as "Ship To")
Name:
Title:
Company:
Department:
Address:

City: State/Province:
Zip/Postal Code: Country:
Telephone:
Fax:
Email:

Ship To (UPS will not deliver to a P.O. Box)
Name:
Title:
Company:
Department:
Address:

City: State/Province:
Zip/Postal Code: Country:
Telephone:
Fax:
Email:

Quantity	Title	SO★	Unit Price	Total
	MPMS Chapter 14.1, Collecting and Handling of Natural Gas Samples for Custody Transfer		$175.00	
	MPMS Chapter 14.4, Converting Mass of Natural Gas Liquids and Vapors to Equivalent Liquid Volumes		$57.00	

☐ Payment Enclosed ☐ P.O. No. (Enclose Copy) ____________

☐ Charge My IHS Account No. ____________

☐ VISA ☐ MasterCard ☐ American Express
☐ Diners Club ☐ Discover

Credit Card No.:
Print Name (As It Appears on Card):
Expiration Date:
Signature:

Subtotal	
Applicable Sales Tax (see below)	
Rush Shipping Fee (see below)	
Shipping and Handling (see below)	
Total (in U.S. Dollars)	

★ To be placed on Standing Order for future editions of this publication, place a check mark in the SO column and sign here:

Pricing and availability subject to change without notice.

Mail Orders – Payment by check or money order in U.S. dollars is required except for established accounts. State and local taxes, $10 processing fee, and 5% shipping must be added. Send mail orders to: **API Publications, IHS, 15 Inverness Way East, c/o Retail Sales, Englewood, CO 80112-5776, USA.**

Purchase Orders – Purchase orders are accepted from established accounts. Invoice will include actual freight cost, a $10 processing fee, plus state and local taxes.

Telephone Orders – If ordering by telephone, a $10 processing fee and actual freight costs will be added to the order.

Sales Tax – All U.S. purchases must include applicable state and local sales tax. Customers claiming tax-exempt status must provide IHS with a copy of their exemption certificate.

Shipping (U.S. Orders) – Orders shipped within the U.S. are sent via traceable means. Most orders are shipped the same day. Subscription updates are sent by First-Class Mail. Other options, including next-day service, air service, and fax transmission are available at additional cost. Call 1-800-854-7179 for more information.

Shipping (International Orders) – Standard international shipping is by air express courier service. Subscription updates are sent by World Mail. Normal delivery is 3-4 days from shipping date.

Rush Shipping Fee – Next Day Delivery orders charge is $20 in addition to the carrier charges. Next Day Delivery orders must be placed by 2:00 p.m. MST to ensure overnight delivery.

Returns – All returns must be pre-approved by calling the IHS Customer Service Department at 1-800-624-3974 for information and assistance. There may be a 15% restocking fee. Special order items, electronic documents, and age-dated materials are non-returnable.

THERE'S MORE WHERE THIS CAME FROM.

API provides additional resources and programs to the oil and natural gas industry which are based on API Standards. For more information, contact:

API MONOGRAM® LICENSING PROGRAM
Phone: 202-962-4791
Fax: 202-682-8070
Email: certification@api.org

API QUALITY REGISTRAR (APIQR®)
> ISO 9001 Registration
> ISO/TS 29001 Registration
> ISO 14001 Registration
> API Spec Q1® Registration
Phone: 202-962-4791
Fax: 202-682-8070
Email: certification@api.org

API PERFORATOR DESIGN REGISTRATION PROGRAM
Phone: 202-682-8490
Fax: 202-682-8070
Email: perfdesign@api.org

API TRAINING PROVIDER CERTIFICATION PROGRAM (API TPCP™)
Phone: 202-682-8490
Fax: 202-682-8070
Email: tpcp@api.org

API INDIVIDUAL CERTIFICATION PROGRAMS (ICP®)
Phone: 202-682-8064
Fax: 202-682-8348
Email: icp@api.org

API ENGINE OIL LICENSING AND CERTIFICATION SYSTEM (EOLCS)
Phone: 202-682-8516
Fax: 202-962-4739
Email: eolcs@api.org

API PETROTEAM (TRAINING, EDUCATION AND MEETINGS)
Phone: 202-682-8195
Fax: 202-682-8222
Email: petroteam@api.org

API UNIVERSITY™
Phone: 202-682-8195
Fax: 202-682-8222
Email: training@api.org

Check out the API Publications, Programs, and Services Catalog online at www.api.org.

1220 L Street, NW
Washington, DC 20005-4070
USA

202.682.8000

Additional copies are available through IHS
Phone Orders: 1-800-854-7179 (Toll-free in the U.S. and Canada)
303-397-7956 (Local and International)
Fax Orders: 303-397-2740
Online Orders: global.ihs.com

Information about API Publications, Programs and Services
is available on the web at www.api.org

Product No. H140503