Designation: D3588 − 98 (Reapproved 2017)

Standard Practice for
Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels[1]

This standard is issued under the fixed designation D3588; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers procedures for calculating heating value, relative density, and compressibility factor at base conditions (14.696 psia and 60°F (15.6°C)) for natural gas mixtures from compositional analysis.[2] It applies to all common types of utility gaseous fuels, for example, dry natural gas, reformed gas, oil gas (both high and low Btu), propane-air, carbureted water gas, coke oven gas, and retort coal gas, for which suitable methods of analysis as described in Section 6 are available. Calculation procedures for other base conditions are given.

1.2 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D1717 Test Method for Test for Analysis of Commerical Butane-Butene Mixtures and Isolutylene by Gas Chromatography (Withdrawn 1984)[4]

D1945 Test Method for Analysis of Natural Gas by Gas Chromatography

D1946 Practice for Analysis of Reformed Gas by Gas Chromatography

D2163 Test Method for Determination of Hydrocarbons in Liquefied Petroleum (LP) Gases and Propane/Propene Mixtures by Gas Chromatography

D2650 Test Method for Chemical Composition of Gases by Mass Spectrometry

2.2 *GPA Standards:*

GPA 2145 Physical Constants for the Paraffin Hydrocarbons and Other Components in Natural Gas[5]

GPA Standard 2166 Methods of Obtaining Natural Gas Samples for Analysis by Gas Chromatography[5]

GPA 2172 Calculation of Gross Heating Value, Relative Density, and Compressibility Factor for Natural Gas Mixtures from Compositional Analysis[5,6]

GPA Standard 2261 Method of Analysis for Natural Gas and Similar Gaseous Mixtures by Gas Chromatography[5]

GPA Technical Publication TP-17 Table of Physical Properties of Hydrocarbons for Extended Analysis of Natural Gases[5]

GPSA Data Book, Fig. 23-2, Physical Constants[5]

2.3 *TRC Document:*

TRC Thermodynamic Tables—Hydrocarbons[7]

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[1] This practice is under the jurisdiction of ASTM Committee D03 on Gaseous Fuels and is the direct responsibility of Subcommittee D03.03 on Determination of Heating Value and Relative Density of Gaseous Fuels.

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[2] A more rigorous calculation of $Z(T,P)$ at both base conditions and higher pressures can be made using the calculation procedures in "Compressibility and Super Compressibility for Natural Gas and Other Hydrocarbon Gases," American Gas Association Transmission Measurement Committee Report 8, AGA Cat. No. XQ1285, 1985, AGA, 1515 Wilson Blvd., Arlington, VA 22209.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

[5] Available from Gas Processors Association (GPA), 6526 E. 60th St., Tulsa, OK 74145, http://www.gasprocessors.com.

[6] The sole source of supply of the program in either BASIC or FORTRAN suitable for running on computers known to the committee at this time is the Gas Processors Association. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee [1], which you may attend.

[7] Available from Thermodynamics Research Center, The Texas A&M University, College Station, TX 77843-3111.

2.4 *ANSI Standard:*

ANSI Z 132.1-1969: Base Conditions of Pressure and Temperature for the Volumetric Measurement of Natural Gas[8,9]

3. Terminology

3.1 *Definitions:*

3.1.1 *British thermal unit*—the defined International Tables British thermal unit (Btu).

3.1.1.1 *Discussion*—The defining relationships are:

$$1 \text{ Btu}\bullet\text{lb}^{-1} = 2.326 \text{ J}\bullet\text{g}^{-1} \text{ (exact)}$$

$$1 \text{ lb} = 453.592\ 37 \text{ g (exact)}$$

By these relationships, 1 Btu = 1 055.055 852 62 J (exact). For most purposes, the value (rounded) 1 Btu = 1055.056 J is adequate.

3.1.2 *compressibility factor (z)*—the ratio of the actual volume of a given mass of gas at a specified temperature and pressure to its volume calculated from the ideal gas law under the same conditions.

3.1.3 *gross heating value*—the amount of energy transferred as heat from the complete, ideal combustion of the gas with air, at standard temperature, in which all the water formed by the reaction condenses to liquid. The values for the pure gases appear in GPA Standard 2145, which is revised annually. If the gross heating value has a volumetric rather than a mass or molar basis, a base pressure must also be specified.

3.1.4 *net heating value*—the amount of energy transferred as heat from the total, ideal combustion of the gas at standard temperature in which all the water formed by the reaction remains in the vapor state. Condensation of any "spectator" water does not contribute to the net heating value. If the net heating value has a volumetric rather than a mass or molar basis, a base pressure must also be specified.

3.1.5 *relative density*—the ratio of the density of the gaseous fuel, under observed conditions of temperature and pressure, to the density of dry air (of normal carbon dioxide content) at the same temperature and pressure.

3.1.6 *standard cubic foot of gas*—the amount of gas that occupies 1 ft^3 (0.028 m^3) at a temperature of 60°F (15.6°C) under a given base pressure and either saturated with water vapor (wet) or free of water vapor (dry) as specified (see ANSI Z 132.1). In this practice, calculations have been made at 14.696 psia and 60°F (15.6°C), because the yearly update of GPA 2145 by the Thermodynamics Research Center, on which these calculations are based, are given for this base pressure. Conversions to other base conditions should be made at the end of the calculation to reduce roundoff errors.

3.1.7 *standard temperature (USA)*—60°F (15.6°C).

3.2 *Symbols:*

3.2.1 *Nomenclature:*

3.2.1.1 *B*—second virial coefficient for gas mixture

3.2.1.2 $\sqrt{\beta_{ij}}$—summation factor for calculating real gas correction (alternate method)

3.2.1.3 (cor)—corrected for water content

3.2.1.4 (dry)—value on water-free basis

3.2.1.5 *d*—density for gas relative to the density of air.

3.2.1.6 d^{id} —ideal relative density or relative molar mass, that is, molar mass of gas relative to molar mass of air

3.2.1.7 G^{id} —molar mass ratio

3.2.1.8 H_m^{id}—gross heating value per unit mass

3.2.1.9 H_v^{id}—gross heating value per unit volume

3.2.1.10 H_n^{id}—gross heating value per unit mole

3.2.1.11 h_m^{id}—net heating value per unit mass

3.2.1.12 h_v^{id}—net heating value per unit volume

3.2.1.13 h_n^{id}—net heating value per unit mole

3.2.1.14 a, b, c—in Eq 1, integers required to balance the equation: C, carbon; H, hydrogen; S, sulfur; O, oxygen

3.2.1.15 *(id)*—ideal gas state

3.2.1.16 *(l)*—liquid phase

3.2.1.17 *M*—molar mass

3.2.1.18 *m*—mass flow rate

3.2.1.19 *n*—number of components

3.2.1.20 *P*—pressure in absolute units (psia)

3.2.1.21 Q^{id} —ideal energy per unit time released as heat upon combustion

3.2.1.22 *R*—gas constant, 10.7316 psia.ft^3/(lb mol•R) in this practice (based upon *R* = 8.314 48 J/(mol•K))

3.2.1.23 (sat)—denotes saturation value

3.2.1.24 *T*—absolute temperature, °*R* = °F + 459.67 or *K* = °C + 273.15

3.2.1.25 *(T, P)*—value dependent upon temperature and pressure

3.2.1.26 *V*—gas volumetric flow rate

3.2.1.27 *x*—mole fraction

3.2.1.28 *Z*—gas compressibility factor repeatability of property

3.2.1.29 δ—repeatability of property

3.2.1.30 ρ—density in mass per unit volume

3.2.1.31 $\sum_{j=1}^{n}$—property summed for Components 1 through *n*, where *n* represents the total number of components in the mixture

3.2.2 *Superscripts:*

3.2.2.1 *id*—ideal gas value

3.2.2.2 *l*—liquid

3.2.2.3 σ—value at saturation (vapor pressure)

3.2.2.4 '—reproducibility

3.2.3 *Subscripts:*

3.2.3.1 *a*—value for air

3.2.3.2 *a*—relative number of atoms of carbon in Eq 1

3.2.3.3 *b*—relative number of atoms of hydrogen in Eq 1

3.2.3.4 *c*—relative number of atoms of sulfur in Eq 1

3.2.3.5 *j*—property for component *j*

3.2.3.6 *ii*—non-ideal gas property for component *i*

3.2.3.7 *ij*—non-ideal gas property for mixture of *i* and *j*

3.2.3.8 *jj*—non-ideal gas property for component *j*

3.2.3.9 *w*—value for water

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[8] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[9] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D03-1007.