



Designation: D 3588 – 98

Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels¹

This standard is issued under the fixed designation D 3588; 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.*

2. Referenced Documents

2.1 ASTM Standards:

D 1717 Methods for Analysis of Commercial Butane-Butene Mixtures and Isobutylene by Gas Chromatography³

D 1945 Test Method for Analysis of Natural Gas by Gas Chromatography⁴

D 1946 Practice for Analysis of Reformed Gas by Gas Chromatography⁴

D 2163 Test Method for Analysis of Liquefied Petroleum (LP) Gases and Propane Concentrates by Gas Chromatography⁵

D 2650 Test Method for Chemical Composition of Gases by Mass Spectrometry⁶

2.2 GPA Standards:

GPA 2145 Physical Constants for the Paraffin Hydrocarbons and Other Components in Natural Gas⁷

GPA Standard 2166 Methods of Obtaining Natural Gas Samples for Analysis by Gas Chromatography⁷

GPA 2172 Calculation of Gross Heating Value, Relative Density, and Compressibility Factor for Natural Gas Mixtures from Compositional Analysis^{7,8}

GPA Standard 2261 Method of Analysis for Natural Gas and Similar Gaseous Mixtures by Gas Chromatography⁷

GPA Technical Publication TP-17 Table of Physical Properties of Hydrocarbons for Extended Analysis of Natural Gases⁷

GPSA Data Book, Fig. 23-2, Physical Constants⁷

2.3 TRC Document:

TRC Thermodynamic Tables—Hydrocarbons⁹

2.4 ANSI Standard:

ANSI Z 132.1-1969: Base Conditions of Pressure and Temperature for the Volumetric Measurement of Natural Gas^{10,11}

3. Terminology

3.1 Definitions:

¹ This practice is under the jurisdiction of ASTM Committee D-3 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 Discontinued, see 1983 *Annual Book of ASTM Standards*, Vol 05.01.

⁴ *Annual Book of ASTM Standards*, Vol 05.05.

⁵ *Annual Book of ASTM Standards*, Vol 05.01.

⁶ *Annual Book of ASTM Standards*, Vol 05.02.

⁷ Available from Gas Processors Association, 6526 E. 60th, Tulsa, OK 74145.

⁸ A program in either BASIC or FORTRAN suitable for running on computers, available from the Gas Processors Association, has been found satisfactory for this purpose.

⁹ Available from Thermodynamics Research Center, The Texas A&M University, College Station, TX 77843-3111.

¹⁰ Available from the American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

¹¹ Supporting data are available from ASTM Headquarters. Request RR:D03-1007.

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

3.1.1.1 *Discussion*—The defining relationships are:

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

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

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 ft³ (0.028 m³) 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.ft³/(lb mol•R) in this practice (based upon $R = 8.314 \text{ 48 J/(mol} \cdot \text{K)}$)

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

3.2.3.10 1—property for Component 1

3.2.3.11 2—property for Component 2

4. Summary of Practice

4.1 The ideal gas heating value and ideal gas relative density at base conditions (14.696 psia and 60°F (15.6°C)) are calculated from the molar composition and the respective ideal gas values for the components; these values are then adjusted by means of a calculated compressibility factor.

5. Significance and Use

5.1 The heating value is a measure of the suitability of a pure gas or a gas mixture for use as a fuel; it indicates the amount of energy that can be obtained as heat by burning a unit of gas. For use as heating agents, the relative merits of gases from different sources and having different compositions can be compared readily on the basis of their heating values. Therefore, the heating value is used as a parameter for

determining the price of gas in custody transfer. It is also an essential factor in calculating the efficiencies of energy conversion devices such as gas-fired turbines. The heating values of a gas depend not only upon the temperature and pressure, but also upon the degree of saturation with water vapor. However, some calorimetric methods for measuring heating values are based upon the gas being saturated with water at the specified conditions.

5.2 The relative density (specific gravity) of a gas quantifies the density of the gas as compared with that of air under the same conditions.

6. Methods of Analysis

6.1 Determine the molar composition of the gas in accordance with any ASTM or GPA method that yields the complete composition, exclusive of water, but including all other com-

ponents present in amounts of 0.1 % or more, in terms of components or groups of components listed in Table 1. At least 98 % of the sample must be reported as individual components (that is, not more than a total of 2 % reported as groups of components such as butanes, pentanes, hexanes, butenes, and so forth). Any group used must be one of those listed in Table 1 for which average values appear. The following test methods are applicable to this practice when appropriate for the sample under test: Test Methods D 1717, D 1945, D 2163, and D 2650.

7. Calculation—Ideal Gas Values; Ideal Heating Value

7.1 An ideal combustion reaction in general terms for fuel and air in the ideal gas state is:

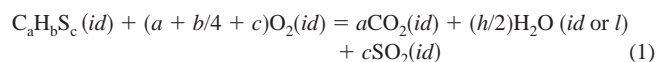


TABLE 1 Properties of Natural Gas Components at 60°F and 14.696 psia^A

| Compound | Formula | Molar Mass, lb·lbmol ^{-1B} | Molar Mass, Ratio, G ^{idC} | Ideal Gross Heating Value ^D | | | Ideal Net Heating Value | | | Summation Factor, b _p , psia ⁻¹ |
|----------------------|---------------------------------|-------------------------------------|-------------------------------------|---|--|---|---|--|---|---|
| | | | | H _n ^{id} , kJ · mol ⁻¹ | H _m ^{id} , Btu · lbm ⁻¹ | H _v ^{id} , Btu · ft ⁻³ | h _n ^{id} , kJ · mol ⁻¹ | h _m ^{id} , Btu · lbm ⁻¹ | h _v ^{id} , Btu · ft ⁻³ | |
| Hydrogen | H ₂ | 2.0159 | 0.069 60 | 286.20 | 6 1022 | 324.2 | 241.79 | 51 566 | 273.93 | 0 |
| Helium | He | 4.0026 | 0.138 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Water | H ₂ O | 18.0153 | 0.622 02 | 44.409 | 1059.8 | 50.312 | 0 | 0 | 0 | 0.0623 |
| Carbon monoxide | CO | 28.010 | 0.967 11 | 282.9 | 4342 | 320.5 | 282.9 | 4 342 | 320.5 | 0.0053 |
| Nitrogen | N ₂ | 28.0134 | 0.967 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0044 |
| Oxygen | O ₂ | 31.9988 | 1.104 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0073 |
| Hydrogen sulfide | H ₂ S | 34.08 | 1.176 7 | 562.4 | 7 094.2 | 637.1 | 517.99 | 6 534 | 586.8 | 0.0253 |
| Argon | Ar | 39.948 | 1.379 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0071 |
| Carbon dioxide | CO ₂ | 44.010 | 1.519 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0197 |
| Air | ^E | 28.9625 | 1.000 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0050 |
| Methane | CH ₄ | 16.043 | 0.553 92 | 891.63 | 23 891 | 1010.0 | 802.71 | 21 511 | 909.4 | 0.0116 |
| Ethane | C ₂ H ₆ | 30.070 | 1.038 2 | 1562.06 | 22 333 | 1769.7 | 1428.83 | 20 429 | 1618.7 | 0.0239 |
| Propane | C ₃ H ₈ | 44.097 | 1.522 6 | 2220.99 | 21 653 | 2516.1 | 2043.3 | 19 922 | 2314.9 | 0.0344 |
| <i>i</i> -Butane | C ₄ H ₁₀ | 58.123 | 2.006 8 | 2870.45 | 21 232 | 3251.9 | 2648.4 | 19 590 | 3000.4 | 0.0458 |
| <i>n</i> -Butane | C ₄ H ₁₀ | 58.123 | 2.006 8 | 2879.63 | 21 300 | 3262.3 | 2657.6 | 19 658 | 3010.8 | 0.0478 |
| <i>i</i> -Pentane | C ₅ H ₁₂ | 72.150 | 2.491 2 | 3531.5 | 21 043 | 4000.9 | 3265.0 | 19 456 | 3699.0 | 0.0581 |
| <i>n</i> -Pentane | C ₅ H ₁₂ | 72.150 | 2.491 2 | 3535.8 | 21 085 | 4008.9 | 3269.3 | 19 481 | 3703.9 | 0.0631 |
| <i>n</i> -Hexane | C ₆ H ₁₄ | 86.177 | 2.975 5 | 4198.1 | 20 943 | 4755.9 | 3887.2 | 19 393 | 4403.9 | 0.0802 |
| <i>n</i> -Heptane | C ₇ H ₁₆ | 100.204 | 3.459 8 | 4857.2 | 20 839 | 5502.5 | 4501.9 | 19 315 | 5100.3 | 0.0944 |
| <i>n</i> -Octane | C ₈ H ₁₈ | 114.231 | 3.944 1 | 5515.9 | 20 759 | 6248.9 | 5116.2 | 19 256 | 5796.2 | 0.1137 |
| <i>n</i> -Nonane | C ₉ H ₂₀ | 128.258 | 4.428 4 | 6175.9 | 20 701 | 6996.5 | 5731.8 | 19 213 | 6493.6 | 0.1331 |
| <i>n</i> -Decane | C ₁₀ H ₂₂ | 142.285 | 4.912 7 | 6834.9 | 20 651 | 7742.9 | 6346.4 | 19 176 | 7189.9 | 0.1538 |
| Neopentane | C ₅ H ₁₂ | 72.015 | 2.491 2 | 3517.27 | 20 958 | 3985 | 3250.8 | 19 371 | 3683 | |
| 2-Methylpentane | C ₆ H ₁₄ | 86.177 | 2.975 5 | 4190.43 | 20 905 | 4747 | 3879.6 | 19 355 | 4395 | 0.080 |
| 3-Methylpentane | C ₆ H ₁₄ | 86.177 | 2.975 5 | 4193.03 | 20 918 | 4750 | 3882.2 | 19 367 | 4398 | 0.080 |
| 2,2-Dimethylbutane | C ₆ H ₁₄ | 86.177 | 2.975 5 | 4180.63 | 20 856 | 4736 | 3869.8 | 19 306 | 4384 | 0.080 |
| 2,3-Dimethylbutane | C ₆ H ₁₄ | 86.177 | 2.975 5 | 4188.41 | 20 895 | 4745 | 3877.5 | 19 344 | 4393 | 0.080 |
| Cyclopropane | C ₃ H ₆ | 42.081 | 1.452 9 | 2092.78 | 21 381 | 2371 | 1959.6 | 20 020 | 2220 | ... |
| Cyclobutane | C ₄ H ₈ | 56.108 | 1.937 3 | 2747.08 | 21 049 | 2747 | 2569.4 | 19 688 | 2911 | ... |
| Cyclopentane | C ₅ H ₁₀ | 70.134 | 2.421 5 | 3322.04 | 20 364 | 3764 | 3100.0 | 19 003 | 3512 | ... |
| Cyclohexane | C ₆ H ₁₂ | 84.161 | 2.905 9 | 3955.84 | 20 208 | 4482 | 3689.4 | 18 847 | 4180 | ... |
| Ethylene (acetylene) | C ₂ H ₂ | 26.038 | 0.899 0 | 1301.32 | 21 487 | 1474 | 1256.9 | 20 753 | 1424 | 0.021 |
| Ethene (ethylene) | C ₂ H ₄ | 28.054 | 0.968 6 | 1412.06 | 21 640 | 1600 | 1323.2 | 20 278 | 1499 | 0.020 |
| Propene (propylene) | C ₃ H ₆ | 42.081 | 1.452 9 | 2059.35 | 21 039 | 2333 | 1926.1 | 19 678 | 2182 | 0.033 |
| Benzene | C ₆ H ₆ | 78.114 | 2.697 1 | 3202.74 | 18 177 | 3742 | 3169.5 | 17 444 | 3591 | 0.069 |
| Butanes (ave) | C ₄ H ₁₀ | 58.123 | 2.006 8 | 2875 | 21 266 | 3257 | 2653 | 19 623 | 3006 | 0.046 |
| Pentanes (ave) | C ₅ H ₁₂ | 72.150 | 2.491 2 | 3534 | 21 056 | 4003 | 3267 | 19 469 | 3702 | 0.062 |
| Hexanes (ave) | C ₆ H ₁₄ | 86.177 | 2.975 5 | 4190 | 20 904 | 4747 | 3879 | 19 353 | 4395 | 0.080 |
| Butenes (ave) | C ₄ H ₈ | 56.108 | 1.937 2 | 2716 | 20 811 | 3077 | 2538 | 19 450 | 2876 | 0.046 |
| Pentenes (ave) | C ₅ H ₁₀ | 70.134 | 2.421 5 | 3375 | 20 691 | 3824 | 3153 | 19 328 | 3572 | 0.060 |

^AThis table is consistent with GPA 2145-89, but it is necessary to use the values from the most recent edition of GPA 2145 for custody transfer calculations.

^B1984 Atomic Weights: C = 12.011, H = 1.00794, O = 15.9994, N = 14.0067, S = 32.06.

^CMolar mass ratio is the ratio of the molar mass of the gas to that of air.

^DBased upon ideal reaction; the entry for water represents the total enthalpy of vaporization.

^EComposition from: F. E. Jones, *J. Res. Nat. Bur. Stand.*, Vol. 83, 419, 1978.

where id denotes the ideal gas state and l denotes liquid phase. The ideal net heating value results when all the water remains in the ideal gas state. The ideal gross heating value results when all the water formed by the reaction condenses to liquid. For water, the reduction from $H_2O(id)$ to $H_2O(l)$ is $H_w^{id} - H_w^l$, the ideal enthalpy of vaporization, which is somewhat larger than the enthalpy of vaporization $H_w^v - H_w^l$.

7.1.1 Because the gross heating value results from an ideal combustion reaction, ideal gas relationships apply. The ideal gross heating value per unit mass for a mixture, H_m^{id} , is:

$$H_m^{id} = \sum_{j=1}^n x_j M_j H_{m,j}^{id} / \sum_{j=1}^n x_j M_j \quad (2)$$

where: x_j is the mole fraction of Component j , M_j is the molar mass of Component j from Table 1, and n is the total number of components.

7.1.2 $H_{m,j}^{id}$ is the pure component, ideal gross heating value per unit mass for Component j (at 60°F (15.6°C) in Table 1). Values of H_m^{id} are independent of pressure, but they vary with temperature.

7.2 Ideal Gas Density

7.2.1 The ideal gas density, ρ^{id} , is:

$$\rho^{id} = (P/RT) \sum_{j=1}^n x_j M_j = MP/RT \quad (3)$$

where: M is the molar mass of the mixture,

$$M = \sum_{j=1}^n x_j M_j \quad (4)$$

P is the base pressure in absolute units (psia), R is the gas constant, 10.7316 psia.ft³/(lb mol•°R) in this practice, based upon $R = 8.31448$ J/(mol•K), T is the base temperature in absolute units (°R = °F + 459.67). Values of the ideal gas density at 60°F (15.6°C) and 14.696 psia are in GPA Standard 2145.

7.3 Ideal Relative Density:

7.3.1 The ideal relative density d^{id} is:

$$d^{id} = \sum_{j=1}^n x_j d_j = \sum x_j M_j / M_a = M/M_a \quad (5)$$

where: M_a is the molar mass of air. The ideal relative density is the molar mass ratio.

7.4 Gross Heating Value per Unit Volume:

7.4.1 Multiplication of the gross heating value per unit mass by the ideal gas density provides the gross heating value per unit volume, H_v^{id} :

$$H_v^{id} = \rho^{id} H_m^{id} = \sum_{j=1}^n x_j H_{v,j}^{id} \quad (6)$$

$H_{v,j}^{id}$ is the pure component gross heating value per unit volume for Component j at specified temperature and pressure (60°F (15.6°C) and 14.696 psia in Table 1, ideal gas values).

7.4.2 Conversion of values in Table 1 to different pressure bases results from multiplying by the pressure ratio:

$$H_v^{id}(P) = H_v^{id}(P = 14.696) \times P/14.696 \quad (7)$$

7.5 Real Gas Values—Compressibility Factor:

7.5.1 The compressibility factor is:

$$Z(T,P) = \rho^{id} / \rho = (MP/RT) / \rho \quad (8)$$

where ρ is the real gas density in mass per unit volume. At conditions near ambient, the truncated virial equation of state satisfactorily represents the volumetric behavior of natural gas:

$$Z(T,P) = 1 + BP/RT \quad (9)$$

where B is the second virial coefficient for the gas mixture. The second virial coefficient for a mixture is:

$$B = x_1^2 B_{11} + x_2^2 B_{22} + \dots + x_n^2 B_{nn} + 2x_1 x_2 B_{12} + \dots + 2x_{n-1} x_n B_{n-1,n} \\ = \sum_{i=1}^n \sum_{j=1}^n x_i x_j B_{ij} \quad (10)$$

where B_{jj} is the second virial coefficient for Component j and B_{ij} is the second cross virial coefficient for Components i and j . The second virial coefficients are functions of temperature. Eq 9 can be used with Eq 10 for calculation of the compressibility factor for the various pressure bases, but it is not accurate at pressures greater than two atmospheres. Special treatment is not required for H₂ and He at mole fractions up to 0.01. Calculations can be made with $B_{jj} = 0$ for hydrogen and helium.

7.5.2 Eq 9 and Eq 10 for calculation of $Z(T,P)$ for a gas mixture are rigorous but require considerable calculations and information that is not always available. An alternative, approximate expression for $Z(T,P)$ that is more convenient for hand calculations is:

$$Z(T,P) = 1 - P \left[\sum_{j=1}^n x_j \sqrt{\beta_{jj}} \right]^2 \quad (11)$$

where $\beta_{jj} = B_{jj}/RT$ and $\sqrt{\beta_{jj}}$ is the summation factor for Component j . Values of $\sqrt{\beta_{jj}}$ at 60°F (15.6°C) appear in Table 2. The method based upon Eq 11 has been adopted for this practice.

7.6 Real Gas Density:

7.6.1 The real gas density ρ at a specific temperature and pressure is:

$$\rho = \rho^{id}/Z \quad (12)$$

where: ρ^{id} and Z are evaluated at the same temperature and pressure.

7.7 Real Relative Density:

7.7.1 The real relative density d is:

$$d = \rho/\rho_a = MZ_a/M_a Z \quad (13)$$

7.8 Real Heating Value—The real heating value is not given by division of the ideal heating value by the compressibility factor. Real gas heating values differ from the ideal gas values by less than one part in 10⁴ at 14.696 psia, which is of the order of the accuracy of the heating values.

7.9 Gross Heating Value of Water Wet Gas:

7.9.1 If the gas contains water as a component but the compositional analysis is on a dry basis, it is necessary to adjust the mole fractions to reflect the presence of water. The corrected mole fractions are:

$$x_j(\text{cor}) = x_j(1 - x_w) \quad (14)$$

The mole fraction of water can range from zero up to the saturated value. The saturated value for x_w is, assuming Raoult's Law:

$$x_w(\text{sat}) = P_w^\sigma/P \quad (15)$$