

AGA Report No. 8

Part 1

Thermodynamic Properties of Natural Gas and Related Gases

DETAIL and GROSS Equations of State

Third Edition

April 2017

(A revision of AGA Report No. 8, 2nd edition, 1994)

Prepared by
Transmission Measurement Committee



American Gas Association

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FOREWORD

AGA Report No. 8, Part 1, is designated as the third edition of the revised 1994 second edition of AGA Report No. 8. As in the second edition, the third edition provides the technical information necessary to compute thermodynamic properties including compressibility factors and densities of natural gas and related gases for states in the gas phase only. Additionally, equations for calculating speeds of sound and other thermodynamic properties are given. Historical information on this document is given in Section 1.2, Background. Analyses of the calculation of uncertainties are provided for various gas temperatures, pressures, and compositions. It is based on research managed and sponsored by the then Gas Research Institute (GRI) in cooperation with AGA and the *Groupe Europeen de Recherches Gazieres* (GERG). Because the equations of state contained within International Standards Organization documents ISO 12213: *Natural Gas – Calculation of Compression Factors*, Part 2: *Calculation Using Molar-Composition Analysis*, 2006 edition, and ISO 20765: *Natural Gas – Calculation of Thermodynamic Properties*, Part 1: *Gas Phase Properties for Transmission and Distribution Applications*, 2005 edition, are based on the same equations in this revision, calculated properties should have the same values.

This revised edition, now designated as AGA Report No. 8, Part 1, uses the same DETAIL and GROSS equations of state as in the 1994 edition of AGA Report No. 8. However, the temperature, pressure, and gas composition limits have been modified in this edition; and therefore, it will be necessary to ensure that the temperature, pressure, and gas composition fall within the new limits for the desired uncertainty. The users are advised to verify the applicability/acceptability of the program for the new limits based on the 1994 edition of AGA 8.

The documentation of programs for calculating properties from the methods described in this document is available as supplementary material in Appendix C. Examples are available in Fortran, VB, and C++ code. The supplementary material also contains a Microsoft Excel spreadsheet for property calculations. This can be used to determine if, for a particular temperature, pressure, and composition, the property values calculated from the equations in Part 1 are within the desired uncertainty (by comparing with those in Part 2) even though one or more of these inputs may be outside the ranges given in Part 1. A file containing calculated points at different compositions (not necessarily related to typical natural gas) is included, which can be used to verify that programs or equipment have been implemented or upgraded correctly to produce values that are in agreement with the equations in this document.

The user is encouraged to compare property values obtained through the use of the software provided in this edition with those obtained from the user's existing software and determine if the differences are within the uncertainty limits of their respective calculation methods. The Excel spreadsheet provided in the supplementary material can be used to determine if property values are within the acceptable uncertainty limits even though the state point may be outside the ranges given in this revision. If the property values are not within the uncertainty limits, the user should consider implementing AGA Report No. 8, Part 2, noted below.

AGA Report No. 8, Part 2, published separately, is based on the GERG-2008 equation of state, and is applicable for temperature, pressure, and composition ranges outside those in Part 1, with uncertainties in density, compressibility factor, and speed of sound still within 0.1 %. Part 2 can also be used for operating conditions and compositions that are applicable for Part 1, with differences in the calculated values within the uncertainty limits of each equation, where uncertainties are given with a 95 % level of confidence ($k=2$). **While adoption of the equations in Part 2 is encouraged, the decisions to upgrade existing installations to use AGA Report No. 8, Part 2, are left to the discretion of the parties involved.**

Some material described in Part 1 also applies to Part 2, and vice versa, and is not repeated in both parts. For example, Part 1 describes an algorithm for obtaining densities through an iterative procedure that can also be used with the equations in Part 2 (and which is applied for this purpose to the GROSS, DETAIL, and GERG-2008 equations of state in the programs in the supplementary material). Similarly, Part 2 outlines the method for reporting calculated results and uncertainties from the equations in both parts, and also describes the experimental

database available for natural gas mixtures (both binary and multicomponent systems), much of which was used in the development of the equations in Part 1. Some information, however, is repeated in both parts, such as the material in Sections 2 and 3. **The combination of Parts 1 & 2 gives a wider overview of the equations of state and their appropriate application to natural gas.**

The publication AGA Report No. 10: *Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases* has been discontinued with the release of this AGA Report No. 8, Part 1. The calculation of the speed of sound no longer requires integration of the compressibility factor equation, as was done in AGA Report No. 10, but is implemented through differentiation of the fundamental Helmholtz energy equation of state. This results in faster calculations through direct computation of the required derivatives.

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Individuals who made substantive contributions are:

Ian Bell, NIST, USA
Ilia Bluvshstein, Union Gas Ltd., Canada
David Bromley, BP Pipelines, USA
Greg Dunn, Eagle Research Corporation, USA
Juan Escobar, ARAMCO, Saudi Arabia
Volker Heinemann, Honeywell, Germany
Randy Herman, Flow-Cal Measurement Applications, USA
Gurwinder Kamboz, Krohne Oil & Gas, The Netherlands
Jason Lu, Thermo Fisher Scientific, USA
Ian McDavid, Flow-Cal Measurement Applications, USA
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James McAdams, Interlink Systems, USA
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Roy Meyer, ExxonMobil, USA
Sam Patel, Consumers Energy Co., USA
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Christina Sames
Vice President, Operations & Engineering

Ali Quraishi
Director, Operations & Engineering Services

TABLE OF CONTENTS

| | |
|---|-----|
| DISCLAIMER AND COPYRIGHT | iii |
| FOREWORD | v |
| ACKNOWLEDGEMENTS | vii |
| 1 INTRODUCTION..... | 1 |
| 1.1 Scope | 1 |
| 1.2 Background..... | 1 |
| 1.3 Overview of Properties from Equations of State | 2 |
| 1.3.1 DETAIL Equation of State | 2 |
| 1.3.2 GROSS Equation of State | 6 |
| 1.4 Uncertainty | 7 |
| 1.4.1 DETAIL Equation of State Uncertainty | 7 |
| 1.4.2 GROSS Equation of State Uncertainty..... | 7 |
| 1.5 Recommendations | 7 |
| 2 DEFINITIONS AND GENERAL EQUATIONS | 8 |
| 2.1 Definitions of Phase Regions | 8 |
| 2.2 Nomenclature | 9 |
| 2.3 General Equations | 10 |
| 3 UNITS, CONVERSIONS, PRECISION, AND ACCURACY | 11 |
| 4 THERMODYNAMIC PROPERTIES FROM THE DETAIL EQUATION OF STATE | 12 |
| 4.1 Nomenclature | 12 |
| 4.2 DETAIL Equation of State for Thermodynamic Properties Including Compressibility Factor and Pressure | 13 |
| 4.3 Equation of State for the Helmholtz Energy..... | 15 |
| 4.4 Speed of Sound and Other Thermodynamic Properties..... | 16 |
| 5 THERMODYNAMIC PROPERTIES FROM THE GROSS EQUATION OF STATE | 23 |
| 5.1 Nomenclature | 23 |
| 5.2 Equation of State for Compressibility Factor | 23 |
| 5.3 Interaction Virial Coefficient Terms for Nitrogen and Carbon Dioxide | 26 |
| 5.4 Interaction Virial Coefficient Terms for the Equivalent Hydrocarbon..... | 26 |
| 6 COMPUTATION OF DENSITIES AND COMPRESSIBILITY FACTORS..... | 28 |
| 6.1 Iterative Procedure to Determine Density from Temperature and Pressure | 28 |
| 6.2 Computer Programs for the Calculation of Properties..... | 29 |
| 7 ASSIGNMENT OF TRACE COMPONENTS..... | 30 |
| 8 REFERENCES..... | 32 |
| APPENDIX A – GROSS EQUATION OF STATE | 33 |
| A.1 Nomenclature | 33 |
| A.2 Reference Conditions | 33 |
| A.3 GROSS Equation of State Computation Procedures | 34 |
| A.3.1 Method 1. Volumetric Gross Heating Value, Relative Density, and Mole Fraction of CO ₂ | 36 |
| A.3.2 Method 2. Relative Density and Mole Fractions of N ₂ and CO ₂ | 36 |
| A.3.3 Method 3. Molar Mass and Mole Fractions of N ₂ and CO ₂ | 37 |
| APPENDIX B – EXAMPLES AND COMPARISON TO MEASUREMENTS..... | 38 |
| B.1 Nomenclature..... | 38 |
| B.2 Calculation Examples | 38 |
| B.3 Comparisons of Calculated Properties with Measurements | 43 |
| APPENDIX C – DESCRIPTION OF THE SUPPLEMENTARY FILES..... | 46 |
| FORM TO PROPOSE CHANGES..... | 49 |

1 INTRODUCTION

1.1 Scope

Part 1 presents information for the computation of thermodynamic properties (*e.g.*, compressibility factor, density, and speed of sound) of natural gas and related gases with the DETAIL and GROSS equations of state. Uncertainty estimations for different compositions, pressures, and temperatures are given. The computations are valid for single-phase gaseous states only. For mixed or liquid phases, refer to Part 2.

1.2 Background

Research in 1928 and 1929 under the direction of Mr. Howard S. Bean of the National Bureau of Standards provided the natural gas industry with its initial compressibility factor data covering pressures up to 600 psia (4 MPa). However, it was not until 1954 that extensive tables of natural gas supercompressibility factors were published, based on tests supervised by Professor Samuel R. Beitler of Ohio State University. The natural gas supercompressibility factor tables were extended and an equation of state was developed in 1956-1962 under the direction of Mr. R. H. Zimmerman of Ohio State University. The results of this project, designated PAR Project NX-19, appear in AGA's *Manual for Determination of Supercompressibility Factors for Natural Gas*, published in 1962.

The research leading to the 1985 and 1992 reports was initiated in 1981 under the sponsorship of GRI in close liaison with the AGA Transmission Measurement Committee. This research, carried out under the direction of Professor Kenneth E. Starling of the University of Oklahoma, was aimed at extending capabilities for accurate computation of compressibility factors beyond the temperature, pressure, and composition ranges of PAR Project NX-19. The results for pipeline-quality natural gas, which were completed in 1984, provided the basis for the 1985 report.

The initial 1981-1984 research used data ranging in pressures up to approximately 900 psia (6 MPa) obtained from the literature and provided by GERG. However, the GERG data bank was extended considerably over the period 1985-1990. The new data showed that the original equation of state, developed in the period 1981-1984, needed to be improved. In addition, speed of sound data obtained under GRI sponsorship during 1985-1989 showed calculations for rich gases were not sufficiently accurate for critical flow applications.

Although the 1992 and 1994 AGA 8 publications of the equation of state are explicit in the compressibility factor Z , the formulation was originally developed with an equation of state explicit in the Helmholtz energy a with independent variables of molar density d and temperature T . The Helmholtz energy equation was not given in the 1992 and 1994 AGA 8 documents, where only equations explicit in pressure and compressibility factor were reported. The Helmholtz energy is a fundamental thermodynamic property from which all other thermodynamic properties can be calculated as derivatives with respect to density or temperature. For example, the expression for calculating pressure is

$$P = d^2 \left(\frac{\partial a}{\partial d} \right)_T. \quad (1-1)$$

When starting from the pressure explicit equation, the calculation of other properties, including the speed of sound, requires not only derivatives of the compressibility factor with respect to density and temperature, but also integration of Z over density, which can be quite complicated. Equations are presented in this revision that start with the Helmholtz energy form, and allow access to other thermodynamic properties such as heat capacities, enthalpies, and entropies by differentiation of this fundamental property. Formulations explicit in the Helmholtz energy have been used heavily over the last two decades to represent the properties of pure fluids and mixtures due to the ease of calculating all other thermodynamic properties.