

AGA Report No. 8
Part 2

**Thermodynamic Properties of
Natural Gas and Related Gases**

GERG-2008 Equation of State

First Edition
April 2011

Prepared by
Transmission Measurement Committee



American Gas Association

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FOREWORD

AGA Report No. 8, Part 2, provides technical information necessary to compute thermodynamic properties including compressibility factors, densities, speeds of sound, and dew and bubble points for natural gas and related gases. It is based on the research performed at the Ruhr University in Bochum, Germany, and published in 2006 as the doctoral dissertation of Oliver Kunz under the direction of Prof. Dr.-Ing. Wolfgang Wagner. The equations in the dissertation are commonly referred to as the GERG-2004 and GERG-2008 equations of state in acknowledgement of partial sponsorship of the research by the *Groupe Europeen de Recherches Gazieres* (GERG). Because these equations are used both in this document and the International Standards Organization document ISO 20765: *Natural Gas – Calculation of Thermodynamic Properties, Part 2: Single-Phase Properties (Gas, Liquid, and Dense Fluid) for Extended Ranges of Application*, 2015 edition, calculations of properties should have the same values.

The companion publication, AGA Report No. 8, Part 1, provides calculation methods for the DETAIL and GROSS equations of state as in the 1994 edition of AGA Report No. 8, but the temperature, pressure, and composition limits for different levels of uncertainties have been modified.

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.

Some material described in Part 2 also applies to Part 1, 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.**

Although Part 2 may be used to calculate thermodynamic properties for pressures, temperatures, and gas compositions applicable for Part 1 (within the uncertainty limits of each equation), the decision to upgrade existing installations to use Part 2 is left to the discretion of the parties involved.

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TABLE OF CONTENTS

DISCLAIMER AND COPYRIGHT	iii
FOREWORD	iv
ACKNOWLEDGEMENTS	v
1 INTRODUCTION.....	1
1.1 Scope	1
1.2 Background	1
2 DEFINITIONS AND GENERAL EQUATIONS	3
2.1 Definitions of Phase Regions	3
2.2 Nomenclature	4
2.3 General Equations	6
3 UNITS, CONVERSIONS, PRECISION, AND ACCURACY	7
4 EQUATION OF STATE FOR THE HELMHOLTZ ENERGY	8
4.1 The Ideal-gas Helmholtz Energy	8
4.2 The Residual Helmholtz Energy	10
4.3 The Reducing Functions.....	11
4.4 Thermodynamic Properties from the Helmholtz Energy	12
4.5 Vapor-liquid Equilibrium (VLE).....	18
5 EXPERIMENTAL DATA	20
6 UNCERTAINTY	22
7 REPORTING RESULTS	24
8 ASSIGNMENT OF TRACE COMPONENTS	25
9 REFERENCES.....	28
APPENDIX A – COEFFICIENTS AND EXPONENTS.....	29
APPENDIX B – EXAMPLES OF CALCULATIONS	44
APPENDIX C – DESCRIPTION OF THE SUPPLEMENTARY FILES	47
FORM TO PROPOSE CHANGES.....	49

1 INTRODUCTION

1.1 Scope

Part 2 presents information for computation of thermodynamic properties, including compressibility factors, densities, and speeds of sound, of natural gas and related gases, for gaseous states, vapor-liquid equilibrium states, and liquid states, based on the GERG-2008 equation of state [1,2]. It also improves upon the performance of the AGA 8 DETAIL equation [3] for gas-phase properties, especially at high pressures and low temperatures. The ranges of temperature, pressure, and composition for which the GERG-2008 equation of state applies are much wider than the AGA 8 DETAIL equation. Uncertainty estimations for different composition, pressures, and temperatures are given. With the availability of vapor-liquid equilibrium and liquid state calculations, Part 2 enables the calculation of dew points, bubble points, and the critical point.

1.2 Background

Work began in the 1990's at the Ruhr University in Bochum, Germany, under the direction of Wolfgang Wagner to develop even more sophisticated models to represent not only the gas phase, as in the case of AGA 8, 1994 edition, but also the liquid phase and retrograde region. The first version of the new equation was released in 2004 for 18 components, and then an updated version was released in 2008 with three additional components. These 21 components, listed at the end of this section, are the same as the components in AGA 8, Part 1. Because the calculation of dew points requires knowledge of the liquid phase as well as the gas phase, the DETAIL method presented in Part 1 is not able to determine the state where liquids will condense from a natural gas stream. With the addition of accurate liquid calculations in the GERG-2008 equation, dew points, as well as bubble points and saturated states in the retrograde region, can now be calculated for any temperature or pressure input. The equations required for these calculations are covered in Part 2.

The GERG-2008 equation is explicit in the Helmholtz energy, which is a fundamental property that allows the calculation of all other thermodynamic properties through analytical derivatives with respect to the independent properties, which are temperature and density. For example, pressure is proportional to the first derivative of the Helmholtz energy with respect to density (at constant temperature). This equation is also applicable in the calculation of two-phase properties (vapor-liquid equilibria). Through the use of a fundamental equation of state, numerical differentiation or integration to obtain thermodynamic properties is not necessary, as was done in AGA 10.

AGA Report No. 8, Part 2, provides all pertinent information required to implement the GERG-2008 mixture model for the calculation of volumetric and caloric properties of natural gases, manufactured fuel gases, and similar mixtures. The model is also applicable to each of the pure natural gas components and to numerous binary and multi-component mixtures not related to natural gas. It is valid at conditions where the mixture may be in the single-phase gas, liquid, or retrograde region, as well as saturation and 2-phase states.

The uncertainties of calculated properties in the gas phase, including both volumetric properties (density) and caloric properties (enthalpy, entropy, heat capacity, speed of sound, *etc.*) are the same or lower in most cases than those for the methods described in Part 1 over the full ranges of validity of the DETAIL equation of state. This is particularly true at lower temperatures, such as the temperature region from $-10\text{ }^{\circ}\text{F}$ to $35\text{ }^{\circ}\text{F}$ (250 K to 275 K). As with Part 1, the uncertainties in density and speed of sound are generally within 0.1 % or less, where uncertainties are given in this document with a 95 % level of confidence ($k=2$). Through the use of a more complex model than that in Part 1, single-phase liquid states, 2-phase states, and dew and bubble points can now be calculated with the Part 2 equations (which was not possible in Part 1).

With the more complex model, the regions of validity increase to cover the full pressure, temperature, and composition ranges for most of the 21 components available. For example, Part 1 is limited to 25 mole percent ethane, 6 mole percent propane, non-hydrogen-rich natural gases, and to very small amounts of the heavier