

REPORT NO. 8 SOFTWARE

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Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases

by
K.E. Starling and J.L. Savidge



Transmission Measurement Committee Report No. 8



American Petroleum Institute MPMS Chapter 14.2



Gas Research Institute



American Gas Association

Catalog No. XQ9212

Second Edition, November 1992

2nd Printing July 1994

3rd Printing, November 2003

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PREFACE

This manual is based on research managed and sponsored by the Gas Research Institute (GRI) and the Groupe Europeen de Recherches Gazieres (GERG) in cooperation with A.G.A. The manual provides all of the technical information needed to compute compressibility factors, supercompressibility factors, and densities for natural gas and related gases. It supersedes the 1985 Version of A.G.A. Report Number 8 and conforms to International Standards Organization Document ISO 12213, Natural Gas -- Calculation of Compression Factors. This A.G.A. document includes FORTRAN computer programs and sample calculations which are optimized for efficient microprocessor and flow computer implementation. Supporting computer programs based on the methods in this manual can be obtained on diskette from the A.G.A.

This manual was updated in July 1994 for the purpose of: (1) correcting typographical errors identified in the November 1992 edition, (2) improving the computer programs, and (3) achieving computational consistency with GPA 2172-94 and the 1992 edition of A.G.A. Report No. 3, Part 3. No changes were made to the basic equations of state, or to the parameters used to calculate the compressibility factor. Properties calculated from this document will be slightly different from the November 1992 version. The differences in the example calculations are caused by changes in the way the gas characterization parameters are obtained from input data. These changes help assure a high level of numerical consistency with other industry standards for flow computer computations. The effects of these changes, however, are expected to be less than 0.01% for typical natural gas found in transmission pipelines and less than 0.03% for typical production gas. This is well within the uncertainty of the experimental data. Therefore no change is required from the November 1992 revision to maintain the stated accuracy.

ACKNOWLEDGEMENTS

This document is the result of many years of effort. It is based on a large amount of related supporting materials which are the product of many dedicated individuals and organizations both domestically and internationally. The individuals and organizations listed below deserve the recognition and thanks of the gas industry for their significant contributions of time, skills and resources.

Foremost among the contributors are Mr. P. Hoglund of Washington Natural Gas and Dr. M. Jaeschke of Ruhrgas AG. Mr. Hoglund led A.G.A. in organizing and articulating the benefits of the R&D program. In addition, he actively promoted international cooperation which initiated A.G.A.'s participation in the International Standards Organization Technical Committee 193/Subcommittee 1. Paul's vision and efforts led to pivotal research interactions that substantially improved the quality of the methods presented in this document.

Dr. Jaeschke's research at Ruhrgas AG made an invaluable contribution to improving compressibility factor prediction through his extensive experimental work on the PVT behavior of natural gases. His initial efforts were in support of GERG virial equation of state research with Dr. J. Schouten. The experimental work was later expanded to help support needs identified at Ruhrgas and in the GRI wide-range equation of state research with Dr. K. Starling and Dr. R. Jacobsen. Dr. Jaeschke's efforts, and those of his coworkers, produced over ten thousand state-of-the-art measurements of the compressibility factor for a wide variety of natural gases, their constituents, and related mixtures. Their data are the predominant experimental basis for the high accuracy equations of state presented in this report.

GRI, A.G.A., and GERG contributed their financial, committee, and technical management. Gasunie, Ruhrgas, Gaz de France, and British Gas contributed to the development of the experimental compressibility factor database and the GERG research program which produced the GERG method. Individual contributions were made by Mr. J. Erickson and Ms. Lori Traweek of A.G.A. through their active support and patience and Dr. A. Smit (Gasunie) through his leadership as chairman of ISO TC 193/SC 1. Mr. J.P. Smith (Transco), Mr. M.L. Williams (Amoco), Mr. G. Givens (Consolidated Natural Gas) contributed through their leadership, advice, and participation as industry liaisons through the A.G.A. F_{pv} Committees. Dr. D. Embry (Phillips Petroleum), Mr. J. Stuart (Pacific Gas & Electric), Mr. P. LaNasa (private consultant), Dr. R. Teyssandier (Texaco) and Mr. R. Beaty (Amoco) contributed by providing valuable industry feedback during the preparation process of this report and provided ideas for the computer programs.

Lastly, the contributions made by the researchers, many students and support staff at the University of Oklahoma, University of Amsterdam, University of Idaho, Texas A&M, and National Institute of Standards and Technology are best represented by the exceptional quality of the results produced for the gas industry. Dr. K.E. Starling's, U. of Oklahoma, contribution helped to produce not only an exceptional equation of state (DETAIL CHARACTERIZATION METHOD) for natural gases, but significantly improved this document in ways which should facilitate its understanding and practical use. Dr. R. Jacobsen and coworkers at the University of Idaho provided an exceptional correlation development methodology and set of tools that helped substantially in developing the DETAIL CHARACTERIZATION METHOD. Dr. J.

Schouten and Dr. J. Michels of the U. of Amsterdam contributed creative research which produced the SGERG equation of state (GROSS CHARACTERIZATION METHOD). Dr. C. Fitz, U. of Oklahoma, and Mr. P. Clarke, U. of Idaho, contributed great personal effort to produce the DETAIL CHARACTERIZATION METHOD. Dr. K. Hall, Dr. J. Holste, Texas A&M U., and Dr. M. Haynes, N.I.S.T., contributed their skills to develop a state-of-the-art PVT Reference Database on natural gas mixtures. Dr. S. Beyerlein and Mr. E. Lemmon, U. of Idaho, made a number of significant technical contributions which improved both the quality of the final results of the research project and this A.G.A. report.

Dr. Jeffrey L. Savidge
Project Manager

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COMPRESSIBILITY FACTORS FOR NATURAL GAS AND OTHER RELATED HYDROCARBON GASES

1 INTRODUCTION

1.1 Scope

This report presents detailed information for precise computations of compressibility factors and densities of natural gas and other hydrocarbon gases, calculation uncertainty estimations and FORTRAN computer program listings. Applications for computations of other properties are summarized but are beyond the scope of this report.

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 A.G.A.'s "Manual for Determination of Supercompressibility Factors for Natural Gas," published in 1962.

The research leading to the present report was initiated in 1981 under the sponsorship of GRI in close liaison with the A.G.A. 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 gases, 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 in 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, velocity of sound data obtained under GRI sponsorship during 1985-1989 showed calculation for rich gases were not sufficiently accurate for critical flow applications. The new equations of state presented in this revision include the most recent GRI and GERG compressibility factor data for natural gas mixtures. In addition, the revised method has applied an improved correlation methodology developed by researchers under the direction of Professor Richard T Jacobsen at the University of Idaho.