Preface to the Second Edition

This edition continues as a source intended for the practicing engineer and interested scientist in accurate thermodynamic property information for cryogenic fluids. Cryogenic fluids display a wonderful spectrum of fluid behavior that spans the highly quantum regime near absolute zero through the classical regime of the very air we breathe. It is our hope that the reader finds enjoyment in visualizing how small changes in atomic and molecular structure result in significant changes to thermodynamic properties in the cryogenic regime.

In the 20 years since the first edition of Thermodynamic Properties of Cryogenic Fluids, the field of thermophysical properties is reaching maturity. Although sparse cryogenic experimental studies have been completed over this time, the computational fitting techniques have greatly improved, even though the functional form of pure fluid equations of state has essentially remained consistent. This maturation has allowed expansion of established techniques to historically challenging fluids and refinement of the software packages used to distribute this information.

The first edition of this text utilized a software package called ICMPROPS developed within the Center for Applied Thermodynamic Studies (CATS) at the University of Idaho. Shortly after the completion of the first edition, Eric Lemmon was employed by the National Institute of Standards and Technology (NIST) to incorporate ICMPROPS into the new software package REFPROP. REFPROP has superseded ICMPROPS and ALLPROPS and remains a leading software package for thermophysical property information. REFPROP can be downloaded directly from NIST, and a special version is available containing the fluids specific to this text. Additional information on REFPROP is included in this edition. As a result, this edition does not discuss the prior software packages.

This edition updates the majority of the property formulations as only neon, fluorine, oxygen, and methane remain unchanged. Xenon and ethane had the highest normal boiling points and were dropped from this edition corresponding to the established definition of the cryogenic fluid regime below 124 K. Work still remains, for example, the oxygen equation, now over 30 years old, is in the process of being refitted to change its use of the IPTS-68 to the ITS-90 scale—a change that alone will correct a 0.1% error in the vapor pressure.

The major change to this text is structural. Cryogenic applications typically utilize a single fluid. Therefore, this edition is formatted with each fluid comprising a chapter and arranged by normal boiling point, from the lowest (helium) through the highest (krypton). This approach allows an introduction to fluid-specific characteristics that may influence the implementation of the formulation. As with the first edition, we invite suggestions on the improvement and expansion of these tools by those who use them.

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Preface to the First Edition

This book is intended to provide the practicing engineer and interested scientist with the most accurate information available on the thermodynamic properties of cryogenic fluids. It may also be useful to universities and colleges as a supplementary reference text for elective courses in cryogenic engineering or engineering systems analysis that study systems with cryogens as the working fluids. Much of the material presented here is the result of a long-term continuing research effort in the Center for Applied Thermodynamic Studies (CATS) at the University of Idaho. While some of the thermodynamic property formulations presented here are the work of CATS staff, many have been developed and published by others. Numerical changes have been made to convert all of the correlations to a single form for ease of computation.

We have included the most accurate available formulation for each fluid, realizing that some of those included will be superseded in the future. We do not apologize for this circumstance, for it is the nature of this rapidly changing, dynamic field that both experimental methods and correlations improve with time. Fortunately, most new works extend the ranges of prior research or correct relatively minor errors in numerical models (e.g., near the critical point), and generally tend to verify the values given by models of the quality of those presented here.

In the presentation of correlations of thermodynamic data, it is customary to provide the reader or user with graphical and statistical information that verifies the accuracy of calculated properties. We have referenced the original works that contain these details for the interested user. We have provided sufficient detail on the model for each fluid that the user may program the formulations in any appropriate language or format consistent with a particular application.

In developing this book, we have given a brief review of the fundamentals of thermodynamic property formulations and a summary of current practices in data analysis and correlation. Although these discussions are intended to be very general, it is likely that the experiences of the authors have influenced the approach. The information included should be sufficient to allow the user to have confidence in the accuracy of calculated properties.

We have included Internet access to executable code for the computer programs used to calculate the fluid properties described in this book. It is our hope that the graphs, tables, and computer programs we have provided will be widely useful to those who need property information for cryogenic fluids. We invite suggestions on the improvement and expansion of these tools by those who use them.

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