

## Preface to the Second Edition

The international research regarding the thermophysical properties of water and steam has been coordinated by the International Association for the Properties of Water and Steam (IAPWS). IAPWS is responsible for the international standards for thermophysical properties. These standards and recommendations are given in the form of releases, guidelines, and advisory notes. One of the most important standards in this sense is the formulation for the thermodynamic properties of water and steam for industrial use.

In 1997, IAPWS adopted the “IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam” for industrial use, called IAPWS-IF97 for short. The formulation IAPWS-IF97 replaced the previous industrial formulation IFC-67 published in 1967.

After the adoption of IAPWS-IF97 in 1997, further so-called backward equations were developed. These studies were coordinated by the IAPWS Task Group on Supplementary Backward Equations for IAPWS-IF97 chaired by one of the authors of this book (H.-J. K.). The final form of these equations is based on contributions by

J. R. Cooper	K. Knobloch	I. Stöcker
A. Dittmann	H.-J. Kretzschmar	R. Span
D. G. Friend	R. Mareš	W. Wagner
J. S. Gallagher	K. Miyagawa	I. Weber
A. H. Harvey	N. Okita	

In addition to these scientists, many other IAPWS colleagues, particularly the members of the working group “Industrial Calculations” (chairman up to 2001: B. Rukes, chairman from 2001 to 2003: K. Miyagawa, and chairman from 2004 onwards: Bill Parry) from 2002 onwards renamed in “Industrial Requirements and Solutions”, and the working group “Thermophysical Properties of Water and Steam” (chairman up to 2000: J. R. Cooper, chairman from 2000 to 2005: D. G. Friend, and chairman from 2005 onwards: H.-J. Kretzschmar), have contributed to the entire success of this IAPWS project; we appreciate their contribution very much. We are particularly grateful to the chairman of the evaluation task group, K. Miyagawa, for his exceptional efforts in testing these backward equations to ensure that they fulfill all requirements and checking the drafts of the several supplementary releases.

In 1998, Springer-Verlag published the book “Properties of Water and Steam” authored by W. Wagner and A. Kruse. This book described the industrial formulation IAPWS-IF97 as it was adopted by IAPWS in 1997. This new book is considered to be the second edition of the book published in 1998, although it has a different title and authorship and is only in English and no longer bilingual English/German. This second edition describes the industrial formulation in its current form, thus including all of the new so-called backward equations adopted by IAPWS between 2001 and 2005.

In addition to IAPWS-IF97, the industrial standard for the *thermodynamic* properties of water

and steam, the most recent equations for the *transport* properties dynamic viscosity and thermal conductivity are also presented. Moreover, equations for the surface tension, dielectric constant, and refractive index are given.

In contrast to the first edition, this second edition contains a number of extensions and new parts, namely:

- Incorporation of all “supplementary” backward equations.
- Inclusion of the uncertainty of the specific enthalpy into the uncertainty values of IAPWS-IF97 for the most important properties.
- Formulas to calculate all partial derivatives of the eight most important thermodynamic properties.
- Additional properties in the steam tables.
- Incorporation of the new basic equation for the high-temperature region (1073.15 K to 2273.15 K) with pressures up to 50 MPa (previously up to 10 MPa).
- Pressure-temperature diagrams with isolines of all properties contained in the steam tables and further properties.
- A compact disc (CD) providing the interactive program “IAPWS-IF97 Electronic Steam Tables” for the calculation of all properties (contained in the book) dependent on freely selectable pressures and temperatures in the single-phase region and on pressure or temperature along the saturated-vapour and saturated-liquid lines. Those properties for which it is reasonable can also be calculated within the two-phase region for given values of pressure or temperature and vapour fraction.

We are very grateful to Dr. K. Knobloch who developed the supplementary backward equations in her dissertation. We would like to thank Mr. M. Kunick for calculating and formatting the tables as Microsoft Excel sheets for Part B. We are very grateful to Dr. I. Stöcker, Dr. K. Knobloch, Ms. M. Weidner, and Mr. S. Buchholz for their help in producing all of the pressure-temperature diagrams in Part C of the book. Our warmest thanks are dedicated to Dr. U. Overhoff for his assistance in preparing the “IAPWS-IF97 Electronic Steam Tables” on the CD in Part D and for several checkups, and to Dr. I. Stöcker for her help in producing the large size Mollier  $h$ - $s$  and  $T$ - $s$  diagrams, which are included as attachments to the book. We thank Mr. R. Preusche, Mr. M. Markward, and Mr. B. Salomo for reprogramming all of the equations presented in the book. We would also like to thank Mrs. B. Esch for typing the text of the manuscript and Mrs. R. Gölzenleuchter for producing all of the figures. Our thanks go to Dr. O. Kunz for his help in creating the electronic printing version of Part A of the manuscript. Finally, we are grateful to Dr. E. W. Lemmon and Mrs. R. Smith for carefully reading the manuscript and for a number of suggestions on improving the English style.

One of us (H.-J. Kretzschmar) is particularly grateful to the Saxon State Ministry for Science and Art for the financial support of the development of the supplementary backward equations at the Zittau/Görlitz University of Applied Sciences from 2001 to 2003.

Bochum and Zittau, November 2007

W. Wagner  
H.-J. Kretzschmar

## Preface to the First Edition

In 1997, the International Association for the Properties of Water and Steam (IAPWS) adopted a new formulation for the thermodynamic properties of water and steam for industrial use. This formulation is called “IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam” and “IAPWS Industrial Formulation 1997” or “IAPWS-IF97” for short. The new formulation IAPWS-IF97 replaces the previous industrial formulation, IFC-67, that has formed the basis for power-plant calculations and other industrial applications since the late 1960’s. IAPWS-IF97 improves significantly both the accuracy and the speed of the calculation of thermodynamic properties. The differences from IFC-67 will require many users, particularly boiler and turbine manufacturers but also power-station companies and corresponding engineering offices, to modify design and application codes. In addition to these applications, IAPWS-IF97 is also of importance for energy-engineering applications in chemical industry and in other branches of industry. Therefore, this book presents the individual equations of IAPWS-IF97 for calculating the thermodynamic properties of water and steam for industrial use.

The IAPWS Industrial Formulation 1997 was developed in an international research project. This development was coordinated by the IAPWS Task Group “New Industrial Formulation” chaired by one of the authors of this book (W. W.). The final form of IAPWS-IF97 is based on contributions and equations by

J. R. Cooper	R. Mareš	Y. Takaishi
A. Dittmann	K. Oguchi	I. Tanishita
J. Kijima	H. Sato	J. Trübenbach
H.-J. Kretzschmar	I. Stöcker	W. Wagner
A. Kruse	O. Šifner	Th. Willkommen.

Besides these “developers” many other IAPWS colleagues, particularly the members of the two working groups “Industrial Calculations” and “Thermophysical Properties of Water and Steam”, contributed to the entire success of this comprehensive project; we appreciate their contribution very much. We are especially grateful to the chairmen of these two working groups, B. Rukes and J. R. Cooper. In addition, we would like to thank the members of the IAPWS Task Group “New Industrial Formulation - Evaluation” for testing IAPWS-IF97 regarding the fulfilment of requirements and checking the influence on real power-cycle calculations; concerning these important pieces of work we are particularly grateful to the chairman of this task group, K. Miyagawa, and his colleagues R. Spencer, R. B. McClintock, and H. W. Bradley for their exceptional efforts.

In addition to IAPWS-IF97, the industrial standard for the thermodynamic properties of water and steam, the most recent equations for the transport properties dynamic viscosity and thermal conductivity are also presented. Moreover, equations for the surface tension, static dielectric constant, and refractive index are given.

The text of this book is bilingual. Part A contains the description of the above mentioned equations for the thermophysical properties in English and Part B the corresponding description in German. Comprehensive tables of the most important thermophysical properties of water and steam are given in Part C in both languages.

The values in the tables of Part C were exclusively calculated from the corresponding equations summarized in Part A and Part B, respectively. These tables, which are mainly based on the new industrial formulation IAPWS-IF97, replace the tables “Properties of Water and Steam in SI-Units” prepared by E. Schmidt and edited by U. Grigull (Springer-Verlag Berlin Heidelberg New York, R. Oldenbourg München, Fourth, Enlarged Printing, 1989) which are based on the previous industrial formulation IFC-67.

We wish to express our warmest thanks to Mr. C. Bosen for his help in handling the computer programs for calculating the transport properties and for producing all the tables. We would also like to thank Mrs. A.-M. Sieg for typing the text of the manuscript. We are particularly grateful to the Deutsche Forschungsgemeinschaft for their financial support of that part of the development of IAPWS-IF97 which was carried out at the Ruhr-University Bochum.

Bochum, February 1998

W. Wagner  
A. Kruse

# Introduction

This book consists of five parts, Part A to Part E.

**Part A** presents the current internationally agreed upon equations for industrial calculations of the most relevant thermophysical properties of water and steam.

The current industrial standard for the *thermodynamic* properties, which replaced the former industrial standard IFC-67 [1], was adopted by the International Association for the Properties of Water and Steam (IAPWS) in 1997 under the name “IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam” or simply IAPWS-IF97 for short. All relevant numerical details about the entire set of equations of IAPWS-IF97 are given in Chap. 2.

As a comprehensive supplement of the first edition of this book, this second edition contains all of the so-called backward equations of IAPWS-IF97 developed after 1997 and adopted by IAPWS between 2001 and 2005. In addition to the uncertainty values given in IAPWS-IF97 for the properties specific volume, specific isobaric heat capacity, speed of sound, and saturation pressure, now uncertainty values for the specific enthalpy and differences in specific enthalpy are given as well. Moreover, formulas are presented in this new work to calculate all partial derivatives from the equations of IAPWS-IF97 formed by any three combinations of the properties pressure, temperature, and the specific properties volume, enthalpy, internal energy, entropy, Gibbs free energy, and Helmholtz free energy. For the high-temperature region (1073.15 K to 2273.15 K), the new basic equation that covers this temperature range for pressures up to 50 MPa (previously 10 MPa) is presented.

In addition to the equations for the thermodynamic properties of water and steam, Chap. 3 of Part A summarizes current equations for industrial use for the *transport* properties dynamic viscosity and thermal conductivity and also presents correlation equations for the surface tension, dielectric constant, and refractive index.

**Part B** contains the tables of the most important properties of water and steam, which were calculated from the corresponding equations of Chaps. 2 and 3 in Part A. In comparison with the first edition, additional tables with values of the properties compression factor, isochoric heat capacity, isobaric expansion coefficient, and isothermal compressibility are given. The table for the ideal-gas state was extended by including the properties isochoric heat capacity, isentropic exponent, and mean isobaric heat capacity between 0 °C and the given temperature  $t$ .

**Part C** of this book presents pressure-temperature diagrams with isolines of all the properties tabulated in Part B and of further properties such as the specific internal energy, Joule-Thomson coefficient, and a number of partial derivatives.

**Part D** contains a CD providing the interactive program “IAPWS-IF97 Electronic Steam Tables” to calculate all of the properties contained in the book dependent on pressure and temperature. In this way, users can calculate “personal” steam tables for arbitrary values of pressure and temperature, as well as properties in the two-phase region as a function of pressure or temperature together with vapour-fraction. With the addition of this possibility, the size of the printed steam tables (Part B) was reduced in comparison with the first edition of this book.

**Part E** contains the two wall charts, a Molier  $h$ - $s$  diagram and a  $T$ - $s$  diagram.

International Steam Tables - Properties of Water and Steam based on the Industrial Formulation IAPWS-IF97  
Tables, Algorithms, Diagrams, and CD-ROM Electronic  
Steam Tables - All of the equations of IAPWS-IF97  
including a complete set of supplementary backward  
equations for fast calculations of heat cycles, boilers,  
and steam turbines

Wagner, W.; Kretzschmar, H.-J.

2008, XIX, 391 p. With CD-ROM., Hardcover

ISBN: 978-3-540-21419-9