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BOOK REVIEW

NBS/NRC Steam Tables

L. Haar, J. S. Gallagher and G. S. Kell

Knowledge of accurate physical properties of water is a fundamental aspect of the design of machinery and equipment and many process technologies of the chemical, petroleum, aeronautical, textile, nuclear, power, food, pharmaceutical, metallurgical, refrigeration, paper, and other industries. The physical properties of water also play an important part in our daily lives as well as act as a standard against which many other things are measured. Thus, the appearance of this new steam tables is of significance to a wide spectrum of people in industry, academia and government, and, as such, requires careful review and consideration.

A new formulation, developed by Lester Haar and John Gallagher of NBS and the late George Kell of NRC, was used to calculate the values in this new Steam Tables. The formulation has undergone extensive validation and testing over a period of years by members of the International Association for the Properties of Steam and others. This evaluation has culminated in the adoption of a dimensionless version of the formulation by the Tenth International Conference on the Properties of Steam held in Moscow in September 1984. The formulation, a fundamental global equation yielding the Helmholtz free energy as a function of density and temperature, has been designated as *The IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use*. The formulation provides the most accurate representation of the thermodynamic properties of the fluid phases of water substance over a wide range of conditions currently available. The NBS/NRC tables, based upon this formulation and in SI units, should find wide international use.

The tables, available in both soft and hard cover editions, extend over an unusually wide range of conditions from the melting line to 2000°C and from zero pressure to 30 kilobars. Included in the usual format are tables for the saturated (coexisting phases) condition and compressed liquid-superheated steam as well as a table of specific heat at constant pressure and a table of the speed of sound. The reference state for all thermodynamic property values is the liquid at the triple point for which state the specific internal energy and the specific entropy have been set to zero. Tabular values are provided to 30 000 bars and 2000°C at intervals generally allowing linear interpolation. The well presented figures include the usual P–H, T–S, and H–S (Mollier) charts as well as those for specific heat at constant pressure, speed of sound, isentropic expansion coefficient, and the isentropic temperature–pressure coefficient for water. One wishes that the T–S and Mollier diagrams were available on a single sheet and to a larger scale. Missing is a conversion table for units.

Earlier internationally endorsed formulations for a number of transport and other thermophysical properties have been used in conjunction with the new thermodynamic property formulation to provide tables and figures for viscosity, thermal conductivity, Prandtl number, static dielectric constant, and a table for surface tension. In several instances this is believed to be the first presentation of a physically correct picture in the region of the critical point. Thus, all of the steam property information likely to be required is available in this one document.

Included is a description of the development and a statement of the formulation, a comparison of calculated property values with experimental data, comparisons with other formulations, and estimates of the uncertainty of the calculated values. This material provides an insight into the tremendous accomplishment of the authors in developing a thermodynamically consistent formulation covering a broad range of experimental data to a high level of certainty.

An appendix contains a listing of (some of) the FORTRAN computer programs used to realize the formulation and to prepare the thermodynamic property tables (not the transport and other properties). Unfortunately, these are not complete and, in a few instances, not entirely correct. For instance, there is no routine to calculate saturated properties as shown in Tables 1 and 2 nor is the Gibbs function (used to define the saturation line) provided in the output of the main program. While most required basic program elements are included, writing a 'main' program for additional functions such as the saturated condition requires considerable investigation into the workings of the provided programs. It should be noted that if the reference state is to be correct to a large number of digits, it must be established for each individual computer and program compilation. This requires adjusting the coefficients UREF and SREF used in subroutine THERM. Also, the convergence criteria on Gibbs function values used to define the saturation line in subroutines TCORR and PCORR should be reduced to at least 10^{-6} and preferably 10^{-8} if calculated values are to be reliable in the least significant digit shown in the tables. This apparently tripped up the authors since the values in Table 2 for enthalpy, entropy etc, do not always agree with the similar property saturation values given in Table 3 for pressures above about 100 bars. The values in Table 3 more correctly reflect the surface. The programs provided achieve values representing the surface to within about 1 K of the critical point. As always, the FORTRAN program statements may require modification to meet the requirements of a particular computer and compiler. When using these programs compiled with Microsoft FORTRAN, data points calculated as a function of P and T were found to require about 4 s on an IBM PC having a maths co-processor.

The 1967 IFC Formulation for Industrial Use, which is the basis of the ASME and many other steam tables, provides values of less certainty and thermodynamic consistency but requires an order of magnitude less computer time. In the commercial environment of the utility industry where complex cycle and similar calculations are required and where industry-wide standardization is desirable, economics are likely to dictate continued use of the 1967 formulation. In design and other calculations justifying a higher level of property knowledge, the new properties may well become commonplace.

This new NBS/NRC Steam Tables represents a new standard for the properties of water substance and will be essential to anyone requiring the most up-do-date knowledge of this especially important substance.

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Engineering Flow and Heat Exchange, *O. Levenspiel*, $34.50, pp 381, Plenum

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Inclusion of a title in this section does not preclude subsequent review.