

**Thermodynamic Properties of Water:
Tabulation from the IAPWS Formulation 1995 for the
Thermodynamic Properties of Ordinary Water Substance for
General and Scientific Use**

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Tables are provided for the density, enthalpy, entropy, and volume of water and steam calculated from the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use. This formulation is the current international standard for water's thermodynamic properties, and is implemented in NIST Standard Reference Database 10. The properties are tabulated along the vapor-liquid saturation curve as a function of both temperature and pressure. They are also tabulated for single-phase states on a grid of temperatures and pressures extending to 2000 °C and 1000 MPa.

Key words: density; enthalpy; entropy; steam; steam tables; thermodynamic properties; volume; water

1. Introduction

The current international standard for the thermodynamic properties of ordinary water is the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use [1,2]. We will refer to this formulation as IAPWS-95.

Unfortunately, the paper describing IAPWS-95 [2] has not yet been published, and there is to our knowledge no source of tabulated property values other than the small number of values given in the IAPWS Release [1] for the purpose of checking computer codes. While we anticipate that the needs of most users will be met by the software implementation of this formulation [3], there is still some demand for printed "Steam Tables." The purpose of this report is to meet that demand, though this report may be superseded at a later time by a more thorough Steam Tables book such as the one that was produced for the previous standard by Haar et al. [4].

2. Generation of the Tables

The numbers in these tables were generated from the Fortran code that implements the IAPWS-95 formulation in NIST Standard Reference Database 10, Version 2.1 [3]. They were then copied directly into tables in a word processing program. Most computed values were rounded to five significant digits. The number of digits printed for any value should not be taken as an indication of the accuracy of the formulation at that point; the IAPWS Release (reprinted as Appendix A) should be consulted for that information.

These tables largely follow the example of Haar et al. [4]. However, in the 14 years since that book was published, the purpose of printed Steam Tables has changed. Users who need high accuracy for scientific research or industrial design will use software, not printed tables. The printed tables are now mainly useful for quick estimates and therefore need not be as finely spaced in their coverage of pressures and temperatures. For this reason, the largest table in this report (the single-phase table, Table 3) is somewhat less than half the size of the corresponding table in the book of Haar et al. The tables for saturation properties are also somewhat shorter.

3. Notes on the Tables

In general, these tables should be self-explanatory. Standard notation (documented in the “List of Symbols”) has been used, and traditional formatting has been followed. Here, a few specifics which may not be obvious are described.

In Table 3, the subcritical isobars cross the vapor-liquid saturation boundary. The first two lines printed for each isobar give the values of properties for the saturated liquid and saturated vapor, respectively. As is customary, a horizontal line is drawn between the points immediately above and below the phase boundary.

The IAPWS-95 formulation is recommended for fluid states at temperatures up to 1000 °C and 1000 MPa, and tests have shown it to extrapolate reasonably to higher temperatures and pressures and also to metastable liquid conditions at subfreezing temperatures at ambient pressures. (For more details on the range of validity and on extrapolation capabilities, consult the Release reprinted as Appendix A.) All points in Table 3 above 1000 °C should be considered extrapolations. Some of the low-temperature points in Table 3 correspond to conditions where the equilibrium phase would be a solid. For those points at low pressures, this is indicated by italicizing the values. At high pressures, these points are not printed at all since there is no way to verify the formulation’s accuracy at those conditions. The solid-fluid equilibrium boundaries were determined from the formulas given by Wagner et al. [5].

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4. References

- [1] Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use, Fredericia, Denmark, 1996. This release is reproduced as Appendix A of this report; copies of this and other IAPWS releases may be obtained from the IAPWS Executive Secretary: Dr. R.B. Dooley, Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA, 94304, USA.
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- [5] W. Wagner, A. Saul, and A. Pruß, “International Equations for the Pressure along the Melting and along the Sublimation Curve of Ordinary Water Substance,” *J. Phys. Chem. Ref. Data* 23, 515-527 (1994).