

The International Association for the Properties of Water and Steam

Doorwerth, The Netherlands

September 2009

Advisory Note No. 4

Roles of IAPWS and CIPM Standards for the Density of Water

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This advisory note contains 3 pages, including this cover page.

This advisory note has been authorized by the International Association for the Properties of Water and Steam (IAPWS) at its meeting in Doorwerth, The Netherlands, 6-11 September, 2009, for issue by its Secretariat. The members of IAPWS are: Britain and Ireland, Canada, the Czech Republic, Denmark, France, Germany, Greece, Japan, Russia, and the United States of America, and associate members Argentina and Brazil, Italy, and Switzerland.

This advisory note presents recommendations for deciding when to use the standard formulation for the density of liquid water recommended for metrology by the International Committee for Weights and Measures (CIPM) [1] or the thermodynamic property formulation for general and scientific use adopted by the International Association for the Properties of Water and Steam (IAPWS) [2, 3]. Further details may be found in the publication of Harvey *et al.* [4].

Further information concerning this advisory note and other documents issued by IAPWS can be obtained from the Executive Secretary of IAPWS or from <http://www.iapws.org>.

1. Background

In 2001, the Working Group on Density of the Consultative Committee for Mass and Related Quantities (CCM) recommended a new standard for the calculation of density for use in metrology in the temperature range from 0 °C to 40 °C at pressures near standard atmospheric pressure [1]. We refer to this as the CIPM recommendation, because it was endorsed by the International Committee of Weights and Measures (CIPM). In 1995, the International Association for the Properties of Water and Steam (IAPWS) adopted “The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use” (known as IAPWS-95) [2, 3]. IAPWS-95 covers a much wider range of temperature and pressure (including the range of applicability of the CIPM standard) and includes other thermodynamic properties in addition to the density.

Since both formulations can be used to calculate highly accurate densities for liquid water, discussions began in 2004 between representatives of IAPWS and the CCM to clarify the relationship between these two formulations and to develop a joint set of recommendations for when it is appropriate to use which one. This Advisory Note documents the recommendations, which have been agreed to by both organizations. Further details, including information about the applicability of corrections for dissolved air and for varying isotopic abundances, are available in a journal publication [4].

IAPWS also has a formulation for thermodynamic properties for industrial use [5, 6], known as IAPWS-IF97. While computationally much more efficient than IAPWS-95, IAPWS-IF97 does not attain the high accuracy that would be desired in many scientific and metrological uses. It is therefore not considered in these recommendations. Similarly, other supplementary releases issued by IAPWS [7, 8] that include liquid water properties for specialized purposes are also not considered here.

2. Recommendations

1. The CIPM density formulation [1] is the preferred standard for use in metrology over its recommended range, which is liquid water from 0 °C to 40 °C at pressures near atmospheric. It should not be extrapolated outside this range.
2. Densities computed from the IAPWS-95 formulation [2, 3] are consistent with the CIPM standard within the region of validity of the CIPM formulation. For use outside the CIPM range of validity, the IAPWS-95 formulation is the preferred method for obtaining accurate densities for water.
3. For uses covering a range of conditions, some of which are inside the range of validity of the CIPM standard and some of which are not, it is generally preferable to use the IAPWS-95 formulation for the entire calculation in order to avoid discontinuities.

Either or both of the CIPM and IAPWS formulations may be updated in the future due to the availability of new experimental data, adoption of a new temperature scale, or some other reason. It is expected that the general nature of the recommendations above would still apply after such an update, but the details might need to be revised.

3. References

- [1] Tanaka, M., Girard, G., Davis, R., Peuto, A., and Bignell, N., Recommended table for the density of water between 0 °C and 40 °C based on recent experimental reports, *Metrologia* **38**, 301 (2001).
- [2] IAPWS, *Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use* (2009). Available from <http://www.iapws.org>.
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- [4] Harvey, A. H., Span, R., Fujii, K., Tanaka, M., and Davis, R. S., Density of water: roles of the CIPM and IAPWS standards, *Metrologia* **46**, 196 (2009).
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- [6] Wagner, W., Cooper, J. R., Dittmann, A., Kijima, J., Kretzschmar, H.-J., Kruse, A., Mareš, R., Oguchi, K., Sato, H., Stöcker, I., Šifner, O., Tanishita, I., Trübenbach, J., and Willkommen, Th., The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam, *J. Eng. Gas Turbines Power* **122**, 150 (2000).
- [7] IAPWS, *Supplementary Release on Properties of Liquid Water at 0.1 MPa* (2008). Available from <http://www.iapws.org>.
- [8] IAPWS, *Supplementary Release on a Computationally Efficient Thermodynamic Formulation for Liquid Water for Oceanographic Use* (2009). Available from <http://www.iapws.org>.