The IAPWS Industrial Formulation for the Thermodynamic Properties of Seawater

Hans-Joachim Kretzschmar[a], Rainer Feistel[b], Wolfgang Wagner[c], Kiyoshi Miyagawa[d], Allan H. Harvey[e], Jeff R. Cooper[f], Michael Hiegemann[g], and Sebastian Herrmann[a]

[a] Zittau/Goerlitz University of Applied Sciences, Zittau, Germany
[b] Baltic Sea Research Institute, Warnemuende, Germany
[c] Ruhr-University Bochum, Bochum, Germany
[d] Nishiogu Arakawa-ku, Tokyo 116-0011, Japan
[e] National Institute of Standards and Technology, Boulder, CO, USA
[f] Queen Mary, University of London, London, England
[g] ALSTOM (Switzerland) Ltd., Baden, Switzerland

Email: hj.kretzschmar@hs-zigr.de

In 2008, IAPWS adopted the IAPWS Formulation 2008 for the Thermodynamic Properties of Seawater [1], where the thermodynamic properties of seawater are calculated from an equation of state, consisting of a water part and a saline part. The water part is computed from the Helmholtz free energy equation of the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use (IAPWS-95). The saline part is formulated as a Gibbs free energy equation. However, the iterative calculation of required properties from the IAPWS-95 Helmholtz free energy equation is computationally intensive, making its use less desirable in applications where speed is important. In desalination and cooling processes, it is more reasonable to use the Gibbs free energy equation of region 1 of the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (IAPWS-IF97) for the water part of the seawater formulation instead of IAPWS-95. In addition, the IAPWS-IF97 Industrial Formulation is used by industry for calculating properties of pure steam and water for power plants and their components.

The purpose of this paper is to introduce the "Advisory Note No. 5: Industrial Calculation of the Thermodynamic Properties of Seawater" [2], which describes the use of IAPWS-IF97 instead of IAPWS-95 for calculating thermodynamic properties of the water part of the seawater formulation, to enable more efficient calculations.

The equation of state for seawater using IAPWS-IF97 is valid for seawater with sea salt of the reference composition within the pressure, temperature, and salinity ranges of 0.3 kPa $\leq p \leq$ 100 MPa, 261 K $\leq T \leq$ 353 K, and $0 \leq S \leq 0.12$ kg kg^{-1}, with some restrictions in certain regions as shown in [1].

When using IAPWS-IF97 instead of IAPWS-95, the uncertainties of the calculated properties for seawater [2] are nearly the same as those given in the release of the IAPWS Formulation 2008 [1]. Only some small deviations caused by the differences between IAPWS-IF97 and IAPWS-95 increase the uncertainties slightly.

The computing speed is increased by up to a factor of 67 (depending on the property function) in comparison with the use of the IAPWS Formulation 2008 [1].

The proposed Industrial Formulation for Seawater can be applied in calculations for analyzing, designing, simulating, operating, and optimizing desalination and cooling processes.

[1] IAPWS, *Release on the IAPWS Formulation 2008 for the Thermodynamic Properties of Seawater (2008)*. Available at http://www.iapws.org.
[2] IAPWS, *Advisory Note No. 5: Industrial Calculation of the Thermodynamic Properties of Seawater* (in preparation).