Proposal for the Development of a New Industrial Formulation for the Properties of Water and Steam

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The industrial formulation IAPWS-IF97 was developed on the basis of the scientific formulation IAPWS-95 for fast and accurate computations of thermodynamic properties of water and steam in industrial applications. IAPWS-IF97 consists of separate basic equations for the liquid, vapor, critical, and high-temperature domains and an equation for the saturation line. Along with the supplementary backward equations, IAPWS-IF97 renders possible fast computations of thermodynamic properties from (p,T), (p,h), (p,s), and (h,s). The industrial formulation IAPWS-IF97 was adopted in 1997 and has proven itself in power engineering since.

In the meantime, however, the numerical methods for flow analysis, transient processes, and the design of power plants have been further developed. These methods place the highest demands on accuracy, computing speed, and numerical consistency. Smaller inconsistencies of the basic equations along the region boundaries can cause numerical problems in high-fidelity simulations and hinder convergence. Similarly, inconsistencies of supplementary backward equations with the basic equations of IAPWS-IF97 exist. Furthermore, the balance equations for mass, energy, and entropy often require the computation of fluid properties from (v,u), (v,h), (T,h), and (T,s). Since there are no backward equations available for these inputs, the desired properties need to be determined from the basic equations by iteration, causing long computing times.

In order to meet the high demands of extensive numerical simulations, the Spline-Based Table Look-up method (SBTL) was developed in an IAPWS project and adopted as a guideline by IAPWS in 2015. The method was first applied to IAPWS-IF97 and to IAPWS-95. It was demonstrated that the resulting SBTL functions reproduce the underlying formulations with high accuracy, while their computing speed is even faster in comparison with IAPWS-IF97, including the supplementary backward equations. SBTL property functions also enable the calculation of analytical inverse functions for full numerical consistency. Due to these advantages, the SBTL method has been used successfully in many applications instead of the actual IAPWS standards. As the SBTL property functions can reproduce the IAPWS formulations with high accuracy, but do not correspond to them exactly, the simulation results cannot be described as conforming to the IAPWS standards either. Nevertheless, the calculated technical parameters from process calculations remain practically unchanged. Industry representatives therefore recommend the development of a new industrial standard based on the SBTL method.

In this contribution, the application of the SBTL method and its use in computational fluid dynamics (CFD), simulations of transient processes, and power-cycle design are discussed. Furthermore, a concept for the development of a new industrial formulation using the SBTL method is presented. This formulation aims to offer highly accurate and at the same time fast and consistent functions for all required thermophysical properties and differentials as functions of (T,v), (p,T), (p,v), (p,s), (p,h), (h,s), (v,u), (v,h), (T,h), and (T,s). An outlook on the application of the SBTL method to mixtures with water and steam as well as to other substances will also be provided.