Supplementary Backward Equations for the Industrial Formulation IAPWS-IF97 of Water and Steam for Fast Calculations of Heat Cycles, Boilers, and Steam Turbines

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The paper gives an overview of the backward equations which have been developed for water and steam as a supplement to the IAPWS Industrial Formulation 1997 (IAPWS-IF97) during the last five years. Firstly, backward equations $p(h,s)$ for the liquid region and the vapor region were developed and adopted as a supplementary release by the International Association for the Properties of Water and Steam (IAPWS) in 2001 (IAPWS-IF97-S01). An international survey revealed that backward equations in the critical and supercritical regions were also required in process modeling. Thus, backward equations $T(p,h)$, $v(p,h)$, $T(p,s)$, and $v(p,s)$ were developed for these regions and adopted as a supplementary release in 2003 and revised in 2004 (IAPWS-IF97-S03rev). Then, backward equations $p(h,s)$ developed for the critical and supercritical regions were adopted by IAPWS in 2004 (IAPWS-IF97-S04). This supplementary release also contains a backward equation for the saturation temperature $T_s(h,s)$ in the part of the two-phase region important for steam-turbine calculations. Finally, backward equations $v(p,T)$ for the critical and supercritical regions became a supplementary release in 2005 (IAPWS-IF97-S05).

In order to determine whether a given state point is located in the single-phase or two-phase region, iterations for the backward functions of the given properties of (p,h), (p,s) or (h,s) are necessary. To avoid these iterations, special boundary equations have been developed and adopted as a part of the supplementary releases.

Using the IAPWS-IF97, along with the supplementary backward and boundary equations here presented, all thermodynamic properties from given property pairs (p,T), (p,h), (p,s), and (h,s) can be calculated without iterations over the entire range of validity including the determination of the region (except for high temperature region). Since the numerical consistency of the backward and boundary equations is sufficient for most heat-cycle, boiler, and steam-turbine calculations, they will significantly reduce the computing time of process modeling.