IAPWS Certified Research Need – ICRN

Thermophysical Properties of Metastable Steam and Homogeneous Nucleation

The IAPWS Working Groups "Thermophysical Properties of Water and Steam" and "Industrial Requirements and Solutions" have examined the published work and common industrial practice in the areas of the thermophysical properties of supersaturated vapor (supercooled vapor, subcooled vapor) and the homogeneous nucleation of droplets from the supersaturated vapor which are of interest to the electric power industry.

IAPWS recognizes that there is a requirement for work to be pursued in this field and has prepared this document to assist potential investigators to obtain sponsorship. The knowledge of the thermophysical properties of metastable steam and homogeneous nucleation is necessary for accurate system design of power plants, in particular steam turbines.

Although encouraging this work, IAPWS is not generally able to provide financial support. The IAPWS contact can provide any further development information and will liaise between research groups.

Issued by the

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Background

The high expansion rate in a steam turbine causes the liquid phase formation to be postponed from the saturated steam line deep into the metastable region of supersaturated steam [1]. Reliable design computations require knowledge of thermophysical properties of steam. Also the rate of droplet nucleation is required to determine the impact of non-equilibrium condensation on turbine efficiency and to estimate the erosion damage.

Previous Work

In the early 90s, the "IAPWS Task Group on Metastable-State Water" (Chairman: H. Sato) performed an extensive investigation on the status and problems in this region [2]. In contrast to the supercooled and superheated water regions, no experimental data for metastable steam were found. Apparently, no data for metastable steam have appeared since then. Consequently, the present IAPWS recommendation for computation of thermophysical properties of metastable steam is based on extrapolation from the stable region [3].
Recent measurements [4] indicate that the number of heterogeneous nuclei present in the steam of contemporary power plants is too small in comparison with the number of droplets formed. Thus, whereas research on the effect of chemistry on condensation process remains an important subject, the decisive role in droplet formation is attributed to homogeneous nucleation. The rates of homogeneous nucleation have been measured for water vapor in inert gases [5] at temperatures lower than the relevant range. Experimental data on nucleation of steam was obtained in Laval nozzles [6]. These measurements are rather indirect. Consequently, nucleation computations are generally based on classical nucleation theory, which fails in quantitative predictions.

With respect to the unavailability of suitable experimental methods and the rapidly developing molecular modeling and simulation methods, it is possible that the latter approach will provide a feasible way of obtaining quantitative data for thermophysical properties of metastable steam, e.g. using computed virial coefficients [7] (which, however, require development of appropriate quantum corrections at low temperatures). Molecular simulation is also promising for studying homogeneous nucleation rates [8].

The Range of Data Required

For this ICRN, the region of practical interest is defined to include the entire range of single-phase states that is required for design of LP steam turbines of fossil-fueled and nuclear power plants (3 kPa to about 700 kPa), high-pressure steam turbines of nuclear power plants with pressurized-water cooled reactors (up to about 8 MPa) and concentrated solar power plants (up to about 13 MPa). The corresponding range of temperatures spans approximately from 260 K up to 600 K.

Measurements or quantitative molecular computations should be performed for pressure-volume-temperature behavior, heat capacity, speed of sound or any other thermodynamic property in the stable single-phase region (for which data already exist) and extend into the metastable region. Measurements or quantitative molecular computations of homogeneous nucleation should be performed in the metastable steam region. Because it is expected that the experimental techniques will provide indirect data with complex evaluation procedures, it is necessary that all experimental circumstances are well documented in order that the experiments can be re-evaluated independently starting from the primary measurements.

Besides obtaining data by experiments and molecular simulation, it is also desirable to develop thermodynamic models combining, in various proportions, theoretical background with limited experimental data, providing predictions suitable for design computations [9].

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