ICRN 28

IAPWS Certified Research Need – ICRN

Thermophysical Properties of Metastable Steam and Homogeneous Nucleation

Closing Statement

In 2011, the IAPWS Working Groups "Thermophysical Properties of Water and Steam" and “Industrial Requirements and Solutions" issued ICRN 28, titled “Thermophysical Properties of Metastable Steam and Homogeneous Nucleation”. This ICRN was renewed in 2014 and expired in 2019.

At present, the knowledge of the properties of metastable steam and homogeneous nucleation of water droplets from supersaturated steam remains incomplete. However, partial understanding was reached.

The properties of supersaturated steam, i.e., steam at greater pressure than the saturation pressure at given temperature, or, equivalently, subcooled steam, i.e. steam at lower temperature than the saturation temperature for the given pressure, can be computed with the help of a suitable equation of state, which provides an extrapolation from the region of stable steam. The fundamental formulation IAPWS-95 should not be used for this purpose, because it predicts unphysically strong real gas effects already for saturated steam at low temperatures [1]. It is recommended to use either “Supplementary Equation for the Metastable-Vapor Region” of IAPWS-IF97 [2], Eq. (18), or the virial equation of state with second virial coefficient given by a more recent correlation of experimental and quantum mechanical data [3]. A broader context is given in a recent review [4]. The related need for data in the region of supersaturated steam is covered in the scope of ICRN 31 [5].

No direct data on homogeneous nucleation of droplets in steam in the temperature range relevant to turbomachinery is available. However, a comprehensive study of steam condensation in nozzles has appeared [6]. Study [7] collects direct nucleation rate data at low temperatures, indirect data at high temperatures, and molecular dynamics results. Several recent publications consider the influence of various gases on the nucleation of water droplets [8].

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2. International Association for the Properties of Water and Steam, IAPWS R7-97(2012) *Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam* (2012).

3. A. H. Harvey and E. W. Lemmon, Correlation for the Second Virial Coefficient of Water. *J. Phys. Chem. Ref. Data* **33**, 369 (2004). https://doi.org/10.1063/1.1587731

4. A. H. Harvey, J. Hrubý, and K. Meier, Improved and Always Improving: Reference Formulations for Thermophysical Properties of Water. *J. Phys. Chem. Ref. Data* **52**: 011501 (2023). https://doi.org/10.1063/5.0125524

5. International Association for the Properties of Water and Steam, IAPWS ICRN 31, *New Thermodynamic Data for Ordinary Water* (2024). https://iapws.org/documents/icrn/ICRN31-2024.download

6. J. Starzmann, F. R. Hughes, S. Schuster, et al., Results of the International Wet Steam Modeling Project. *Proc. Inst. Mech. Eng. A: J. Power Energy* **232**, 550 (2018). https://doi.org/10.1177/0957650918758779

7. J. Hrubý, M. Duška, T. Němec, and M. Kolovratník, Nucleation rates of droplets in supersaturated steam and water vapour-carrier gas mixtures between 200 and 450 K. *Proc. Inst. Mech. Eng. A: J. Power Energy* **232,** 536 (2018). https://doi.org/10.1177/0957650918770939

8. M. M. Campagna, J. Hrubý, M. E. H. van Dongen, and D. M. J. Smeulders, Homogeneous water nucleation in carbon dioxide–nitrogen mixtures: Experimental study on pressure and carrier gas effects. *J. Chem. Phys.* **154**, 154301 (2021). https://doi.org/10.1063/5.0044898