Speed of sound measurements in hydrogen up to 100 MPa and an equation of state for normal hydrogen

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The availability of thermophysical properties of fluids is crucial for any process simulation and design. Especially concerning a shift towards a hydrogen-based economy, the thermophysical properties of hydrogen are decisive for a successful energy transition. As the trade of hydrogen will take on a similar significance to that of natural gas, establishing flow metering standards for hydrogen with, e.g., critical flow venturi nozzles (CFVN) is essential, which is the task of the MetHyInfra project funded by the European metrology programme for innovation and research (EMPIR). To determine the flow in CFVN, the speed of sound in the fluid is a required quantity. However, the equation of state (EOS) for normal hydrogen developed by Leachman et al. [1], predicts the speed of sound with a relative uncertainty of about 0.5%. This large uncertainty results from the fact that for the development of this EOS, no speeds of sound in gaseous hydrogen were available at temperatures above 34 K and 0.1 MPa. Therefore, new speed of sound data were measured within this work at temperatures from (273 to 323) K and pressures from (1 to 100) MPa. A cylindrical resonator was used for pressures up to 10 MPa and a dual-path pulse-echo system from 20 MPa upwards. The relative expanded uncertainty ($k = 2$) of the data was estimated from (0.03 to 0.05)%. As shown in Figure 1, the EOS of Leachman et al. [1] shows larger deviations from the experimental data than attributed to the measurement uncertainty, increasing significantly with increasing pressure. Therefore, a new EOS was developed based on the new speed of sound data and other thermodynamic property data from the literature. This equation was developed for the implementation in measurement sensors as well as CFD simulations of CFVN and is kept as short and simple as possible with polynomial terms and integer exponents only. Nonetheless, the new EOS calculates the experimental speeds of sound within deviations of 0.09% (see Figure 1), thus, the deviation is considerably lower. By using data for other thermodynamic properties from the literature, the EOS is valid at temperatures from (140 to 370) K and pressures up to 100 MPa, whereby 140 K is the lower limit of temperatures occurring in CFNV.

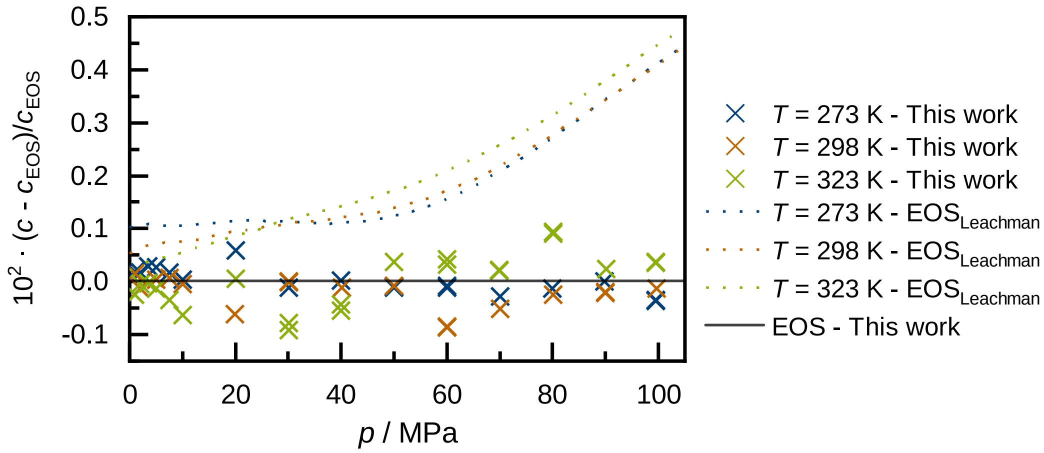

Figure 1. Relative deviations of the experimentally determined speed of sound in hydrogen at three different temperatures and the EOS by Leachman from the newly developed EOS.

References

[1] Leachman JW, Jacobsen RT, Penoncello SG, Lemmon EW. Fundamental Equations of State for Parahydrogen, Normal Hydrogen, and Orthohydrogen. Journal of Physical and Chemical Reference Data 2009;38(3).