Viscosity Measurements of Hydrogen and a (Hydrogen + Methane) Mixture with a Two-Capillary Viscometer

Betken Benjamin[1,2], Austegard Anders[1], Finotti Francesco[1], Caccamo Chiara[1], Stang Hans Georg Jacob[1], Khosravi Bahareh[3], Span Roland[2]

[1] SINTEF Energy Research, NO-7465 Trondheim, Norway
[2] Thermodynamics, Ruhr University Bochum, D-44780 Bochum, Germany
[3] Department of Chemical Engineering, Norwegian University of Science Technology, NO-7491 Trondheim, Norway

Corresponding author's e-mail address: benjamin.betken@thermo.ruhr-uni-bochum.de

Keywords: Transport properties, Viscosity, Experimental data, Two-capillary viscometer Hydrogen, Methane, Mixture

ABSTRACT

The increasing contribution of fluctuating renewable energy sources, such as wind and solar, to the European energy mix requires large-scale energy storage systems to balance the seasonal mismatch between renewable energy supply and demand. Hydrogen production, utilizing excess renewable energy, and storage in geological formations could be one pathway to provide the required storage capacities over seasonal time scales. Besides aquifers and salt caverns, depleted oil and gas reservoirs qualify as suited storage sites, due to their extensive storage capacities, well characterized storage properties, proven gas tightness, and the opportunity to re-purpose already existing infrastructure for injection and depletion. For a safe, cost-effective, and efficient implementation of such storage systems, understanding the behavior of thermodynamic and transport properties of hydrogen and mixtures of hydrogen with typical reservoir gases like methane is essential. However, while extensive experimental data sets and accurate calculation models for thermophysical properties are available for pure hydrogen, mixtures of hydrogen and methane lack the experimental data base to reliably validate thermophysical property models for mixtures. This is particularly true for the viscosity, as one of the key properties to describe transport processes, at conditions relevant for underground hydrogen storage. Therefore, the viscosity of hydrogen and a binary (hydrogen + methane) mixture with a nominal hydrogen content of 90 mol % was measured at temperatures between (298 and 348) K and at pressures of up to 18 MPa. The measurements were carried out with a two-capillary viscometer, which was recently put in operation at SINTEF Energy Research in Trondheim. The measurement principle is based on the Hagen-Poiseuille equation, which relates the fluid viscosity to the fluid flow, applied to a capillary, and the resulting pressure difference along the capillary. In order to avoid the necessity to know the flow rate and the capillaries' dimensions accurately, viscosity ratios were measured instead of absolute viscosities, utilizing two in series connected capillaries. In addition, relative measurements were conducted with helium as reference fluid. Applying highly accurate reference data for helium [1], the expanded combined uncertainty of the experimental results is between (0.65 and 3.2) %. Measurements on pure hydrogen were compared to a state of the art viscosity

correlation [2], as implemented in the Reference Fluid Thermodynamic and Transport Properties Database REFPROP v10.0 [3]. Relative deviations to the viscosity correlation are 0.22 % on average, proving the functionality of the experimental set-up for low-viscous fluids like hydrogen. Measurements on the (hydrogen + methane) mixture were compared to an Extended Corresponding states (ECS) model [4] for the prediction of mixture viscosities. However, relative deviations between the experimental data and the ECS model exceed the experimental uncertainty, indicating that inaccuracies in calculated mixture viscosities have to be expected.

The results of this work have been published in the *International Journal of Thermophysics* under the title "Measurements of the Viscosity of Hydrogen and a (Hydrogen + Methane) Mixture with a Two-Capillary Viscometer" and are accessible open-access via https://doi.org/10.1007/s10765-023-03328-6 [5].

Acknowledgements

The authors acknowledge funding from the Norwegian Research and Innovation Centre for Hydrogen and Ammonia HYDROGENi (Grant. No. 333118) and the Research Council of Norway, which funded this work within the HYSTORM project (Grant No. 315804).

References

[1] W. Cencek, M. Przybytek, J. Komasa, J.B. Mehl, B. Jeziorski, K. Szalewicz, Effects of adiabatic, relativistic, and quantum electrodynamics interactions on the pair potential and thermophysical properties of helium, J. Chem. Phys. 136 (2012) 224303. https://doi.org/10.1063/1.4712218.

[2] C.D. Muzny, M.L. Huber, A.F. Kazakov, Correlation for the Viscosity of Normal Hydrogen Obtained from Symbolic Regression, J. Chem. Eng. Data 58 (2013) 969–979. https://doi.org/10.1021/je301273j.

[3] E.W. Lemmon, I.H. Bell, M.L. Huber, M.O. McLinden, NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP) Version 10 - SRD 23, National Institute of Standards and Technology, Gaithersburg, 2018.

[4] J.C. Chichester, M.L. Huber, Documentation and assessment of the transport property model for mixtures implemented in NIST REFPROP (version 8.0), National Institute of Standards and Technology, Gaithersburg, MD, 2008.

[5] B. Betken, A. Austegard, F. Finotti, C. Caccamo, H.G.J. Stang, B. Khosravi, R. Span, Measurements of the Viscosity of Hydrogen and a (Hydrogen + Methane) Mixture with a Two-Capillary Viscometer, Int J Thermophys 45 (2024). https://doi.org/10.1007/s10765-023-03328-6.