Freeze-out Measurements of Impurities in Hydrogen with a Microwave Resonant Cavity

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Hydrogen has been the subject of growing global attention due to its prospects as a clean energy vector. Similar to natural gas, liquefying hydrogen is an attractive means to increase energy density for efficient storage and transport. However, as hydrogen is cooled, impurities can freeze-out and block cryogenic heat exchangers, even at parts-per-million concentration, resulting in reduced hydrogen production and costly plant shutdowns [1]. As hydrogen liquefaction occurs at much lower temperatures than LNG, impurity specification to avoid the risk of freeze-out is even more critical.

Despite this foreseeable challenge, there is currently limited data available on the freeze-out behaviour of trace impurities from hydrogen. In this project, a re-entrant microwave resonant cavity, developed at the University of Western Australia, has been used to successfully measure the freeze-out conditions of carbon dioxide as an impurity in hydrogen. It measures a resonant frequency dependent on the dielectric permittivity of the fluid contained in the cavity. A change in the measured dielectric permittivity indicates the formation of a new phase. The cavity geometry is designed to have high sensitivity to phase changes in a small region at the base of the cavity where the electric field is strongest [2]. By maintaining a temperature gradient across the cavity with two separately controlled liquid nitrogen heat exchangers, a localised cold spot is created at the base of the cavity where solids are preferentially formed.

Accurate data could reduce conservative estimates in hydrogen liquefaction process design and improve the efficiency and reliability of process operation. Additionally, data at various pressures and concentrations, and for other impurities including argon, oxygen, and nitrogen, will further advance this effort. This research demonstrates that microwave resonant cavities are a reliable and accurate measurement technology to directly monitor the freeze-out risk of low concentration impurities in high-pressure mixtures at the cryogenic temperatures required for liquid hydrogen.

References

1. S. Z. S. Al Ghafri *et al.*, "Hydrogen liquefaction: a review of the fundamental physics, engineering practice and future opportunities," *Energy & Environmental Science,* vol. 15, no. 7, pp. 2690-2731, 2022, doi: 10.1039/D2EE00099G.
2. M. G. Hopkins, A. Siahvashi, X. Yang, M. Richter, P. L. Stanwix, and E. F. May, "A microwave sensor for detecting impurity freeze out in liquefied natural gas production," *Fuel Processing Technology,* vol. 219, p. 106878, 2021, doi: https://doi.org/10.1016/j.fuproc.2021.106878.