In-situ hydrogen wettability characterisation for Underground Hydrogen Storage (UHS)

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Introduction

Viable energy alternatives to fossil fuels have been explored extensively for many decades (MA Green, 1982, Dresselhaus, 2001, Michael et al., 2010). The purpose of energy storage research is two-fold. First, to develop energy solutions that meet the demand of daily energy consumption, and second, to produce energy in a more environmentally friendly manner.

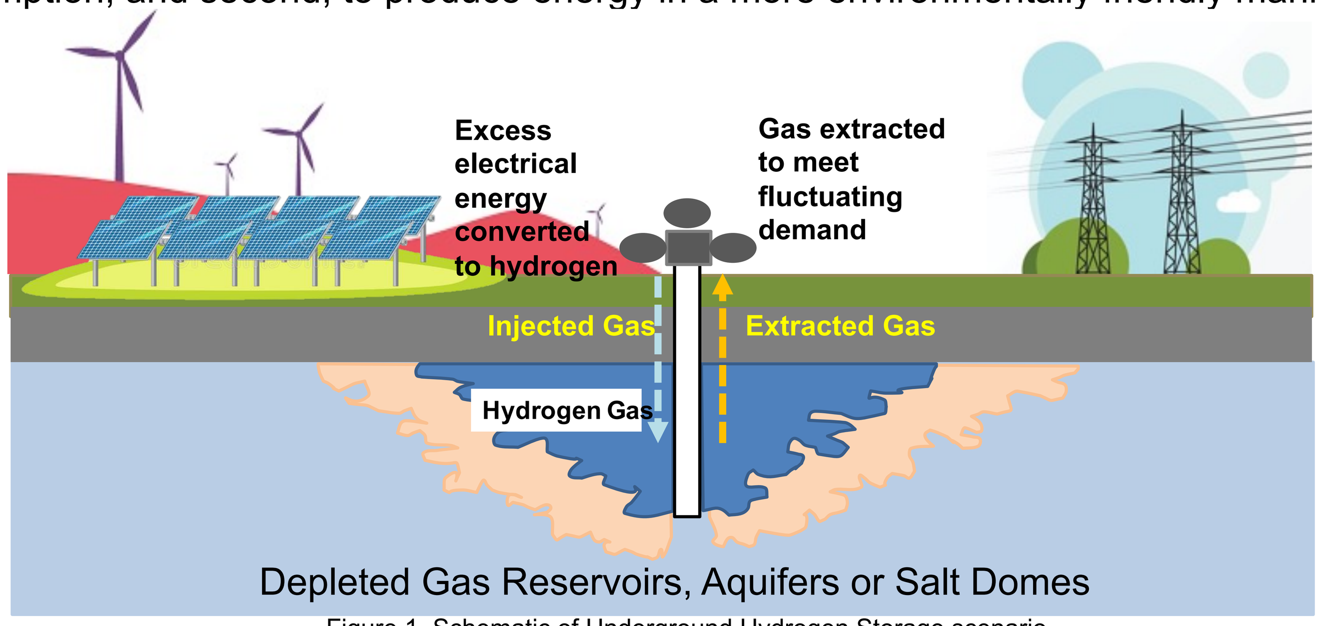

Figure 1. Schematic of Underground Hydrogen Storage scenario

UHS requires knowledge of the physical properties of hydrogen, such as density, viscosity, and solubility, which are well known (De Lucia et al. 2015, Li et al. 2018, Leachman and Jacobsen, 2007) and the petrophysical properties of interfacial tension, wettability, and relative permeability, which until this paper are lesser known, to determine the storage capacity as well as injection and production rates of the gas (Juanes et al., 2006).

Australia wants to be a world leader in hydrogen export which will require large volumes of storage. UHS can store volumes $10^8 m^3$ for periods of months or years. There many depleted gas reservoirs and aquifers to implement hydrogen storage nationally.

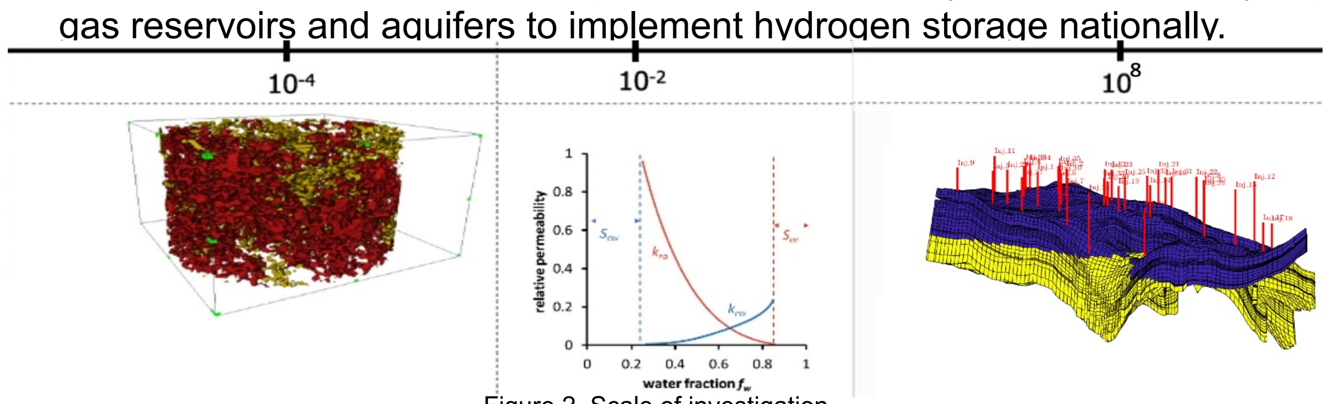

Figure 2. Scale of investigation

Methods

Six methods were used to determine the contact angle and IFT of the hydrogen-water system in sandstones.

- The captive bubble method provided the effective contact angle (Kaveh et al., 2014)
- The topological approach determined the macroscopic contact angle (Sun et al., 2020)
- Curvature analysis determined the wetting state of the rock using fluid characteristics (Lin et al., 2019)
- 3D local method provided contact angle distribution (Alratrout et al., 2017)
- Manual measurements were used to verify results
- Pendant drop method determined IFT (Drelich, 2002)

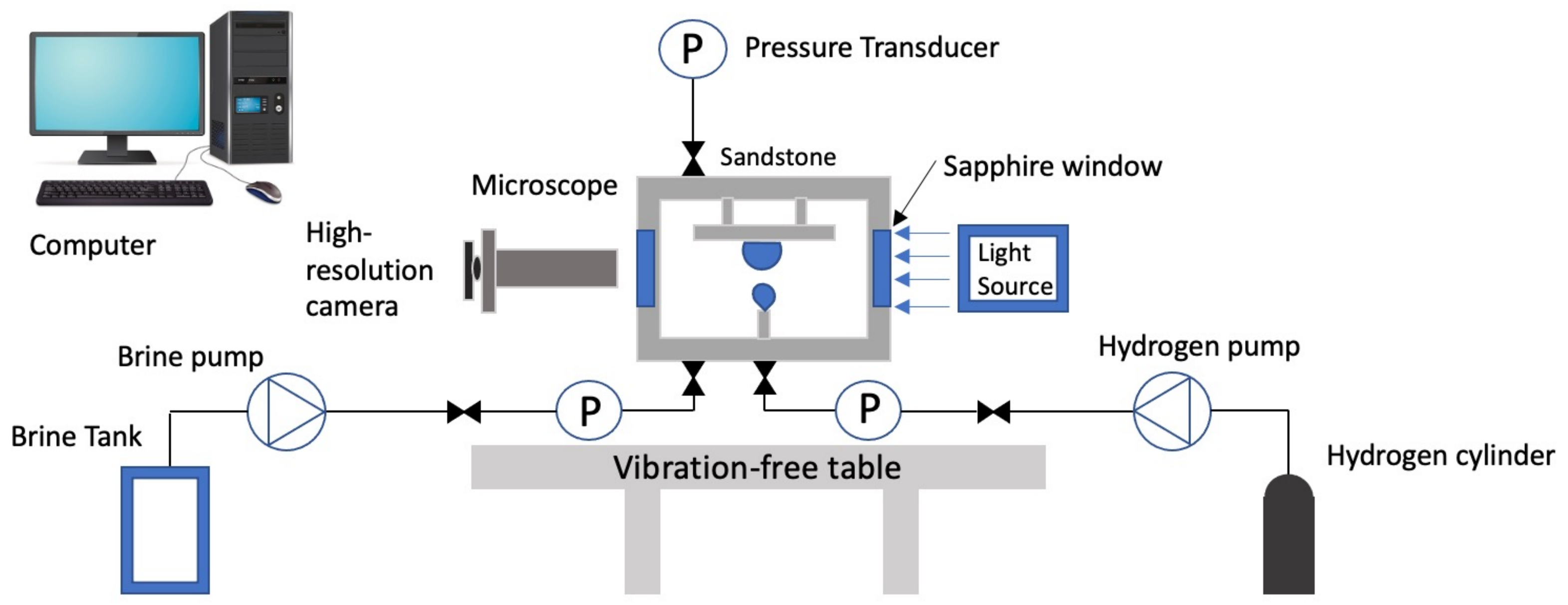

Figure 3. HPHT cell laboratory setup for pendant drop and captive bubble methods

The sample for the micro-CT analysis was a 5mm diameter core of Bentheimer sandstone which is 88-97.5% quartz and is representative of many sandstone formations globally including some structures in the Otway Basin. A 16.7wt% KI solution was used as a contrast agent.

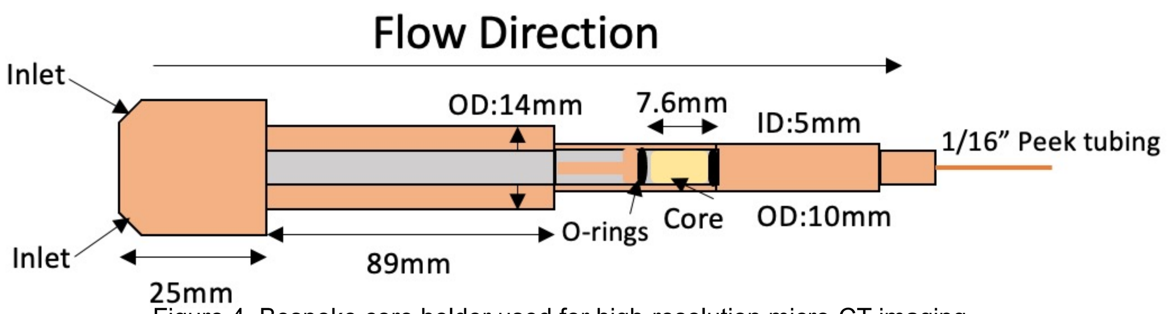

Figure 4. Bespoke core holder used for high-resolution micro-CT imaging

Grey-scale micro-CT images were segmented to analyse fluid characteristics in-situ

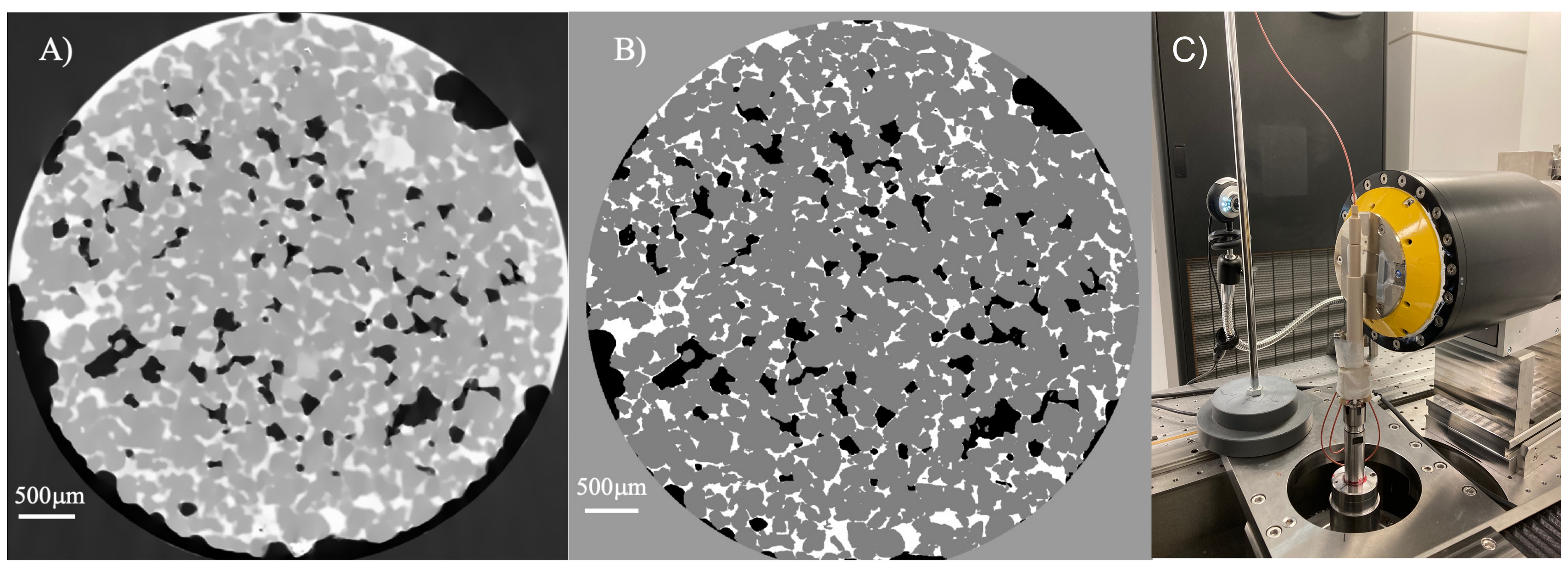

Figure 5.A) Grey-scale image showing rock grains (dark grey), 16.7% KI brine (white) and hydrogen gas (black) B) Segmented Image C) Micro-CT machine scanning sample

Results

Interfacial tension values in this study were found to be 71.99mN/m at 0.77MPa to 69.43mN/m at 20.68MPa. The effective contact angle ranged between 27-39° for all pressures and salinities

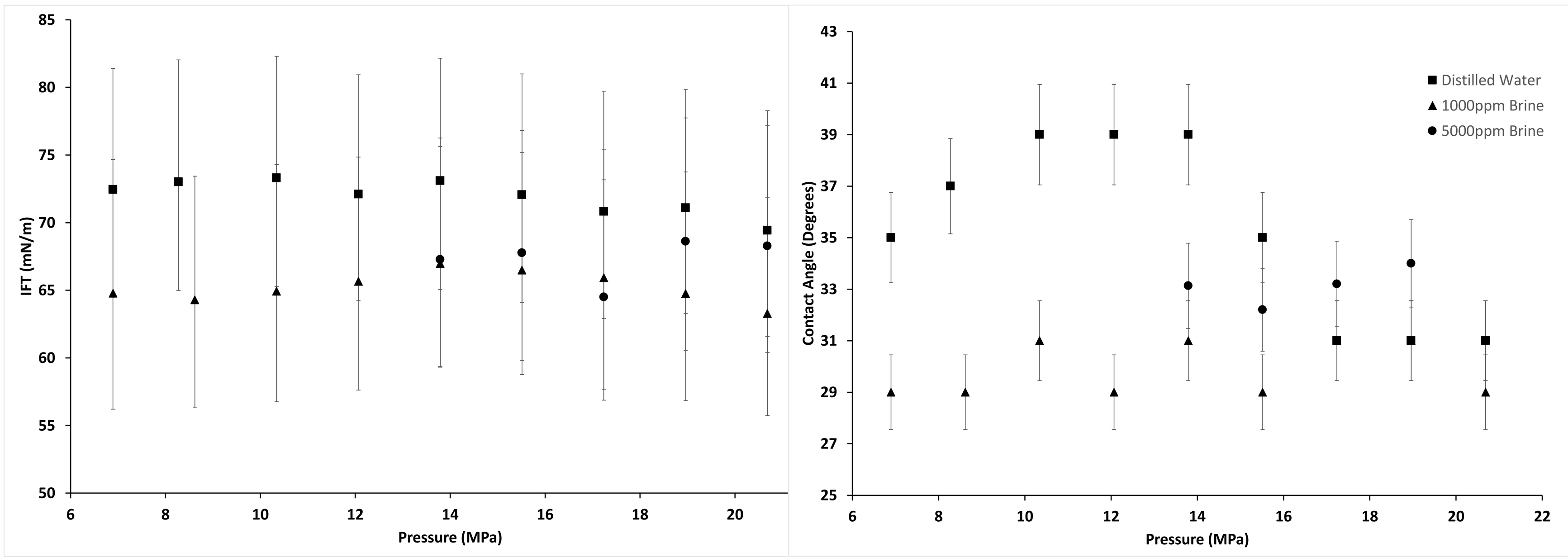

Figure 6. IFT and effective contact angle determined by pendant drop and captive bubble methods

The macroscopic contact angles (θ_{macro}) originally displayed a mean value of 53.13° for fluid clusters with a Euler characteristic of 1. When extreme Gaussian curvature values are neglected, the mean value is 39.77°. Manual measurements resulted in a median contact angle of 36° and a mean of 36.8°. The standard deviation was 20.7°. The 3D local method determined the mean value of the contact angle distribution to be 59.75°

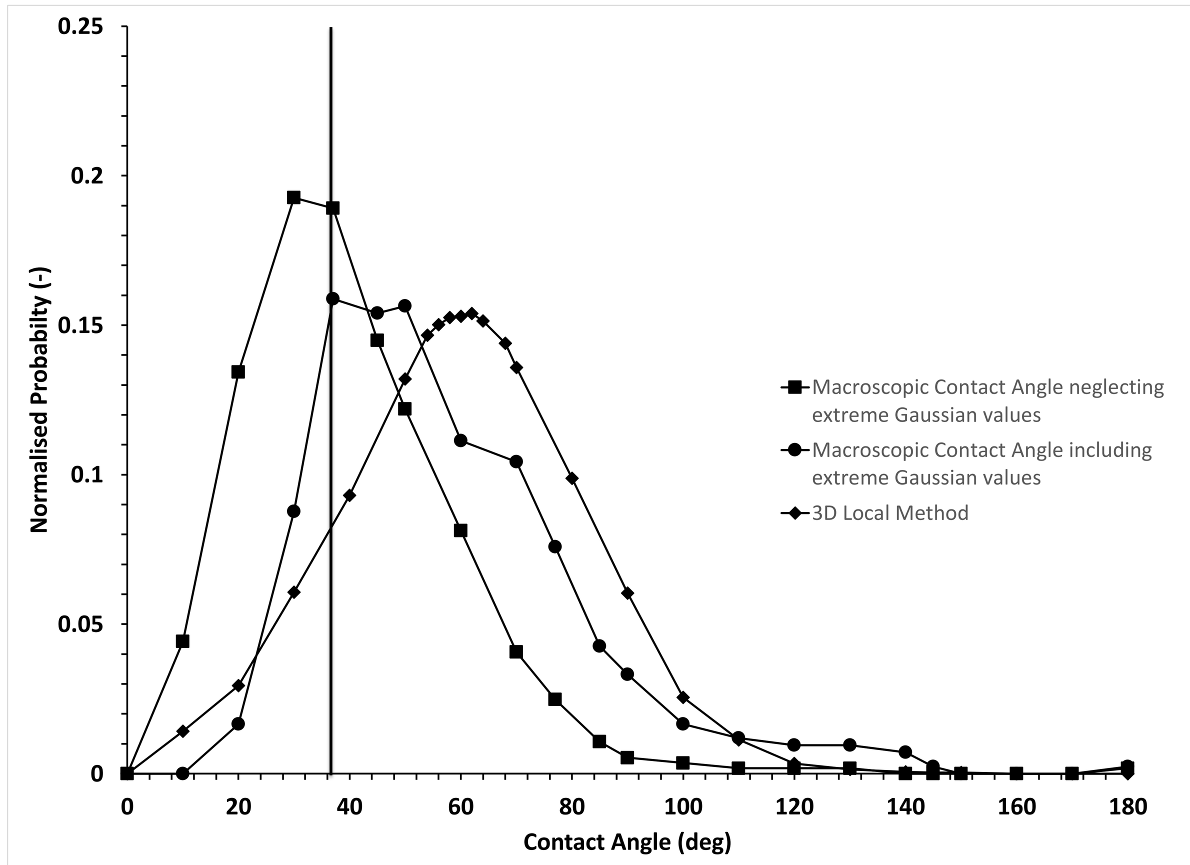

Figure 7. Distribution of contact angles from topological and 3D local methods with manual mean shown as black line

Curvature analysis indicates that hydrogen-brine-quartz is a water-wet system with the distribution of the sum of all mean curvatures greater than zero

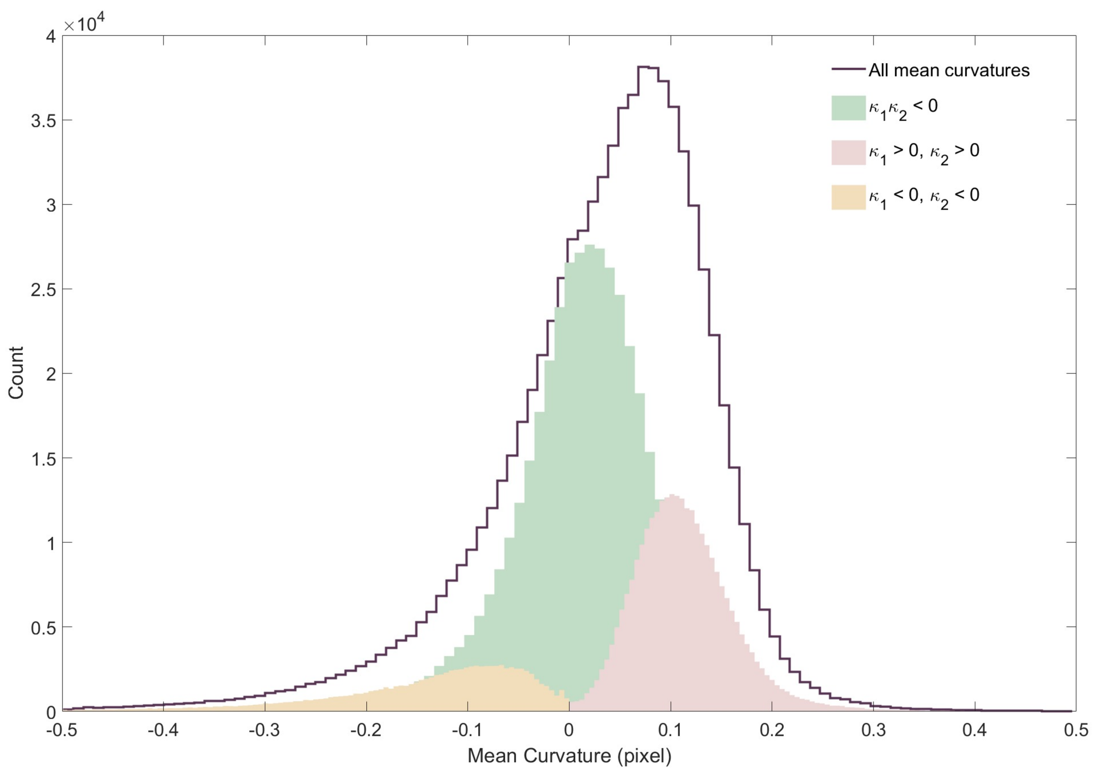

Figure 8. Curvature analysis showing water-wet surfaces in pink and gas-wet surfaces in yellow

Conclusions

Effective contact angle laboratory measurements, macroscopic contact angle (θ_{macro}), curvature analysis, manual measurement of fluid clusters on segmented micro-CT images, and the 3D local method all indicate that the hydrogen-water-quartz system is water-wet with median contact angles around 36°. This confirms the results of previous literature that determined effective contact angles ranging between 25° and 45° (Hashemi et al., 2021) and 0° to 50° (Iglauer et al., 2021) and adds to the characterisation of wettability by providing in-situ analysis. IFT data indicates hydrogen can be safely stored without diffusion or loss through cap-rocks. Water-wet formations are more prone to higher residual gas saturations which needs to be considered

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