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Impacts of viscous fingering on bio-methanation risks during underground hydrogen storage

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Hydrogen (H2) can be used as an effective energy vector and is a key element in the energy transition [1]. To accommodate the significant volume of H2 involved in the future energy mix, subsurface porous media, such as saline aquifers and depleted hydrocarbon reservoirs, is increasingly promoted as a viable option for underground H2 storage [2]. However, the reliability of this form of storage is not yet proven. One of the concerns is the impacts of microbial activity on the storage performance of H2 [3]. This is because H2 is a superb electron donor and can trigger a variety of microbial metabolism [4]. For example, H2 may initiate the bio-methanation process when carbon dioxide (CO2) is used as cushion gas in the subsurface environment. This process may lead to H2 loss and the contamination of the back produced gas. On the other hand, H2 has very low viscosity and thus is susceptible to the development of viscous fingering, when being injected to displace a more viscous fluid [5]. In this numerical work, we investigated the joint impacts of bio-methanation and viscous instability on the storage and recovery performance of H2. We have performed a range of 2D vertical cross-sectional models with a very fine cell size (0.1 m) to capture the viscous fingering in detail. It has been found that the viscous instability can expand the total size of the mixing zone and thus promote H2 consumption by methanogenesis. Since the process leads to the reduction in total gas volume, the primary purpose of cushion gas injection, which is to prevent water breakthrough, can be compromised. As a comparison, a gravity-dominated operational strategy is designed to isolate and thus ascertain the role of viscous instability on the bio-methanation process. Although gravity can drive the segregation between H2 and CO2, permeability heterogeneities lead to flow dispersions and gas mixing. However, the total mixing zone is much reduced and thus the methanogenesis is suppressed. The results of this work can be used to improve the numerical simulations associated with H2 storage in subsurface porous media, including both hydrodynamic and microbiological processes. This study should also provide useful insights and definitions of "target properties"(e.g. acceptable rate of methanogenesis) for experimentalists and industry engineers involved in screening projects for subsurface H2 storage.

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References

Primary author: WANG, Gang (Heriot-Watt University)

Co-authors: Prof. MACKAY, Eric (Heriot-Watt University); SORBIE, Kenneth (Heriot-Watt University)

Presenter: WANG, Gang (Heriot-Watt University)

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