Bio-Reactive Transport in Underground Hydrogen Storage: Heterogeneity and Patterns

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In the era of energy transition and in alignment with the international agreement for a climate-neutral economy by 2050, intensive research is being carried out around the adoption of renewable energies. Key challenge in this transition is the storage of surplus energy generated by intermittent sources, such as photovoltaic cells and windmills. The conversion of this surplus electricity into hydrogen in geological formations as gas offer an optimal solution. The conversion of hydrogen into electricity is not the only option. The produced hydrogen can be converted into methane by methanogenic bacteria that use hydrogen and carbon for their metabolism producing methane and water through a process known as in situ bio-methanation. However, controlling the mixture of such system is challenging due to the self-organization phenomenon and the formation of patterns, i.e., areas with high hydrogen concentration and other areas with low concentration. These patterns result in non-uniform gas mixing, reducing the purity of the stored gas. We demonstrated the appearance of several types of patterns. The existence of such structures implies spatial heterogeneity of hydrogen and methane, indicating incomplete methanation. Another form of heterogeneity, induced heterogeneity was analyzed. This heterogeneity results from biomass growth, biofilm formation and pore-clogging. In this context, we developed a conceptual model of bio-clogging simulating reactive transport coupled with bacterial dynamics. Our results showed that induced heterogeneity significantly influences gas transport within the reservoir. We demonstrate that in the absence of bacteria, when gas is injected into the aquifer, it rapidly rises to the surface, spreading as thin layer above the geological structure. However, in the presence of bacteria, due to their increased activity along gas upward flow lines, bacteria form plugs on vertical gas pathways, forcing the gas to spread horizontally, resulting in a more propagation of hydrogen covering the entire reservoir.

Références

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