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Migration and dissolution of stray gas in shallow groundwater: a high-resolution laboratory investigation

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Summary

Stray gas migration (the flow of gas outside the surface casing of a damaged or inadequately sealed wellbore) has been identified as a critical mechanism that allows gas from deeper zones to enter shallow aquifers. This gas, mostly methane, can be released to the atmosphere (surface expression) contributing to greenhouse gas (GHG) emissions, or it can dissolve in groundwater (aqueous expression) leading to decreased water quality. Despite the concerns associated with stray gas migration, there have been no detailed laboratory studies to investigate fundamental flow and mass transfer processes to complement on-going field investigations and provide a basis for the validation of numerical models.

In this study, a series of intermediate-scale (10s to 100s of cm) flow cell experiments were conducted to investigate gas flow and gas dissolution using the injection of either CH_4 or CO_2 in homogeneous and heterogeneous sand packs. Experiments were conducted in both 25 × 25 × 1 cm^3 and 150 × 150 × 2 cm^3 flow cells built with transparent walls to facilitate high-resolution measurements of gas saturations in space (1-5 mm) and time (5-30 s) using a light transmission visualization technique. In the case of the CO_2 experiments, visualization was also used to assess the dissolved plume using a pH indicator dye. In the case of the CH_4 experiments, dissolution was investigated using depth-discrete sampling at the effluent edge of the flow cell. The results of this study showed that upward gas flow was unstable and discontinuous (bubble flow), with fluctuating emissions at the surface. When subjected to horizontal water flow, the aqueous plume produced by dissolution of the gas was affected by that water flow, including complete arrestment of the plume at higher aqueous flow rates. Dissolution was also affected by the distribution of gas saturations (architecture), leading to higher dissolved concentrations downgradient of more laterally-extensive gas accumulations, and increased concentrations immediately after gas flow was stopped before decreasing due to gas depletion. Finally, and importantly, gas flow and dissolution were significantly affected by multicomponent partitioning, where the mass transfer of background dissolved gases resulted in dramatic changes to gas composition between injection and surface emission, and created persistent trapped gas saturations after the injected gas was depleted. Collectively, the results of this series of experiments enhance our conceptual models of stray gas migration, with significant implications for the development of investigation and monitoring strategies, and provide an unprecedented dataset for future comparison to numerical simulations.