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Geomechanical assessment of potential gas leak pathways: a numerical modeling study on caprock integrity of natural gas storage site

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Summary

Fugitive gas emissions are the unintended releases of gas from energy operations. Fugitive emissions from natural gas operations are composed mainly of methane, a potent greenhouse gas. Thus, any releases contribute to greenhouse gases in the atmosphere. In addition, gas accidently released in the subsurface (such as from production wells or underground gas storage) can migrate into overlaying formations towards surface and negatively impact shallow groundwater quality (Cahill et al., 2019). When considering utilizing natural gas as a bridging fuel in the transition from more carbon intensive fossil fuels to alternative and renewable green energy sources, more storage sites may be needed to meet seasonal demands. Therefore, understanding how fugitive gas emissions make their way into the atmosphere or the groundwater during the storage stage is important. Underground storage formations have high porosity and permeability to allow for the high volumes of stored gas (Speight, J.G., 2018). These formations, which includes depleted oil and gas reservoirs, salt caverns, and aquifers, play key roles as natural warehouses for natural gas storage reinjection. The storage formations are sealed by caprocks with low permeability. Historically, there have been documented releases of stored natural gas due to caprock integrity issues, and potentially more occur that are not detected (Bruno et al., 2014; Evans and Schultz, 2017). Injection induced failure and fractures in caprocks could increase caprock permeability and act as potential leakage pathways for natural gas. In this study, we investigated caprock integrity to further understand how site selection and operating parameters could ensure safe gas storage.

Methodology

We investigated caprock seal integrity using a 3D thermo-hydro-mechanical (THM) conceptual model of storage site consisting of reservoir layer, caprock, and overburden layer (Figure 1). A depleted gas reservoir was chosen to model over other types of storage reservoirs due to their abundance in Alberta (Canada Energy Regulator, 2018). An elasto-plastic model was adopted to define rock behavior, normal effective stress, and vertical displacement were used as metrics for fracture development. Natural gas, modelled as 100% methane in the simulation, is injected into the depleted gas reservoir via a single injection well located at the middle of the model and perforated in the reservoir layer. Methane PVT properties are modelled using Peng-Robinson equation of state.

The opening of fractures is considered only in the caprock and their permeability variations is calculated using a modified Barton-Bandis fracture model based on normal effective stress change. Simulations are carried out using the coupled non-isothermal multiphase flow and geomechanics simulator CMG-GEM (GEM User's Guide, 2019).

Results

The effects of the gas injection rate and temperature, and the storage reservoir permeability on natural gas underground storage caprock integrity were investigated by numerical modeling. Our simulations confirm that higher injection rates initiate fracture opening earlier than lower rates and low gas temperatures injection have the potential to delay caprock failure. Furthermore, reservoir permeability, as a crucial parameter defining hydraulic diffusivity, has a prominent role on determining caprock cracking onset. Lower storage permeability slows pressure diffusion into the reservoir which increases pore pressure and decreases effective stresses in the caprock around the well, hence, initiates fractures earlier than in higher permeability reservoirs. Our results emphasize the importance of prior storage site characterization for optimizing injection parameters to mitigate the risk of fracturing the caprock.

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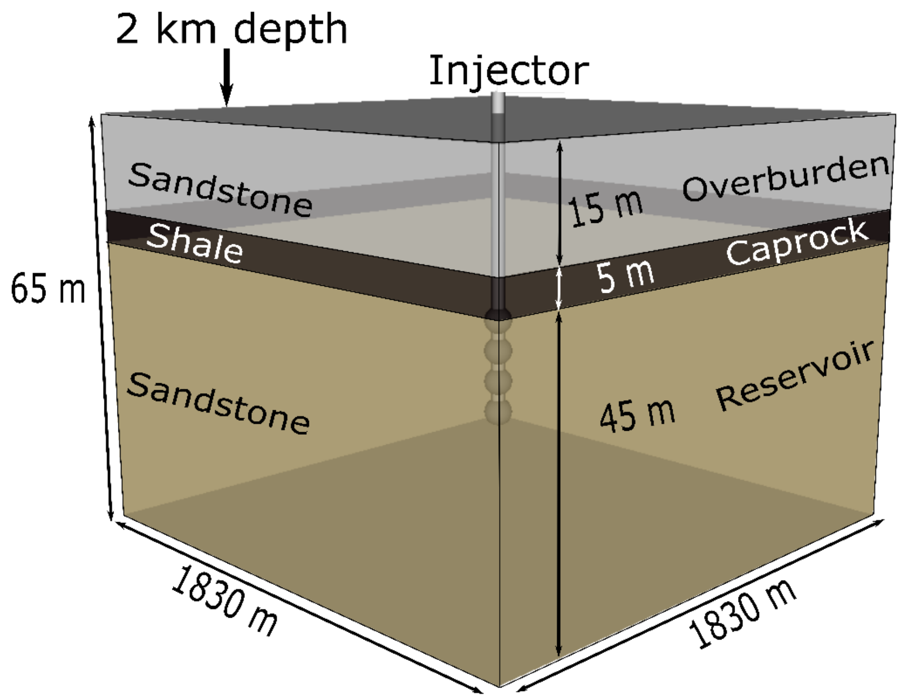

Figure 1. 3D schematic illustration of the conceptual model used in our study. The model is located at 2 km depth and initialized using vertical, maximum horizontal, minimum horizontal stress gradients of 12, 14, 20 MPa/km, respectively. Reservoir and overburden permeabilities are typical of sandstone while caprock permeability resembles shale permeability.