Geomechanical modeling of potential leakage pathways through caprocks at natural gas storage sites

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Fugitive gas emissions are unintended releases of gas from energy processes. Natural gas emissions are composed mainly of methane and can contaminate groundwater or contribute to greenhouse gases after migrating from production wells or underground storage. As natural gas is relied on as a low-carbon energy option, more storage sites will be needed, increasing opportunities for gas leakage. This study investigated methane leakage from storage reservoirs due to injection induced caprock fractures by varying injection rate, gas temperature, and reservoir permeability and possible policy improvements to ensure safe gas storage.

Sensitivity analyses were performed on a 3D thermo-hydro-mechanical model of a storage reservoir, caprock, and overburden layer using normal effective stress and vertical displacement as metrics for fracture development. Analyses used coupled fluid-flow and geomechanics simulator CMG (Computer Modeling Group) GEM-2019[1]. Higher injection rates initiated fractures earlier than lower rates (Figure 1). Cooler gas temperatures reduced volumetric strain, which delayed caprock failure. Lower reservoir permeability slowed pressure diffusion which decreased effective stress around the well and initiated fractures earlier than higher permeability reservoirs. After fracture initiation, gas pressure diffused into caprock and overburden (Figure 2) and gas saturation increased in layers overlying the reservoir.

The results showed the importance of injection rate and reservoir characterization for optimizing injection parameters and reducing gas permeable fractures. For instance, reservoir permeability controlled the onset of fracture initiation, and cooler gas delayed fracturing in fault-free reservoirs such as the one modeled but may reactivate any pre-existing faults[2].

Currently, Alberta regulates factors such as maximum operating pressures and caprock testing. However, the model results could inform regulatory modernization to ensure rigorous characterization of reservoirs to reduce fracture formation. Reduced emissions through caprock would decrease the risk of contaminating shallow groundwater, especially for communities relying on groundwater or close to storage sites, including indigenous communities.

Word Count: **299**

Footnotes:

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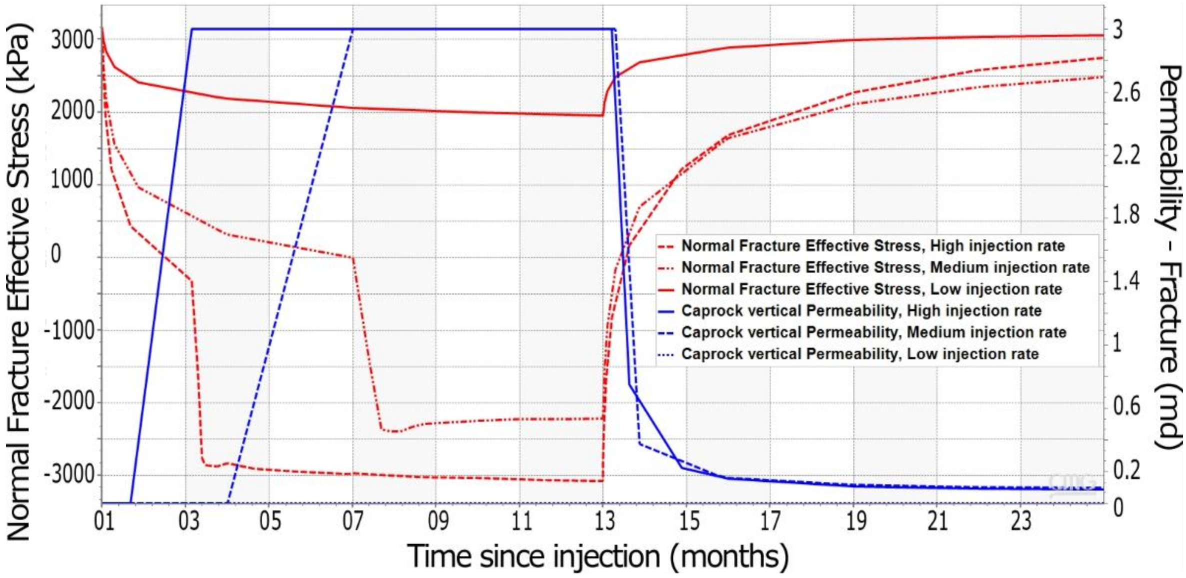

Figure 1. Normal fracture effective stress (red lines) and vertical permeability of caprock (blue lines) for three injection rates. When normal effective stress dropped below 0 fractures initiated. Figures were generated using CMG-GEM[1].

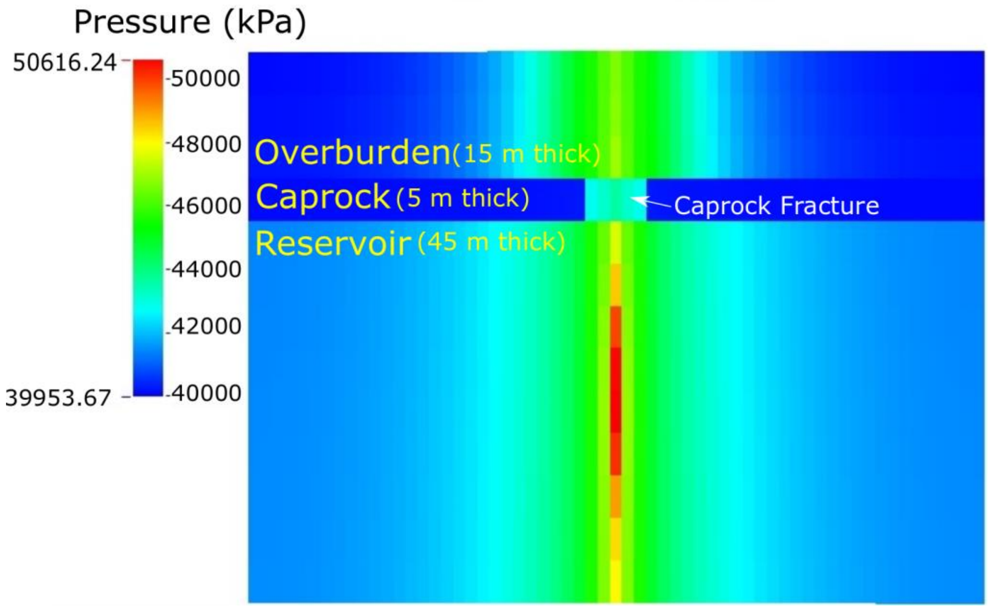

Figure 2. Gas pressure diffusion into overlying layers from the storage reservoir. Once normal effective stress in the caprock fell below zero, fractures initiated in the caprock and gas started to escape the reservoir into the overlying layers diffusing pore pressure in the reservoir. The bottom of the model domain is located 4 km below ground surface. Figures were generated using CMG-GEM[1].

Acknowledgments:

Authors are scholarship recipients of CREATE REDEVELOP Grant #386133824, a collaborative research and training experience in responsible energy development funded by the Natural Science and Engineering Research Council of Canada (NSERC). We gratefully acknowledge the knowledge made available through the Indian Resources Council Inc. Special thanks to Brent McGarry and Ryan Green of the Alberta Energy Regulator, the staff at CMG Calgary for their mentorship. Thanks also to Dr.. Bernhard Mayer, Dr. Jennifer Winter and Dr. Celia Kennedy for their guidance.

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