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Static characterization and dynamic simulated scenarios for monitoring a shallow CO_2 injection target

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Summary

A 25 sq. km static geomodel was constructed to characterize a shallow injection into the 7 m thick Basal Belly River Fm. at 295 m depth in Newell County, AB. Effective porosity and intrinsic permeability were calculated and calibrated to six core lab analyses. Variography analyses were completed to obtain correlation lengths, and the 5 km by 5 km model was populated using a Gaussian Random Function Simulation algorithm. A P10-50-90 framework was run to give conservative, typical, and optimistic scenarios of the reservoir's storage capacity. The regressional shoreline sandstone interval remains consistent across the study area giving a mean effective porosity of 11% and permeability of 0.57 mD. Dynamic simulation was completed on the P10-50-90 static cases for multiple injection scenarios, totaling 3150 t/CO_2 after a 5-year period. The evolution of the CO_2 plume was observed at 1-year during injection and 5-years during injection, as well as the 1-year and 10-year mark for the post-injection period. The final 10-year post-injection result simulated a laterally extensive plume, expanding to 350 m in length and 20 m of vertical migration into the caprock. The target interval proves as an ideal reservoir, and the seal interval demonstrates containment over a 10-year post-injection period. Uncertainties remain in the static and dynamic realm, and include but are not limited to the reservoir, fracture, and capillary pressure, k_V/k_H ratio, and the relative $k_{CO2\text{-}H2O}$.

Introduction

This study is based on the 5 km by 5 km geostatic model constructed for the Field Research Site (FRS), to serve as an initial baseline characterization of a target and seal interval A. The field pilot site was established by the Containment and Monitoring theme of CMC Research Institutes. The FRS serves to bridge the gap between research completed on the lab bench scale, and is focusing towards building technologies that are economically sustainable to operate and be implemented at a larger industrial CCS project scale. The study area is located in Newell County, AB, which is 188.9 km southeast of Calgary (Figure 1) in Section 22, Township (TWP) 17, and Range 16 west of the 4^{th} Meridian. The lease of the land is courtesy of Cenovus Energy, giving access to approximately a ¾ section and the FRS utilizes 1 square-kilometre (sq. km) of the area.

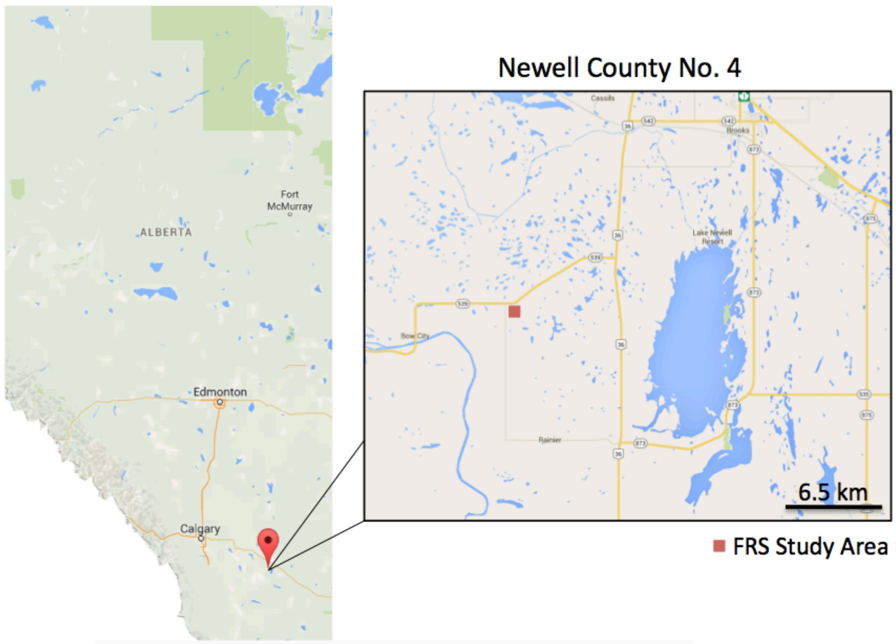

Figure 1. Location map illustrating the FRS pilot site within Newell County, AB (© Google Maps).

Well locations, deviation surveys, well tops, well logs, and core data from 198 wells within a 10 km radius of the main FRS onsite well 10-22 was obtained. For the construction of the petrophysical model, only 88 of the 198 wells were analyzed thoroughly and are found within TWP 17. For the well-tie process, only three wells were tied to the two 3-D seismic volumes. A map of the FRS site, the surrounding wells, and the two 3-D seismic datasets are shown in Figure 2.

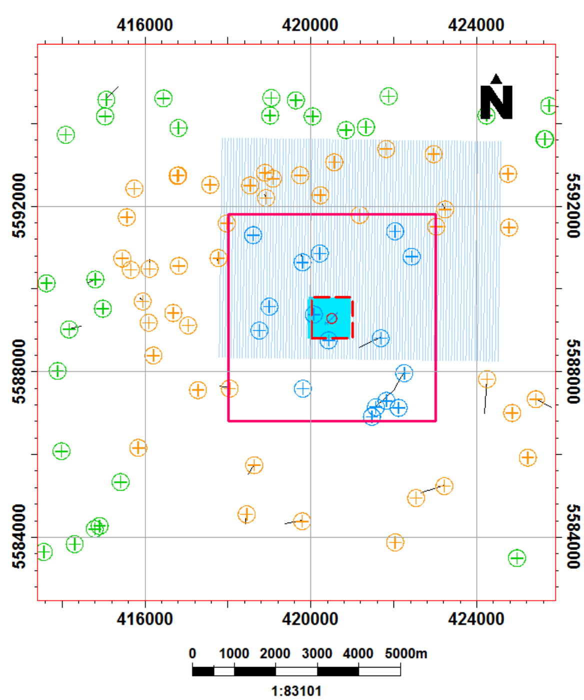

Figure 2. The wireline and 3-D seismic reflection volumes used to construct the FRS geostatic model. The 88 wells are colour-coded, where the green wells are located in the outer TWP 17, orange wells are located within 10 km radius, and the blue wells are located within a 5 km radius of the FRS. The 25 sq. km polygon outlines the extent of the property model, and the 1 sq. km polygon outlines the extent of the FRS study area.

The caprock interval A is known as the Foremost Formation, and consists of interbedded sandstone, siltstone, marine clays, and impermeable coal zones – all of which represent transgressive and regressive cycles (Hamblin and Abrahamson, 1996). The high water-saturation in the coals, alongside the methane (CH_4) gas that resides, provides little relative permeability (Pedersen, 2014). Thus the coal zones and marine clays within the Foremost Formation should be capable of providing caprock integrity, and will limit vertical migration of any injected CO_2 in the BBRS reservoir. The Basal Belly River Formation is known as the shallow target A. The regressional shoreline sandstone deposit is described as fine- to medium-grained sandstone that has poorly to well sorted, angular to sub-angular grains packed loosely with calcite cement (Hamblin and Abrahamson, 1996).

The global objective behind this study is to construct a static geomodel that incorporates both geological and geophysical characterization of the target A and seal A intervals of the FRS site. The analyses and fluid-flow simulation results, where a total of 3150 t/CO_2 in gas-phase is injected into the main target interval A over a total 5-year duration, will be used towards obtaining an injection license as part of Directive 051 from the Alberta Energy Regulator.

Development of the FRS model

The two main properties of concern for the geomodel were effective porosity and intrinsic permeability. The petrophysical calculations were approached in a manner that considers the clay content, as well as the bound and free fluids as derived by Swager (2015). The intrinsic permeability was calculated using the free-fluid Timur-Coates model (Timur, 1968; Coates and Dumanoir, 1974), based on the PHIT and the volume ratio of free-fluids to bound-fluids. Six core lab measurements were used for log-to-core calibration. The regressional shoreline sandstone interval remains consistent across the study area giving a mean effective porosity of 11% and permeability of 0.57 mD. The caprock interval is indicative of a tight seal interval, demonstrating intrinsic permeability values less than 0.001 mD.

Due to the lack of structure in the region, a vertical pillar gridding method was chosen. The properties were upscaled using an arithmetic mean method into the model cells. Minor variogram work was completed on both properties to obtain the correlation lengths, and then populated into the 3-D model using a Gaussian Random Function simulation algorithm. To gain a better understanding of the uncertainty within the data, a P10-50-90 framework was used to characterize the conservative, typical, and optimistic storage capacity of target A. The three scenarios were the direct input data for the dynamic modeling of the fluid-flow injection simulations.

Fluid-flow simulation results

For the purpose of dynamic modeling, the upper and lower seal, as well as the target interval were upscaled using a tartan gridding method. The pressure at 300 m depth was calculated to be 2.94 MPa using the hydrostatic pressure gradient. The salinity of formation water is brackish, ranging from 1,000 – 10,000 ppm as determined by a Worley Parsons Komex (2008) study. To avoid fracturing the reservoir or borehole during injection, the maximum allowable bottom hole pressure (BHP) was used as a guideline to mitigate this risk. The maximum BHP is considered to be 90% of the lithostatic pressure at reservoir depth needed to fracture the rock. Considering the lithostatic pressure gradient is 24.5 MPa/km (Karner, 2005), at 300 m depth the maximum BHP was calculated to be 6.615 MPa. Of the flow parameters, the ratio of k_V/k_H was estimated to be 0.1, which assumes primary fluids will flow horizontally (Lee, 2015).

The initial injection plan was modified from a consistent but controllable injection 1000t/CO_2 over a five-year period, to ~600t/CO_2 over the duration of a year. However, injection periods last up to 3 months, and allow for a one-month shut-in period to allow pressures to dissipate. The CO_2 gas saturation profile is displayed in the E-W direction for the (A) 1-year during injection, (B) 5-years during injection, (C) 1-year post-injection, and (D) 10-years post-injection periods in Figure 3. Over the total 10-year post-injection period, the CO_2 plume is laterally extensive and measures a total plume diameter of 350 m. Minor vertical migration occurs into the caprock interval of ~20 m, with the low k_V/k_H and tight core lab measurements acting to contain the plume volume within the target interval A. The gas saturation of CO_2 is most concentrated at the borehole, reaching up to 0.5 and radially decreases as the plume extends laterally.

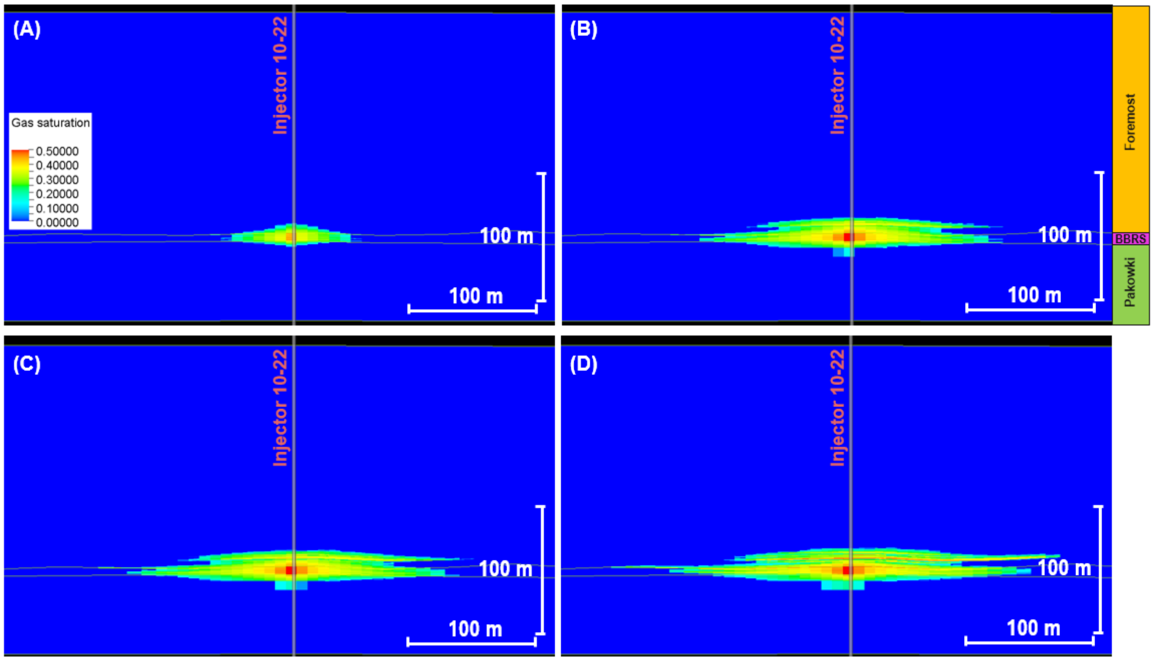

Figure 3. CO_2 saturation profile along the E-W direction for the P50 case of the heterogeneous geodynamic model. (A) After 1-year during the injection period, (B) after 5-years during the injection period, (C) 1-year post-injection period, and (D) 10-years post-injection period. Figures modified from Lee (2015).

Conclusions

A 25 sq. km static geomodel was developed for the FRS study area as an initial baseline characterization that incorporates both geological and geophysical datasets. The model workflow used has built-in manual and automatic mechanics, thus the model can be easily updated with the arrival of new data. The target A has effective porosity up to 11% and intrinsic permeability up to 0.57 mD. Seal A has complex lithology, but demonstrates high caprock integrity with low permeability values up to 0.001 mD. The fluid-flow simulations demonstrate containment of the CO_2 plume in the target A reservoir, with minor vertical migration into the caprock, totaling 3150 t/CO_2 injected over an intermittent five-year injection period. As a result of injection, the induced pressure plume differential does not raise concern for breaching the caprock, remaining under the maximum allowable BHP of 6.615 MPa. The fluid-flow simulations serve as a best estimate of how the characterized subsurface with behave in both the static and dynamic realms.

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