Modeling CO_2 Injection into Fractured Duperow Formation at Kevin Dome Using a Multi-Continuum Approach

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Abstract

The Big Sky Carbon Sequestration Partnership (BSCSP) recently drilled a monitoring well and a CO_2 production well into Kevin Dome as part of the Kevin Dome BSCSP Phase III project. The cores extracted from both wells and the step-rate injection tests at the monitoring well showed that the target production/injection formation, the Middle Duperow, is highly fractured in its high-porosity zone. To predict pressure buildup and CO_2 plume evolution in response to the planned injection rate of 1 million tonnes CO_2 in four years, we developed a multiple interacting continua (MINC) model for the 30 m-thick high-porosity layer. Sensitivity analysis was conducted to understand the effects on pressure buildup and CO_2 plume evolution of fractures, fracture permeability, and fracture-matrix interactions. Simulation results indicated that the presence of fractures of small spacing and relatively higher permeability significantly reduces the bottomhole pressure buildup in comparison with the matrix-only case. With fractures accounted for, the maximum bottomhole pressure buildup is on the order of 60 bar, which is far less than 90% of the measured fracturing pressure of 144 bar. In contrast, if we assume a hypothetical matrix-only case, bottomhole pressure buildup is higher than 144 bar, indicating that fractures are needed to meet the total injection requirement for the project.

TOUGH2/MINC Model Development

- The developed MINC model has one fracture continuum and four matrix continua, with volumetric fraction of 0.01, 0.05, 0.20, 0.34, and 0.40, and porosity of 1.0, 0.15, 0.10, 0.10, and 0.08, respectively;
- In this model, global fracture-fracture connections, global matrix-matrix connections, and local fracture-matrix connections are considered;
- Four fracture permeability (Kf) parameters are considered;

TOUGH2/MINC Model Development

- Fracture spacing of the high-porosity layer of the Middle Duperow is based on core fracture mapping and FMI logging, and fracture aperture or fracture permeability is based on the step-rate injection test analysis and sensitivity analysis;
- The matrix permeability (Km) is based on the effective permeability derived from the step-rate injection tests, while matrix porosity is based on core measurements;
- In addition to the MINC layer, only the matrix continuum is considered for the underlying Lower Duperow and overlying Upper Duperow and Nisku formations, with a total model thickness of 237 m;
- Two scenarios for pressure dissipation into other formations from the injection zone are considered (see Table 1);
- An initial pressure of 100 bar and a temperature of 34 °C at the injection layer top are used at the model injection well, which is assumed to have the same properties as the monitoring well.

Table 1: Permeability and porosity values of the five formation layers used in the numerical model in two scenarios of pressure dissipation

Formations	Scenario I	Scenario II
Nisku (23.8 m)	Kx = 0.0002 md Kz = 0.0001 md Φ = 0.05	Kx = 0.00002 md Kz = 0.00001 md
Upper Duperow (58.5 m)	Kx = 0.05 md Kz = 0.01 md Φ = 0.06	Kx = 0.00005 md Kz = 0.00001 md
Injection Zone (30 m)	Kmx = 20 md Kmz = 10 md Φm = 0.15, 0.10, 0.10, 0.08 Kf = 40, 60, 80, 100 md	unchanged
Middle Duperow (42.2 m)	Kx = 3 md Kz = 1 md Φ = 0.08	Kx = 0.00003 md Kz = 0.00001 md
Lower Duperow (82.6 m)	Kx = 0.03 md Kz = 0.01 md Φ = 0.05	Kx = 0.00003 md Kz = 0.00001 md

Simulated Pressure Buildup (ΔP)

- Figure 1 shows the simulated ΔP at the bottom of the injection well for six cases in Scenario II, while Figure 2 shows ΔP for the entire storage system in the case of Kf = 40 md and Km = 20 md in Scenario II;
- The bottomhole injection pressure linearly depends on Km in the case of no fractures;
- The difference between different Kf cases is not as large because of the fracture-matrix interactions for pressure dissipation;
- Higher ΔP is obtained for Scenario II because of smaller ΔP dissipation into other formations.

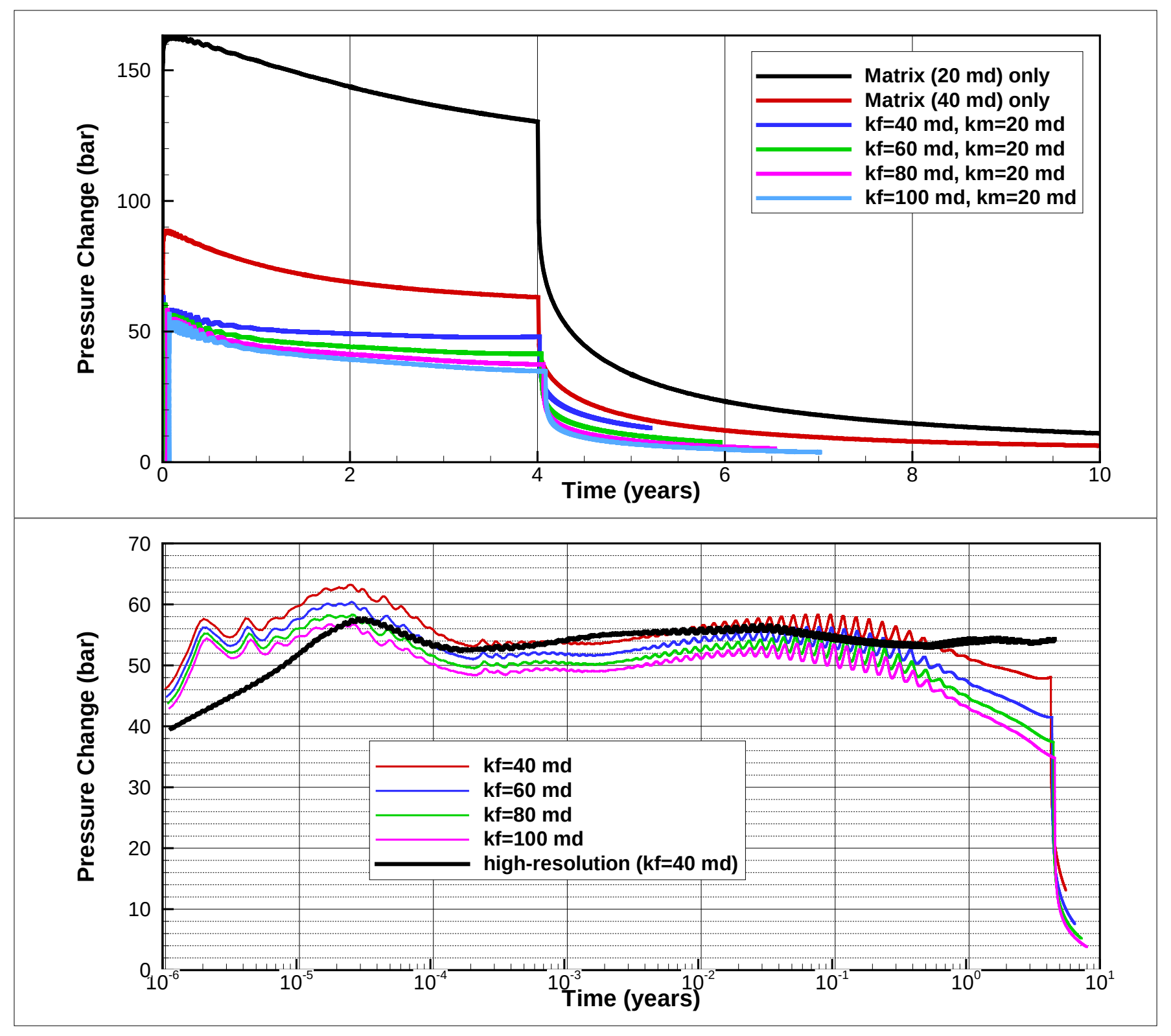

Figure 1: Simulated bottomhole injection ΔP, as a function of time in 6 cases

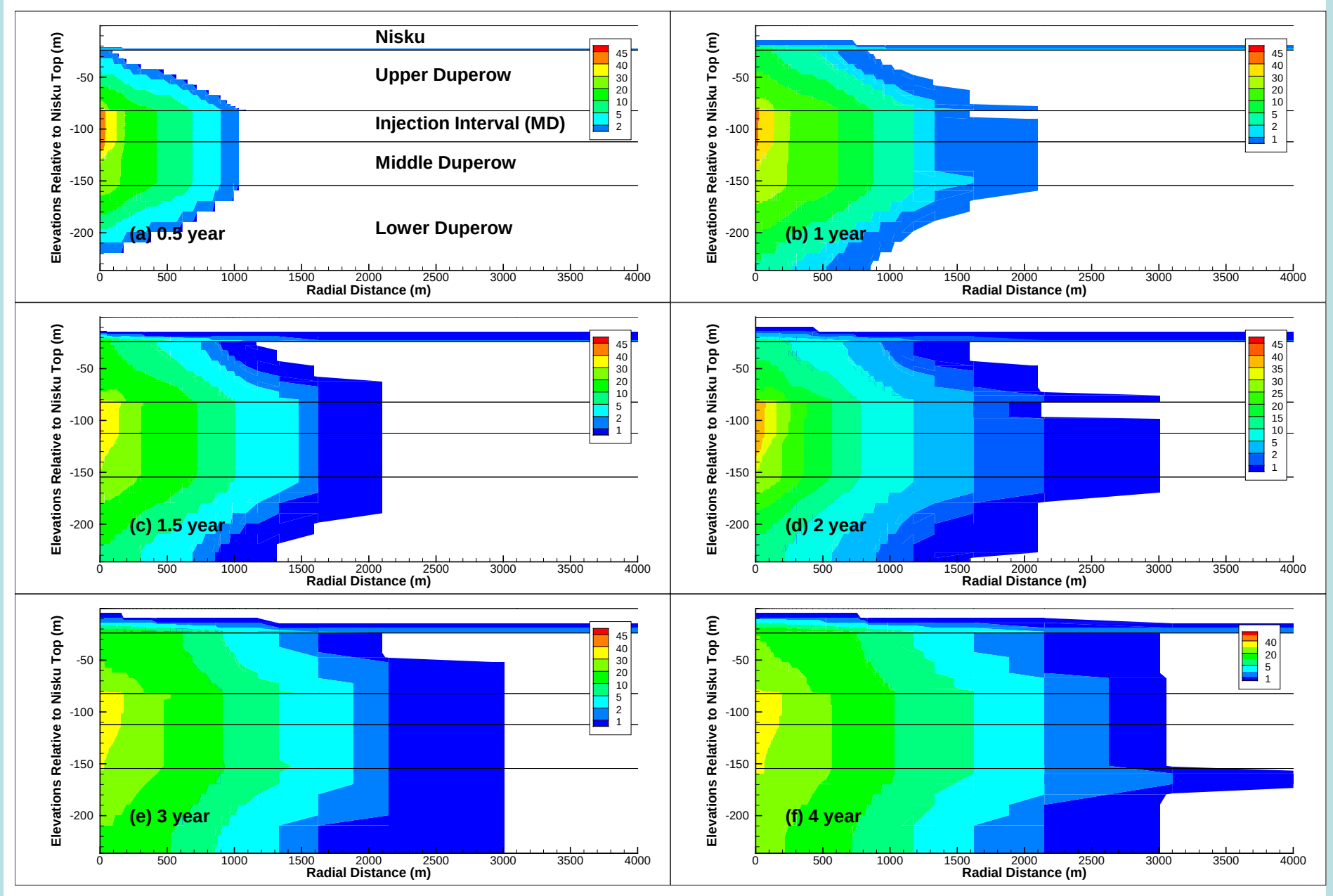

Figure 2: Simulated ΔP in the entire storage system in the case of Kf = 40 md, Km = 20 md, Scenario II.

Simulated CO_2 Plumes

- The simulated CO_2 plumes in the fracture continuum and four matrix continua have similar spatial extent at any injection time (see Figures 3 and 4). The similarity is caused by the low entry capillary pressure (α^{-1} = 0.02 bar) and relatively high permeability (20 md) of the rock matrix;
- The CO_2 saturation differs in different continua at a given spatial location and time, with highest saturation in the fracture continuum, and lowest saturation in the last matrix one;
- The high CO_2 saturation in fractures results in a higher relative permeability and smaller ΔP;
- Matrix CO_2 saturation is very sensitive to α^{-1}.

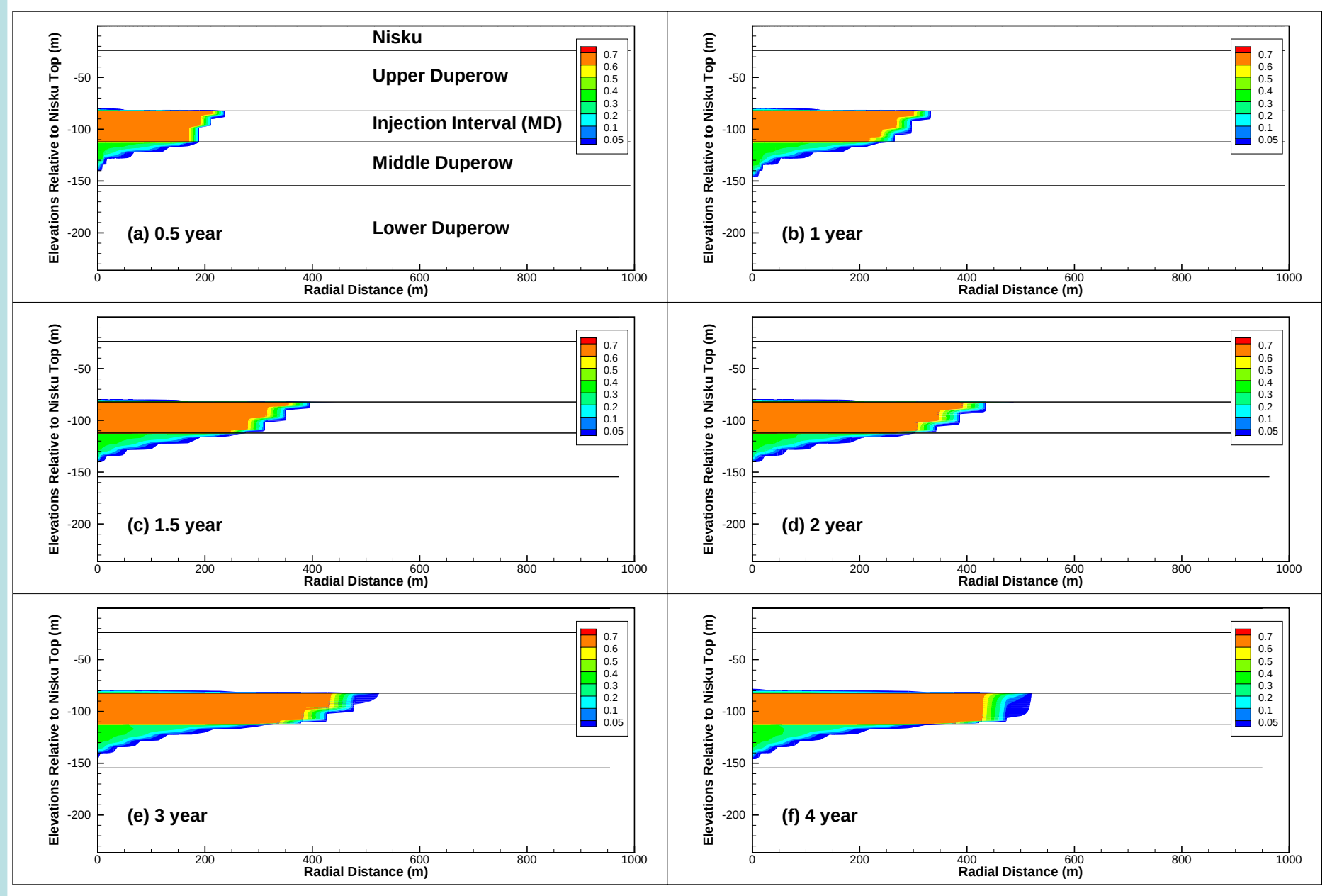

Figure 3: Simulated CO_2 plumes in the fracture continuum at different time of injection in the same case as Figure 2.

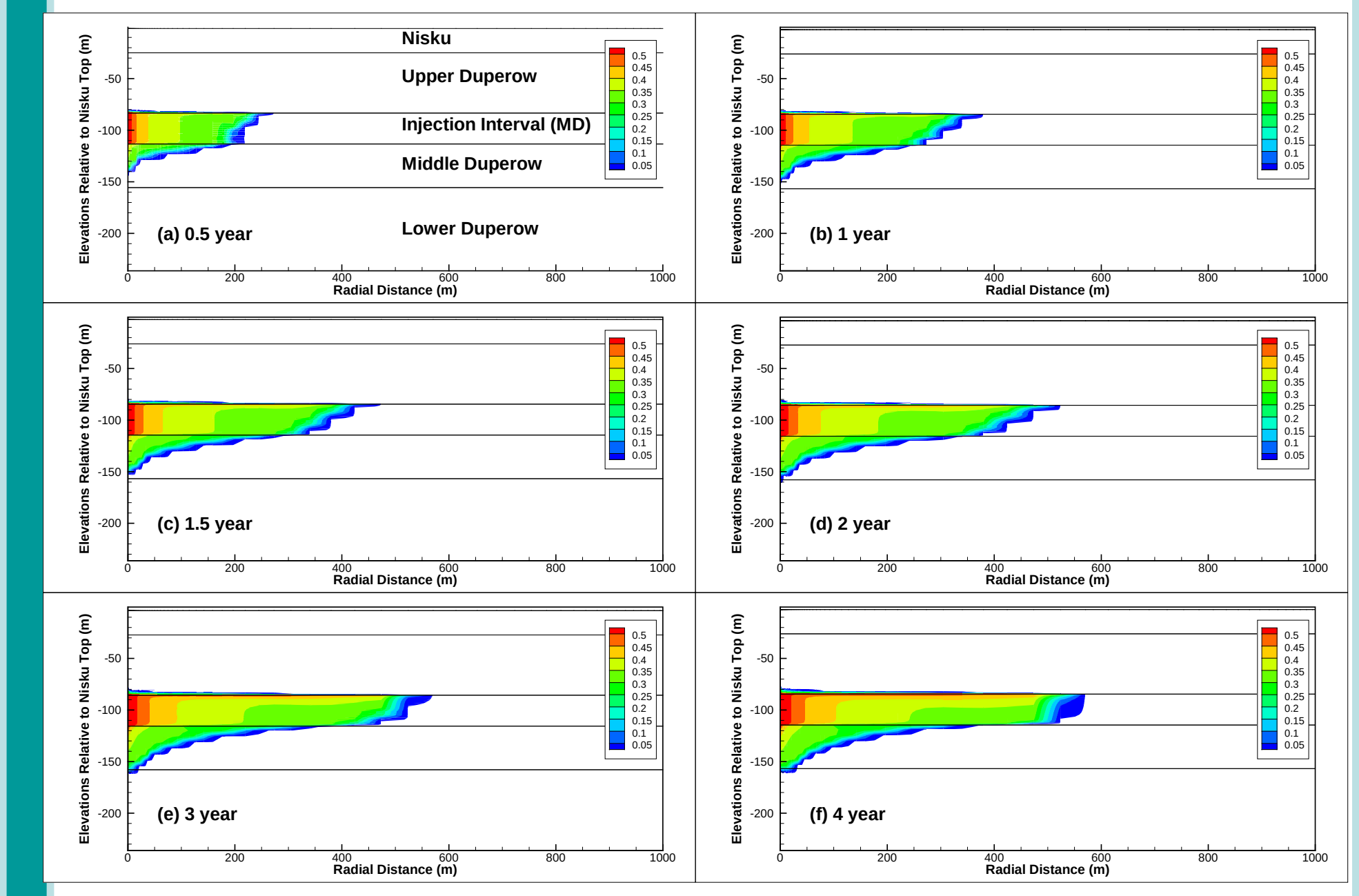

Figure 4: Simulated CO_2 plumes in the first matrix continuum next to the fracture continuum at different times of injection.

Summary and Conclusions

- At the Kevin Dome site, site-specific data show the Middle Duperow layer to be used for CO_2 injection is highly fractured;
- To assess the impact of the presence of fractures on pressure buildup and CO_2 plume evolution, we developed a MINC model for a 2D radial TOUGH2 model, with one fracture continuum and four matrix continua;
- The site-specific data used in the model include matrix porosity from core measurements, matrix permeability from the step-rate injection test, fracture spacing from core images, and fracture permeability through different sensitivity cases;
- The injection rate is constant at 250,000 Mt CO_2 over four years;
- The simulated bottomhole injection pressure indicates that the fractured Middle Duperow has sufficient injectivity because fractures significantly lower injection pressure in comparison to matrix only cases;
- The majority of injected CO_2 is stored in the rock matrix because of the strong fracture-matrix interactions of CO_2 flow;
- The benefits of enhanced injectivity and sufficient storage efficiency in fractured rock can be attributed to the high mobility of CO_2 flow in fractures, with high CO_2 saturation and thus relative permeability, and to the strong fracture-matrix interaction of CO_2 flow.

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