Geologic Carbon Storage: Implications of Two-Phase Flow on Injection-Induced Stress on Faults

Samir Prasun[1], Seunghee Kim[2], and Seyyed A. Hosseini[3]

1. Petroleum Engineering, Louisiana State University, Baton Rouge, LA, US
2. Department of Civil Engineering, University of Nebraska-Lincoln, Omaha, NE, US
3. Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, Austin, TX, US

INTRODUCTION: Major challenges associated with CO_2 geologic storage:

- ❑ Pore-pressure buildup and subsequent poroelastic stress changes may result in injection-induced seismicity on faults
- ❑ Inaccurate prediction of stress on faults: Previous studies implemented numerical simulations based on a single-phase flow condition ignoring multiphase effects

The goal of this study is to:

- ❑ Examine the effect of multiphase flow and CO_2 compressibility on the injection induced stress changes for conductive basement faults,
- ❑ Compare it with the results from single phase flow

COMPUTATIONAL METHODS: **Jaeger et al. 2009; Kim and Hosseini 2017**

2-D Equation based modeling interface coupled with Solid mechanics interface using COMSOL MULTIPHYSICS

Constitutive equation of Solid mechanics interface:

$\sigma = C\varepsilon - \alpha p_f I$ (1) (Fluid-to-solid coupling)

Immiscible two-phase (CO_2+water) flow equation defined via the PDE user interface:

$$\rho_g S_g S_{\epsilon g}\frac{\partial(p_w)}{\partial t} + \left(\varphi\rho_g + \rho_g S_g S_{\epsilon g}\frac{\partial p_c}{\partial S_g} + \alpha\rho_g\varepsilon_{vol}\right)\frac{\partial(S_g)}{\partial t} + \nabla.\rho_g\left[-\lambda_g\left(\nabla p_w + \frac{\partial p_c}{\partial S_g}\nabla S_g + \rho_g g\nabla h\right)\right] = \boxed{-\alpha S_g\frac{\partial(\rho_g\varepsilon_{vol})}{\partial t}} \quad (2)$$

Solid-to-fluid coupling

$$\rho_w(1-S_g)S_{\epsilon w}\frac{\partial(p_w)}{\partial t} - (\varphi\rho_w + \alpha\rho_w\varepsilon_{vol})\frac{\partial(S_g)}{\partial t} + \nabla.\rho_w[-\lambda_w(\nabla p_w + \rho_w g\nabla h)] = \boxed{-\alpha(1-S_g)\frac{\partial(\rho_w\varepsilon_{vol})}{\partial t}} \quad (3)$$

Solid deformation complies with force equilibrium:

$$\nabla.\sigma + \left(\left((1-S_g)\rho_w + S_g\rho_g\right)\varphi + \rho_d\right)\vec{g} = \vec{0} \quad (4)$$

Model Properties (Chang and Segall (2016))

Model properties	Unit	Mudrock	Sandstone	Basement	Fault
Permeability	m^2	10^{-19}	6.4×10^{-14}	2×10^{-17}	10^{-13}
density	kg/m^3	2600	2500	2740	2500
Shear modulus	GPa	11.5	7.6	25	6
Biot's constant	-	0.35	0.55	0.24	0.79
Poisson's ratio	-	0.3	0.15	0.2	0.2
Porosity	-	0.1	0.25	0.05	0.02
Friction coefficient	-	0.5	0.6	0.6	0.75

Model set-up

Parameters	Unit	Value
Volumetric rate (Q) at Reservoir Conditions	m^3/s	3000
Length of Target Formation	m	15000
Thickness of target formation	m	100
Initial formation pressure	MPa	20
Formation temperature (T)	F	150
Depth of target formation	m	1900

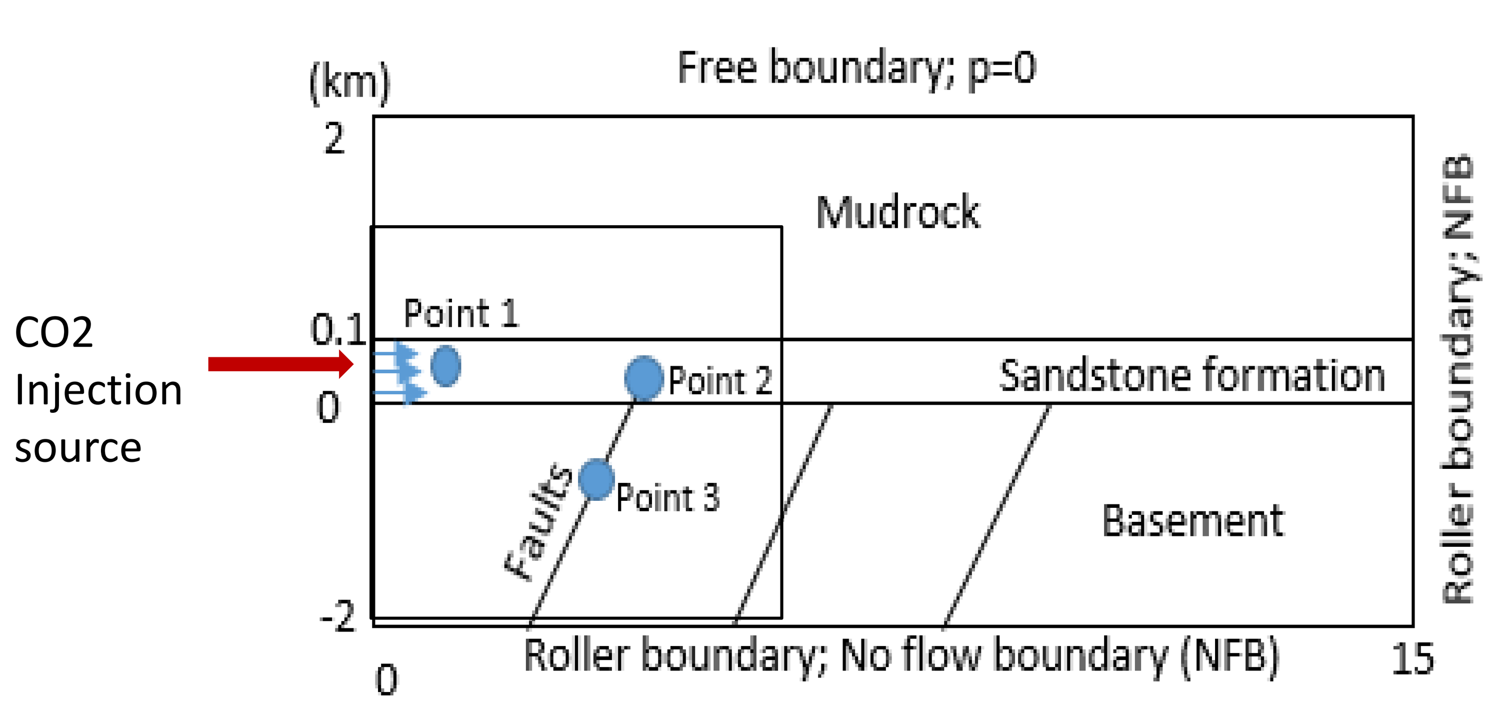


Figure 2. Schematic of Three-Layer Geometry along with Faults

RESULTS:

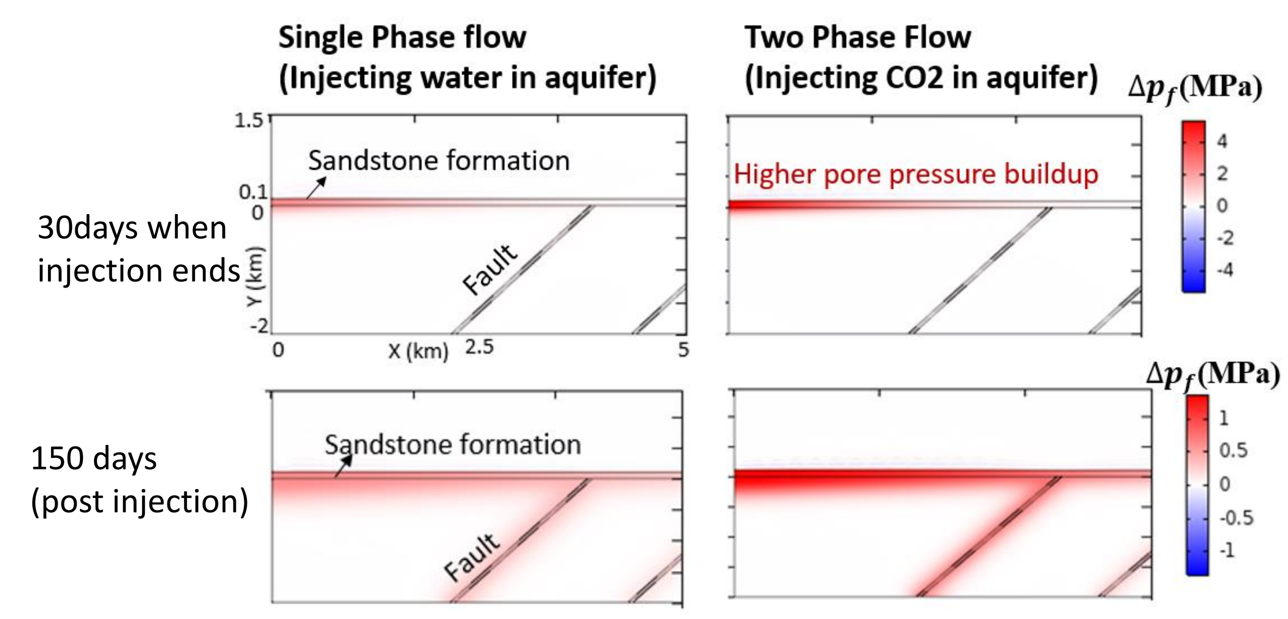


Figure 3. Higher pore pressure build-up in two-phase flow as compared to single phase

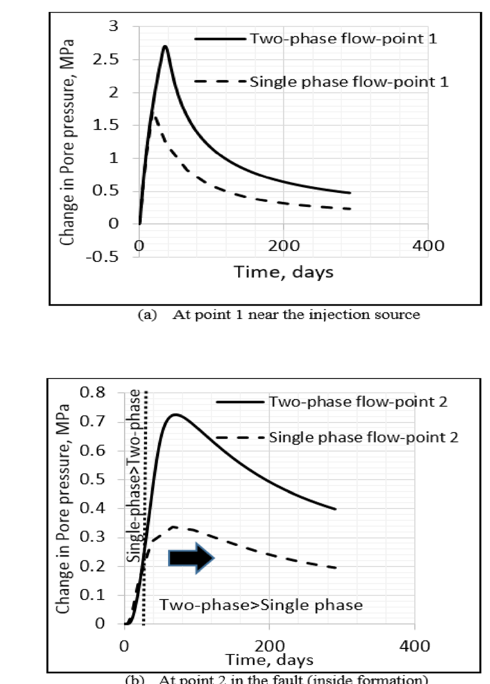


Figure 4. Comparison of pore pressure at points 1 & 2

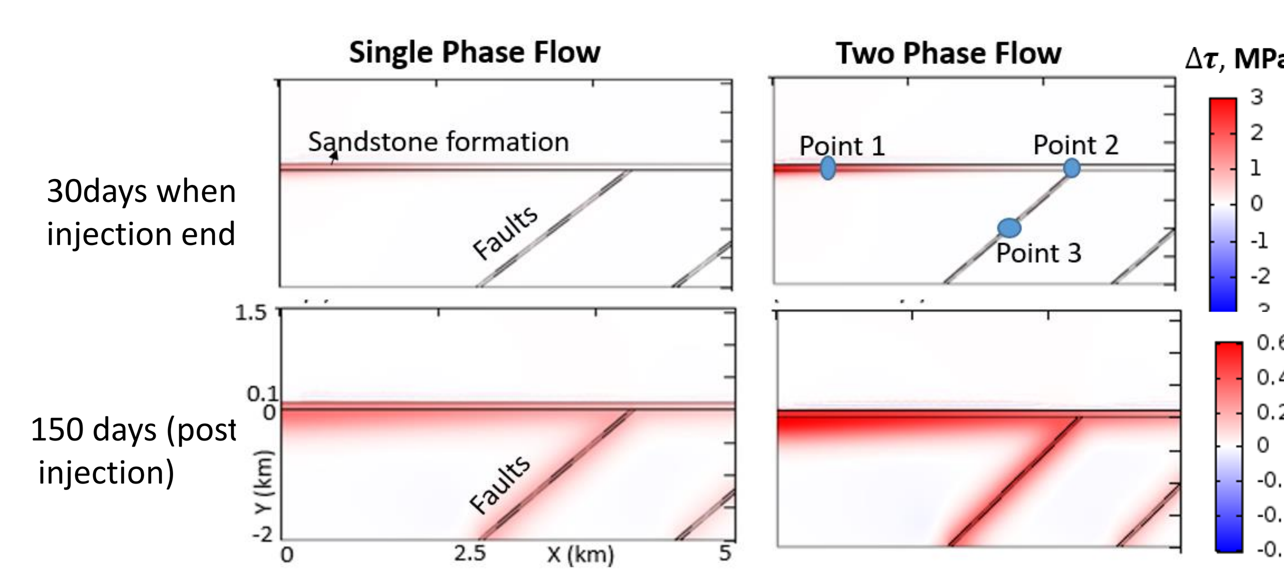


Figure 4. Higher Coulomb stress changes in two-phase flow as compared to single-phase

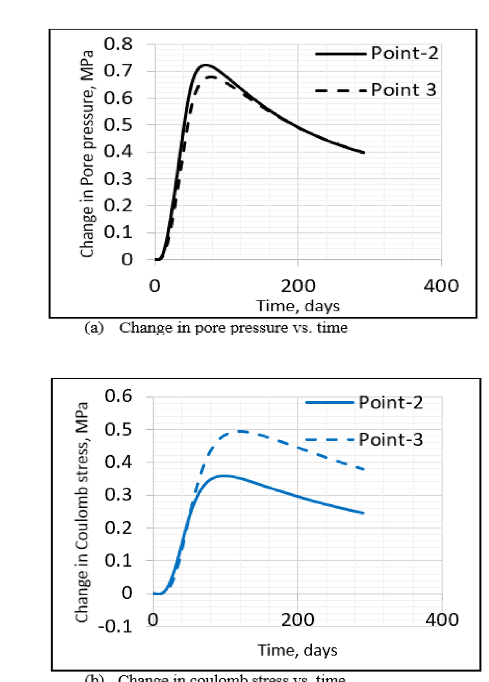
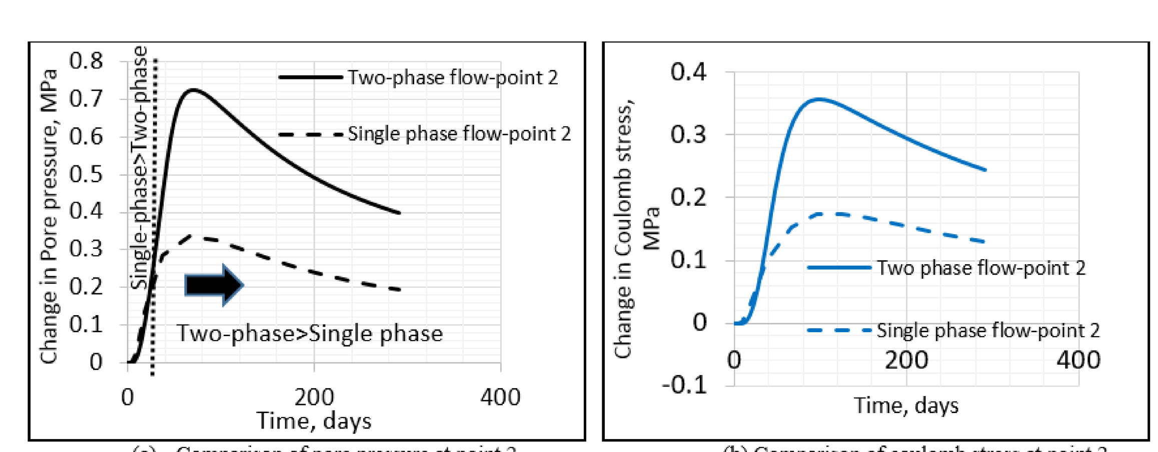


Figure 5. Higher pore pressure at point 2, whereas higher coulomb stress at point 3



- Coulomb stress resembles pore pressure change
- Initially slow diffusion causes pressure of two-phase <single-phase
- Later, diffusion of high pore pressure buildup results in two-phase>single phase

Figure 6. Comparison of pore pressure and coulomb stress changes at point 2

CONCLUSIONS:

- ❑ Two phase flow simulation predicts higher pore pressure buildup and (thereby higher coulomb stress) in the formation and in faults as compared to that of single phase flow simulation due to slow pressure diffusion owing to lower hydraulic diffusivity (of two-phase flow)
- ❑ Single phase flow condition can potentially underestimate the injection induced seismicity
- ❑ Coulomb stress at faults in basement is higher than at faults in the formation

REFERENCES:

1. Jaeger, J. C., Cook, N. G., & Zimmerman, R., *Fundamentals of rock mechanics*, John Wiley & Sons (2009).
2. Chang, K. W., & Segall, P., Injection-induced seismicity on basement faults including poroelastic stressing. *Journal of Geophysical Research: Solid Earth*, *121*(4), 2708-2726 (2016).
3. Kim. S., and Hosseini, S., Study on the Ratio of Pore-Pressure/Stress Changes During Fluid Injection and its Implications for CO2 Geologic Storage. *Journal of Petroleum Science and Engineering*, 149, 138-150 (2017).