Pressure Measurements and Buildup Analysis at the Frio Brine Pilot

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Outline

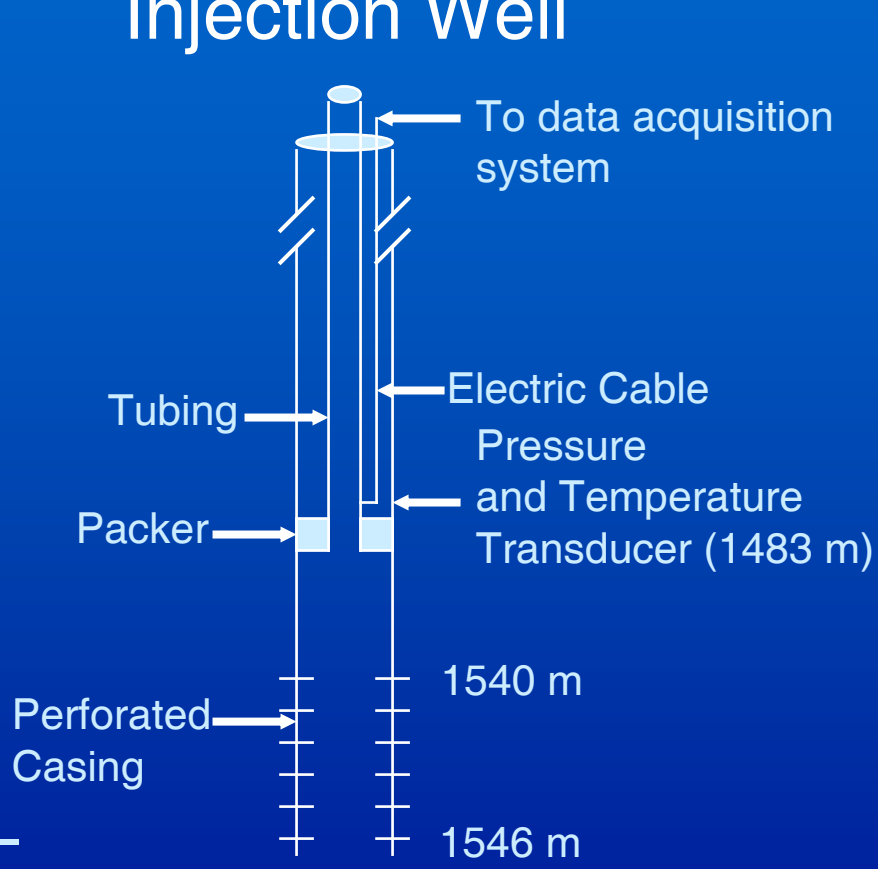
- Purposes for pressure transient monitoring
- Pressure transient data collection and evaluation
- Physical processes and implications for pressure buildup during multiphase flow of CO_2 and water
- Approximate analytical solution for calculating pressure buildup at CO_2 injection wells
- Data inversion for parameter estimation
- Lessons learned

Purposes for Pressure Transient Data Collection

- Measurement of field-scale k and ϕc_t
  - Detection of free phase methane
- Estimation of injection pressures at CO_2 injection wells
- Comparison between single-phase and multiphase flow
- Estimation of multi-phase flow parameters
- Detection of formation plugging or permeability enhancement

Data Collection

- Pre-CO_2 injection pumping test
  - ~ 24 hours
- Recirculating water pumping test
  - ~ 14 days
- CO_2 injection test
  - ~ 10 days, with 4 shut-in periods



Downhole pressure and temperature data collection

Pressure data provided by Sandia Technology

Data Collection

- Pre-CO_2 injection pumping test
  - ~ 24 hours
- Recirculating water pumping test
  - ~ 14 days
- CO_2 injection test
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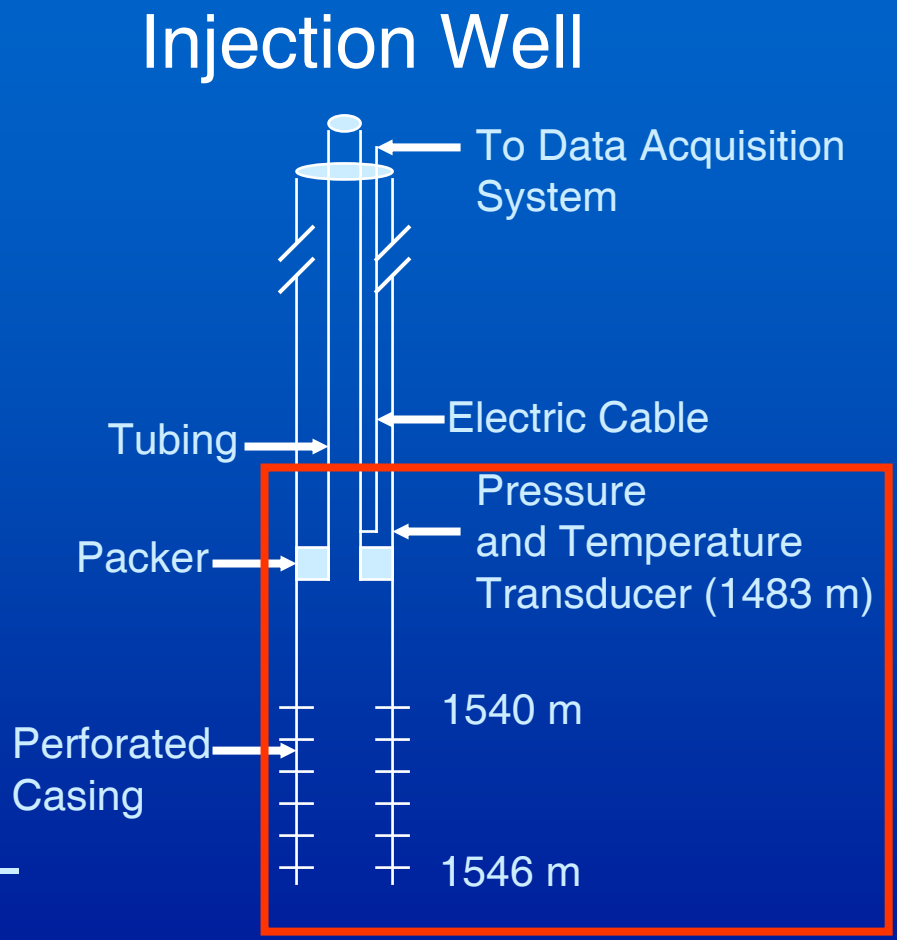


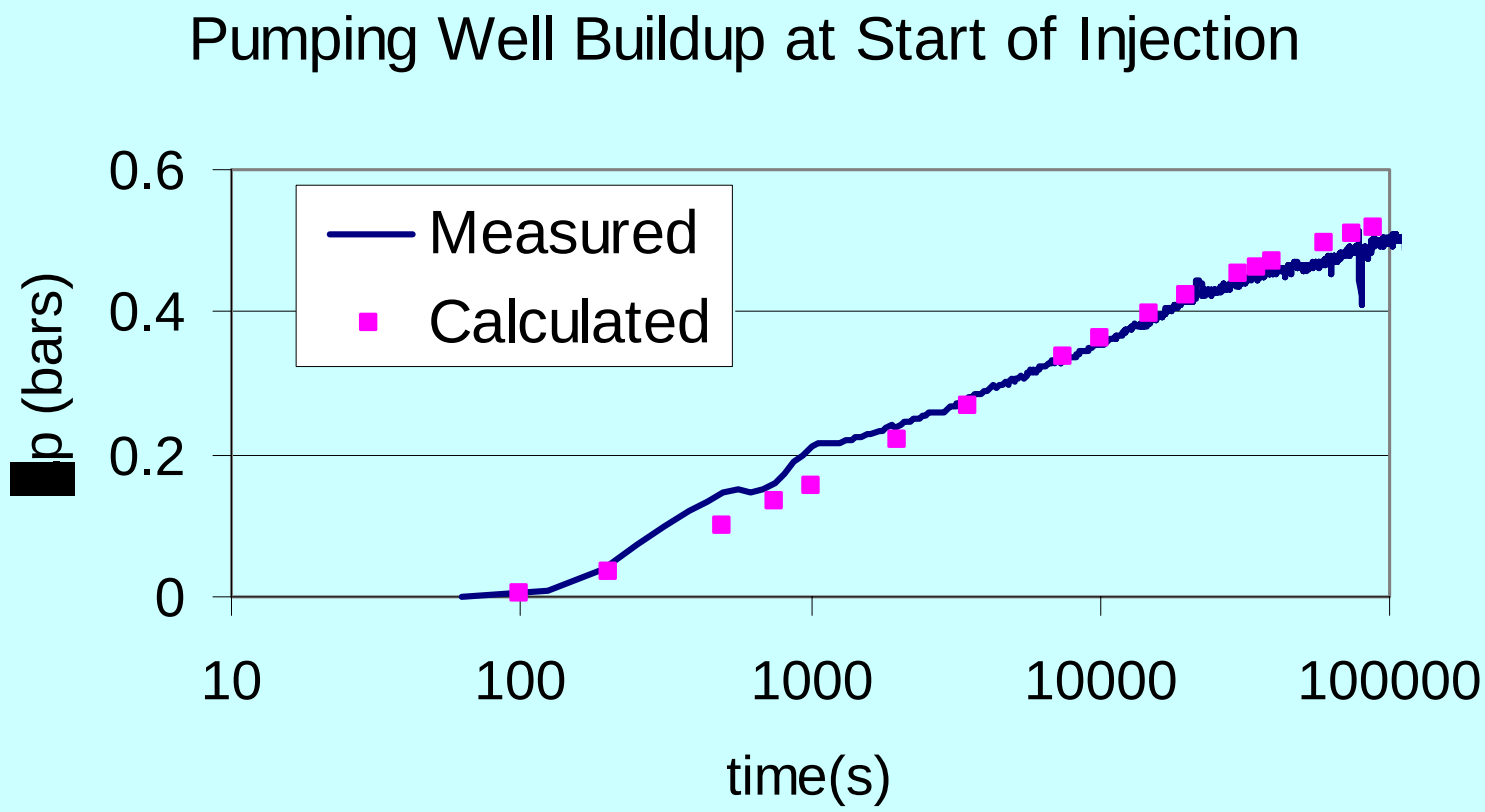
Downhole pressure and temperature data collection

Pre-CO_2 Injection Test

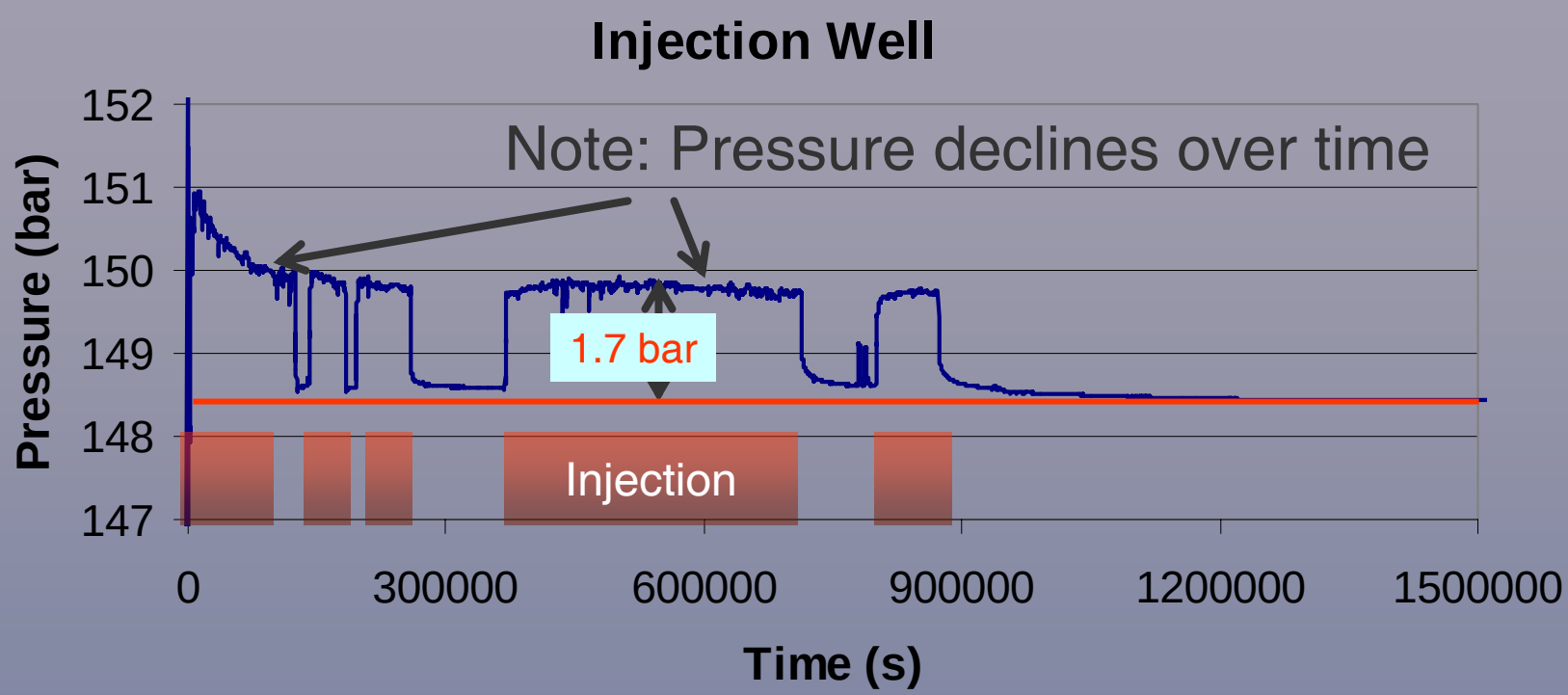
K = 2.1 D

$\phi ch = 1.1\ 10^{-8}$ m/Pa

- Confirms laboratory k data
- No free methane
- No hydrologic boundaries



Pressure Buildup During CO_2 Injection



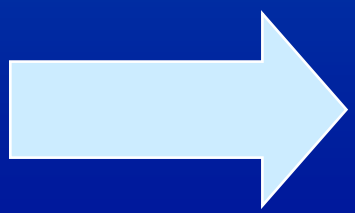
Injectivity

Injectivity = $Q/\Delta p$

$Q \sim 3$ kg/s

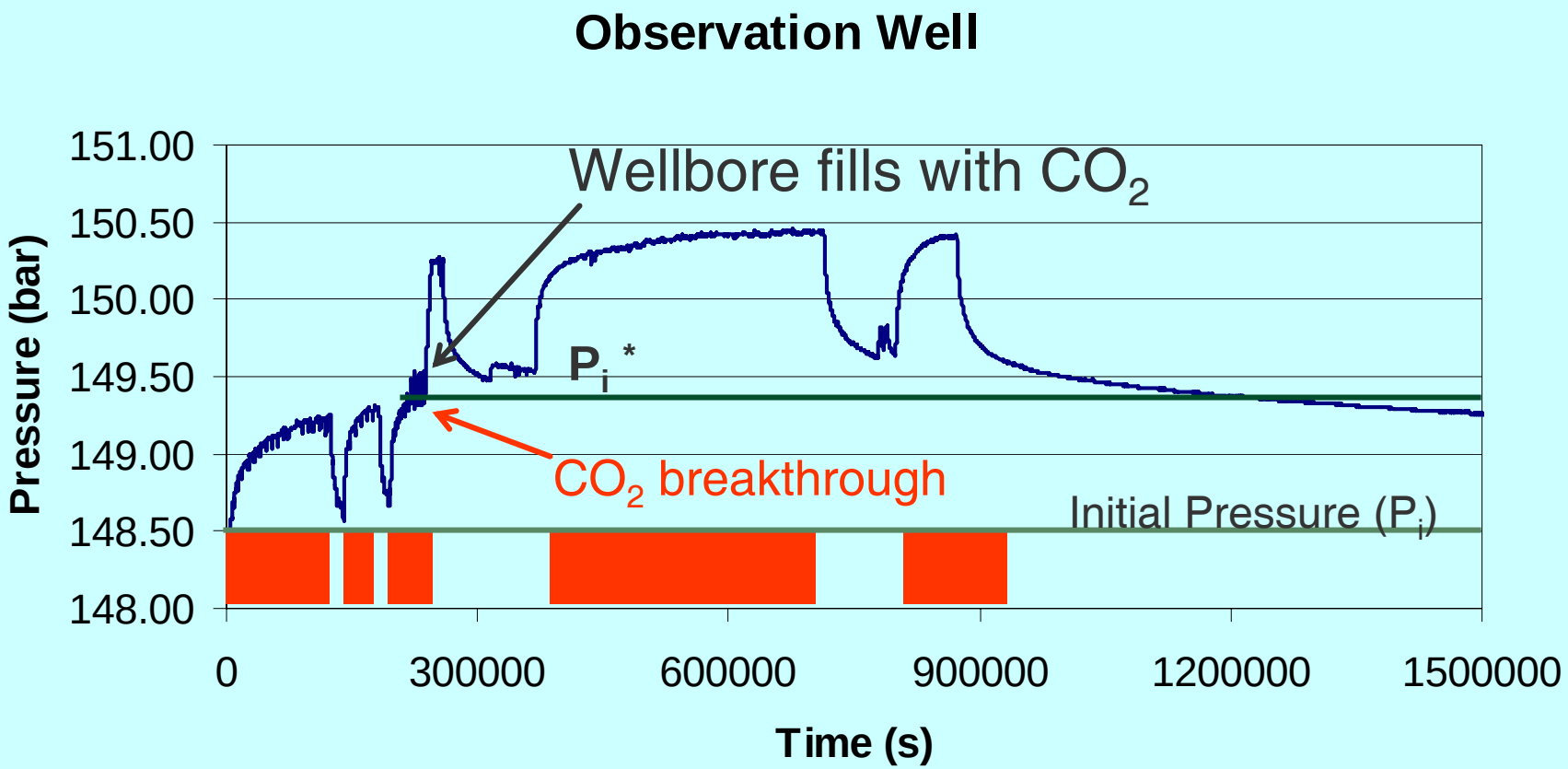
$\Delta p = 1.7$ bar

Injectivity = 1.8 kg/s/bar



Very high injectivity
18 bar pressure increase for 1 Mt/year
Well below fracture gradient

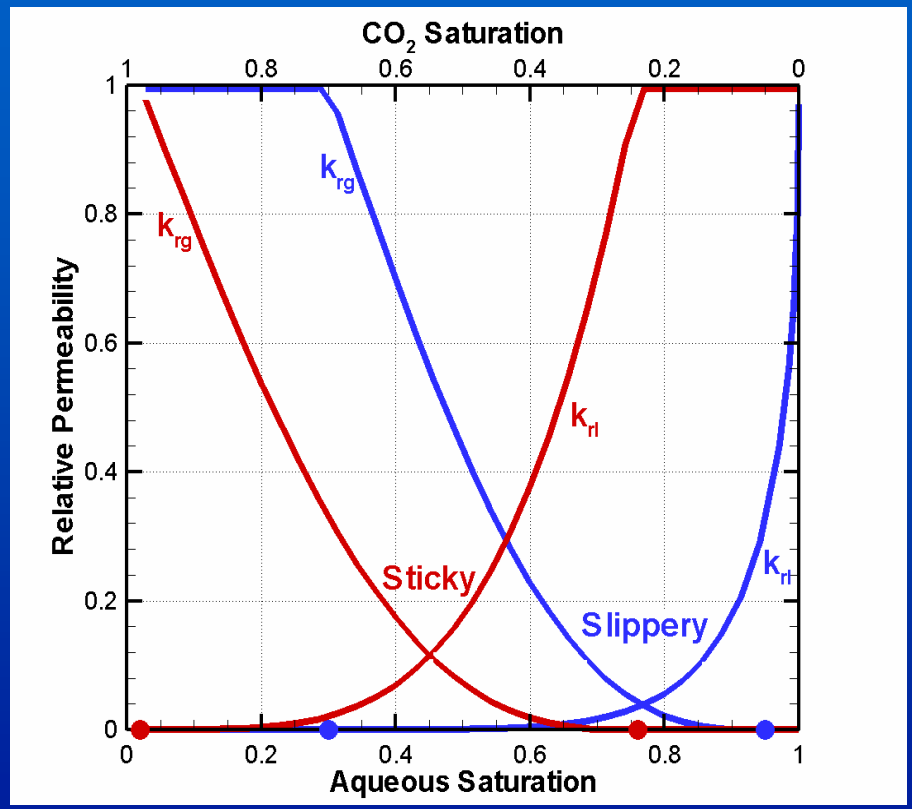
Pressure Buildup During CO_2 Injection



Physical Processes During Injection of CO_2 into Water

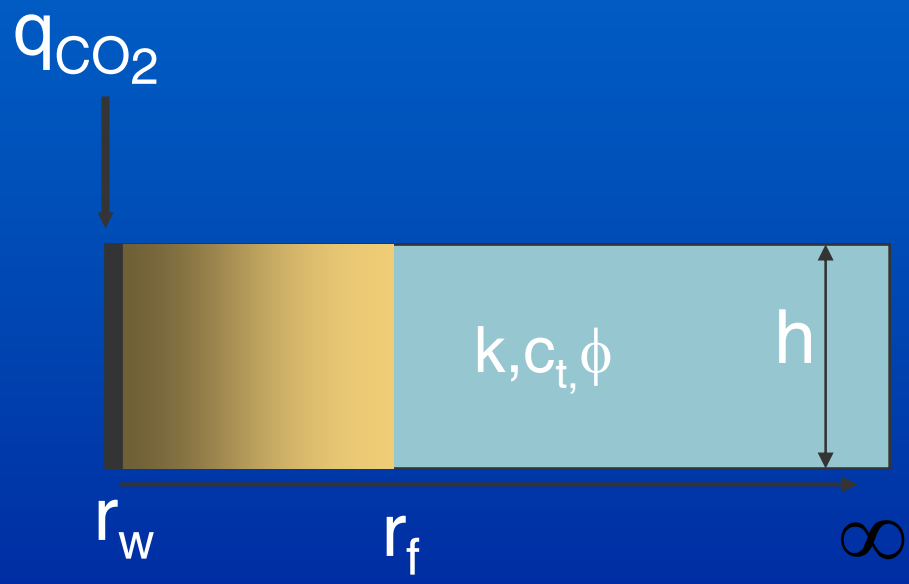
- Immiscible displacement of water by CO_2
  - Relative permeability effects
  - Capillary pressure effects
  - Adverse mobility ratio

    $\mu_{water} >> \mu_{CO_2}$
- Pressure and temperature dependent CO_2 viscosity and density
- Partitioning of CO_2 into the water phase
- Partitioning of water into the CO_2 phase



Approximate Analytical Solution For Pressure Buildup

- Assumptions
  - Buckley-Leverett type displacement
  - Vertical equilibrium Horizontal reservoir
  - Homogeneous reservoir
  - Neglect capillary pressure (not required)
  - Slightly compressible fluid
- Based on technique developed by Benson (1984, 1987)



Pressure Buildup Solution

- Solution consists of two components
  - Steady state pressure buildup behind the CO_2 front ($\Delta p_{s.s.}$)
  - Pressure transient buildup outside of the front (Δp_t)

$$\Delta p(r_w,t) = \Delta p_{s.s.}(r_w,t) + \Delta p_t(r_f,t)$$

$$\Delta p_{s.s.}(r_w,t) = \frac{q_{CO_2}}{2\pi kh}\int_{r_w}^{r_f} \frac{f_{CO_2}(r,t)}{\rho_{CO_2}(r,t)}\frac{\mu_{CO_2}(r,t)}{k_{r_{CO_2}}(r,t)}\frac{dr}{r}$$

$$\Delta p_t(r_f,t) = \frac{q_{CO_2}\mu_w}{4\pi kh\bar{\rho}_{CO_2}} Ei\left(\frac{r_f^2\phi\mu_w c_t}{4kt}\right)$$

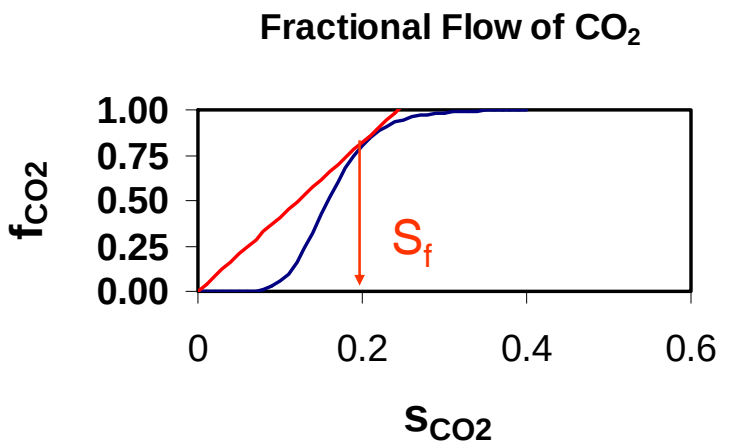
Approximate Analytical Solution

$$\Delta p(r_w,t) = \Delta p_{s.s.}(r_w,t) + \Delta p_t(r_f,t)$$

$$\Delta p_{s.s.}(r_w,t) = \frac{q_{CO_2}\bar{\mu}_{CO_2}}{2\pi\bar{\rho}_{CO_2}kh}\left[\frac{f_{CO_2}}{k_{r_{CO_2}}}\Big|_{r_w}\ln\frac{r_f}{r_w} + \left(\frac{f_{CO_2}}{k_{r_{CO_2}}}\Big|_{r_f} - \frac{f_{CO_2}}{k_{r_{co2}}}\Big|_{r_w}\right)\cdot\left(1-\frac{r_w}{r_f-r_w}\ln\frac{r_f}{r_w}\right)\right]$$

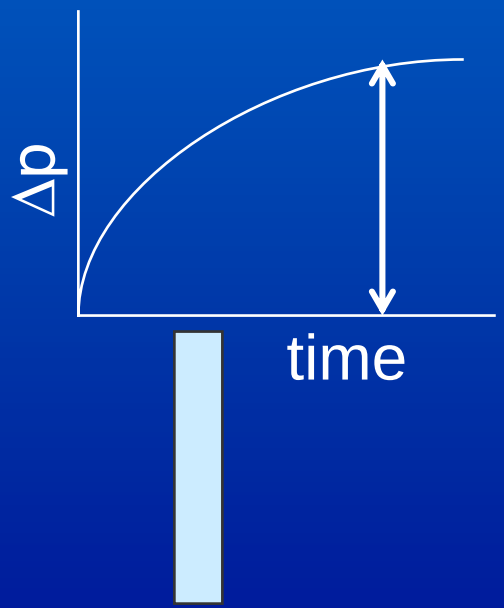
$$\Delta p_t(r_f,t) = \frac{q_{CO_2}\mu_w}{4\pi\bar{\rho}_{CO_2}kh}\left[\ln\frac{kt}{\phi\mu_w c_t r_f^2} + .80907\right]$$

$$r_{s_{CO_2}} = \sqrt{\frac{Qt}{\pi\phi h}\frac{\partial f_{CO_2}}{\partial s_{CO_2}}\Big|_{s_{CO_2}}}$$

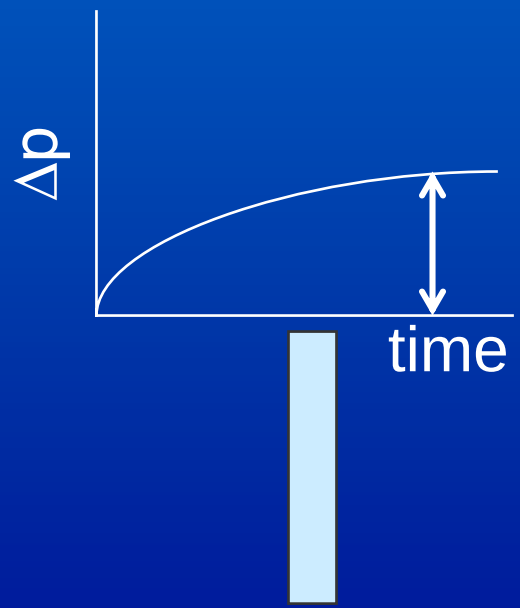


A New Kind of Inversion

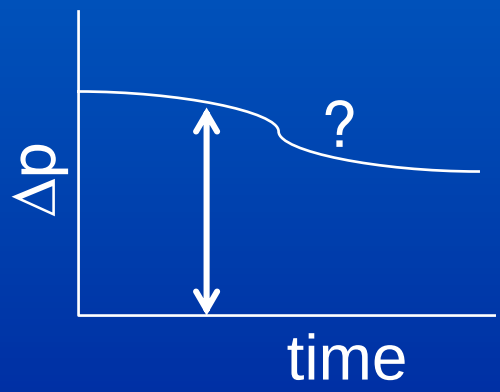
- Needs to be robust under realistic data conditions
- Needs sensitivity to multiphase flow parameters



Injection Well

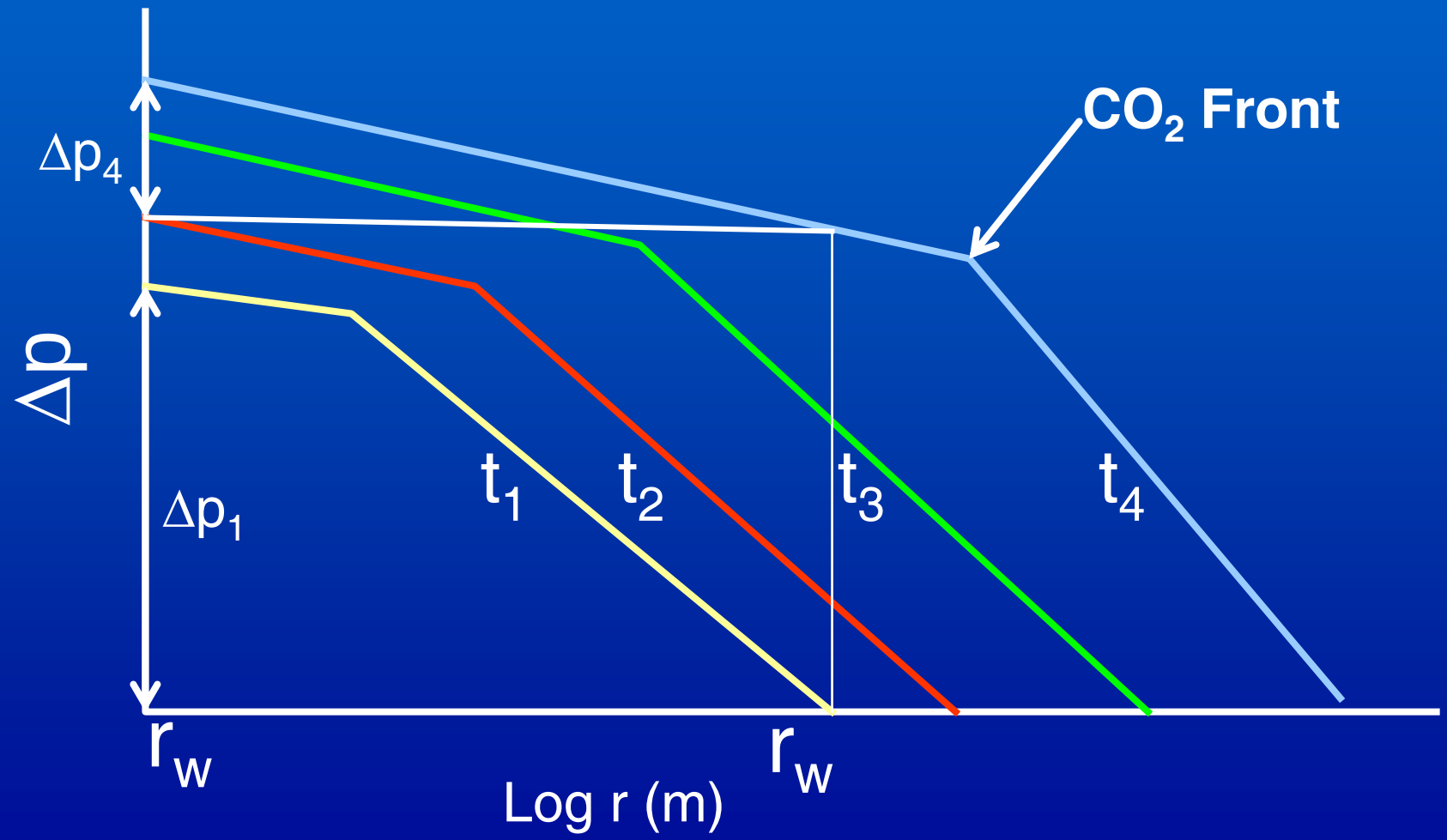


Observation Well

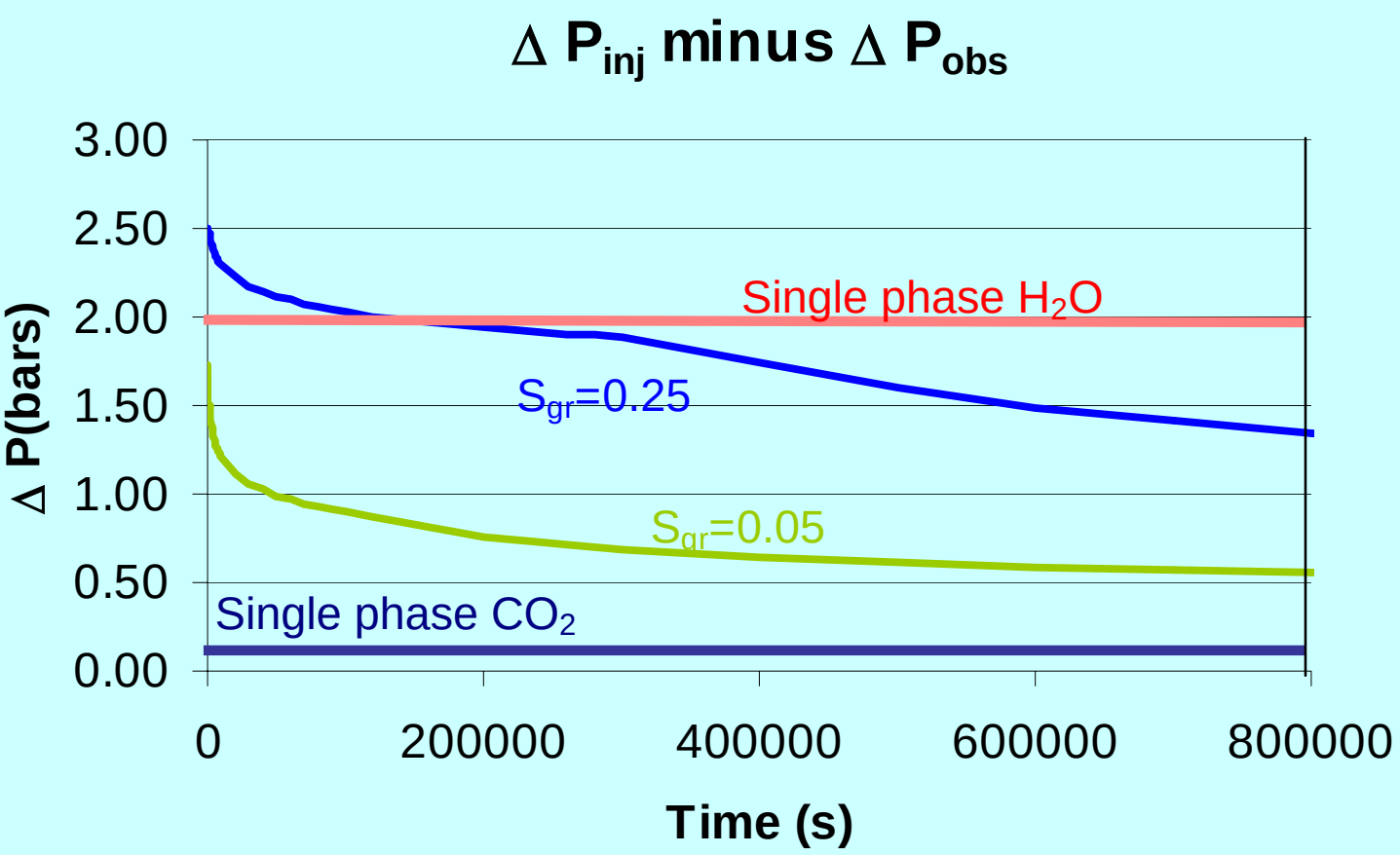


$\Delta p_i(t) - \Delta p_o(t)$

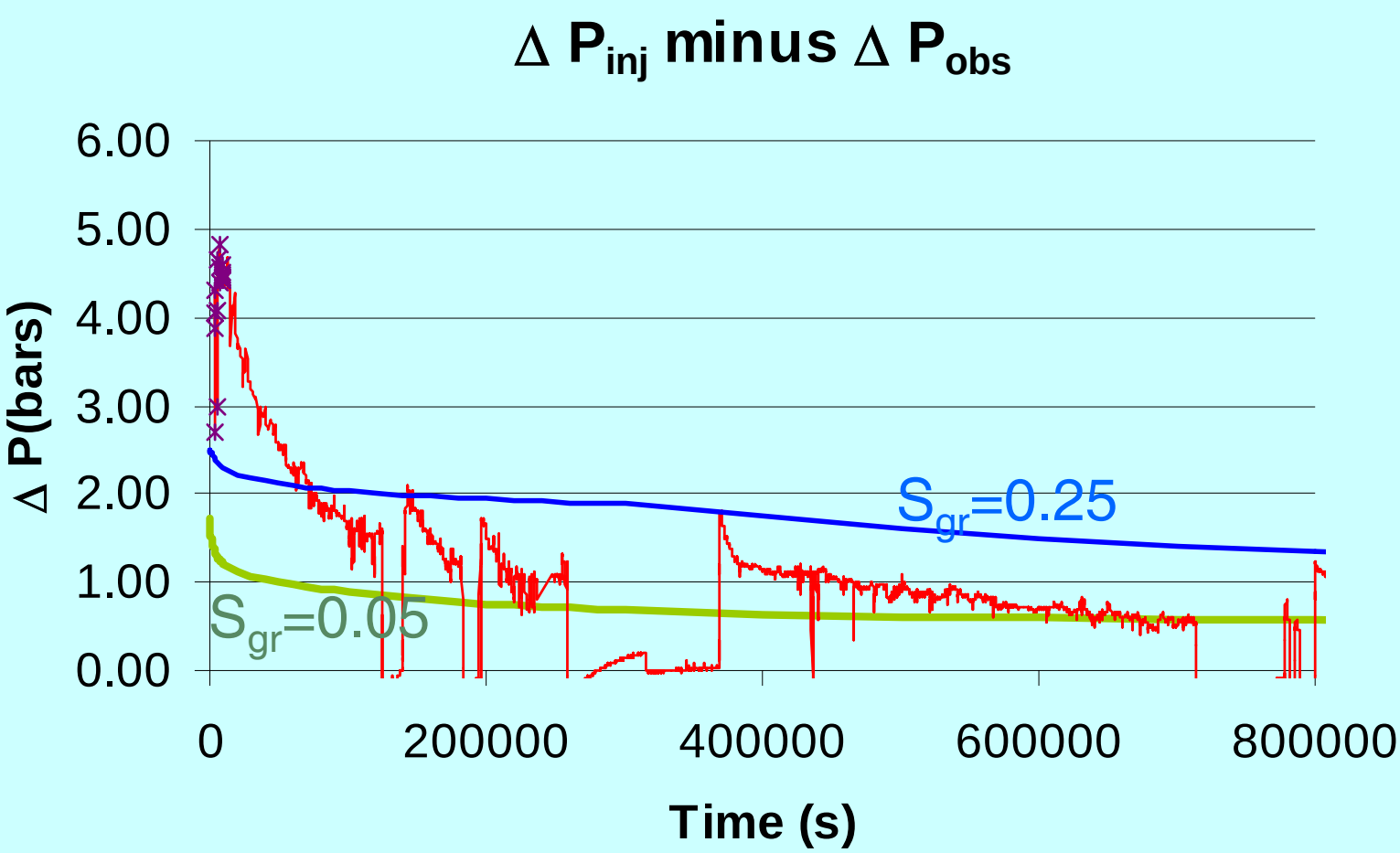
CO_2 Front Propagation and and Spatial Pressure Gradients



Analytical Solution Show High Sensitivity to S_{gr}



Frio Test Data Most Consistent with S_{gr} ~ 0.05



Summary

- Pressure transient tests yield valuable data on injectivity
- New inversion technique may provide field-scale estimates of multi-phase flow parameters
- Inversion of data are consistent with a low residual gas saturation
- Other factors such as changing skin conditions need be addressed
- Future data acquisition should be designed to avoid complications from wellbore fluid dynamics
- Much more work is needed to fully interpret the available data set