Behavior of CO_2 Injection Wells

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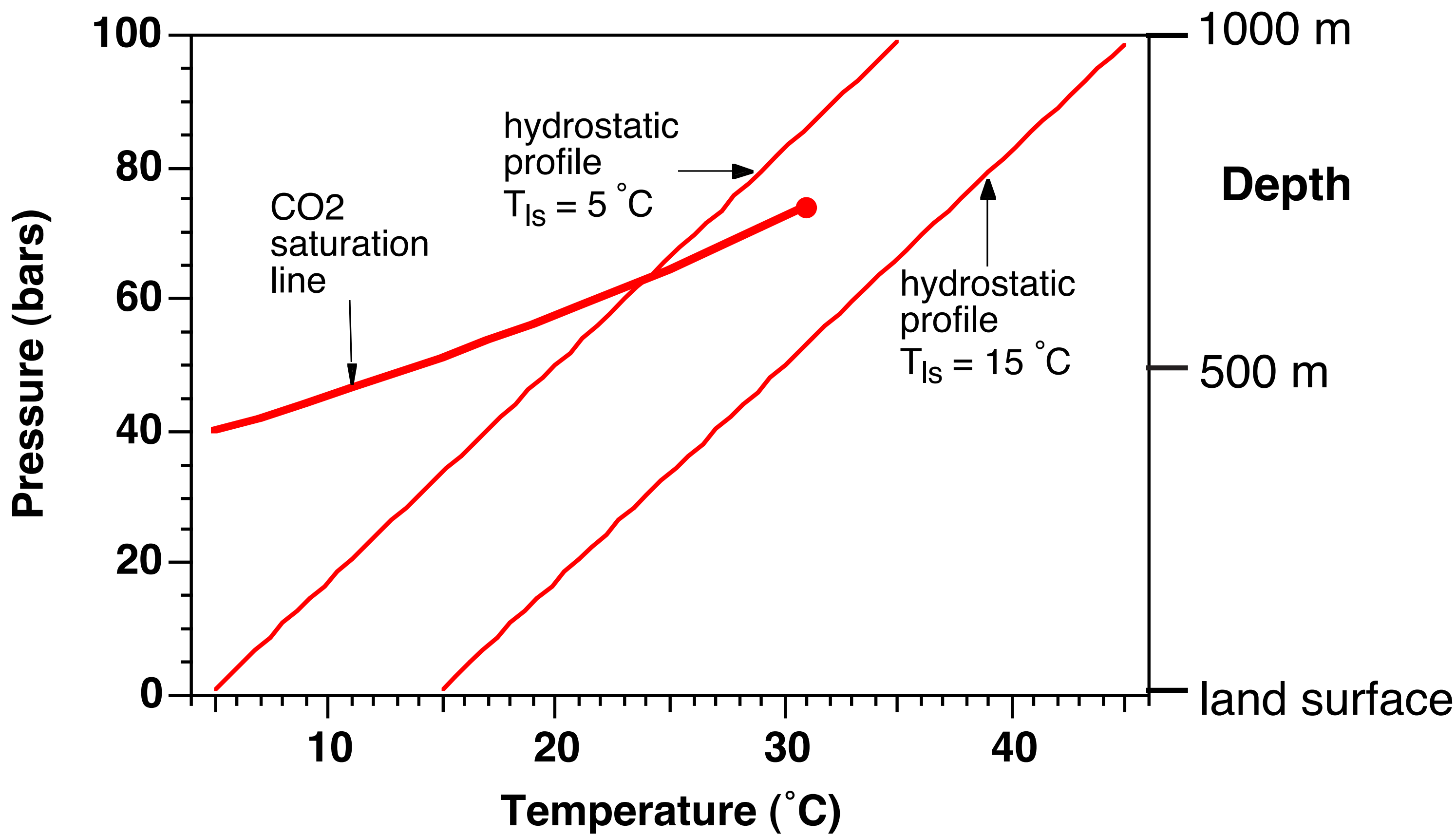
P, T, S - Profile in CO_2 Injection Well

- body force ρg
- frictional pressure drop
- phase change? drag liquid-gas
- thermal effects
    - geothermal gradient
    - (de-)compression
    - heat exchange w/surroundings
    - latent heat
- thermodynamics and thermophysical properties of CO_2
- dissolution in water
- interaction with flow in the reservoir

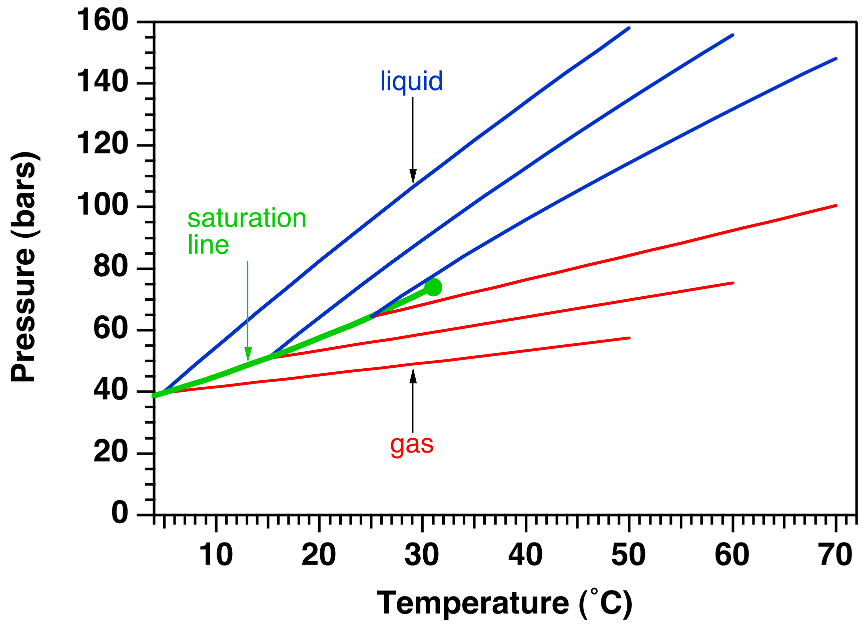
Temperature-Pressure Paths



- Geothermal (temperature) gradient ≈ 30 ˚C/km
- Hydrostatic (pressure) gradient ≈ 100 bar/km
- Average land surface conditions: T_{ls} = 5 ˚C, 15 ˚C; P_{ls} ≈ 1 bar

Static Column of CO_2 in a Geothermal Gradient

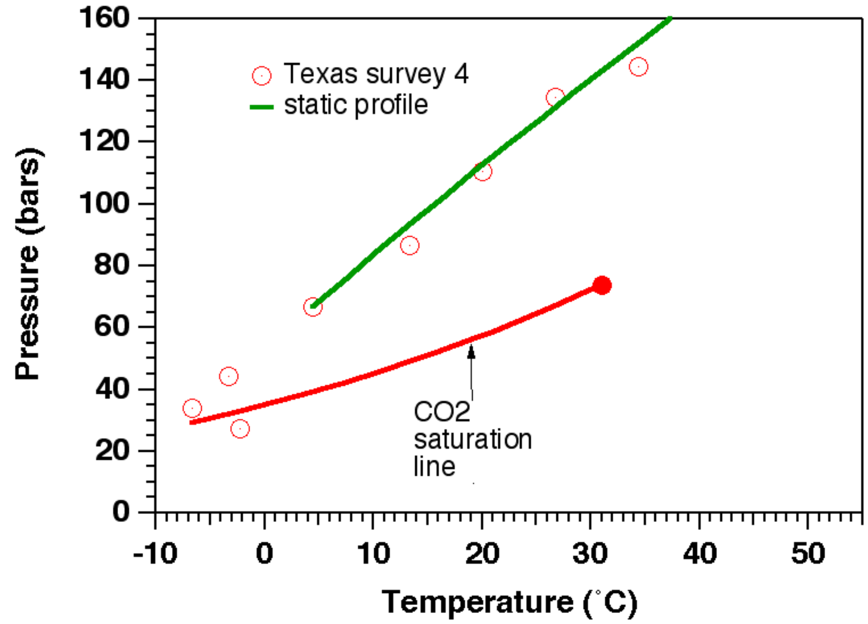
$$T = T_0 + |\nabla T| z \qquad P = P_0 + \int_0^z \rho g \, dz'$$



- when starting with liquid density, ΔP outruns ΔT
- when starting with gas density, ΔT outruns ΔP
- top-down integration is stable; always maintains same phase composition
- bottom-up integration is unstable near saturation line; requires extremely small Δz

North Texas CO_2 Injection Well

- T = 61.1 ˚C @ 1984.2 m depth
- injection rate 2.3 MMscf/d (= 120.1 tonnes/d; 1.39 kg/s)



(survey data from W.A. Flanders, personal communication, 2002)

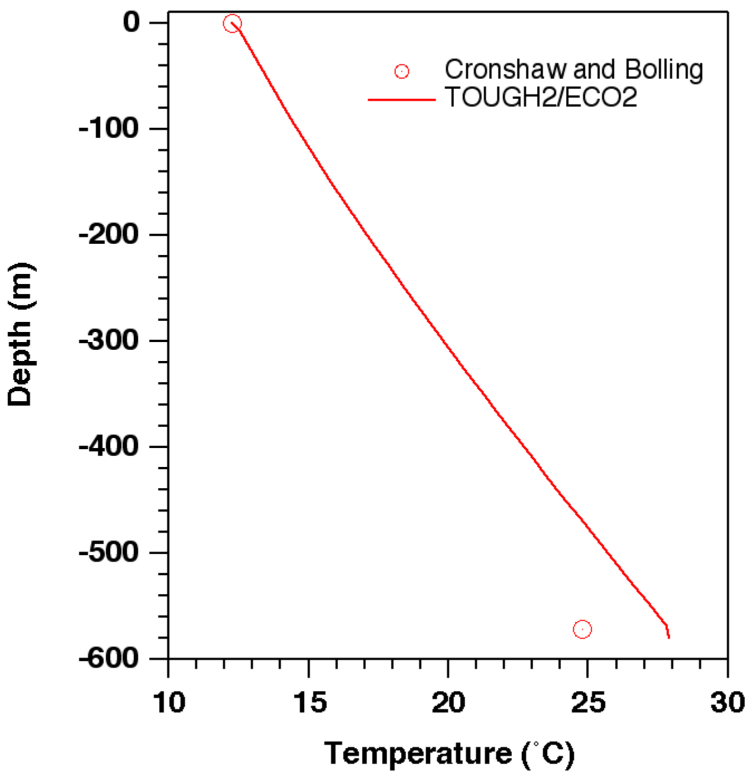
Transient Effects in Unsteady CO_2 Injection

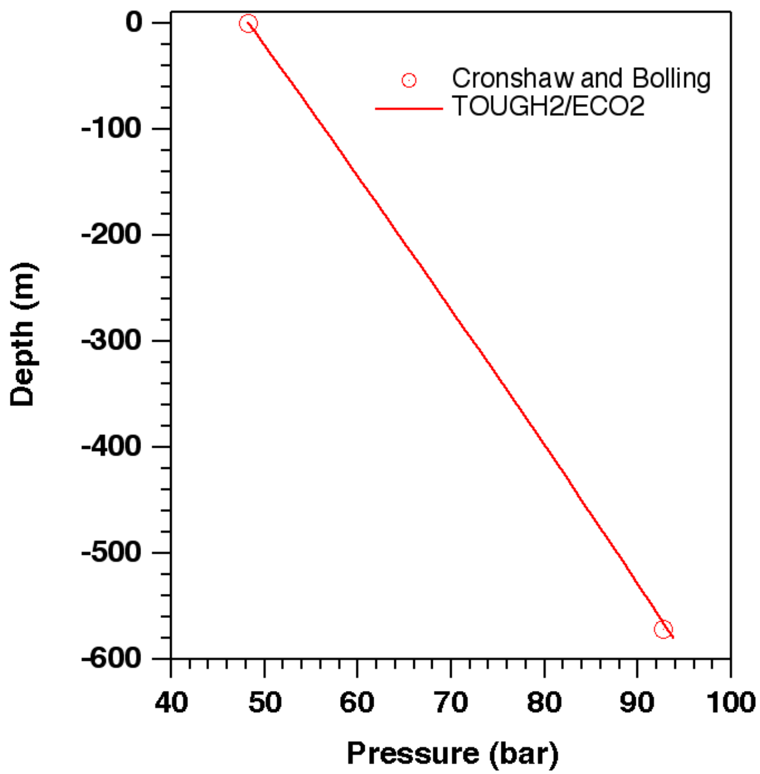
- heat transfer, temperature changes in wellbore
- different two-phase flow regimes (bubble, slug, mist, …)
- for single-phase flow can neglect frictional pressure drop (Carroll and Maddocks, 1999)
- use a reservoir simulator with 2-D R-Z grid: wellbore flow plus heat exchange with formation
- represent wellbore by very large permeability ($\approx 10^5$ darcy)
- TOUGH2/ECO2; test against published (T, P) data
- apply to injection/falloff testing for pilot CO_2 injection project in Frio formation

Test against SPE-10735

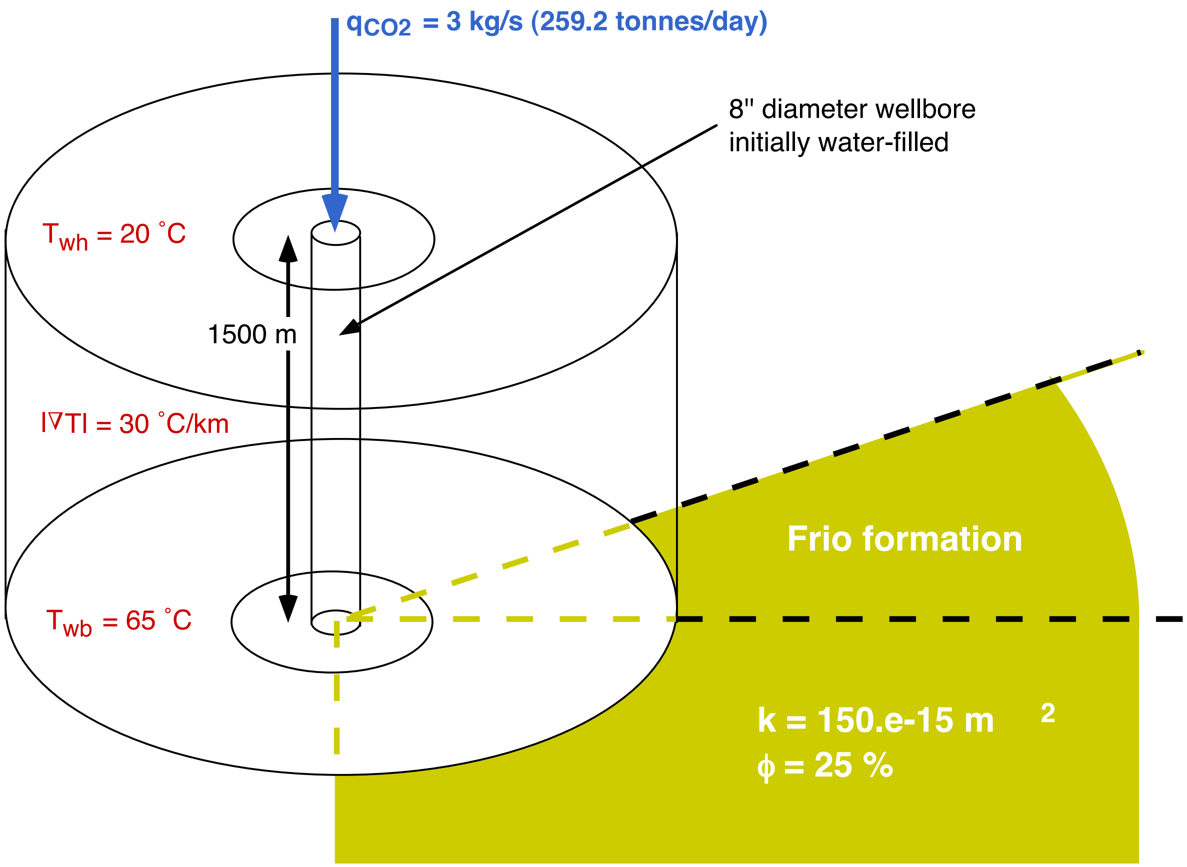
(Cronshaw and Bolling, 1982)

- 1.76'' I.D. tubing to 1875 ft
- inject CO_2 for 7 days at 500 Mscf/d =0.306 kg/s
- temperatures: 62 ˚F @ surface, 96.7 ˚F downhole





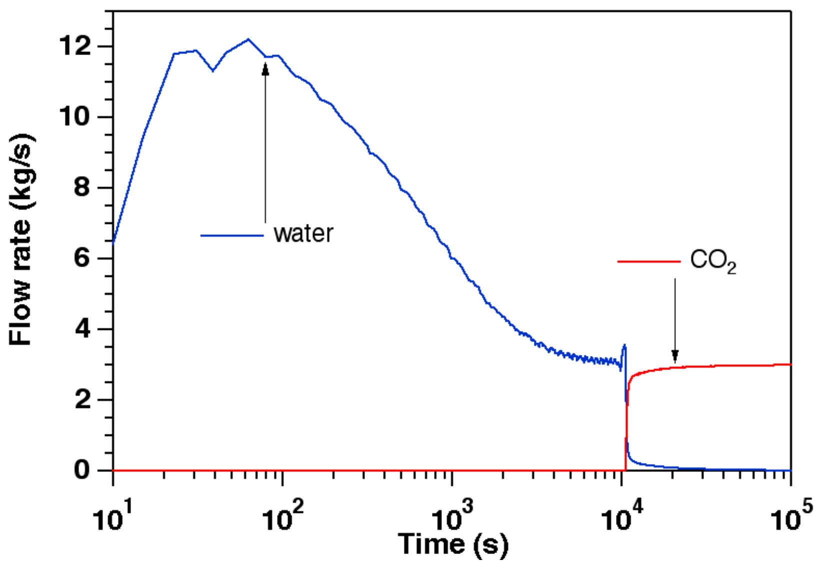
Transient CO_2 Injection into Frio Formation



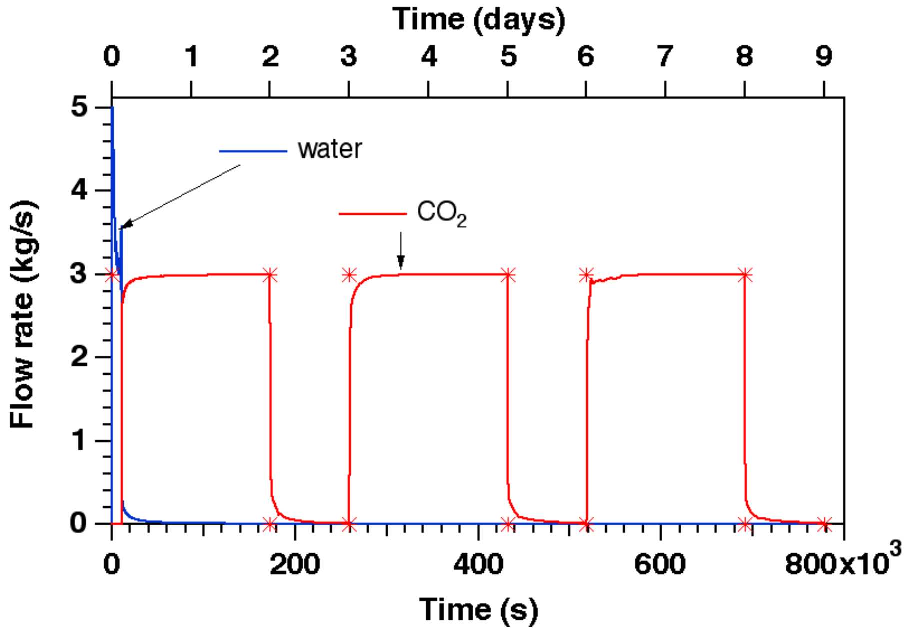
Transient Behavior for CO_2 Injection

- evolve free gaseous CO_2 phase at wellhead
- rapid increase of wellhead pressure;
  reaches 57.32 bars [= P_{sat}(20 ˚C)] within about 20 minutes
- pressurization propagates rapidly down wellbore
- bottomhole (sandface) flow begins within less than one minute, and at initially high rates (≈ 12 kg/s)
- within less than 1 hour, water rate at sandface stabilizes to something near 3 kg/s
- CO_2 reaches sandface in slightly less than 3 hours
- CO_2 is in liquid or supercritical conditions throughout wellbore
- bottomhole rates of CO_2 stabilize at 3 kg/s

Sandface Flowrates

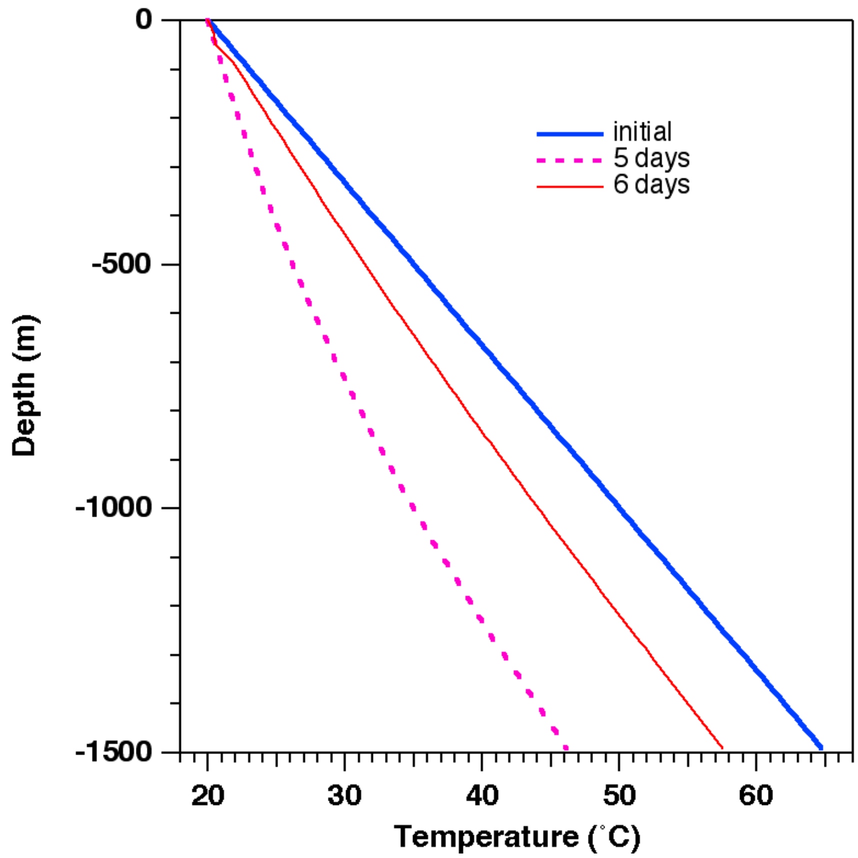


log-time

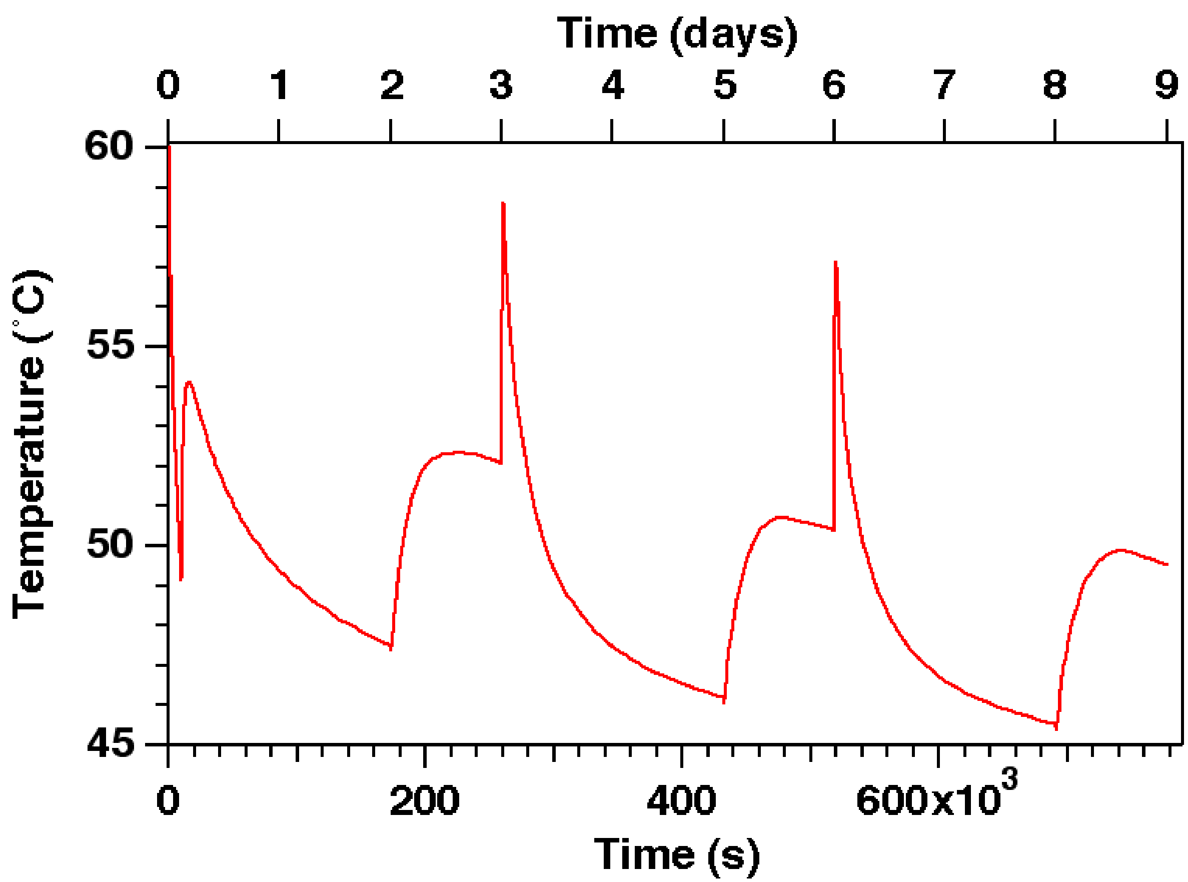


linear time

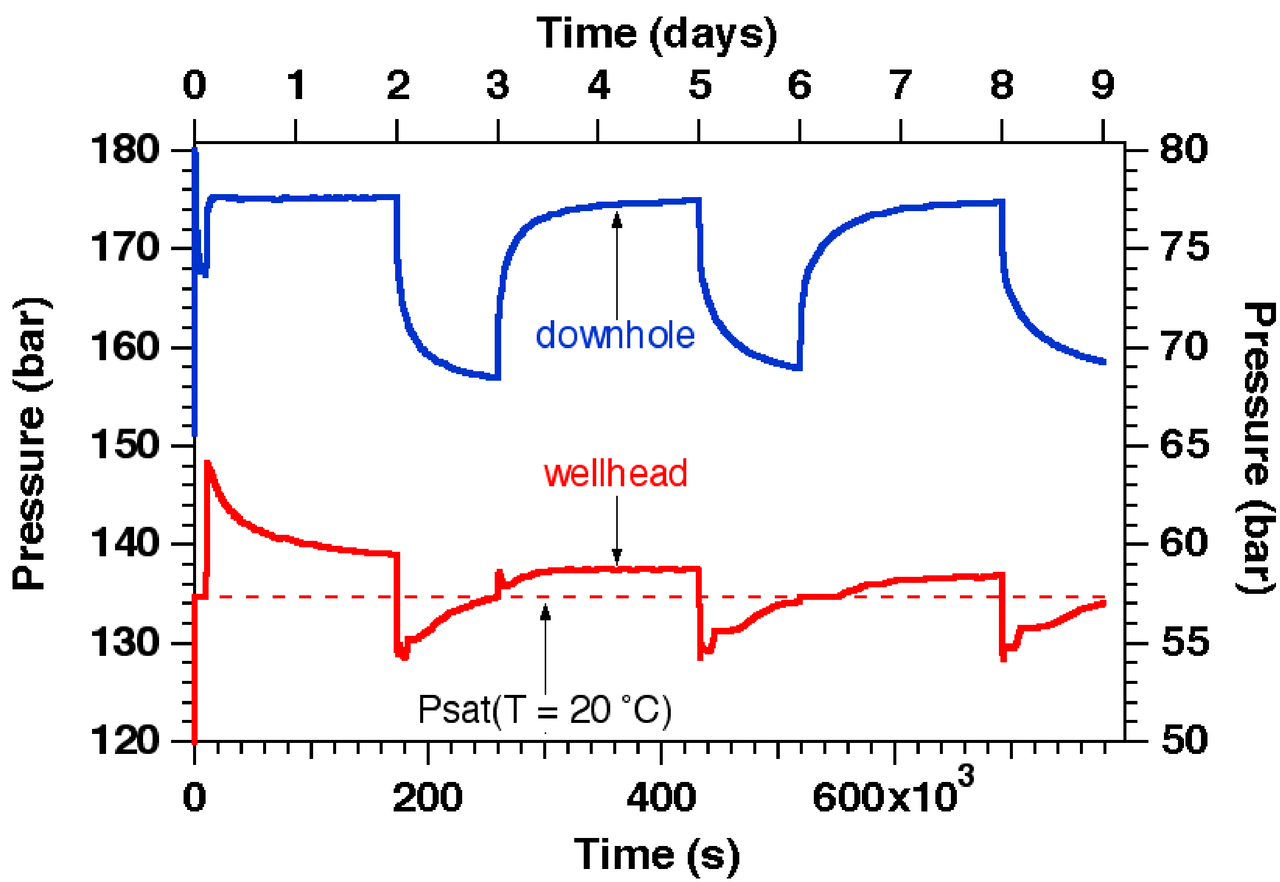
Wellbore Temperature Profiles



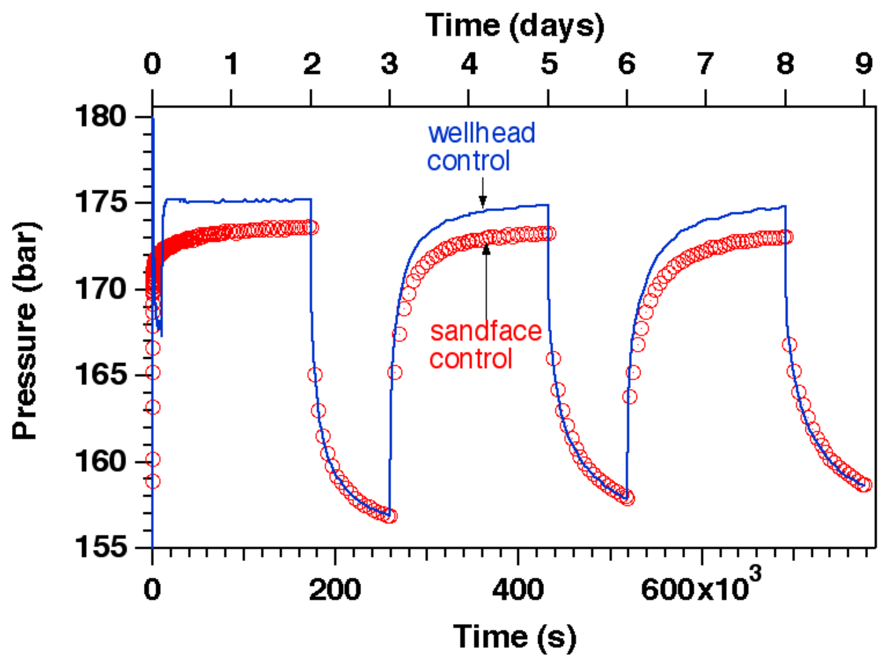
Downhole Temperature Response



Pressure Response

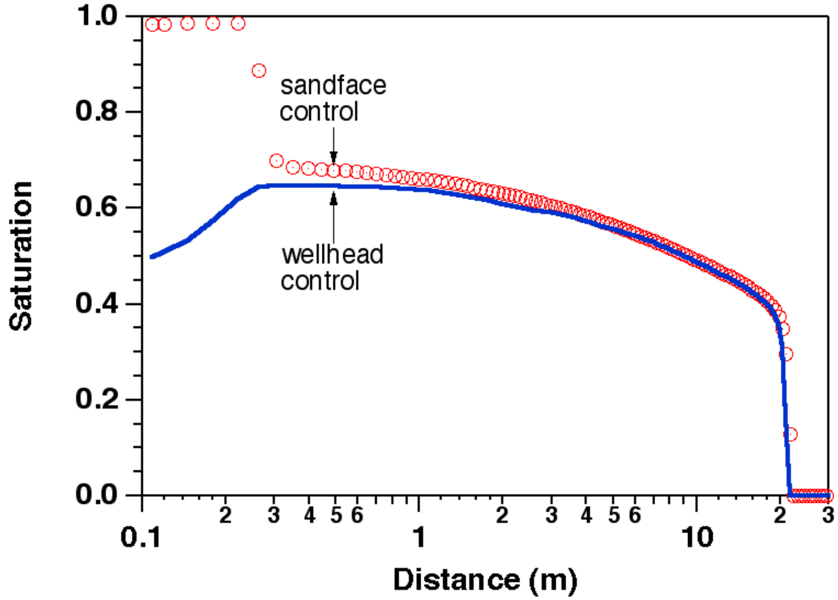


Downhole Pressure Response

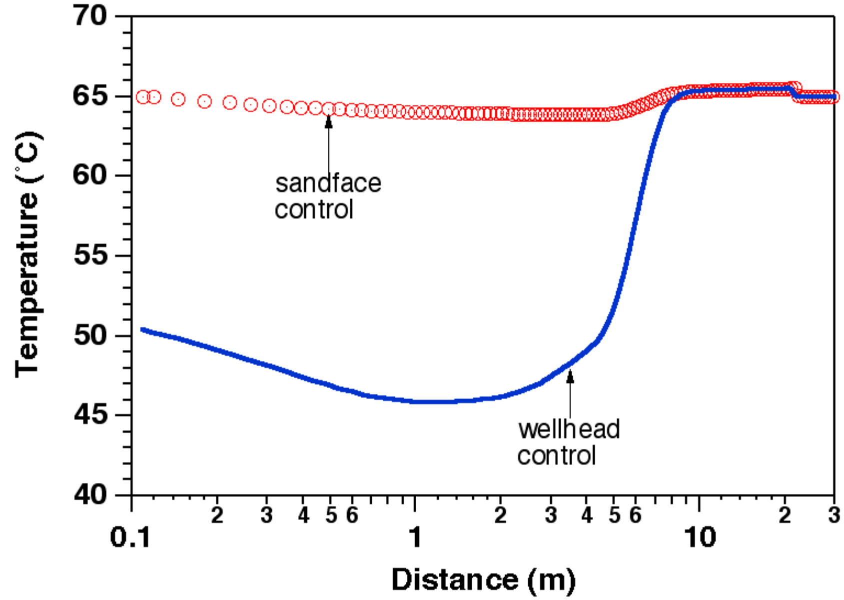


- pressure response to injection is rapid
- wellhead-controlled system initially injects water into the formation
- pressure fall-off is nearly identical for both cases
- wellhead-controlled system shows stronger buildup, acts like it has fluid of lower mobility
- in later cycle, have smaller pressure amplitude

Radial Profiles after 6 Days

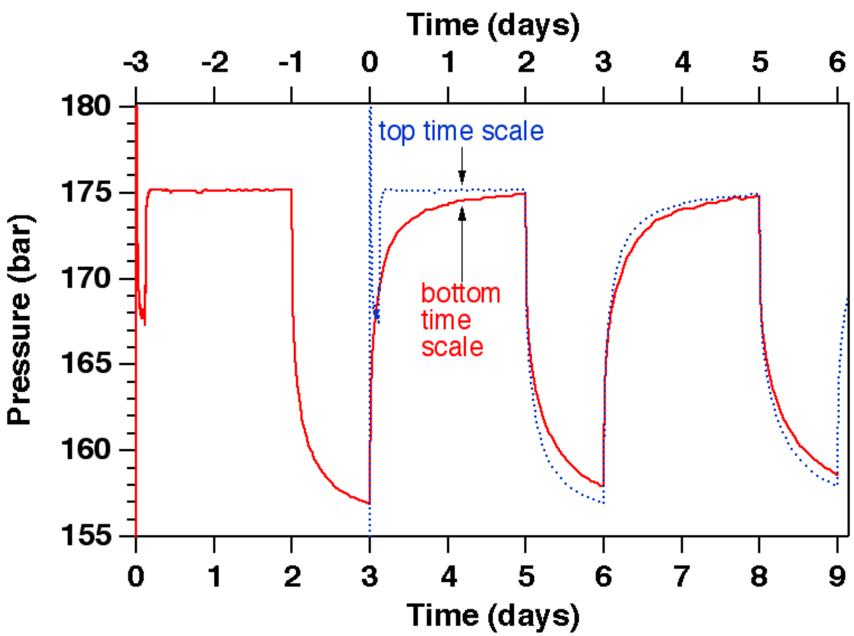


CO2 Saturation

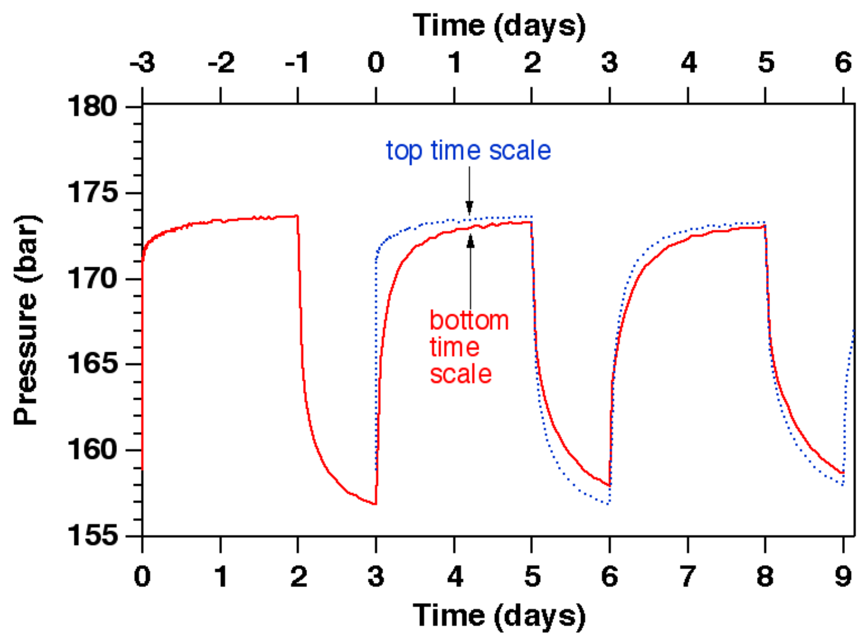


Temperature

Temporal Evolution

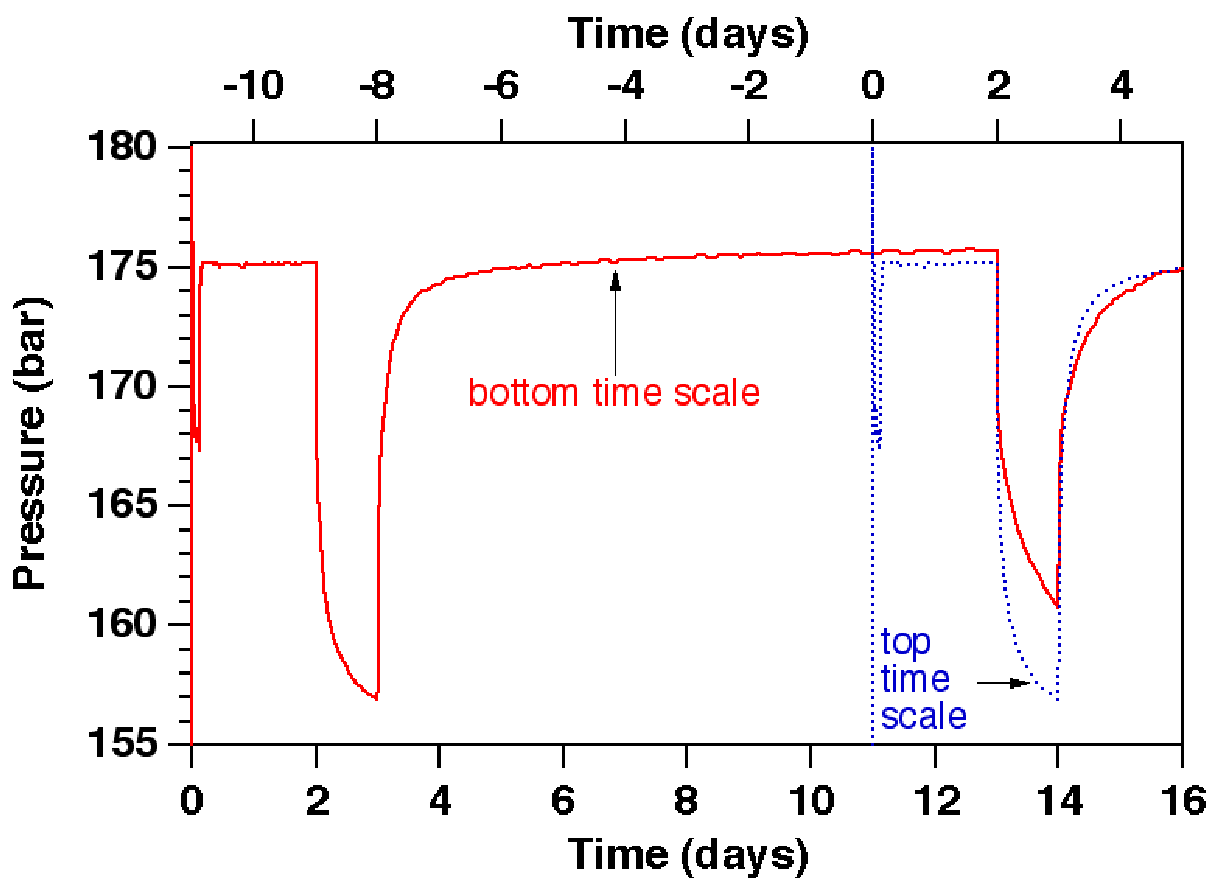


wellhead control



sandface control

Longer Second Injection Period



Concluding Remarks

- frictional pressure drop is expected to be small
- can model wellbore flow with a reservoir simulator; use large permeability (here: $k \approx 10^5$ darcy)
- heat transfer effects are important and need to be represented accurately
- wellbore flow adds considerable complexity
- characterization of CO_2 plume from pressure transients will not be easy
- interest in fluid mixtures: CO_2, SO_x, NO_x, H_2S,…, CH_4

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