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Non-isothermal flow of CO_2 in injection wells: evaluation of different injection modes

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Introduction

During the injection of CO_2, the fluid density within the injection pipe could vary significantly along the well in response to pressure and temperature variations, thus affecting the CO_2 injection rate at the reservoir depth (Figure 1). Flow of CO_2 in non-isothermal wells involves solving the partial differential equations that express energy, mass and momentum conservation (Lu and Connell, 2008).

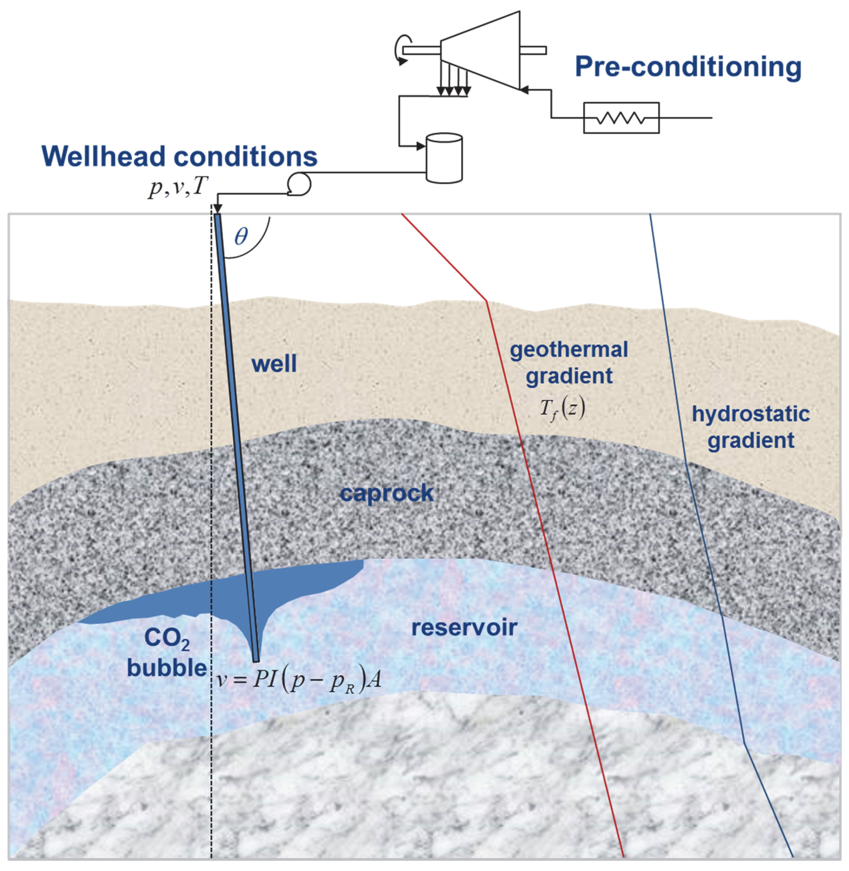
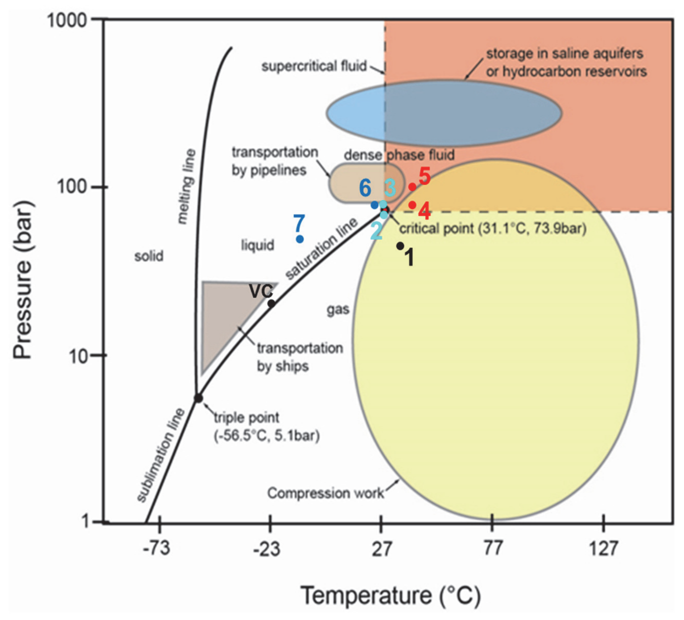


Figure 1. CO_2 flow in injection wells. Higher CO_2 densities are advantageous because are closer to the density of the resident brine, which reduce buoyancy effects in the reservoir and the potential risks of caprock failure and subsequent CO_2 leakages.

Objective

The objective of this work is to evaluate different CO_2 injection strategies (Figure 2) by using a non-isothermal flow model implemented in Comsol.



	Injection conditions	P, MPa	T, °C	Compression work, kW
1	Gas	4.5	35	305.7
2	Gas near CP	7.0	31	245.4
3	Liquid near CP	8.0	31	125.8
4	Supercritical	8.0	40	241.3
5	Supercritical	10.0	40	146.6
6	Liquid	8.0	25	103.1
7	Liquid	5.0	-10	19.66

CP: critical point
VC (vessel conditions): -20 °C, 2.0 MPa

Figure 2. CO_2 phase diagram: pipeline transportation is done in liquid conditions and geological storage stays in SC conditions (left). The table (right) summarizes seven different injections conditions and the associated energy consumption assuming that CO_2 is stored in vessels at -20 ºC and 2.0 MPa and the injection flowrate is 1.0 kg/s.

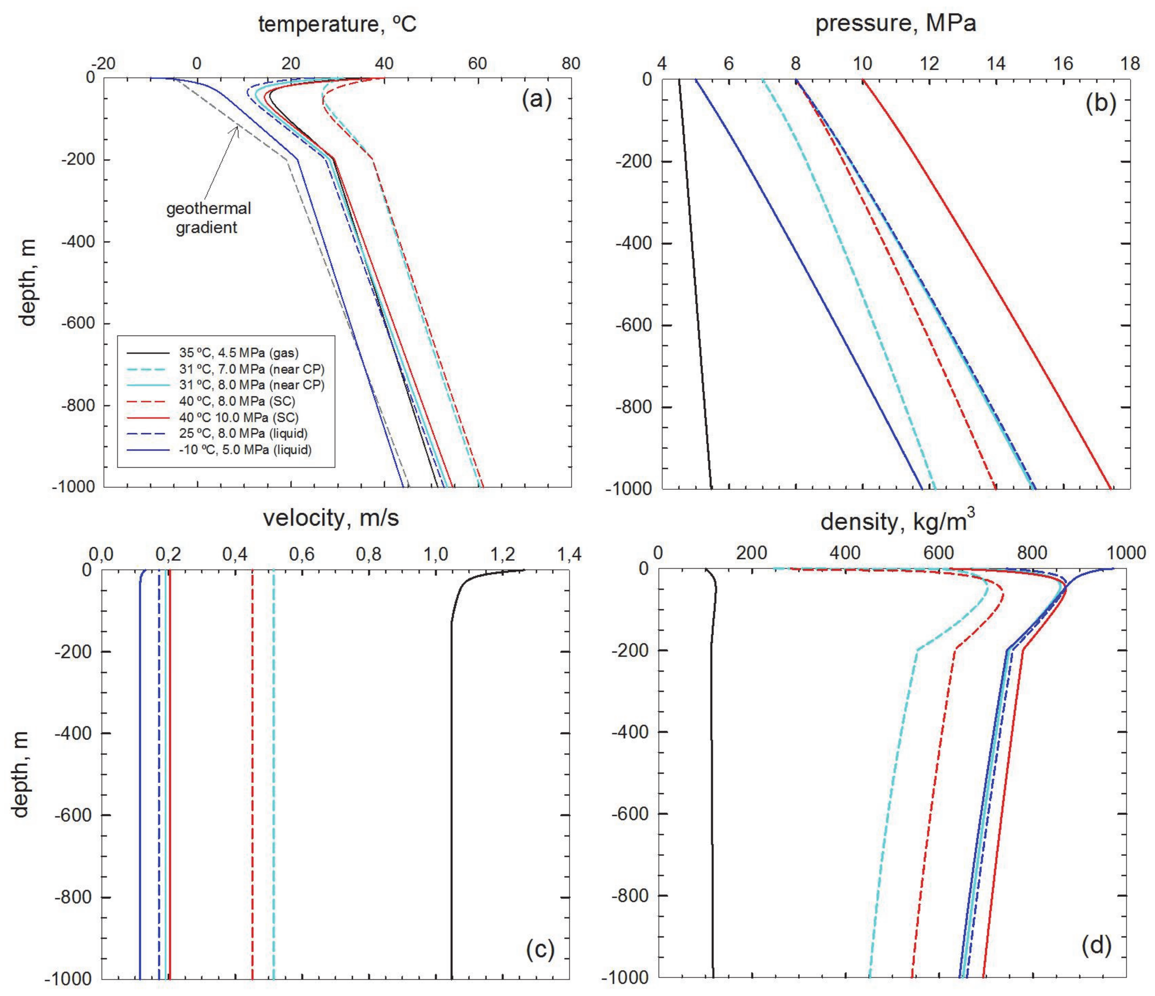


Figure 3. Comparison of different injection modes: temperature (a), pressure (b), velocity (c), and density (d) profiles in steady state. (Injection flowrate = 1.0 kg/s; diameter of injection pipe = 0.1 m; overall heat transfer coefficient = 4.0 W/m²-K)

Modeling approach

A 1D model of non-isothermal single-phase flow of CO_2 through an injection well is developed following the approach of Lu and Connell (2014), in which the flow equations are based on the averaged-flow model (Hasan and Kabir, 2002). The model has been implemented in Comsol through the coefficient's form of the PDE module with multiple dependent variables.

Results

Energy consumption due to surface conditioning is higher when injecting CO_2 in gas-phase, near critical and SC conditions at the wellhead. Contrarily, injecting liquid CO_2 reduces substantially the energy demand because pumping/compression is easier and heating is minor.

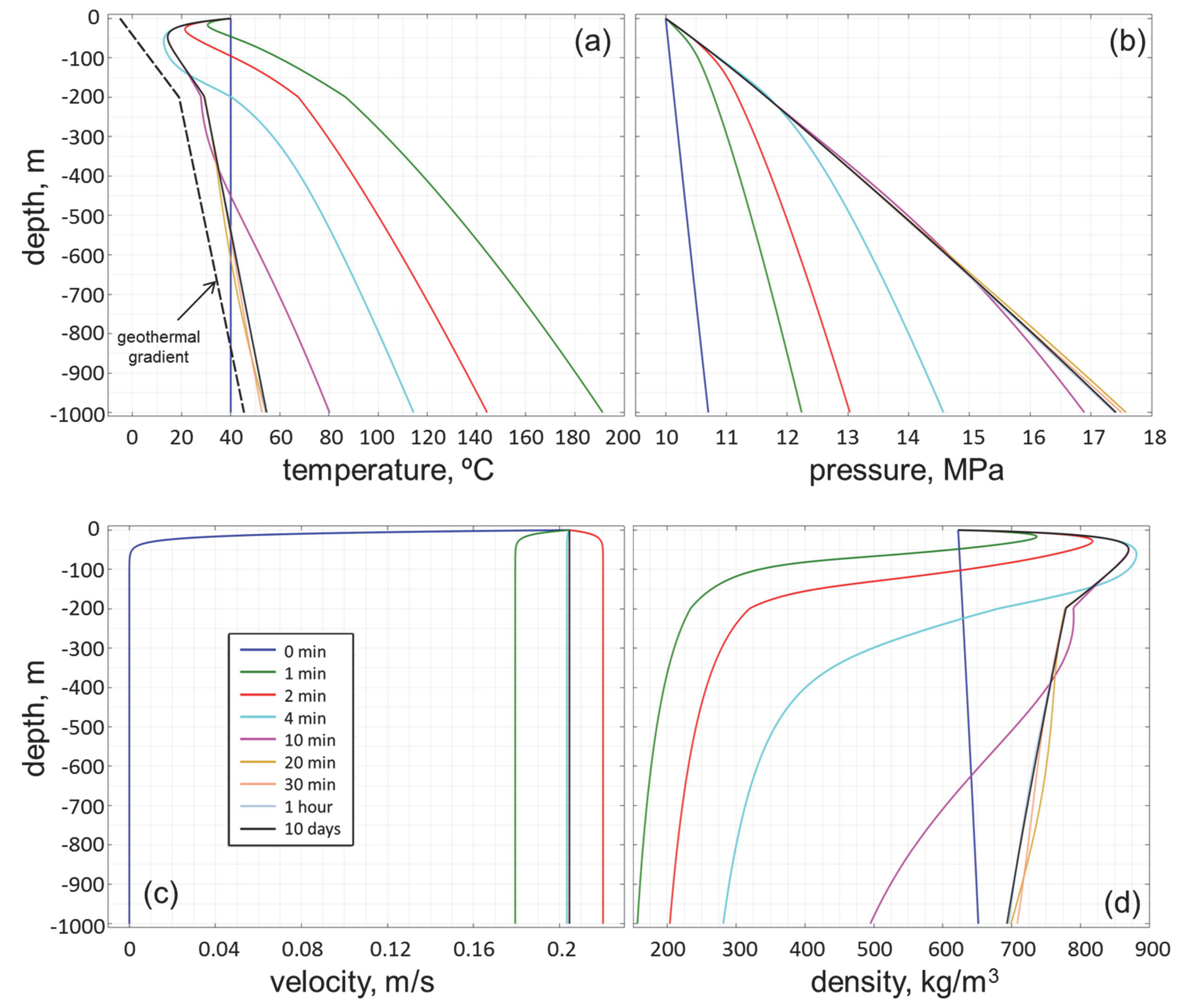


Figure 4. Evolution of temperature (a), pressure (b), velocity (c), and density (d) profiles. CO_2 is injected SC (40 ºC and 10 MPa) at 1.0 kg/s. Steady state is reached after 1.0 hour.

Injecting gaseous CO_2 causes very low densities through the wellbore (Figure 3). CO_2 injection in gaseous near the CP and SC (8 MPa) conditions increase density but at the bottom this is still lower than 600 kg/m³. By contrast, injecting dense CO_2 (liquid, liquid near the CP and SC (10 MPa) conditions) lead to higher bottomhole densities. Transient simulations reveal that steady state is reached faster by injecting at higher pressures (compare Figure 4 and Figure 5).

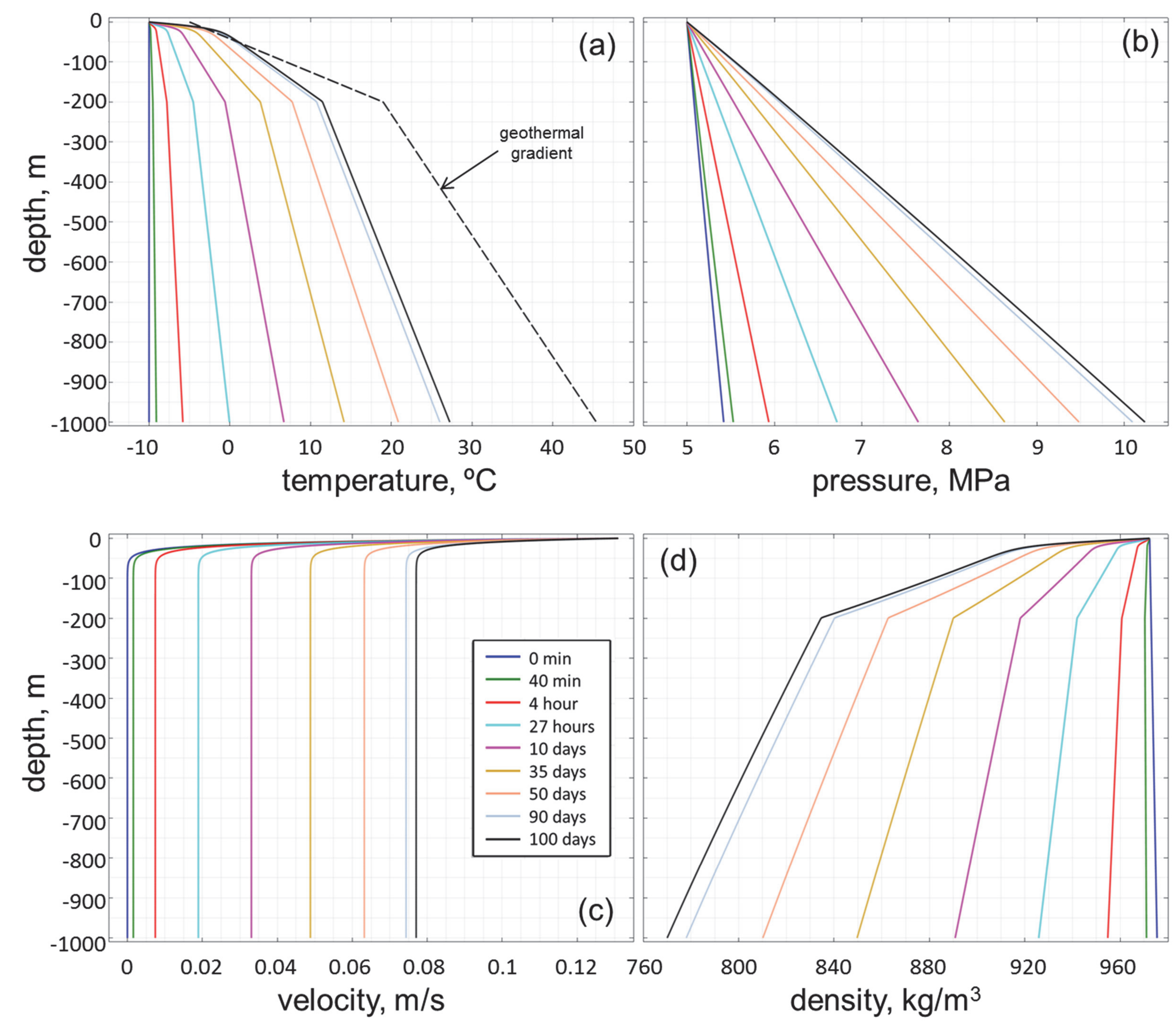


Figure 5. Evolution of temperature (a), pressure (b), velocity (c), and density (d) profiles. CO_2 is injected liquid (-10 ºC and 5 MPa) at 1.0 kg/s. Steady state is reached after 100 days.

Conclusions

CO_2 injection conditions should be tuned considering a balance between optimal storage densities and the stability of the operation. The present model can also be used to evaluate injection strategies with dynamic wellhead conditions.

References

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Lu, M. and Connell, L.D., 2008. Non-isothermal flow of carbon dioxide in injection wells during geological storage. *International Journal of Greenhouse Gas Control* 2, 248-258.

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