Universität Stuttgart, Germany

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Department of Hydromechanics and Modeling of Hydrosystems

Numerical Simulation of CO_2 Storage in Geological Formations using MUFTE-UG

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Outline

- CO_2 related projects
- Model concept implemented in MUFTE-UG
- Examples that show model capabilities

- Non-isothermal effects during CO_2 leakage

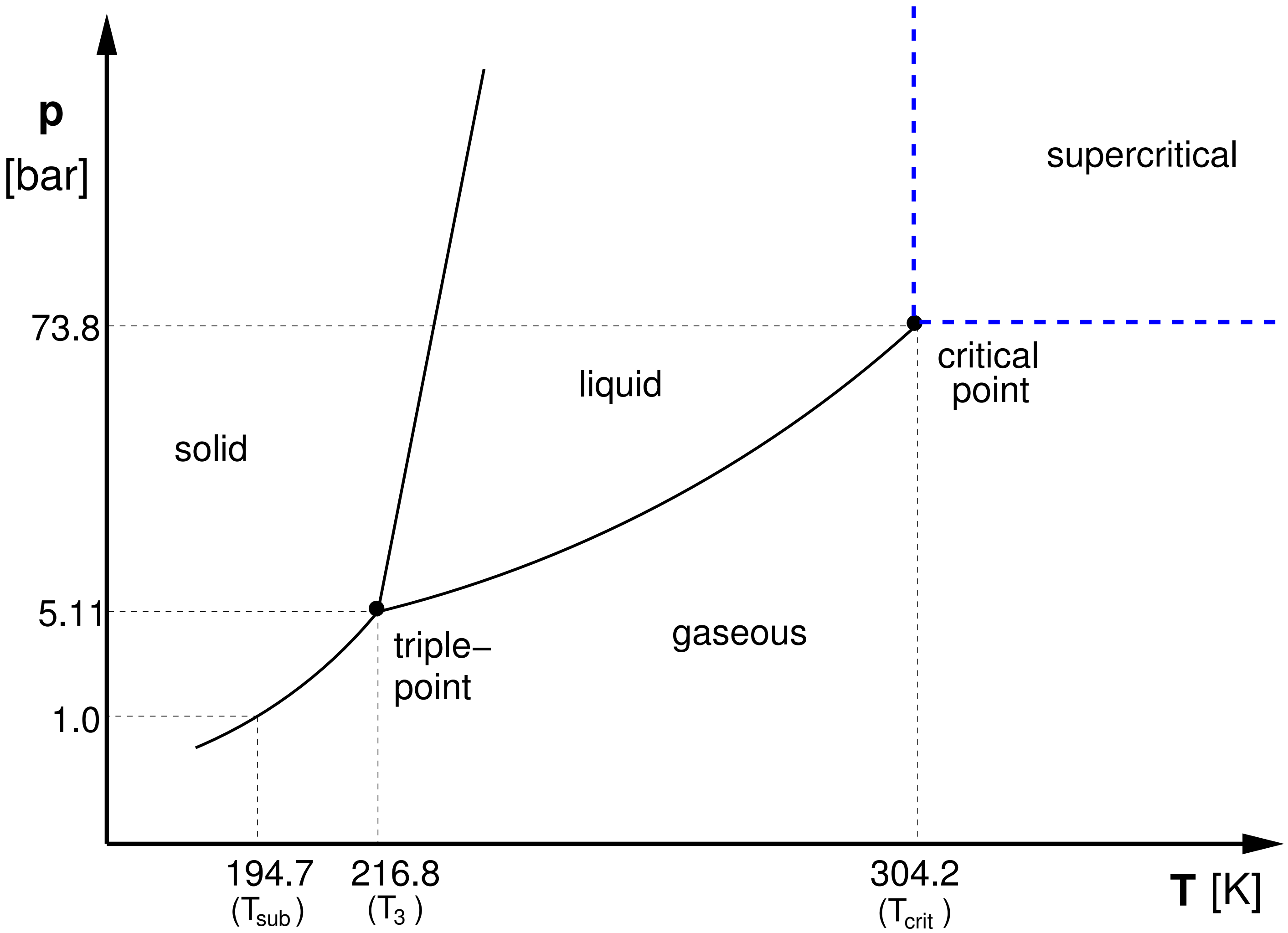
Universität Stuttgart: CO_2-related projects

- Development of physical-mathematical model concepts for the simulation of CO_2 injection in geological formations
  - Development of model concept and implementation into numerical simulator MUFTE-UG
  - Funding: DFG (German Research Foundation)

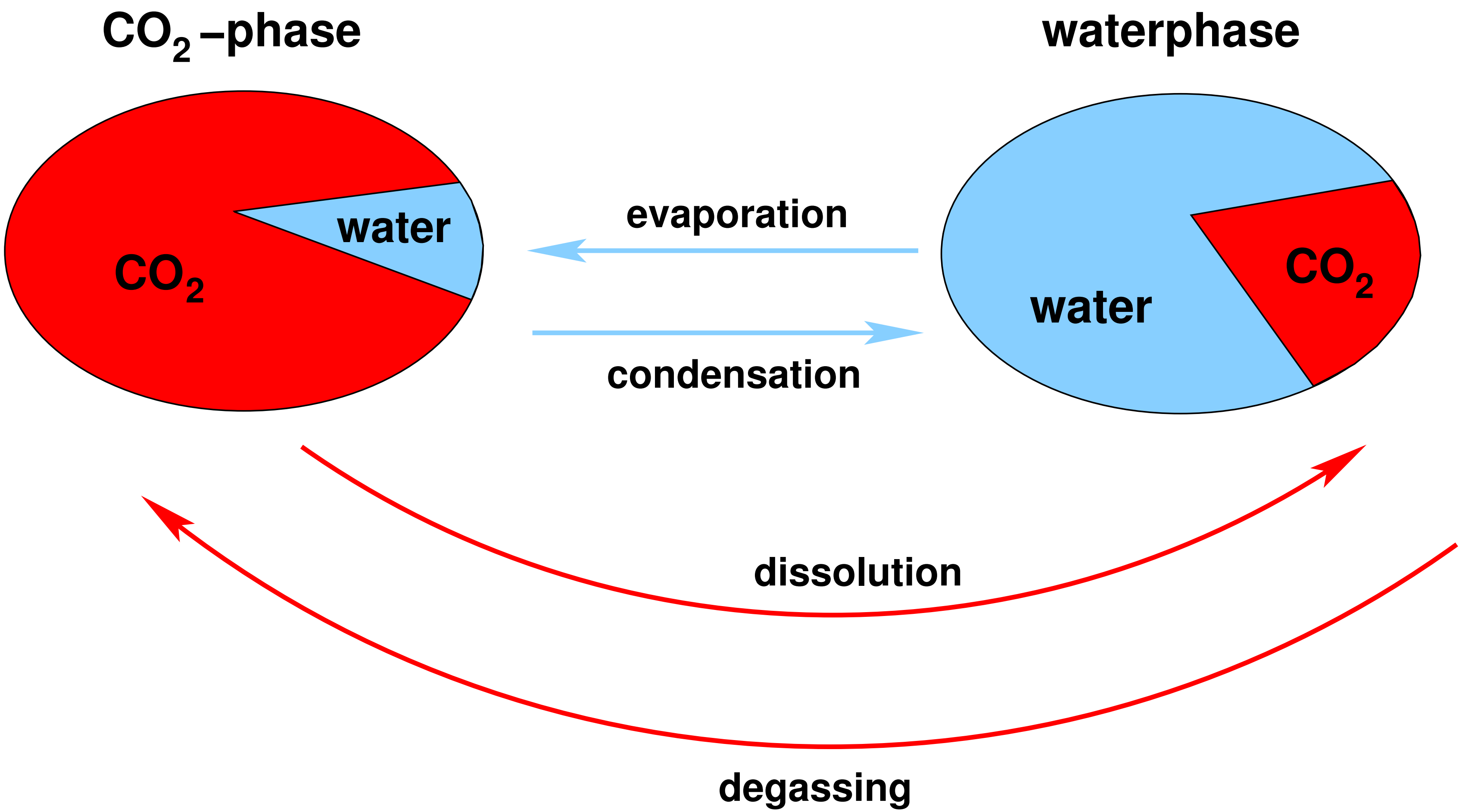
- CO2SINK – In-situ R&D Laboratory for Geological Storage of CO_2
  - Large-scale application of the model to a field study close to Berlin, Germany
  - Funding: EU (European Union)

- Numerical Investigation of CO_2 Sequestration in Geological Formations - Problem-Oriented Benchmarks
  - Setting up of benchmarks for the scientific community
  - Funding: DFG (German Research Foundation) and BMBF (Federal Ministry of Education and Research)

Phase Diagram of CO_2

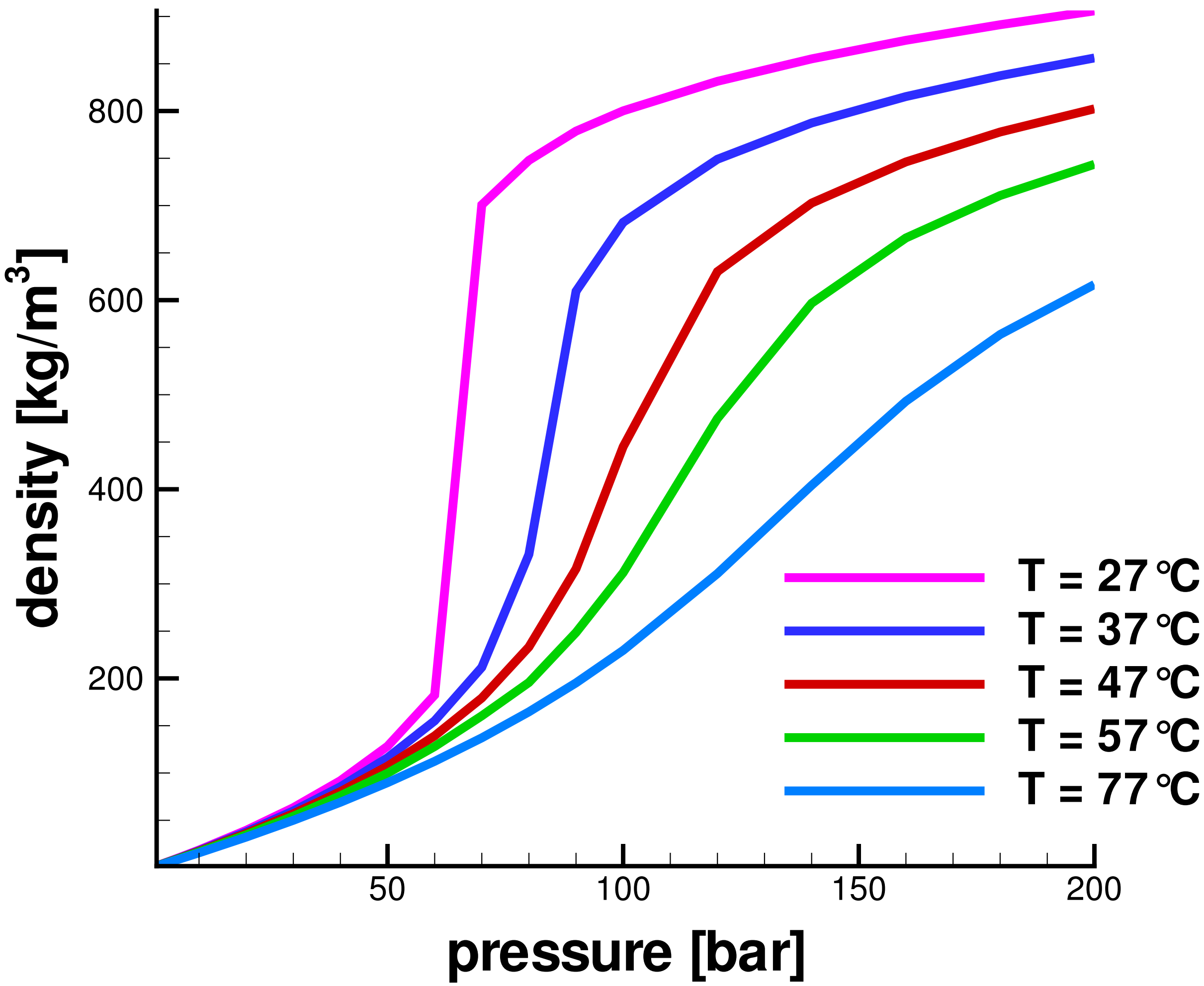


Model Concept: Two-phase Two-component



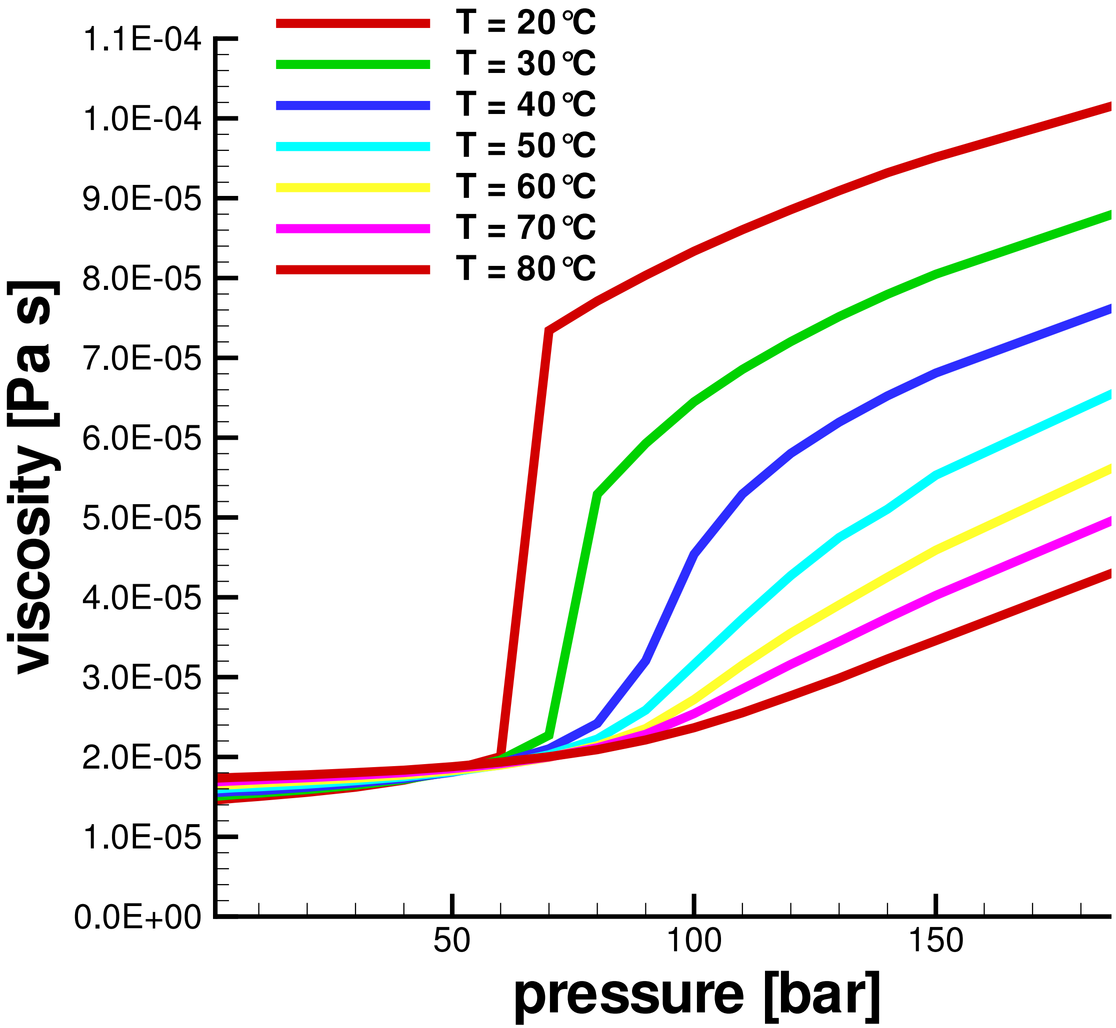
Density of CO_2

(Span & Wagner, 1996)



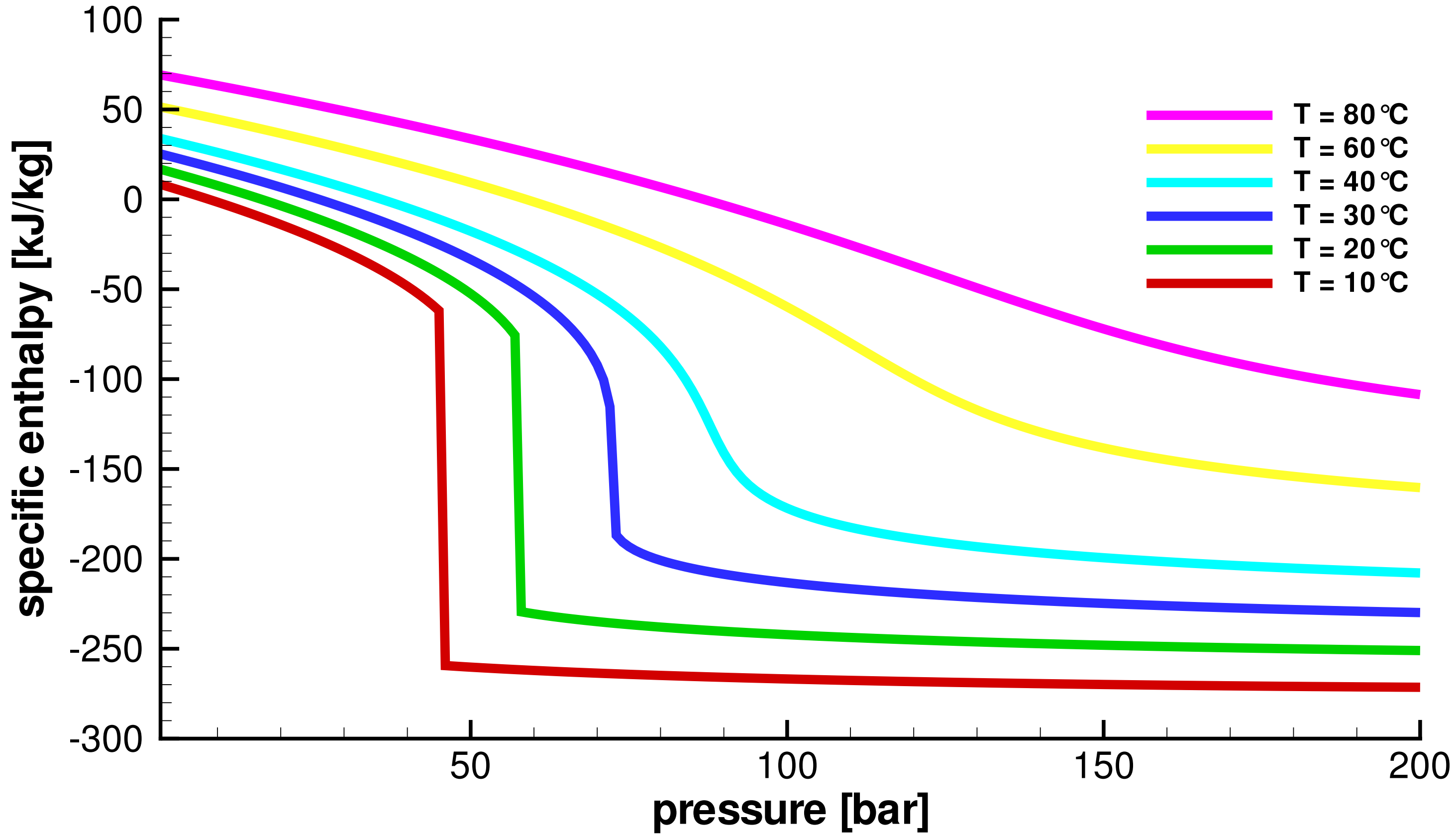
Viscosity of CO_2

(Fenghour et al., 1998)



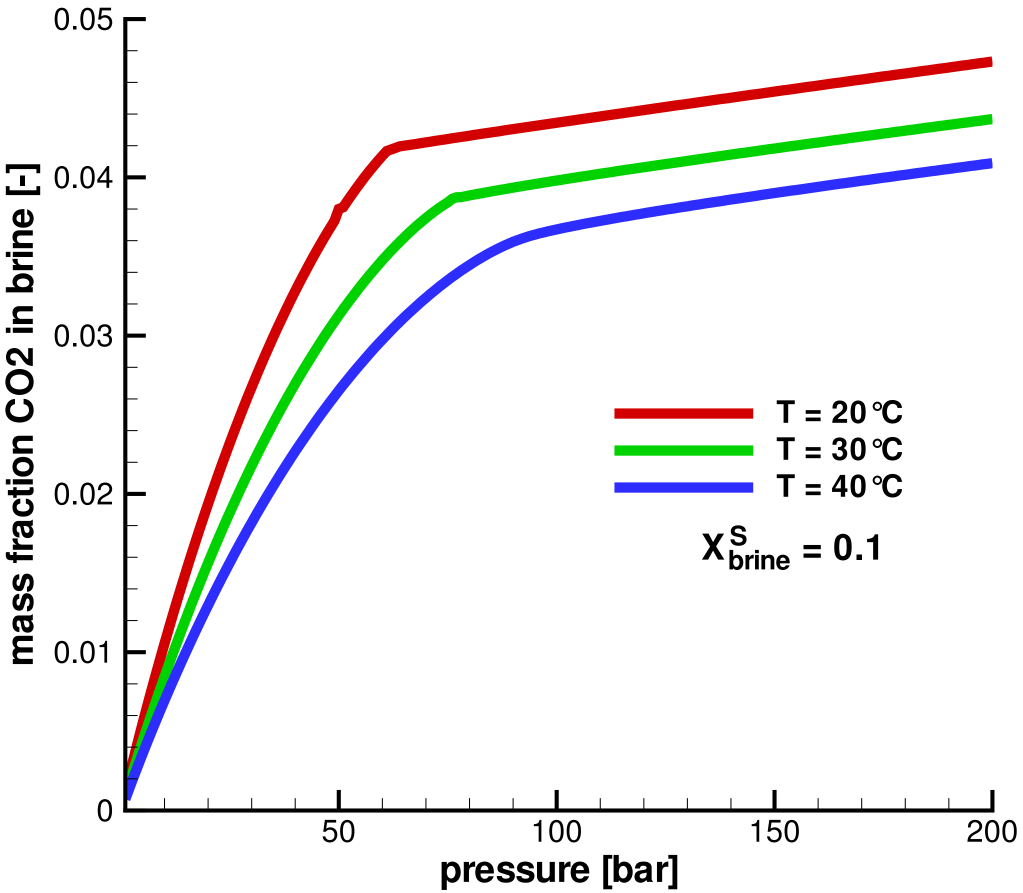
Enthalpy of CO_2

(Span & Wagner, 1996)



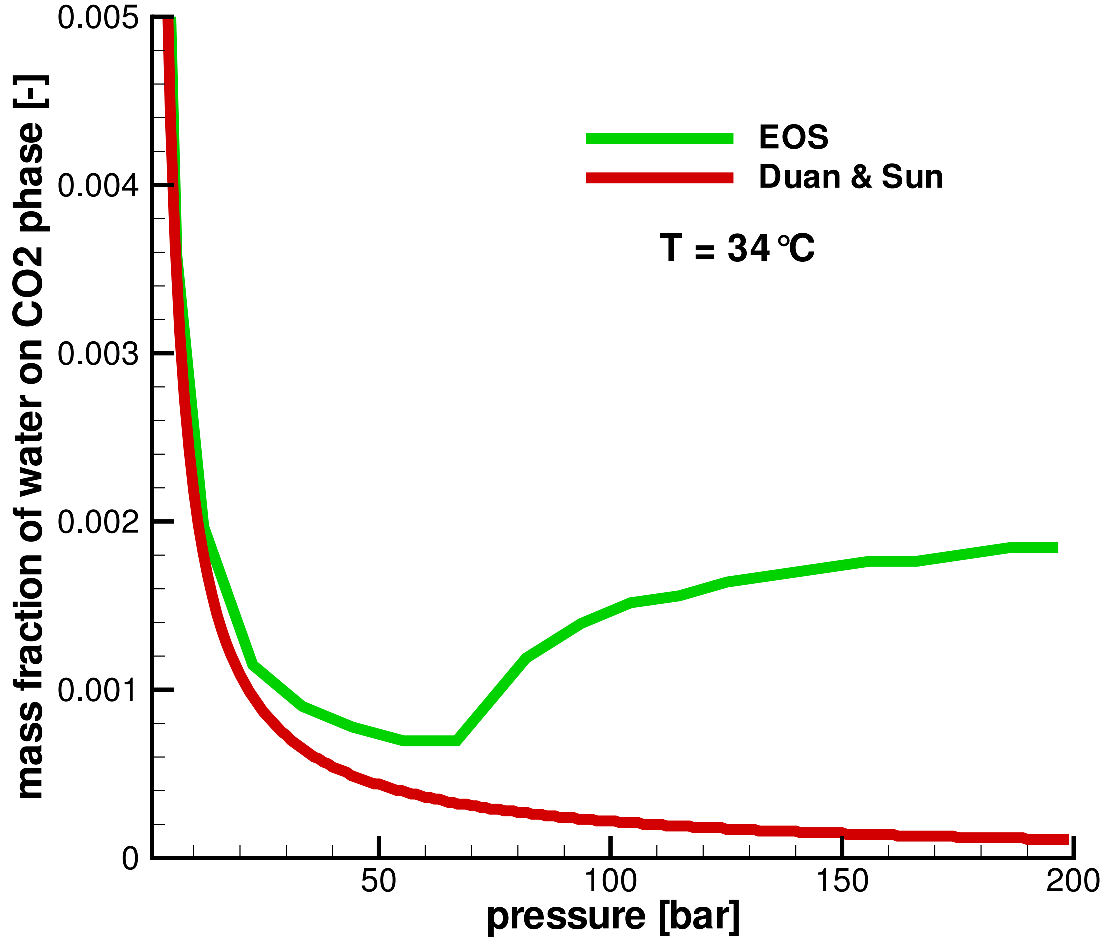
Solubility of CO_2 in Brine

- $X^{\text{CO2}}_{\text{brine}} = f(p, T, X^{\text{S}}_{\text{brine}})$ (Duan & Sun, 2003)
- dissolved CO_2 influences brine density and enthalpy



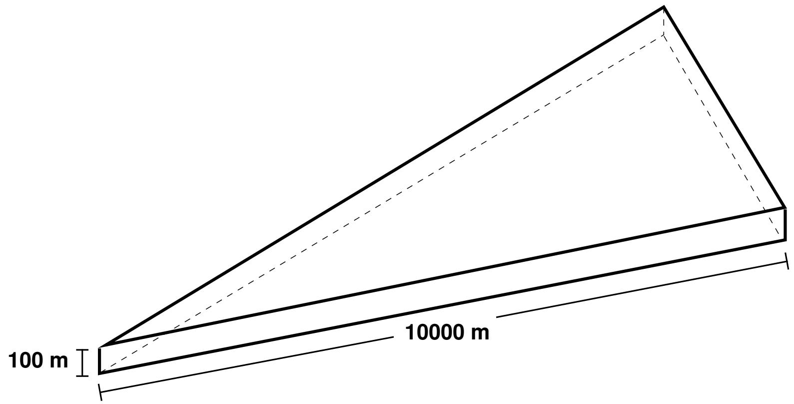
Solubility of Water in CO_2

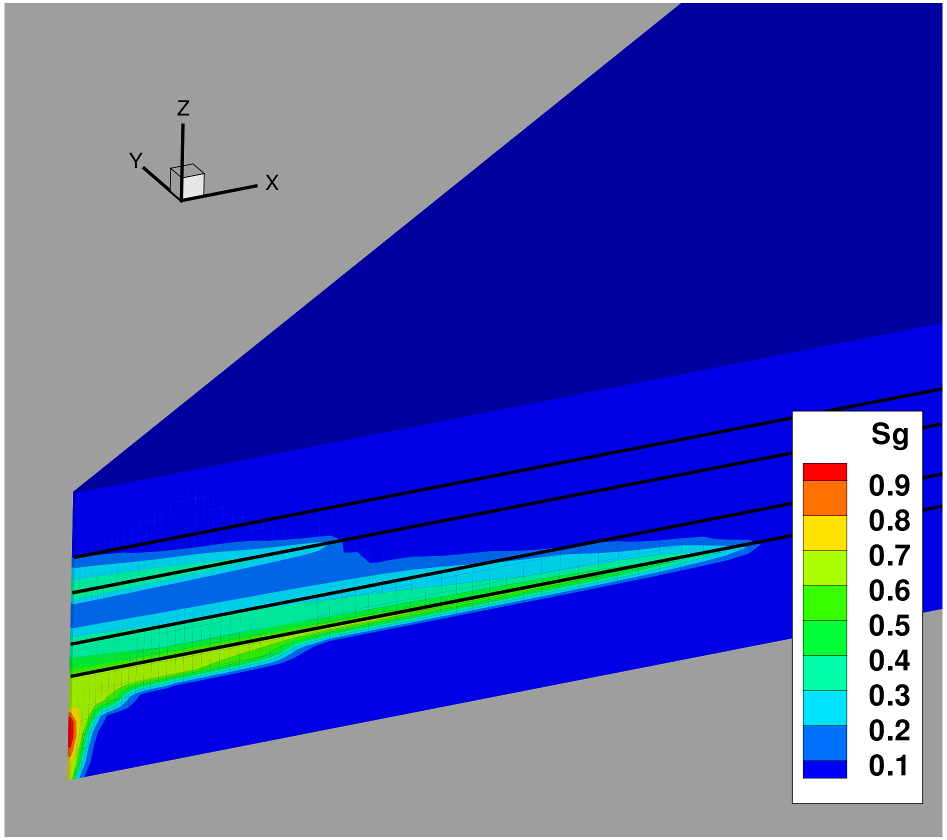
- $X^{w}_{CO2} = f(p, T)$
- dissolved water does not influence CO_2 fluid properties



Simulation Results: Radially Symmetric CO_2 Propagation

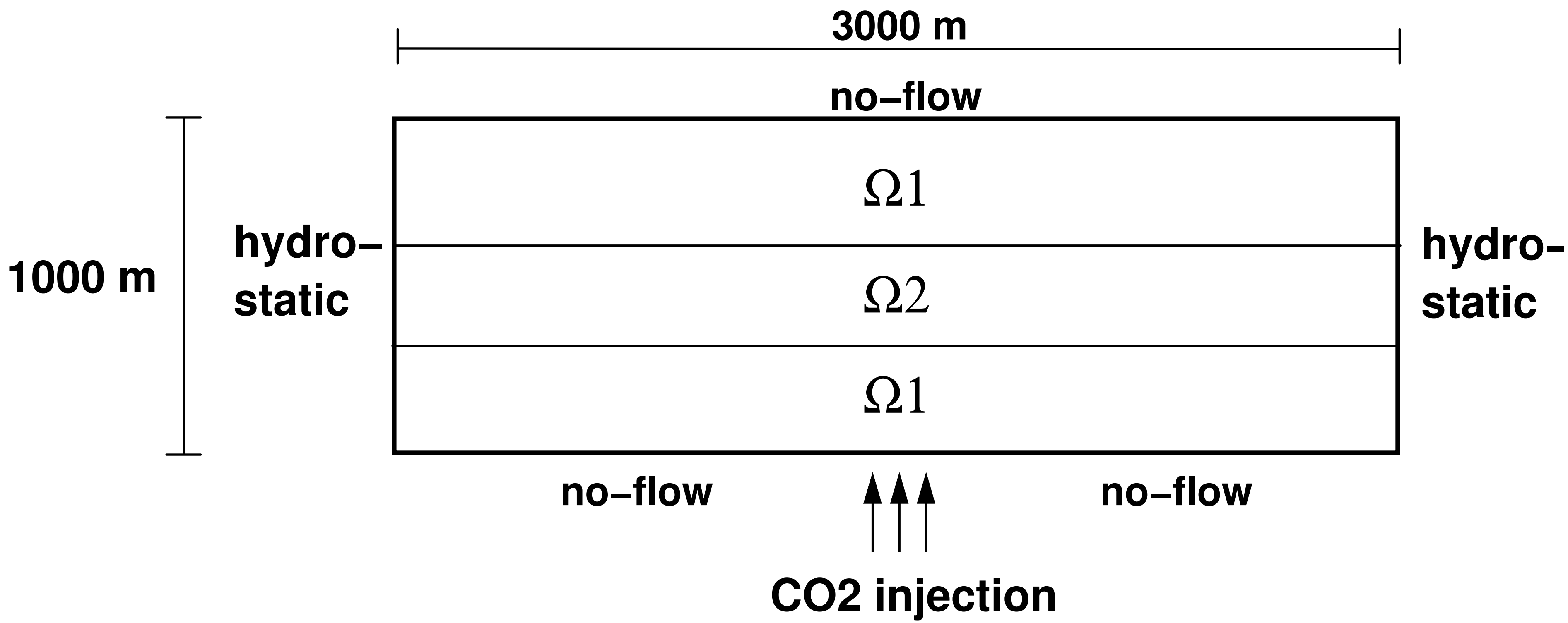
- 15,000 unknowns
- 2 layers of low permeability





Simulation Results: Long-Term Effects

- $K_1 >> K_2$
- $\phi_1 > \phi_2$

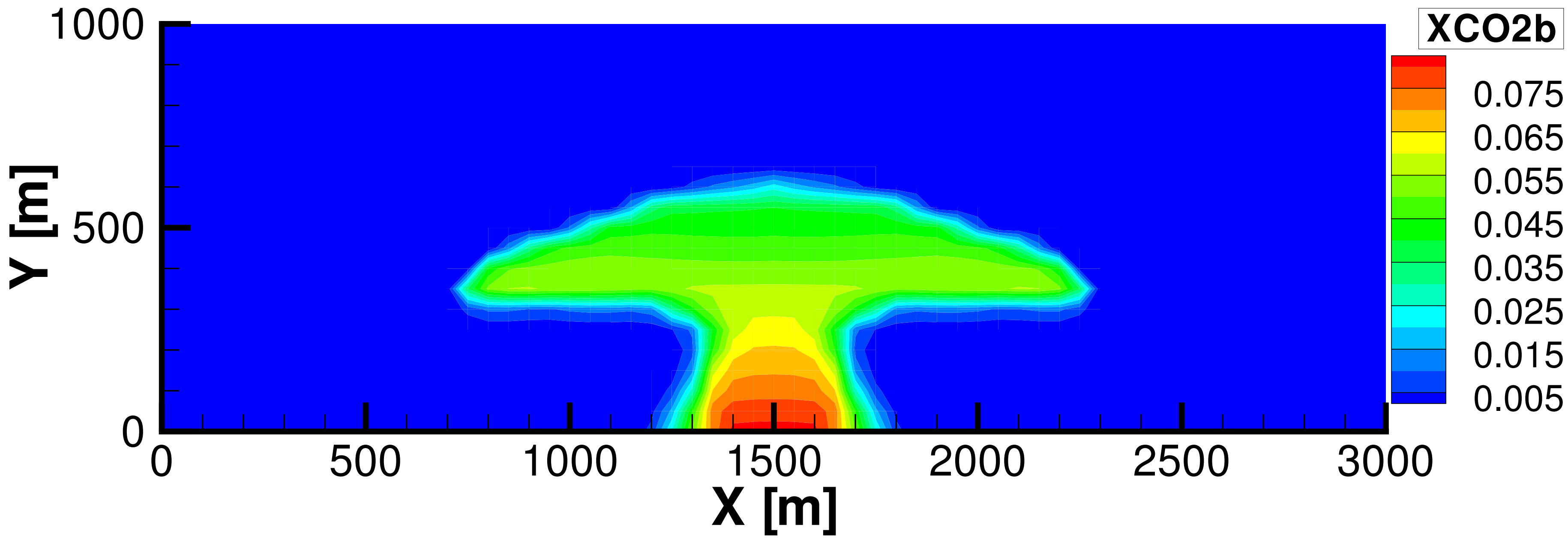


Simulation Results: Long-Term Effects

movie

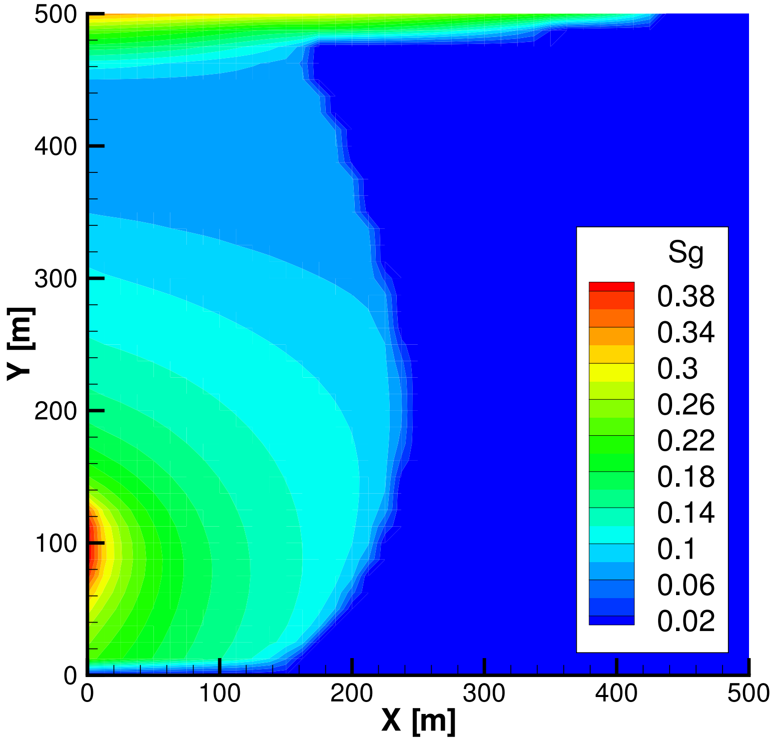
- $\varrho_{\text{brine}} = f(p, T, X^{\text{S}}_{\text{brine}}, X^{\text{CO2}}_{\text{brine}})$

Distribution of dissolved CO_2 after 2 years simulation time.

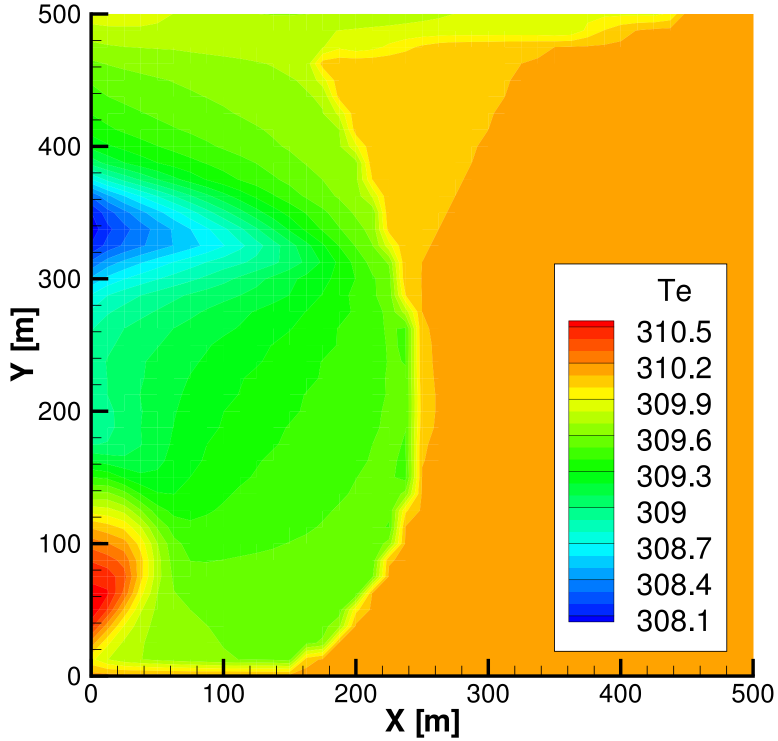


Simulation Results: Non-Isothermal Effects

- cooling due to expansion (Joule-Thomson effect)
- cooling due to evaporation



CO_2 saturation [-]



temperature [K]

Can thermal effects be neglected during CO_2 leakage from a geological reservoir to the atmosphere?

CO_2 Leakage from a Geological Reservoir

Can thermal effects be neglected during CO_2 leakage from a geological reservoir to the atmosphere?

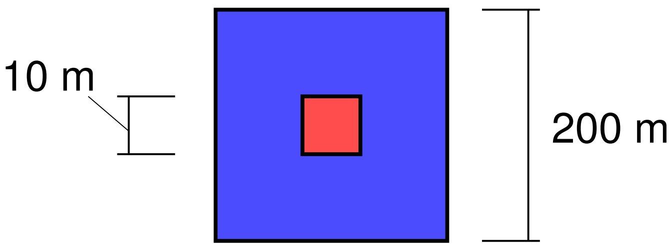
- Karsten Pruess
  Numerical Simulation of CO_2 Leakage from a Geological Disposal Reservoir, Including Transitions from Super- to Sub-Critical Conditions, and Boiling of Liquid CO_2, *Soc. Pet. Eng. J.,* pp. 237 - 248, June 2004b.
  - “System behavior is **dominated by cooling effects** from CO_2 decompression and boiling of liquid CO_2 into gas.“

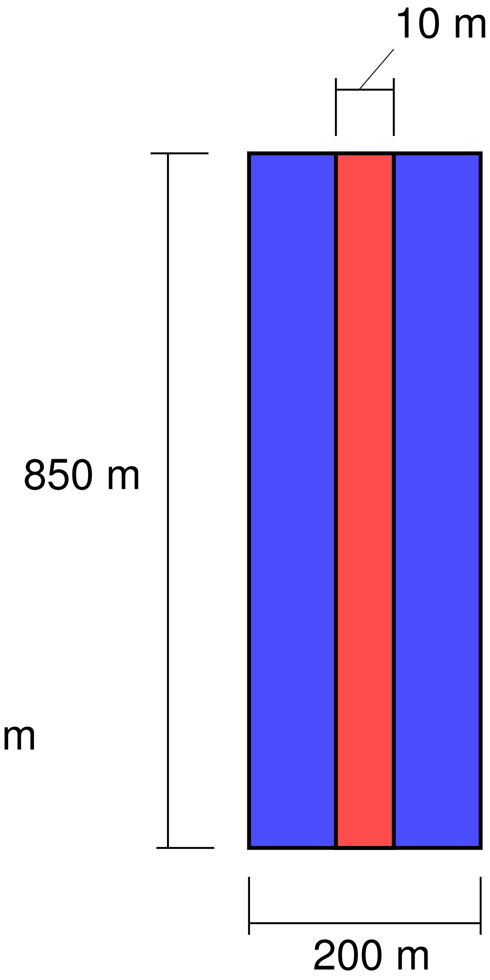
CO_2 Leakage from a Geological Reservoir

Simulation model

permeability:

red 1 D
blue 0.01 D





atmosphere:

T = 283.15 K
p = 1.013 bar

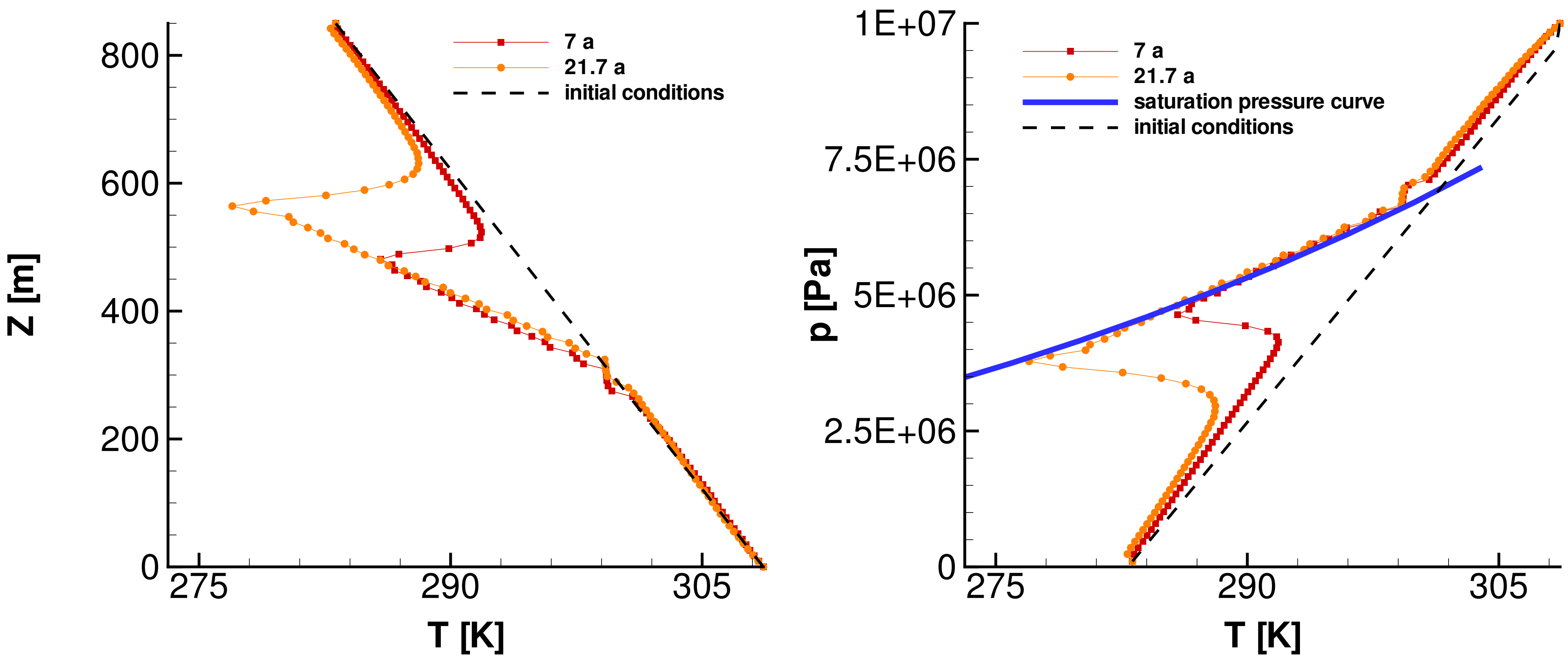
geothermal gradient
0.03 K/m

no mass flux
accross the sides

reservoir:

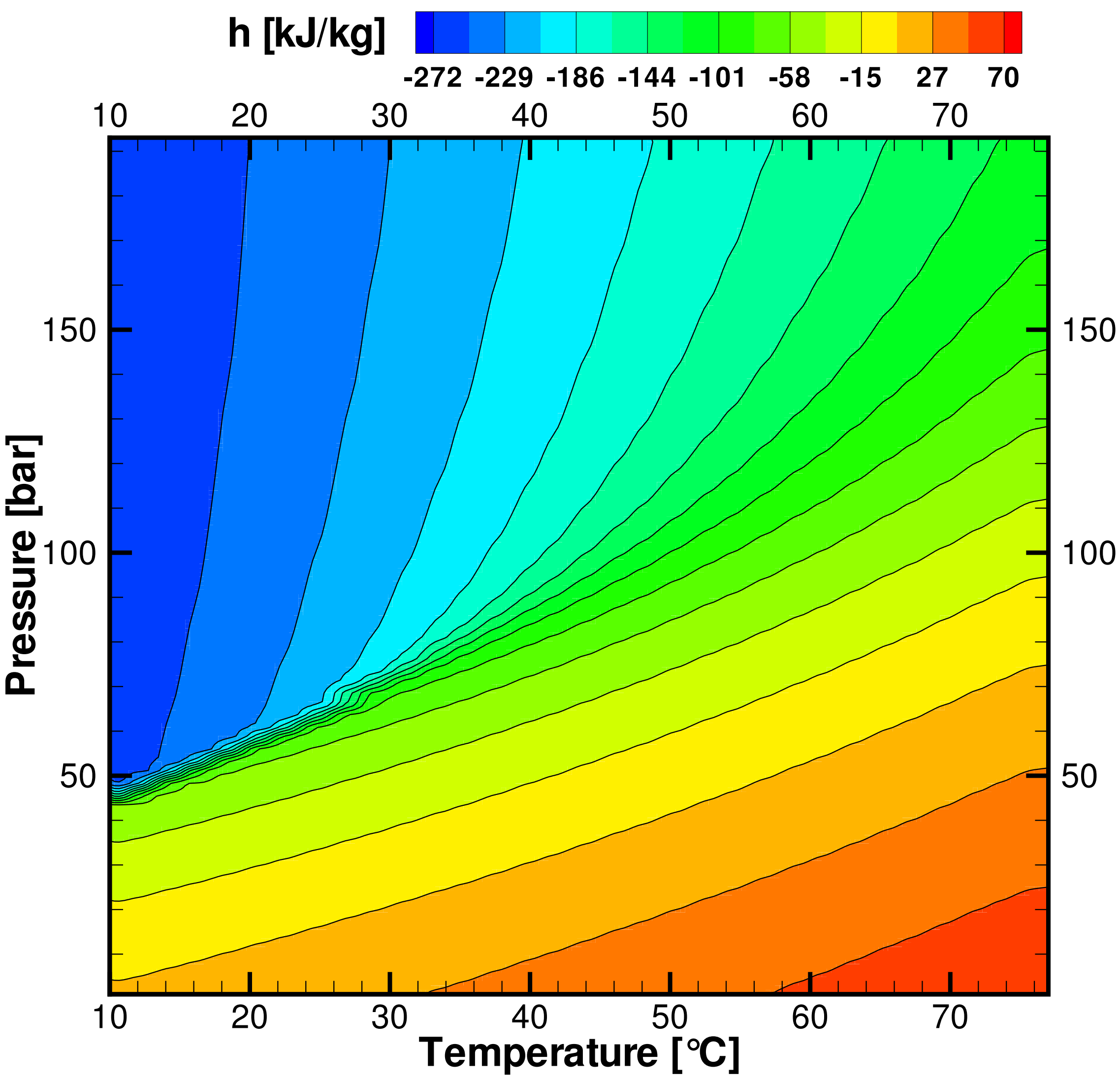
T = 308.65 K
p = 3.7 bar above
hydrostatic pressure
S_{CO2} = 0.3

CO_2 Leakage from a Geological Reservoir

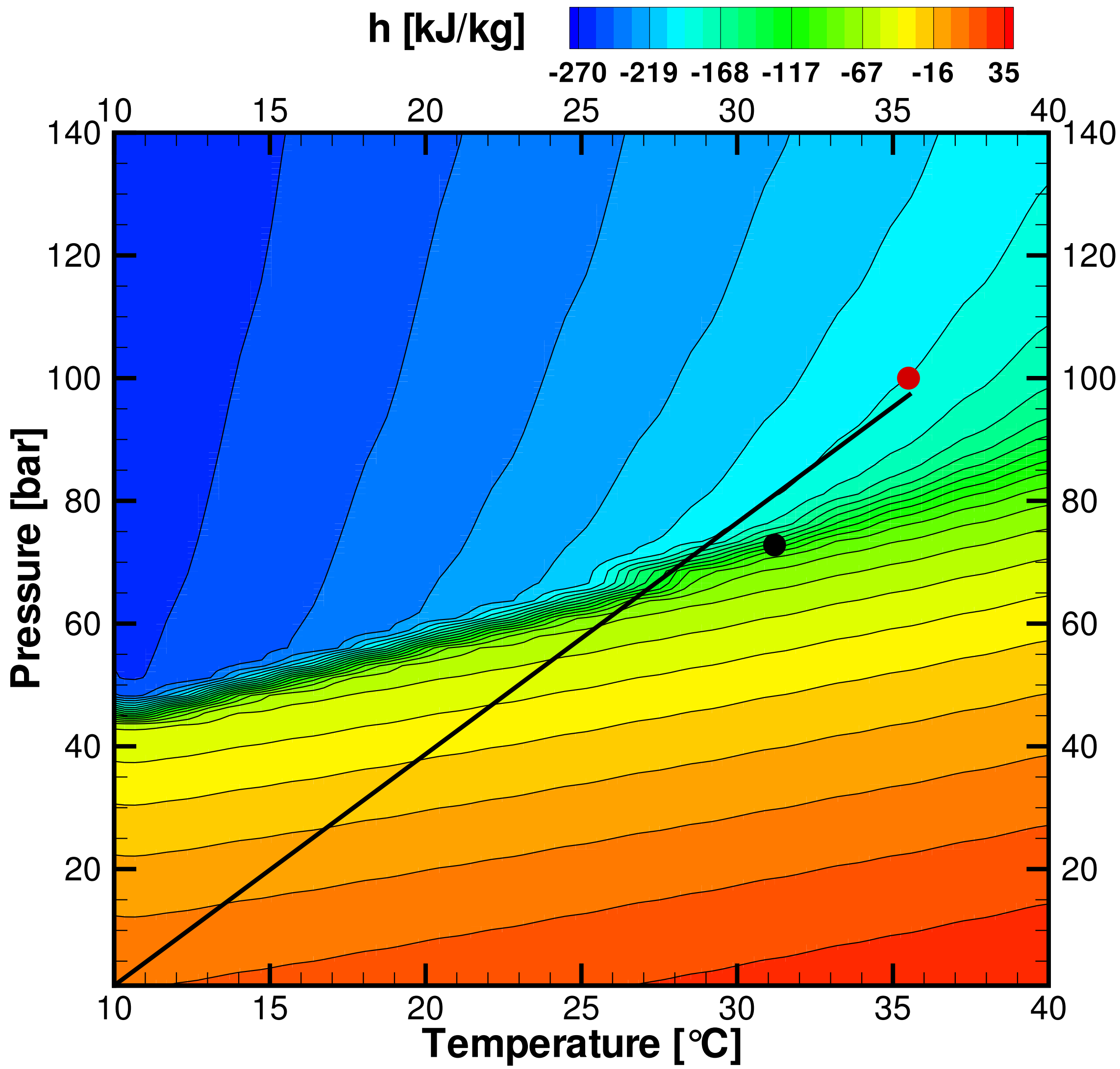


Temperature and pressure in the channel of higher permeability.

Specific Enthalpy of CO_2 [kJ/kg]



Specific Enthalpy of CO_2 [kJ/kg]

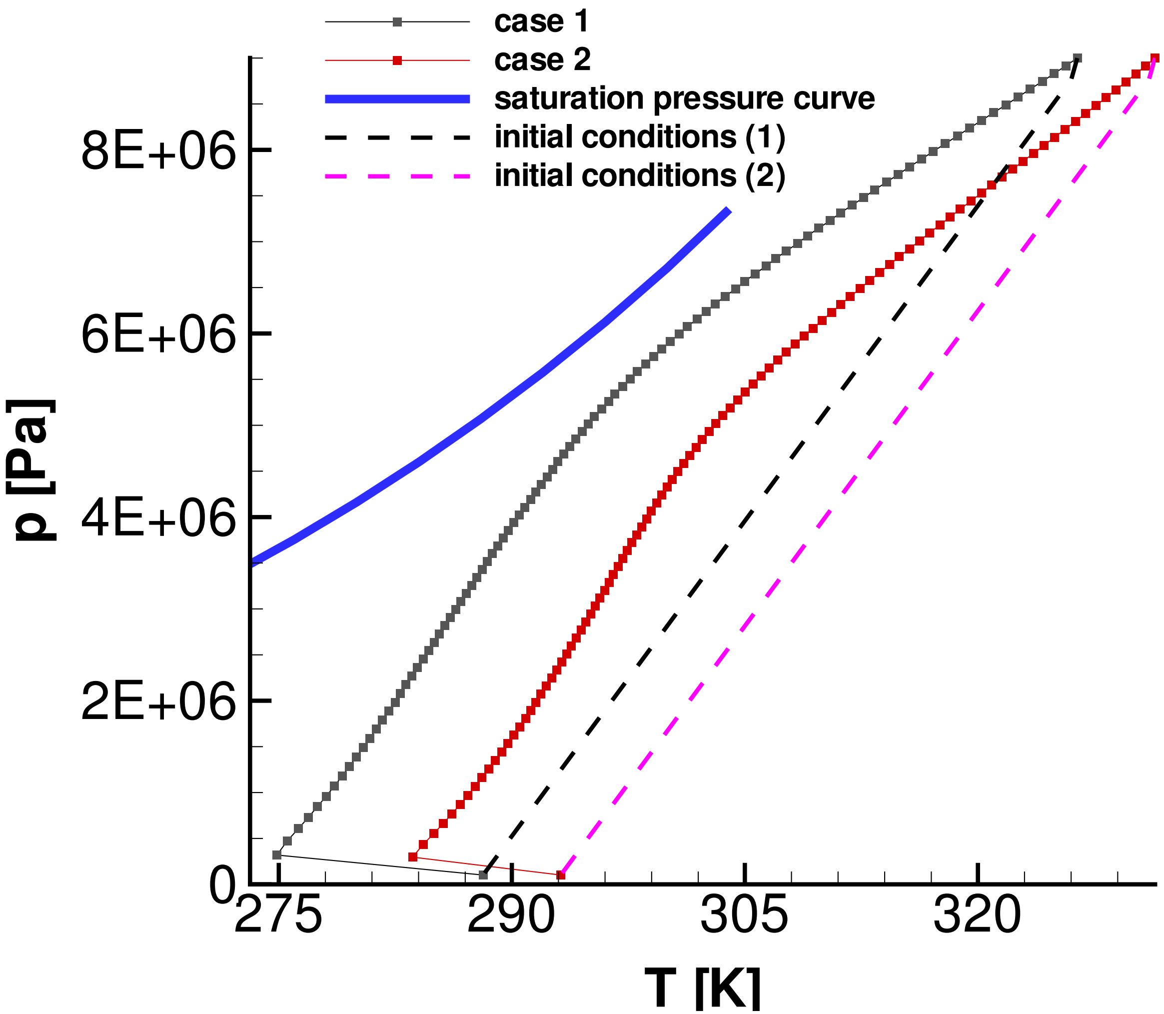


New simulations

	new parameters		
	case 1	case 2	former simulation
surface temperature [K]	**288.15**	**293.15**	283.15
geothermal gradient [K/m]	**0.045**	**0.045**	0.030
temperature (bottom) [K]	**326.40**	**331.40**	308.65
brine density [kg/m^3]	**1050**	**1050**	1143
simulation time	21.7 years		

CO_2 Leakage from a Geological Reservoir

New simulations



Two-Phase & Three-Phase Models

CO_2 may occur as a gas and a liquid in the same region. This causes a reduction of the relative permeabilities in this three-phase region and hence

- a reduction of the upward CO_2 velocity (reduction of the leakage flux).
- lateral spreading of the CO_2 plume.
- increased thermal interaction of the CO_2 in the region with its surroundings.

These effects are not accounted for by a two-phase model.

Conclusions

- The simulated models and literature (*Pruess*, 2004) suggest strong cooling effects during sustained CO_2 leakage from a geological reservoir which may have important consequences for the CO_2 leakage flux.
- These cooling effects however depend on the properties of the aquifer and reservoir depth.

Topics that require more Research

- Flow instabilities
  - Gravity fingering
  - Viscous fingering
- Constitutive relationships for the CO_2-brine system
  - Capillary pressure - saturation relationship
  - Relative permeability - saturation relationship
- Effect of impurities on CO_2 fluid properties (e.g. water, H_2S)