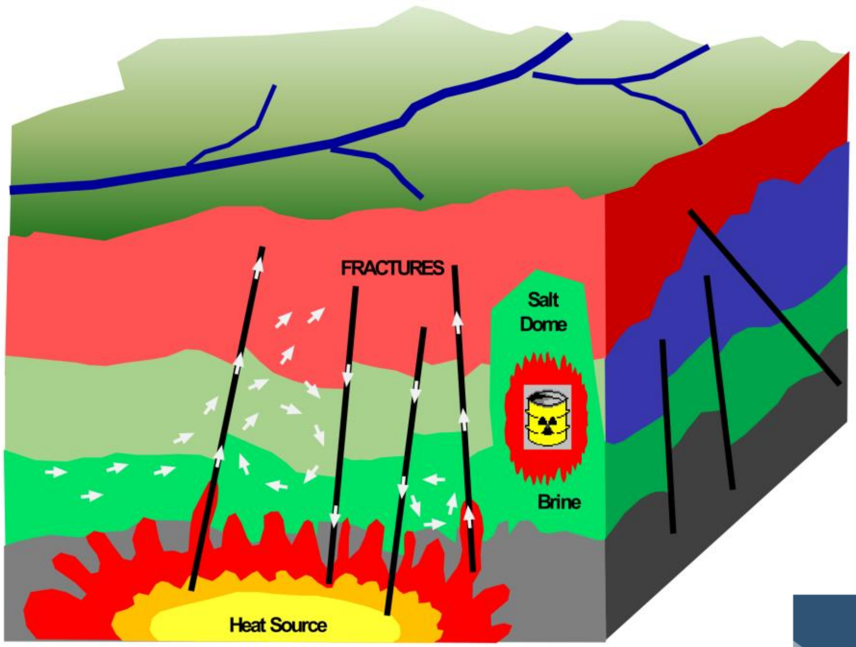
Variable-density and variable-viscosity flow in nuclear waste disposal

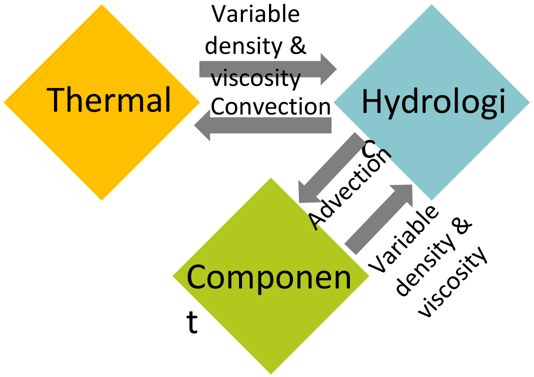


 Jonas Suilmann & Andrea Perin

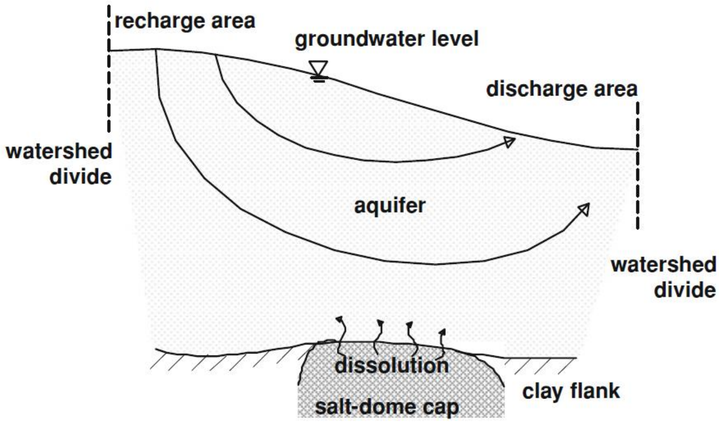
BGE BUNDESGESELLSCHAFT FÜR ENDLAGERUNG

Groundwater flow around a salt dome

- Groundwater flow around salt domes
- Transport of a radionuclide and solute salt
- Heat transport due to geothermal gradient
  and heat generation of waste



- Variable density and viscosity flow: dependency on temperature and salt concentration
- Coupled THC simulations in fractured
  porous media
- Using heatflow-smoker code
  (John Molson, Université Laval)

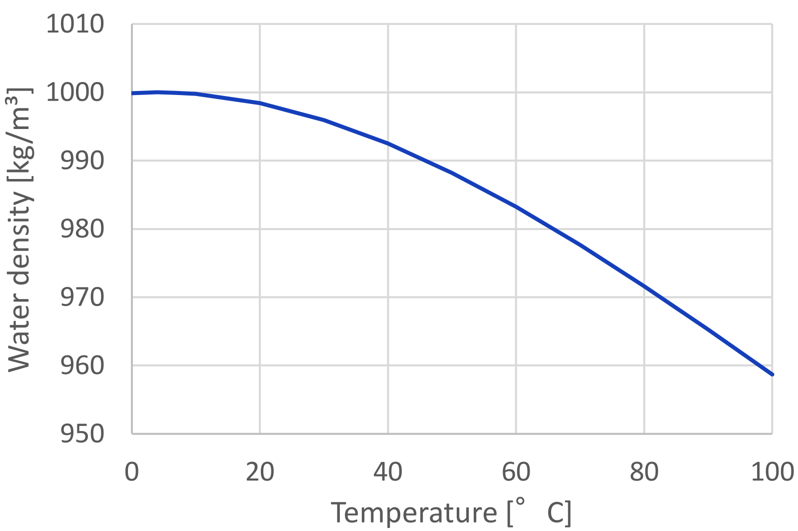


Holzbecher et al. 2010

Why is water density variable?

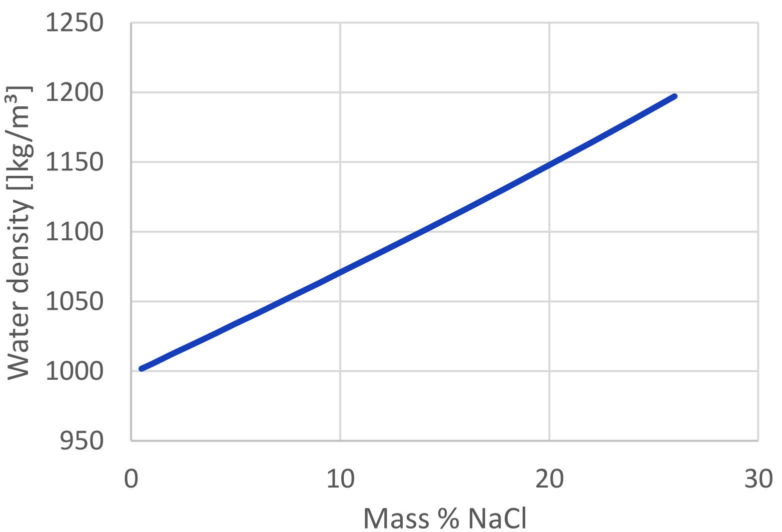
- Fluid density depends on:
  - Temperature, Salt concentration, pressure

Temperature



Data from Lide 2005

Salt mass %

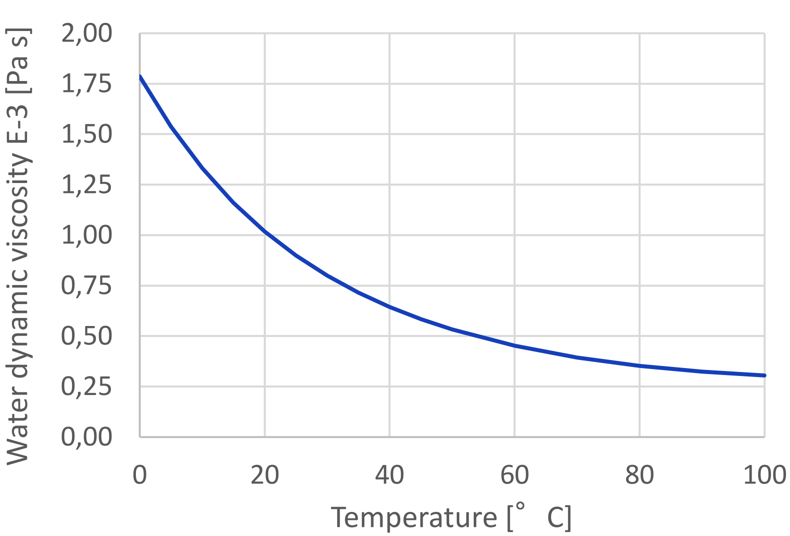


T = 20 ° C Data from Lide 2005

Why is water viscosity variable?

- Fluid viscosity depends on:
  - Temperature, Salt concentration, pressure

Temperature



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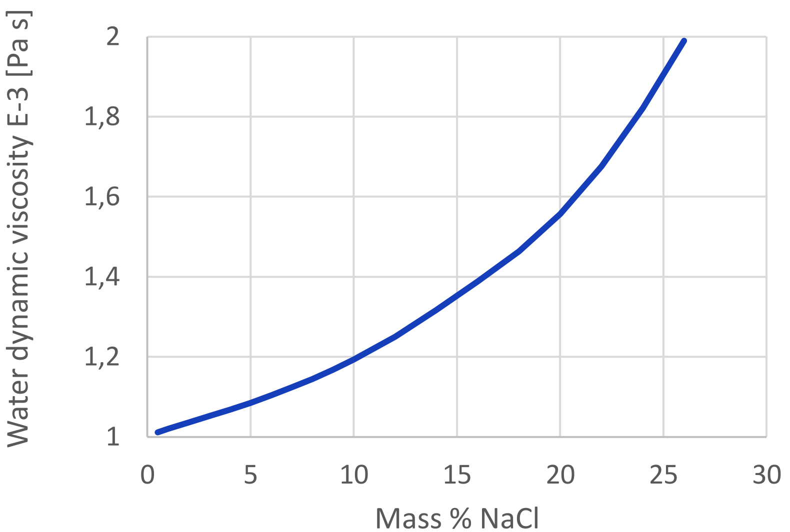


Data from Lide 2005

Why does variable density/viscosity impacts flow

Darcy equation:

- $q_i = -\frac{k_{ij}}{\mu}\left(\frac{\partial p}{\partial x_j} + \rho g \frac{\partial z}{\partial x_j}\right)$

Continuity equation for flow

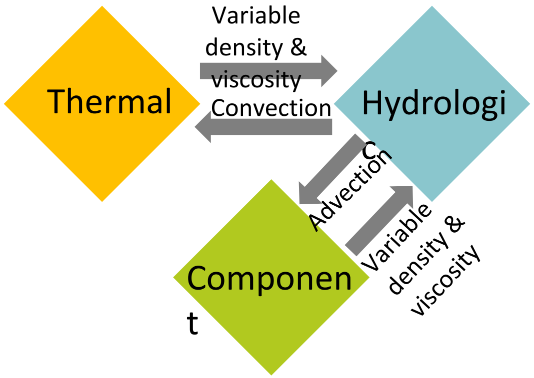
- $\frac{\partial}{\partial x_i}\left[\frac{k_{ij}}{\mu}\left(\frac{\partial p}{\partial x_j} + \rho g \frac{\partial z}{\partial x_j}\right)\right] = S_s \frac{\partial p}{\partial t}$

Heat transport equation

- $\frac{\partial}{\partial x_i}\left[\lambda \frac{\partial T}{\partial x_j}\right] - c^w \rho^w \frac{\partial}{\partial x_i}(v_i T) = c\rho \frac{\partial T}{\partial t}$

Mass transport equation

- $\frac{\partial}{\partial x_i}\left[D_{ij} \frac{\partial c}{\partial x_j}\right] - \frac{\partial}{\partial x_i}(v_i c) = \frac{\partial c}{\partial t}$



Why does variable density/viscosity impacts flow

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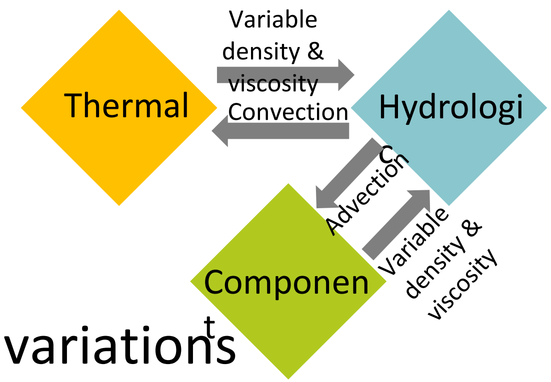
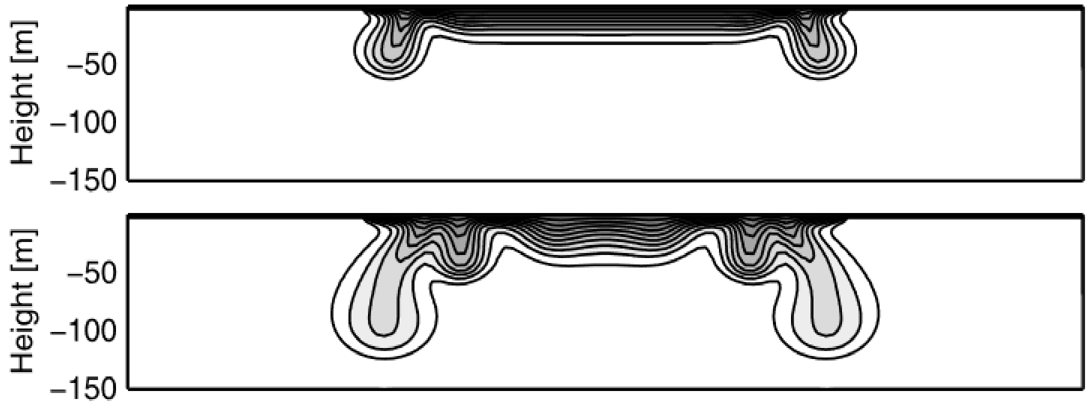


- Darcy velocity changes due to density/ viscosity variations
- Transport of heat and components affected
- Flow patterns can be density driven due to buoyancy forces
- Can lead to unstable systems, buoyoncy driven flow and free convection
- Density changes have strong driving force potential

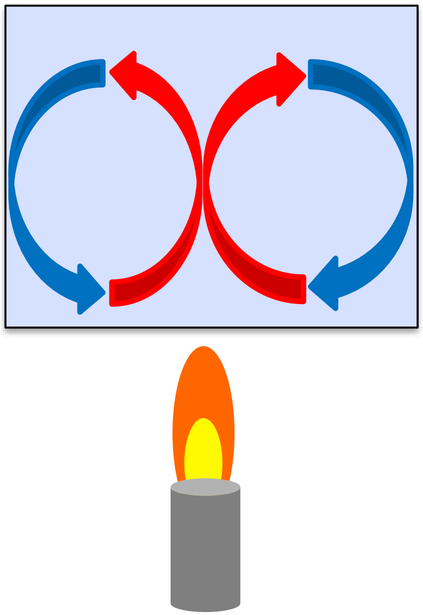
Variable density/viscosity flow examples

- Solutal Elder problem
- Salt concentration on top boundary



(Post and Prommer 2007)

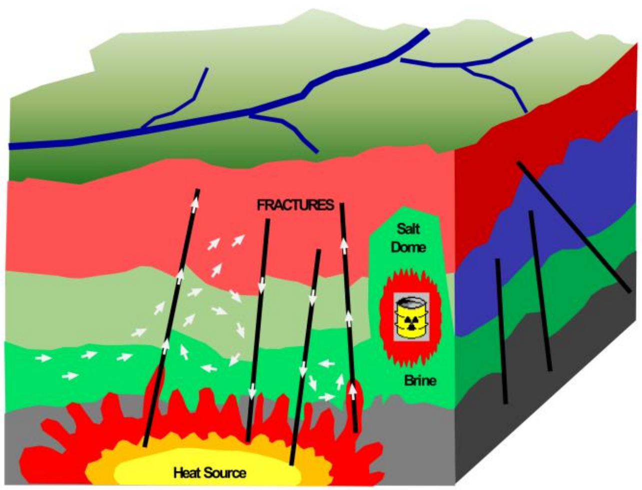
Free Convection when heated from below

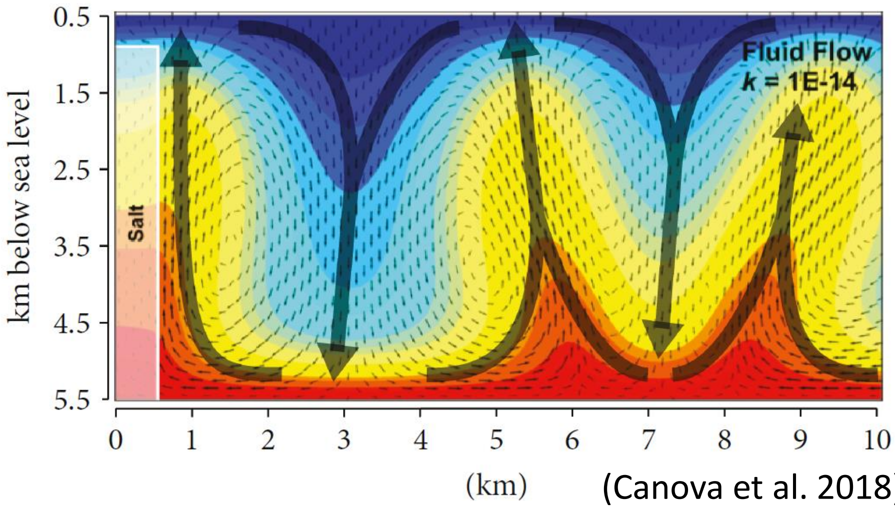


- Highly reduced time scales for mixing

Variable density/viscosity in nuclear waste disposal

- Flow around salt domes yields to high density brines
- Geothermal gradient and heat generation of waste
- Salt chimney effect (Canova et al. 2018)
- High th. conductivity of salt compared to surrounding rock can lead to free convection cells
- Radionuclide transport can be affected

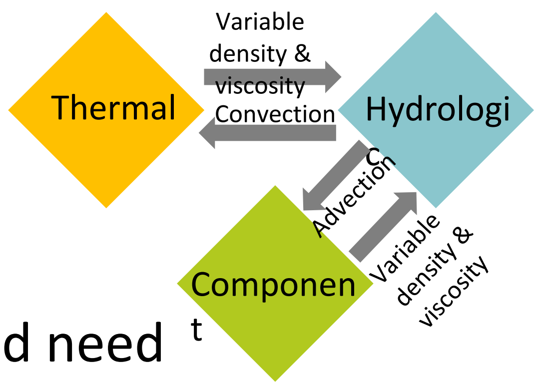




(Canova et al. 2018)

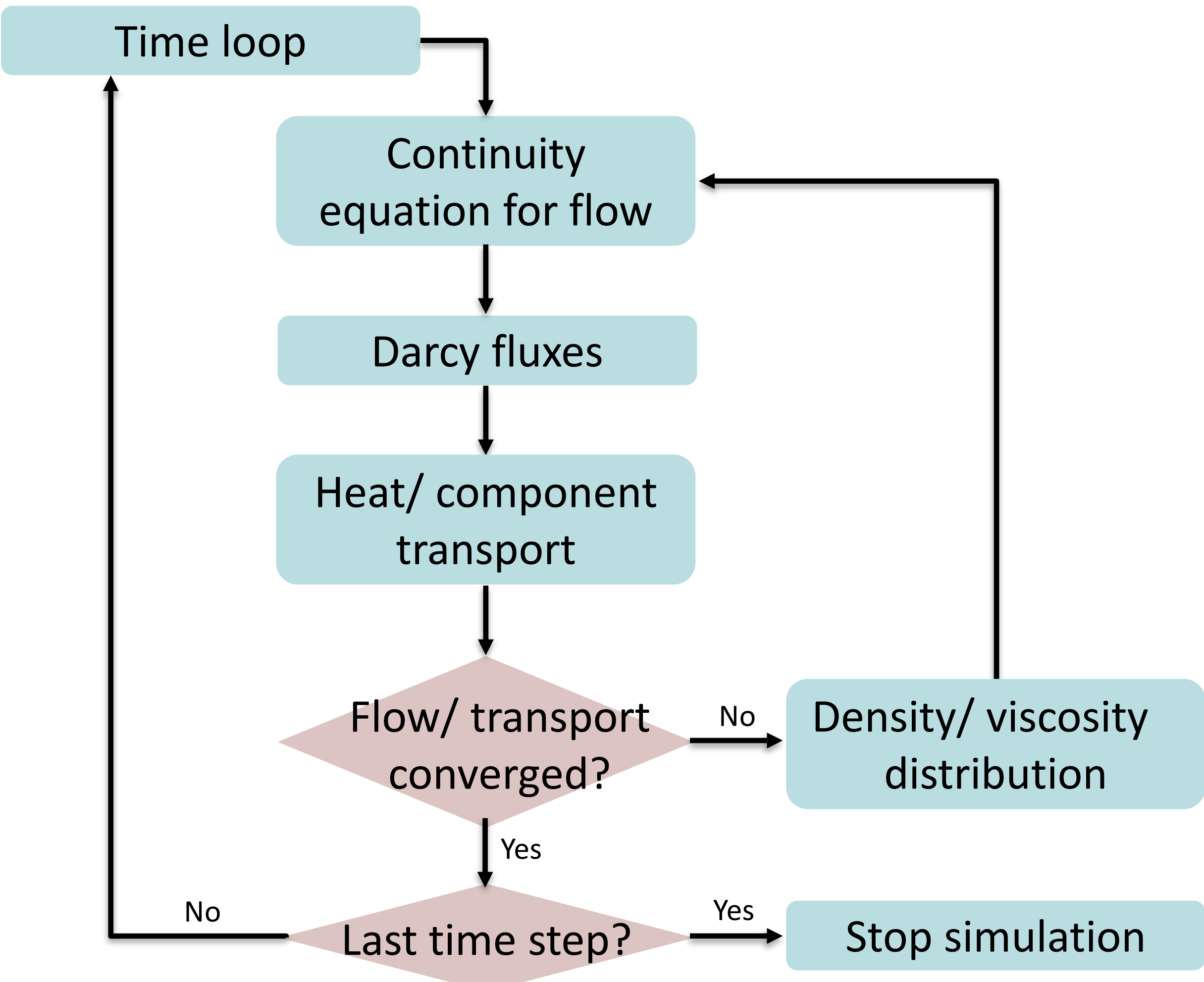
Variable density/viscosity impacts on modelling

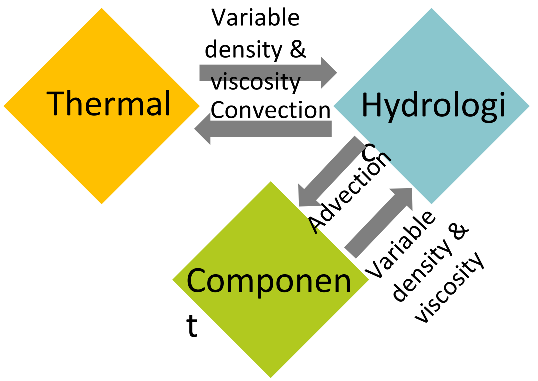
- For Modelling of variable density/viscosity flow processes need to be coupled:
  - Groundwater flow, heat & component transport
- The system of equations are highly nonlinear and need linearization to be solved numerically



- Linearization is achieved by iteration
  - Picard
  - Newton Raphson
- Iterations can lead to extensive computing times and make nonlinear problems costly

Why does variable density/viscosity impacts flow





Adapted from (Molson and Frind 2021)

Literature

- Canova, David P.; Fischer, Mark P.; Jayne, Richard S.; Pollyea, Ryan M. (2018): Advective Heat Transport and the Salt Chimney Effect: A Numerical Analysis. In: *Geofluids* 2018, S. 1–18. DOI: 10.1155/2018/2378710.
- Lide, David R. (Ed.) (2005): CRC Handbook of Chemistry and Physics. Internet Version 2005. Boca Raton, FL: CRC Press.
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- Post, V. E. A.; Prommer, H. (2007): Multicomponent reactive transport simulation of the Elder problem: Effects of chemical reactions on salt plume development. In *Water Resour. Res.* 43 (10). DOI: 10.1029/2006WR005630.