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Flow Partitioning and Viscosity-Driven Dynamics in a Geothermal Multilayer Aquifer of the North German Basin

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MOTIVATION

Changes in Flow Partitioning in multilayer aquifers due to temperature-dependent viscosity?

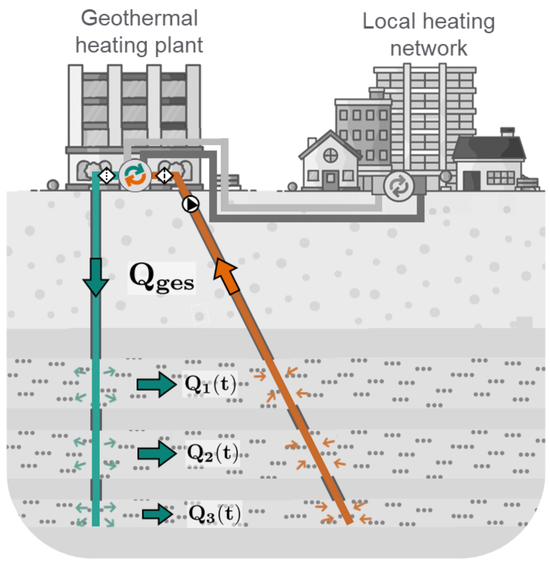


Figure 1. Conceptual sketch of a hydrothermal doublet in a multilayer aquifer.

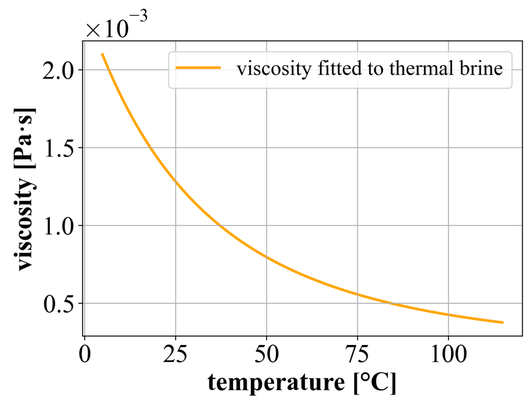


Figure 2. Temperature-dependent viscosity fitted to data for thermal brine (Mao and Duan, 2009).

→ **Darcy:** $$\boxed{q} = -\frac{k}{\eta(T)} \cdot \nabla(p + \rho_l\, g\, \nabla z)$$

MODELING APPROACH

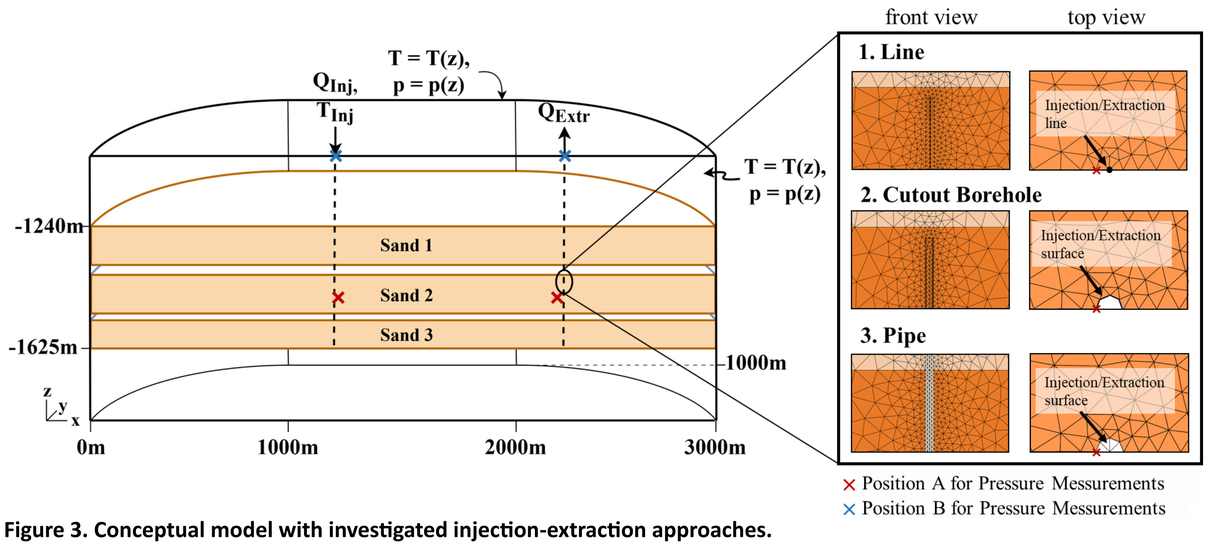


Figure 3. Conceptual model with investigated injection-extraction approaches.

Flow: $$\underbrace{\nabla \boxed{q}}_{\text{flux divergence}} = \underbrace{\Gamma}_{\text{source / sink term}}$$

Heat transport: $$\underbrace{(\rho\, c_p)_{eff}\, \frac{\delta T}{\delta t}}_{\text{time derivative}} - \underbrace{\nabla(\lambda_{eff}\, \nabla T)}_{\text{conduction}} + \underbrace{\rho_l\, c_{p,l}\, \boxed{q} \nabla T}_{\text{advection}} = 0$$

⇒ Numerical simulations were conducted with the open-source software OpenGeoSys (OGS).

Comparing injection/extraction approaches

⇒ The partitioned, imposed flow (line, cutout borehole approach) was distributed according to transmissibility.

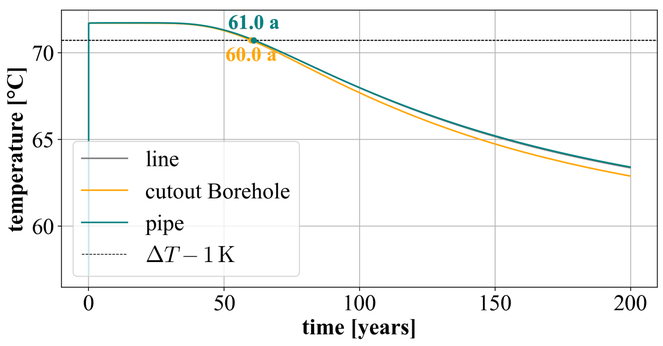


Figure 4. Comparison of production temperature over time across the different modelling approaches.

⇒ The simulated pressure evolution is similar across the model setups.

⇒ Note that the pump-relevant pressure at the top of the domain can only be simulated with the pipe approach.

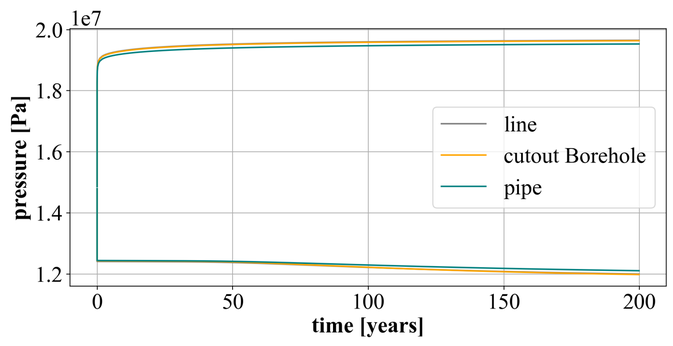


Figure 5. Pressure development over time using different model approaches at position A.

Influence of temperature-dependent viscosity

⇒ Assuming constant viscosity leads to a steady flow field and causes thermal breakthrough (-1°C) to be reached approximately 14% earlier than in the case of temperature-dependent viscosity.

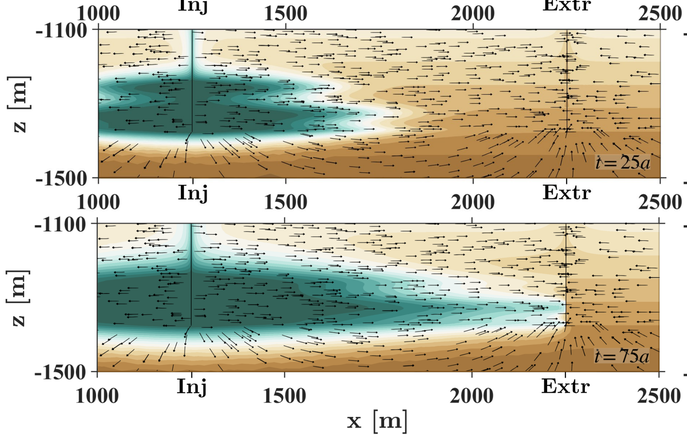


Figure 6. Comparison of production temperature over time in the pipe model using constant and temperature-dependent viscosity.

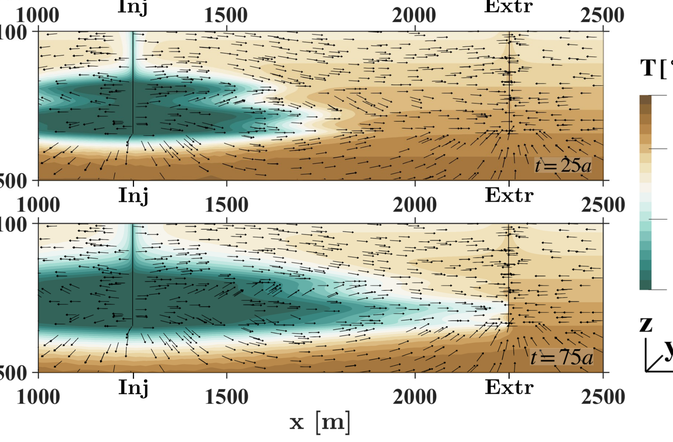


Figure 7. Pressure development over time using constant and temperature-dependent viscosity at position B in the pipe model.

Figure 8. Temporal evolution of the flow field in the pipe model comparing constant and temperature-dependent viscosity, shown for the front view.

COMPUTATIONAL COST

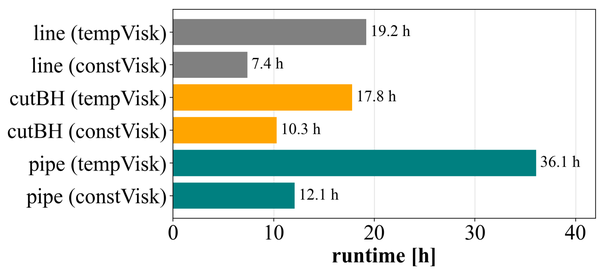


Figure 9. Computational cost of the investigated modelling approaches for a 200-year simulation period.

CONCLUSION

⇒ In a homogeneous multilayer aquifer, transmissibility-weighted forced-flow partitioning across the sandstone layers (line, cutout borehole approach) closely reproduces the free-flow case (pipe approach), supporting this approach for prescribing layer-wise fluxes.

⇒ Including temperature-dependent viscosity is essential in hydrothermal doublet simulations to capture reinjection-driven cooling effects and the associated transient flow redistribution.

⇒ For simplified simulations, the cutout borehole approach with temperature-dependent viscosity offers a favourable balance between computational cost and predictive fidelity.

⇒ For higher-complexity scenarios (e.g., heterogeneous reservoir properties), the pipe model with temperature-dependent viscosity could be better suited to resolve flow distribution across layers.

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