# Assessment of thermal energy storage potential in abandoned mines with a stochastic discrete fracture network model: a case study in Freiberger gneiss

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## Background and introduction

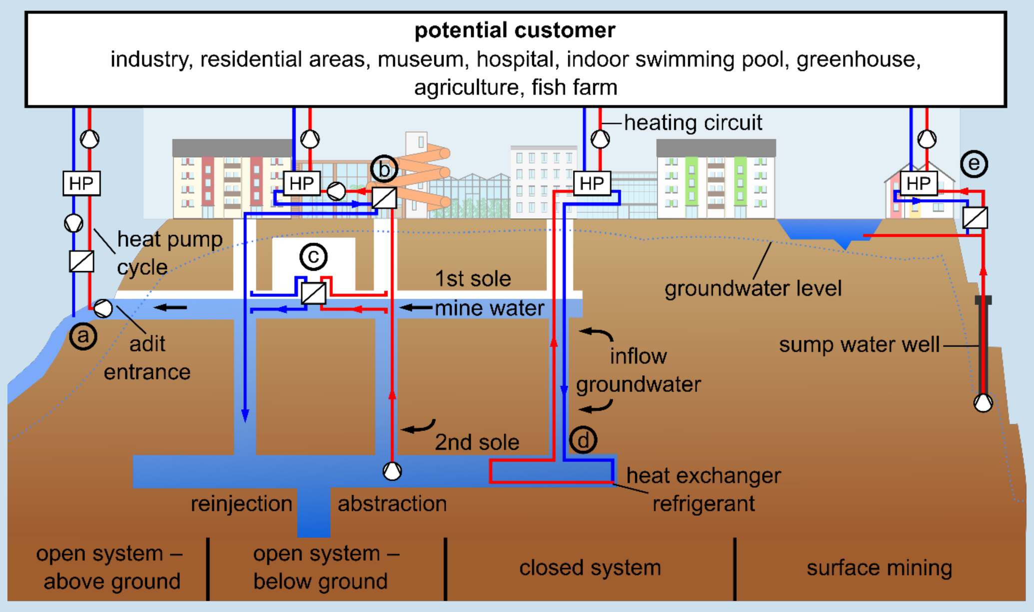


Fig. 1: Geothermal energy utilization with mine water.

- Large-scale Thermal Energy Storage (TES) in subsurface
- Repurposing flooded abandoned mines
- Discrete fractures distributed in surrounding formation
- Mine water acted as the media to store heat in rocks in the operation

## Methodology

### 1. Governing equations of Hydro-Thermo-Component process

(1) Hydraulic equation (pressure):

$$S\frac{\partial p}{\partial t} + \nabla \cdot \mathbf{v}_\mathrm{w} = 0 \tag{1}$$

the Darcy velocity ($\mathbf{v}_\mathrm{w}$) is calculated by,

$$\mathbf{v}_\mathrm{w} = -\frac{k}{\mu}(\nabla p + \rho_\mathrm{w}\mathbf{g}) \tag{2}$$

(2) Heat transport equation (temperature):

$$[\phi\rho_\mathrm{w}c_\mathrm{w} + (1-\phi)\rho_\mathrm{s}c_\mathrm{s}]\frac{\partial T}{\partial t} + \nabla \cdot (\rho_\mathrm{w}c_\mathrm{w}\mathbf{v}_\mathrm{w}T) - \nabla \cdot (\Lambda\nabla T) = 0 \tag{3}$$

(3) Component transport equation (concentration):

$$\frac{\partial(\phi Rc)}{\partial t} + \nabla \cdot (\mathbf{v}_\mathrm{w}c) - \nabla \cdot (\phi D\nabla c) - \phi\alpha Rc = 0 \tag{4}$$

### 2. Model Verification

The model has been implemented in OpenGeoSys (OGS) software and verified with the analytical solution in the single fracture for Hydro-Thermal (HT) and Hydro-Component (HC) process, respectively.

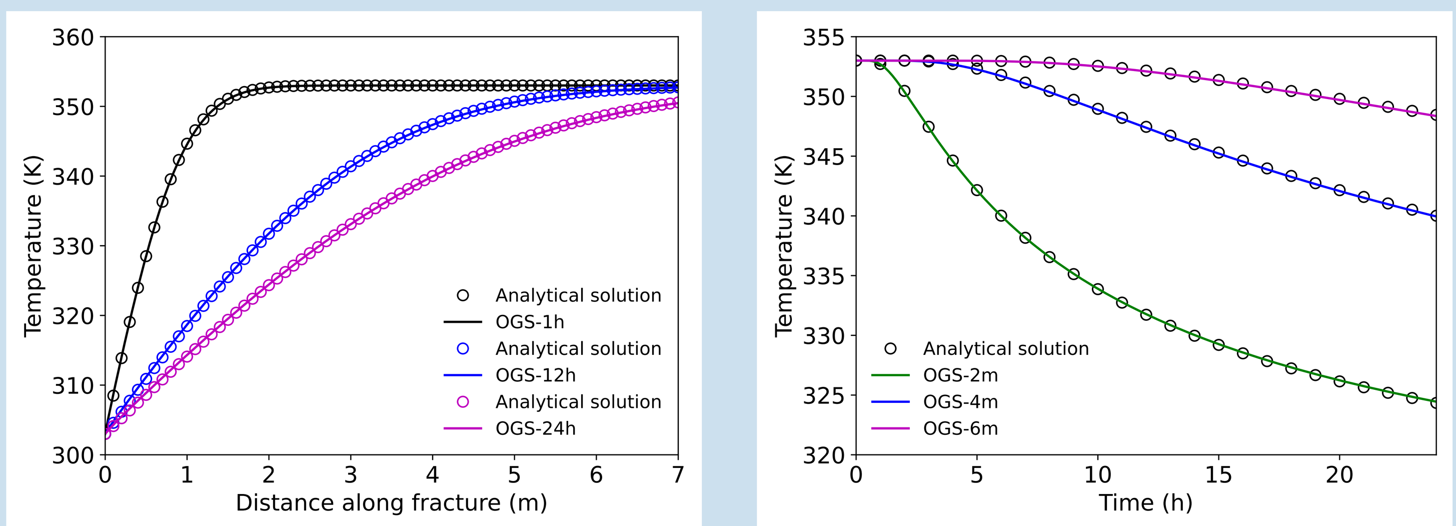


Fig. 2: The model verification results of HT process against the analytical solution (Ma et al. 2020; Juliusson et al. 2012) over (a) the fracture line: the comparison of temperature distribution along the single fracture after 1, 12 and 24 h, and (b) time: The comparison of temperature evolution in the location of 2, 4, 6 m after the cold water continuous injection of 24 h.

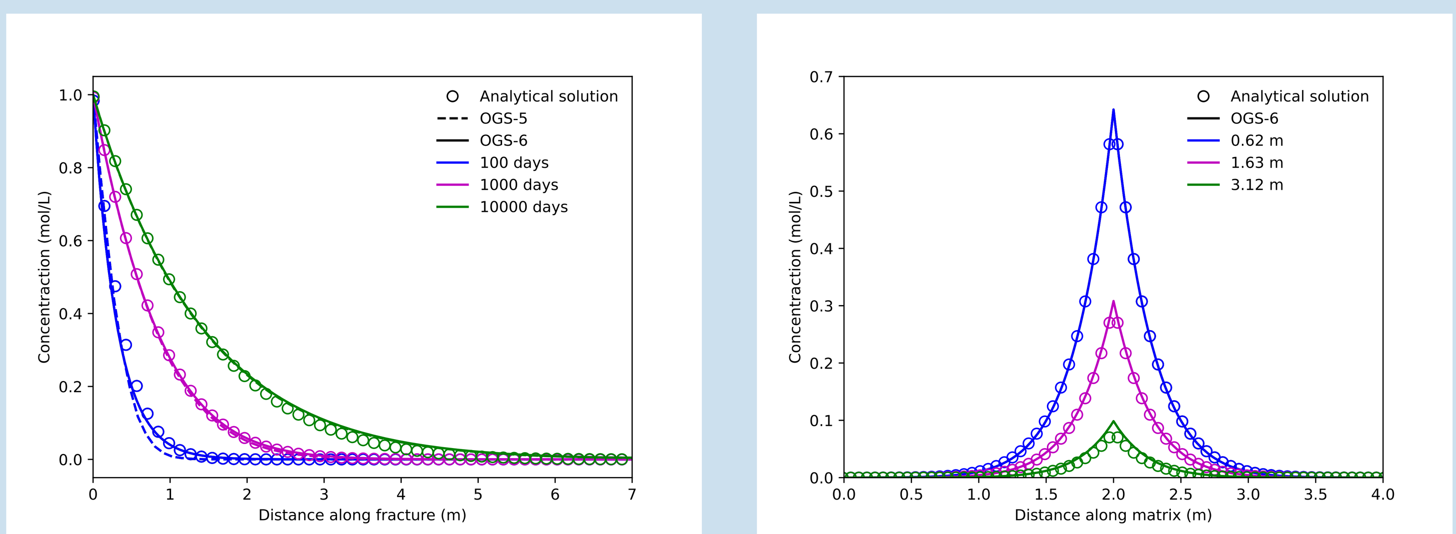


Fig. 3: The comparison results of HC process: (a) The concentration profiles comparison along the fracture after 100, 1000 and 10 000 days among the analytical solution (Tang et al. 1981), OGS-5 (Hu et al. 2022), and OGS-6 results; (b) The concentration distribution in the matrix at the location of 0.62, 1.63 and 3.12 m away from the fracture injection point after 10 000 days.

The finite element method-flux corrected transport (FEM-FCT) is employed.

## Model configuration

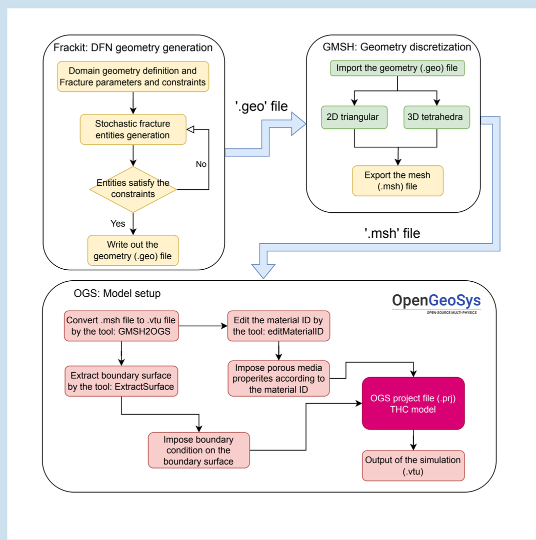

Fig. 4: The flowchart of using Frackit, GMSH and OGS on the model construction and configuration.

- Using Frackit to generate 3D domain with the discrete fracture network (DFN).
- Using GMSH to generate 2D triangular elements for the DFN and 3D tetrahedral elements for the matrix.
- Using OGS to simulate HTC process of heating and cooling scenarios.

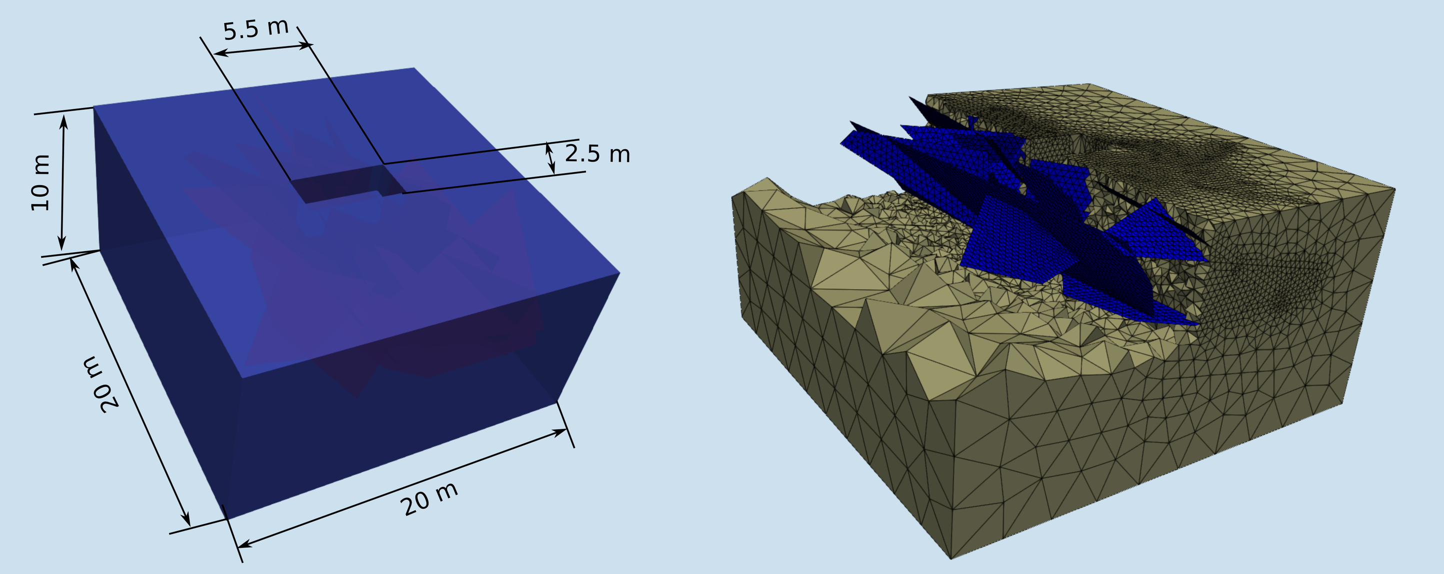


Fig. 5: The generated 3D domain by Frackit with the discrete fracture network around the flooded reservoir based on the site of a pilot mining cavity in Reiche Zeche in Freiberg, Germany: (a) The model geometry, and (b) The mesh for OGS simulations, including tetrahedral elements of the matrix and triangular elements of the embedded DFN. The reservoir depth is 1.7 m.

## Results and discussion

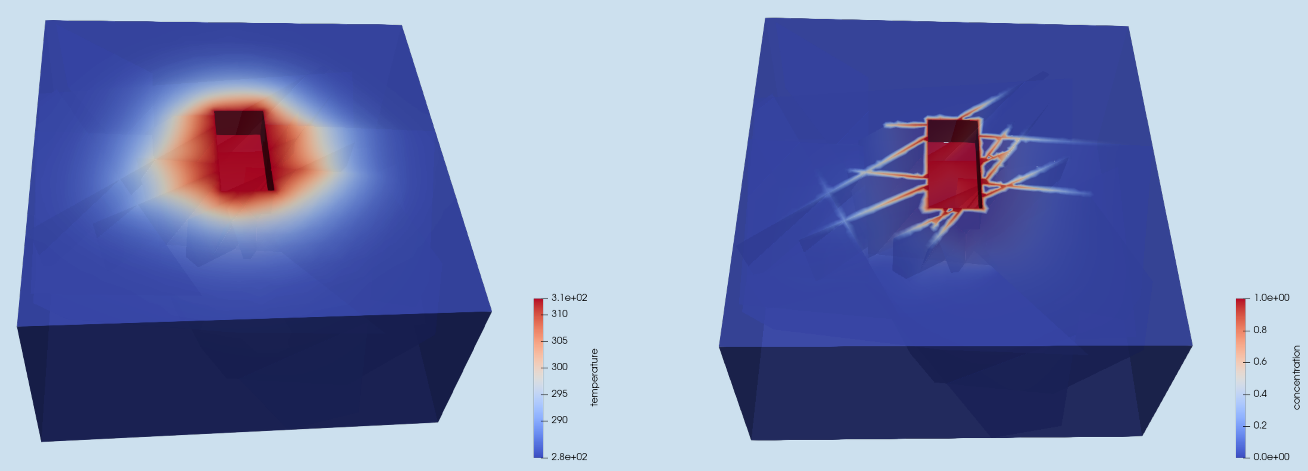

Fig. 6: 3D simulation with DFN embedded in the domain based on Reiche Zeche in Freiberg: (a) The temperature distribution after the reservoir is heated for 15 days, and (b) The concentration distribution after 3 hours.

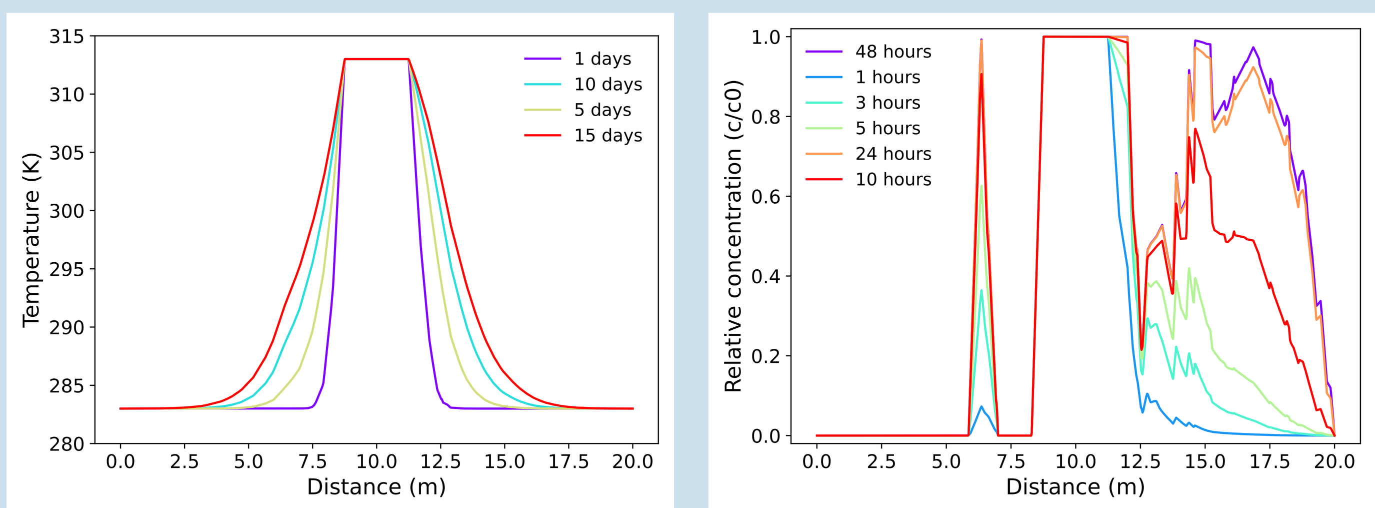


Fig. 7: The temperature and solute distribution over the line cross the middle point of the reservoir length and perpendicular to the length direction: (a) The temperature profiles after different days, and (b) The concentration profiles after different hours.

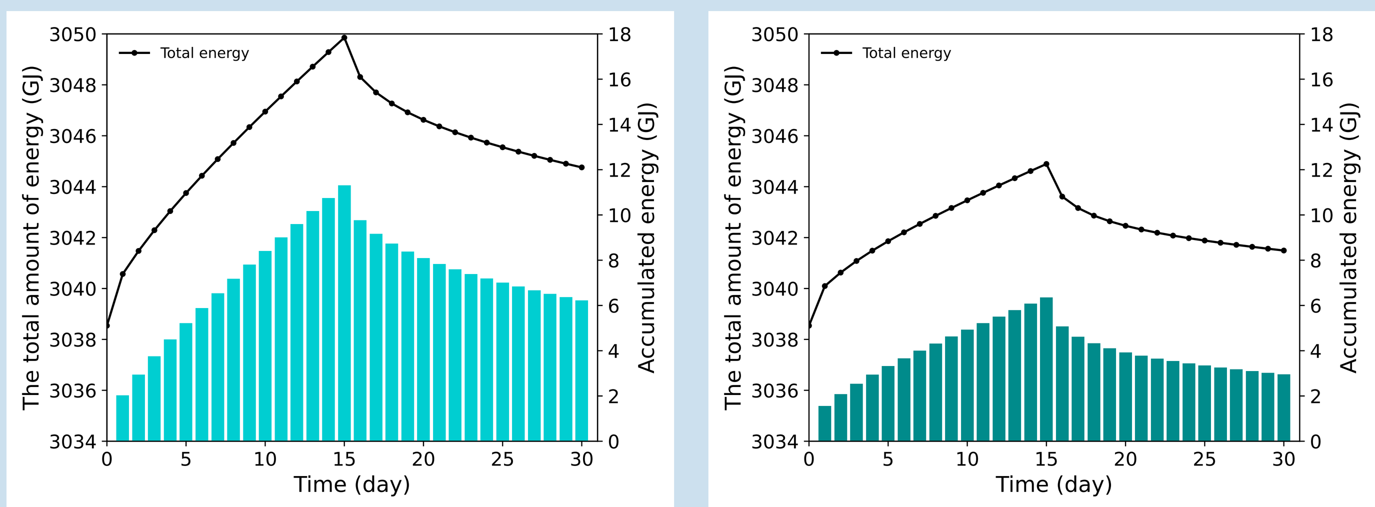


Fig. 8: The amount of total and accumulated energy in the surrounding formation of the cavern reservoir: (a) With the fractured DFN formation, and (b) Without the DFN in the surrounding formation.

## Conclusion

- HTC model has been implemented and verified in the OGS software.
- DFN influence on the heat and mass transport distance is quantified when using mine-based TES systems.
- The fracture density and groundwater flow have significant influence of the thermal energy storage capacity and energy recovery ratio.

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