Exploring the interaction of water extraction and injection in a simplified model of the Chingshui geothermal field using thermal-hydraulic-mechanical coupling numerical models

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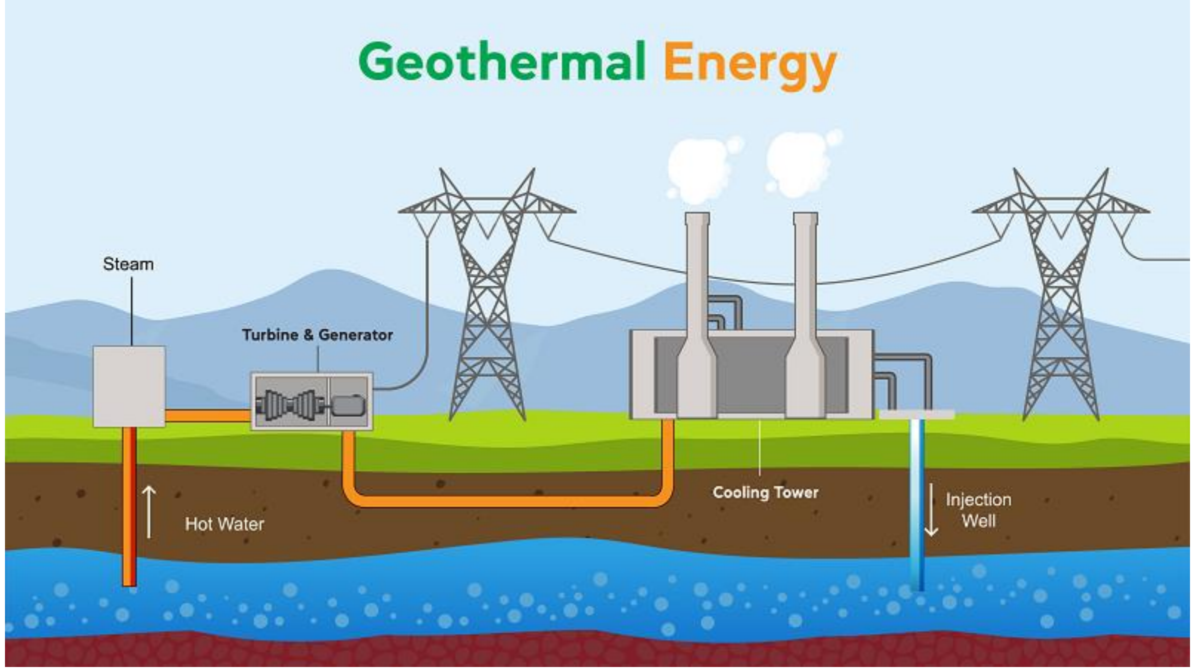
Outline

Introduction

Introduction

◆ Geothermal energy

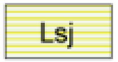


- Geothermal energy is heat energy from the earth.
- Geothermal resources are reservoirs of hot water that exist or are human made at varying temperatures and depths below the Earth's surface.
- Wells, ranging from a few meters to several kilometers deep, can be drilled into underground reservoirs to tap steam and very hot water that can be brought to the surface for use in a variety of applications, including electricity generation, direct use, heating and cooling.

Introduction

◆ Study area

The Chingshui geothermal field is located in Datong Township, Yilan County, and belongs to the Miocene Lushan Formation.

- ✓ Jentse Member 

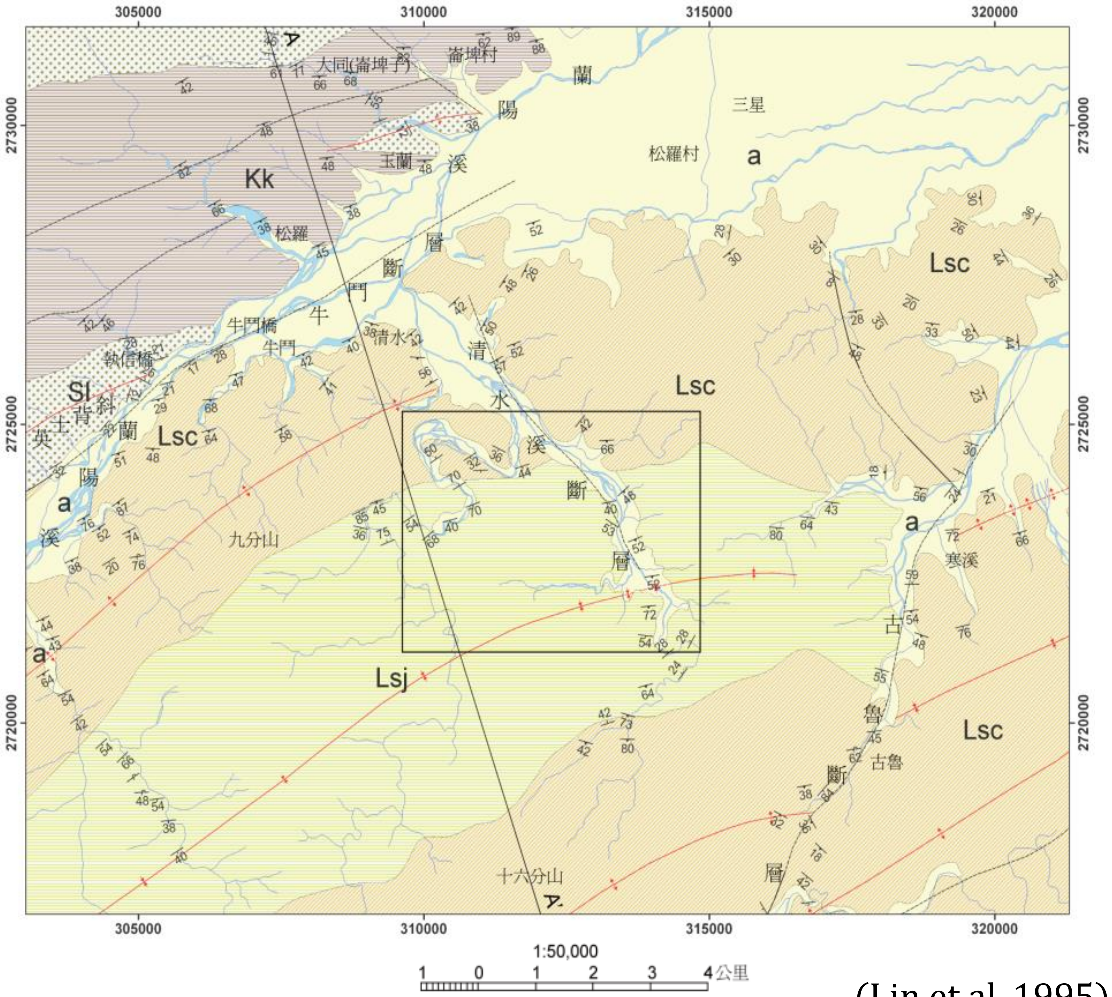
  Argillite or thin Interbeds of Argillite and Meta Sandstone.

- ✓ Chingshuihu Member 

  Argillite or Slate, Occasionally Intercalated with thin Layers of Meta Sandstone.

- ✓ Chingshuihsi fault

  Considered an important conduit for guiding the upward flow of heat.



(Lin et al, 1995)

Introduction

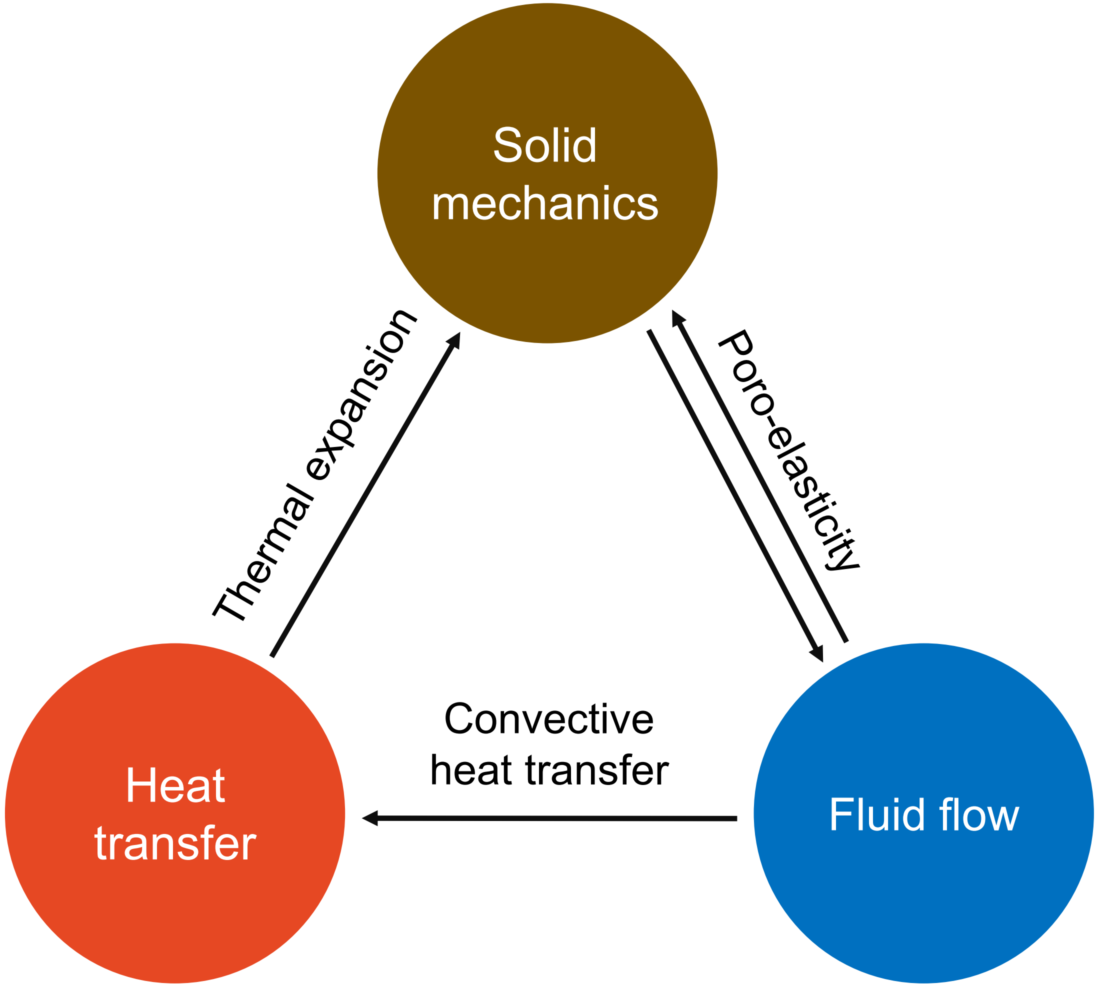
- Objective
  - Exploring the impact of thermal-hydraulic-mechanical coupling in geothermal production processes.
  - Observing the impact of different parameters (porosity, pumping rate, and injection water temperature) on simulation results.

Introduction

◆ Thermal-Hydraulic-Mechanical coupling

Governing equations

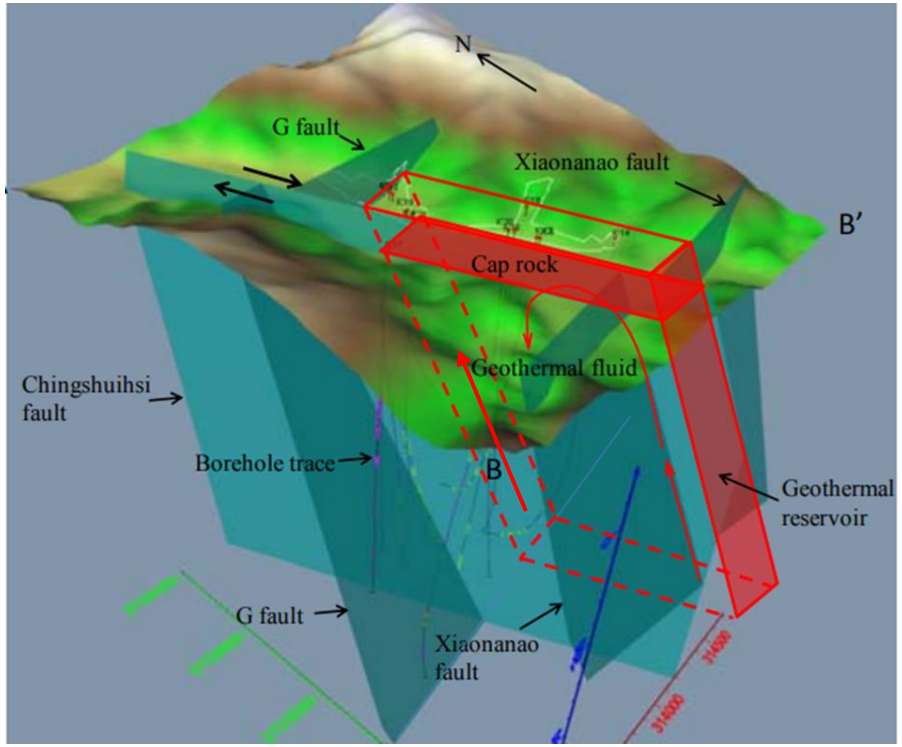
- $v = -\frac{k}{\mu}(\nabla p + \rho_f g \nabla D)$
- $G\nabla^2 u_i + \frac{G}{1-2\mathrm{v}}\frac{\partial^2 u_k}{\partial x_i \partial x_k} = \alpha\frac{\partial p}{\partial x_i} - (\rho_s + n\rho_f)g$
- $\rho_f \alpha \frac{\partial}{\partial t}(\nabla \cdot \boldsymbol{u}) + \rho_f S \frac{\partial p}{\partial t} + \nabla \cdot (\rho_f v) = Q_m$
- $(c\rho)_{eff}\frac{dT}{dt} + c_f \rho_f v \cdot \nabla T + \nabla \cdot (-k_{Teff}\nabla T) = Q_T$



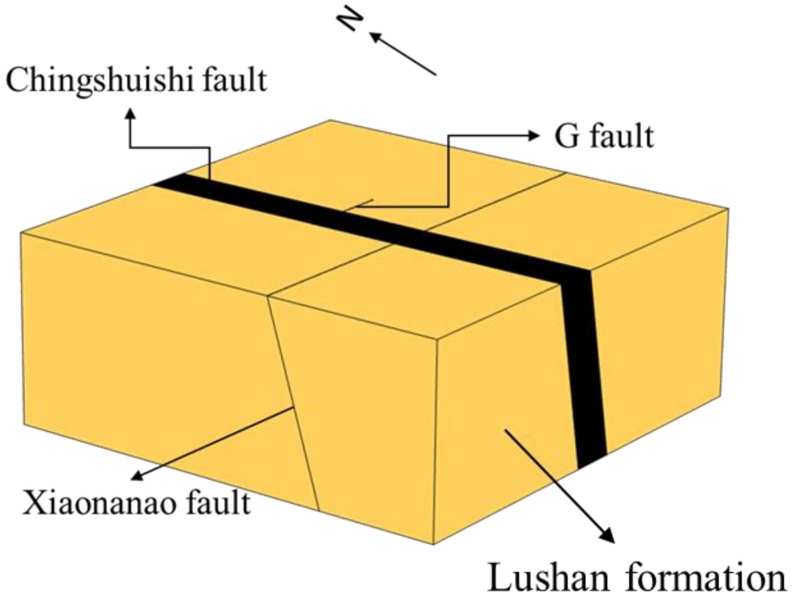
Methodology

Methodology

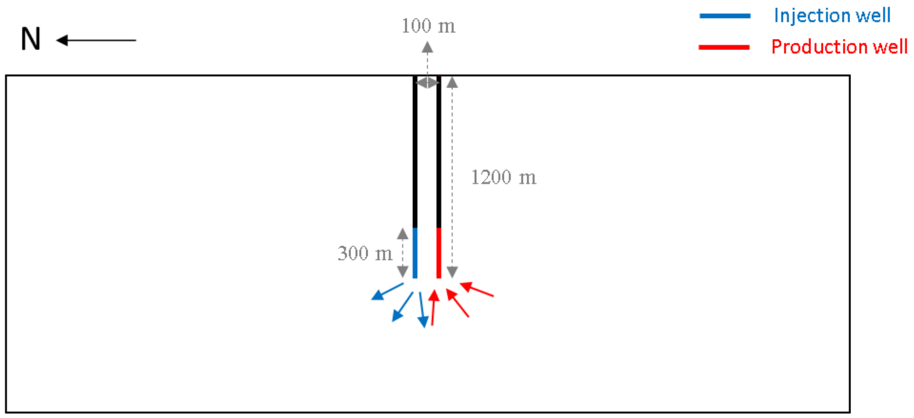
◆ Conceptual model & Geological model



⬆ Conceptual model of Chingshui geothermal field (Lee et al, 2012)



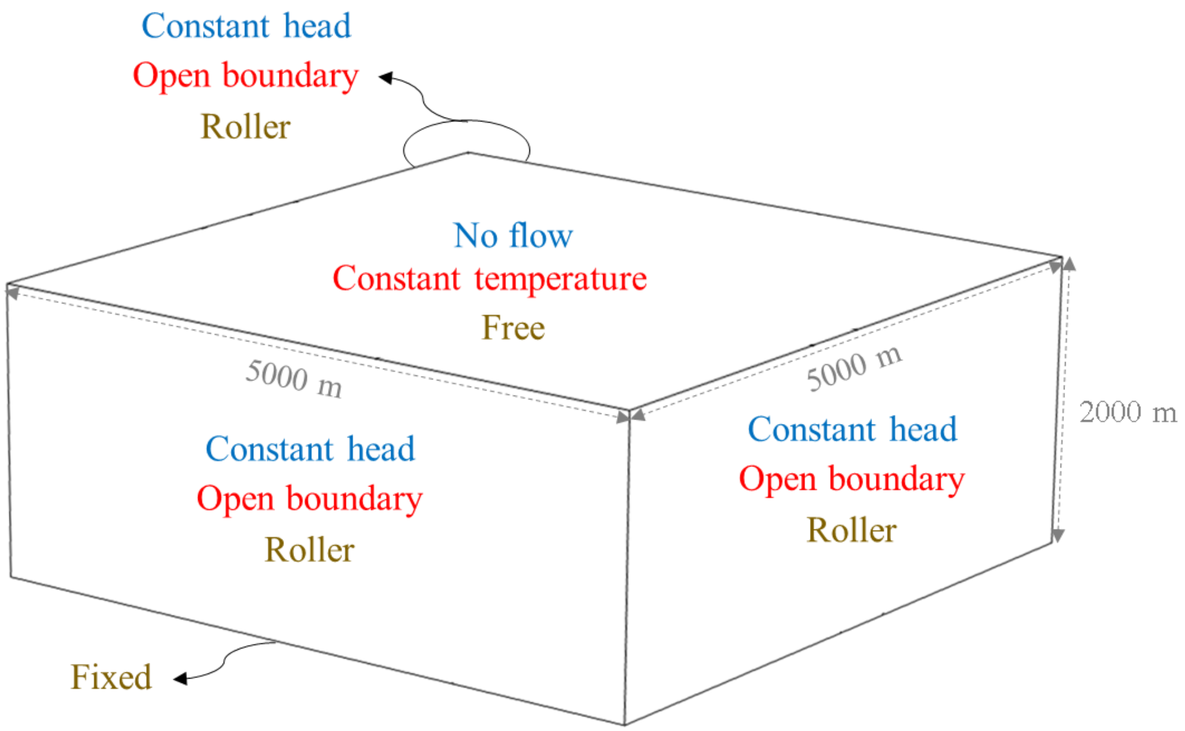
⬆ Simplified geological model



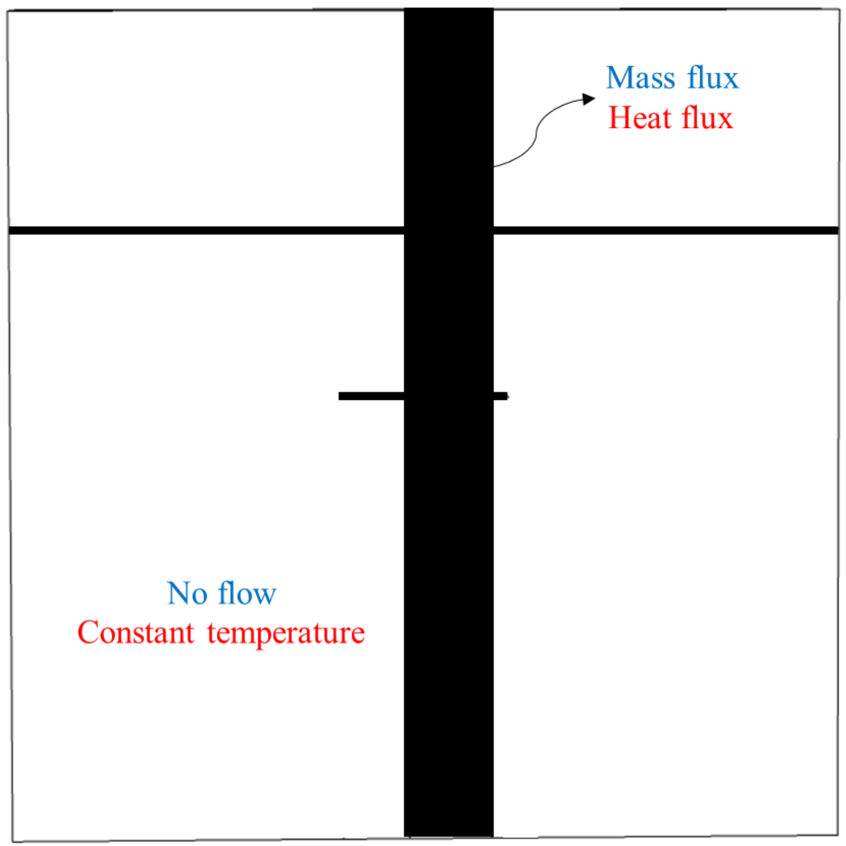
⬆ Injection & production well

Methodology

◆ Boundary conditions



Bottom view



Methodology

◆ initial conditions

- Given the model with a top boundary temperature of 20 °C and an increasing geothermal gradient (65°C /km) from top to bottom.

- Given the model a hydraulic gradient (0.1 mm/m), causing groundwater flow from south to north.

Fluid & Matrix parameter settings

Parameter	Unit	Fluids
		Water (20˚C)
Density	$\frac{kg}{m^3}$	997.03
Compressibility	$\frac{1}{Pa}$	4.44×10^{-10}
Dynamic viscosity	$Pa \cdot s$	8.925×10^{-4}
Heat capacity	$\frac{J}{kg \cdot K}$	4200
Thermal conductivity	$\frac{W}{m \cdot K}$	0.6

Parameter	Unit	Matrix			
		Lushan Formation	**Chingshuishi fault**	**Xiaonanao fault**	**G fault**
Density	$\frac{kg}{m^3}$	2700			
Porosity	–	0.015	0.05	0.1	0.1
Young's modulus	Pa	3.17×10^{10}			
Poisson ratio	–	0.31			
Permeability	m^2	10^{-16}	10^{-14}	10^{-14}	10^{-10}
Thermal conductivity	$\frac{W}{m \cdot K}$	3			
Heat capacity	$\frac{J}{kg \cdot K}$	800			
Thermal expansion coefficient	$\frac{1}{K}$	13×10^{-6}			

Methodology

◆ Sensitivity analysis

The parameter sensitivity analysis in this study involved varying parameters such as **porosity**, geothermal well **flow rate**, and **injection water temperature** by **±50%** from the base-case values to observe their impact on the simulation results.

Parameter	Unit	Matrix			
		Lushan Formation	**Chingshuishi fault**	**Xiaonanao fault**	**G fault**
permeability	m^2	10^{-16}	10^{-14}	10^{-14}	10^{-10}
Flow rate	$\frac{ton}{hr}$	60			
Injection temperature	$°C$	60			

⬆ The parameter settings for the base-case

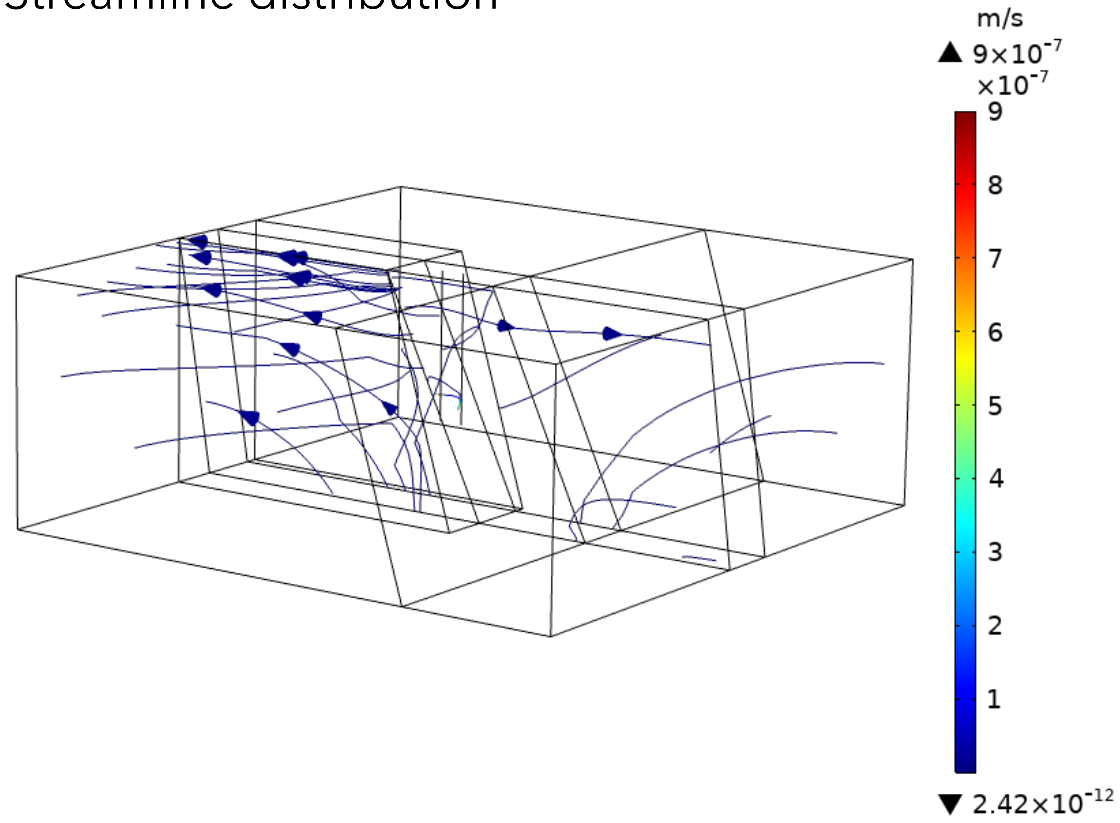
Results

Results

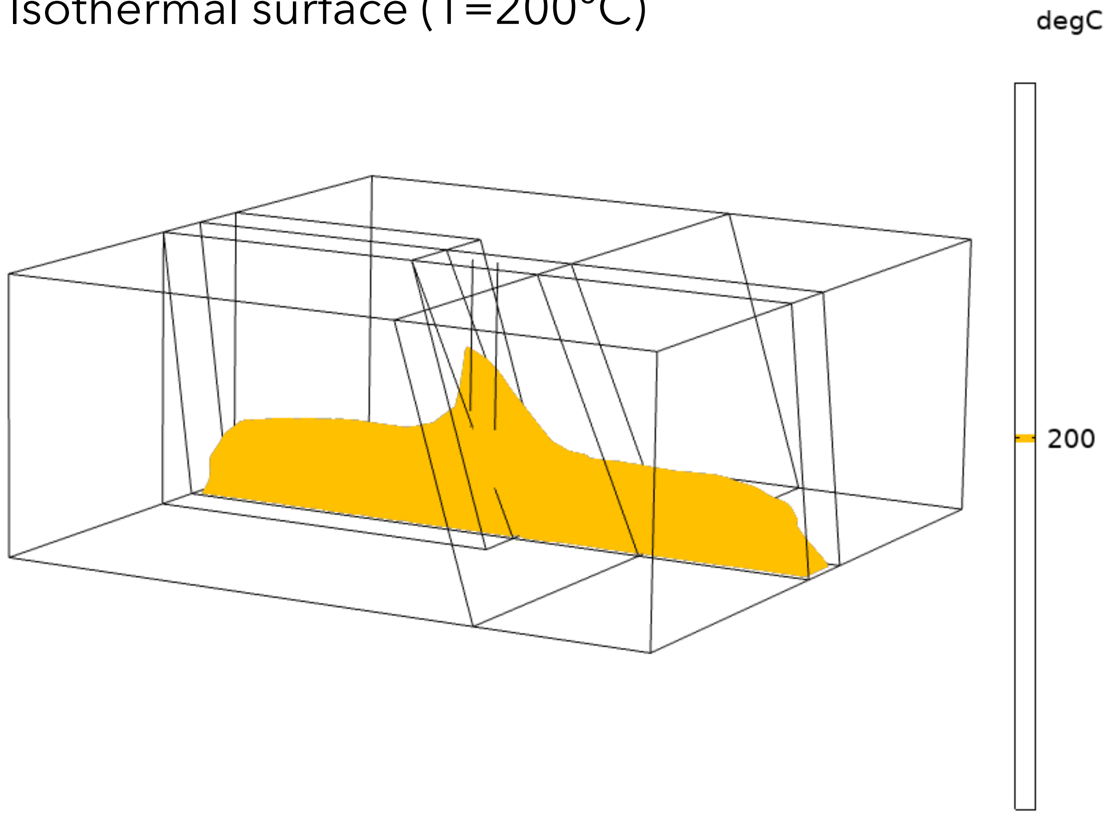
✓ In a steady-state simulation, the model ran for fifty thousand years until all the physical fields reached a steady state.

◆ Steady-state simulation

➢ Streamline distribution



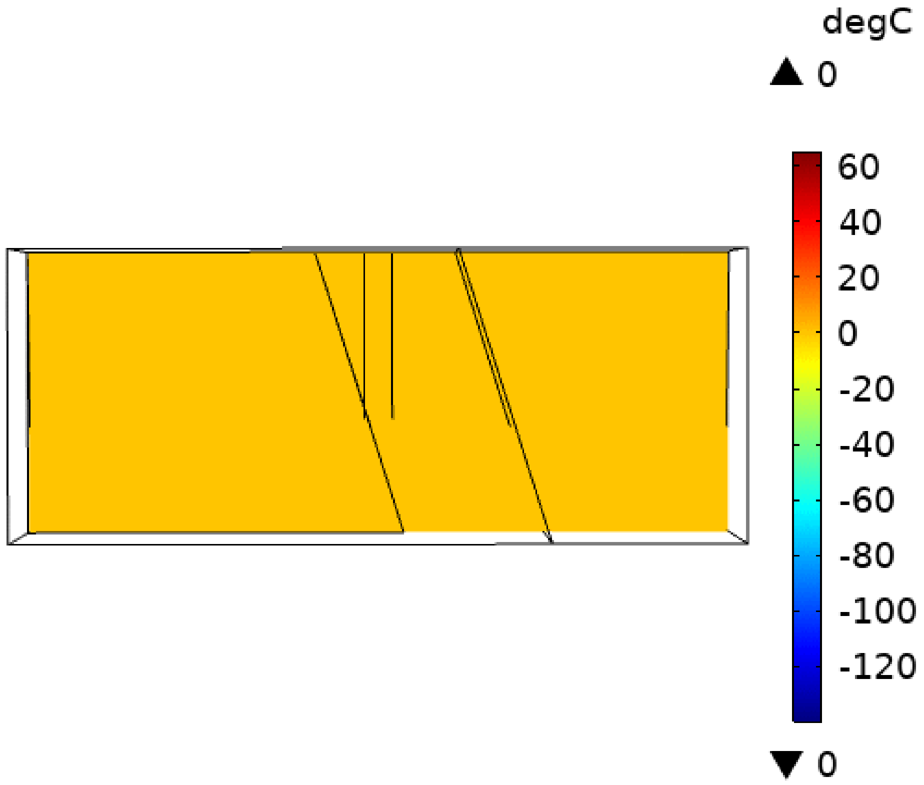
➢ Isothermal surface (T=200°C)



Results

◆ Transient simulation

✓ In a transient simulation, the geothermal well was activated to begin pumping, and the simulation ran for 30 years.



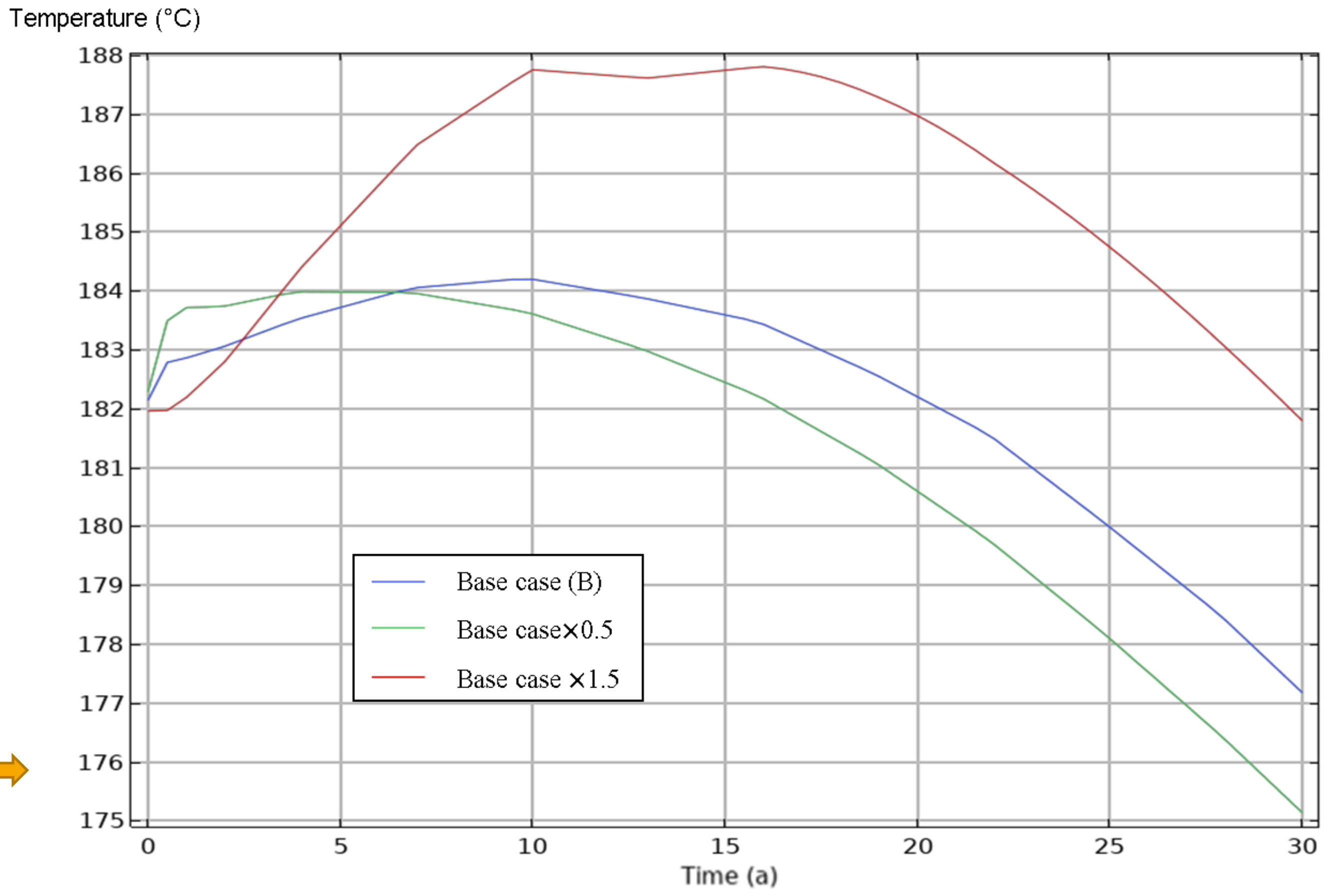
Temperature changes during cold water injection

Results

◆ Impact of permeability

Case	Initial	After 30a	Difference
B	182.38°C	177.18°C	-5.2°C
B×0.5	183.49°C	175.14°C	-8.35°C
B×1.5	181.96°C	181.80°C	-0.16°C

Temporal variation of temperature around the production well

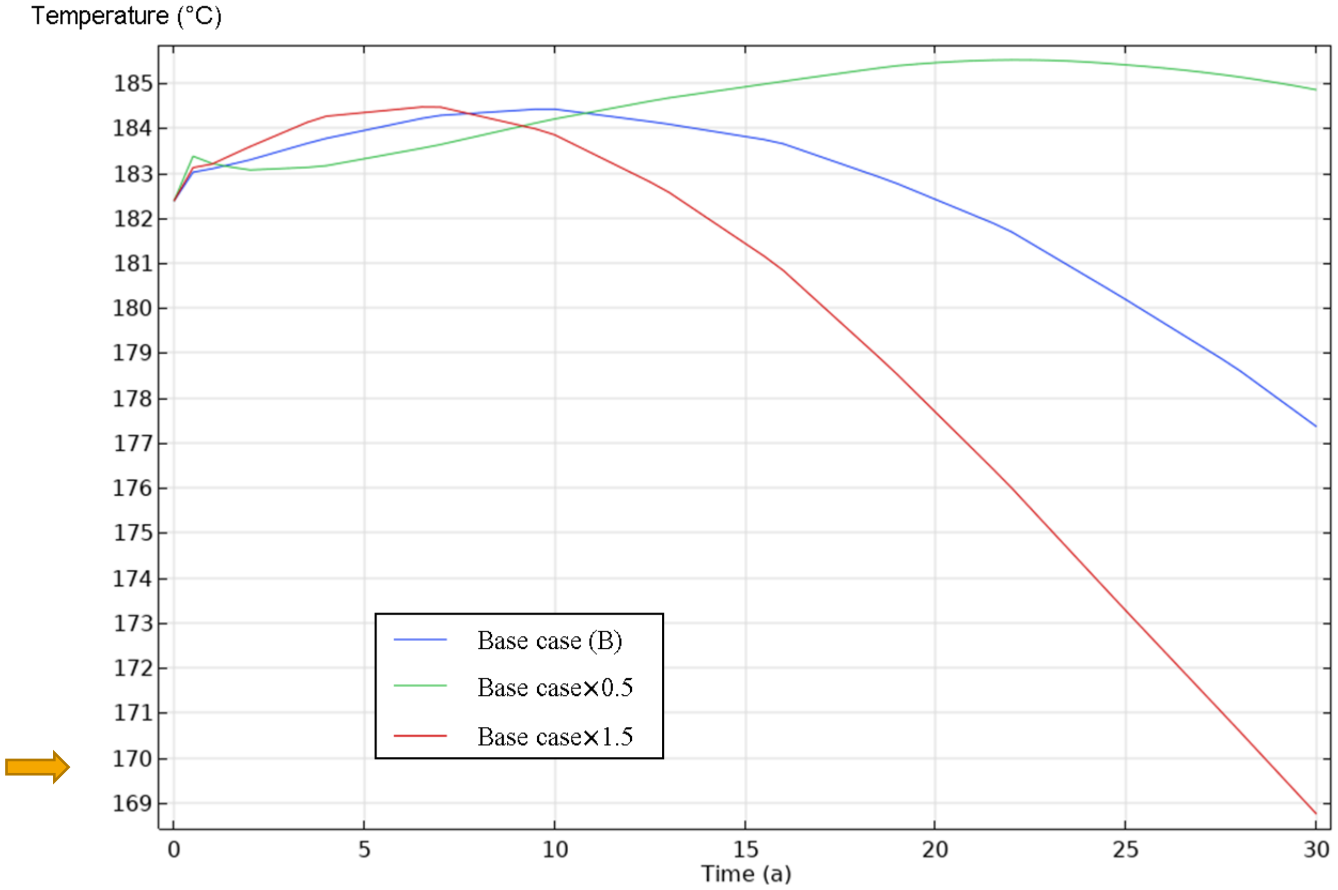


Results

◆ Impact of different pumping rates (with hydraulic gradients = 0.1 mm/m)

Case	Initial	After 30a	Difference
B	182.38°C	177.36°C	-5.02°C
B×0.5	182.38°C	184.85°C	+2.47°C
B×1.5	182.38°C	168.75°C	-13.63°C

Temporal variation of temperature around the production well

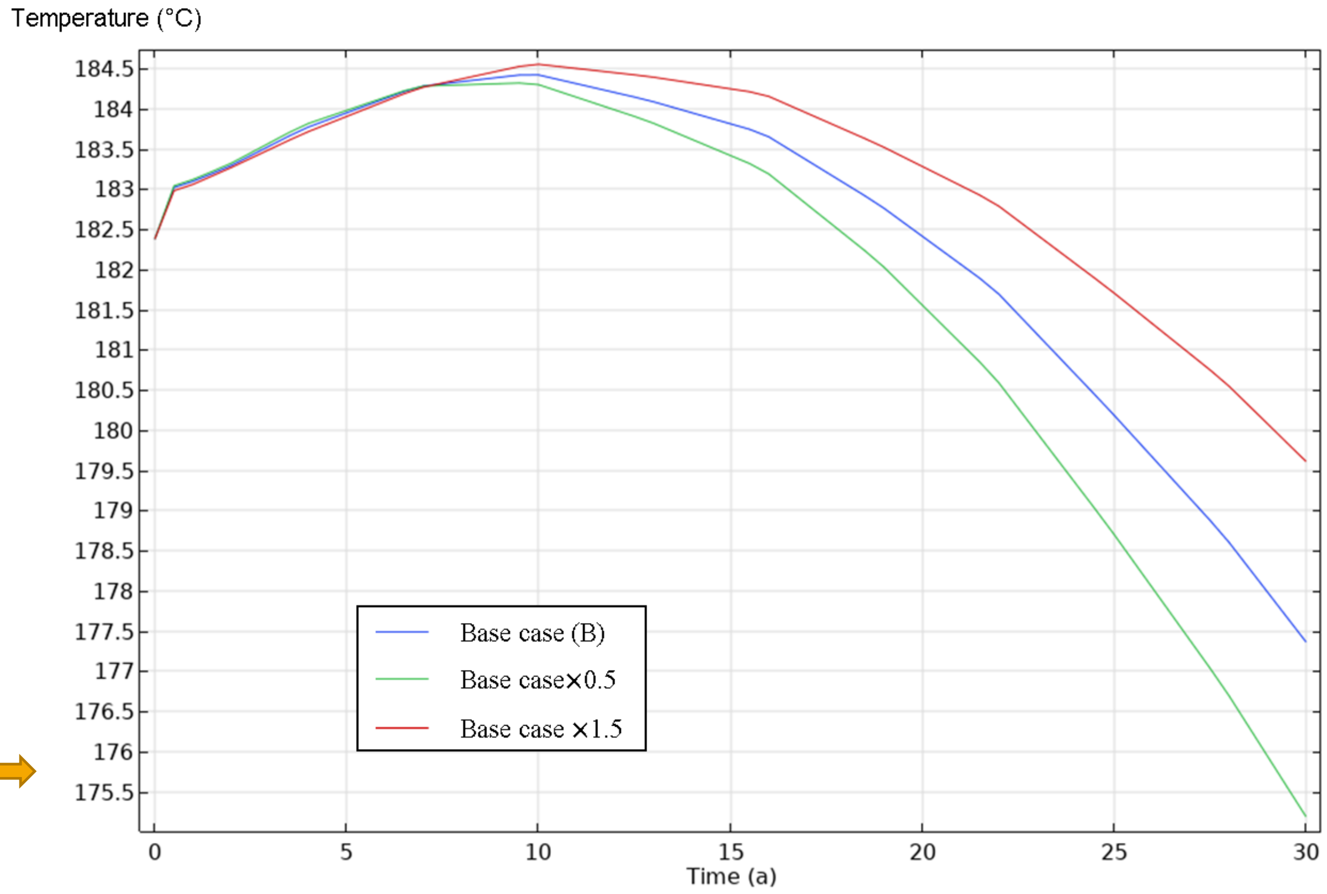


Results

◆ Impact of different injection temperatures (with hydraulic gradients = 0.1 mm/m)

Case	Initial	After 30a	Difference
B	182.38°C	177.36°C	-5.02°C
B×0.5	182.38°C	175.19°C	-7.09°C
B×1.5	182.38°C	179.61°C	-2.77°C

Temporal variation of temperature around the production well



Conclusions

Conclusions

- This study successfully established a thermal-hydraulic-mechanical coupled numerical model. The results of parameter sensitivity analysis indicate that the production temperature exhibits higher sensitivity to pumping rate and permeability, while showing lower sensitivity to the injection water temperature.

- In future work, the actual distribution of geothermal well locations and pumping rate data will be incorporated. Based on the results of this study, a more careful parameter setup for the numerical model will be conducted, considering the impact of dependent parameters on the system.

Thank you for listening