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Estimation of Rock Temperature in Geothermal Reservoir by Coupled THMC Model

Keywords: Geothermal, THMC, Rock Temperature

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Introduction

Estimation of rock temperature in Geothermal reservoir has been studied for Enhanced Geothermal System (EGS). It is necessary to develop new geothermal reservoir and improve production performance of EGS (Brehme *et al.*, 2016; Yao *et al.*, 2018). Thermal-hydraulic-mechanical (THM) coupling was used to simulate and analyze the heat extraction in EGS (Yao *et al.*, 2018). In this study, TH coupled was used to estimate the rock temperature in geothermal reservoir by adopting fractured porous media model.

Methods

The fractured porous media model consists of two parts; there are the rock matrix and discrete fractures. The rock matrix permeability is less than that of the discrete fractures. Because of that, flow in the rock matrix was calculated by Darcy's law and that in the discrete fractures was done by the modified Darcy's law. The equations for the rock matrix and discrete fracture flow are expressed as (Liang *et al.*, 2016):

$$S\frac{\partial p}{\partial t} + \nabla\left(-\frac{\kappa}{\eta}(\nabla p + \rho_w g \nabla z)\right) = -\frac{\partial e}{\partial t} + Q \quad (1)$$

$$d_f S_f \frac{\partial p}{\partial t} + \nabla_\tau\left(-d_f\frac{\kappa_f}{\eta}(\nabla_\tau p + \rho_w g \nabla_\tau z)\right) = -d_f\frac{\partial e_f}{\partial t} + Q_f \quad (2)$$

Where S is the rock matrix storage coefficient [1/Pa], p is the hydrostatic pressure [Pa], t is the time [s], κ is the rock matrix permeability [m^2], η is the dynamic fluid viscosity [Pa·s], ρ_w is the fluid density [kg/m^3], g is the gravitation [m/s^2], e is the volumetric strain of rock matrix [-], Q is the source-sink term of the seepage process [s^{-1}], d_f is the discrete fracture thickness [m], S_f is the discrete fracture storage coefficient [1/Pa], ∇_τ is the gradient operator restricted to the fracture's tangential plane, κ_f is the discrete fracture permeability [m^2], e_f is the volumetric strain of discrete fracture [-], Q_f is the flow exchange between rock matrix and discrete fracture [s^{-1}].

Energy conservation in rock matrix is described as (Saeid *et al.*, 2013):

$$\rho C_s\frac{\partial T_s}{\partial t} + \nabla\cdot(-\lambda\nabla T_s) = 0 \quad (3)$$

Where ρ is the rock density [kg/m^3], C_s is the specific heat capacity of rock matrix [J/kg/K], T_s is the rock temperature [^{o}C], λ is the thermal conductivity of rock [W/m/K].

Energy conservation in discrete fracture is defined as (Chen *et al.*, 2013):

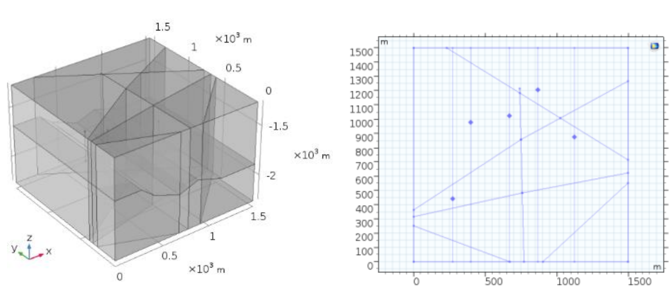
$$d_f\rho_w C_w\frac{\partial T_f}{\partial t} + d_f\rho_w C_w\cdot u_f\nabla_\tau T_f = \nabla_\tau\cdot\left(d_f\lambda_f\nabla_\tau T_f\right) + h(T_s - T_f) \quad (4)$$

Where C_w is the specific heat capacity of fluid [J/kg/K], T_f is the water temperature in the discrete fracture [^{o}C], u_f is the fluid flow velocity in the discrete fracture, λ_f is the thermal conductivity of fluid [W/m/K], h is the convection efficiency [W/m^2/K].

EGS case from Lahendong Geothermal field located in Tomohon, North Sulawesi, Indonesia, is simulated to evaluate EGS reservoir temperature. In this study, there are five wells in the cluster 5 comprising three injection wells (LHD-19, LHD-20, LHD-21) and two production wells (LHD-5, LHD-23). At the production wells, 40 kg/s of steam was supplied, and the temperature of the injection well is 70 °C. Initial temperature in the reservoir is 230 °C, and the hydrostatic pressure is 12 MPa. The length of the well-slotted liner is 300 m. **Figure 1** shows the 3D computational model in COMSOL Multiphysics in (1500m x 1500m x 1000 m). Parameters used in this model are listed in **Table 1.**

Table 1: Model parameters in reservoir

Parameter	Value	Parameter	Value
ρ_w [kg/m^3]	1,000	S_f [1/Pa]	1.0 x 10^{-9}
η [Pa·s]	9.54 x 10^{-5}	C_s [J/kg/K]	1000
C_w [J/kg/K]	4,200	λ_s [W/m/K]	3
λ_f [W/m/K]	0	α_T [1/K]	2.0 x 10^{-6}
h [W/m^2/K]	3000	ϕ	0.01
ρ_s [kg/m^3]	2720	d_f [m]	0.001
κ [m^2]	1.0 x 10^{-15}	κ_f [m^2]	1.00 x 10^{-10}
S [1/Pa]	1.0 x 10^{-8}	g [m/s^2]	9.81



(a) 3D Geometry (b) a cut plane at Z = 500 m

Figure 1: Model geometry in COMSOL Multiphysics

熱 - 水 – 力学 - 化学連成モデルによる地熱貯留槽の岩盤浸透率変化の推定

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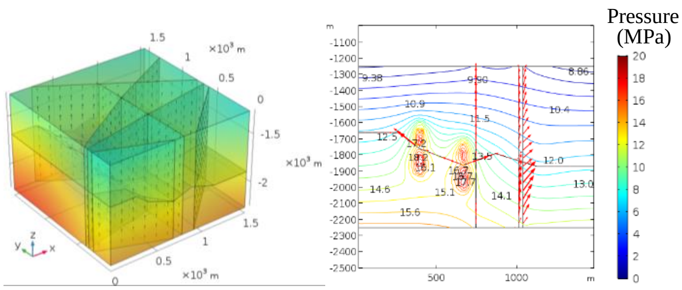
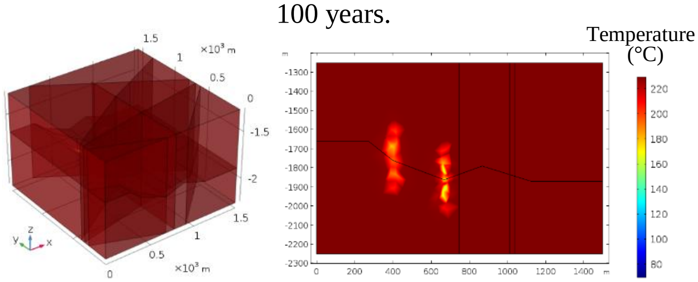
Results

The evolution of pressure distribution and velocity for 100 years is shown in **Figure 2**. The increasing of the water pressure clarifies fluid flow particularly through the fracture rather than that of the rock matrix. The fractures that may be a main seepage pathway will directly influence heat transport significantly in the geothermal reservoir.

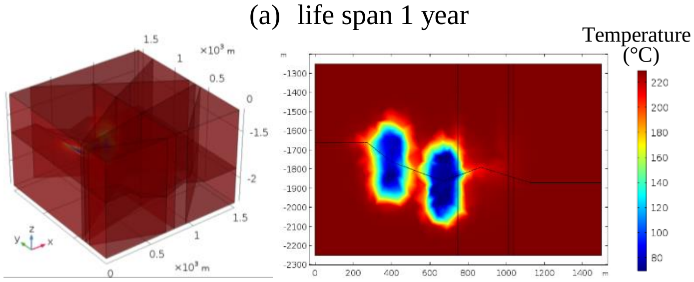


(a) fracture surface (b) a cut plane at Y = 1000 m

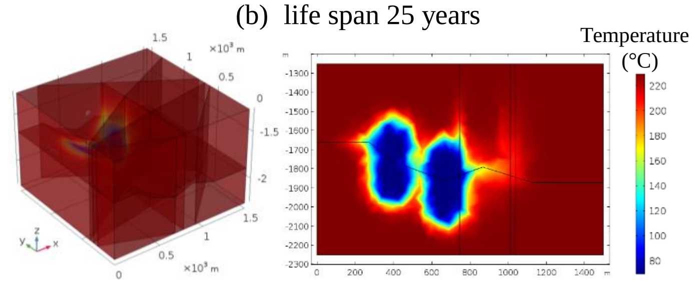
Figure 2: Pressure and velocity distribution for life span 100 years.



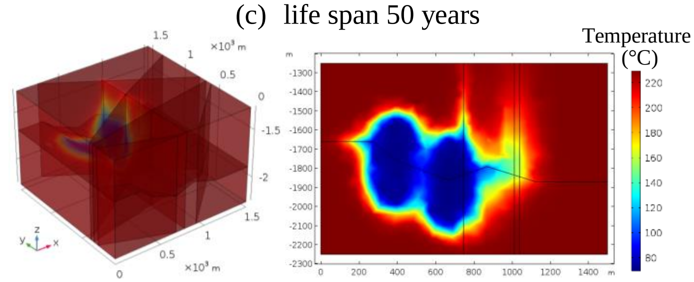
(a) life span 1 year



(b) life span 25 years



(c) life span 50 years



(d) life span 100 years

Figure 3: Temperature evolution in the fracture and a cut plane at y = 1000 m.

The change of the rock temperature distribution with time is shown in **Figure 3**. In the initial stage, with the injection of 70 °C water temperature, the rock temperature exchange occurs between rock matrix and discrete fractures. The temperature of rock mass at the discrete fracture surface decreases quickly compared to the rock matrix region. The effect of temperature convection in discrete fractures are more significant due to the high fluid velocity. Because of that, the rock temperature evolution performance extremely depend on the circulation of fluid. However, the rock temperature near from the production wells almost has no change, so the system can guarantee the sustained and stable output of heat.

Conclusion

TH coupling by adopting fractured porous media model was established to estimate the rock temperature of the Lahendong geothermal reservoir. Discrete fractures become more important media for distribution of the rock temperature than rock matrix. However, the effects of mechanical and chemical reaction on the consequence of thermal recovery are not considered. In the future, the effects of mechanical and chemical reaction should be studied to integrate and describe the actual conditions in EGS.

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