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Evaluation of Rock Temperature Evolution in the Lahendong Geothermal Reservoir, North Sulawesi Indonesia: Preliminary Results

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Introduction

Natural state simulations in the Lahendong geothermal field has been studied. It is necessary to find out the reservoir characteristics, hydrogeology, location and total energy of the heat source. Several conceptual and numerical models have been developed to do such investigation. In this study, we tried to improve the numerical model that was developed by Yani (2006). COMSOL Multiphysics (COMSOL 5.3a, 2017) was used for modeling the 3D numerical model to predict the evolution of rock temperature in the steady-state condition. The steady-state conditions have been reached when the numerical results corresponding to the wells temperature data.

Methods

The coupled mass and heat transfer in porous media are used in this model. Flow in the rock matrix is calculated by Darcy's law and that in the discrete fractures is done by the modified Darcy's law. The equations for the rock matrix and discrete fracture flow are expressed by:

$$\frac{\partial}{\partial t}(\rho_w \phi) + \nabla \cdot (\rho_w \cdot -\frac{K}{\mu}\nabla p) = Q_m \quad (1)$$

$$d_f \frac{\partial}{\partial t}(\rho_w \phi_f) + \nabla_T \cdot (d_f \rho_w \cdot -\frac{K_f}{\mu}\nabla_T p) = d_f Q_m \quad (2)$$

where t is the time [s], ρ_w is the fluid density [kg/m^3], ϕ is the rock matrix porosity [-], κ is the rock matrix permeability [m^2], μ is the dynamic fluid viscosity [Pa·s], p is the hydrostatic pressure [Pa], Q_m is the mass source [kg/m^3/s], d_f is the discrete fracture thickness [m], ϕ_f is the discrete fracture porosity [-], and κ_f is the discrete fracture permeability [m^2].

Energy conservation in rock matrix and discrete fracture area described as:

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

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

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], 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].

The Lahendong geothermal field is located in Tomohon, North Sulawesi, Indonesia. Currently, the Lahendong geothermal field has six units with a total production capacity of 120 MW. The locations of injection and production wells are shown in **Figure 1**. The rocks and faults for the model were assigned based on geology, geochemistry, geophysics and the conceptual model. In the side boundary, there is no heat or mass coming into the reservoir. The temperature gradient is 0.09 ºC/m from the top to the bottom of the layer. The total mass flow from the heat source in the bottom is 90 kg/s with the temperature about 380 ºC. Meanwhile, the total inflow from the surface is 120 kg/s with the temperature about 40 ºC. **Figure 2** shows the 3D computational model in COMSOL Multiphysics in (4500 m x 5500 m x 3600 m). The natural state model was run for 100,000 years. Parameters properties used in this model are listed in **Table 1.**

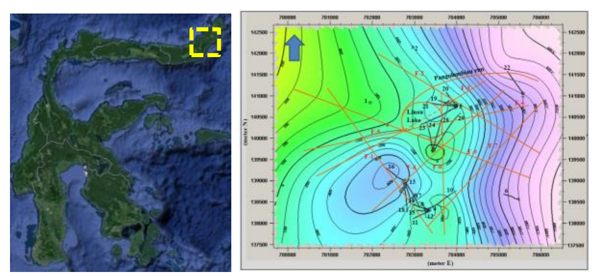
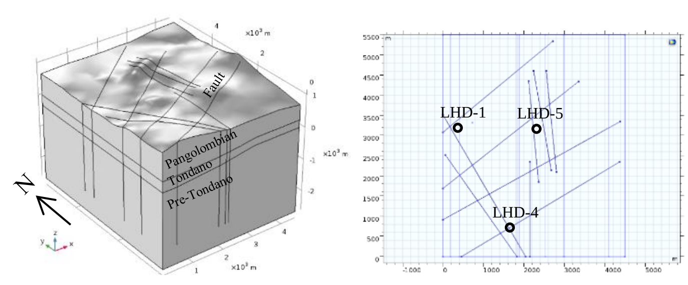


Figure 1: Location of the research area and wells at Lahendong geothermal field (Koestono, 2010)



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

Figure 2: Model geometry in COMSOL Multiphysics

Table 1: Rock and faults properties (Yani, 2006)

Name	Parameter				
	ϕ	ρ [kg/m^3]	κ [m^2]	λ [W/m/K]	C [J/kg/K]
Pang.	0.15	2500	1x10^{-15}	2	1000
Ton.	0.22	2500	5x10^{-16}	2.9	1000
Pre-Ton.	0.1	2500	1x10^{-16}	3.5	1000
Faults	0.1	2500	7x10^{-15}	2	1000

Results

The temperature of natural state simulation results is shown in **Figure 3**. It can be seen that the heat source comes from the southern area towards the northern area. Because of that, the southern area has a higher reservoir temperature than the northern area.

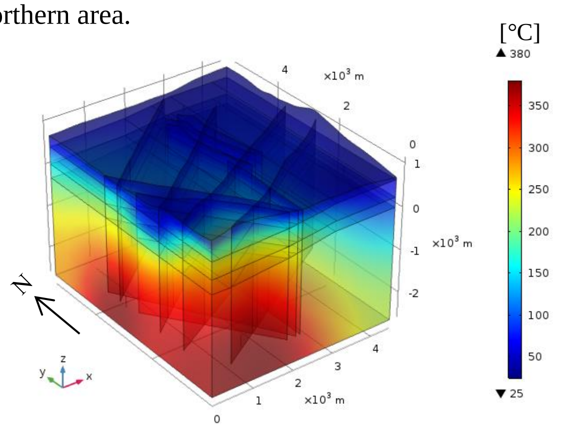
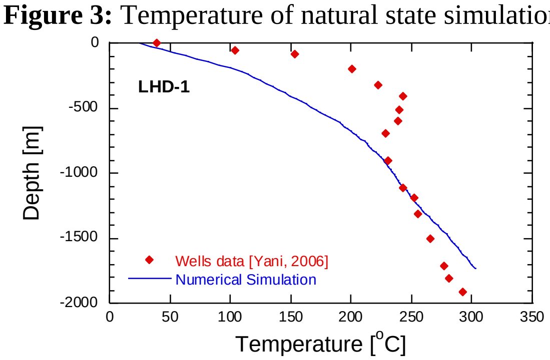
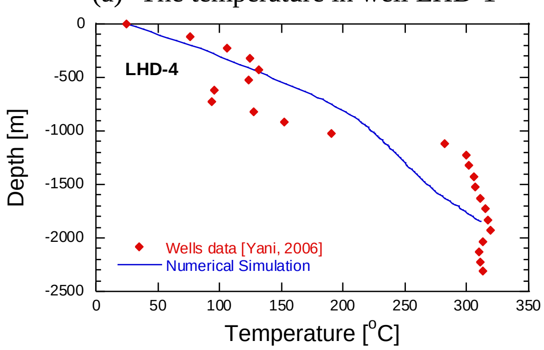


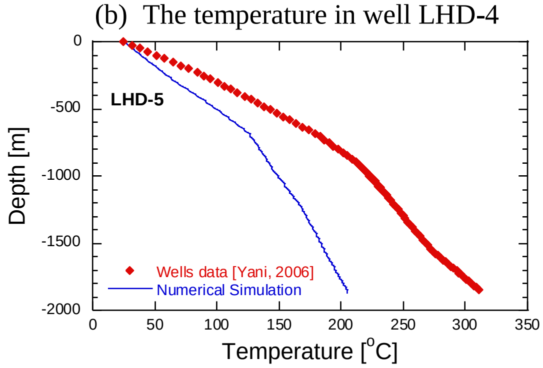
Figure 3: Temperature of natural state simulation



(a) The temperature in well LHD-1



(b) The temperature in well LHD-4



(c) The temperature in well LHD-5

Figure 4: Comparison of temperature with depth between wells data and numerical simulation

The wells in the southern zone looked more promising as the production wells than wells in the northern zone. It means that the development of this area would be focused in the southern zone. Brine and condensate from production wells are reinjected back into the reservoir in the northern area, such as in the well LHD-7 which has a low temperature as explained by Prabowo *et al.* (2015).

As shown in **Figure 4**, the numerical result from natural state simulations is compared to the actual temperature data from the report by Yani (2006). In this result, three of the horizontal production wells are explained as representative of the other wells. The temperature results in the well LHD-1 (**Figure 4.a**) at well depth less than 1000 m is lower than well data. This might be because the mass flow was slow to flow from the bottom to the top. For this layer, the permeability in z-axis needs to increase. After the well depth more than 1000 m, the result is similar to the well data.

The temperature results in the well LHD-4 (**Figure 4.b**) match with the well data until depth 500 m. However, after that the result was different. The temperature results from numerical simulation more slightly increase with depth. Based on Yani (2006), wells in pad LHD-4 are affected by lateral cold water flow at sea level depth. It means that this layer may have slightly different character from the others.

The last well in well LHD-5 (**Figure 4.c**) did not well-match to the well data. This is because the location of the well LHD-5 is far from the heat source in the LHD-1 and LHD-4. The mass flow was slowly to flow. Thus, the permeability in x, y, z-axis need to re-adjustment again.

Conclusion

In the southern area is suitable to be a production well because it is close to the heat source, while the northern area may be appropriate to be the reinjection location. The results obtained in this natural state model are important to further analyze reservoir conditions in terms of development and increase production. Therefore, further research is still needed. Re-adjustment of the parameters that affect the results of the modeling must be considered in order to produce an appropriate model.

References

COMSOL 5.3a (2017) 'COMSOL Multiphysics Reference Manual', p. 1150. Available at: www.comsol.com.

Koestono, H. (2010) *Lahendong Geothermal Field , Indonesia : Geothermal model based on wells LHD-23 and LHD-28*. United Nations University.

Prabowo, T. *et al.* (2015) 'Tracer Test Implementation and Analysis in Order to Evaluate Reinjection Effects in Lahendong Field', *World Geothermal Congress 2015*, (April), pp. 1–6.

Yani, A. (2006) 'Numerical modeling of the Lahendong geothermal system, Indonesia', *United Nations University*, (24), p. 34.