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Simulation of Vapor and Liquid Reservoir Evolution in Geothermal System

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1. Introduction

Occurrence of geothermal systems, in which vapor-dominated conditions are found, are less frequent than liquid-dominated conditions. However, how vapor conditions may evolve in geothermal systems is worth to investigate. The well-known conceptual model illustrating how the vapor-dominated conditions are formed in the natural state are tested using the 3D model TOUGH2. The model represents a system in a moderate topografic relief with an extensive near-vaporstatic vapor-dominated zone and a possible lack significant liquid reservoir throughflow underneath the vapor-dominated zone. This condition may be developed due to increasing heat or decreasing permeability from the upper boundary which causes more water to be boiled off than is replaced by recharge. The purpose of this study is to build a numerical model in order to understand the development of vapor and liquid reservoir in geothermal systems based on the description of the proposed well-known geothermal conceptual models.

2. Model Development

2.1. Model Preparation

Before a numerical model being set up, a conceptual model must be developed. The numerical model was constructed based on the conceptual model. TOUGH2 computer code was used to carry out the natural state simulation (Pruess *et al.*, 1999). In model preparation, the rock properties such as permeability, rock density, specific heat capacity were assigned to each block in every layers in the model. Initial and boundary conditions were also defined according to measured data. In order to have a reliable model which closely represents the real condition of reservoir, a model must be validated through the matching process between observed data and simulation result. This process involves an iterative process which requires running the models to steady state until a good matching or agreement between the simulation result and the observed data obtained.

2.2. Grid system and layer

The model was constructed with size of 4000 x 4000 x 3000 cubic meters which is divided into 8000 cells. In vertical, the model is divided into 20 layers, while laterally each layer is divided into 20 x 20 cells.

The entire model domain has a density of 2600 kg/m3, porosity of 10%, thermal conductivity of 2.5 W/mK, and a specific heat of 1 kJ/kg.

2.3. Initial and boundary conditions

The initial condition of the model is fully liquid saturated at a normal geotherm (30°C/km) with hydrostatic pressure.

During the period of time, the boundary condition has to be set up to maintain the system inside the reservoir which allows the system to be equilibrated.

The side boundary was set to be conductive heat and mass flow with relatively tight permeability. The initial state of the simulations is a normal thermal gradient and a hydrostatic pressure gradient.

A number of grids at the bottom layer was set as heat source with very high temperature and huge volume factor to indicate the magnitude of intense heat source which drives the pressure temperature profile in the upper layers.

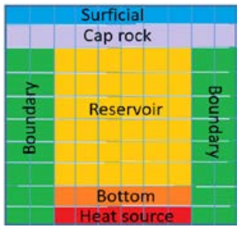

Fig. 1: Illustration of the model.

The illustration of the model configuration is as shown in Fig. 1. At the top is the surficial layer represents the surface layer underlying caprock. The reservoir permeability is set to be fixed at 10^{-13} m^2. While the other permeability values were assigned using trial and error method.

3. Results and Discussion

As mentioned earlier, only permeability value for reservoir is set to be fixed while others were assigned using trial and error approach to be able to replicate a probable geothermal system condition. After several times simulation, the configuration of permeability settings for cap rock, side, and bottom boundary is 10^{-16} m^2, while for surficial, reservoir, and heat source is 10^{-13} m^2.

To understand the process happening in a geothermal system, the model was run for a long period of time. We run a series of simulation. Each stage of simulation series is run for 10 kyr. The choice of 10 kyr for the duration of the high basal heat flow phase was influenced by the time for vapor-dominated conditions to form as stated in Raharjo *et al.* (2016).

In the natural-state, the simulation should be carried out over long period of time. This suggests that the simulation in natural state condition requires running the simulation until it reaches steady state condition. Even though there is no rule as to how long is the time to be set to create natural state condition, some modellers tend to set the simulation time as long as for example 300,000 years. But, since the aim of this study is not to understand the condition after it reaches the equilbrium, instead we use a series of simulation time in order to understand the evolution of geothermal system in every slice of time.

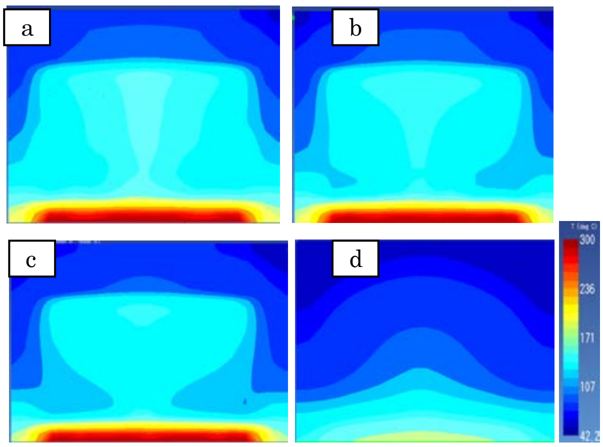

Fig. 2: Temperature distribution development result after 10,000 years simulation time. a = sliced in the middle part of the model (x = y = 2000 meter), b = at 2500 meter, c = at 3000 meter, d = at 4000 meter (boundary).

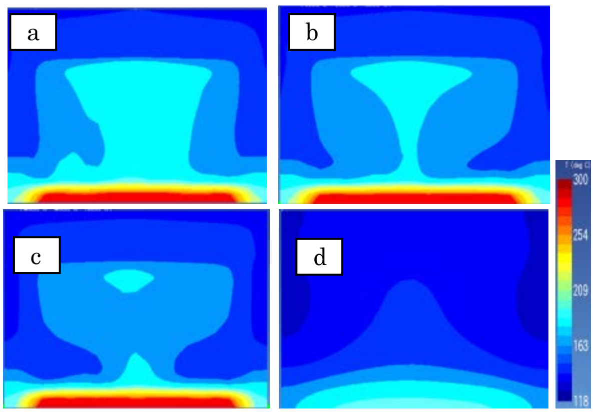

Fig. 3: Temperature distribution development result after 20,000 years simulation time. a = sliced in the middle part of the model (x = y = 2000 meter), b = at 2500 meter, c = at 3000 meter, d = at 4000 meter (boundary).

As shown in Figs. 2 and 3, the temperature growth can be seen after 10 and 20 kyrs. The temperature distribution is also strongly influenced by the location. The development of heat body becomes less and less in near boundary and more intense in the center of the model. The temperature becomes hotter after 20,000 years suggesting more intense heat added into the reservoir.

While, the vapor formation cannot be seen clearly after 10 kyr (Fig. 4) suggesting that additional time needed to create such condition. However, two phase condition at the top of the reservoir can be formed after 10 kyr. After ~20 kyr, vapor starts to appear and develop at the top of the reservoir as shown in Fig. 5.

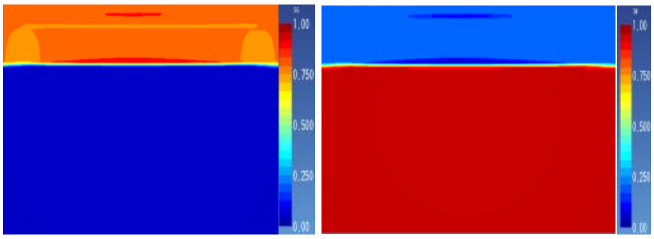

Fig. 4: Vapor (left) and liquid (right) reservoir development after 10.000 years simulation time.

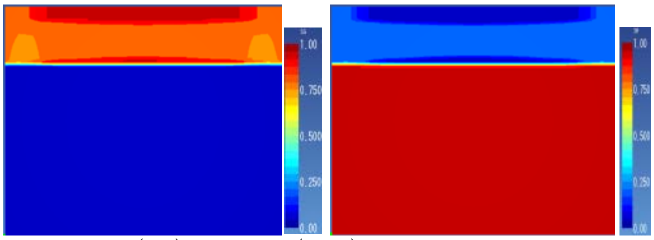

Fig. 5: Vapor (left) and liquid (right) reservoir development after 20.000 years simulation time.

4. Conclusion

It has been simulated the evolution of vapor and liquid reservoir formation in a geothermal system. As the simulation time increases, it can be seen the growing of the heat in the entire model and vapor formation at the top of the model.

Such condition can be achieved in a geological settings where reservoir is overlain by low permeability value body (cap rock) as indicated by the conceptual model.

The formation of vapor is detected after 20 kyr suggesting that with certain geological properties as used in the model, additional heat and time is needed to make the evolution of geothermal system from liquid reservoir to two-phase and finally vapor reservoir at the top of the model.

It is also found that the convergence issue in TOUGH2 is the main challenge to simulate a behaviour of the model. Even though the model seems to be a simple generic model, the issue cannot be easily overcome. Sometimes it can take many hours only to solve the convergence issue. Therefore, for the modellers, the convergence issue has been more challenging than the simulation itself.

References

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