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Clarification of Generation Mechanism of Distinct Pressure and Temperature Regimes in Geothermal Systems around the Bandung Basin, Indonesia by Numerical Simulation

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ABSTRACT

This research aims to clarify the generation mechanism of distinct pressure and temperature regimes in the adjacent geothermal systems around the Bandung Basin, West Java, Indonesia. Deep downhole measurement data revealed an interesting feature of the system that the reservoir has different pressure and temperature regimes located within in a relatively close to each other in the field. To simulate such condition using information of geologic anomalies and TOUGH2, we constructed different hypothetical reservoir models by using many geologic, geophysical, and deep downhole pressure and temperature data. Through calibration of model parameters about permeability, heat and recharge magnitude and locations, and geometry of the geologic feature, the reasonable result was obtained by the small difference in pressure and temperature between the simulated and observed values. A merit of this result is that the most influential fault on driving the fluid flow in this system was identified.

1. INTRODUCTION

Reservoir modelling is an important task to do in order to understand the behavior of the resources as well as to manage them in a sustainable way (Dipippo, 2016). As many important characteristics as possible should be included in the model to provide accurate prediction and define a model's usefulness (O' Sullivan *et al*., 2001).

In a green geothermal field when production activities have not been initiated, the reservoir is still in an undisturbed state. At this stage, all available data is used to calibrate the reservoir model. However, higher level of confidence of a reservoir model only can be achieved when downhole data have been measured. By this measurement, all the necessary data such as pressure and temperature distribution in the subsurface can be figured out better. The first stage of reservoir model calibration is usually known as natural state calibration that considers the subsurface pressure and temperature distribution data carefully. The second stage is when a geothermal field has been produced, where a reservoir model calibration is commonly done by adjusting several important physical model parameters near wellbore in order to have close agreement with the measured production history data, so that a so called 'history matched model' should yield a quite unique solution. Ideally, a history matched model should have a higher confidence level than a natural state model. Two steps of model calibration are condemned to be sufficient once it has encompassed all the necessary objectives. In practice, however, uncertainty still may exist to some extent because of the data limitation. Incomplete data mean that the measurements do not include the entire geothermal system or some part of areas are poorly defined since only limited measurement has been done to confirm the hypothesis that may appear in the beginning of the reservoir studies. Therefore, in some cases, assumption simplifications must be made because many properties of the system remain unknown and cannot be measured. However, either be it computational or data limitation, there are still some certain things we can do with reservoir modelling to give a better picture of subsurface behavior as long as we can justify our assumptions clearly.

A distinguished feature in some parts of Bandung Basin, West Java is that the system has distinct pressure and temperature region located within in a relatively close to each other. Figure 1 shows the pressure distribution at depths obtained from several downhole measurements. It can be observed that at shallower depths some pressure values distinct in one region from another region. This distinction discontinued at the deeper depth in which it shows that the pressure distribution at deeper depth are similar in all regions.

The focus of this work is to study the behavior of the natural state mass fluid and heat flow of the Bandung Basin-like geothermal system for which it can clarify the generation mechanism in some parts around the Bandung Basin. To understand this phenomena we created several generic models and numerically compute them using TOUGH2, a very well-known geothermal reservoir simulator, to explore the effect of the system's setting (cap rock, internal boundary, locations and magnitude of the upflow, and topography) on the geothermal fluid circulation.

The detailed features being investigated are given in the following section. It is also discussed the effects of each features or the combinations of them.

2. MODEL DESCRIPTION

As a reference model, a hypothetical numerical 3D model was developed from the conceptual model to have characteristics similar to those found in a two-phase vapor-dominated geothermal systems hosted within volcanic settings. As many important characteristics as possible are included to account for important physical processes of a Bandung Basin-like geothermal system. To achieve such an objective as mentioned above, a model is carefully designed to cover the region of interest. It also assigned approximation numerical values of the physical parameters in each grid in which the values were constrained to the most appropriate for the system. In addition, this also involves a suitable definition of boundary conditions with a further description is in the following sub section.

Beside the hypothetical model, several generic models were also developed to explore the effects of system's setting for understanding the behavior of the geothermal circulation under certain conditions. Detailed of the cases are given in the following section.

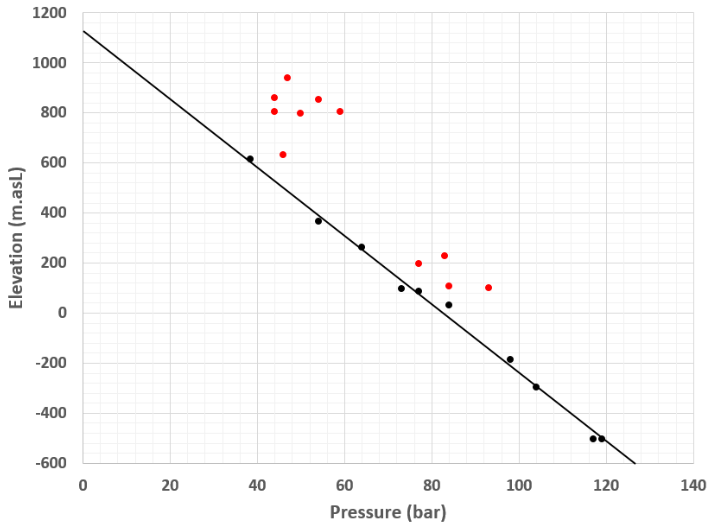

Figure 1: Baseline reservoir pressure in the brine and vapor reservoirs

2.1 Model Domain

The general view of the hypothetical model is given in Figure 2. Some details of the structure settings may differ with the physical parameter.

The shape of the generic grid is rectangular regular with the size of 250 m, extents horizontally 5,000 m and 5,000 m, and vertically 3000 m. It consists of 16-20 layers, dependent on the topographic feature. Figure 3 shows the generic base model with a flat topography.

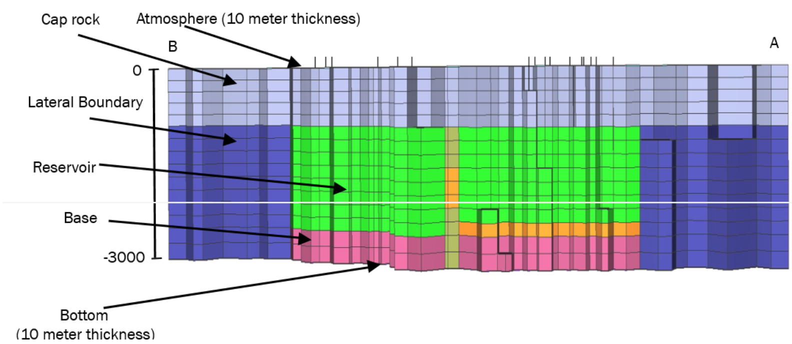

Figure 2: General view of the hypothetical model

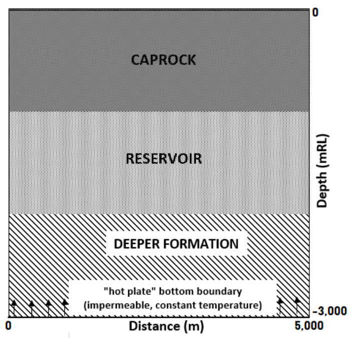

Figure 3: General view of the generic model case 1

2.2 Permeability Structure

Typical values for the rock density, the formation heat conductivity, and the specific heat are 2500 kg/m^3, 2.5 W/m ºC, and 1000 J/kg ºC, respectively were applied uniformly to all formations. Corey relative permeability correlation was used.

2.3 Boundary Conditions

The top side of the model is a fully saturated with groundwater and fixed to a constant pressure and temperature at the atmospheric level. Both lateral boundaries are assumed to be closed without any fluid and mass flowing in or out of the system.

The definition of the bottom boundary condition is tricky, because in deep geothermal systems, supercritical conditions at high pressures (≳220 bar) and high temperatures (≳374 ºC) are most likely to occur. While the most commonly used versions of the software limit the fluid thermodynamic conditions to below the critical pressure and temperature for water. Therefore, some adjustments to the boundary conditions should be defined thoroughly. Hence, the shortcoming of the model for not including the deeper part of the system can be accepted. The two most commonly used boundary conditions, the background heat flux approach (Clearwater et al., 2011; O'Sullivan et al., 2016; Ratouis et al., 2016; Ratouis, T. M. and Zarrouk, S. J., 2016) and the "hot-plate" approach (Burnell and Kissling, 2005; Bjornsson and Arnaldsson, 2015; Gunnarsson and Aradóttir, 2015; Hernandez et al., 2015) were applied at the bottom of the model. A study on the effect of bottom boundary has been nicely conducted by O'Sullivan and O'Sullivan (2016) which implied either approach for modelling the heat flow at the bottom boundary can be used to produce a reservoir model capable of producing accurate predictions of a geothermal system's behavior.

For this work, "hot-plate" approach was used in which the constant temperatures were applied at the bottom of the model. The value of the temperature boundary was adjusted with trial and error to the most appropriate reservoir temperature distribution as inferred from the measured formation temperature data. The blocks at the bottom boundary are assigned as impermeable blocks to ensure no unnecessary additional fluid flow from the bottom boundary to which each active block in bottom of reservoir is connected.

3. NATURAL STATE MODELING RESULTS

3.1 Simulation Result of Hypothetical Model

The hypothetical model was developed to have characteristics similar to those found in some parts of Bandung Basin region. Some parts of the system are not clearly defined and therefore, it is worth to use numerical modeling to develop a model and test geological hypotheses. The use of numerical modeling can be beneficial to clarify whether the hypotheses can be accepted.

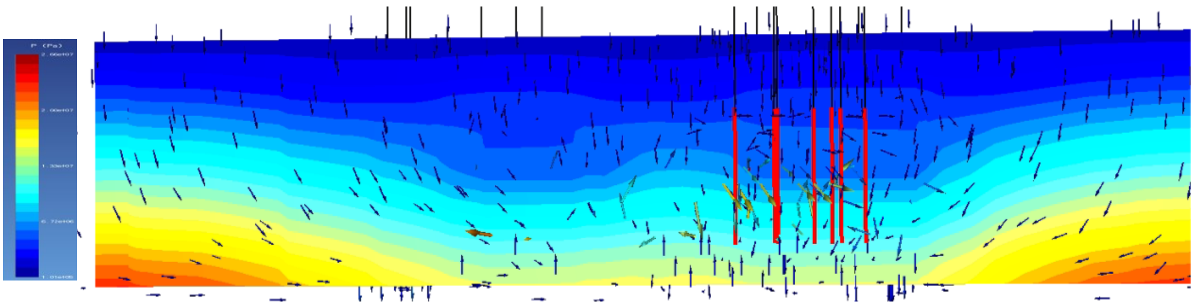

Figure 4: Pressure distribution of the hypothetical model

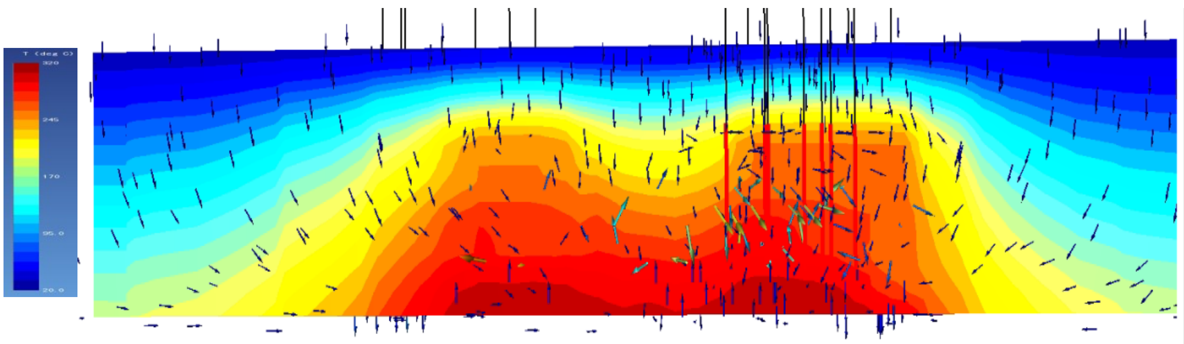

Figure 5: Temperature distribution of the hypothetical model

Based on geological and geophysical studies, it may be inferred that there is an impermeable body separating the system into several parts which may result in the different pressure and temperature. This may not be the single cause which can create such a system. Although the existence of different heat source cannot be confirmed yet through geophysical studies, using numerical modelling can develop a hypotheses model which may resemble the 'real' system. Figures 4 and 5 demonstrate the pressure and temperature distributions in which an impermeable fault and different magnitude of upflows between the two zones were applied in the model.

Using geophysical hypothesis, an attempt has been made and results quite reasonable match between the measured data and the simulation results as presented in Figure 6. The temperature profile shows better matching than the pressure profile.

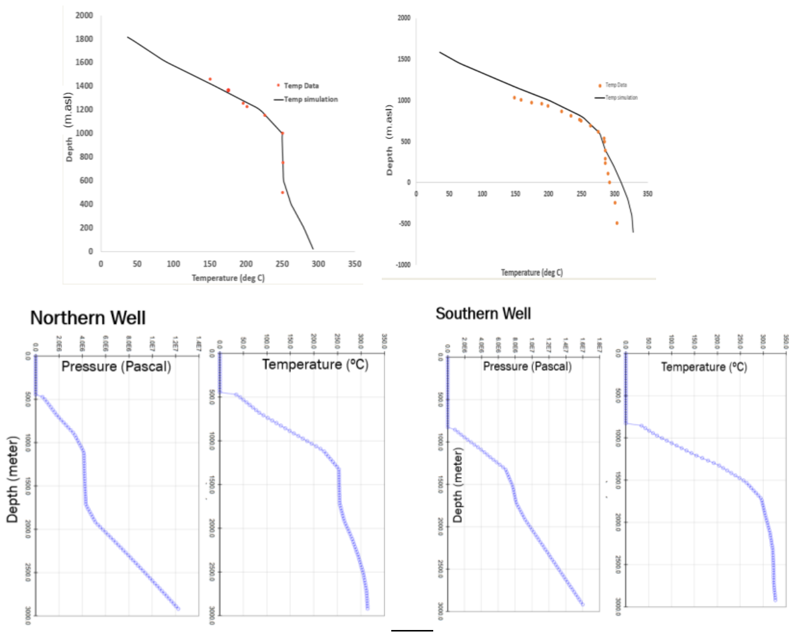

Figure 6: General view of the generic base model

3.2 Simulation Result of Generic Models

The generic model was developed to explore the effect of the system setting on reservoir. The effect observed mainly are the distribution of reservoir pressure and temperature. The model geometry is designed to include some important parameters needed to reconstruct a two-phase vapor-dominated geothermal system. However, the design of generic model was simplified to some degree to avoid unnecessary complexity so that each system's setting and its effect can be observed independently.

<u>3.2.1 Case 1: impact of the depth and thickness of the caprock</u>

The depth of caprock was tested in models of Figure 7 and was varied in two values (900 and 544 m). The pressure and temperature profiles along the depth for the two models are shown in Figure 8. The pressure distribution along the depth and below the caprock shows quite correlation with the pressure of the vapor reservoir. The higher the caprock thickness, the higher the reservoir pressure, however the thickness of the caprock also affects the thickness of the vapor reservoir. In Figure 7, the caprock thickness is revealed to affect the reservoir zone in thickness which shows that the deeper the bottom of the caprock the

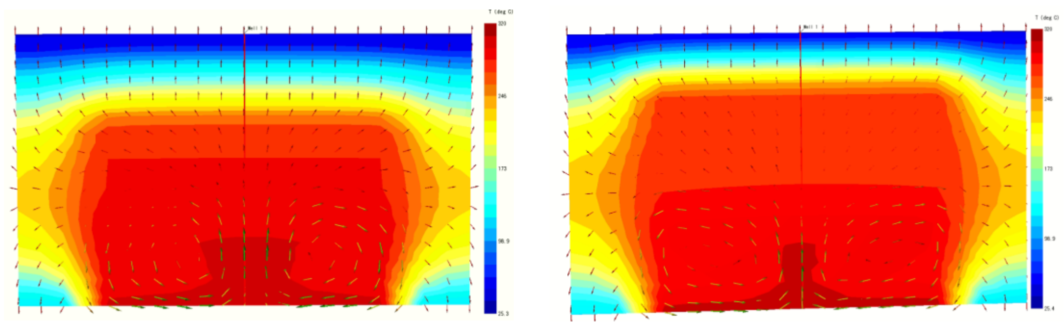

Figure 7: Temperature distribution for model a (left) and b (right). Model a and b were developed with caprock thickness 900 and 544 m

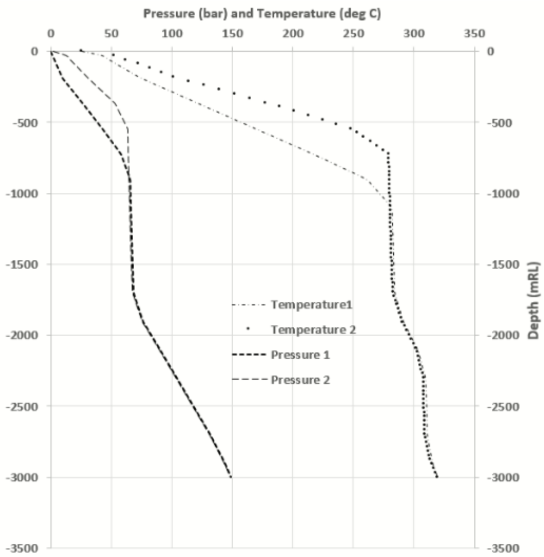

Figure 8: Pressure temperature profile along the depth

It is worth to note that the reservoir pressure is also strongly influenced by reservoir permeability. The models a and b were assigned with the permeability of 10^{-14} m^2. Different value of reservoir permeability shall show different result. Therefore, the depth of caprock controls to some extent the reservoir pressure and temperature. The model geometry of generic model case 1 is given in Figure 3.

3.2.2 Case 2: impact of topography

In some modelling cases, the topography is not always considered. This study was conducted to judge whether this simplification can be justified or not. The elevation difference is 400 m while the caprock depth is maintained the same laterally as illustrated in Figure 9.

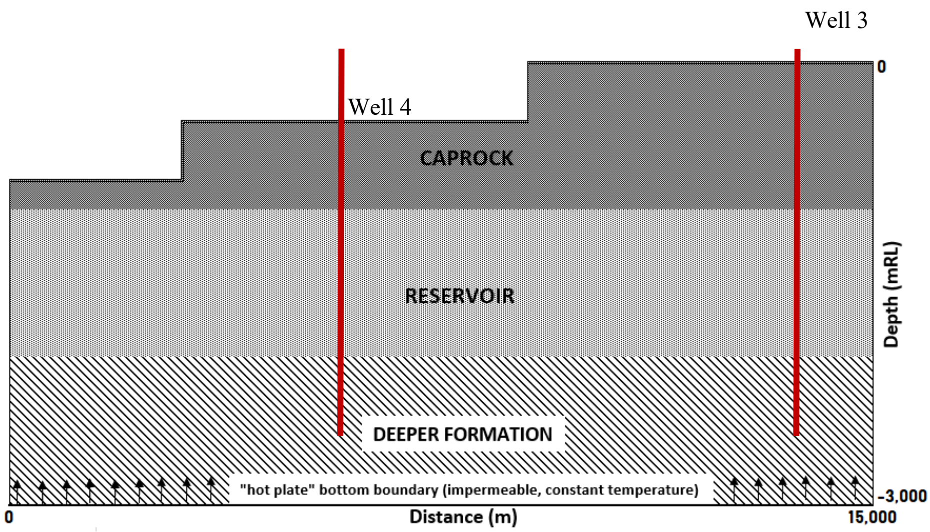

Figure 9: General view of the generic model case 2

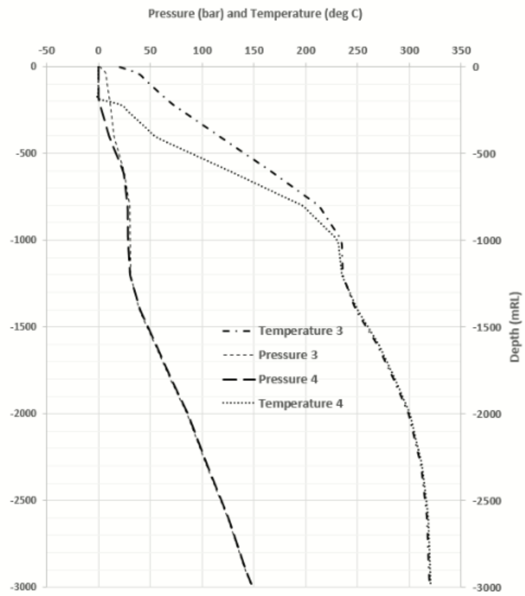

Figure 10: General view of the generic model case 2

As shown in Figure 10, the formation pressure and temperature in the shallower depth are different. However, the reservoir pressure and temperature show no difference between wells 3 and 4. This implies that the caprock depth plays major impact on the reservoir pressure and temperature distribution.

However, further studies must be conducted to understand more broadly the effect of topography in high terrain in which the effect of topography may be stronger.

4. DISCUSSION AND CONCLUDING REMARKS

A reservoir containing a vapor-dominated zone over a liquid-dominated region is known to be interesting and difficult to model. This study presents a three-dimensional modelling experiments on a two-phase vapor-dominated zone. A hypothesis model was developed to resemble the study case located around the Bandung Basin that has several geothermal fields located near to each other, which can be observed and studied further numerically to understand the formation and behavior of such system.

The modelling results clarified as:

1. Low permeability caprock is important to the formation of a high temperature vapor geothermal reservoir. In addition, the depth of caprock has strong correlation of the pressure temperature profile along the reservoir.
2. The reservoir pressure is observed to be strongly influenced by its reservoir permeability, the depth of the caprock, and the magnitude of the heat source.
3. Topography has no significant effect on the pressure and temperature reservoir distributions, whereas the depth of caprock does. Meanwhile it is important to note that this is observed only in a low-moderate terrain topography with range of 400 m. Therefore, in some cases it may be accepted to disconsider the topography in the modelling.
4. Impermeable fault is considered to have strong impact on the pressure and temperature distributions which distinguishes the system into several zones with different values on the pressure and temperature at the same depth.
5. In addition to impermeable fault, different magnitude of heat source should be assigned in order to obtain good match between measured and simulated values.

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