Numerical Simulation for Natural State of Two-Phase Liquid Dominated Geothermal Reservoir with Steam Cap Underlying Brine Reservoir

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Abstract. Hydrothermal reservoir which liquid-dominated hydrothermal reservoir is a type of geothermal reservoir that most widely used for power plant. The exploitation of mass and heat from the geothermal fluid will decrease the pressure in the reservoir over time. Therefore the pressure drop in the reservoir will have an impact on the formation of boiling zones or boiling will increase. The impacts are an increase in the fraction of steam, dryness, in the reservoir and with good vertical permeability will form a steam cap underlying the brine reservoir. The two-phase liquid dominated reservoir is sensitive to the porosity and difficult to assign average properties of the entire reservoir when there is boiling zone in some area of the reservoir. These paper showed successful development of two-phase liquid dominated geothermal reservoir and discussed the formation of steam cap above brine reservoir through numerical simulation for state natural conditions. The natural state modeling in steam cap shows a match with the conceptual model of the vapor-dominated developed. These paper also proved the presence of transition zone, boiling zone, between steam cap and brine reservoir.

1. Introduction
Numerical model of geothermal system developed by conceptual model that develops from geosciences data and the reservoir engineering data is important to describe the condition in the reservoir. The first step is to match the natural state. The natural state of a geothermal system refers to the condition of the system before any form of exploitation. The relevant data are the natural temperatures and pressure and the amount of surface discharge as both heat and mass. The research of two-phase liquid-dominated reservoir are less than both single-phase (liquid) reservoir and vapor-dominated reservoir. These reservoirs is interesting and difficult to model because it contains a vapor-dominated zone underlain by a liquid-dominated region [1]. It has similarity with Wayang Windu – Indonesia [2]. The main objective of this work is to develop of two-phase liquid-dominated geothermal reservoir with numerical study and achieve their natural conditions. The model should be described for all major physical process such as mass transport, heat transfer, boiling and condensation process that take place in these system.

2. Conceptual Model
The model for this study is based on liquid dominated that has a steam cap above liquid reservoir area such. Therefore the reservoir model needs a conceptual model of synthetic liquid-dominated reservoir with steam cap underlying brine reservoir. The conceptual model in these synthetic model developed based on four geothermal fields such as Wairakei, Tongonan, Awibengkok and Wayang Windu at production stage.
The synthetic conceptual model of liquid-dominated with steam cap at top reservoir shown in Figure 1 and has a reservoir characteristics shown in Table 1. These studies used six exploration wells (XXA-1, X XB-1, XXC-1, XXD-1, XXE-1 and XXF-1) and is shown in Figure 1 and Figure 2. These wells delineate the reservoir. The pressure and temperature profile of XXX-1 and XXB-1 show a high temperature well, whereas the rest of the wells have a medium temperature well.

**Table 1.** The Characteristics of synthetic geothermal reservoir.

| Area of Reservoir | Proven Area (km$^2$) | Temperature ($^\circ$C) | Pressure (bar) | Thickness (m) |
|-------------------|----------------------|-------------------------|----------------|---------------|
| Steam Cap         | 13                   | 240                     | 34             | 500-1000      |
| Brine Reservoir   | 23                   | 240-320                 | 55             | 1400-1500     |

![Figure 1](image1.png)  
**Figure 1.** The conceptual model of synthetic liquid-dominated geothermal reservoir with steam cap underlying brine reservoir.

![Figure 2](image2.png)  
**Figure 2.** Pressure and temperature profile at two-phase liquid dominated geothermal wells with steam cap above brine reservoir.
3. Computer Model

The methodology of this study is shown in Figure 3. The first step is reviewed liquid-dominated geothermal reservoir then build a synthetic conceptual model. The second is developing computer model in the simulator with applying EOS, mesh type and geometry model. The third step is applying both of boundary conditions and rock properties into computer model, then running the model to achieve their natural conditions based on pressure and temperature matching. The data input is very tricky because there are a lot of unknown information in subsurface Material data should be updated to gain natural condition of model computer hence the reservoir model computer can represent their natural conditions.

![Figure 3. Methodology of natural state liquid-dominated geothermal reservoir with steam cap underlying brine reservoir.](image)

3.1. Grid System

The Computer model has 7x7 km² with reservoir area around 4.5x4.5 km². Therefore the mesh type applied into a computer model is rectangular and a distributed parameter approach is used. The refine mesh placed in the productive area that have a high temperature and good permeability. The fine mesh has propose of the block is only trough by one well. The fine mesh is 200x200 m and the course is 1000x1000 m and placed on the edge of the computer model as boundary conditions. Those grid-blocks shown in Figure 4.

![Figure 4. Cross section of the top section which is divided by a grid.](image)

![Figure 5. Distribution of layer of the conceptual model based on productive area.](image)
The vertical extend of the model based on proposed synthetic conceptual model. It’s divided into 20 layers and the thinner placed (100 m) into the area where a steam cap estimated in the top of reservoir because of lower density than brine otherwise the thickness of liquid reservoir is 200 m. The thicker layer (500 m) placed into the bottom of the model as boundary conditions for put heat source, therefore there is no change of pressure and temperature. Those shown in Figure 5.

3.2. Rock Properties
The characteristics data that represent geothermal system such as a heat source, cap rock and reservoir have been assigned in the computer model and set to reach the natural state condition. The properties of the rocks that represent geological conditions in the model is shown in Table 2. These material data assigned to each block in the computer model shown in Figure 6. Material data that has a good permeability assign into a productive area and material data that has tight permeability used as outside boundary.

| Material Type | Rock Density (kg/m$^3$) | Porosity | Permeability (m$^2$) |
|---------------|-------------------------|----------|----------------------|
|               |                         |          | XY                   | Z        |
| Atmosphere    | 2600                    | 0.99     | 1E-10                | 1E-12    |
| Ground Water  | 2500                    | 0.02     | 2E-18                | 2E-18    |
| Caprock       | 2600                    | 0.05     | 1E-18                | 1E-18    |
| Boundary1     | 2600                    | 0.001    | 1E-19                | 2E-19    |
| Boundary2     | 2600                    | 0.01     | 1E-20                | 1E-20    |
| Heat source   | 2650                    | 0.07     | 1E-14                | 1E-15    |
| Reservoir1    | 2500                    | 0.25     | 1E-13                | 5E-14    |
| Reservoir2    | 2550                    | 0.2      | 8E-14                | 4E-14    |
| Reservoir3    | 2600                    | 0.15     | 6E-14                | 3E-14    |
| Reservoir4    | 2600                    | 0.15     | 5E-14                | 2E-14    |
| Reservoir5    | 2600                    | 0.1      | 3E-14                | 1E-14    |
| Reservoir6    | 2600                    | 0.1      | 9E-15                | 6E-15    |
| Reservoir7    | 2600                    | 0.1      | 7E-15                | 3E-15    |
| Reservoir8    | 2600                    | 0.09     | 5E-15                | 2E-15    |
| Reservoir9    | 2500                    | 0.05     | 3E-17                | 1E-17    |

Figure 6. 3D block model at computer model.
Each block is connected to each other block, therefore the diversity of permeability, porosity, water saturation in the reservoir and fluid, both laterally and vertically, were taken into account. The magnitude of the pressure, temperature, water and steam saturation in each block and the mass flow rate from one block to another block for a range of time is calculated by using the simulator. Thus the results of the calculation can illustrate the changes in pressure and temperature versus depth, both in well and in other places as well as other changes in reservoir characteristics versus time.

3.3. Initial and Boundary Conditions

The initial and boundary conditions such as outside, heat source and the atmosphere were assigned in this model. The objective is to give initial conditions from a model therefore the simulator can calculate every thermodynamic properties in each block. Each block has a boundary condition used 1E+30 for volume factor, hence it gives stationary of pressure and temperature versus time. The assumptions of boundary condition are:
1) The top of layer is atmosphere layer. In this layer, each block is considered to have similar properties with typical atmosphere condition (1 atm and 25°C).
2) The Outside layer is the boundaries representing a surrounding environment.
3) The heat source layer is located in the bottom of model. The thickness is 500 m.

4. Natural State

Pressure and temperature profile at natural state is shown at Figure 7. It shows a perfectly match between a model output and actual well data. The pressure and temperature in steam cap close to steam-static pressure and slightly above temperature saturation. The pressure and temperature in brine reservoir have a hydrostatic pressure and temperature below temperature saturation. It is obvious there are transition zones between steam cap and brine reservoir.

![Figure 7](image)

**Figure 7.** Matching pressure and temperature data between model computer and actual well data.

The cross-section of the natural state model of liquid dominated with a steam cap at the top reservoir is shown at Figure 8. This cross section of natural state has similarity with a conceptual model of a vapor dominated system of Kamojang Geothermal Field proposed by Hochstein [3] but have a thinner steam cap. This natural state of the steam cap has a similarity with a conceptual model of vapour dominated proposed by White et al [4] and enhanced by D’amore and Trusdell [5].
Figure 8. Cross section natural state model. Pressure (top), temperature (middle) and gas saturation (bottom) simulation results (Y-axis = 3500).

The conductive heat transfer occurs from heat source into the reservoir and convective entire steam cap reservoir (Figure 9a). Hot water is heated by hot reservoir rock and will go up because high temperature fluid has a lower density. Throughout the heat transfer, the boiling zone will segregate vapour and liquid phase. The greater boiling zone, the greater of a steam cap will be formed. The steam has formed will be moved laterally through the reservoir and spread, a steam cap formed (Figure 9b and Figure 9c). The steam saturation formed at steam cap is 80% and close to value of 85% of vapour dominated geothermal field.
Figure 9. Heat transfer pattern (top), the mass transfer of water (middle) and the mass transfer of steam (bottom) on cross section natural state model (Y-axis = 3500).

The steam mass transfer is hindered by impermeable layers above the top reservoir and the heat loss from steam take place. Therefore steam will be condensed and move downward by the influence of gravity. The concept of steam and condensate movement is counterflow heat transfer. The steam move upward while the condensate move downward. This counterflow heat transfer occurs continuously hence the pressure gradient will show the steam gradient pressure (34 bar) and uniform temperature 245°C throughout the whole steam cap.
At the natural state mode, the highest permeability found on top of the reservoir and surrounding by poor permeability at cooler rock outside the steam reservoir. Therefore the natural state model output has similarities with the conceptual model from D’Amore and Truesdell [5].

Studies of the reservoir mineralogy indicate that all of the four vapor-dominated fields ware at one time liquid dominated [6] and have somehow “boiled dry” to produce current state. The previous study [7] shown the expansion steam cap with vertical extends occur in the liquid dominated with moderate production. If these production applied in the long time, hence it will create a thicker steam cap. Therefore the liquid dominated reservoir with the steam cap underlying brine reservoir will evolve to vapor-dominated geothermal reservoir.

5. Conclusion
The model of liquid dominated reservoir with steam cap underlying brine reservoir successfully developed and it showed a good match with actual data after tested and validated. There is an evidenced of transition zone between steam cap and brine reservoir. The steam cap has a similarity with the model of vapor-dominated reservoir model.

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