Study of sustainable production in two-phase liquid dominated with steam cap underlying brine reservoir by numerical simulation

To cite this article: Heru Berian Pratama and Nenny Miryani Saptadji 2017 IOP Conf. Ser.: Earth Environ. Sci. 103 012005
Study of sustainable production in two-phase liquid dominated with steam cap underlying brine reservoir by numerical simulation

Heru Berian Pratama¹, Nenny Miryani Saptadji¹

¹Study Program of Geothermal Engineering, Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology, Indonesia
Jl. Ganesha No.10, Bandung, West Java, Indonesia. 40132
heru.berian@geothermal.itb.ac.id

Abstract. The main issue in the management of the two-phase liquid-dominated geothermal field is rapid decline pressure in the reservoir so that the supply of steam to the power plant cannot be fulfilled. To understand that, modelling and numerical simulation used reservoir simulators. The model is developed on liquid-dominated geothermal fields are assessed in various scenarios of production strategies (focusing only steam cap, brine reservoir and a combination) and injection strategies (deep and shallow injection, centered and dispersed injection), with the calculation using separated steam cycle method. The simulation results of the model for sustainable production are production 25% from steam cap + 75% from brine reservoir, dispersed and deep reinjection with make-up wells from steam cap results 9 make-up well number. The implementation of production-injection strategy needs to be planned right from the beginning of exploitation so that the strategy can adapt to changes in reservoir characteristics.

1. Introduction
The type of geothermal reservoir that most widely used for power plant is hydrothermal reservoir liquid-dominated. The exploitation of mass and heat from the geothermal fluid will decrease the pressure in the reservoir over time. Thus 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.

In general, after steam cap was formed at relatively shallow depths or at the top of reservoir, production will be focused on that area. The drilling point of view, drilling cost, will be lower because the drilling target is at shallow depths. From the aspect number of injection wells, brine from separator decreases as dryness at the wellhead increase thus the number of injection wells will be decrease. Therefore the use of separator becomes less as the increasing of steam flow entering separator. These reasons for economies makes the geothermal developer exploited mass and heat from the steam cap.

Based on the study of two-phase liquid-dominated as described earlier, the steam production from the steam cap can’t be offset by the formation of steam cap itself. Therefore, the production of steam will be further decreased and may not sustain to power generation as long as contractual time. Nevertheless the strategy must be balanced with production from liquid reservoir and injection strategies even the steam cap formed. The injection strategies should be optimized so the pressure drop especially in the steam cap or the whole reservoir may be maintained at acceptable point.
The changes of properties in the reservoir can be described by numerical model of geothermal system that has been developed by conceptual model from geosciences data and reservoir engineering data. The first step in numerical simulation is develop a computer model that has a good match with actual data (pressure and temperature), which is a natural state. If the geothermal field hasn’t been develop, the model can be running to forecasting with various production-injection strategies to achieve sustainable production.

The numerical simulation researches of two-phase liquid-dominated reservoir are less than both single-phase (liquid) reservoir and vapor-dominated reservoir. These reservoir is interesting and difficult to model because it contains a vapor-dominated underlying liquid-dominated reservoir [1].

Considering the things mentioned above, it is interesting to do a study of model and simulate the two-phase liquid-dominated with steam cap underlying brine reservoir using numerical simulation. These study is based on natural state of reservoir with steam cap underlying brine reservoir [2] and the study of production-injection scenarios at the identical model [3]. By observing changes in pressure, temperature and steam saturation and mass flow in the numerical model as a function of time, therefore these model can forecast the reservoir performance over time with various production-injection strategies.

The objective of comparison the output from the reservoir model for multiple production-injection strategy is to achieve a sustainable production. These strategy is used to maintain installed capacity by adding make-up well. The well to be used as a make-up wells produced mass and heat either from steam cap, brine reservoir or both of them. The objective is to determine a suitable make-up well strategies.

2. Methodology

In general, the methodology in this study is shown in Figure 1. The previous study of synthetic numerical model two-phase liquid-dominated with steam cap underlying brine reservoir for natural state and production-injection strategies have been done [2, 3].

![Figure 1. Methodology for sustainable production](image)

The further study is forecast for 30 years of contractual and the next 20 years as prolongation of utilization. The scenario is make-up well from brine reservoir, steam cap or both of them to sustain steam the steam supply for power generation of 220 MW. Furthermore, each strategy will be calculated and analysed to achieve the lowest of decline rate.

3. Conceptual Model

The model of this conceptual is based on liquid dominated geothermal fields that have steam cap at the top of reservoir. The characteristics shown in Table 1. This study used six exploration wells (XXA-1, XXB-1, XXC-1, XXD-1, XXE-1 and XXF-1) and is shown in figure 2. These wells delineate the reservoir. The pressure and temperature profile of XXX-1 and XXB-1 show a high temperature in the center of reservoir and the other wells has lower temperature because at the edge of reservoir.
### Table 1. Characteristics of the synthetic model.

| Reservoir           | Steam cap | Brine Reservoir |
|---------------------|-----------|-----------------|
| Proven Area         | 13 km²    | 23 km²          |
| Temperature         | 240°C     | 240-320°C       |
| Pressure            | 34 bar    | Brine res. = 55 bar |
| Thickness           | 500-1000 m| 1400-1500 m     |

#### Figure 2. Conceptual model of synthetic reservoir.

### 4. Natural State
The geothermal system have been assigned in computer model as described in previous study. The properties of the each rocks that represent geological conditions in the computer model used distributed parameter approach (Table 2). The boundary conditions such as outside boundary, heat source and atmosphere was assigned in this model. The objective is give initial conditions to a model therefore the simulator calculate every thermodynamic properties in each blocks.

### Table 2. Material data for computer model.

| Material Type     | Rock Density (kg/m³) | Porosity | Permeability (m²) |
|-------------------|----------------------|----------|-------------------|
| 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       |
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 (figure 3).

![Figure 3. 3D block model at computer model.](image)

The subsurface full of unknown information and it has steam cap underlying brine reservoir therefore the data input is very tricky. The properties in each block should be adjust and these process repeat continues until the reservoir model computer can represent their natural conditions and this process.

![Figure 4. Matching pressure and temperature data between model computer and actual well data.](image)

The output of pressure and temperature from the model shown a perfectly match between actual data (figure 4). The model represent a steam cap underlying brine reservoir. This natural state at steam cap zone has a similarities with conceptual model of vapour dominated proposed by White [4] and enhanced by D’amore and Trusdekk [5] and it is shown in figure 5. The conductive heat transfer occurs from heat source into reservoir and convective entire steam cap reservoir. Steam saturation formed at steam cap
zone is 80% and close to value of 85% of vapour dominated geothermal field [6]. These models have a steam cap covering around 4-23 km² and thickness around 500-1000 m.

Figure 5. Natural state, (a) temperature, (b) pressure, (c) steam saturation, (d) heat transfer.

5. Forecast
Separated steam cycle has been used in numerical model as previous study (Pratama and Saptadji, 2015) to generate 220 MW. It is described that the study used four production strategies:
1) Production strategy is focused on 100% from steam cap.
2) Production strategy is focused on 100% from brine reservoir.
3) The combination from both 50% of steam cap and 50% of brine reservoir.
4) The combination from both 25% of steam cap and 75% of brine reservoir.

Then the injection used four strategies:
1) Centered injection (single well pad for each brine and condensate)
2) Dispersed injection (multiple well pad for brine injection and single well pad for condensate, both areas are surrounding the reservoir)
3) Shallow injection (both brine separator and condensate injected into the liner of 1100 – 400 msal or 900 – 1600 meter depth).
4) Deep injection (both brine separator and condensate injected into the liner of 300 – (-500) msal or 1700 – 2500 meter depth).

Figure 6. Schematic both of steam cap production well and brine reservoir production well.
The schematic of production heat and mass from steam cap and reservoir shown in figure 6 therefore the placement wells of production and injection shown in figure 7.

Sixteen model and simulation has been carried out and the output compare each other. The numerical model of two-phase liquid-dominated with steam cap underlying brine reservoir has the best production strategy if fluid is produced from 25% of steam cap and 75% of brine reservoir and paired with dispersed and deep injection. Furthermore these scenario of production-injection strategy has the lowest decline in pressure compare to the other scenarios. A higher production rate from brine reservoir will be accelerated the increase of steam saturation that fills into reservoir rocks hence the expansion of steam saturation. Thus it have a rapid decline pressure and increased the boiling, hence the two-phase zone will expand.

Figure 7. Production and injection placement in the model.

Figure 8. Evolution of reservoir pressure for Production 25% steam cap and 75% brine reservoir with dispersed and deep injection.
Figure 9. Evolution of reservoir temperature for Production 25% steam cap and 75% brine reservoir with dispersed and deep injection.

Figure 10. Evolution of reservoir steam saturation for Production 25% steam cap and 75% brine reservoir with dispersed and deep injection.

The evolution of reservoir shown in figure 8, figure 9 and figure 10 for pressure, temperature reservoir and gas saturation respectively. Dispersed and deep injection generate a relatively lower of pressure drop both in steam cap and brine reservoir. This is because the reinjection of brine separator performed spreading with well pad surrounding the production reservoir. Therefore, this strategy give additional pressure uniformly for balancing the production induced pressure drop and maintain the pressure drop at a lowest level as possibly. While the deep injection strategy improve a thermal recovery
because both of brine separator and steam condensate injected at deeper reservoir which have a higher temperature and minimize a cooler reinjected fluid back to production reservoir [3].

6. Sustainability

A decrease in mass flow rate of the geothermal reservoir occurs naturally as injection rate is lower than production rate. Furthermore it caused pressure drop in the reservoir and decline in flow rate. Therefore, in order to maintain the steam supply to power plant is required to add make-up wells. There are three strategy of make-up wells; all make-up wells from steam cap, all make-up wells from brine reservoir and the combination of them. The make-up wells combination is done by opening the make-up wells from steam cap and brine reservoir with a certain period. The simulation output of sustainable prediction is the number of make-up wells over 30 year of exploitation.

The simulation of sustainable production has done to get a production-injection strategy to maintain the steam supply to 220 MW power plant. The production strategy of 25% from steam cap and 75% from brine reservoir compared to 50% steam cap and 75% brine reservoir and both of them paired with dispersed and deep injection strategy.

![Figure 11. Strategy make-up wells from the steam cap.](image1)

![Figure 12. Strategy make-up wells of the brine reservoir.](image2)

The graph in figure 11, figure 12 and figure 13 shown the campaign of make-up wells drilling both for early production strategies and make-up wells to sustain 220 MW. The outcome of both scenarios for sustainable production, as mentioned above, production of 25% steam cap has a lowest number of
make-up than production of 50% steam cap. Furthermore the best makeup wells is all make-up wells from the steam cap because it has a lowest number of well compare with make-up strategy from all brine reservoir and the combination.

![Make-up Well Strategy from Steam Cap Reservoir and Brine Reservoir](image)

**Figure 13.** Strategy make-up wells of a combination from steam and brine reservoir cap.

Make-up form steam cap is the best scenario for sustain production over 30 year of exploitation nevertheless it is only visible for production from 25% of steam cap and 75% brine reservoir with dispersed and deep injection. It required 8 make-up wells compare to 15 make-up wells from early production 50% steam cap and 50% brine reservoir with identical injection strategy (figure 14 and figure 15). The higher production from brine reservoir induced pressure drop at deep region therefore increasing boiling process so the dryness increase as a boiling area extended and or thickening. It will supply steam to the steam cap region. These process is the opposite if the main production come from brine reservoir. Make-up well from brine reservoir show a slightly similar results from production 25% steam cap compare to 50% steam cap. It required make-up 12 and 13 wells for 25% steam cap and 50% steam cap respectively. The combination make-up well strategy shown a similar result with make-up wells from brine reservoir.

![Make-Up Well](image)

**Figure 14.** The requirement number of make-up well for each production and injection strategies.

In early production, it is recommended that produced heat and mass from deep reservoir or brine reservoir thus the boiling increase as the pressure in the brine reservoir decreasing. It caused the increasing dryness at boiling area as boiling process become greater. Therefore the boiling area will be
expand and thickening. Nevertheless the production from steam cap becoming more economical as the steam from these area is supported by the greater boiling zone.

**Figure 15.** The total production wells and injection wells for each production and injection strategies.

**7. Conclusion**

1. The sustainable production is the production strategy from 25% steam cap and 75% brine reservoir combined with dispersed and deep injection.
2. The optimized strategy of make-up well is make-up all from steam cap with 9 wells for 30 years of exploration.
3. Total wells for 30 years of sustainable production are 35 wells with 15 wells from steam cap and 20 years from brine reservoir.

**Acknowledgment**

This research was supported by Beasiswa Unggulan Program, KEMENDIKBUD (Biro Kerjasama Luar Negeri). We thank our colleagues from Institut Teknologi Bandung (ITB) who provided insight and expertise that greatly assisted the research.

**References**

[1] O’Sullivan, M.J., Karsten, P., Lippmann, M.J., 2000, Geothermal Reservoir Simulation: The State-of-Practice and Emerging Trends, World Geothermal Congress 2000, Kyusu-Tohoku, Japan.

[2] Pratama, H.B. and Saptadji, N.M., (2016), Numerical Simulation for Natural State of Two-Phase Liquid Dominated Geothermal Reservoir with Steam Cap Underlying Brine Reservoir, 5th IIGW, Bandung, Indonesia.

[3] Pratama, H.B. and Saptadji, (2015), Study of Production-Injection Strategies of Synthetic Geothermal Reservoir Liquid-Dominated Model with Numerical Simulation, 37th NZGW, Rotorua, New Zealand.

[4] White, D.E., Muffler, L.J.P., Truesdell, A.H., 1971. Vapor-dominated hydrothermal systems compared with hot-water systems. Econ. Geol.

[5] D’Amore, F., Truesdell, A.H., 1979, Models for steam chemistry at Larderello and The Gesyers. Proceedings, 4th Workshop on Geothermal Reservoir Engineering, Stanford University.

[6] Grant, M.A., Donaldson I.G., Bixley P.F (1st edition 1982, 2nd edition 2011): Geothermal Reservoir Engineering, Academic Press, Oxford.