Numerical Simulation of a Vapor Core Geothermal System, Ungaran Geothermal Field, Indonesia

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ABSTRACT

The geoscience conceptual model shows that Ungaran geothermal system is a possible vapor core system and has an approximately 280°C reservoir temperature. In this paper, the numerical model of the Ungaran geothermal system was constructed based on the previous geoscience survey results in 2017 including geological survey results, geochemistry, geophysics, hydrology, and surface manifestations parameter. The aim is to build a numerical reservoir simulation and to update the conceptual model of Ungaran Geothermal Field. The numerical model of Ungaran geothermal prospect reservoir was simulated using TOUGH2 with EOS1 software. Based on this reservoir simulation result, the updated conceptual model of Ungaran geothermal system has been created, and it visualizes several updated information including the occurrence of subsurface geothermal components, fluid flow, and the distribution of subsurface temperature. This updated conceptual model might be used as an input of updated resource assessment of Ungaran Geothermal Prospect.

1. INTRODUCTION

Ungaran Geothermal Working Area (UGWA) is located in both Semarang and Kendal Districts, Central Java Province, Indonesia. It has 29.800 Ha area with probable resource 100 MW (MEMR, 2017). PT PLN (Persero), as one of a state-owned company in the energy sector, has been assigned by the government to develop Ungaran GWA started in 2018. The geothermal project of Ungaran is still on the exploration stage and has target COD 2024 from the government so that it can supply electrical energy to fulfill the electricity demand in Semarang and Central Java.

Several geoscientific survey has been done by (Nukman 2009, Setyawan et al. 2009, Setyawan et al. 2010, Phuong et al. 2012, Bogie et al. 2015, Sinuhaji and Herlambang 2015, PLN 2017), and the results are represented in a conceptual model which shows that Ungaran Geothermal System is a vapor core geothermal system which has characteristics of a high enthalpy reservoir. Due to its high enthalpy reservoir, Ungaran Geothermal System might be suitable for generating power. Regarding this information, an approach to estimate the resource has been done by building a numerical model of Ungaran Geothermal System that might support the decision making in further exploration and development stages. The numerical model was built by assigning blocks with its physical properties and arrange these blocks similar to the conceptual model from the geoscientific survey. Each block of this numerical model becomes the input to the reservoir simulation which was performed using TOUGH2 program. Furthermore, this study aims to update the conceptual model of Ungaran Geothermal System as it might be valuable information to help the decision making in the further exploration stage of Ungaran Geothermal Prospect.

2. GEOSCIENTIFIC STUDY

The recent geological, geochemical, and geophysical surveys were conducted by PLN in 2017. The results were evaluated in advance, resulting in a conceptual model which elaborate that Ungaran Geothermal System is a vapor core system which is described as a system, consisting of a chimney-like acidic vapor dominated zone, linking deep magmatic-high temperature zones to the floor of the crater (Reyes et al., 1993). The term vapor core is closely related to a volcanic hydrothermal system, which is situated at a volcano. Such system generally appears to be a high terrain and high enthalpy geothermal system. Those categories of geothermal systems are essential to be considered in the model building.

2.1 Geological Study

The study involved the analysis of regional geology, geomorphology map, stratigraphy column, structural map, alteration map, and the distribution of geothermal manifestations. Based on Van Bemellen (1949), the evolution of Ungaran Volcano began in the early Pleistocene as the Old Ungaran. It began to collapse in the late Pleistocene and caused the new incoming magma supply, which formed Young Ungaran Volcano. Regarding this evolution brief of Ungaran Volcano, it leads to consider Ungaran Geothermal Prospect is hosted by a quaternary volcanic complex. The justification of the geothermal resource occurrence is based on the appearance of geothermal manifestations which are distributed around the Ungaran Volcano. A fumarole, hot springs, warm springs, and altered rock outcrops are distributed as shown in Figure 1.

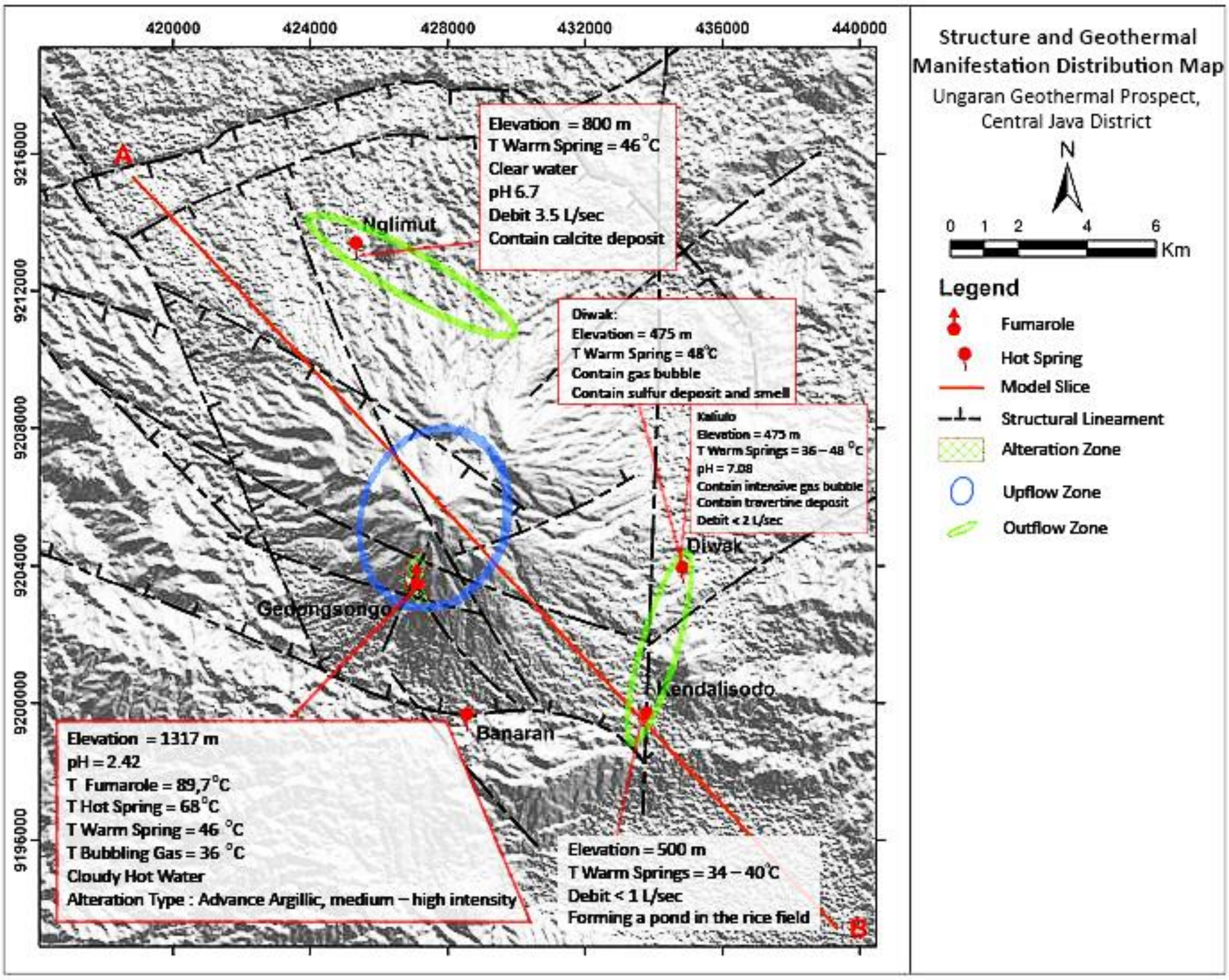


Figure 1: Structure and geothermal manifestation distribution map. (Modification from PLN Pre-Feasibility Study Report, 2017)

The distribution of these manifestations, with each physical characteristic, helps to determine the location of the upflow and outflow zone of this geothermal system, which will be represented in the model as vertical and lateral fluid flow beneath those zones, respectively. The upflow zone is located around the peak of Ungaran volcanic cone as shown in Figure 1. Regarding the occurrence of fumarole in the upflow zone leads to the argument that the system possibly has a volcanic or young magmatic heat source that lay straight under the upflow zone. As the geothermal fluid appears on the surface through channels, the distribution of structures, as seen in Figure 1 is considered to be the permeable path for the upflowing geothermal fluid. The argument is supported by the analysis of soil gas (Radon and Carbon dioxide) from Phuong (2012), which delineates the permeable zone along with the available structures in this prospective area (Figure 2).

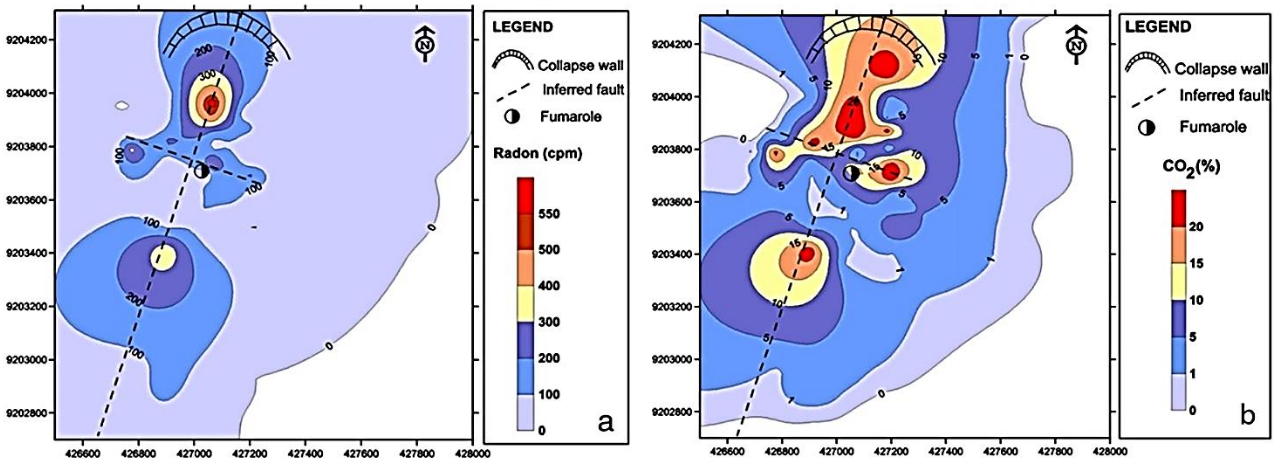


Figure 2: Radon (a) and CO2 (b) anomaly distribution (Phuong, 2012)

The detailed geological survey result reveals that the type of alteration rock around the upflow zone is advance argillic (halloysite, kaolinite, amorph silica, cristobalite, illite, marcasite, and pyrite) with its impermeable physical property, is considered suitable as a potential cap rock in this geothermal system. The occurrence of advance argillic alteration rocks also indicated the presence of acidic fluid with temperature in the range of 70º – 200º C beneath this manifestation (Indarto, 2006). On the other hand, the reservoir of this geothermal system is considerably accommodated by the Old Ungaran Volcanic Product and the Tertiary Sediment Units (Volcanic Breccia, Sandstone, Claystone, Shalestone) which were strongly deformed by the tectonic activity or gravitationally fall.

2.2 Geochemical Study

The analysis of geochemistry consists of water and gas geochemistry analysis. The water samples are taken from 5 different geothermal manifestations, namely (hot spring) Gedongsongo, Kendalisodo, Diwak, Kaliulo, and Nglimut. Based on the Cl-SO_4-HCO_3 ternary diagram plots (Figure 3), water from Gedongsongo Hotspring is steam-heated water, which represents the presence of high enthalpy acidic steam relatively close to the water table beneath the hot spring. The zone with such manifestation may identify areas overlying a permeable boiling zone (Nicholson, 1993), most likely upflow zone. The other group of thermal water in which the samples were taken from Diwak, Nglimut, and Kendalisodo Hot Spring are similarly characterized as bicarbonate water. In a high terrain system, the appearance of such type of water indicates the boundary of a geothermal system. The last type of thermal water is taken from Kaliulo Hot Spring, which appears to be in the mature water category based on the ternary diagram plot. Such a type of water represents reservoir water, which is transported upward without any significant influence from the transportation process itself (e.g., rock water interaction, boiling, mixing and dilution, and conductive cooling). This type of water possibly occurs on the surface due to an existing highly permeable pathway which accommodates the thermal fluid to flow without any significant process that might affect the fluid equilibrium (Nicholson, 1993).

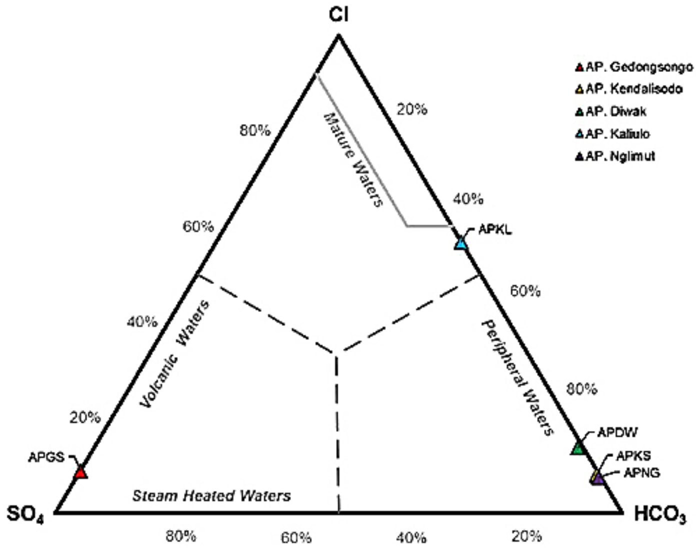


Figure 3: Cl-SO4-HCO3 ternary diagram (PLN Pre-Feasibility Study Report, 2017)

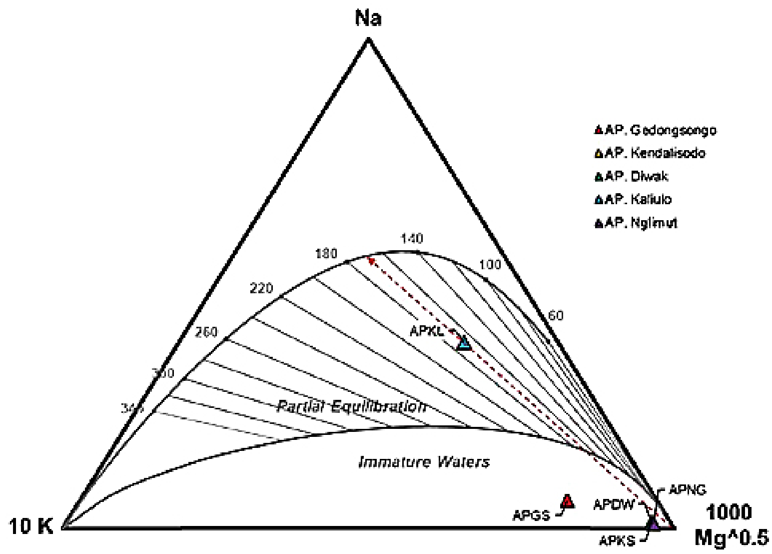


Figure 4: Na-K-Mg ternary diagram (PLN Pre-Feasibility Study Report, 2017)

The analysis of the Na-K-Mg ternary diagram plot (Figure 4) elaborate that most of the water samples are influenced by the presence of groundwater, except for the water sample from Kaliulo Hot Spring. It could be inferred that the geochemical data of the sample from Kaliulo Hot Spring is the only valid sample to be applied in the geothermometer equation. Based on the application of Na/K geothermometer from Giggenbach (1988) to data from the Kaliulo Hot Spring sample, give a reservoir temperature estimation of 169^{o}C.

The analysis of stable isotope around the Gedongsongo area suggesting that thermal waters are of meteoric origin (Phuong, 2012) since all samples from the Gedongsongo plot along the meteoric water line in the δD vs δ ^{18}O diagram (Figure 5).

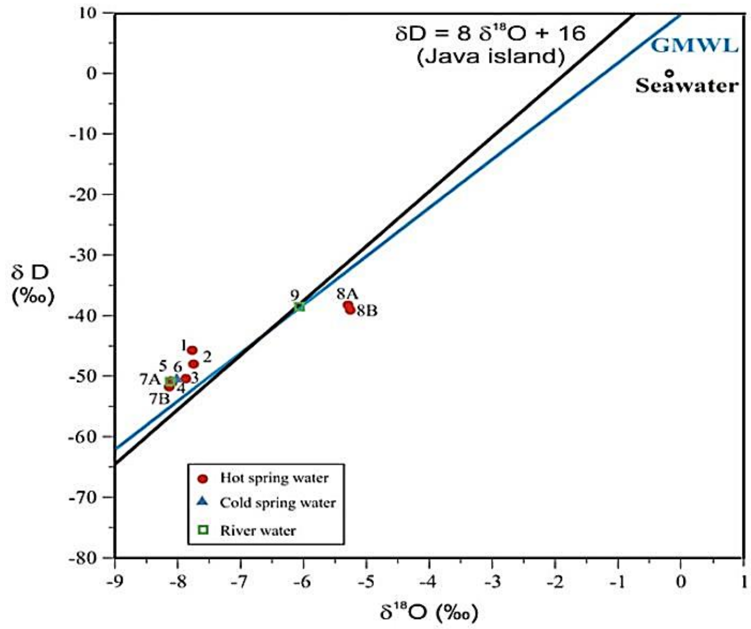


Figure 5: Oxygen and deuterium isotope ratio (Phuong, 2012)

The gas geochemistry analysis was also conducted, involving 4 periods of gas sampling in Gedongsongo Fumarole. The data from each period was plotted to the N_2-CO_2-Ar diagram to estimate the origin of gasses (Figure 6), and plotted to H_2/Ar – CO_2/Ar diagram to estimate the temperature and its phase of the reservoir (Figure 7). From the N_2-CO_2-Ar diagram, it could be inferred that the gasses from fumarole are originated from magmatic sources since the plots are aligned with the magmatic line. From the H_2/Ar – CO_2/Ar diagram, it could be inferred that the estimated reservoir temperature is in the range of 280^{o} – 295^{o} C and the phase in the reservoir is estimated as two-phase, liquid dominated since the plots are between the estimated temperature line of 275^{o} and 300^{o} C, and within the two-phase zone in the diagram respectively.

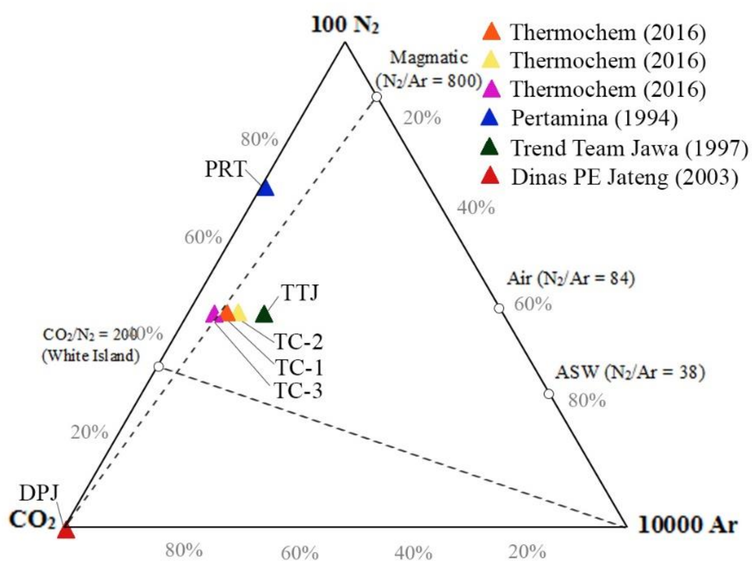


Figure 6: N2-CO2-Ar ternary diagram (PLN Pre-Feasibility Study Report, 2017)

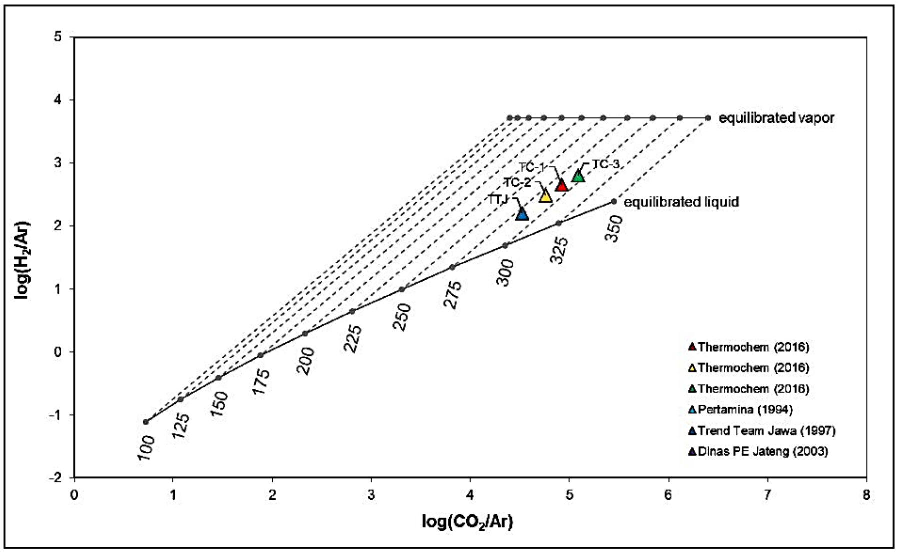


Figure 7: H2/Ar vs. CO2/Ar diagram (PLN Pre-Feasibility Study Report, 2017)

This information is major to give illustrations of how fluids flow in the system, including the flow of deep and shallow meteoric water recharge and the permeable paths which accommodate the fluid flow. The information on reservoir temperature approximation from the geothermometer is also substantial for building the numerical model. In this case, the result from the gas and water geothermometer is significantly different. By considering the appearance of steam phase manifestation on the surface, it was decided that the estimated reservoir temperature is 280^o C instead of 169^{o}C which is unlikely able to produce steam phase manifestation.

2.3 Geophysical Study

The study involves images of subsurface resistivity variation from the magnetotelluric survey (MT). The analysis of these MT survey results (Figure 8) is aimed to give an illustration of caprock and reservoir dimensions in the subsurface. The distribution of low resistivity values ($\rho < 4$ Ωm) at the shallower depth (varies from 1000 – 2000 m thick) and consistently appear until -1000 masl are interpreted as the clay cap of this geothermal system. In contrast, starting from 0 masl, the value of resistivity around the peak of Ungaran Volcano is significantly rising ($\rho > 100$ Ωm) and gradually rising through depth, interpreted as the reservoir of this geothermal system (1000 – 1500 m thick). Both of the low resistivity and high resistivity value variations appear to be the up dome-shaped resistivity structure with the low resistivity value overlaying and surrounding the high resistivity value (Figure 8). Such a system with this resistivity structure in a volcano is known as a vapor core system (Cumming, 2014). These dimensional illustrations of subsurface structures become the basic information in assigning material properties of each block in the model building.

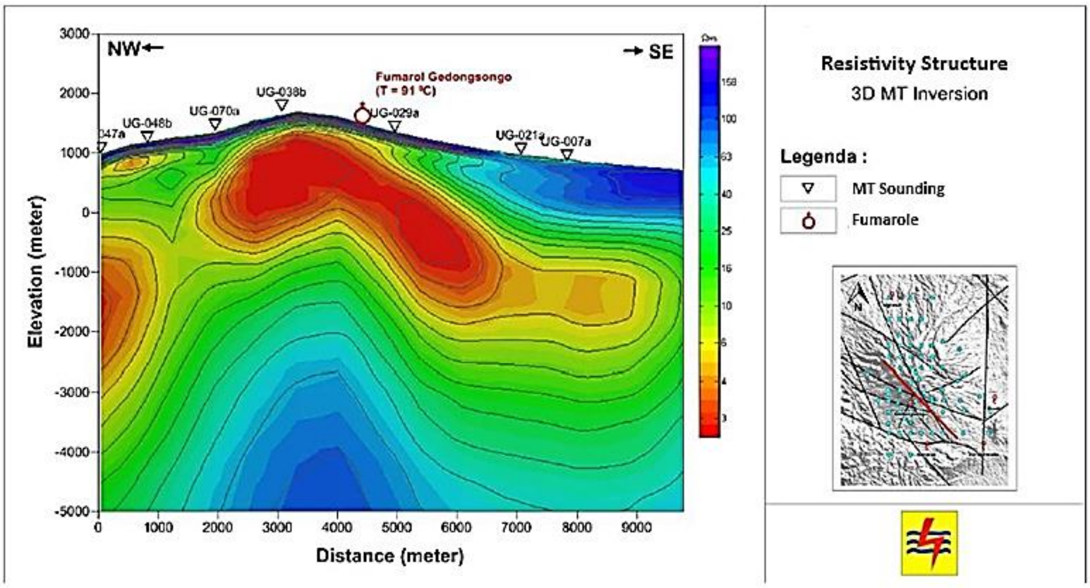


Figure 8: 2D vertical resistivity structure (Modification from PLN Pre-Feasibility Study Report, 2017)

2.4 Conceptual Model

The conceptual model sums up the information of the geothermal system dimension in the subsurface. Furthermore, it describes how fluid flow within the system and the temperature distribution based on water and gas geochemistry. This is a high terrain, volcanic hydrothermal system with a high enthalpy reservoir and a vapor core (Bogie, 2015) linking the magmatic heat source to the surface. This conceptual model becomes the benchmark of the expected reservoir simulation result, specifically the one with similar fluid flow and isothermal line (Figure 9). The upflow zone is around the peak of Mount Ungaran, where the fumarole appears on the surface. The heat source is presumed as a young magmatic body or an active volcanic body, laying straight beneath the upflow zone. The outflow zone is located on the lower flank of Mount Ungaran, surrounding Mount Ungaran volcanic cone except on the West and the Nort East part of Mount Ungaran. The caprock is specified as clay cap (advance argillic) with thickness varies from 1000 – 2000 m, starting from elevation 1918 masl to -1000 masl. The reservoir is laying under the caprock, starting from elevation 0 masl to -2200 masl with thickness varies from 1000 – 1500 m. The cold water infiltrates the reservoir from shallow and deep recharge mechanism. The heat source is laying straight beneath the upflow zone, where the possible vapor core is also proposed to exist.

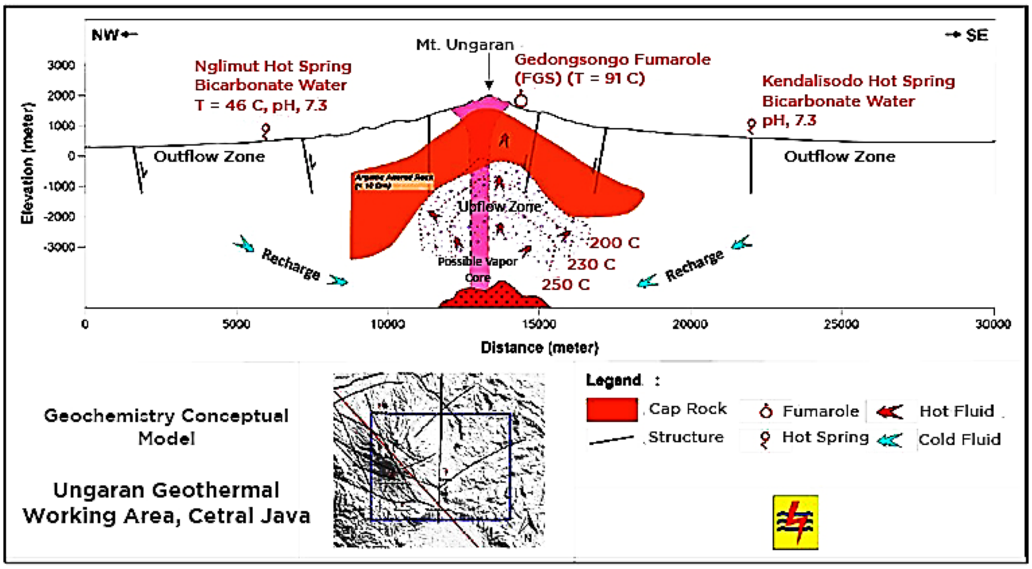


Figure 9: Ungaran geothermal system conceptual model (PLN Pre-Feasibility Study Report, 2017)

3. NUMERICAL MODEL OF UNGARAN GEOTHERMAL FIELD

3.1 Model Building

In general, this step is where the visualization of the subsurface conceptual model is being represented numerically. The numbers are the value of some physical properties of the subsurface. These physical properties were assigned as blocks in the numerical model. Each block may have different properties as it represents the heterogeneous subsurface. Each different configuration of these physical properties could be defined as material. As the geothermal system consists of its components, including reservoir, caprock, recharge and discharge area, and heat source, the model requires materials with suitable physical properties to represent each of those components in the model. As well as structure within the reservoir model, the boundary conditions may be adjusted; a side boundary may be impermeable or may allow contact to a lateral aquifer, and the model bottom is adjustable as those adjustments are representing the convective process within the model (Sullivan, 2000). Therefore, boundary materials were defined. The details of each material are shown in Table 1. The value of the lateral permeability of a material (Kxy) has the same value, while vertical permeability (Kz) is less than its lateral permeability value (Kurniawan, 2017) (Grant, 1982).

Table 1: Material properties

Material Type		Color Code	Density	Porosity	Permeability		Heat Conductivity	Rock Spesific Heat
					x,y	z		
			kg/m3	-	mD		W/m.°C	J/kg°C
Atmosfer	ATM		2400	0.05	0.1	0.05	2.5	1000
Ground Water	GWT		2400	0.06	0.1	0.05	2.5	1000
Caprock 1	CPR1		2400	0.05	0.01	0.001	2.5	1000
Caprock 3	CPR3		2400	0.05	0.007	0.001	2.5	1000
Reservoir 1	RSV1		2400	0.08	80	40	2.5	1000
Reservoir 2	RSV2		2400	0.08	50	25	2.5	1000
Reservoir 3	RSV3		2400	0.1	10	5	2.5	1000
Basement	BST		2400	0.05	100	100	2.5	1000
Heat Source	HS		2600	0.07	100	100	2.5	1000
Boundary 1	BDR1		2400	0.05	0.001	0.001	2.5	1000
Boundary 2	BDR2		2400	0.05	1	0.01	2.5	1000
Fault 1	FTP		2400	0.1	80	40	2.5	1000
Chimney	CHY		2400	0.08	200	1000	2.5	1000

The conceptual model from the geoscientific survey and resistivity structure images become the references to assign these materials spatially. The model dimension was defined to accommodate the prospective production zone both laterally and vertically based on the estimated reservoir dimension from the 2D lateral and vertical resistivity structure images (PLN, 2017), resulting from the 8x10 km^2 area and 5 km thick model. Furthermore, through the interpretation of the resistivity structure images, it was decided to divide the model into 5 main layers, including the atmosphere, groundwater, caprock, reservoir, and basement. Each layer has its sublayers to increase the resolution of the model. Not only vertically, but the model was also divided laterally for a similar purpose, which is called mesh. The smallest mesh with a 200x200 m^2 area was defined. For the defined dimension, the model has been divided as layers and meshes which are described in detail through the following Figure 10.

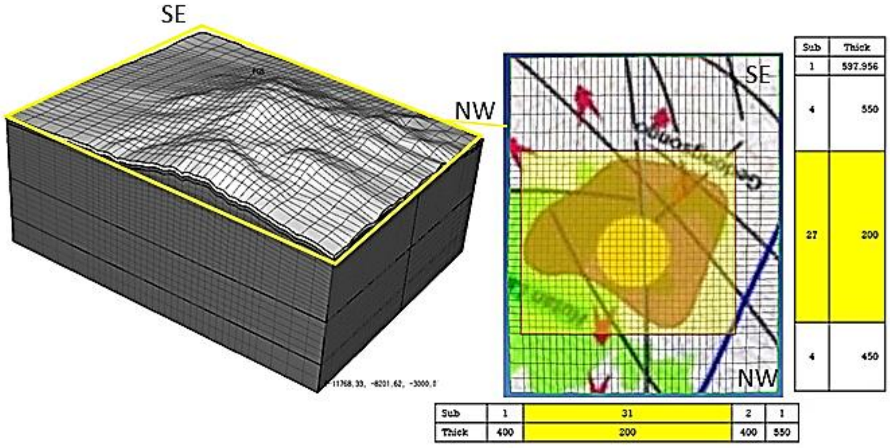


Figure 10: Dimension of the block model and meshing details

As the material at each layer was assigned and formed an illustration of a geothermal system, the distribution of permeability and porosity were formed as well. The other concern is not only to assign those materials in a similar position as in the conceptual model, but it also needs to consider the expected fluid flows that have been stated in the conceptual model are accommodated by those materials assignment, since the distribution of permeability and porosity is the primary control of the fluid flow in the model.

The system has a 100 m thick surface with groundwater, followed by a 1364 - 2000 m thick cap rock, and a 1200 m thick reservoir. Those layers are wrapped by layers defined as the boundary layer. On the top of the model, the atmosphere layer is defined as a layer with 1 bar pressure and 30^o C temperature as the initial boundary condition, the basement layer at the bottom of the model, and boundary 1 & 2 surrounding the model are set to be impermeable (Figure 11). The basement layer has 150–190 bar pressure, and $255–270^o$ C as the initial boundary condition.

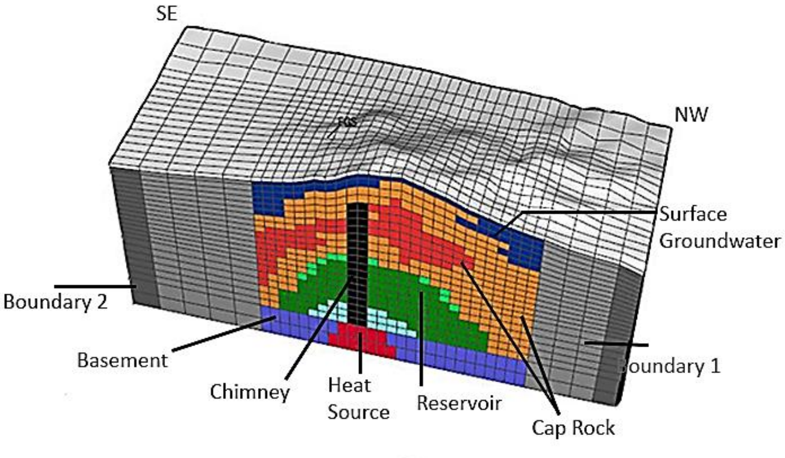


Figure 11: Block model of the prospective production zone

The first 3 layers, namely atmosphere, groundwater, and caprock, has its surface following the contour as the representation of the updoming cap rock. Each layer consists of only one kind of material, except for reservoir has 3 reservoir materials with gradually increasing permeability from the deeper to the shallower as the configuration of a two-phase reservoir model. The heat source material is assigned at the bottom layer of the model, somewhere vertically straight beneath the fumarole as the indicator of an upflow zone. This assignment is conceptually illustrated in a conceptual model from Nicholson (1993), that a heat source occurrence is vertically straight under the upflow zone.

To support the vertical fluid flow to reach the surface, the heat source material is arranged to be high pressure, up to 190 bar. The temperature of the heat source was changed iteratively, adjusting to the simulation result, which supposed to match the reservoir temperature from the conceptual model. The suitable heat source temperature is 290 ^{o} C.

The CHY material is assigned, forming a vertical continuous permeable zone right beneath the peak of the Ungaran volcanic cone. This is the representation of the vapor core in the geothermal conceptual model, which accommodates most of the vertical fluid flow position in the model, especially the steam phase fluid.

To obtain a reasonable simulation result which has proper pressure and temperature distribution, the pressure at each different layer is set to be (vertically) changed gradually through depth following these equations which were resulted from a temperature gradient hole, in Setyawan (2010):

$$T(^{o}C) = 33.82 - (0.0086\ x\ H) \tag{1}$$

$$P(Pa) = 2.03E7 - (1.0E4\ x\ H) \tag{2}$$

Where *T*, *P*, and *H* are the temperature at depth H (ºC), the pressure at depth H (Pa), and depth (m).

3.2 Simulation Result

The simulation was executed with the TOUGH2 EOS1 program. The simulation result represents 23.9 million years of an evolved geothermal system, which is in its natural state. The natural state of a geothermal system refers to initial conditions before a geothermal system is exploited. The term natural state is assumed to be achieved when all parameters remain constant after several simulations (Vereina, 2005). An attempt to validate that the simulation has reached its natural state was done by comparing the simulated temperature with the calculated temperature at the top of the reservoir (Sullivan, 2000) by using the equation from Saputra (2016) (Figure 12) due to the absence of actual observation temperature data. The estimation of subsurface temperature using the method from Saputra (2016) was calculated, resulting the estimated temperature beneath the gedongsongo fumarole is 176^{o}C at elevation 115 mbsl and compared with the temperature at the same position and depth in the model which temperature is 168^{o}C has an 8^{o}C deviation. This similarity confirming the natural state of the model has been reached. The thermal flow and fluid flow direction from natural state simulation results were compared to the conceptual model until found a good match that will validate the model to be used as an updated version of Ungaran geothermal system conceptual model. The natural state. The correct flow was obtained by modifying and adjusting P and T heat source, permeability, and porosity. Specifically, to get the vapor core simulation, P and T of the heat source and permeability value of chimney material are the most sensitive parameter to get the steam cap and upwelling fluid flow beneath the upflow zone.

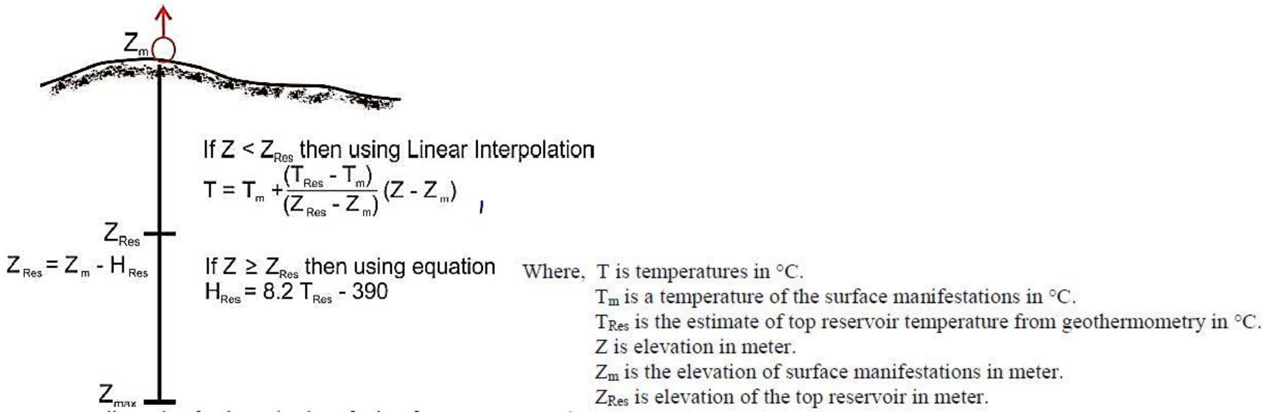


Figure 12: Illustration for determination of subsurface temperature using temperature from surface manifestation (Saputra, 2016)

Figure 13 illustrates the mass flow of the Ungaran model, which is similar to the heat flow pattern. The model illustrates that the recharge area is located at the flank of Mount Ungaran where water penetrates to the reservoir, heated, and flowing upward to the surface. The fluid phase changes through temperature degradation as the fluid moving upward. The liquid phase fluid formed at the surface and flows laterally downhill due to the hydraulic gradient. Some mass also flows out to Gedongsongo Fumarole (FGS) due to the occurrence of a permeable fault. A deep recharge also comes from a low terrain area and infiltrates the reservoir.

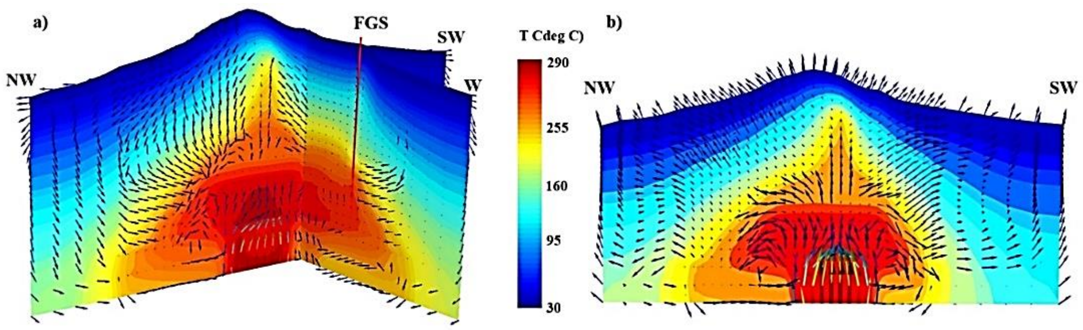


Figure 13: Simulation result, showing temperature distribution as a) fluid flow, and b) heat flow

Furthermore, the simulation result shows that there a maximum temperature at the reservoir zone is 280° C. This temperature value fits the estimated reservoir temperature from the geothermometer.

Figure 14 shows that the accumulation of gas (steam), forming a steam cap right under the bottom of the caprock. The gas saturation around the presumed steam cap area varies from 0.337 to 0.9. It is interpreted that the steam continuously formed until the shallow deep under the Ungaran peak. Some steam also formed under FGS and appear as a steam phase manifestation on the surface. This visual indicate that the simulation resulting a two-phase reservoir, which has not been stated in the conceptual model from the geoscientific study.

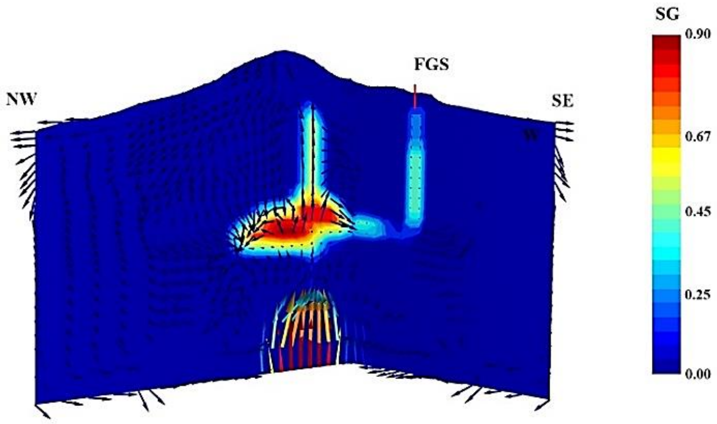


Figure 14: Simulation result, showing gas saturation (SG) which represent steam phase fluid

3.3 Updated Conceptual Model

The updated conceptual model is presented in Figure 15(b), showing similar fluid flow with the previous conceptual model. The differences are the presence of the steam cap at the top part of the reservoir, the vapor core is already confirmed, and the fluid recharge is not coming from the surface but only flows laterally as a deep recharge. The temperature of the system is generally higher than the temperature in the previous conceptual model, and the isothermal lines form a different pattern from the previous one. A conceptual model with a different direction is also built to give more illustration about the geothermal system Figure 15(c).

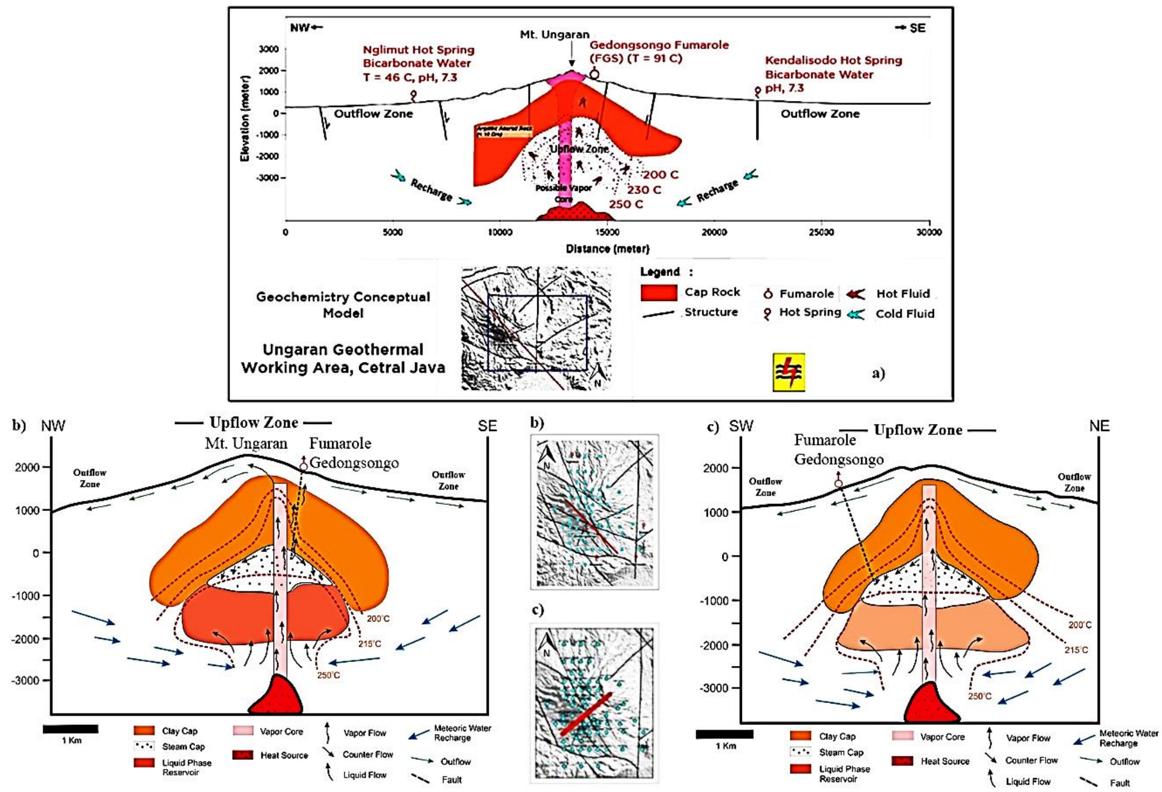


Figure 15: Updated conceptual model (b), compared to previous conceptual model (a), and conceptual model with another direction (c) (Modification from PLN Pre-Feasibility Study Report, 2017)

3.4 Discussion

The process of building the model was conducted by following the shape of the resistivity structure. It helps a lot to guide how to assign material spatially, but the application is limited only for building the cap rock model. This approach needs to be re-evaluated when it comes to assigning materials for building the reservoir part. Specifically, for the reservoir modeling, the materials were assigned based on how the expected result is supposed to be.

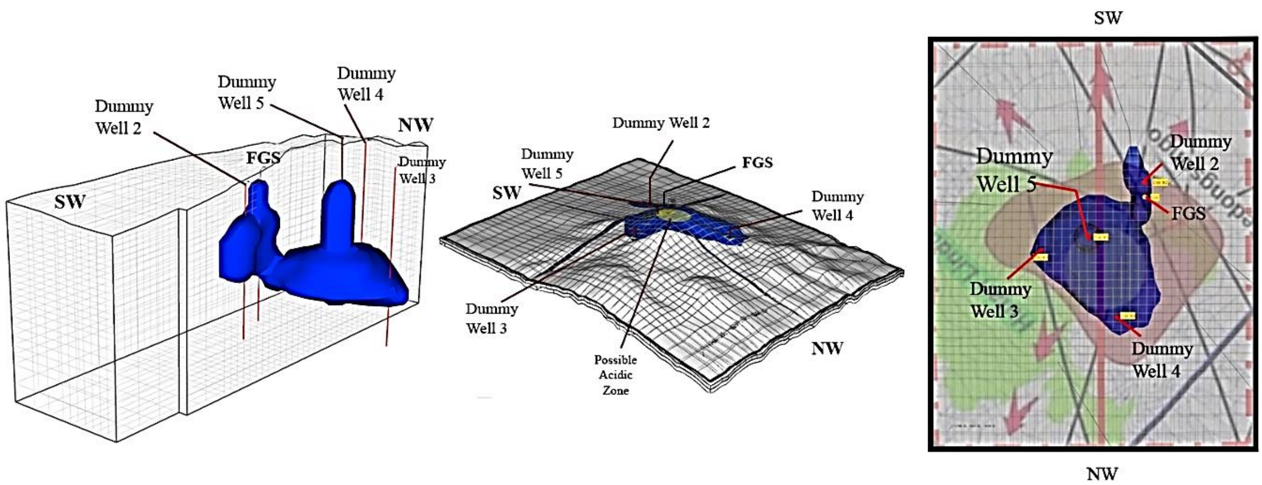
The indication of vapor core occurrence in the system was followed up by assigning chimney material linking the deep magmatic heat source to the shallow surface of the Ungaran Volcano Summit. This approach supports the fluid flow in such a thick model, which fits the conceptual model from the geoscientific survey. It could strengthen the argument that Ungaran Geothermal System is a vapor core system.

The model was built spatially limited, considering the working time efficiency. The well-defined zone of the model is only around 14,8 km^2 regarding the stated prospective area from the earlier survey, and the rest of the model was defined as a side boundary. Even though the side boundaries are set to be impermeable, the outflow direction is still clearly seen in the simulation result.

The temperature distributions of the simulation result are generally higher than the temperature distribution in the geoscientific conceptual model. The occurrence of SG anomaly in the simulation result might be interpreted as a steam phase fluid instead of a high saturation of gas due to the limitation of EOS1 mode that only does simulation for water and water with tracer (Pruess et al., 2012), not for gas flow simulation.

The Steam cap that was inferred from SG anomaly at relatively shallow depth is ideal for well targeting in the drilling campaign. The position of the steam cap is at 837 to 3000 m depth. The reservoir itself start to occur from -1100 meter, which means it needs to drill around minimum 2700 m depth of caprock to reach the top of the reservoir.

Figure 16: Location of dummy wells (Modification from PLN Pre-Feasibility Study Report, 2017)



All of the dummy wells targets is the steam cap. Dummy well #5 (DW #5) is dedicated to reservoir logging from Ungaran summit through a doming steam cap until reservoir basement. Reservoir logging result from DW #5 shows that caprock thickness from Ungaran summit is around 1000m depth (Figure 17). Beneath the caprock is a steam cap area that has SG value from 0.377 – 0.9. In that area, the maximum temperature is 250 ^oC and Pressure around 50 bar. The deep reservoir is located from 3000 – 4200 m depth with a temperature range 250 – 280 ^oC and pressure range 50 – 140 bar.

Three other dummy well to give an illustration about drilling location. Dummy well #2 (DW #2) location is around FGS. The pressure and temperature graph of DW #2 show that the reservoir beneath is water dominated with temperature ± 130 ^oC in 800 m depth. Temperature above 200 ^oC will be gotten in 2000 m depth. Three feed zone appears in this location due to the presence of fault around this area. Dummy well #3 (DW #3) location is 1200 m NE from the Ungaran summit. The pressure and temperature graph of DW #3 show that the reservoir beneath is 2-phase. The reservoir temperature is 260 ^oC, and the top of reservoir is 2700 m depth. Dummy well #4 (DW #4) location is 2000 m NW from Ungaran summit. The pressure and temperature graph of DW #4 show that the reservoir beneath is 2-phase. The reservoir temperature is 260 ^oC, and the top of reservoir is 2500 m depth.

From three locations above, area DW #2 has thin caprock around 800 m depth. The temperature of the reservoir starts from 120 – 250 ^oC and water dominated. DW #2 also has three feed zone area due to its location in the fault area. The location is far from the forest that usually forest area is prohibited for project development. The location of DW #2 area is recommended for drilling development considering those reasons. DW #3 and DW #4 area are not recommended for drilling due to the thickness of caprock around 2600 – 2800 m depth. The drilling cost will be high if those areas are developed as production wells. It also can be predicted that up to 3500 m depth, there is only one feed point is founded for these two locations.

Figure 17: Reservoir pressure and temperature logging (Dummy well 5)

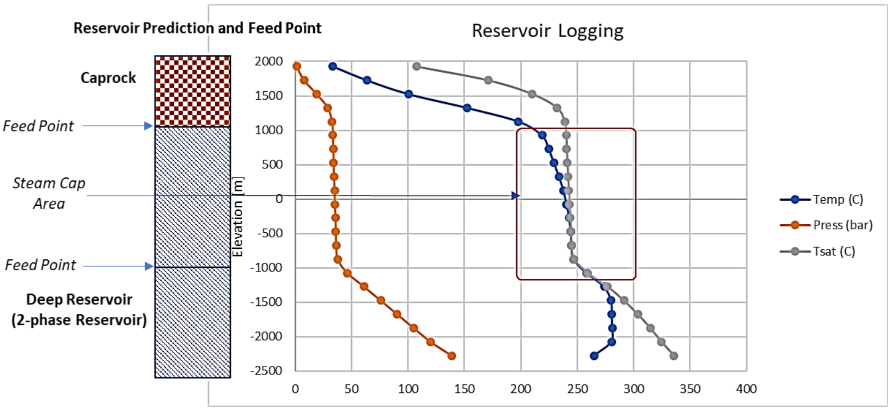


Figure 18: Pressure and temperature logging (Dummy well 2)

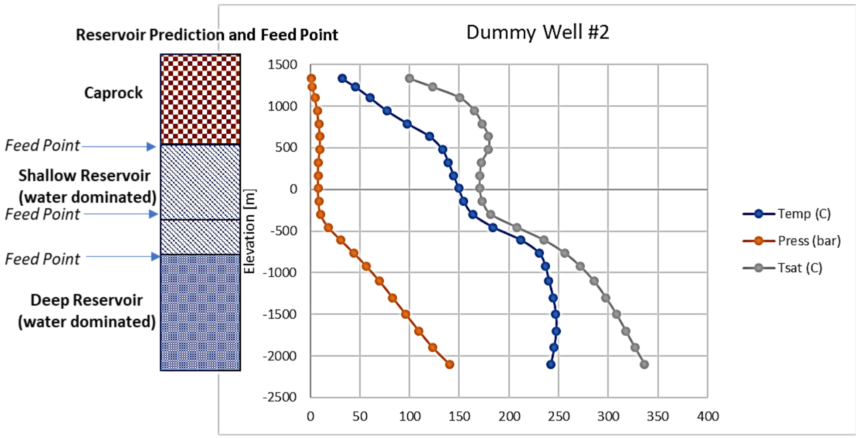


Figure 19: Pressure and temperature logging (Dummy well 3)

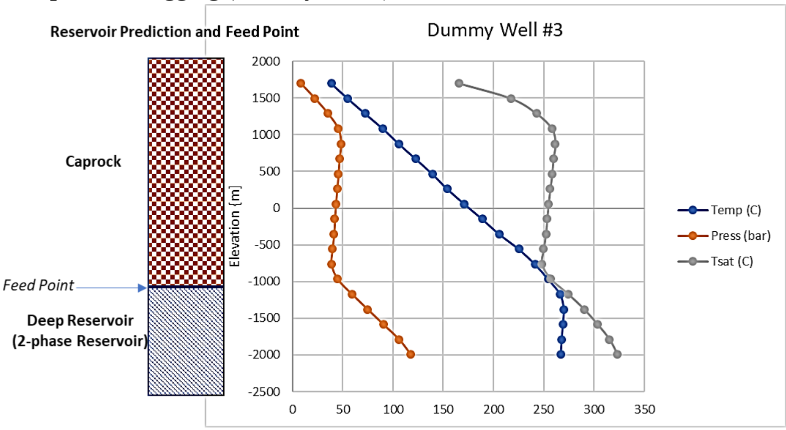
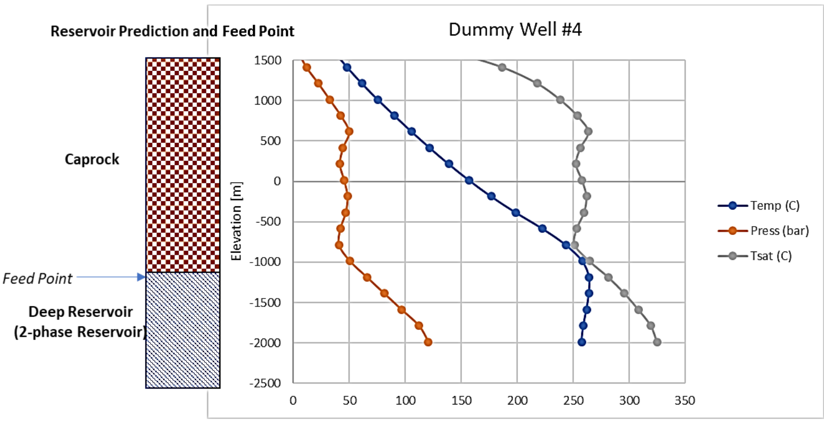


Figure 20: Pressure and temperature logging (Dummy well 4)



The center of steam cap or the chimney area is not recommended to be drilled due to the occurrence of the possible acid zone since this zone might contain a high amount of unreleased magmatic gases that can form acidic condensate, with 800 m diameter. The ideal location for the drilling area is above the FGS manifestation to target the shallow steam cap. The range of areas that recommended for steam cap drilling is 800 – 1400 m to NW direction and 800 – 1860 m to NE direction away from Ungaran peak. Furthermore for field sustainability, further drilling is recommended at deeper depth to reach water dominated zone. This drilling recommendation is expected to help to maintain the steam cap volume balance due to production for longer vapor production sustainability.

4. CONCLUSION

The natural state model of the Ungaran geothermal field has been successfully developed and matches the reference from the previous conceptual model. The updated conceptual model shows new information including the occurrence of vapor core and steam cap in the model. The best possible location to drill the well has been proposed by considering the occurrence of high gas saturation, high temperature, and the possibility of further technical problems due to the possible acid zone. The reservoir is expected to have a maximum temperature of 280 °C. Based on the simulation result, several drilling point suggestions have been proposed considering the benefits and the drawbacks of each simulated drilling point. The result of this study is proposed to be considered in the further exploration stage of Ungaran Geothermal Prospect.

5. DISCLAIMER

This study is based on the data from the PLN Pre-Feasibility Study of Ungaran Geothermal Working Area in 2017. Shall the updated data are accessible, the model might be reinterpreted.

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