Resource Assessment of Ungaran Geothermal Field Using Numerical model and Monte Carlo Simulation

Bambang Wahyu Jatmiko1,2, Muhamad Hasbi Assiddiqy1, Prajamukti Ediatmaja1,2, Ricky Prabowo1,2, Sutopo1, Heru Berian Pratama1, Muhamad Ridwan Hamdani1
1Geothermal Engineering Master’s Program, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Jl. Ganesha 10 Bandung 40132, Indonesia
2PT. PLN (Persero), Jl. Trunojoyo Blok M-1 No. 135, Jakarta, Indonesia
E-mail: heru.berian@geothermal.itb.ac.id

Abstract. A careful decision needs a comprehensive and effective way to estimate the subsurface condition and the possible resource contained in the geothermal system. Numerical model and simulation sum up the result of geoscience study and its correlation to the behavior of the subsurface fluid flows. A well-developed numerical simulation could give a thorough analysis of a geothermal system and be utilized as input parameters to apply the resource assessment method. This study applied the numerical simulation to the Ungaran geothermal field using TOUGH2 reservoir simulation software. Several parameters were referring to these simulation results and used as the input parameters to the resource assessment method using Monte Carlo simulation. The result shows that the resource value with the highest confidence is lower than the earlier resource estimation of the Ungaran Geothermal System, which is only based on geoscience study. This study gives a careful analysis to support decision-making, especially in a geothermal green field.

Keywords: Resource assessment, Monte Carlo simulation, numerical model, Ungaran geothermal field.

1. Introduction
In general, a decision to estimate the subsurface condition in an exploration stage of a geothermal prospect is challenging to decide, especially in a greenfield area, because its potential resource is still not detailed yet. A decision to develop a geothermal prospect might be strengthened by presenting an estimated resource of a geothermal system. An assessment of geothermal resources could be done during the reconnaissance and exploratory stage prior to well drilling regarding a conceptual model, which is an integrated representation of geology, geochemistry, and geophysics analysis [1,2]. Furthermore, a reservoir simulation, which partially represents the conceptual model dimensionally and hydrothermal fluid flow within an enclosed geothermal system, would be better used as a resource estimation input parameter. However, Ungaran geothermal field (UGF) is still in the exploration stage; a numerical simulation and resource assessment would be necessary to be done.

At the exploration stage, with limited data available, reservoir numerical simulation is unlikely to provide a more realistic long-term. However, it has a value at that stage, but this method may be best for checking for consistency or updating the conceptual model. This method has applied in Arjuno-Welirang [3], Atadei [4–7], Patuha [8–11], Cisolok-Cisukarame [12], Kerinci [13], Tompaso [14,15],
Ulumbu [16–18], Mataloko [19,20], Karaha-Talaga Bodas [21–23], Songa-Wayau [24], Danau Ranau [25,26], Lumut Balai [27].

In this study, a numerical model of the Ungaran geothermal system was built and used as a resource estimation input parameter. This method became the best practice in resource assessment. Several researchers [28–30] had applied a probabilistic approach using Monte Carlo simulation and geothermal reservoir numerical simulation to estimate the geothermal resources. Each block of this numerical model becomes the input to the reservoir simulation performed using the TOUGH2 program [31]. The resource estimation of the Ungaran geothermal field was conducted using a heat stored principal. It involves a probabilistic approach in the resource assessment.

2. Geosciences Review

A thorough geological, geochemical, and geophysical survey was recently executed by PLN in 2017 [3]. The appearance of geothermal manifestations simply indicates the occurrence of geothermal resources within the UGF (e.g., fumarole, hot springs, warm springs, and alteration zone). The possible main host for a geothermal system in UGF is Ungaran Volcano. Since it is situated at the subduction zone where the oceanic plate (Hindia Plate) subducting against the continental plate (Eurasia Plate), it gives a clue that Ungaran Volcano is most probably supplied by basaltic-andesitic magma. It has 1200°C - 750°C temperature as the possible heat source for this geothermal system. By considering the distribution of geothermal manifestations and each physical characteristic such as temperature, pH, debit, color of water, and the deposit around the manifestation, the geothermal system is categorized as a high terrain, high enthalpy geothermal system. The distribution of alteration minerals (advance argillic) and the occurrence of sulfur deposits on the Ungaran volcanic cone delineate the upflow zone and the possible location of clay cap of this geothermal system. The geological structure distribution gives a clue of the permeable pathway for the geothermal fluid to ascend, known as a discharge zone. Water and gas geochemistry also reveal that this geothermal system might be a two-phase reservoir with a 280°C maximum reservoir temperature. The geophysical survey results give the subsurface geometry model of the Ungaran geothermal system.

![Figure 1. The conceptual model of Ungaran Geothermal System](image)

The results were compiled and represented by a simple conceptual model which explains that the geothermal system in UGF is a vapor core system. The term vapor core is explained as a chimney-like acidic vapor dominated zone, linking deep magmatic-high temperature zones to the floor of a crater [32]. Therefore, such a system should at least have a magmatic heat source that commonly occurs in a mountainous environment. More than a visualization of the subsurface dimension, it also describes the
fluid flow and the temperature distribution within the geothermal system. Ungaran geothermal system is a high terrain, a volcanic hydrothermal system with a high enthalpy reservoir and a vapor core [33] linking the magmatic heat source to the surface. Based on the conceptual model (Figure 1), the upflow zone is located around the appearance of the Gedonsongo fumarole, which covers the peak of the Ungaran volcano and its surrounding up to 500m radius.

Based on the conceptual model, the outflow zone covers most of the lower flank of the Ungaran volcanic cone, except the west and the northeast flank. The system has a 1000 – 2000 m thick advance argillic clay cap, from elevation 1918 masl to -1000 masl. The reservoir is under the clay cap, occurring from elevation 0 masl to -2200 masl, with various thicknesses from 1000 to 1500 m thick. The heat source lays beneath the upflow zone, at the deeper elevation than -3000 masl, which is presumed as a young magmatic body. The meteoric water infiltrates the reservoir through the shallow and deep mechanisms as the recharge mechanism. A vapor core is proposed to exist as a permeable pathway for reservoir fluid to ascend. This piece by piece information will be essentially regarded during the model building process.

3. Computer Model and Numerical Simulation
In the model building step, the conceptual model of the Ungaran geothermal system is being represented numerically. The term numerical could be elaborated as the value of several physical properties of the subsurface material. In the model, these values of physical properties are represented by blocks. Each block may have different physical property values to represent the heterogeneous subsurface. Generally, the physical property values configuration will be adjusted to resemble the material making up the components of a geothermal system, namely cap rock, reservoir, recharge, discharge area, and a heat source.

![Figure 2. Numerical model of the Ungaran prospective production zone](image)

The model should be constructed to simulate the cycle within a geothermal system as it could be unaffected by the condition outside the system. Therefore, a boundary condition was determined and applied in the model. Several boundary conditions were adjusted as a barrier of the system to the outside condition, involving impermeable material on every side and bottom of the model, and the atmosphere-like condition as the top boundary condition. Specifically, the side boundary may also allow contact to the lateral aquifer, and the bottom of the model is adjustable to represent the convective process inside the model [34]. A configuration of physical properties known as material (Table 1) is adjusted to be unique. As known in general application, the lateral permeability value of the material (Kxy) is set to be the same. In contrast, the vertical permeability value (Kz) is less than (generally half of) the lateral permeability value. 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°C temperature as the initial boundary condition, the basement layer at the bottom of the model, and boundaries 1 and 2 surrounding the model are set to be impermeable (Figure 2). As the initial boundary condition, the basement layer has 150–190 bar pressure and 255–270°C.

The assignment of these materials referred to the resistivity structure images from the magnetotelluric survey. The model dimension (8×10 km² and 5 km thick) was specifically created to cover only the prospective production zone on the lateral and vertical extent. The model is divided into five main layers: atmosphere, groundwater, caprock, reservoir, and basement. For better resolution, those five main layers are furtherly divided into sub-layers. The model is also divided laterally (mesh) with the smallest mesh size, 200×200 m².

As illustrated in the conceptual model, assigning subsurface materials with their physical properties is expected to accommodate how the hydrothermal fluid flows within the system. The permeability and porosity are happened to be the primary control of the fluid flow within the model. The system is modeled as it has a 100 m thick surface containing groundwater-like material, followed by a caprock with 1364 - 2000 m thick in the greater depth and a 1200 m thick reservoir beneath the caprock. The boundary layer wraps the model. The bottom of the model is set to be a high temperature, high pressure, and impermeable layer (150-190 bar, 255-270°C) to represent the basement layer. The top of the model is set to be adaptable with the atmosphere layer (1 bar, 30°C). The surrounding boundary is defined as boundaries 1 and 2, which are set to be impermeable layers.

![Figure 3](image-url)

**Figure 3.** An updated conceptual model based on the numerical simulation result (natural state)

The numerical simulation result has been confirmed to be reaching its natural state by comparing the subsurface temperature from the simulation result to subsurface temperature estimation using an approach from Saputra [35] at the corresponding depth. The calculation result shows the estimated temperature beneath the Gedongsongo fumarole is 176°C at elevation 115 mbsl and compared with the temperature at the same position and depth in the model, which temperature is 168°C has an 8°C deviation. This similarity confirming the natural state of the model has been reached. The simulation
result also corresponds to the geothermometer result, which shows that the maximum reservoir temperature is 280°C. The simulation result also updates the conceptual model, specifically in the prospective area (Figure 3).

4. Resource Estimation

The resource estimation of the Ungaran geothermal field was conducted using the Monte Carlo simulation method principle. Monte Carlo simulation calculates the probabilistic model that simulates physical properties value distribution concerning the heat stored principal iteratively. In this simulation, the minimum, maximum, and most likely value of each parameter of geothermal resource was estimated. Reservoir temperature is determined based on the model's temperature at the top and bottom of the reservoir area. Each has a temperature 225°C at an elevation of approximately -250 msal and 280°C at an elevation of -2000 msal. The thickness of the reservoir is 1200 m approximately, with rock porosity around 0.05. All material properties values assigned to this model were calibrated and selected to control the mass and heat flow to match the natural state conditions and established conceptual model. The recovery factor is obtained based on the correlation value between recovery factor and porosity [36,37] around 0.375. The conversion factor is assumed to be 10%, and the project time is assumed to be 30 years. The input parameter and assumptions are shown in Table 1.

The result of the Monte Carlo simulation, with 60,000 Random Numbers, is presented as geothermal resource value, following its degree of confidence rank (P10, P50, and P90). The sensitivity analysis result for the calculation of Ungaran resource assessment is shown in Figure 4. The results show that reservoir area, initial reservoir temperature, and recovery factor are the most sensitive parameters. The recovery factor is affected by the permeable reservoir as well as the heat sweep efficiency of these permeable channels. This parameter is affected by the reservoir's thermodynamic and hydraulic properties [38]. As a result, these parameters must be determined carefully to avoid incorrect estimation. The Monte Carlo simulation results show that Ungaran geothermal field resource values are P10: 74.2 MW, P50: 116.4 MW, and P90: 173 MW. Based on this simulation, the Ungaran geothermal resource at the highest degree confidence is lower than the possible resource (100 MW) which was predicted by ESDM [39].

| Variable                    | Unit | Min. | Max. | Most Likely | Reference                      |
|-----------------------------|------|------|------|-------------|--------------------------------|
| Area                        | km2  | 8    | 21   | 15          | Model at natural state condition |
| Thickness                   | m    | 1080 | 1320 | 1200        | Model at natural state condition |
| Rock Density                | kg/m3| 2300 | 2500 | 2400        | Model at natural state condition |
| Rock Heat Capacity          | kJ/kg.°C | 0.9 | 1.1   | 1           | Model at natural state condition |
| Porosity                    |      | 0.05 | 0.10 | 0.05        | Model at natural state condition |
| Recovery Factor             |      | 0.25 | 0.50 | 0.38        | Muffler and Cataldi, 1978       |
| Electric Efficiency         |      | 0.9  | 1.1  | 1           | SNI-13-6482-2000                |
| Initial Water Saturation    |      | 0.6  | 0.8  |             | Model at natural state condition |
| Final Water Saturation      |      | 0.3  | 0.5  |             | Prediction of field condition after 30 years |
| Initial Temperature         | °C   | 225  | 280  | 250         | Prediction of field condition after 30 years |
| Final Temperature           | °C   | 180  | 200  | 190         | Prediction of field condition after 30 years |
| Life Time                   | year | 30   |      |             | SNI-13-6482-2000                |
5. Conclusion
The numerical simulation of the Ungaran geothermal system based on geoscience review results has been successfully reaching its natural state. The numerical simulation result combined with the values of blocks within the numerical model effectively represented the required input parameters for the resource estimation method. The estimated resource value (74.2 MW) gives a lower value than the initial estimation (100 MW). This approach provides a better perspective to determine a geothermal resource value and support the geothermal exploration stage decision-making.

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

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