Natural state modeling of Mataloko Geothermal field, Flores Island, East Nusa Tenggara, Indonesia using TOUGH2 simulator

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Abstract. Mataloko Geothermal Field is located approximately 15 km east of Bajawa City in Southern Central Flores Island, Indonesia. The geothermal system of this field is two-phase dominated with steam dominated zone at the shallower part of the field and liquid dominated at the deeper part with temperature of 210°C and 275°C, respectively. From the exploration effort and preliminary study, the possible reserve of this field is up to 62.5 MWe [1]. This study was carried out by numerical natural state modeling using TOUGH2 simulator. The objective of this study is to present numerical modeling of the Mataloko Geothermal Field based on the currently published paper of previous geological, geophysical, and geochemical study, also the actual measurements on the established wells. The model was matched with actual shut-in temperature and pressure measurement on Well MT-3, also mass and heat flow on the conceptual model to achieve natural state condition. The results conclude that the area of the reservoir is up to 10.2 km² with exploitable reservoir thickness up to 1750 meter. Temperature of the suspected productive deep liquid dominated reservoir is 275°C. The final permeability of the reservoir is ranging from 18-40 mD with exceptional 91.5 mD at the main fault. Furthermore, this study proposes a more accurate prediction specifically on the shallow vapour region. The potential reserve was calculated using Monte Carlo simulation based on the simulation result. Calculated potential reserve is 52 MWe with 90% confidence level (P₁₀). Expansion of 5×10 MWe power plant capacity is suggested by drilling effort to elevation of -1000 to 0 masl through the productive hot deep liquid dominated zone.

1. Introduction

Mataloko geothermal field is located in the central southern part of Flores Island in East Nusa Tenggara province in Indonesia (see Figure 1). Located around 15 km east of Bajawa City at an elevation around 1000 masl in typically flat terrain surrounded by 10 volcanic cinder cones.

The geothermal system of this field consists of shallow vapour dominated reservoir and deep high-temperature liquid dominated reservoir. The vapour dominated reservoir has a temperature around 200°C with dominantly wet steam and sat atop the deep liquid dominated reservoir with temperature of
280-300°C. The shallower vapour dominated reservoir has temperature of 125-135°C proved by measurements on first drilling efforts.

The development of this field carried out in two phases. The first phase is done by a collaboration of Indonesian government (Directory of Mineral Resources Inventory) and Japanese government (GSJ, West JEC, MRC, and NEDO) for 5 years (1997-2002). The first development phase was done by remote sensing, geology, geochemistry, geophysics and preliminary study of the reservoir. This phase resulted in shallow exploration drilling (Well MT-1 and MT-2) in 1999 and 2000. However, the drilling did not reach the expected depth due to dry steam blows out in shallow depth for Well MT-1 and increasing temperature of drilling mud for Well MT-2 [16].

The second development phase was implemented in 2002 afterward by Indonesian governments. In this phase, Indonesian Minister of Energy and Mineral Resources granted the working permit of Mataloko Geothermal Area to PLN for 35 years period started in 2015 [7]. In Geothermal Development Project Plan, 3 production wells and 1 production well would be drilled for small scale geothermal power plant and expected to produce for maximum 5 MWe electrical power.

Figure 1. Location of the Mataloko prospect area (red dot) with comparison of Ulumbu area (green dot) and Sokoria area (blue dot)

2. Geosciences and Wells Data

2.1. Geosciences Findings
Mataloko geothermal field is located in the central southern part of Flores Island and surrounded by 10 young volcanic cinder cones. The lithology reservoir rocks of the field are believed to be lava (Lava Watumanu) and tuff (Green Tuff). The lithology of clay cap rock is pyroclastic flow and lava flow overlain by young volcanic product [9].

The Mataloko field is controlled by the Wae Luja normal fault and most likely related to the Wolo Belu lava dome. The fault is marked by an alignment of thermal manifestations such as hot springs and altered rocks. Hence, the Wae Luja fault acts as an up-flow pathway for the Mataloko prospect [10]. Also, there are other two main faults termed Hubusora (WNW-SSE trending in the northern part of the Mataloko area) and Boba (NW-SE oriented located in the southern part of the area).

A very small input of deep fluid is existed on the field as proven by low Cl/SO4 ratios [6]. Most thermal waters on the field are meteoric waters [14]. NCG exists in the discharged fluid in relatively
low ratio [13]. Analysis of isotopic and chemical geothermometers presented in Table 1 concludes that deep liquid dominated zone is probably exist with temperature of minimum 179°C and maximum 352°C, with most likely at temperature of 290-300°C.

There was broad negative gravity anomaly in Mataloko prospects that indicates graben structure exists beneath with infill in the surrounding denser rock, similar magnetic anomaly also found on the position that is correlated with the location of thermal manifestations and indicated possible hot graben structure in deep of central Mataloko prospects [2]. Resistivity measurement using MT methods conducted by NEDO in 1999 found high resistivity layer existed at shallow depth with southeastern trend, and over lain by a thick extreme low resistivity. Beneath the extremely low resistivity, high resistivity layer was found up to 3 km depth. High permeability unaltered rocks exists at shallow depth as indicated by high resistivity [4]. The extremely low resistivity indicated cap rock and the high resistivity layer beneath it indicated the geothermal reservoir.

| Isotopic/Chemical Analysis | Prospected Temperature (°C) |
|---------------------------|-----------------------------|
| δ¹⁸O(SO₄-H₂O)             | 179 – 352                   |
| δ²H(H₂O-H₂)               | 278 – 294                   |
| log(CH₄/CO₂) vs log(H₂/H₂O)| Greater than 330            |
| log(H₂/H₂O) vs log(H₂/Ar) | 290 – 320                   |

2.2. Wells Data
There were 6 wells which have been drilled in Mataloko geothermal prospects with different conditions. Well MT-1 was completed in October 2000, but there is no PT logs recorded due to blowout occurred at 745 masl. Well MT-2 was completed in February 2001, one shut-in and two flow tests were conducted in this well. From all tests that have been conducted, accumulation of NCG occurred in the upper well section. Hence, vapour static gradient is not in agreement with the fluid condition on the PT plot unless 2.5 bar to 2.8 bar partial pressure of NCG is present [12]. However, due to shallow depth reached by this well, the data is quite limited for this study.

Well MT – 3 was completed in February 2004. This well reached up to 613 meter depth. From the shut-in test, the recorded low pressure of 8.4 barg at 300 meter depth in the boundary of steam phase and water level indicates a non-commercial producer due to low initial pressure and lack of permeability. Same with the case of Well MT-2, partial NCG pressure of 2.4 bar was expected to be present [5]. Shut-in PT measurement of this well is used as the comparison purposes of this study (see Figure 2). Well MT – 4 was completed in 2003 and reached up to 756.5 meter depth. This well completed with slotted liner installed from 735 masl to 227 masl. Only one pressure and temperature measurement conducted in flowing condition in this well [5].

Well MT – 5 was completed in 2005. The maximum temperature reached 103.7°C at 104 meter depth, due to limited depth reached by the well, these two logs are quite limited for this study. Well MT – 6 was planned to be a steam condensate injection well drilled down to 123.8 depth. There were no published pressure and temperature measurements [7].

3. Conceptual Model
The conceptual model is presented on Figure 3. The geology, manifestations, geochemistry, geophysics and wells data study for the conceptual model construction are summarized as below:

3.1. Geological Setting
From geological data, three faults exist on the area (Hubusora, Boba, and Wae Luja) with Wae Luja fault as the main geothermal fluid conduit for the prospect area.
3.2. Heat Source
From manifestation and alteration zone analysis, heat source is probably located vertically beneath the surface manifestation zone and alunite alteration zone. Furthermore, this hypothesis is supported by geophysical gravity measurement.

3.3. Cap Rock
From geophysics study, cap rock region exists at 500 masl to the surface. Reservoir region exists below the cap rock region.

3.4. Reservoir Geometry
From geochemistry analysis, deep hot liquid dominated reservoir with temperature of 290-300°C probably exists. Furthermore, meteoric waters recharge phenomenon is dominant on the reservoir. Also, minimum movement of the deep fluid into the shallow region is analyzed. From the well measurement and discharged fluid, steam cap and transition probably exists around 500 masl up to the surface surrounding the Wae Luja Fault. From this data and strengthened by geothermometry analysis, iso-temperature on the reservoir could be constructed.

4. Numerical Modeling
4.1. Gridding and Layering System
EOS1 for water and water with tracer was used for the model. The model consists of total 16 layers with 14 layers follow the topography. The model was tilted about 47 degrees counter clockwise in order to make the main fault contributing to the Mataloko geothermal system (Wae Luja fault) was projected in
the vertical manner on the model. Furthermore, this approach was chosen in order to simplify the validation process of the model to the conceptual model.

Gridding system for this model is regular grid model. The size of grids was variable to main geological structure. Smaller grid size of 100 m × 100 m is assigned to formation around the well and fault structure. On the other hand, larger grid size for up to 431 m × 200 m is assigned for boundary formation. The model consists of total 17,296 cells encompassing 39.76 km² area (see Figure 4).

4.2. Material Properties and Configurations

Material properties values that were assigned into this model was calibrated and selected in purpose of control the mass and heat flow to achieve satisfactory match with both conceptual model and actual well measurement.

There are 14 different materials that have been used in this model which consist of a liquid dominated zone material, 2 vapour dominated zone materials, 2 cap rock materials, 2 fault structure materials, 2 surrounding formation materials, 2 materials for surface and groundwater, a heat source material, a boundary material, and a basement rock material. Detailed final values of the material properties are presented on Table 2.

The consideration for material configuration (see Figure 5) was referred to geophysical exploration specifically to MT exploration data that had been done by [8], [2], and [15]. The geological study results that have been summarized through the conceptual model is also considered. The notable distinct feature on this model is assignment of high permeability region surrounding the Wae Luja fault structure specifically at the shallow depth, despite of the nature of cap rock region that has been indicated by the conceptual model. This approach is done to reach an accurate match with the actual shut-in measurement (which showed steam zone nature in shallow depth), the discharged dry steam from the shallow exploratory wells, and the MT measurement showing an anomaly of high resistivity region that exists on the shallow depth.

4.3. Boundary, Surface, and Initial Condition

The normal gradient was used for initial condition temperature, which is around 0.03°C/m. On the other hand, less than the normal gradient was used for initial condition pressure, which is around 6,100 Pa/m. The rainfall precipitation data was using annual average rainfall data in Flores Island, which is around 2,281 mm/year (BMKG, 2017). With assumption of only 10% rainfall recharged into the geothermal systems, the resulting recharge mass rate is 6.9E-06 kg/s.m². Enthalpy of 105 kJ/kg was assigned to the recharged meteoric water which corresponds to enthalpy of water at standard condition. Those parameters were assigned to the whole cell of the top layer in the model. The atmosphere layer was assigned to be fixed value of 1 bar pressure and 25°C temperature. Nevertheless, the groundwater layer was assigned to follow the global initial condition. Both layers used big volume factor to maintain all the parameters are relatively constant.

The side boundary material was set to be low permeability than the other materials to provide minimal flows of heat and mass. The permeability of the side boundary was set to 0.005 mD. The bottom boundary was set to be heat source and basement rock materials. Due to limited depth of exploration data, heat source temperature and pressure of the model are cannot be assigned with good confidence. So, the two parameters are part of iterated parameters during the simulation. Final iteration resulted to 174 bar pressure and 285°C temperature. Great volume factor of 10E38 was used to keep the temperature and pressure of the heat source constant during the simulation.

5. Natural State Modeling Result

5.1. Comparison to the Conceptual Model

The iso-temperature comparison showed reasonable match with the conceptual model where the transition zone exists at elevation 500 masl with temperature of 200-210°C and the upflow region with temperature up to 275°C (see Figure 6). Two-phase dominated reservoir with liquid dominated reservoir
beneath the steam cap structure (consisting mostly of wet steam) was showed in Figure 7. The steam cap was formed at which the vapourized liquid at 400-500 masl was accumulated near the impermeable cap rock. Furthermore, due to the existence of the Wae Luja fault across the impermeable cap rock structure, steam was moving through the fault and accumulated on the shallow steam cap and formed thicker steam cap than suspected on the conceptual model (shown in gas flow vector at Figure 7).

**Figure 3.** Conceptual Model of Mataloko prospect area (After [3])

**Figure 4.** Grid system of the model
Figure 5. Final permeability distribution of the model

Figure 6. Iso-temperature contour at Y=3500
Figure 7. Steam cap structure and gas flow vector

Table 2. Material properties that has been used in the model

| Materials Name Color | Density of rock (kg/m^3) | Porosity | XYZ Permeability (m^2) | Wet Heat Conductivity (W/m.K) | Specific Heat (J/kg.K) | Explanation |
|----------------------|--------------------------|----------|------------------------|-------------------------------|------------------------|-------------|
| ATM                  | 2150                     | 0.99     | 1.00E-06               | 2.00                          | 1000                   | Atmospheric layer |
| GW                   | 2200                     | 0.01     | 5.00E-16               | 1.99                          | 1000                   | Ground water layer |
| RTI                  | 2200                     | 0.05     | 6.50E-19               | 1.50                          | 1200                   | Cap rock layer |
| RTa                  | 2250                     | 0.02     | 3.00E-19               | 1.70                          | 1100                   | Basement material |
| GT                   | 2500                     | 0.03     | 2.00E-16               | 1.90                          | 1000                   | Liquid dominated |
| LD                   | 2500                     | 0.07     | 1.70E-14               | 1.60                          | 1100                   | Steam dominated |
| DSC                  | 2275                     | 0.12     | 3.50E-15               | 1.60                          | 1100                   |             |
| SSC                  | 2200                     | 0.1      | 4.00E-14               | 1.55                          | 1200                   |             |
| FAULT                | 2350                     | 0.01     | 9.15E-14               | 1.65                          | 1100                   | Permeable fault structure |
| FAULB                | 2350                     | 0.01     | 1.00E-18               | 2.00                          | 1000                   | Impermeable fault structure |
| HS                   | 2550                     | 0.1      | 4.00E-14               | 1.90                          | 1000                   | Heat source materials |
| NEAD1                | 2275                     | 0.1      | 3.00E-14               | 1.90                          | 1000                   | Reservoir surrounding materials |
| NEAD2                | 2275                     | 0.08     | 5.00E-15               | 1.90                          | 1000                   |             |
| BOND                 | 2350                     | 0.01     | 5.00E-18               | 1.97                          | 1000                   | Boundary materials |

5.2. Comparison to the Actual Well Measurement
Due to the scope of this study is to conduct a natural state modeling of the prospect area, only shut-in test result was used for validation of the model by comparing to actual pressure and temperature from the well measurement. This approach is done in purpose of validating the model to the best data represents the static condition of the reservoir. Hence, only shut-in test conducted in Well MT-3 is used for validation purpose.
Figure 8 shows the comparison of actual Well MT-3 measurement with the result of the model temperature simulation. Temperature below the depth of 700 masl on the model result shows higher temperature than the actual well measurement. This phenomenon is analyzed probably due to small inflow of colder liquid on the actual reservoir condition that cannot be accounted on the model with high accuracy. Nevertheless, the model result shows a reasonable match within the temperature gradient that clearly shows vapour phase on the shallow depth. Furthermore, the result also shows the boundary between the convective and conductive nature on the shallow reservoir at 840 masl which is proved by changing gradient on the temperature profile.

For analysis of pressure, partial pressure of about 2.4 bar was accounted on the comparison due to NCG accumulation that probably exist under shut-in condition [13]. Because of the simulation on this study only uses simple EOS1 and not accounting for NCG effects, the comparison is done between the pressure simulation result added by partial NCG pressure and the actual pressure measured on the well. The result showed a fair agreement. Furthermore, the result also shows the transition zone between liquid and vapour zone which is identified by changing pressure gradient occurs at 520 masl elevation.

5.3. Heat and Fluid Flow

On the conceptual model, the upflow region is vertically beneath the surface manifestation region and controlled by the Wae Luja fault. The other two faults (Hubusora and Boba fault), despite of minimum confidence, seem to act as the recharge region of the meteoric waters to the Mataloko geothermal systems and define the impermeable boundary to surrounding formation. There is no clear outflow direction on the Mataloko geothermal system as only controlled by the phenomena of counter flow which hot fluid upward movement was halted when encountered the impermeable cap rock.

The simulation of the model confirms both predictions from the conceptual model. The Wae Luja acts as the main geothermal conduit for the geothermal system both fluid and heat flow. The nature of the Hubusora and Boba fault are also confirmed from the simulation result as the impermeable boundary, where surrounding formation act as the recharge region to the geothermal system. The phenomena of counter flow is also presented on the simulation result as the convection of heat and fluid flow on permeable formation is halted when it encounters the impermeable cap rock region (see Figure 8).

On convective region, most of the heat were carried out by the movement of the fluid, so both heat and fluid flow moved in the same direction (see Figure 9). Furthermore, the model confirms gas flow vector into the small region of the altered region which has abundance of surface manifestations. This proved the vapour movement to the shallow region as the main contributor of the acid surface manifestations that exist in the field (acid fumaroles, acid hot spring and acid rock alteration).

The outflow region was characterized by the counter flow of hot fluid that was halted at the transition zone and moved downward to the heat source area due to the existence of the impermeable boundary (see Figure 10). Accumulation of hot fluid around the transition zone also showed on the result.
5.4. Reservoir Characterization

From the simulation results, the matching process of the model with the conceptual model and the actual well measurements, the reservoir of the Mataloko field is a two-phase dominated reservoir. The vapour dominated reservoir exists on the shallow depth and the liquid dominated reservoir exists underlying the vapour dominated region.

The liquid vector flow from the simulated model (see Figure 11) shows the liquid flow was halted when encountered the impermeable materials and moving downward in a convective nature. On the other hand, the boiling zone occurs on the 400 – 500 masl elevation that shown from the gas vector flow (see Figure 7). The vapour phase moves upward through the Wae Luja fault due to the buoyancy force and accumulated on the permeable lithology that exists on the shallow depth and formed a steam cap.

The steam cap, from the result of the simulation, shows thicker structure than the prediction from the conceptual model (see Figure 7). This is consequence of the approach that has been chosen in this study, as explained before on the material properties and configurations section. The result from this model is proposed to be the more accurate representation of the steam cap nature, specifically on the shallow depth. More detailed explanation of this discrepancy is presented on the discussion section.

Based on the reservoir model, the liquid dominated region has permeability of 18 mD, while the vapour dominated region has permeability between 35 to 40 mD. Reservoir thickness was determined by using gas saturation delineation at cut-off value of 0.8 for vapour dominated, and minimum value of gas saturation delineation for liquid dominated region. The resulted thickness for vapour dominated reservoir is around 400 m and for liquid dominated reservoir is around 1,350 m on the broadest part.
The area of the reservoir was estimated using grid area estimation on TOUGH2 Interface. For liquid dominated reservoir, the area determined as the exploitation area was cut by values of iso-temperature at 225°C (see Figure 12). This approach was done by referred to Hochstein classification of high enthalpy reservoir. The resulted area of the liquid dominated reservoir was around 10.2 km² on the broadest part. On the other hand, the exploitation area for vapour dominated reservoir was cut by values of gas saturation above 0.4 (see Figure 13). The resulted area of the vapour dominated reservoir was around 4.5 km² on the broadest part.

The drilling of production wells through liquid dominated zone at the elevation of -1000 to 0 masl is suggested based on the temperature simulation and economical drilling depth consideration. The unexploited region of the liquid dominated zone at this depth on the established optimistic area is expected to be productive.

**Figure 9.** Heat flow at Y=3500

**Figure 10.** Liquid flow vector at outflow area
Figure 11. Liquid flow vector and iso-pressure

Figure 12. Iso-temperature at suspected productive deep liquid dominated reservoir
Table 3. Monte Carlo calculation result at liquid dominated zone

| Confidence | Electric Power |
|------------|---------------|
| (P<sub>10</sub>) 90% | 50 MWe |
| (P<sub>50</sub>) 50%  | 70 MWe |
| (P<sub>90</sub>) 10%  | 95 MWe |

Table 4. Monte Carlo calculation result at vapour dominated zone

| Confidence | Electric Power |
|------------|---------------|
| (P<sub>10</sub>) 90% | 2 MWe |
| (P<sub>50</sub>) 50%  | 3 MWe |
| (P<sub>90</sub>) 10%  | 5 MWe |

5.5. Reserve Estimations

The reserve estimation of Mataloko prospect area in this study is done by Heat Stored method. Due to the high uncertainty of the actual reservoir parameters, probabilistic approach was done using the Monte Carlo calculation. This calculation was run by using 50,000 random numbers. Parameters used in the probabilistic calculation are the results of natural state simulation, general assumptions, and literature study (see Table 5). The Monte Carlo calculation was done for both liquid and vapour dominated system region in separate calculations.

Table 3 and Table 4 above show the result of Monte Carlo calculations on both the vapour and liquid dominated zone. On the vapour dominated zone, the calculated reserve from the model simulation is 2 MWe with confidence up to 90%, which is on agreeable match with the recent actual 1×2.5 MWe installed capacity in Mataloko area. Based on SNI 03-5012-1999, the proven geothermal reserve is defined as the reserve that proved by more than one exploratory wells successfully discharging hot fluid, actual well measurement, geological preliminary study, and reservoir simulation. With the consideration above, so it is reasonable to conclude the calculated reserve from this study is the proven reserve of the Mataloko prospect area. With the same consideration, the proven reserve on the liquid dominated zone was calculated to be 50 MWe.

To conclude, the total proven reserve calculated from the natural state simulation result is 52 MWe (50 MWe reserve from liquid dominated reservoir, and 2 MWe from vapour dominated reservoir) with high confidence level. 5×10 MWe expansion of the power plant capacity on the Mataloko prospect area in addition to currently 1×2.5 MWe installed power plant capacity is a reasonable suggestion for future Mataloko field development by targeting into deep liquid dominated reservoir.
Figure 13. Saturation gas contour at steam cap structure (Z=550)

Table 5. Input parameters for Monte Carlo calculation

| Parameters                     | Liquid dominated zone | Vapour dominated zone |
|--------------------------------|-----------------------|-----------------------|
| Area (km\(^2\))               | Min       | Most    | Max    | Min   | Most    | Max    |
| Thickness (m)                  | 8.0       | 10.2    | 12.0   | 3.0   | 4.5     | 5.0    |
| Porosity                       | 0.07      | 0.075   | 0.08   | 0.10  | 0.12    | 0.13   |
| Rock specific heat (J/kg.K)    | 940       | 960     | 1000   | 900   | 1050    | 1100   |
| \(S_{wi}\)                     | 0.93      | 0.95    | 1.00   | 0.10  | 0.30    | 0.40   |
| \(S_{wf}\)                     | 0.3       | 0.4     | 0.5    | 0     | 0.05    | 0.10   |
| \(T_i\) (°C)                   | 225       | 275     | 290    | 185   | 210     | 220    |
| \(T_f\) (°C)                   | 180       | 180     |        |       |         |        |
| Recovery Factor                | 0.18      | 0.19    | 0.2    | 0.25  | 0.30    | 0.33   |
| Electric Conversion Factor     | 0.085     | 0.125   | 0.135  | 0.090 | 0.100   | 0.105  |

6. Discussion
The main discrepancy of the result of this study with the established previous study concerning the Mataloko prospect area is on the difference of the shallow steam cap nature resulted from the model with the conceptual model.

This model proposed more accurate condition specifically on the shallow depth. This model represents unaltered region at the shallow depth beneath the drilled wells that correspond to higher permeability surrounded by tight clay cap rock lithology as concluded from geophysical exploration. The result shows this unaltered area contributes to thicker steam cap than suspected on the conceptual model. The model result is confirmed by the agreeable match with shut-in PT measurements on Well MT-3 and the discharged saturated steam from shallow wells (MT-1, MT-2, and MT-5) as well. This model also showed more reasonable temperature gradient in the cap rock structure by accounting for convective nature surrounding the Wae Luja fault structure in the cap rock. Furthermore, the result is
confirmed through reserve estimation using Monte Carlo method that showed 2 MWe reserve which is close to recent 1×2.5 MWe installed power plant capacity in Mataloko prospect area as explained on previous section.

However, due to limitation of using only simple EOS1 in this study, further study to simulate the Mataloko prospect which takes into account the NCG contribution on the fluid using EWASG is strongly encouraged. This approach is suggested to provide more accurate and realistic representation to the nature of the reservoir, specifically on the shallow depth.

7. Conclusion
Important points that can be concluded from this study are:
1. The numerical model was validated and compared to actual well measurement and the conceptual model with satisfactory match. The natural state model of Mataloko Geothermal Field was established successfully.
2. The highly productive area of the Mataloko geothermal reservoir was in range of 4.5 km² at shallow vapour dominated zone and up to 10.2 km² at liquid dominated zone. The total thickness of the exploitable reservoir is around 1750 m with economical drilling depth. The initial temperature of the reservoir is in range of 210°C up to 275°C. Finally, the permeability of the reservoir is in range of 18 – 40 mD with exceptional permeable region of 91.5 mD on the Wae Luja fault structure.
3. The reserve estimation calculation was resulted to total 52 MWe (50 MWe reserve from liquid dominated reservoir, and 2 MWe from vapour dominated reservoir) with high confidence level. Therefore, this field could be expanded for up to 5×10 MWe power plant capacity by drilling effort to unexploited liquid dominated zone.

8. Recommendation
Some recommendation to improve the model in order to represent the reservoir nature better such as:
1. The result of this model should be validated further by using heat loss and mass flow of surface manifestation measurement.
2. The TOUGH2 simulation using EWASG is strongly encouraged to account for NCG contribution to the reservoir nature, specifically on the shallow depth.
3. Sensitivity analysis for all parameters using experimental design is strongly encouraged. Experimental design is a method which a control variable (in this case is a reservoir parameter) is changed while the other variables is kept constant in purpose to determine the sensitivity of each parameters into the result (in this case is the accuracy of calibration process). This approach is suggested in purpose to achieve more accurate calibration result with relatively less iteration attempts.

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