NUMERICAL SIMULATION UPDATE of DIENG GEOTHERMAL FIELD, CENTRAL JAVA, INDONESIA

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ABSTRACT

Dieng Geothermal Field has been operated for 17 years with installed capacity of 60 MW. Next target, Dieng field will be developed for additional 2x55 MW. For development purposes, numerical model is used to evaluate initial permeability and temperature distribution and to forecast future reservoir performance as well. After 2013, several geoscience surveys and well testing have been conducted in order to estimate the changes of reservoir behavior during production and to update the conceptual model. Several numerical models of Dieng have been developed in 2006 and 2013 by using single porosity approach. Generally, the single porosity models give more optimistic result in forecast simulation and to account this issue dual porosity approach were implemented in the model. The recent numerical model is built by using TOUGH2 with EOS1. This paper describes the possibility and sustainability for the next 2x55 MW development. Several PT shut-in surveys data and production well histories were used to validate the model. During forecast simulation, the model was also coupled with Excel based wellbore model.

1. INTRODUCTION

Dieng geothermal field is located in Wonosobo regency, Cental Java province, as shown in Figure 1. Dieng field is situated in volcanic arc and resulted from volcanism in the quaternary. Dieng is categorized as high temperature-liquid dominated field (Layman, 2002). The main area of the developing field is divided into two parts, northwestern part (Sileri) and southeastern part (Sikidang).

The Dieng geothermal field is well known as a prospective field for geothermal development in Indonesia indicated by the presence of active geothermal manifestations around the Sileri crater and the Sikidang crater, moreover, hot springs and altered grounds are observed surrounding them. Since 1970, many geothermal explorations had been carried out by Geological Survey of Indonesia, Pertamina, Himpurna California Energy Ltd. and some other companies. Totally, 5 gradient holes (TCH) and 47 wells have been drilled in Dieng field (27 DNG wells by Pertamina in the period 1977-1993 and 20 HCE wells by California Energy in the period 1995-1998) (WestJEC, 2006).

All production wells are located in Sileri area. Sileri hosts a high temperature liquid dominated reservoir producing neutral fluids of low non-condensable gas content from 1500-2500 m MD. Most wells are directional with inclination of 20°-30°. The Sikidang sector of the field was attempted to be developed by Pertamina in the 1980s and early 1990s, but had a much lower success rate, lower productivity, high acidic fluids, and high non-condensable gas content. For this reason, all of wells in Sikidang part were considered as a reinjection area of Unit 1 (PWC, 2013).

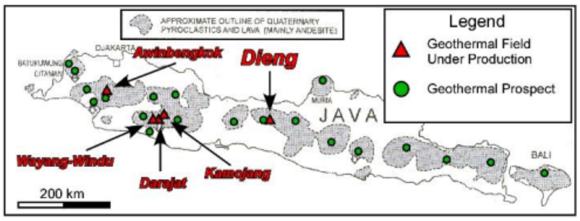


Figure 1: Geothermal location and prospect in Java (modified from Hochstein M.P. and Sudarman S, 2008)

Several data, such as geology, geochemist, geophysics, and well data, have been collected in order to update the conceptual model. Figure 2 shows the updated conceptual model that has been built by Geodipa Energy (GDE) team in 2019. According to this model, Dieng field has three upflow zones located in Sileri, Merdada, and Sikidang. This assumption was strengthened by the contour of temperature distribution and low resistivity value shrinking around these 3 upflow zones. Based on the MT data, it can be estimated that the thickness of clay cap in the Sileri area and Merdada is around 1000 m and increasing between the Merdada and Sikidang areas and then decreasing into the area of Pakuwaja. Based on geological data, the recharge of the geothermal system in the Sileri area comes from southern part of the field and dominated by old sedimentary rocks. Reservoir temperature is around 280-330°C estimated from well data.

Dieng unit 1 is producing 45 MW with initial installed capacity of 60 MW. For the next, Dieng will be planned for 2x55 MW development (Unit 2&3) and will focus in Sileri Area.

The understanding of resources is essential and can provide important input related to risks and mitigations. The reservoir simulation was conducted in this study to support the development and maintain existing generation capacity. The results of reservoir simulation studies can also be input for constructing drilling plan, and production and injection strategies. The aim of this paper is to examine the capacity and sustainability of the resources that Dieng field has.

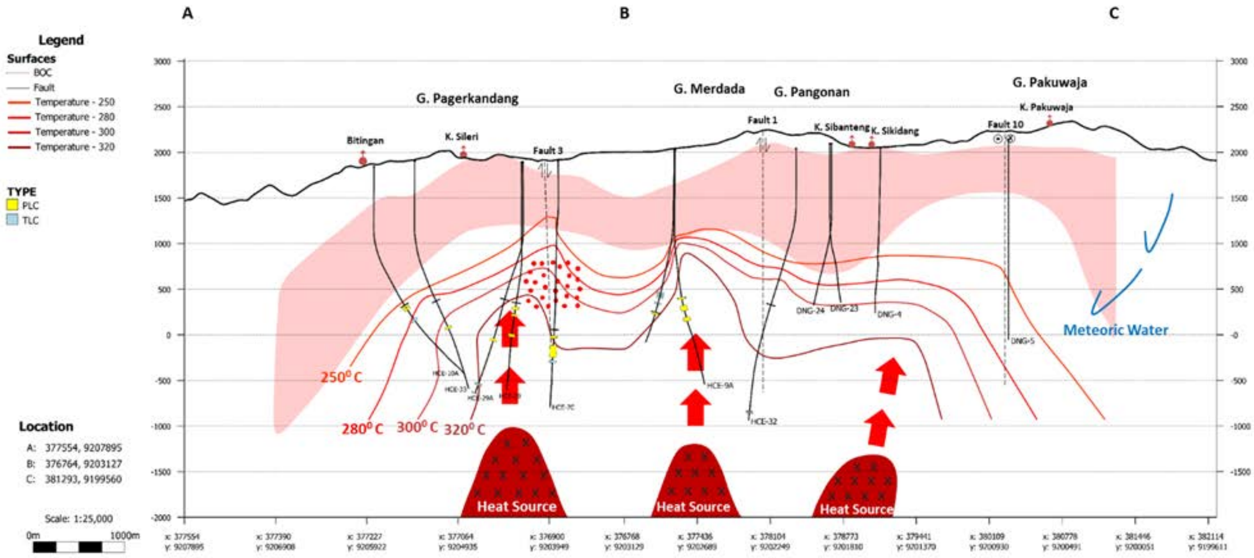


Figure 2: Updated Dieng conceptual model

2. DYNAMIC MODEL DEVELOPMENT

The reservoir model is based on a conceptual model as shown in Figure 2. Petrasim, a commercial pre and post processor of TOUGH2, was used to develop the reservoir model using dual porosity approach. EOS1 is used to model the thermodynamic conditions in reservoir. The reservoir model workflow is presented in the following paragraphs.

2.1 Gridding

The model is aligned at N 47° W to consider the direction of main structure in the field. The model covers a total area of 13 km x 16 km or equal to 208 km^2 and a total thickness of 3.96 km (i.e. from 2160 masl to -1800 masl). The grid block horizontal dimension varies from the smallest 200 m x 200 m to the biggest 2000 m x 2000 m. The model is divided into 17 layers with total number of model blocks of 17,255.

A dual porosity model is used to properly model transient phenomena (such as injected water returns impact) in fracture-dominated reservoirs. In dual porosity model, each block has porosity and permeability elements both in the matrix and in the fractures, this causes the total number of grid blocks in the model to double becoming34,510 grid blocks. A 3D visualization of the model grid blocks is presented in Figure 3.

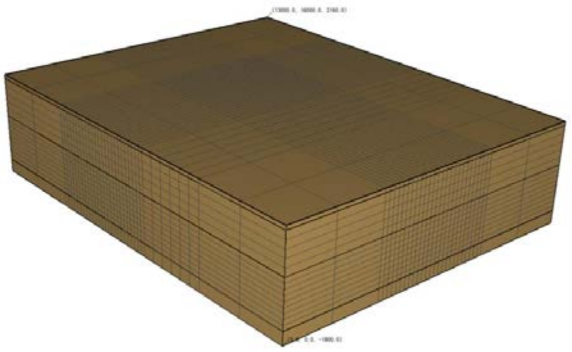


Figure 3: 3D visualization - Dieng numerical model by Petrasim

2.2 Boundary Condition

An impermeable atmospheric block is put in the top layer, bottom layer, and lateral side of the reservoir to allow conductive heat loss out of the reservoir. In Petrasim, the upper and the bottom layer model is activated by adding extra cells. This configuration of extra cells are shown in Table 1.

Table 1: The extra cell configurations

Layer	Pressure (Pa)	Temperature (°C)	Permeability (m^2)
Upper layer	1.01E5	20	1E-20
Bottom (inner reservoir)	2.4E7	325	1E-22
Bottom (outer reservoir)	3.87E7	240	1E-22

2.3 Heat Source and Recharge

Hot water with constant enthalpy and mass rate is injected into the base reservoir to represent an upflow recharges to the system. High temperature fluid recharge with enthalpy of 1500 and 1700 kJ/kg with total mass rate of 160 kg/s were assigned into Sileri area. In Sikidang area, enthalpy and total mass rate were set to 1400 kJ/kg and 80 kg/s. The location of recharge is shown in Figure 4.

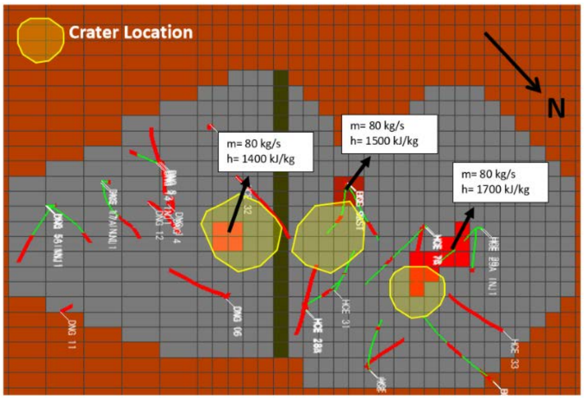


Figure 4: The upflow recharge location

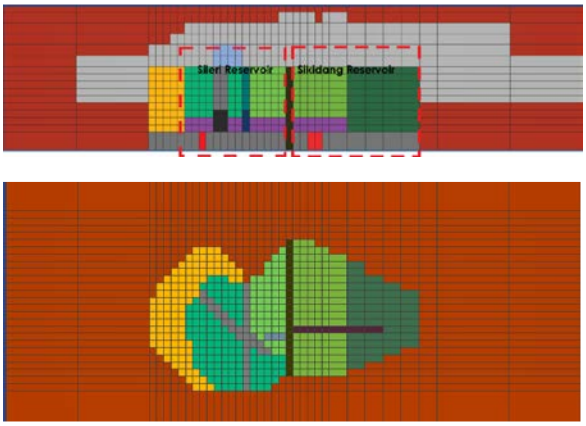
The natural discharges representing manifestation are modeled by putting in artificial wells on deliverability at a constant wellbore pressure.

2.4 Rock Properties

The dual-porosity model consists of a network series of fractures and grid blocks, where fractures are interconnected in three dimensions while allowing the rock matrix to fully connect to fractures and partially connect to adjacent matrix grid blocks.

The nature of the fractures has a small volume but highly permeable, and act as conduits for geothermal fluid. The matrix grid blocks have much larger volume but very low permeability, and act as storage units for fluid in the field. In general, the reservoir fluid movement mostly occurs through the fracture network (Pruess, 1999).

In the natural state, material properties play an important role. The most important property to give the best match in natural state calibration process is fracture permeability. Fracture permeability are the main parameters used to adjust the modelled pressures and temperatures. Once a reasonable match is obtained, it is assumed that the model represents quite accurately the distribution of fracture permeability. The storage parameters such as porosity is not very sensitive in natural state and it should be validated during production history.



Material	Color	kfx, kfy, kfz (mD)
Rock1	🟩	40, 40, 20
Rock2	🟩	30, 30, 15
Rock3	🟩	60, 60, 30
Rock4	⬛	40, 40, 20
Rock5	⬛	0.001
Rock6	▩	100, 100, 50
Rock7	🟨	0.5, 0.5, 0.2
Rock8	⬜	0.001
Rock9	🟫	0.01

Figure 5: Simplified material properties distribution

Figure 5 shows the slicing and fracture permeability value that assigned in model. Generally, the permeability profiles in Sileri area varies from 30 to 100 mD of which the productive fault has the highest fracture permeability value. Due to lack of PT survey in Sikidang area, fracture permeability in Sikidang reservoir is adjusted to match reservoir pressure only.

Other parameters including matrix porosity, matrix permeability, fracture spacing, and fracture volume fraction assigned in the model are 5%, 0.05 mD, 150 m, and 1% respectively. Grant's curves of relative permeability and linear capillary pressure functions are applied in the calculation. To all rock types, the density, wet heat conductivity, and specific heat are specified to 2600 kg/m^3, 2 W/(m.K), and 1000 J/(kg.K).

Permeability structures are obtained from iteration process until natural state and production history matching are achieved. The average block permeability assigned in the model ranging from 0.001 (to model barriers) to 100 mD. For comparison, to match more than 15 years production history data, the maximum permeability in Salak and Darajat model is 400 mD.

3. NATURAL STATE

During the natural state process, the model was run without any production and injection until a steady state condition were reached. To obtain a good fit between the model and actual measurement, several steps were enacted using an iterative process such as: changing in permeability value, determining the amount and enthalpy of deep mass recharge, adjusting the location and rate of upflow recharge, refining block using a new rock type to improve matching process.

Figure 6: Total shut in days of HCE wells

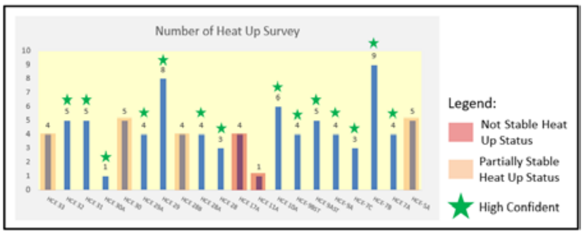


Figure 7: Total number of heat up survey of HCE wells

Figure 6 and Figure 7 show the results of Dieng PT data QC. Overall there are 14 wells which are categorized as stable (i.e. the temperature is closed to the natural temperature of reservoir), 4 wells as partially stable, and 2 wells as not stable. In general, the wells in Dieng need around 2-3 months for heating up process to reach its natural temperature, even more if the permeability is not good.

Dieng initial Pressure correlation has been built using pivot points obtained from heating up surveys as shown in Figure 8. This correlation was constructed from several wells which represent good stability pressure in wellbore (e.g. HCE 7A, HCE 7B, HCE 28B, HCE 31, HCE 32). Due to lack of data survey in Sikidang, only HCE 17A and DNG-17 data were used to construct Sikidang initial pressure.

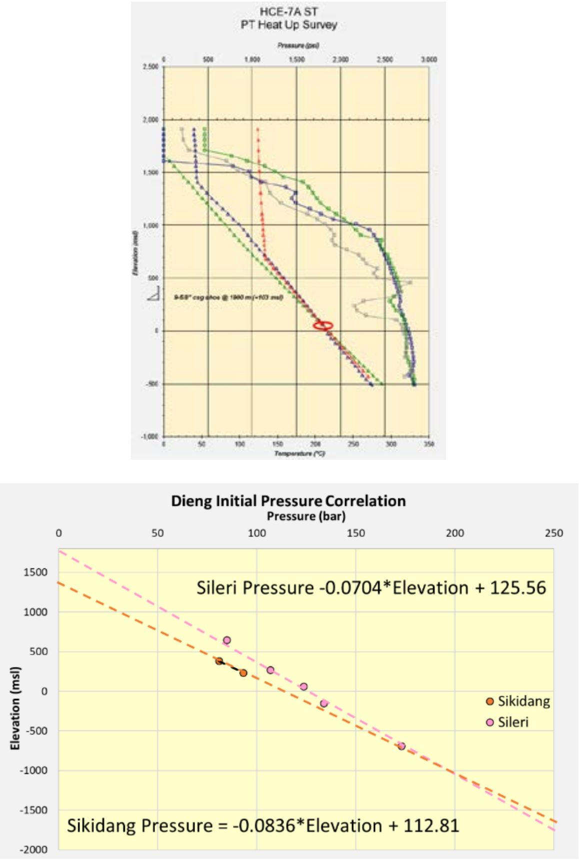
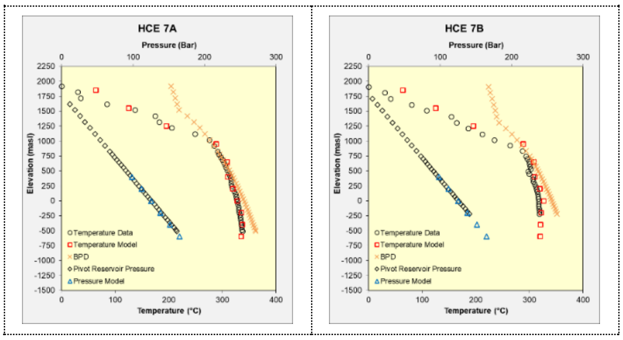


Figure 8: Dieng initial pressure correlation

The results of the natural state validation are summarized in Figure 9. Pressure and temperature in the model have been successfully matched against the actual measurements. According to boiling point versus depth (BPD) plot, boiling occurred localized around Pad 7, Pad 28, Pad 29 and Pad 31. Figure 10 presents a cross section of the model natural state temperature showing a reasonable agreement with the conceptual model as presented in Figure 2.



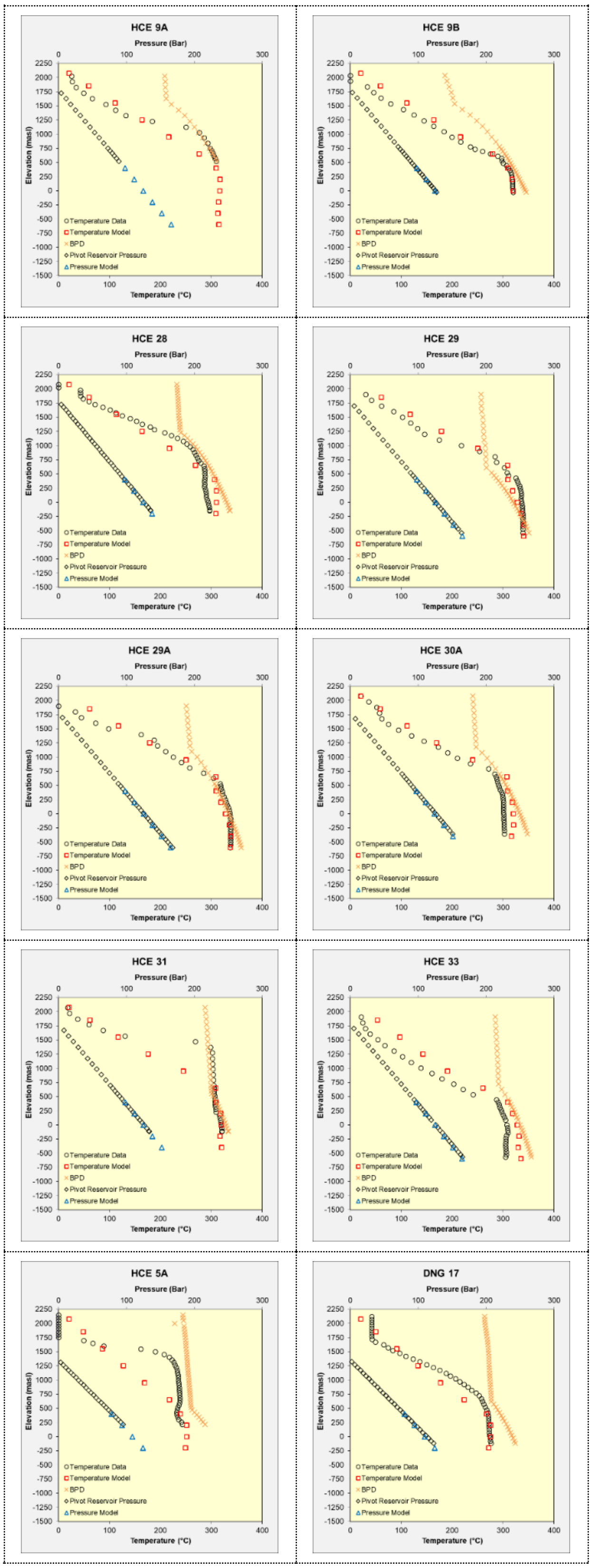


Figure 9: Pressure and temperature validation results

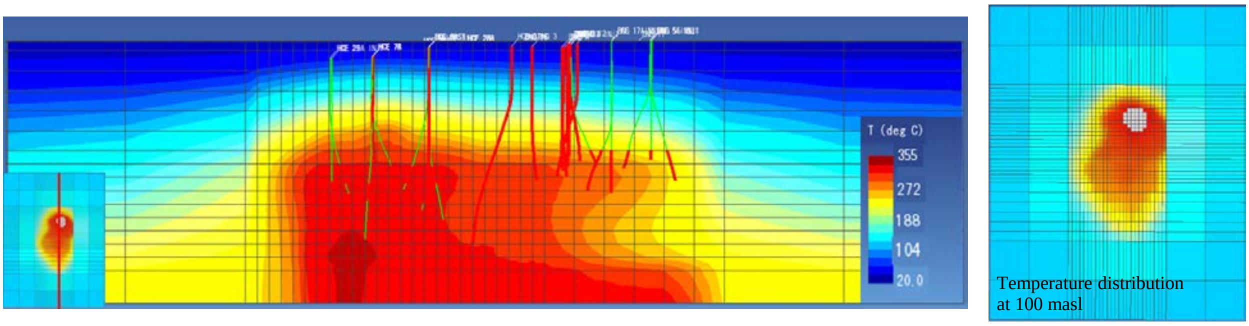


Figure 10: Vertical and lateral cross section of the model natural state temperature distribution

4. HISTORY MATCHING

Dieng geothermal has been operating for 17 years since commercial operation date (COD) in 2002. Production history data are only available for several wells (e.g. HCE 7B, 7C, 28A, 29, 30, and 31). Tracer Flowing Test (TFT) results in 2012, 2016, and 2018 was used in this step to validate the enthalpy of the model.

For reservoir pressure validation, reservoir pressure monitoring data using capillary tube is not available. The only available data is from PT shut in of HCE 10A. A plot of pressure changes over time can be generated from the history pressure monitoring survey of HCE 10A as shown in Figure 11. Pressure at feed point or major permeable zone is extracted from each survey and plotted against time. In the last figure of Figure 12 shows HCE 10A profile pressure generation over time.

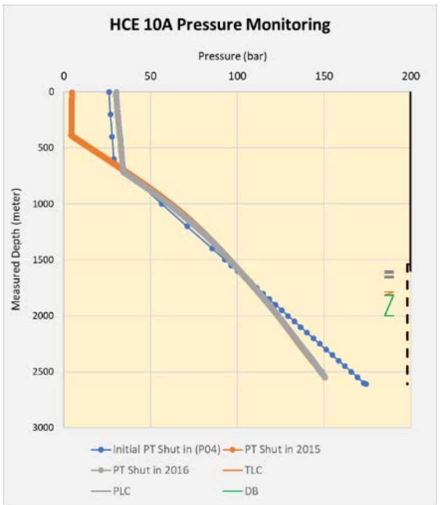
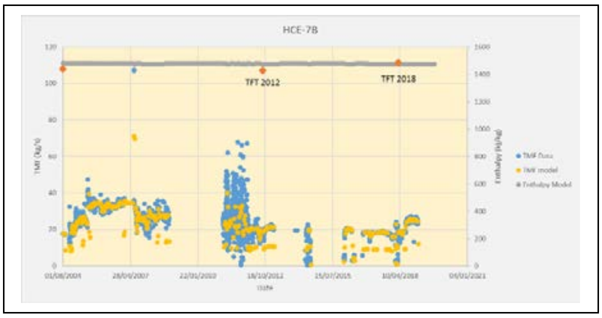
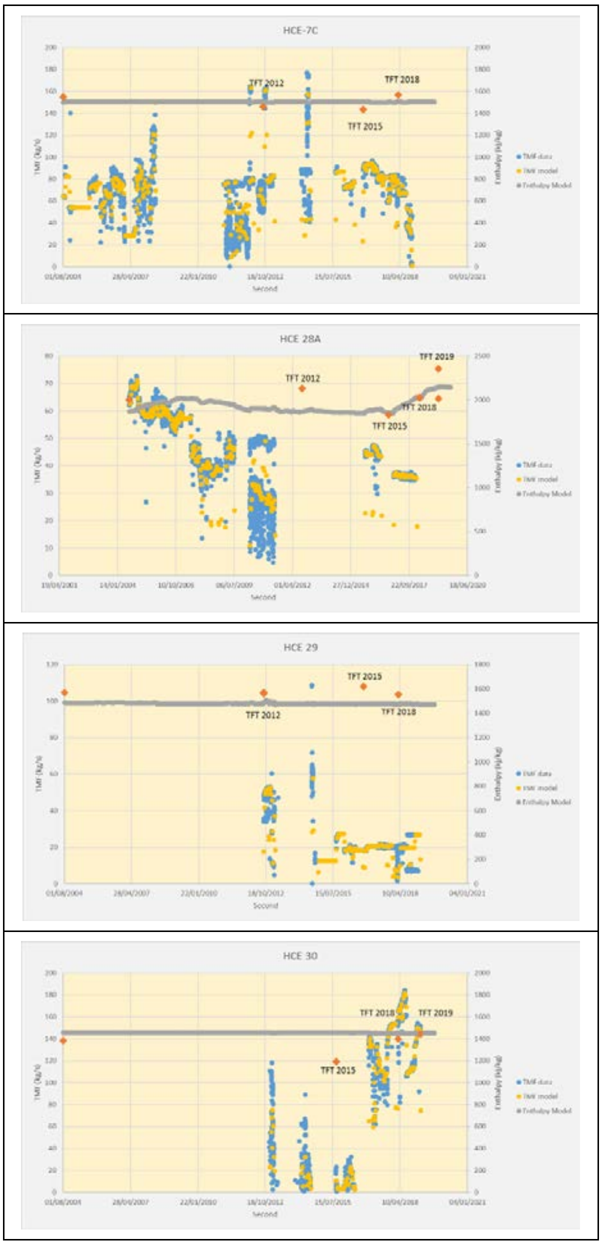


Figure 11: HCE 10A Pressure monitoring





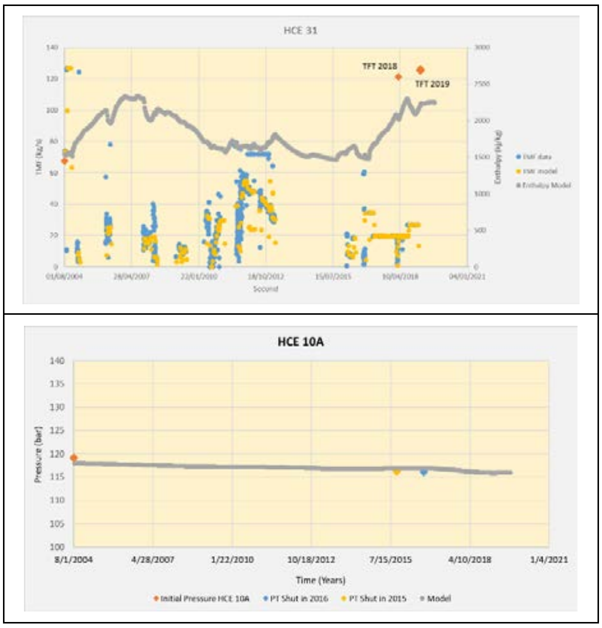


Figure 12: Production history results

5. FORECAST

As the model has been calibrated to natural state and production history, it is now ready to be applied to forecast the reservoir performance and response. In forecast model, TOUGH2 output was coupled with an excel based wellbore simulator to estimate and evaluate the steam available to the production system. Well throttling is done when the steam availability is greater than the steam requirement. Make-up wells are opened as required to maintain full capacity power generation. The program also calculates separated brine that needs to be injected. Several assumptions have been applied to evaluate the reservoir capability to sustain steam production to Unit 2 and 3, such as:

- All assigned production wells are constrained to operate at a constant operating WHP throughout the life of the project.
- At the beginning of the simulation, each individual well productivity Index (PI) value is adjusted to meet an assumed steam deliverability. As the reservoir exploitation begins, the steam deliverability of individual well is updated (every three months) following the pressure and enthalpy changes
- Mass extraction imposed in the model is equal to the total steam demand multiplied by turbine availability (96%).
- If the total steam available is higher than the demand, the imposed production rate of all production wells is proportionally reduced.
- If total steam available is lower than steam demand, additional active well(s) (make-up well) is put online.
- Brine injection flow rate is evaluated base on flowing enthalpy changes.

5.1 Production and Injection Strategy

All the field development scenarios are concentrated in Sileri sector in which all the production and injection of the additional power plant unit(s) will take place.

For generating Unit 2 and 3, as many as 12 wells have been prepared for production wells. An additional makeup well plan location is prepared as shown in Figure 13 as small red circle. Production well completion in model which represents feed zone were assumed at depth from 300 to -250 masl. Dummy wells were also assigned in the model for monitoring the pressure in shallow and deeper reservoir.

10 wells are prepared for injection well for generating Unit 2 and 3. The assumption for injection well capacity follows well field assumption which is 70 kg/s. The location of injection well located in reservoir peripheral. The well completion of injection wells is assumed from 0 to -500 masl.

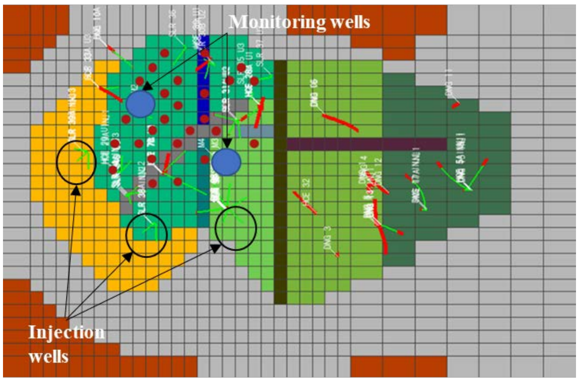


Figure 13: Production and injection wells location

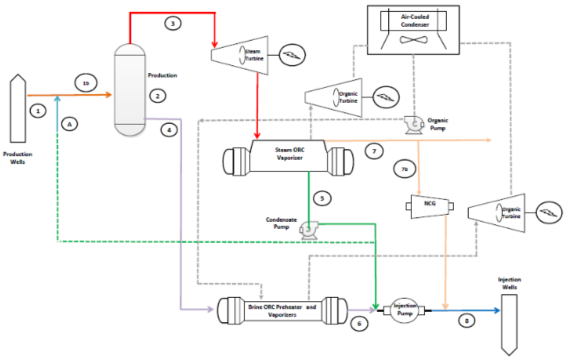


Figure 14: Single Flash Combined Cycle Power Generation Scheme (Thermochem, 2019)

In the forecast, Unit 2 and 3 are assumed to use single flash-combined cycle following silica scale mitigation study result (Thermochem, 2019). Unit 1 were run using full installed capacity of 60 MW, as shown in Table 2 . The process design and parameter for Unit 2 and 3 are shown in Figure 14 and Table 3.

Table 2: General Assumptions for Unit 1 (after load factor 96%)

Description	Unit	Unit 1
Installed Capacity	MW	60
Total Flow	Ton/hr	1440
Operating Wellhead Pressure	Bara	20
Separation Pressure	Bara	10
Turbine Steam Demand	Ton/hr	432
Total Injection	Ton/hr	1008
Brine Injection Temperature	deg-C	40

Table 3: General Assumptions for Unit 2 and 3 (after load factor 96%)

Description	Unit	Unit 2 and 3
Installed Capacity	MW	55
Total Flow	Ton/hr	796.7
Operating Wellhead Pressure	Bara	25.7
Separation Pressure	Bara	21.2
Turbine Steam Demand	Ton/hr	261
Total Injection	Ton/hr	786
Brine Injection Temperature	deg-C	84.7

The model was run to evaluate the reservoir capability to sustain 170 MWe. The model specific input parameters were listed below:

- 60 MWe Unit 1 Single flash as is
- 55 MWe Unit 2 Single-stage flash combined-cycle
- 55 MWe Unit 3 Single-stage flash combined-cycle

As presented in Figure 15 and Figure 16, the model is capable to sustain total of 170 MW power generation for 30 years with 10 initial production and 4 makeup wells. In Unit 1, the enthalpy increasing in the first 10 years around 100 kJ/kg due to new additional Unit 2 and 3 which caused pressure drop. After 10 years of production, the model shows that enthalpy decreases around 0.8 kJ/kg per year. The reservoir pressure decline is in range of 0.3 to 0.6 bar per year.

The change of temperature and steam cap distribution are presented in Figure 17 and Figure 18. Overall, the temperature changes and steam cap distribution are not quite aggressive due to low pressure decline. Considering the temperature and pressure decline, the number of production wells and makeup well required, suggest that the model still capable to handle Unit 2 and 3.

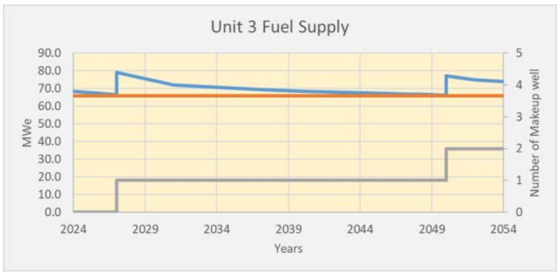


Figure 15: Fuel supply

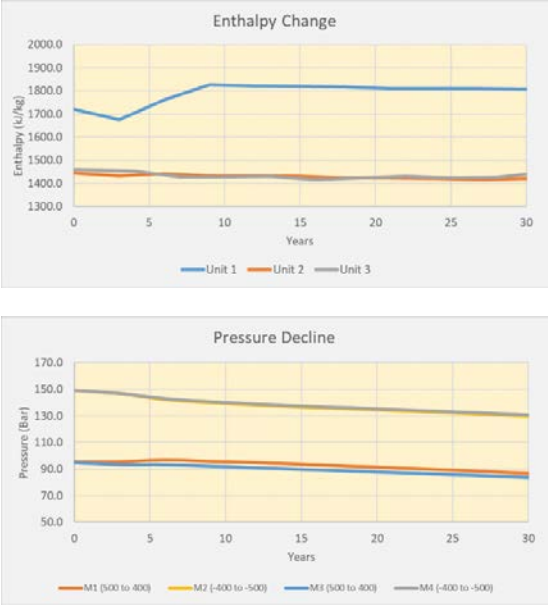


Figure 16: Enthalpy change and pressure decline

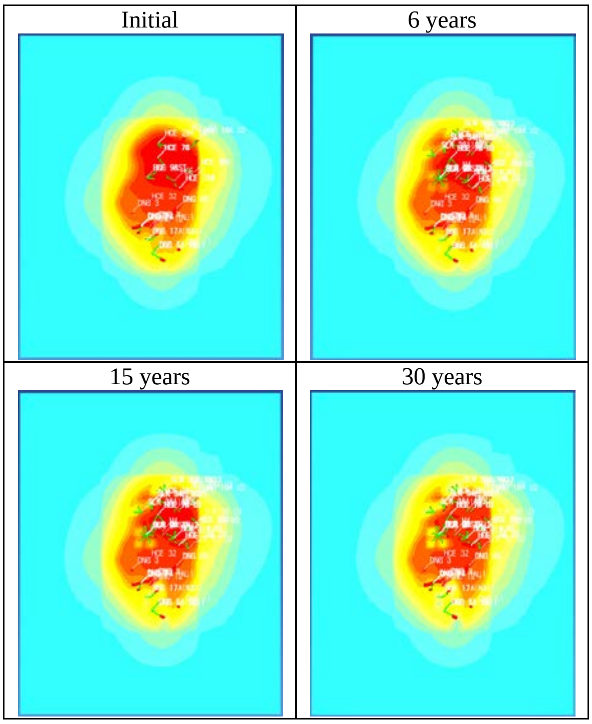
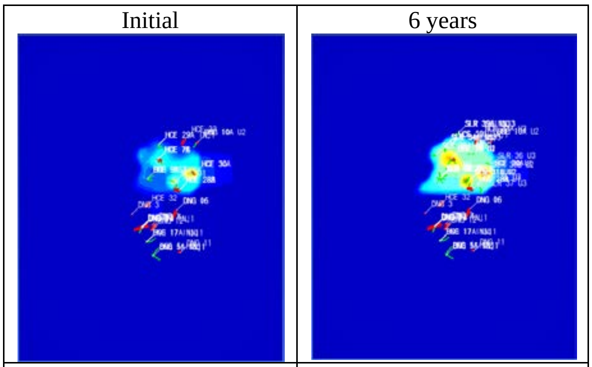


Figure 17: Temperature distribution

Initial 6 years



15 years 30 years

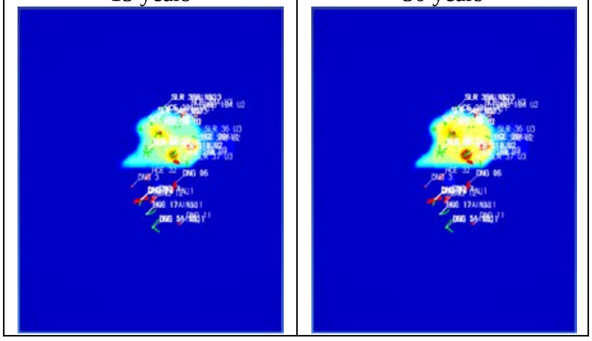


Figure 18: Steam cap distribution

6. CONCLUSION

Several conclusions can be drawn from this reservoir simulation study, as follow:

1. An update Dieng reservoir model into dual porosity model has been successfully developed with a reasonable matched result in natural state and production history.
2. The model has been able to assess fracture permeability distribution ranging from 30 to 100 mD in the reservoir.
3. The reservoir modelling study result shows that by using single-stage flash combined-cycle and with the total of 12 production and 10 injection wells, the model still capable to handle Unit 2 and 3. The additional 4 make up wells are needed in order to sustain Dieng unit 2 and 3 production for 30 years.

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