CONCEPTUAL MODEL AND NUMERICAL SIMULATION UPDATE OF PATUHA GEOTHERMAL FIELD, WEST JAVA, INDONESIA

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ABSTRACT

Patuha geothermal field is located about 50 km southwest from Bandung, West Java Province, Indonesia and developed by state owned company PT Geo Dipa Energi (Persero). The field has been in operation since September 2014 with plant capacity of 55 MW. Several geoscience surveys had been carried out from 1983 until 1998. The drilling was started by Patuha Power Limited with a slim hole campaign in 1996 (17 wells) continued by drilling large and standard diameter wells until 1998 (14 wells). Since 2014, several geoscience additional activities have been carried out, such as geological mapping, geochemical survey, reprocessing geophysical data and micro earthquake survey. Integrated analysis of those geoscience data combined with all wells data are used to update Patuha conceptual model. The 3D conceptual model from all data also has been developed to give comprehensive information in the subsurface existing area and development plan area in the north Patuha. Based on the updated conceptual model, numerical model has been developed by using TOUGH2 with EOS1 and dual porosity approach. The numerical model has been validated by natural state. This paper describes the implementation of Patuha reservoir simulation to support the field development plan.

1. INTRODUCTION

Patuha Geothermal Field started operating in September 2014 with a capacity of 55 MW. Located about 50 km southwest from Bandung, the capital city of West Java Province, Indonesia as presented in Figure 1. Patuha is a vapour dominated reservoir that produces mostly single-phase saturated steam with benign low non-condensable gas composition. Initially, 17 slim hole wells were drilled in this area by Patuha Power Limited in 1996 followed by 14 large and standard diameter wells in 1998. Currently this geothermal field is being developed by PT Geo Dipa Energi (Persero).

PT Geo Dipa Energi is the only Geothermal State-Owned Enterprise (BUMN) in Indonesia which is also one of the Special Mission Vehicle (SMV) under the Ministry of Finance to support government programs in providing safe and environmentally friendly geothermal power and providing great benefits to the Indonesian people.

PT Geo Dipa Energi is in the stage of developing Patuha geothermal field which is included in the Phase II Fast Track Program (FTP) of 10,000 MW, as part of the 35,000 MW government program in the field of electricity infrastructure development. This is stated in Minister of Energy and Mineral Resources Regulation No. 21 of 2013, namely the Second Amendment to Minister of Energy and Mineral Resources Regulation No. 15 of 2010 concerning List of Projects to Accelerate Development of Power Plants that use Renewable Energy, Coal, Gas and related Transmissions. Therefore, one of the efforts to increase the installed capacity of PT Geo Dipa Energi is by planning an additional 55 MW for Patuha II in 2022.

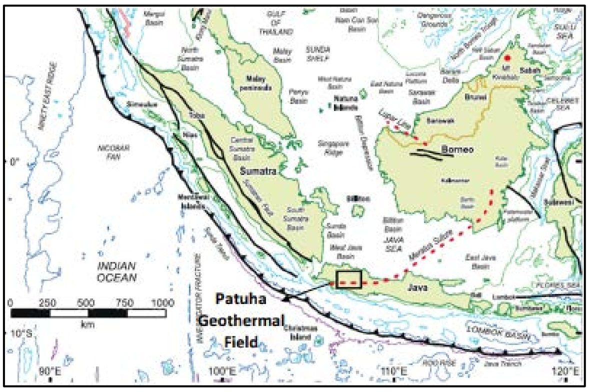

Figure 1: Location of Patuha Geothermal Field (Elfina, 2017).

In order to support the development and maintain existing generation capacity, a Patuha resource has been assessed using reservoir simulation. This study was carried out with the aim of providing a full picture in terms of sustainability resources related to the development plan to be carried out by PT Geo Dipa Energi. Understanding of resources is essential and can provide important input related to risk, mitigation and direction of company policies both short, medium and long term. The results of reservoir simulation studies can also be used as an input related to optimization of drilling, production and injection strategies in Patuha Field.

Since 2014, several geoscience additional activities have been carried out, such as geological mapping, geochemical survey, reprocessing geophysical data and micro earthquake survey. Those data combine with all the wells data supported the

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updated conceptual model in Patuha. 3D conceptual model has been developed to give comprehensive information in the subsurface existing area and development plan area in the north Patuha.

Numerical simulation of Patuha Geothermal Field had been conducted previously by several studies (West JEC, 2007), (ELC, 2013), (Schotanus, 2013), (Firdaus, et al, 2016), (Ashat, et al, 2019). However, few of these studies only covers a part of Patuha Geothermal Field, only conducted until the natural state or history matching stage and uses the single porosity model. Above all previous conceptual model are the basis of those studies. Therefore, it is essential to build a new numerical model based on the updated conceptual model and recent data to get a better understanding of the geothermal field. The updated conceptual model is presented in Figure 2 and Figure 3.

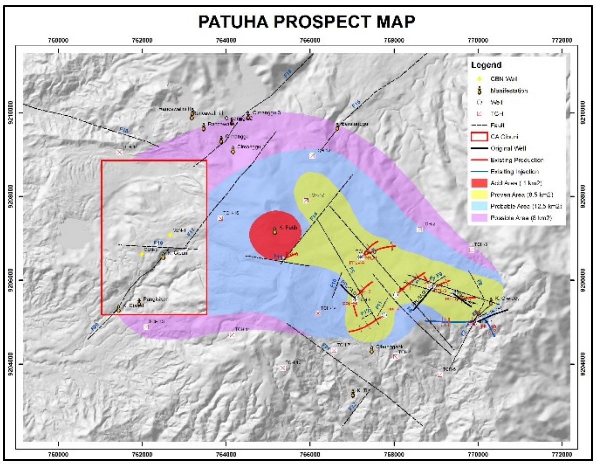


Figure 2: Map of the updated Patuha Geothermal Field conceptual model.

2. OBJECTIVE

This reservoir simulation study generally aims to examine the capacity and sustainability of Patuha Geothermal Field resource related to the development program that will be implemented as a strategy of PT Geo Dipa Energi.

Understanding and assessment of the capacity and capability of resources in Patuha is very important considering both parameters illustrate how much energy (in MWh) can be generated within the period of the working area contract according to regulations in Indonesia, which is 30 years. The size of MWh is directly proportional to the gross revenue that the company will get. The amount of investment needed to maintain the sustainability of resources compared to the revenue obtained will provide an overview from an economic perspective.

In a more complex objective, this study provides technical optimization of well targeting, quality assessment and quality check of the available well monitoring data, superheat phenomenon anticipation, further production injection strategy, lastly the number of make up wells needed until the end of the contract.

3. DYNAMIC MODEL DEVELOPMENT

3.1 Gridding

A numerical model was created and developed based on the updated conceptual model covering a total area of 221 km^2 with length of 13 km in the X axis (NE-SW direction) and 17 km in the Y axis (NW-SE direction). Figure 4 shows the lateral gridding for the numerical model underlying the updated conceptual model. It was oriented in N55^{o}W direction considering the existing structures and faults of Patuha geothermal field. The area covered by the model was intended to be larger than the existing proven area to capture future developments opportunities. The grid blocks being used vary from 200 m x 200 m to 2000 m x 2000 m.

In the vertical orientation, the model is divided into 15 layers as shown in Figure 5 underlying the updated conceptual model which represents 3.5 km of depth (2000 until -1500 masl) including 9 layers of 200 m as the main Patuha reservoir. Above the reservoir there are layers assigned as cap rock and ground water while below are assigned as basement. The total number of blocks in the numerical model is 23760.

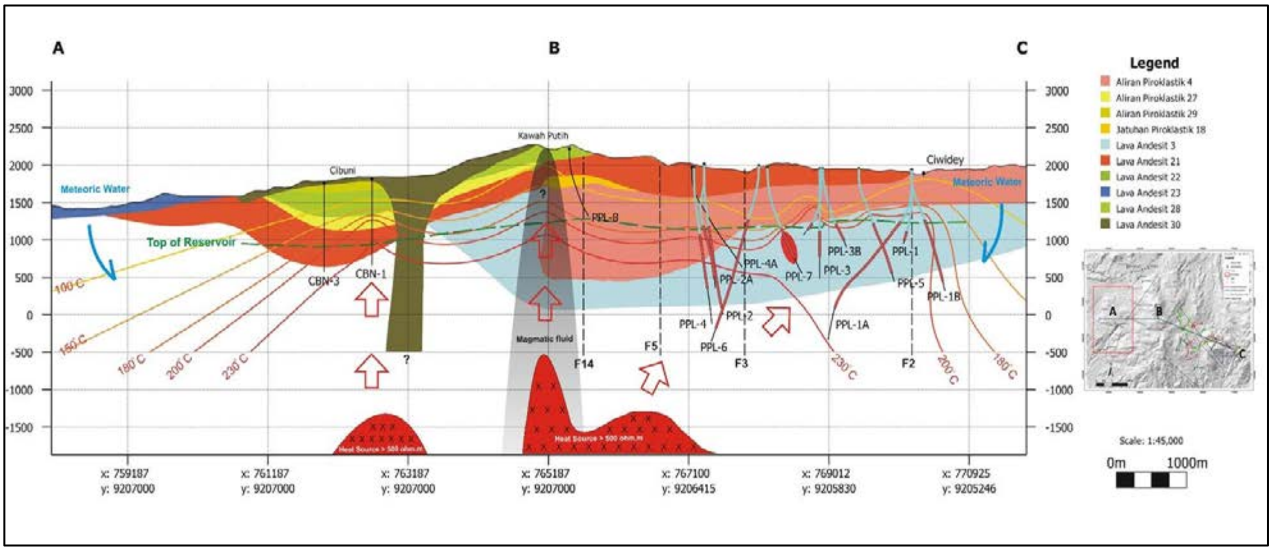


Figure 3: Cross section of the updated Patuha Geothermal Field conceptual model.

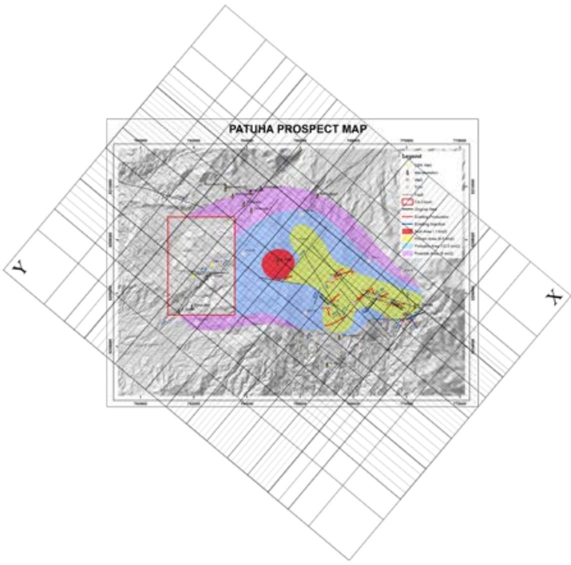


Figure 4: Patuha numerical model gridding.

The long-term heat and mass flow within a geothermal reservoir can be adequately modelled using a simple course grid block, single-porosity model. However, to properly model transient phenomena (such as impacts associated with returns of injected water in specific well) in fracture-dominated reservoirs, a refined dual porosity model is required. As it is a 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, reaching a total of 47520 grid blocks. A 3D visualization of the model grid blocks can be seen in Figure 6.

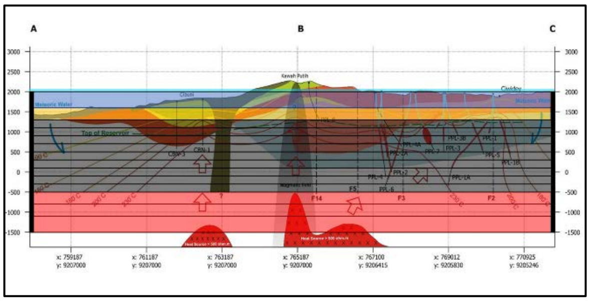


Figure 5: Patuha numerical model layers.

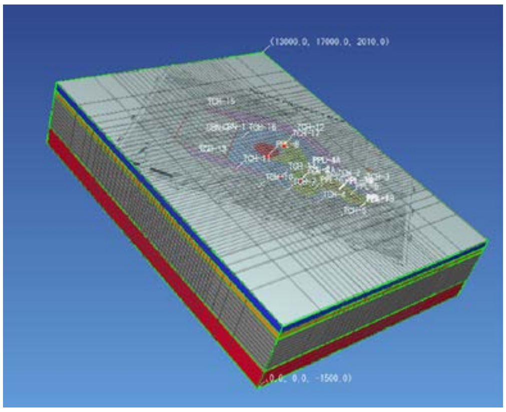


Figure 6: Patuha numerical model visualization.

3.2 Boundary Condition

The top layer of the Patuha model is assigned to be 1 bar and 20^{o}C to mimic the generic atmospheric layer, while the bottom layer of the model is assigned to be at 315 bar with temperature ranging from 180^{o}C until 260^{o}C. The top layer is put in a contact with an impermeable atmospheric block at surface elevation to allow conductive heat loss out of the reservoir. On the lateral sides of the reservoir, an impermeable material is assigned with permeability of 1.0E-18 m^2 or 1μD.

3.3 Heat Source and Recharge

Hot water with constant enthalpy and mass rate is injected into the base reservoir to represent a deep heat recharges into the system. As can be seen in Figure 5 the updated conceptual model main difference from earlier studies is the absence of Mt. Urug heat source. The main heat source is interpreted to be below Kawah Putih Crater flowing until the Ciwidey crater. High enthalpy fluid of 2600 kJ/kg is injected into the reservoir with a rate of 8 kg/s in the Kawah Putih area, 40 kg/s east of Kawah Putih area and 30 kg/s in the Cibuni area. Natural discharges which represent manifestation are modeled by putting in artificial wells on deliverability at a constant wellbore pressure. The locations of the reservoir heat source recharge and discharges is shown in Figure 7**.**

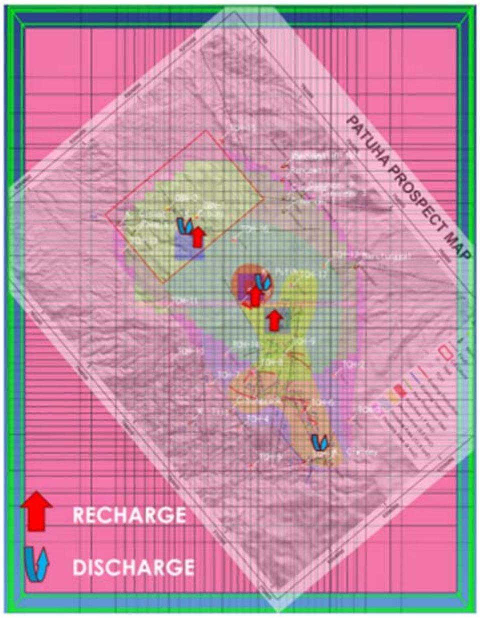


Figure 7: Recharge and discharge location.

3.4 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 is that they have a small but highly permeable volume, and act as conduits for geothermal fluid. In contrast, the matrix grid blocks have much larger volume but very low permeability, and act as storage units for fluid in the field. Under this arrangement, the main route for the movement of reservoir fluid is mostly controlled through the fracture network.

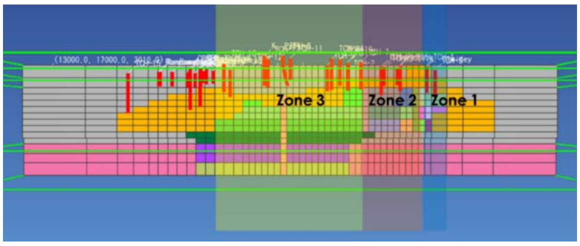


Figure 8: Rock properties on a vertical section through the model.

The subsurface pressure and temperature measurements provide the most reliable criteria for calibrating the initial-state model. In the natural state modelling, the selection of material properties plays an important role and the most important property to give the best match is fracture permeability. Fracture permeability will affect pressure and temperature distribution as well as the fluid movement direction in model. Fracture permeability in the x, y, and z directions are the main parameters used to adjust the modelled temperatures and match the measured temperatures before exploitation. Once a good match is obtained, it is assumed that the model represents quite accurately the distribution of fracture permeability. The initial-state is not very sensitive to storage parameters such as porosity. Therefore, production history data is used to validate that the storage values used within the model are reasonable and tested within production time.

Table 1: Material properties.

Color	Material	kf_{xy}(mD)	kf_z (mD)
	BOUND	0.001	0.001
	BSMNT	0.001	0.001
	BSMT2	0.001	0.001
	IMPZ	0.001	0.001
	HEATS	50	80
	KPTH	10	30
	BARR	0.001	0.001
	BARR2	0.8	0.8
	BARR3	0.15	0.15
	CAPR	0.001	0.001
	RES1A	100	100
	RES1B	60	60
	RES1C	80	80
	FLT1A	110	110
	FLT1B	70	70
	FLT1C	90	90

Top reservoir and top cap rock area distribution are assigned base on the updated conceptual model and magnetotelluric data. The material properties assigned is presented in Table 1 and the vertical material distribution of Patuha geothermal field numerical model is shown in Figure 8. The initial pressure and temperature data in Patuha geothermal field suggest that the reservoir is in general divided into three separate zones by two semi-impermeable barriers as presented in lateral slicing Figure 9. Significant different of pressure and temperature at each zone has been proved from the initial wells' PT data. Zone 3 with the highest pressure regime is assigned to have permeability around 100 mD at the top of reservoir, Zone 2 60 mD and Zone 1 80 mD. The permeability of each zones is assigned to gradually decrease with depth.

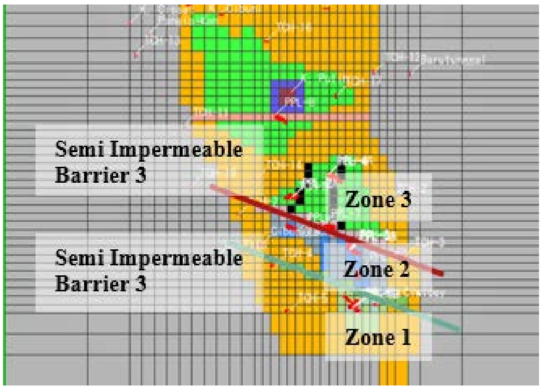


Figure 9: Rock properties distribution at 1000 masl lateral section.

Other parameters including matrix porosity, matrix permeability, fracture spacing, and fracture volume fraction assigned in the model are 10%, 0.01 mD, 100 m, and 5%, respectively. Grant's curves of relative permeability and linear capillary pressure functions are applied in the calculation. For 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) respectively.

4. INITIAL STATE

During the natural state process, the model was run without any production and injection for 100,000 years, to reach a steady state condition. Several validation processes have been used to check the reliability of model, such as pressure and temperature (PT) and heat losses from surface manifestation if necessary. To obtain a good fit between the model and actual measurement, several steps were enacted using an iterative process such as changing permeability value, determining the amount and enthalpy of deep mass recharge, upflow location adjustment and block refinement.

4.1 Available Data Quality Assessment and Checking

PT heating up data are available from 14 PPL wells, 17 Temperature Core Holes (TCH) wells and 2 CBN wells. However, data quality control conducted to the PPL wells ended up only nine wells categorized as stable (i.e. the temperature is closed to the natural temperature of reservoir) with the others being partially stable and not stable as presented in Figure 10. Therefore, the validation process focuses more on high confident data.

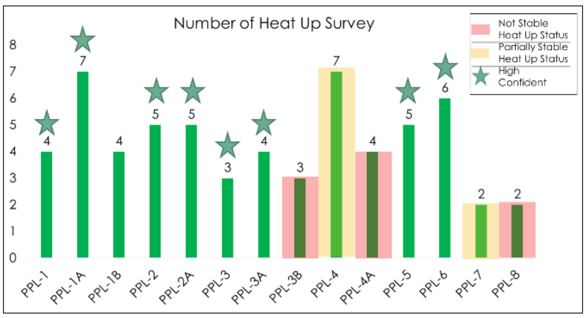
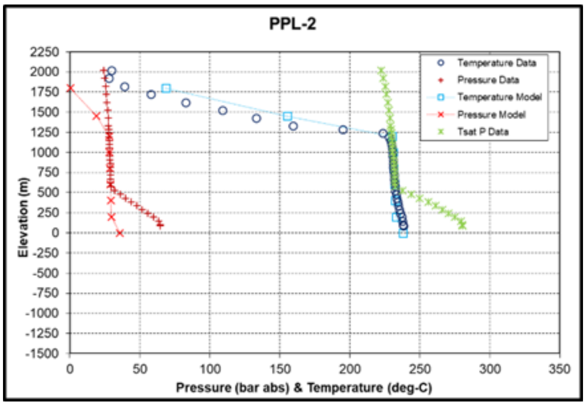


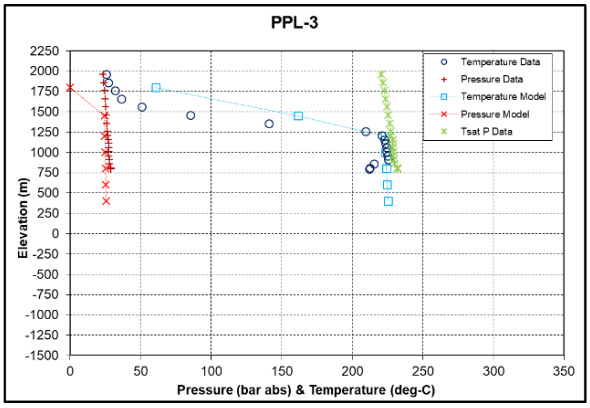
Figure 10: Data quality check result.

4.2 PT Matching Result

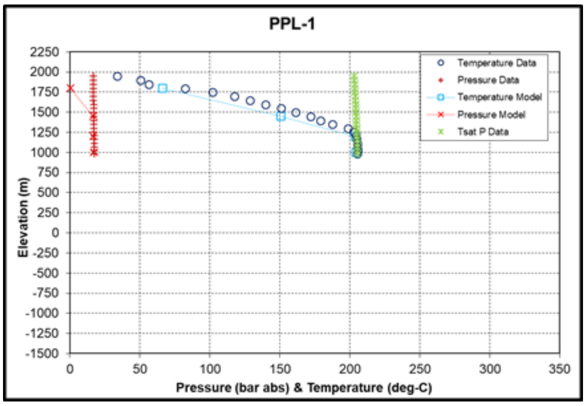
Overall, the result from numerical model delivers a good match compared to actual measured data. Figure 11 shows wells matching result for PPL wells representing high-pressure, medium-pressure, and low-pressure areas.



(a)



(b)



(c)

Figure 11: Temperature and pressure matching of high pressure area (a), medium pressure area (b) and low pressure area (c).

The pressure of high, medium and low area are around 29 bar, 25 bar, and 16 bar respectively. Majority of the wells show a static pressure and convective temperature indicate the reservoir to be a steam dominated and high permeability reservoir. The latest finding in PPL-2 from downhole samples and video log had shown that the hydrostatic profile below 500 masl depth is not geothermal fluid but ground water which occurs due to casing leakage in the shallow depth of the well. Therefore, the numerical model did not replicate this anomaly by assuming it is still saturated steam by looking at other wells at the same depth. Moreover, due to this finding, the exact depth transition zone between steam and compressed liquid is still unclear. Further study and deeper exploration should be conducted to gain this information. In this numerical model it is assigned at 0 masl. Natural state temperature distribution are presented in Figure 12 and 13.

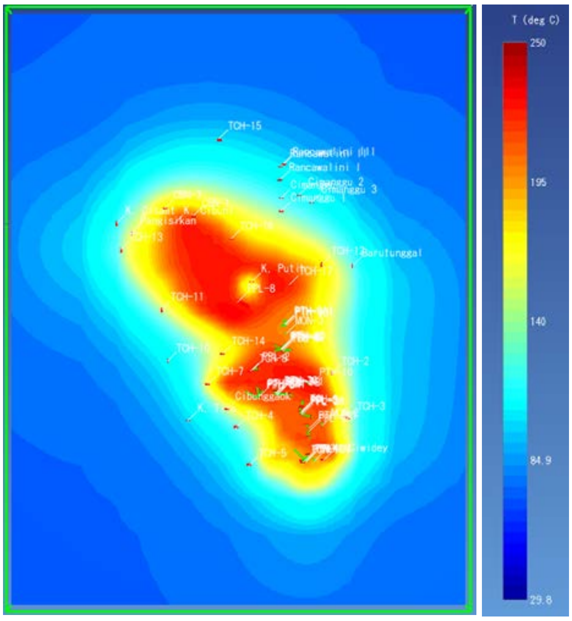


Figure 12: Lateral Numerical model temperature distribution at 1000 masl.

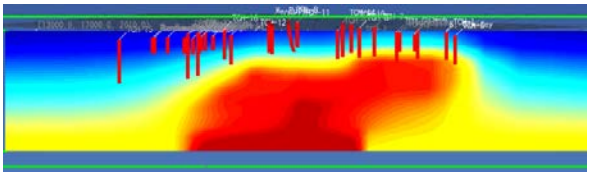


Figure 13: Side numerical model temperature distribution.

5. CONCLUSION

An updated numerical model of Patuha Geothermal Field based on the updated conceptual model has been successfully developed. The natural state result from the numerical model has shown a satisfactory result. From the natural state it is obtained that Patuha Geothermal field is mainly vapour dominated reservoir and the transition zone between steam and liquid reservoir is still uncertain. However, the model assumed it to be at 200-0 masl. Reservoir area of Patuha Geothermal field is divided into three different pressure regimes, with high pressure area around 29 bar near the Kawah Putih heat source and reduces towards Ciwidey crater area with reservoir pressure of 16 bar.

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