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Conceptual modeling and characterization of Puga geothermal reservoir, Ladakh, India

Shibani K. Jha[a,*], Harish Puppala[b]

[a] Department of Civil Engineering
[b] Birla Institute of Technology and Science, Pilani 333 031, India

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ABSTRACT

Evaluation of a potential geothermal reservoir depends on the conceptual model which governs fluid flow and heat transfer in the reservoir. Knowing the spatial variation of reservoir parameters is essential to develop a conceivable and explicable conceptual model. Lack of deep reservoir characteristics impaired the development of conceptual model for Puga geothermal field, India. This study proposes a methodology to develop a conceptual model of Puga geothermal field. The proposed methodology utilizes the resistivity model developed by National Geophysical Research Institute as preliminary data. The conceptual model developed in this study, maps the spatial variation of thermo-hydro-geological properties of Puga reservoir. The mapped properties of the reservoir are porosity, thermal conductivity, specific heat, radioactive heat capacity, density and permeability of reservoir. Furthermore, lateral extent of the possible heat source and spatial variation of steady state temperature of the reservoir are also estimated. The estimated reservoir temperature from the conceptual model of Puga geothermal field is in agreement with temperature interpretations of Na/K and Na-K-Ca geothermometer studies. The resulting conceptual model will further aid in the operational phase of reservoir development like volumetric assessment of reservoir potential and reservoir potential estimation under various extraction configuration.

1. Introduction

Energy extracted from Earth's heat is known as geothermal energy. Typically, the entrapped heat in Earth's strata, is extracted by injecting water as working fluid that transports the entrapped heat of the reservoir. Although, geothermal energy is disseminated all over the earth's crust, its magnitude varies with location. Since the installation of geothermal plant involves huge capital investment, it is necessary to predict reservoir potential in advance before installing geothermal plant. This helps to reduce the possible uncertainties associated with energy extraction. The preliminary step in assessing the potential of a geothermal reservoir is to develop a conceptual model from geological and geophysical data. Aspects of heat source, recharge zones and initial temperature distribution within the reservoir are typically unified in developing a conceptual model. Furthermore, knowing the variation of reservoir properties along the length and depth of reservoir from a comprehensive conceptual model will be used in simulating the dynamic processes of reservoir exploitation.

From literature, a wide range of conceptual models are identified. The conceptual models of geothermal fields in Iceland have been prepared by incorporating the variation of permeability, temperature, pressure distribution and the fluid composition (Arnórsson, 1995). Las Tres Virgenes geothermal field in Mexico is conceptualized using structural, hydro chemical, geological and isotopic data of the region (Portugal et al., 2000). Considering the geophysical investigation results, together with information of the geology, conceptual model of Chingshui geothermal reservoir has been prepared (Zhang et al., 2016). Furthermore, the geophysical data obtained from the bore wells with depth ranging between 500 and 3000 m is also used in the preparation of Chingshui conceptual model.

Ohaaki geothermal system in New Zealand has been conceptualized, using borehole data for depth range of 2200–3000 m. Reservoir characteristics such as temperature, pressure and permeability distributions have also been included (Mroczek et al., 2016). Geological, geophysical and fluid properties of the Ngatamariki geothermal field are used in preparing the conceptual model of the reservoir (Chambefort et al., 2016). A conceptual model of Los Humeros which determines geological properties till the depth of 2750 m approximately and variation of temperature have been prepared using the data obtained by physical exploration through 42 bore wells of which few bore wells were

* Corresponding author.
E-mail addresses: shibani@pilani.bits-pilani.ac.in (S.K. Jha), harishpuppala.ce@gmail.com (H. Puppala).

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Nomenclature

R_{Eb}	Equivalent resistivity of each band in the scale
R_L	Lower limit of the resistivity
R_U	Upper limit of the resistivity
R_{ij}	Resistivity values of each of the pixels within the shifting window
N	Total number of pixels within the shifting window
E_p	Effective parameter of the block
p_i	Geological property of rock
w_i	Weightage allotted to each of rock type
α_i	Inverse of absolute distance between mean resistance values of each type of rock
k	Intrinsic permeability of the reservoir
μ	Dynamic viscosity of the working fluid
g	Gravity vector
P	Hydraulic pressure
ρ_f	Density of fluid
ρ_s	Density of rock
c_f	Specific heat of fluid
c_s	Specific heat of rock

explored till the depth of 2500 m (Arellano et al., 2003).

In India, *hot spring committee*[1] was commenced to explore the feasibility of utilizing the existing hot springs for small scale power generation and other domestic applications (Jawaharlal, 2002; Ravishanker, 1991). After extensive studies, a report submitted by hot spring committee provided the framework for geothermal investigation in India. Systematic efforts have been made to explore geothermal resources during the year 1973, by launching Puga geothermal project in Ladakh, Jammu and Kashmir. This remarkable project is followed by the identification of few other geothermal provinces also (Jawaharlal, 2002). From the field investigations conducted by Geological Survey of India (GSI) and National Geophysical Research Institute (NGRI), several areas in India have been marked as economic geothermal provinces (Craig et al., 2013; SubbaRao and Viswanadhan, 2003). Geophysical, thermal logging, drilling and magnetotelluric investigations have been carried out at few of these identified provinces. The identified geothermal fields are explored through borewells, however explorations were limited to shallow depths due to lack of machinery and expertise (Jawaharlal, 2002; MNRE, 2016).

Tentative geothermal potential of India is estimated as 10,600 MW (Craig et al., 2013). The power potential of Puga geothermal system is estimated for shallow homogenous reservoir with an assumption of constant porosity and density (Gupta et al., 1979). Moreover, porosity assumed for assessing the reservoir potential is derived using empirical relation which is dependent on resistivity of surface hot water and representative resistivity of reservoir (Gupta et al., 1979). With these assumptions the potential of reservoir is estimated as 36.5 MW (Gupta et al., 1979). This assessment may not be pertinent as the assumption of homogenous reservoir may not be realistic as it may underestimates or overestimate the reservoir potential. Therefore, conceptualizing geothermal field as block heterogeneity, which captures the spatial variation of reservoir properties, should be emphasized in future studies.

More recently, a conceptual model of Puga geothermal reservoir extending in N-S direction with dimensions of 7300 × 1500 m has been developed for simulation works to study reservoir response in terms of temperature and pressure variation due to exploitation (Absar et al., 1996). Alluvium in the top layer, underlain by breccia, granite and the gneiss over the entire reservoir at discrete locations are the elements of block heterogeneity. Temperature and pressure distributions of the reservoir have been evaluated at few vertical cross sections. From the results presented by Absar et al. (1996), it is observed that the temperature increases with depth till 500 m, where a maximum temperature of 150 °C is observed. However, a temperature reversal to 100 °C is noticed at a depth of 1500 m. From the conceptual model addressed by Absar et al. (1996), it is stated that the reservoir till 1500 m may not be sufficient to entrap heat energy that may produce electricity on an industrial scale.

Following the conceptual model of Absar et al. (1996) and Gupta et al. (1979), another conceptual model of Puga geothermal field is developed by Jha and Puppala, (2016). The developed model trends in east-west direction for a length of 3270 m and up to a depth of 3200 m with an injection and an extraction well. Cold water is injected through the injection well. This injected water drives the entrapped heat within the reservoir rock and transports the heat with flowing water. This heat is further extracted through the production wells. This typical combination of injection and extraction well is referred as geothermal doublet. The reservoir production potential is sensitive to this doublet configuration. The study by Jha and Puppala, (2016) considers log-normal distribution of thermo-hydro-geological properties, which follows regional geology. However, constant thermal gradient is assumed for initial condition of reservoir for simulating the dynamic behavior of reservoir under doublet configuration. The probable extraction temperature has been obtained, however it is associated with significant uncertainty due to the underlain assumptions for spatial variation of properties. To overcome the limitation of constant thermal gradient for entire valley, Kriging interpolation technique had been adopted by Jha and Puppala, (2017) to develop spatially varying thermal gradient of the shallow reservoir. This study couldn't establish the varying thermal gradient for deep geothermal reservoir. However, these studies establish the fact that assumption of constant thermal gradient is not a realistic assumption for both shallow and deep geothermal reservoir.

The limitations of the past research works (Absar et al., 1996; Gupta et al., 1979; Jha and Puppala, 2016) as discussed in the aforementioned sections, are kept in view to propose a new conceptual model of Puga geothermal reservoir in this study. The proposed conceptual model follows a methodology that maps the spatial variation of thermo-hydro-geological properties by conceptualizing the reservoir as block heterogeneity. The thermo-hydro-geological properties of reservoir includes porosity, thermal conductivity, specific heat, radioactive heat capacity, density and permeability. The resistivity model by National Geophysical Research Institute (Azeez and Harinarayana, 2007) is adopted as base data to estimate and map thermo-hydro-geological properties. In absence of original resistivity model, this paper considers the published imagery by Azeez and Harinarayana, (2007) and performs image processing by Arc GIS/Arc map software® to extract the electrical resistivity data. This base data of electrical resistivity model is followed to estimate effective values of thermo-hydro-geological properties of each block of conceptual model of reservoir. In addition, spatially varying steady state temperature along a vertical section trending in east-west direction is also mapped. The spatial variation of temperature further delineates the lateral extent of heat source. Thus, conceptual model of block heterogeneity in terms of spatial variation of thermo-hydro-geological properties and temperature is established in this study. The resulting conceptual model will also aid in the operational phase of reservoir development and in estimating the amount of energy that can be extracted from the geothermal reservoir throughout the operation phase in future studies.

[1] A committee formed by Indian government to carry out the field investigations in exploring geothermal potential.