



Modeling studies for production potential of Chingshui geothermal reservoir



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ABSTRACT

The Chingshui geothermal power plant was decommissioned in 1993 due to a continued decline in production. Although some geothermal exploration and field investigation had been exercised, the production potential of the reservoir is still not well understood. In this paper, numerical modeling approaches for characterization of the geothermal reservoir, investigation of reservoir production performance, and evaluation of exploitation scheme design are presented. At first, a site-scale refined grid numerical model was developed for simulating the natural state of Chingshui geothermal reservoir. Through the model, the production potential of the geothermal reservoir was estimated and the availability of water resources was assessed. We further built production model to simulate the production history during 1981–1993. From the production model, we can conclude that the abnormal drop of the reservoir production capacity is mainly caused by carbonate scaling. Potential production schemes with different reinjection designs were evaluated through the model. Simulation results indicated that a sustainable hot water production capacity of Chingshui geothermal reservoir is about 200 t/h without reinjection, and 300 t/h or even higher with reinjection which is enough for a 3 MWe power plant. The simulation results indicate that reinjection provides an effective approach for maintaining reservoir pressure during hot water/steam production.

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1. Introduction

The Chingshui geothermal field is located in the northeast portion of Taiwan, approximately 20 km southwest of Lotung town. In the area, several high-temperature hot springs along the Chingshui River have been historically noted. This fact, and exploration activities that are discussed below, led to the construction of the Chingshui geothermal power plant in 1981. The installed capacity of the plant was a 3 MWe flash power plant. Unfortunately, by 1993, the pilot power plant was decommissioned due to continued decline in production to uneconomic levels. Although geothermal reservoir exploration and field tests had been exercised in the past, the production performance of Chingshui geothermal reservoir is still not well understood. There are several hypotheses

for the failure: special characteristics of the Chingshui geothermal reservoir not being adequately understood at the time, and/or inappropriate power generator being used and severe scaling of the pipelines [7]. Many engineers and researchers believe that the most important reason for the production capacity drop is carbonate scaling in the reservoir [8,12]. In the field, extensive calcite deposits were observed inside well pipes. In the other way Chen and Sanyal [3] believed that the major reasons for the relatively low level production capacity were the high skin factor in the wells drilled with mud and the lack of produced water reinjection. However, it is also of the view that the production decline is due to the limitation of available water resources in the area. The purpose of this study is aimed at building a geothermal reservoir model to investigate the reservoir fluid flow process at the site and validate a particular hypothesis regarding reservoir failure. Specific details of the study are given below. Since reactivation of the plant is being contemplated, it is critical that we thoroughly understand reasons for the drop in production and the maximum potential for production.

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A number of studies have been conducted to characterize the Chingshui geothermal reservoir. A reconnaissance survey of this site was performed by the Industrial Technology Research Institute (ITRI) from 1973 to 1975. Further exploration was subsequently conducted by the Chinese Petroleum Corporation (CPC) from 1976 to 1980 [13]. Dozens of deep exploration and production wells were drilled along a 6-km bank of the Chingshui stream. During the site characterization and production period, a total of 19 geothermal wells were drilled. Eight of them were for exploration and the other 11 wells were for production (three production wells failed). There was no reinjection in production period. According to the survey, the water origin of Chingshui geothermal reservoir is from natural recharge. Geological and geochemical exploration data show that the natural recharge at Chingshui geothermal field mainly comes from the rainfall. Rainfall in the mountain area at the east side of the catchment seeps into the deep aquifers through the dip formations. In addition, numerical simulations and tracer tests were performed to investigate natural recharge of the reservoir [4,6]. Fan et al [4] combined the use of both tracer and interference tests to evaluate the natural recharge of Chingshui geothermal reservoir. Their estimations for mean residence time and natural annual recharge for the Chingshui geothermal reservoir are 15 years and $1.3 \times 10^7 \text{ m}^3/\text{year}$, respectively. In addition, they analyzed the interference test results for determining total fluid in place, which is about $2 \times 10^8 \text{ m}^3$. However Cheng et al [6] obtained a much smaller natural recharge value for the reservoir by analyzing naturally existing tritium in groundwater. Their calculated natural recharge rates for Chingshui geothermal reservoir were $5.0 \times 10^5 \text{ m}^3/\text{year}$ and $6.7 \times 10^5 \text{ m}^3/\text{year}$ with a plug flow and dispersive model, respectively, and the corresponding groundwater residence times estimated by the two models were 15.2 and 11.3 years. All these calculations were based on limited data and simple models with high uncertainty.

Well skin effects of the testing wells at Chingshui geothermal field were investigated to quantify formation damage or reservoir clogging through buildup tests and radon measurements [2,8]. Based on the observation of radon behavior during the flow tests of well IC-09 and a high skin factor ($S = 78.5$) determined from a pressure test, Lin et al [8] believed formation damage resulted from carbonate scales in the skin zone. They estimated reservoir permeability and the altered permeability of skin zone are approximately 1.06 md and 0.066 md, respectively. Similar conclusions were also reached by Chen et al [2]. Chen and Sanyal [3] believed that the well skin is one of the most important factors for improving the reservoir productivity. Through calculation of productivity for a geothermal well at the site, they concluded that much higher production potential can be reached, if (1) the range of skin factor (6.6 to -2) is achievable by the present drilling technology, and (2) the present state of binary plants and downhole pump technologies are adopted. In a recent exploration, at the depth of 600 m–800 m of a production well drilled into the reservoir of slate host rocks, fractures, veins and open cracks filled up with calcite or aragonite minerals were observed [12]. Surveys on outcrops show that there are many quartz veins occurred in slate formation, but a few or no calcite veins. These observations strongly suggest that formation scaling rather than carbonate precipitation occurs inside the wells of the Chingshui geothermal field [12].

Numerical simulation is an effective approach for characterizing geothermal reservoirs and for assessing and predicting the reservoir response to planned development. It has been successfully used in different geothermal reservoirs [9,14,15]. Chen et al [16] developed a single-porosity model to investigate the subsurface heat exchange process in an Enhanced Geothermal System (EGS), which employs two energy conservation equations to describe heat transfer in the rock matrix and in the fractures. A

phenomenological study was carried out by Siffert et al [17] using TOUGH2 to simulate fluid flow and heat transfer for various boundary conditions at Soultz site. Kumar and Gutierrez [18] built a three-dimensional heat flow model for EGS using the boundary element method. Their model was tested in the injection and production well pair of the Hijiori field circulation. In optimization of the reservoir exploitation design, the works of Hajmohammadi et al [19–21] could be interested. However, most of the above mentioned works are for conceptual studies and the models are limited by small scale or coarse grid.

The production potential of the Chingshui geothermal reservoir is still a puzzle and has still not been quantitatively investigated through numerical models. No convincing explanation to the failure of the geothermal plant has been reported. The flow system of the Chingshui geothermal reservoir has not been well understood. Even though Chen and Sanyal [3] conducted an investigation on the power generation potential for the Chingshui geothermal field, their conclusion is quite optimistic, because their calculation is fully based on the well performance and neglected the influence of availability of water resources. A systematic study of recoverable reserves and commercial power generation potential was needed. The main purpose of this study is to investigate the reasons of production declination of the Chingshui Geothermal power plant and to determine production potential of the site through numerical simulations. Early version of the model, used for evaluation of different production scenarios, has been reported by Lee et al [11]. In this study, a site-scale refined grid model was constructed for assessing the responses of the reservoir system under different production conditions and the influence of formation scaling on the well productions. The model was first calibrated by adjustment of the inflow rate from the bottom boundary until a satisfactory match obtained with the natural state condition. Inclusion of CO_2 in the model, as observed in the field, has shown further improvement in simulation results. The calibrated model was then used to simulate the production history during 1981–1993. With the model for the different production scenarios, we intend to investigate the impact of availability of water resources on the production well performance. Moreover, the influence of formation scaling on well production was modeled through reduction of permeabilities at the skin zone surrounding the production wells. Finally, proposed new production schemes with or without produced water reinjection were simulated to evaluate the effect of reinjection on the reservoir performance. Simulation results show that the production failure of Chingshui Geothermal plant is due to the formation scaling, and slight limitations of the groundwater resource. With the development of refined grid model, we are able to calculate the amount of total geothermal resource in place, optimize the design of reinjection and production schemes, investigate approaches for preventing formation scaling, and further re-evaluate the feasibility of resuming commercial exploitation of the Chingshui geothermal system. Compared to previous work by Lee et al [11], significant improvements to the current model have been made. The key improvements include adding CO_2 fluid component in the model to make the simulation closer to reality, covering 236% larger model domain to reduce the boundary effects, adopting finer grids in both horizontal and vertical direction to catch details of the geological features, and using different modeling approaches for the water/steam production activities to achieve better simulation of the well performance. In addition, improvements also include the setting of boundary conditions, using updated reservoir fluid and rock parameters, and in depth calibrations of the model.

In this paper, a novel numerical modeling approach for characterization of geothermal reservoir, investigation of reservoir production performance, and evaluation of exploitation scheme design is presented, a site-scale refined grid model for catching

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