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Modeling of heat extraction from variably fractured porous media in Enhanced Geothermal Systems

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ABSTRACT

Modeling of heat extraction in Enhanced Geothermal Systems is presented. The study builds on recent studies on the use of directional wells to improve heat transfer between doublet injection and production wells. The current study focuses on the influence of fracture orientation on production temperature in deep low permeability geothermal systems, and the effects of directional drilling and separation distance between boreholes on heat extraction. The modeling results indicate that fracture orientation with respect to the well-pair plane has significant influence on reservoir thermal drawdown. The vertical well doublet is impacted significantly more than the horizontal well doublet.

1. Introduction

Enhanced Geothermal Systems (EGS) have the potential to extract heat in low permeability fractured rock in locations largely unsuitable for conventional hydrothermal systems. EGS allows extraction of heat through natural reservoirs with suitable permeability or stimulated reservoirs where permeability and heat transfer area are mechanically or chemically enhanced. The economic viability of EGS is dependent on variables such as drilling costs, initial reservoir temperature, decrease in temperature during the operational time (thermal drawdown), and fracture permeability. Understanding the relationships and dependencies between these variables will enable developers to optimize system design to increase viability and reduce economic risk.

Estimation of extraction of heat from fractured geothermal reservoirs has been a subject of study for decades. Gringarten et al. (1975) used mathematical models to produce analytical solutions to predict heat extraction from fractures in hot dry rock using injection and withdrawal wells. The authors investigated the use of directional drilling to optimize heat extraction based on orientation of fractures. Similar studies using the analytical method were conducted by other researchers (Gringarten and Sauty, 1975; Cheng et al., 2001; Ghassemi et al., 2003; Yang and Yeh, 2009). To overcome the limitations of the analytical solutions (dimensionality and constant parameter values) various numerical models have been developed to study the effect of fracture characteristics on reservoir behavior (Juliusson and Horne, 2010; Hao et al., 2013; Doe et al., 2014). The various numerical models use different mathematical models designed for specific applications. The majority of the EGS studies consider the vertical wells. Only a few studies evaluated horizontal wells (Shiozawa and McClure, 2014). Our study provides in depth analysis of both, vertical and horizontal wells.

Previous studies have looked at thermal performance and economic evaluation of the use of directional wells for EGS (Lowry et al., 2014; Kalinina et al., 2014a,b) and showed that well orientation played an important role in thermal drawdown with the most advantageous configuration consisting of a horizontal well-pair with the injection well below the production well. The economic viability was highly influenced by the drilling and pumping costs, the latter being a function of the effective permeability between the wells.

For this study the Fracture Continuum Method (FCM) was used to develop stochastic representations of reservoir permeability. The FCM was developed by McKenna and Reeves (2006) to generate multiple permeability fields using field observations of fracture set data. The method was later enhanced by adding anisotropy using the approach of Chen et al. (1999). Applications of the FCM method to modeling EGS are reported in recent publications (Kalinina et al., 2012a,b, 2014a,b). The FCM does not need upscaling because the REV-size grid blocks used are sufficiently small. McKenna and Reeves (2006) recommended that the size of the numerical model

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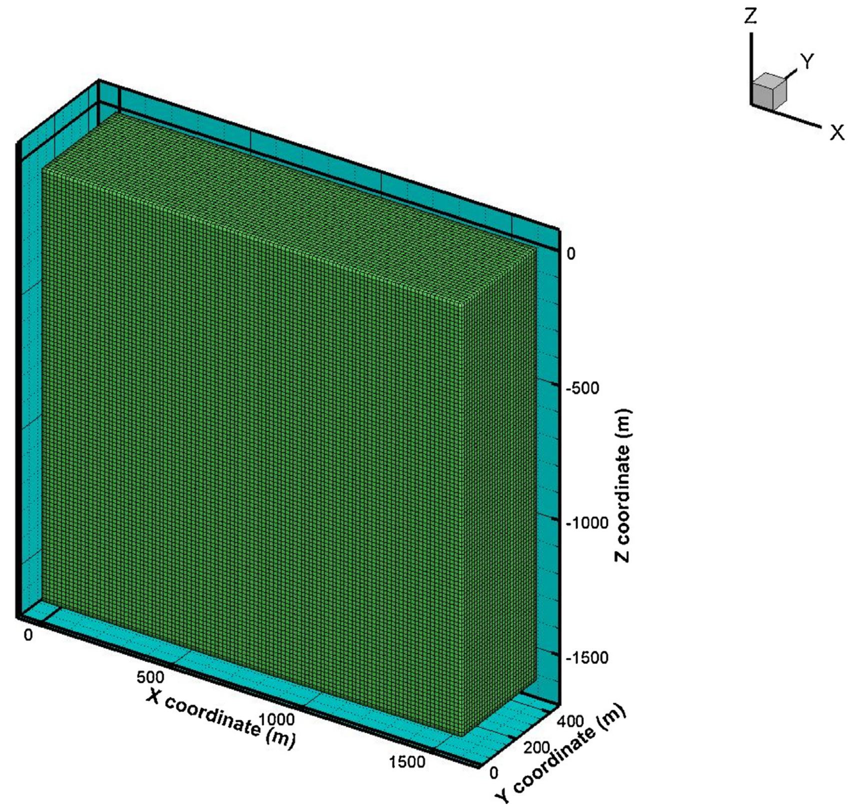

Fig. 1. Geometry and meshing of the model domain.

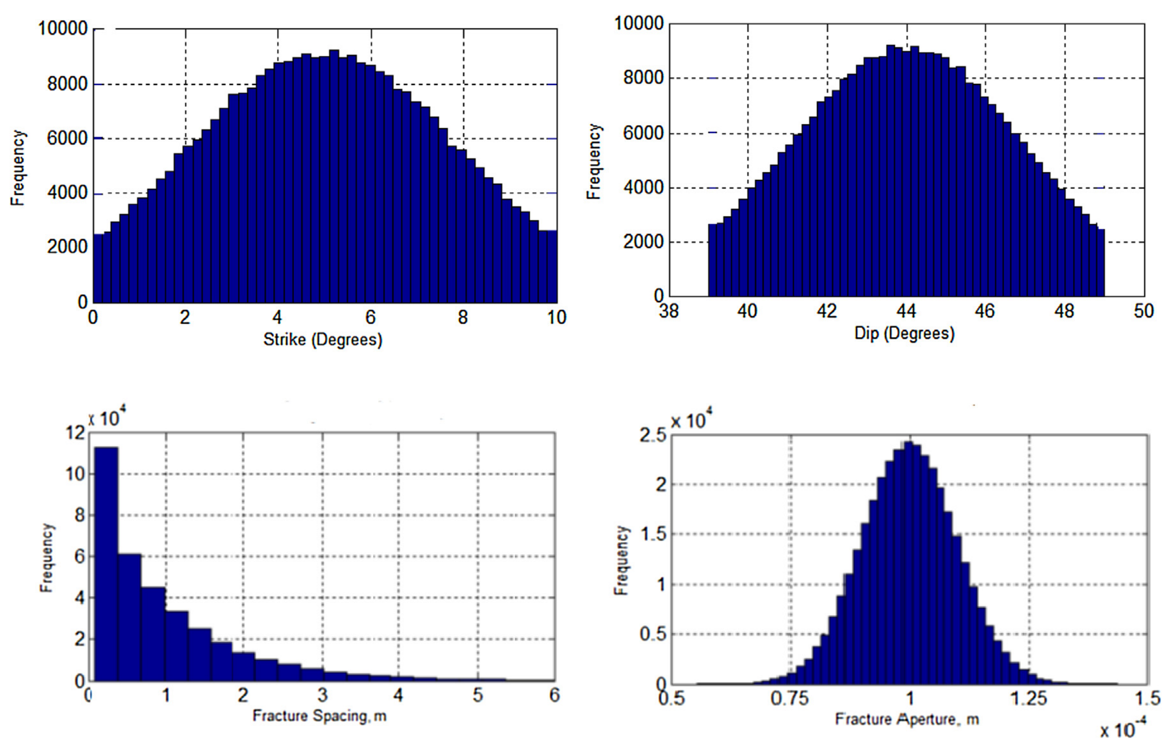

Fig. 2. Simulated values of fracture strike, dip, spacing, and aperture for the 5° strike and 44° dip case.

grid blocks to be kept small enough that fracture properties can be assumed constant over the size of the grid block. The constant grid block size and the fracture properties used in this study are in line with the recommendation of McKenna and Reeves (2006). Hao et al. (2013) showed that the output of a continuum model is comparable to that from a discrete fracture model.

The method of Chen et al. (1999) allows representation of multiple fracture sets for different fracture orientations. FCM maps the permeability of discrete fractures onto a regular grid using a