Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **17**, No. 1, pp. 1-30

DOI: 10.4208/aamm.OA-2024-0122
February 2025

Method to Improve Heat Extraction in Enhanced Geothermal Systems with Heterogeneous Fracture Network

Qiang Huang[1], Ning Guo[1], Haibo Huang[1], Jie Yu[2], Gang Pei[1] and Maobin Hu[1,*]

[1] *School of Engineering Science, University of Science and Technology of China, Hefei, Anhui 230026, China*
[2] *Hefei Institutes of Physical Science, Chinese Academy of Sciences, Hefei, Anhui 230031, China*

Received 5 June 2024; Accepted (in revised version) 3 July 2024

Abstract. In typical EGS fracturing projects, the fracture network is denser in the region close to the fracturing wells. The distribution of fractures has a significant impact on the heat extraction performance of enhanced geothermal system (EGS). In order to avoid premature thermal breakthrough and improve the thermal extraction efficiency, this paper studies the heat extraction performance of EGS in heterogeneous fractured reservoirs under different injection-production methods. First, a heterogeneous discrete fracture network generation method based on relative pressure distribution is developed. A thermo-hydraulic-mechanical (THM) coupling model is established to simulate the fluid flow and heat transfer in reservoirs. The heat extraction performance under different production and injection modes is compared with different fracture densities. The results show that injection in the dense side of the anti-parallel well configuration will be more efficient for heat extraction. Under the condition of same injection mass flow rate, the heat extraction performance is positively correlated with the fracture density. Although sparse-side injection is not conducive to fluid flow, under the condition of same injection mass flow rate with anti-parallel well configuration, it will improve the thermal extraction performance.

AMS subject classifications: 76S05, 35Q99

Key words: Enhanced geothermal systems, heterogeneous discrete fracture network, injection and production modes, heat extraction.

*Corresponding author.
Email: humaobin@ustc.edu.cn (M. Hu)

1 Introduction

As one of the most potential sustainable energy sources [1,2], geothermal energy has large reserves and is widely distributed in the world [3–5]. More than 90% of the available geothermal resources are stored in the hot dry rock (HDR) [6,7]. To facilitate heat extraction from HDR, the enhanced geothermal system (EGS) fractures HDR to obtain interconnected fracture networks. The fracturing methods include hydraulic fracturing [8,9], gas fracturing [10–12], thermal stress fracturing [13–15] and chemical stimulation [16]. During the fracturing process, the newly generated fractures will interact with the original fractures to produce complex fracture structures [17–19]. Because the HDR is located deep in the formation and the environment is complex, the experimental study of fractured reservoir is difficult [20]. Therefore, numerical simulation of geothermal reservoir plays an important role in the design and planning of geothermal projects. There are still some difficulties in the description of actual fractured reservoirs [21]. Especially, most literatures adopt homogeneous fracture network to represent the fractured reservoirs.

In fact, in the fracturing process, the distribution of fractures in the reservoir is highly heterogeneous. The density of the fracture network is higher in the region near the fracturing well. The performance of thermal recovery in EGS depends significantly on the distribution of the fracture network in the reservoir. Additionally, an efficient well layout can improve HDR resource extraction. Optimizing thermal recovery in fractured reservoirs with heterogeneous fracture networks is crucial for the development of geothermal resources. Therefore, this paper studies the thermal extraction performance of heterogeneous fractured reservoirs under different injection and production methods (different well layout).

In order to improve the heat extraction efficiency of EGS, researchers have carried out many interesting studies on well layout and fracture structure. The geometric structure of fracture network has a great impact on the performance of fractured reservoir. The appropriate well layout is also helpful to improve the heat recovery efficiency of hot dry rock. Ma et al. studied the effects of different well layout schemes with a specific injection-production ratio on the EGS thermal recovery performance [22]. They found that longer production and injection well spacing was conducive to the thermal recovery of reservoirs, and the production temperature had a greater competitiveness when one injection and one production pattern was used. Li et al. conducted probabilistic research on the heat extraction performance of EGS under discrete fracture network [23], and the results showed that probabilistic performance evaluation was helpful to design and optimize the efficient heat recovery of deep geothermal reservoir. Zhang et al. studied fluid driven fracture propagation in naturally fractured rock mass [24]. The results show that due to the highly inhomogeneous of natural fractured rock mass, hydraulic fracturing stimulation in this medium may lead to complex fracturing system rather than simple planar fractures. Xu et al. studied the joint effects of fracture geometry and thermal stress on the THM behavior of EGS [25]. The results show that the geometric connectivity of fracture network plays a leading role in determining the THM process and thermal