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Numerical simulation of flow heterogeneities within a real rough fracture and its transmissivity

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Abstract

Core analysis studies the fractures characteristics and explains the fluid-rock interactions to provide the information of permeability of a reservoir or an enhanced geothermal system (EGS). This study presents a numerical simulation of flow through a single fracture of an experimented core of an EGS. The injection pressure plots with respect to injection flow rate were compared with available experimental results. The transmissivity of the fracture was evaluated and compared to the experimental measurements. All results indicated good agreements with corresponding experimental results and showed the efficiency of numerical methods to determine the transmissivity of single fractures.

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Keywords: Enhanced Geothermal Systems (EGS); Real fracture; Intrinsic transmissivity; Core analysis;

1. Introduction

Geothermal energy in the Earth's crust is usually stored in the host rocks containing pores saturated with water and varying amounts of dissolved salts. Those rocks may also involve fractures in their structures. Geothermal resources that have been utilized to extract economic amounts of heat from low permeability and/or porosity

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reservoirs are defined as Enhanced (or Engineered) Geothermal Systems (EGS). In the application side, the scheme of pressurized injection of a cold fluid into the hot fractured medium produces electricity and heat in many countries worldwide. In the United States, the amount of thermal energy, which comes from hot rocks and fluids in sedimentary rock formations, are substantially larger and more widely distributed in comparison to hydrocarbon (oil and gas) [1]. It is estimated that 2% of the total thermal energy stored in the reservoir between depths of 3 km and 10 km in US area, would be sufficient to provide the US primary energy needs for 2,800 years [1]. Recently, Breede et al. [2] provided a review of the existing EGS projects worldwide and classified them by country, reservoir type, depth, reservoir temperature, stimulation methods, associated seismicity, plant capacity, and status. They concluded that EGS technology should be studied more to make benefits from the historical projects and prosper to conventional EGS systems. More studies related to the methodology and applications of EGS [3] were recently reviewed.

Fractured rock systems in EGS heat reservoir are low permeable, and conduction dominated [4]. Hydraulic stimulation or enhancement creates a network of more open connected fractures through which fluid can be heated by contact with the hot rock after injection through an injection well. The hot fluid is pumped out through production wells to the surface. Fluid-rock interactions result in permeability evolutions in the fracture network and create newly engineered fractures. The evolution of permeability leads rock systems to be more permeable and consequently convection dominated. The EGS heat reservoir as a fractured rock system is almost considered as a porous medium in numerical studies, so that the detailed information such as configuration and distribution of fractures in the reservoir were neglected [5-8]. Recently, a subsurface thermo-hydraulic process during a complete loop of EGS heat extraction was studied [9-11]. In these studies, fracture network, rather than a single fracture, was considered as the whole domain of the reservoir. The configuration of single heterogeneous fracture and its permeability evolution due to different chemical and mechanical conditions were not under attention in the literature sufficiently. Lately, Guo et al. [12] showed flow paths in a large size single fracture including injection and production wells focused on heat production in EGS. They observed flow channeling and reservoir performance reduction due to aperture heterogeneity.

Among many aspects of EGS, numerical modeling of the natural fracture is less studied. For example, Sarkar et al. [13] presented a numerical simulation of fluid flow in natural fracture aperture applying Computational Fluid Dynamics (CFD). Steady state, viscous, laminar flow simulations for a Newtonian fluid were carried out for 2D and 3D fracture surface models using a commercial CFD software package, FLUENT, to estimate the pressure drop and volumetric flow rate of a fracture [14]. It should be noted that, there were no corresponding experimental results to show the validity of the numerical simulations. This problem refers to the lack of adequate instrumented laboratory experiments including the changes of the fracture's morphology following chemical and dissolution phenomena, occurring within the fracture. Free face dissolution type and pressure solution type are two types of dissolution phenomena in chemical reactions [15]. The pressure solution effect is dominant when the rough-surface within the fracture leads to greater mineral solubility due to localized concentration of pressure at the contact zones. McGuire et al. [16] investigated that higher pressurized injection fluids increased the chemical corrosion of the fracture features. The stress corrosion process is known as another factor, which makes a compaction of the fracture by linking mechanical and chemical phenomena resulting in inaccuracy in measurements and modeling [17]. The cracks that were created due to tensile stresses of mechanical loading can grow because of the presence of fluid, which leads to chemical reactions. Accordingly, the presented numerical studies were suffering from the lack of the ability to numerically simulate the chemical reaction's effects on the geometry of the fracture. On the other hand, various experimental works [18] were conducted with "artificial" in lab-made fractures. In these studies, fresh lab-made fractures cannot resemble the real localized fractures in a reservoir as they are free of mineral deposits and coating and their asperities have a high angularity. The history of the fracture is also missing in these sorts of works.

Recently, Blaisonneau et al. [19] developed an experiment to study the permeability of a single natural fracture under mechanical loading before and after chemical reaction. They showed that chemical reactions alter the morphology of the fracture. Next, they compared the permeability measurements of the fracture before and after chemical reaction. Chemical factors such as dissolution type effects [19] were involved in the tests, providing promising results. Our study provided a conceptual model to numerically investigate the inert fluid flow within the experimented fractured rock sample in Blaisonneau's apparatus [19]. Its focus was especially on how fracture permeability alters due to changes in mechanical loading and percolation.