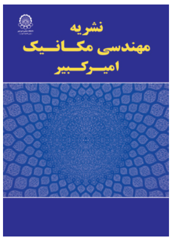

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(2) (2018) 115-118
DOI: 10.22060/mej.2017.12233.5285

An Analytical Investigation into Effects of Fracture Dispersion Coefficients and Thermal Conductivity on Geothermally Fractured Reservoirs

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ABSTRACT: Renewable energy is defined as sort of energy whose producing resources possess the capability to renew through nature during a short period of time. The analytical model of water injection into geothermal reservoirs process which is used to describe more complex matters, can explain the heat transfer processes in the porous media better. The presented corresponding studies so far are based on numerical and semi-analytical methods while here, a fully exact analytical solution is introduced considering phenomena of convection, conduction and dispersion inside fractures, conduction inside matrix blocks, and matrix-fracture heat transfer. In this regard, geothermal fractured reservoir related heat transfer equations are solved, ignoring fracture dispersion and heat conduction phenomena, which appears to be an appropriate assumption in high injection velocity values and then the effects of injection water velocity and distance from injection well parameters on the amount of error percent of these two models are investigated. Moreover, thermal recovery efficiency is employed to investigate cold water flooding into such reservoirs followed by a comparison to a numerical model for the purpose of validation.

Review History:

Received: 6 December 2016
Revised: 8 February 2017
Accepted: 5 March 2017
Available Online: 11 March 2017

Keywords:

Geothermal energy
Fractured reservoir
Convection
Conduction
Dispersion

1- Introduction

Growing interest in geothermal energy has motivated numerous attempts to develop a method to extract thermal energy from hot dry rock, which may constitute a resource much greater than that permeated by groundwater. This concept is based on creating an adequate fracture surface in order to enhance heat transfer rate. Due to the fact that thermal conductivity of rock is low, a very large heat transfer area must be provided; otherwise, meaningful amounts of energy cannot be extracted at feasible rates.

Geothermal energy from hot rocks can be considered as a promising unconventional renewable energy production technology. Lauwerier [1] investigated thermal fronts propagation in a single phase fractured porous media. He derived an analytical solution for hot water injection into the oil-bearing fractured rocks. Gringarten & Sauty [2] obtained a mathematical model for an investigation of the unsteady temperature trends of an aquifer during reinjection of a fluid at a temperature different from the initial temperature of water for a single horizontal fracture. A semi-analytical solution for vertical fractures was also developed by Gringarten et al. [3]. Bödvarsson and Tsang [4] presented a similar model to Gringarten and Sauty, but they considered horizontal fractures in their model. A configuration of disk shaped, uniform aperture, the vertical fracture was used by McFarland and Murphy [5] in order to represent the underground fracture. Cheng et al. [6] considered one vertical fracture in an unbounded domain to create their model.

Authors like Lauwerier [1], Pruess and Bödvarsson [7] assumed that a single-phase liquid flow is established in the fracture with the heat conduction from a semi-infinite matrix and attempted to achieve an analytical solution of the temperature in a fractured media. the solution is also given in Carslaw and Jaeger [8]. Kasameyer and Schroeder [9], Romm [10], Gringarten et al. [3] and Bödvarsson and Tsang [4] studied the influence of fractures on thermal front movement during injection.

In this study, an analytical solution for temperature as a function of time and spatial dimensions (x and y) in a single fracture model is presented. Heat transfer within the rock matrix is modeled as conduction, while heat transport within the fracture includes thermal advection, conduction, and dispersion in the vertical plane. Another important section of this study is calculating thermal recovery efficiency. In order to validate the predicted temperature by convection and conduction heat transfer model in geothermal reservoirs, the presented analytical model is compared with a numerical model on the synthetic case.

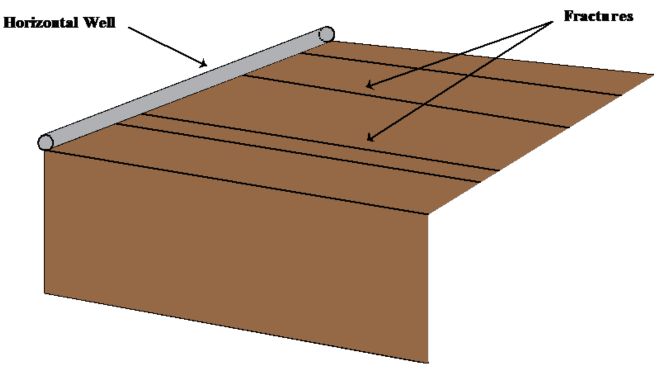

Figure 1. Schematic diagram of the Enhanced Geothermal Systems (EGS).

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2- Physical System and Governing Equations

A fractured geothermal system and a thermal front propagation in a single fracture have been depicted in Fig. 1. During the injection of cold water into the hot fractured rocks, the injected cold water circulates through hot fractured rocks and is extracted at the surface through the production well as hot fluid. Either water or steam or even a combination of both could be the resultant hot fluid obtained from the geothermal system depending upon the system is liquid-dominated or vapor-dominated. Fig. 1 also shows a single vertical fracture. In this Figure, 2b is the fracture aperture related to the parallel plate model, and 2B is the half fracture spacing. The major transport process within fracture is thermal advection, while conduction is considered to be the major transport process within the matrix. Also, heat flux transfer between matrix and fracture is considered.

3- Governing Equations for Heat Transfer

The differential equation which governs the fluid temperature in the fracture can be derived by applying energy balance in a control volume in the fracture. The derivation is similar to those presented by Lauwerier [1], Gringarten et al. [3], and Bödvarsson and Tsang [4]. The fracture equation is:

$$\frac{\partial T_f}{\partial t} = D_f \frac{\partial^2 T_f}{\partial x^2} + D_L \frac{\partial^2 T_f}{\partial x^2} - v \frac{\partial T_f}{\partial x} + \frac{\lambda_m}{\rho_f c_f b} \left. \frac{\partial T_m}{\partial y} \right|_{y=b} \quad (1)$$

The temperature distribution in the rock matrix is governed by the one-dimensional heat conduction equation:

$$\frac{\partial T_m}{\partial t} = D_m \frac{\partial^2 T_m}{\partial^2 y} \quad (2)$$

4- Results and Discussion

A synthetic model is made use of to verify the derived analytical solution by comparing them with those based on the numerical model.

Comparison of the energy production rate calculated by numerical (TETRAD) solution with the analytical solution as well as the analytical solution for a semi-infinite matrix is displayed in Fig. 2. It is worth mentioning that the last model overestimates the energy production rate, while the numerical simulation and analytical results are in a good agreement. Therefore, it can be concluded that for the purpose of energy depletion, the assumption of semi-infinite matrix block dimension is not a very good approximation under these conditions.

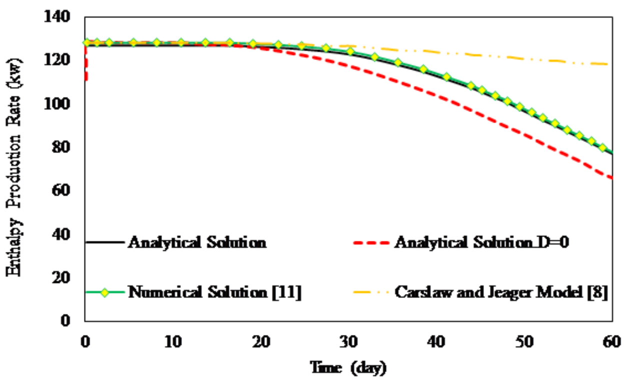

Figure 2. Energy production rates for the single vertical fracture model: analytical model, numerical (TETRAD) solution [11], and infinite matrix (Carslaw and Jaeger [8]).

5- Conclusions

A general transient solution has been developed for the problem of heat transfer in discrete, parallel fractures. The solution is in the form of a double integral that is evaluated by Gaussian quadrature. Processes that are accounted for are convection along the fractures, mechanical dispersion, and conduction along the fractures, conduction from the fractures into the intervening porous matrix. A simpler solution has also been presented that is valid when it is reasonable to neglect longitudinal dispersion and conduction in the fractures. The analytical solution is remarkably simple and fast, thus sensitivity studies are readily done and important parameter groupings can be readily identified. Although a number of assumptions that were made resulted in a highly idealized system, the analytical models provide a framework for studying the mechanics of heat transfer in fractured porous media and as such can be regarded as a basic building block for solutions to problems involving more complicated systems. They will also be useful in verifying numerical models developed for this purpose. By applying the analytical solutions to field or laboratory data, they will assist in the task of parameter identification, thus enabling predictions to be made with models of more elaborate fractured systems.

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Please cite this article using:

M. Abbasi, M. Sharifi, A. Kazemi, An Analytical Investigation into Effects of Fracture Dispersion Coefficients and Thermal Conductivity on Geothermally Fractured Reservoirs, *Amirkabir J. Mech. Eng.*, 50(2) (2018) 359-368.
DOI: 10.22060/mej.2017.12233.5285