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MICROHOLES FOR IMPROVED HEAT EXTRACTION FROM EGS RESERVOIRS: NUMERICAL EVALUATION

Yingqi Zhang[1], Lehua Pan[1], Patrick Dobson[1], Ken Oglesby[2], and Stefan Finsterle[1]

Lawrence Berkeley National Laboratory[1]
One Cyclotron Road, MS 90-1116
Berkeley, CA 94720, USA
e-mail: yqzhang@lbl.gov

Impact Technologies LLC[2]

ABSTRACT

The use of microholes is a potential approach to enhance fluid flow and heat exchange within an engineered geothermal system (EGS). Multiple microholes, created using coiled tubing drilling technology, are drilled as sidetracks off of injection or production wells. Because microholes can be spread widely, thus intersecting a larger portion of the fracture network, the use of microholes increases the rock volume that is accessed by the circulating working fluid, therefore extracting more heat from the geothermal reservoir. The objective of this study is to evaluate EGS performance of microhole configurations using numerical simulations. This is performed by comparing the amount of heat that is extracted over a period of time using a conventional EGS design and one based on microholes. We examined multiple scenarios using numerical simulations with explicitly discretized microholes. Different scenarios have been considered and comparisons of energy production were made to contrast the conventional and microhole designs, providing preliminary insights into the potential of microholes to improve the efficiency and robustness of heat extraction from an EGS.

INTRODUCTION

Two of the major obstacles to the commercial development of Enhanced Geothermal Systems (EGS) are the high costs of drilling deep, large-diameter wells, and the difficulties of creating a distributed fracture network to facilitate heat exchange (Tester et al., 2006). EGS reservoirs typically require the use of stimulation methods (hydrologic, thermal, and chemical) to improve the permeability of existing fractures, to create new fractures, or to address wellbore skin effects or formation damage associated with drilling (Schulte et al., 2010). One additional means to improve fluid circulation between injection and production wells and to increase the surface area between the circulating fluid and the hot rock matrix in an EGS reservoir is to improve the connection between the wellbores and the existing fracture network (either natural or enhanced) through the use of microholes. The microholes would be created as multiple completions for injection and/or production wells, and could be targeted to intersect specific faults or fractures.

Slimholes and microholes have been used by the mining, oil and gas, and geothermal industries as a way to explore the subsurface at lower cost (e.g., Finger et al., 1995; Finger et al., 1999; Albright and Dreesen, 2000). This type of well also provides the possibility for small-scale production of geothermal fluids (Pritchett, 1995), as well as allowing for more widely distributed stimulation of fractures within an EGS reservoir (Bracke and Wittig, 2011). A detailed review of reservoir injection and flow tests conducted in conventional and microhole wells suggested that injectivity and productivity tests in both kinds of wells yielded similar results, provided that the flow regime remains single-phase (Garg and Combs, 2002). Use of small diameter boreholes may complicate fluid flow for low permeability reservoirs and/or under two-phase flow conditions, which could occur when used as a production well.

A key objective of the current study is to evaluate the feasibility of using microholes, created using proprietary coiled tubing drilling technology, to create an effective connection between injection and production wells and a subsurface fracture network. The microholes would be directionally drilled as multiple completions off of injection and production wells, and could be targeted to intersect important faults and fractures that serve as conduits for distributed heat exchange between the rock mass and the working fluid. This approach might avoid some

of the problems that exist with using either only a wellbore heat exchange system (such as for an injection-production well doublet with multilaterals, e.g., Nalla and Shook, 2004), or relying solely on the development of a stimulated fracture network to enhance permeability. Microholes can be drilled over a wide area, thus intersecting a larger portion of the fracture network and increasing the volume that is accessed by the circulating working fluid. Because of the distributed nature of flow originating from or converging to spatially separated microholes, the risk of creating thermal short circuits can be reduced. Moreover, heat mining relies on the exchange of energy between the hot rock matrix and the fluid circulating in the fracture network. Microholes deliver the working fluid to more such fractures, thus increasing the heat-exchange area.

The focus of this study is an evaluation of the performance of microhole configuration for an EGS reservoir using numerical simulations. This modeling effort has led to the development of simulation capabilities for microhole technology, which includes a wellbore simulator for liquid water, steam and heat transport (Zhang et al., 2011) that is coupled to the TOUGH2 reservoir simulator.

MICROHOLE CONFIGURATIONS

Microholes are defined as less than 4” bores. Only a few drilling methods can create these small bores, especially in very deep hard rocks. Use of traditional rotary bit methods with less than 4-3/4" bits in these conditions is difficult due to limited Weight-On-Bit (WOB) and torque capabilities. Newer methods are being tested to drill microholes for EGS, including FLASH abrasive jetting, high energy / Direct Energy (DE) methods (millimeter wave, laser, spallation) as well as some hammer methods. The FLASH abrasive slurry jet (ASJ) drilling technology as illustrated in Figure 1 utilizes very high velocity particles to erode the brittle hard rock ahead of the nozzle. Low flow rates (2-5 gpm) and low pressures (5000 psi) can be used, which allows microholes to be drilled effectively and efficiently.

It is envisioned that multiple microholes would be drilled, extending out of a larger injection or production bore within the target reservoir zone. With limited real-time directional drilling control (due to the depth, temperature, small bore and pipe) a large target (or distributed fracture network) is needed. Simple directional control called ‘point and shoot’ (kickoff depth, azimuth, and beginning inclination) can be used, where the effect of gravity and penetration velocity combined with bottom hole assembly inclination control can be used to aim for a target zone in the reservoir. Well surveys can be made during and after drilling to determine the actual location of the well bore.

Figure 1: Illustration of FLASH ASJ drilling technology.

A move toward more bores and toward even smaller bores may allow for better flow and heat extraction distribution and balancing of flow throughout the reservoir.

COMPARISON BETWEEN MICROHOLE AND CONVENTIONAL EGS

To demonstrate EGS performance of microhole configurations, we have defined a number of synthetic scenarios for energy production using both microhole designs and a conventional EGS design. We have performed numerical simulations for both designs. The evaluation of microhole design performance is through comparing numerical simulation results from both configurations.

TOUGH2 (Pruess et al., 1999), a simulation program for nonisothermal multiphase flow and transport in fractured porous media, is used for all the simulations performed below.

Scenario 1.

The first scenario under consideration is a synthetic system that contains a doublet – an injection well and a production well, as shown in Figure 2. The two wells are 500 m apart, with a fracture zone between. The fracture zone under consideration is assumed to be 100 meters thick and 50 m wide. For the microhole design, the second wellbore, which is connected to 40 microholes, is drilled outside the fracture zone, then the 40 microholes are drilled into the fracture zone, as shown in Figure 3. Geothermal reservoir parameters used for this scenario are listed in Table 1.

Table 1: Reservoir parameters for Scenario 1.

Fracture permeability	1 D
Fracture porosity	0.07
Fracture depth	-4060 ~ -3960 m
Matrix permeability	0.1 mD
Matrix porosity	0.05
Injection fluid temperature	50 ºC
Geothermal gradient	40 ºC/km

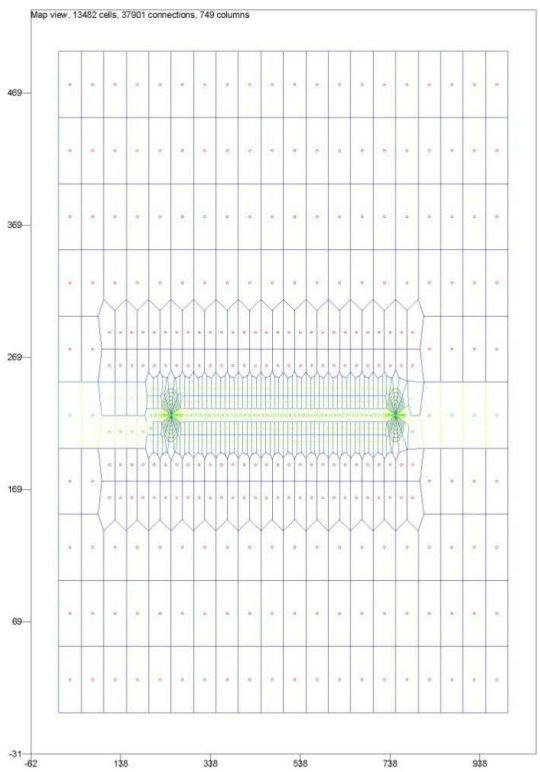

Figure 2: Model plan view for the conventional EGS design using Scenario 1.

For this scenario, we have made the following assumptions:

- In the conventional EGS design, the second well was drilled into the fracture zone, which was created using the first wellbore. This is an optimistic assumption for the conventional EGS design;
- In the EGS microhole design, we assume that four microholes (10% of the total) missed the fracture zone and were drilled into the rock matrix. The remaining 36 microholes were able to hit the fracture zone, which was created by the first main borehole.
- Fluid flow in the fracture zone can reach equilibrium instantly. As a result, a single-continuum approach can be applied for this scenario. In other words, fracture properties are applied to the fracture zone, and for the rest of the model matrix properties listed in Table 1 are used.

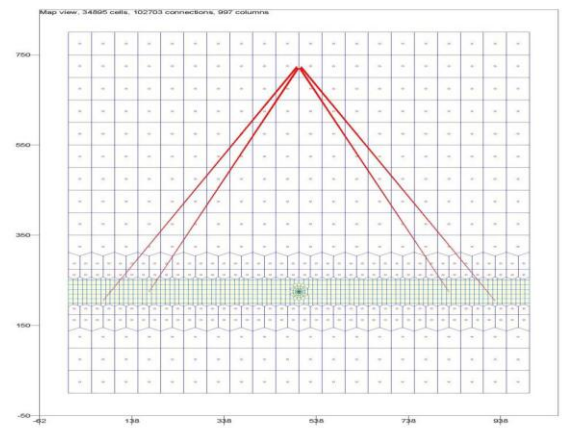

Figure 3: Model plan view for the microhole design of EGS using Scenario 1. Notice the 40 microholes are collapsed into 4 lines.

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Figures 4 and 5 show the temperature profiles within the plane of the fracture zone at the end of 10 years for the conventional EGS design and EGS design with microholes, respectively. Figure 6 is a comparison of the temperatures of the produced fluid over time for the two designs. An additional simulation considering impermeable matrix was performed to investigate the influence of matrix permeability. Figure 7 is the comparison of the corresponding heat flux at the outlet of the production well.

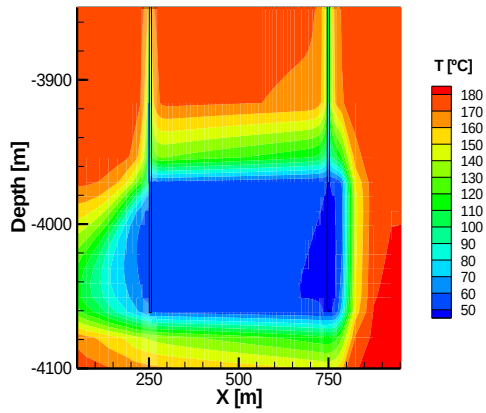

Figure 4: Temperature distribution for the conventional EGS design after 10 years. The injection well is on the right.

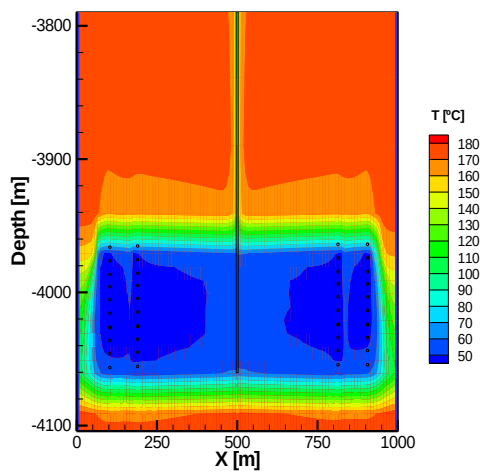

Figure 5: Temperature distribution for the EGS design with microholes after 10 years. Injection takes place through the microhole array.

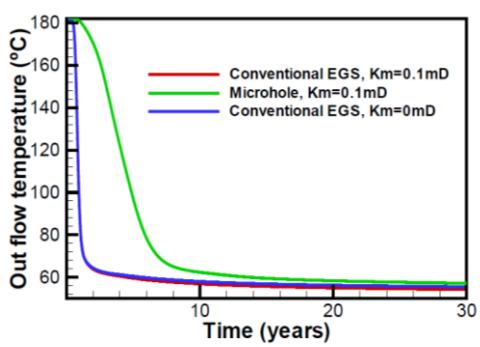

Figure 6: Comparison of the temperature change over time for the two designs.

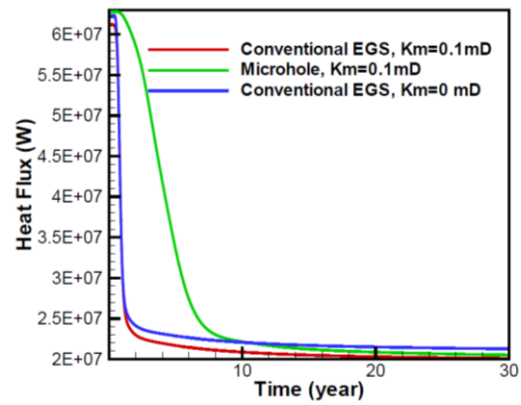

Figure 7: Comparison of the heat flux at the production well over time for the two designs.

These preliminary results show:

- Significant improvement in energy production can be achieved by injecting working fluids from a microhole array into the fracture network;
- When a single continuum approach is used to model the system, the energy production is not very sensitive to matrix permeability;
- For the microhole design, if some of the microholes have missed the fracture zone, the design is able to self-regulate and assign more flow to other microholes. As a result, microhole design is robust to drilling uncertainties.

Scenario 2.

Scenario 2 is a variant of Scenario 1. The difference is that it is assumed that there is a fast flow path in the middle of the fracture zone for Scenario 2. As shown in Figure 8, both reservoir designs have poorer performance relative to Scenario 1 due to flow focusing leading to thermal breakthrough. However, the microhole configuration again shows a strong improvement over the conventional EGS design.

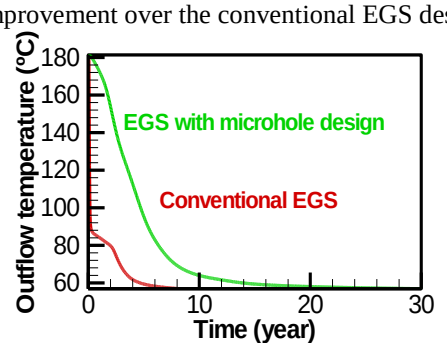

Figure 8: Outflow temperature for Scenario 2 in which a fast flow path exists for a conventional EGS design and for a configuration with microholes.

Scenario 3.

Scenario 3 is made to be more realistic by adapting some geological conditions from the Soultz EGS reservoir (Sausse et al., 2010). As shown in Figure 9, there are two production wells and one injection well (the one in the middle) for the conventional design. For the microhole configuration, the injection wellbore is connected to 40 microholes, as shown in Figure 10. The model domain considered is between -3800 m ~ -5300 m. The fracture zone is assumed to be between -4400 m ~ -4800 m, which is modeled using a dual permeability model. In addition, there also exists a 30 m thick fault zone, through which most flow occurs.

The temperature distributions of the model domain after 10 years for both designs are plotted in Figures 9 and 10. Temperatures at the two production wells for both designs are plotted in Figure 11. Comparing the two designs, the production temperature using conventional EGS is higher for the first few years and lower later on as shown in Figure 11. The reason is that, in the conventional EGS design, the heat mainly comes from the major fault zone, which is at the lower part of the geothermal reservoir, and thus has a higher temperature than the upper part of the reservoir. Once the heat from the fault zone is exhausted, the temperature decreases. Compared to the conventional EGS, more flow in the microhole design goes through the somewhat cooler fracture zone, which explains the lower temperature at earlier time, but provides access to a larger rock volume and allows more heat mining from the matrix of the dual permeability zone. Therefore, the temperature at the end of the ten years is higher for a more sustainable operation of the EGS system.

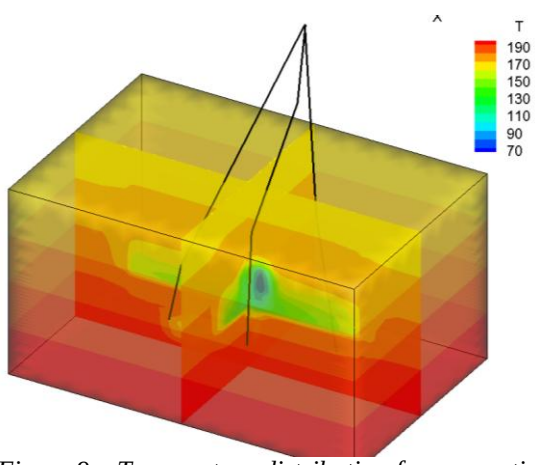

Figure 9: Temperature distribution for conventional EGS after 10 years. The injection well is in the middle of the system.

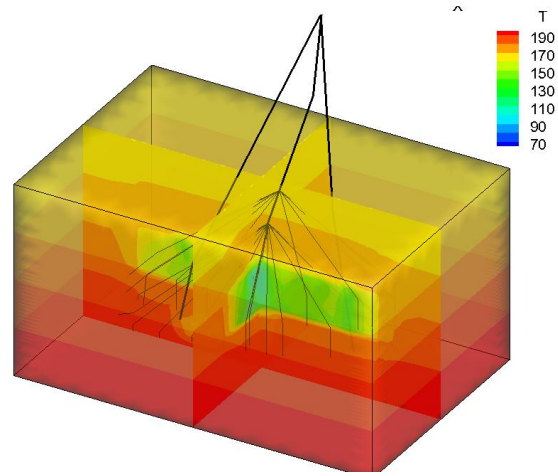

Figure 10: Temperature distribution for EGS with microhole design after 10 years. Injection takes place through the microhole array.

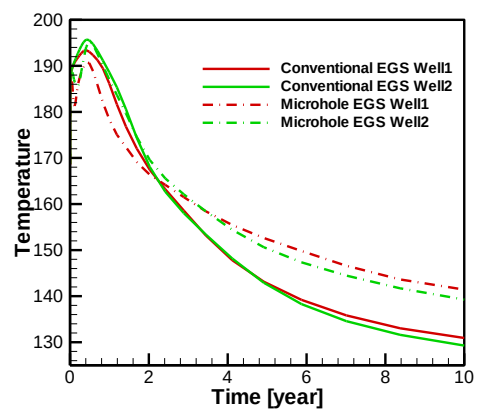

Figure 11: Production temperature history of the two production wells for both conventional EGS design and microhole designs.

CONCLUSIONS

Based on the simulation results, some preliminary conclusions can be drawn:

1. A microhole design has the potential to improve the heat mining efficiency compared to conventional EGS design;

2. For a doublet design of a conventional EGS, it is challenging to guarantee the second wellbore will hit the fracture zone; in other words, the probability that the two wells are connected may not be very high. In contrast, if some of the microholes missed the fracture zone, the circulating fluid can self-regulate and flow through the remaining microholes that intersect the fracture zone. Using a microhole design reduces the possibility of a failed design.

3. The basic idea of improving the robustness and sustainability of an EGS using microhole arrays is conceptually demonstrated. Conditions leading to thermal breakthrough are reduced, and a larger area between the flowing working fluid and the hot rock is created by distributing injection points over a much larger volume of the reservoir.

4. The performance of the microhole-based EGS could be higher than demonstrated here for different locations of preferential flow zone, and can potentially be further increased by optimizing the configuration of the microhole array.

ACKNOWLEDGEMENT

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