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A downhole heat exchanger for horizontal wells in low-enthalpy geopressured geothermal brine reservoirs

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ABSTRACT

Geothermal energy is a clean, renewable energy resource that is widely available and reliable. Improved drilling and heat conversion systems make geothermal energy an increasingly attractive alternative. Downhole heat exchangers (DHEs) can accelerate the development of geothermal energy by reducing the capital cost and the risk of microquakes or subsidence. However, low-enthalpy geothermal resources are difficult to develop economically because of low heat extraction efficiency.

In this study, a coaxial DHE concept is proposed to exploit forced convection driven by a downhole pump inside a horizontal wellbore. Two configurations of the proposed design are introduced, each having different flow paths for working and reservoir fluids. One system – which circulates working fluid through the inner-most tubing in the coaxial arrangement has better thermal exchange efficiency of about 29%, and is evaluated by coupling it to a simple model for a binary power generation plant and a geothermal reservoir simulator. Thermodynamic analysis evaluates the DHE performance for electricity generation. A field case study of the Camerina A reservoir (Vermillion Parish, Louisiana) demonstrates a net power of about 350 kW can be generated by a turbine even after 30 years of production.

1. Introduction

Geothermal energy is attractive due to its enormous potential (MIT Report, 2006; Cutright, 2009), renewability (Rybach, 1999, 2007), availability (U.S. DOE, 2005), low emission potential (Bloomfield et al., 2008), and low levelized costs (Cutright, 2009). According to Cutright (2009), with improvements in technologies including drilling, completion, and binary cycle power plants and relatively high petroleum prices, geothermal energy is becoming an economically viable alternative. Nonetheless, many challenges remain. High capital requirements have impeded geothermal resource development in the past. The required investment could be 3000–4000 per kW for hydrothermal resources, in which 47% is invested in the power plant and 42% is spent on drilling wells (U.S. DOE, 2009). Hydraulic fracturing, reinjection, depletion, and thermal stresses may induce seismicity or subsidence in the formation (Majer, 2009). Produced brine needs to be reinjected rather than disposing to surface waters to avoid any environmental impacts (John et al., 1998). Water disposal further increases capital and maintenance costs. Because of high capital costs, geothermal projects must provide sustained power over many years (Rybach, 2007).

A downhole heat exchanger (DHE) reduces construction costs by eliminating surface facilities and dedicated injectors for brine disposal (Lund, 2003). The proposed single-bore DHE configuration avoids surface handling of geofluids and disturbs the reservoir chemo-poromechanical equilibrium minimally to further reduce the risks of any associated geomechanical problems.

Several designs for downhole heat exchangers have been proposed. However, downhole heat exchangers in vertical wells may perform poorly because of the poor thermal coupling between the wellbore and the formation and the absence of free convection in the reservoir (Nalla et al., 2004). In another coaxial design with two concentric annuli between the tubing, an inner insulated casing and the outer casing in a vertical configuration (Alkhasov et al., 2000), hot water was injected through the tubing and working fluid was injected into the outer annulus and returned to the surface through the middle annulus. Wang et al. (2009) proposed a single-well EGS configuration with a thermosiphon, in which thermally induced density differences between the wellbore and reservoir fluids drive convection. The heat extraction efficiency was further enhanced by free convection in fractures. Feng et al.

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(2011) included natural convection in their model for heat extraction with a DHE in a horizontal well. The DHE was approximated as a line sink with a linearly varying temperature along the well, and the DHE burial location and its length were optimized.

This paper introduces a DHE design for saturated geothermal reservoirs to improve heat extraction and sustainability. The proposed design uses forced convection through the horizontal wellbore heat exchanger. One benefit is that the forced geofluid circulation delivers more heat to the DHE, enlarges the thermal extraction volume and increases the profitable life of the geothermal project. The forced convection within the DHE also increases heat exchange efficiency between the working fluid and the reservoir fluid.

2. Proposed downhole heat exchanger configurations

The DHE design that is proposed in this article exploits improvements in directional drilling and well completions. Horizontal or deviated wells can access geofluids from the highest enthalpy region of a geothermal reservoir. Current completion techniques and downhole equipment make a coaxial DHE possible in a horizontal section of the well, and an electric submersible pump can be placed inside the wellbore to drive the geofluid and increase heat exchange to the working fluid. A deviated well exits the overburden and follows a (nearly) horizontal path within the reservoir. A coaxial DHE is placed inside the horizontal section of the wellbore, and forms three fluid pathways (Fig. 1). Two paths circulate the working fluid, and the third path is used to transport the geofluid between production and re-injection completion intervals.

The proposed design can be configured in two ways: the geofluid can travel through the tubing (geofluid through tubing, indicated as *G*, Fig. 2a); or the working fluid can be injected through the tubing (working fluid through tubing; indicated as *W*, Fig. 2b). The return path for the working fluid is insulated to reduce heat loss to the working fluid injection path. In either configuration, the geofluid is injected into the reservoir away from the heat exchanger using the pressure head from a downhole pump.

2.1. Geofluid through tubing: description and analysis

The geofluid enters the tubing through a cross-over at the heel of the deviated wellbore (the end nearest the wellhead or the dog-leg kickoff location), flows through the heat exchanger, and is reinjected into the reservoir at the wellbore toe, some distance away from the DHE. Radial paths in the cross-over (Fig. 3) allow geofluid to enter the tubing from the reservoir; the tubing insulation should decrease heat transfer between the hot, returning working fluid and the relatively low temperature, injected working fluid. The axial holes at different azimuthal locations could provide paths for the working fluid to flow into the outer annulus and out of the inner annulus of the coaxial DHE.

The working fluid is injected into the outer annulus (Annulus II), and exchanges heat from the reservoir via conduction as it flows along the DHE length. The outer casing (Casing II) and surrounding

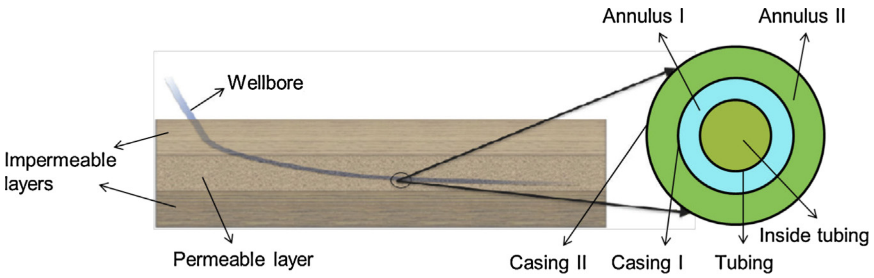

Fig. 1. Schematic of wellbore paths and DHE cross-section (Tyagi and White, 2010).

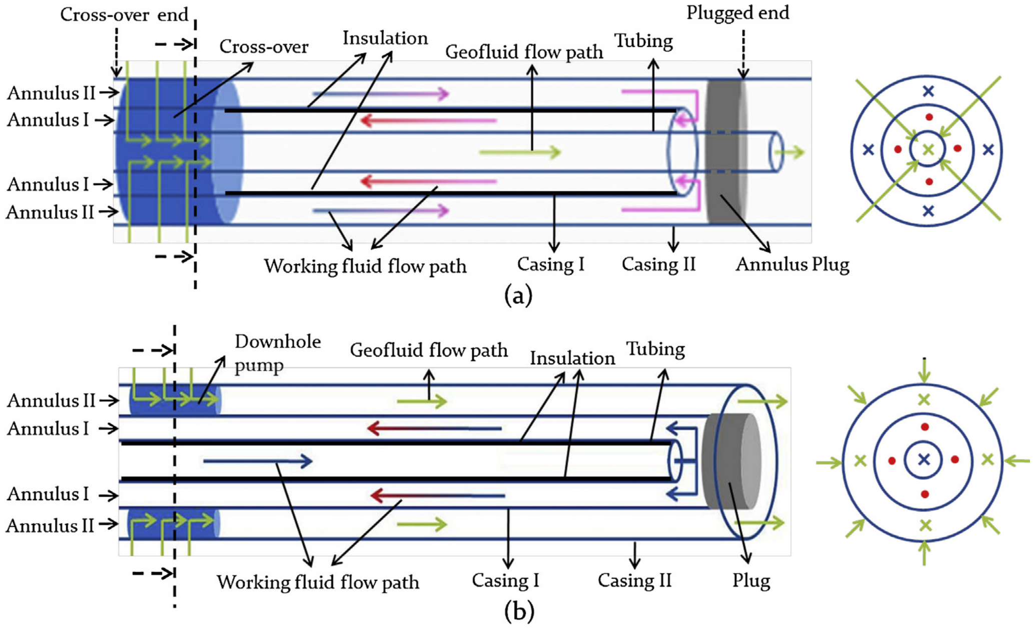

Fig. 2. Schematics of two configurations for the DHE: (a) *G* and (b) *W*.