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An Experimental Test of a Deep Downhole Heat Exchanger in Tianjin, China

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ABSTRACT

We report an experimental test of a Deep Downhole Heat Exchanger (DDHE) conducted in Tianjin in the winter season of 2018. The DDHE was specially designed and installed in a directional well with a depth of 2070 meters. The tested well has a configuration of two casing sections and one slotted liner section. A coaxial tube-in-casing DDHE was designed, and the hot water was pumped out through the thermally insulated inner tube, and the returned cold water flows down through the outer annular to the deep reservoir. The test duration was lasted for 10 days and after that a heat recovery test was performed. The test result shows that the heat extraction rate for the DDHE is about 267 kW, which much larger than that of the shallow borehole heat exchanger per meter depth. The theoretical analysis shows that heat conduction rather than heat convection was the dominant mode of heat transfer in this test.

1. Introduction

The up to date well drilling technology could make a deep geothermal reservoir be accessible in almost any continents if this was not prevented economically. Recently, China has issued a series of preferential policies urging to use clean and renewable energy resources for space heating and power generation, especially at a new assigned economic development zone of Xiongan New Area. This is mainly due to the increasing frequency of air polluted days occurred in a large part of northern China that the smog covered two of biggest cities of Tianjin and Beijing (capital). In the 13th national Five-Year-Plan on geothermal utilization, the heat load capacity will be doubled from 20 million tons of coal equivalent (year 2015) to 40 million tons (year 2020), and the area of Beijing-Tianjin-Hebei only will install a half of the total load. There will be, of course, some doubts on how to realize the ambitious goal. One of important questions is that how many production wells should be drilled, and what would be happened if those waste geothermal fluids were not reinjected back to the aquifer, and if there are any advanced and sustainable techniques that can be used. Therefore, the technique of "no water withdrawn but heat only" Deep Downhole Heat Exchanger (DDHE) become one of the options to be considered on the table.

The expansive drilling cost of a deep geothermal well is, probably, the major barrier for using deep DHE for space heating in winter in the northern regions. Another reason for preventing the deep DHE from becoming prevalent is that the heat extraction performance of a DHE is relative low comparing with the conventional way of pumping geothermal water directly out of surface with or without reinjection. By considering some drawbacks of traditional ways in geothermal utilization, much tougher environmental laws or regulations have been issued by central and local governments. This will, in some extent, force some real estate companies to choose an environmental friendly way for space heating and air conditioning.

Most of previous uses of DHEs, such as Culver G. and Lund (1999), Dai (2008) and Lund (1999, 2003), were mainly limited in shallow geothermal well, Some studies were for deep Borehole Heat Exchangers (BHE) (Marita *et al.*, 1992) (Kohl *et al.*, 2002) (Sliwa *et al.*, 2015). The major distinction between a DHE and a BHE is whether the cold water loop tube (U tube or coaxial tube-in-tube) is contacted directly with its surrounding porous formation. The heat transfer of BHEs is mainly performed through heat conduction from the porous formation surrounding the wellbore to the circulating water inside the tubes such as the U shaped tube loop buried in shallow ground. However, if the U tube suspended in a geothermal well, the heat transfer process will be performed by convection since the geothermal water inside the well could be circulated due to natural convection. The geothermal water inside the well is the heat transfer medium taking the heat far from the well in the aquifer, releasing heat at the tube surface, and then returning to the aquifer to be heated again. Therefore, in a geothermal well where a DHE are installed, a slotted liner is used, in general, for the fluid flow back and forth freely from the aquifer to the space inside the well. A DHE system has a better heat extraction performance than a BHE, for example, the DHEs installed in Turkey and Oregon (Lund, 1999), while BHEs can only have a heating load of 2 kW to 6 kW for a BHE with a depth of about 100 m. In addition, most of shallow BHEs are used for air-conditioning with both heating and cooling rather than a heating duty alone. However, most of shallow DHEs were only for heating, and installed in region with a high geothermal gradient. The functions of BHEs and DHEs are different in a thermodynamic point of view of Dai and Chen (2008). To our knowledge, there are very few studies available in the literature related to the "deep" DHEs. Strictly speaking, we have not found an experimental study or a case using DDHE in practice so far. Even though there are quite a few studies related to the deep BHEs in recent years. In this paper, we report an experimental study of a deep DHE. The configuration of this deep DHE was realized according to our new design. The major difference of this DDHE from the previous DBHE is that the space inside the well is open to the water in aquifer. The inner tube is acted as suction tube for driving the relative hot water up to the surface by a borehole pump. After releasing heat, the water can be returned back to the aquifer through the annular channel formed by the inner tube and the wellbore naturally. This open loop DDHE is similar to a Standing Column Well geothermal heat exchanger except that there is no fluid barrier plate in the wellbore in DDHE.

2. Experimental Setup of the DDHE

2.1 Tested Geothermal Well

The tested geothermal well is located at Tanggu, a city 53 km east of Tianjin. The well was completed in 2014 and had been used as a reinjection well for two years. The original highest reservoir temperature, T_r, is about 64 ^{o}C at a pumping flow rate of 60 tons/h just after the completion of the well. The static water level in the well is about 138 m down from the surface. As shown in Fig. 1, the test well is a directional well with a maximum inclination angle of 19°, and the horizontal distance shifting from the well toe to the well head is about 462 m. Figure 2 shows the temperature profile of the formation measured just at completion of the well, T_f, (dashed line), and before this test, T_{or} (solid line). The length of the inner tube inside the well was 1780 m. The measured geothermal gradient is about 0.02^{o}C/m.

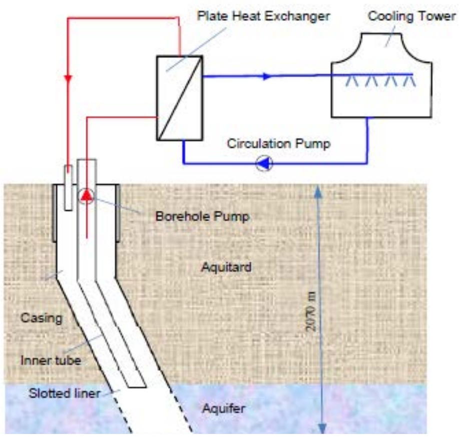

Figure. 1: Schematic test system of DDHE

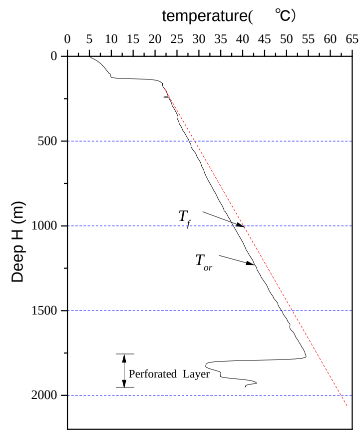

Figure 2: Temperature-depth profile of water in the test well

2.2 DDHE test system

As shown in Fig.1, This test was conducted in the last cold winter season, an air cooling tower was used for releasing the extracted heat from the DDHE to atmosphere. A plate heat exchanger was used in order to keep the water flowrate in the DHE side stable. A borehole pump was used to lift the water in the well up to the surface. Therefore, in fact, the heat transfer between the geothermal fluid with the secondary clean water was finished at the surface rather in the downhole. However, we insist on calling this system as DHE with mainly the consideration of open interface between the space inside the well with its surrounding porous matrix. The static water level in the well is about 130 m deep. The electric power of the borehole pump is around 31 kW. The inlet and outlet temperatures of water through the well were measured by Pt1000 resistance thermometers. The flowrate can be adjusted by varying the motor frequency of the borehole pump. The flow rate is maintained at 40 m^3/h during well test period, and measured by an electromagnetic flowmeter.

3. Experimental Results

Figure 3 shows the measured inlet and outlet temperatures through the DHE in the well. It can be seen that considering the ambient temperature fluctuation, both inlet and outlet temperatures were quite stable. In the first four days, the outlet temperature from the DHE decreased quickly, but very slowly thereafter. The simulated temperatures by assuming the constant inlet water temperature, and using pure conduction model were also shown in Figure 3. Therefore, the thermal power extracted can be calculated by multiplying the measured temperature difference and the flowrate through the DDHE. It can be seen that a stable thermal power can be reached after about two weeks, as shown in Figure 4. The averaged thermal power was about 267 kW. The values of both inlet and outlet temperatures were quite stable after a few days.

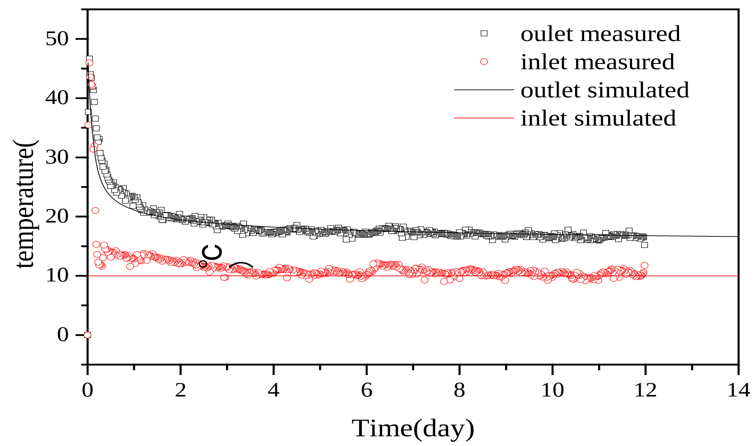

Figure 3: The measured and simulated inlet and outlet temperatures with time

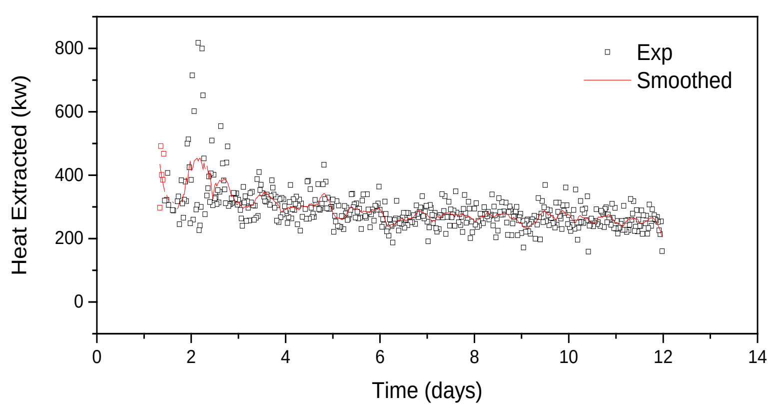

Figure 4: The heat extraction of the DDHE with time

4. Conclusions

In the present paper, a novel deep DHE was designed and tested in a well once used for reinjection. The test was lasted for about half a month, the thermal power output seems getting stable after about four days, which is much shorter than that of we expected. A simple heat conduction model was established for matching the experimental data. The effects of some important factors on the final heat output was calculated based on this model. The results indicate that the heat conduction radically is the main contribution, however, the open free configuration at the bottom of the inner tube definitely has a positive effect on the heat output. Further experiments are urged to be done on considering various influencing factors such as the thermal conductivity of inner tube and wellbore diameter.

Acknowledgements

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