PROCEEDINGS, 44th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 11-13, 2019
SGP-TR-214

Heat Transfer Experiment of a Deep Downhole Heat Exchanger

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Keywords: Deep Downhole Heat Exchanger (DDHE), coaxial tube, heat output

ABSTRACT

Heat transfer experiment of a Deep Downhole Heat Exchanger (DDHE) was carried out in winter in Tianjin. The DDHE was installed in a 2070 m deep well, the hot water was pumped out through the insulated inner tube and returned through the outer annular to the geothermal reservoir. The test result shows that the average thermal output is 270 kW. A heat conduction model was established and the parameters affecting the thermal output of DDHE were studied. The results show that the temperature gradient has radial heat conduction is the main influencing factor, and the opening at the bottom of the inner tube is beneficial for increasing the thermal output. The results show that the temperature gradient has a large effect on the heat output, and the heat output increase linearly when the temperature increases from 0.02℃/m to 0.04℃/m; the lower inlet temperature can obtain a larger heat output.

1. INTRODUCTION

The deep downhole heat exchanger (DDHE) is an effective way to use geothermal energy without taking water. The fluid inside the tube exchange heat with surrounding formation by heat convection, thus the efficiency is higher than that of borehole heat exchanger. Different from most previous studies of deep borehole heat exchangers (DBHE) (Morita, 1992; Kohl, 2002; Kujata, 2006; Doelling, 2010; Yekoladio, 2013), the bottom of well casing of the DDHE is open to the deep geothermal reservoir. So far, there has been little research on deep downhole heat exchangers. Therefore, this paper conducted an experiment of a deep downhole heat exchanger (DDHE) in winter in Tianjin and established a simple heat conduction model to study the influencing parameters of its heat output.

2. STRUCTURE OF THE DDHE SYSTEM

The test well was completed in Tianjin in 2014 and used to be a reinjection well for two years. The maximum outlet water temperature T_f is 64℃ when the flow rate is 60 t/h, and the static water level is 138 m after well completion. As shown in Fig.1, the test well is a directional inclined well with an inclination angle of 19°. Fig.2 shows the measured formation temperature profile T_1 (after well completion) and T_2 (before this test). It is obvious that T_2 is slightly smaller than T_1, this is because the well was used as a reinjection well, injected cold water reduces the formation temperature.

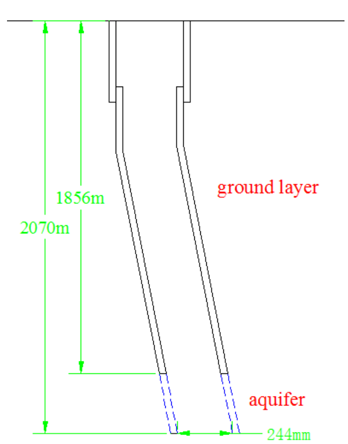

Figure1: The casing profile of test well

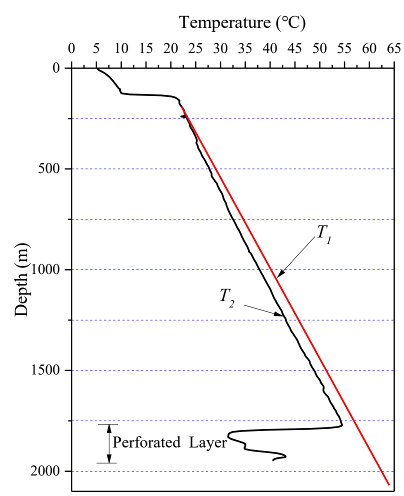

Figure 2: Formation temperature profile

An air cooling tower is used to release the heat of DDHE into the air, and a heat exchanger is placed on the ground, so the heat exchange of the geothermal water and the circulating water is actually carried out on the ground. The reason why it is called “downhole heat exchanger” is because the end of the inner tube is open, and the heat exchange between the fluid and the formation is carried out by heat convection. Fig.3 shows the measured the inlet and outlet temperatures of the DHE. It can be seen that if the fluctuation of the ambient temperature is considered, the inlet and outlet temperature is quite stable after 4 days. The outlet water temperature drops faster in the first four days and then stabilized. The heat output of DHE system can be calculated by multiplying the temperature difference and the flow rate, and the average heat output is 275 kW, as shown in Fig.4.

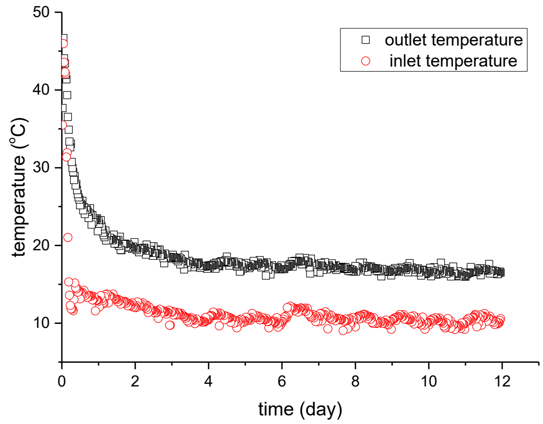

Figure 3: Measured and simulated inlet and outlet temperatures

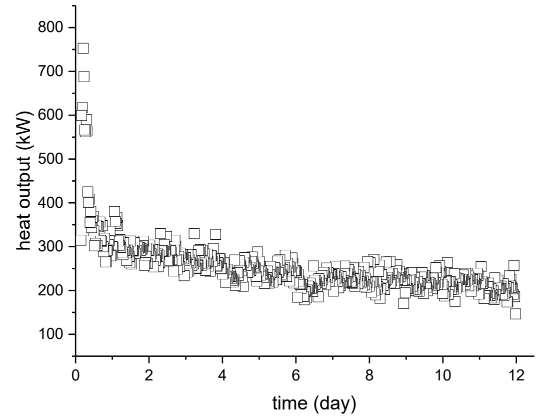

Figure 4: Heat output changes over time

2.1 Mathematic Model

A two-dimensional unsteady-state heat conduction model was established, thermal dynamic properties of the formation were obtained through the measured temperature. The interface condition between the wellbore and formation was coupled with forced convection between inner tube and annular section. One-dimensional energy equations with a source term and a convective term are as follows:

$$\frac{\partial(\rho_{\mathrm{r}}\,\mathrm{c}_{\mathrm{r}}\,T)}{\partial t}=\frac{1}{r}\frac{\partial}{\partial r}(\lambda_{\mathrm{r}}r\frac{\partial T}{\partial r})+\frac{\partial}{\partial z}(\lambda_{\mathrm{r}}r\frac{\partial T}{\partial z}) \quad \text{in porous formation} \tag{1}$$

$$\frac{\partial(\rho_{\mathrm{w}}\,\mathrm{c}_{\mathrm{w}}\,T_{dw})}{\partial t}+\rho_{\mathrm{w}}\mathrm{c}_{\mathrm{w}}\mathrm{v}_{dw}\frac{\partial T_{dw}}{\partial z}=(\pi d_1U_1(T_{up}-T_{dw})+\pi d_4U_2(T-T_{dw}))/S_2 \quad \text{in annual section} \tag{2}$$

$$\frac{\partial(\rho_{\mathrm{w}}\,\mathrm{c}_{\mathrm{w}}\,T_{up})}{\partial t}+\rho_{\mathrm{w}}\,\mathrm{c}_{\mathrm{w}}\,\mathrm{v}_{up}\frac{\partial T_{up}}{\partial z}=-\pi d_1U_1(T_{up}-T_{dw})/S_1 \quad \text{in inner tube} \tag{3}$$

Where, S_1 and S_2 are the cross-sectional areas of the inner tube and the annular space, respectively. The subscript “dw”, “up” indicate water flowing direction, there is T_{up} (H) = T_{dw}(H). U_1 is the overall heat transfer coefficient between downward and upward water flow, and $1/U_2$ is the overall thermal resistance, which includes convection thermal resistance inside the casing and thermal resistance of the casing.

2.2 Heat Output Calculation

The model used in this paper is similar to the one in previous studies (Tago, 2005; Lous, 2015). Considering the open loop configuration, when the cold water in the annular section flows to the bottom of the casing, it may not completely return to the inner tube, so the previous model may not fully applicable to the condition in this paper. However, we can still use the similar model to predict heat output by changing some parameters, such as geothermal gradient, flow rate, inlet temperature, etc.

As shown in Fig.5, the geothermal gradient has a great effect on thermal output. It can be seen that there is a linear increase in thermal output when temperature gradient increases from 0.02℃/m to 0.04℃/m. For every 0.01℃/m increment in temperature gradient, the thermal output increases by 100 kW. Fig.6 shows the inlet water temperature also affects thermal output. The lower the inlet water temperature, the greater the temperature difference between the reservoir and the water inside DHE.

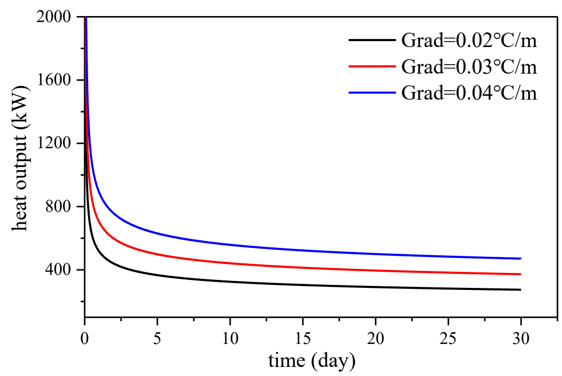

Figure 5: Heat output at various temperature gradients

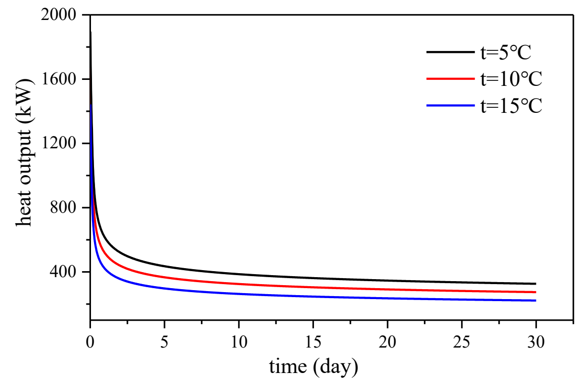

Figure 6: Heat output at various inlet temperatures

3. CONCLUSIONS

This paper designed an open loop downhole heat exchanger and a two-week heat transfer experiment was conducted in a used reinjection well. After 12 days of operation, the measured average heat output of the system is 275 kW. A simple heat conduction model was established and the parameters affecting the heat output were analyzed. The results show that heat output increases linearly when the temperature gradient increases from 0.02℃/m to 0.04℃/m, i.e. heat output increases by 100 kW for 0.01℃/m increase in temperature gradient; the smaller the inlet water temperature, the greater the heat output. Further experiments will consider the effect of thermal conductivity of inner tube and wellbore diameter.

NOMENCLATURE

C	specific heat capacity (J/kg/K)
d	tube diameter (m)
r	radius (m)
S	area (m^2)
T	temperature (K)
t	time (s)
$\underline{U}$	overall heat transfer coefficient ($W/m^2/K$)
Greek letters	
v	average velocity in channels (m/s)
ρ	density (kg/m^3)
λ	thermal conductivity (W/m/K)
Subscripts	
1	inner tube
2	annular space
up	up
dw	down

ACKNOWLEDGEMENTS

This work is financially supported by the National Natural Science Foundation of China (Grant No. 41574176 and 41672234) and International Clean Energy Talent Program (iCET) of China Scholarship Council.

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