DOI: 10.23977/jemm.2022.070105
ISSN 2371-9133 Vol. 7 Num. 1

# *Discussion on geothermal recovery process of deep borehole heat exchanger in layered stratum*

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***Keywords:*** deep coaxial heat exchanger, finite element method, geothermal recovery.

***Abstract:*** To explore the characters of geothermal recovery process of deep borehole heat exchanger, a geothermal recovery process was simulated to explore the difference in stratum temperature distribution change under layered model and uniform model. The results indicated that the geothermal recovery rate is sharp at first and slow down then. The outlet temperature would be higher in the next heat extraction stage if the longer geothermal recovery period was adopted. Considering the time cost during the geothermal recovery period, the suggesting proportion of heat extraction and geothermal recovery could adopt 1:1. In addition, the uniform model cannot reveal the ground temperature variety of layered in geothermal recovery process accurately.

## 1. Introduction

The borehole heat exchanger (BHE) is the core component of the close ground source heat pump system (CGSHPS), in the form of geothermal energy extracted by the heat exchanger can avoid problems such as ground water pollution, geothermal reservoir pressure imbalance, etc. [1-3]. The selections of BHE including U-type, double U-type, spiral tube type and coaxial tube type. The appropriate application occasion involved a vertical borehole and horizontal buried pipe system [4-6]. In addition, for the deep geothermal system, the heat exchanger adopted coaxial tube type was more suitable than that adopted U-type or double U-type because the heat loss between the inner tube and the annular space of the coaxial heat exchanger was smaller than the U-tube heat exchanger [7-9], and the heat transfer performance of the coaxial heat exchanger would be higher while the working fluid flows into the annular space and flows out of the inner tube than that flows into the inner tube and flows out of the annular space [10].

Recent studies of mid-deep geothermal energy were related on heat extraction of single borehole heat exchanger, however, the geothermal recovery period is important to the long-term operation. Two geometric model of deep-borehole coaxial heat exchanger (DCBHE) was established which was shown in Figure 1, and the physical parameters are shown in Table 1.

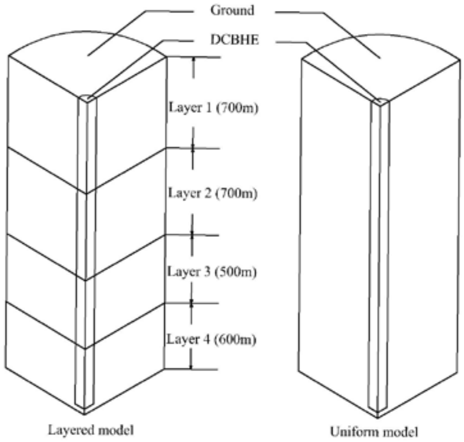



Figure 1:  Geometry model of layered and uniform.

Table 1: The geometry and material properties parameters of typical model

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Radial of inner tube | $r_1$ | 20 | mm |
| Radial of outer tube | $r_2$ | 100 | mm |
| Radial of backfill material | $r_3$ | 150 | mm |
| Radial of ground stratum | $r_G$ | 30 | m |
| Depth of borehole | $D$ | 2500 | m |
| Thermal conductivity of inner tube | $\lambda_i$ | 0.38 | W/(m·K) |
| Thermal conductivity of outer tube | $\lambda_o$ | 17 | W/(m·K) |
| Thermal conductivity of backfill material | $\lambda_b$ | 2 | W/(m·K) |
| Thermal conductivity of ground: layer 1 | $\lambda_{g1}$ | 1.55 | W/(m·K) |
| Thermal conductivity of ground: layer 2 | $\lambda_{g2}$ | 2.19 | W/(m·K) |
| Thermal conductivity of ground: layer 3 | $\lambda_{g3}$ | 3.9 | W/(m·K) |
| Thermal conductivity of ground: layer 4 | $\lambda_{g4}$ | 2.8 | W/(m·K) |
| Thermal conductivity of ground in case 4 | $\lambda_g$ | 2.8 | W/(m·K) |

## 2. Numerical model

### 2.1. Governing equation

The heat transfer process without ground water advection between ground stratum and DCBHE could be considered as heat conduction which occurred in the ground stratum, backfill material and the wall of DCBHE, and the governing equation of each layer can be expressed as Eq. (1):

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (\lambda \nabla T) \tag{1}$$

Where $\rho$ is the density of each layer material, $C_p$ is constant pressure specific thermal capacity, $\lambda$ is thermal conductivity, $\nabla T$ refer to temperature gradient.

The continuity equation of working fluid flow in the tube was expressed as Eq. (2):

$$\frac{\partial A\rho}{\partial t} + \nabla \cdot (A\rho u) = 0 \tag{2}$$

Where $A$ is the cross-sectional area of working fluid.

Heat transfer process of the working fluid in the DCBHE including heat conduction and convention, and the energy balance governing equation was shown in Eq. (3):

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T + \nabla \cdot \left( -\lambda \nabla T \right) = Q \tag{3}$$

The second term on the left side of the equation is the part of heat convection, $u$ represented the fluid velocity field, and the physical meaning of others symbol were consistent with Eq. (1).

Eq. (2) and (3) always solve with the momentum equation at the same time, and the momentum equation of working fluid can be expressed as Eq. (4):

$$\rho \frac{\partial u}{\partial t} + \rho \left( u \cdot \nabla u \right) = -\nabla p + \mu \Delta u + F \tag{4}$$

The second term on the right side of the equation is viscous force, $F$ is the external force which apply on the fluid which equals to zero in this study.

## 2.2. Boundary and initial conditions

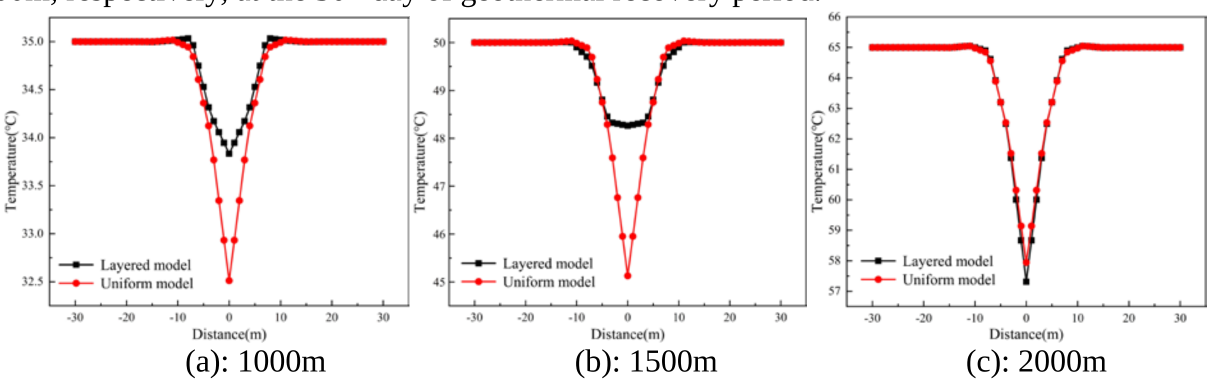
In this study, the depth of ground stratum below DCBHE was 5m and the radius of ground stratum was 30m. The cycle mode of the working fluid was flow into the annular space and flow out of the central tube and the temperature of the inlet water was 20℃. According to the data of heat flow in the mainland of China, the value of terrestrial heat flow $Q$ was 75mW/m$^2$ and it was considered as a constant value. The upper surface of the ground stratum is considered an adiabatic boundary and the temperature was 5℃. The initial temperature distribution of ground stratum, backfill material, and inlet temperature of working fluid was based on the geothermal gradient equal to 3℃/m.

# 3. Results and discussing

## 3.1. Comparison of geothermal recovery period under different models

In the geothermal recovery period of this study, the flow of the working fluid in DCBHE was stopped after 30-day's operation. Relying on the terrestrial heat flow to conduct the geothermal recovery process of layered model and uniform model, compared the difference of results.

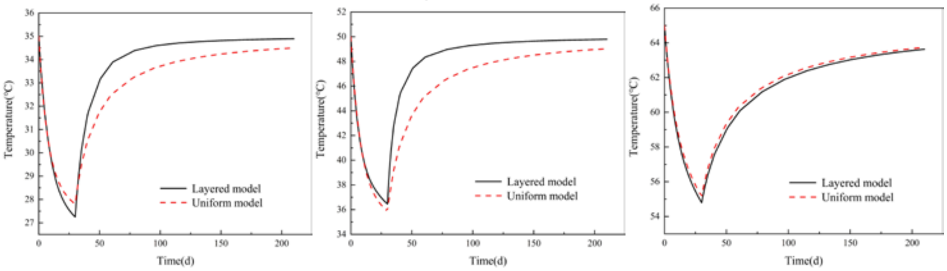
Figure 2 reveals the radial ground temperature field of DCBHE at depths of 1000m, 1500m, and 2000m, respectively, at the 30$^{th}$ day of geothermal recovery period.




(a): 1000m (b): 1500m (c): 2000m

Figure 2: Ground stratum temperature field distribution at the 30th day of heat recovery period at different depth.

The main factor affected the temperature distribution of ground stratum in geothermal recovery period was the thermal conductivity of ground. The ground temperature distribution of uniform model has similar character at different depth since the thermal conductivity of it was 2.8 W/m·K At the depth of 1000m, the stratum of layered model was layer 2, and the thermal conductivity of it was 2.19 W/m·K, therefore, the ground temperature distribution of uniform model and layered model has a different character. At the depth of 1500m, the ground temperature distribution character of layered model is difference with uniform model since the stratum of it is layer 3, the thermal conductivity of it was 3.9 W/m·K. At the depth of 2000m, the thermal conductivity of uniform model and layered model is close, therefore, the ground temperature distribution of them displayed the same trend when the depth changed to 2000 m.




(a): 1000m (b): 1500m (c): 2000m.

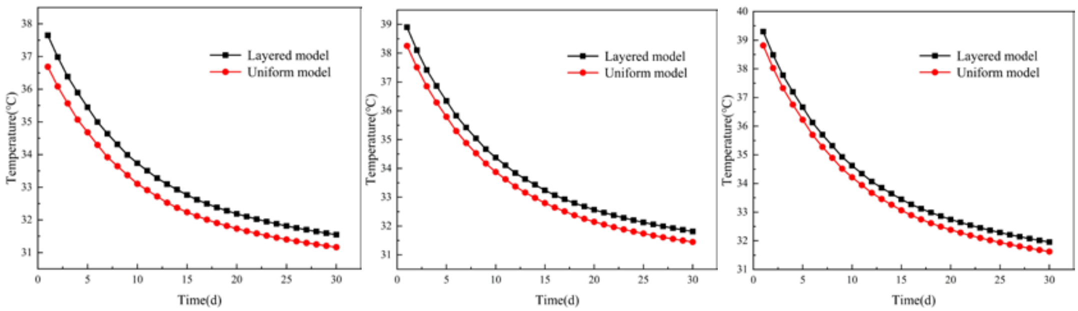
Figure 3: Temperature variety on the wall of DCBHE at different depth.

The variation in temperature in the wall of DCBHE during the period of heat extraction and geothermal recovery at different depths is shown in Figure 3. As similar as Figure 2, the trend of temperature variation in the same stratum layer agrees well with each other. Hence, the uniform model could not accurately reveal the ground temperature distribution in the geothermal recovery process.

After the beginning of the geothermal recovery process, the temperature growth rate of each measurement point is high at first and reduces later. Take the temperature change of borehole wall surface at the depth of 2000m in uniform model as an example (Figure 3 c), during the period of geothermal recovery, the temperature increase of the first 30 days (0-30 days of geothermal recovery period) is 13.49℃, but the temperature increase of the second 30 days (30-60 days of geothermal recovery period) is only 2.87℃, and in the third 30 days, the difference of temperature is just 1.31℃, after period of the third 30 days, it would take more than 48 days to make the temperature raise 1℃. Hence, the fastest growth rate of temperature increase is the period of the first 30 days.

### 3.2. Second heat extraction period

To explore the influence caused by the time length of geothermal recovery period to the heat transfer efficiency of DCBHE in the next heat extraction process, the outlet temperature of DCBHE in the second heat extraction process under different time length geothermal recovery period was discussed.




(a): 30 days (b): 90 days (c): 180 days

Figure 4: (a) Outlet temperature of DCBHE in the second heat extraction process with different geothermal recovery period.

As is shown in Figure 4, the average outlet temperature of DCBHE increases with the increase of geothermal recovery period, take the outlet temperature of DCBHE in uniform model as an example, the average outlet temperature is 32.72°C when the geothermal recovery period was 30 days, and it is 33.36 and 33.65°C respectively when that adopted 90 and 180 days, the growth rate is only 1.2% and 2.8%, and the time cost of geothermal recovery reached 3 and 6 times. Longer geothermal recovery period could improve the outlet temperature in the next heat extraction period, the effect was limited with increasing geothermal recovery period, hence, in practical engineering applications, the method of heat extract by multi-borehole should be considered to strive longer thermal recovery period for single well to ensure the quality of heat extraction.

In the second heat extraction period, the maximum relative error of uniform model and layered model is 5.6% and the average relative error is 2.3%.

## 4. Conclusion

(1) The main factor that affects the temperature distribution of the ground stratum in the geothermal recovery period was the thermal conductivity of the ground. In this study, the stratum temperature distribution and temperature variety on the wall of DCBHE have the same change character when the thermal conductivity of the stratum layer was the same.

(2) When the heat extraction period was 30 days, the fastest growth rate of the increase in ground temperature was the first 30 days in the geothermal recovery period, after which the growth rate has decreased dramatically. For the time cost and afterward heat extraction quality considerations, it is important to apply the method of multi-borehole heat extraction.

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