Numerical Simulation on Heat Transfer Characteristics of Soil Around U-Tube Underground Heat Exchangers

Weihua Yang
Southeast University

Shuhong Li
Southeast University

Xiaosong Zhang
Southeast University

NUMERICAL SIMULATION ON HEAT TRANSFER CHARACTERISTICS OF SOIL AROUND U-TUBE UNDERGROUND HEAT EXCHANGERS

Weihua Yang[1*] Shuhong Li [2] Xiaosong Zhang[3]

school of Energy and Environment, Southeast University, Nanjing, Jiangsu
13776676498, feieryang0912@163.com

*Female, 1982 , postgraduate

ABSTRACT

Temperature distribution in the soil around the underground heat exchangers are simulated by a two-dimensional model based on the column heat source theory, with the help of user interface tool--pdetool of matlab software. Through single-tube model, temperature distribution around heat exchangers and thermal radius under such conditions were got. In order to find out heat coupling effect among adjacent boreholes and temperature distribution in the soil, multiple boreholes were simulated on the basis of single-tube model, the coupling degree between tubes was got as well, from which , a concept(heat affected public area)is proposed. To eliminate or decrease the heat imbalance of heat emitted to soil in summer and absorbed from the soil in winter, water heater was added to the GSHP system. Experimental results of the hybrid system show the highest EER of the system could rise to 4.

Keywords: GSHP, numerical simulation, U-pipe underground heat exchanger, coupling, water heater

INTRODUCTION

At present, energy conservation is drawing more and more attention. According to the study, in almost all industrialized countries air-conditioner and refrigeration equipment were the first major power consuming which were about 30~40% of the total power consumed in city, that's why we must pay attention to it. Ground source heat pump (GSHP) is an environment friendly and energy conservation technology, which uses the solar energy stored in soil emitting heat to it in summer and extracting heat in winter. The technology saves not only equipment of cooling tower compared with conventional air-cooled heat pump system, but also saves boiler when GSHP hybrid with water heater. In the study of GSHP, underground heat exchange between soil and buried pipes is an important part which has great impact on performance of the whole unit. Based on the study of single pipe model, the coupling influence among pipes is especially studied.

1. MODEL INTRODUCTION

In practical application, underground heat exchangers of GSHP are usually made up of multiple boreholes, rather than a single pipe. The boreholes' arrangements could be linear, L-shaped[1], double L-shaped, U-shaped, open rectangle and filled rectangle. Connections of pipes between boreholes could be parallel when that the fluid average temperature in every borehole is the same or serial when that the outlet fluid temperature in one borehole is the inlet fluid temperature in the next borehole. Commonly, there are many boreholes in a heat pump system, to illustrate the general problem, pipes of serial are adopted in this paper and only nine typical boreholes in pipe group area are simulated, as shown in Figure 1.
Li Xinguo (2004) from Tianjin University simulated single and double seasons' running with software Autough2 on the basis of inner heat source[2]. Zhao Jun (2007) simulated the soil temperature around level pipes[3], from which there was a temperature distribution around double pipes as shown in Figure 2. It can be seen that the temperature of the middle point between the two pipes arrived at the polar point simultaneously, where the influence of one pipe to

the other was stopped so it cannot get across the middle point to influence other parts. On the basis of above conclusion, it's supposed when analyzing a single borehole among multiple boreholes, boundary on the middle line between two pipes was adiabatic[4], thus the four line boundaries were adiabatic, as the broken lines were shown in Figure 1.

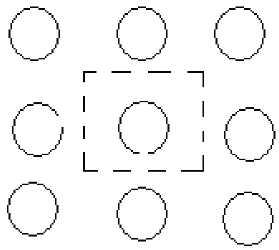


Figure.1: Borehole arrangement

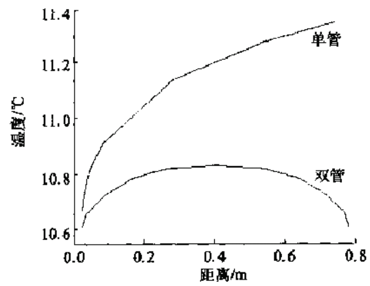


Figure.2: Ground temperature around double pipes (0.8 m in horizontal direction) in winter

1.1 Model's basic data

Heat transfer in the simulation was unsteady and only carried out in summer in the middle and low reaches of Yangtze River. Depth of borehole is 36 meters and the diameter is 0.1 meter. Inner and outer diameters of pipes in the borehole are respectively 0.0025 m and 0.0032 m, space between adjacent boreholes is 5m and the space distance from the area fringe to the borehole is 3m, the whole area is 16×16 m^2. According to experimental data, heat exchanged between the soil and exchangers was 50 w/m along the depth of borehole, initial soil temperature is supposed to be 16℃。Parameters[5] of soil are shown as follows: ρ=1600kg · m^{-3}, λ=2.3w · $(m \cdot k)^{-1}$,C_P=1725J · $(kg \cdot k)^{-1}$.

Parameters of inner part in borehole are formed of fluid, pipe wall and backfills. Suppose the fluid is water, backfill is soil, and parameters of pipe wall are ignored as is very thin. The weighted average parameters are: ρ=1558kg · m^{-3}, λ=2.18w · $(m \cdot k)^{-1}$,C_P=1871J · $(kg \cdot k)^{-1}$.

1.2 Model's simplification

1) Ignoring the soil parameters varying with the depth, supposing soil properties are uniform.
2) Neglecting the influence of wet transfer in soil, supposing there will be just conduction.
3) Assuming that heat was transferred in level plane, no heat transfer at vertical direction.
4) Heat flux produced by the borehole is steady.

2. SIMULATION ON A SINGLE BOREHOLE AMONG MULTIPLE BOREHOLES

Figure 3 shows the mesh map, in which the four boundaries were adiabatic. Entire simulative area is 5 × 5 m^2. A cross section of the borehole and the soil around it was taken to be studied.

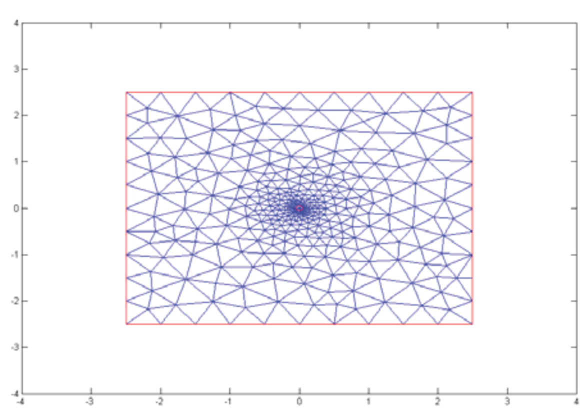


Figure.3: Grid setting in single borehole of pipe group

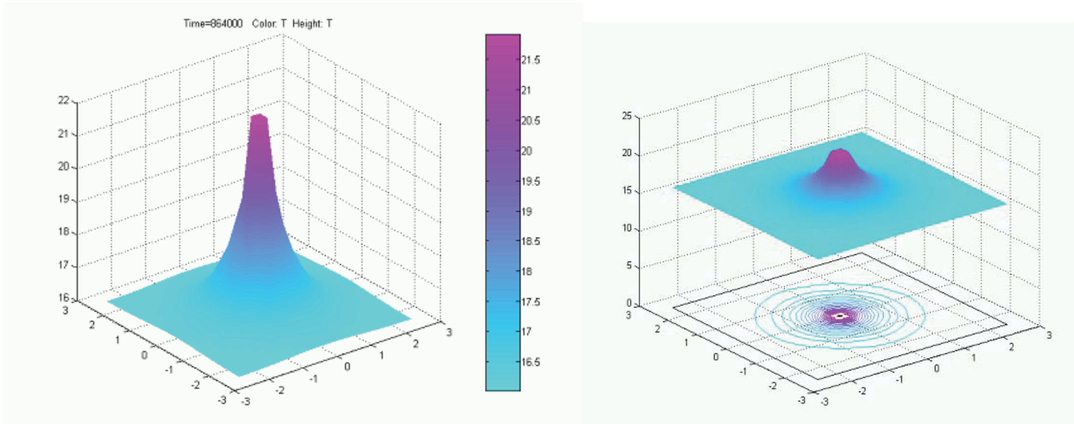


Figure.4: Temperature distribution in single borehole of group pipes after running for 30 days

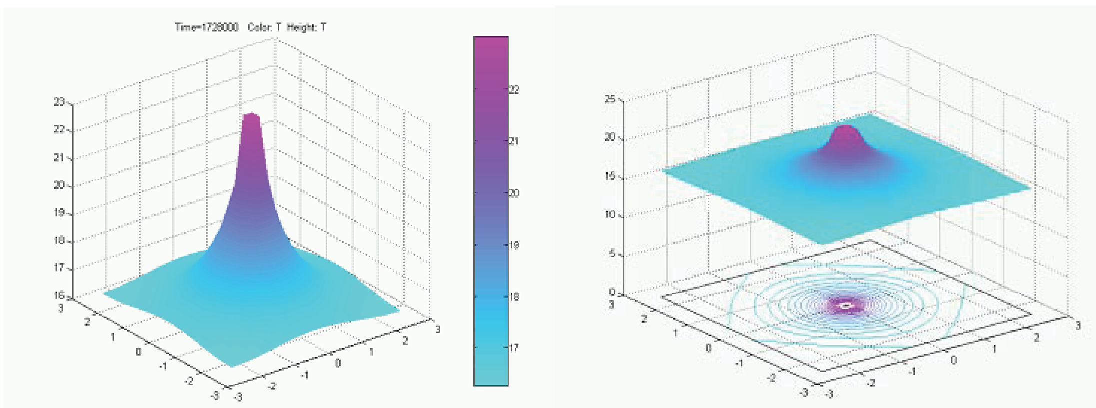


Figure.5: Temperature distribution in single borehole of group pipes after running for 60 days

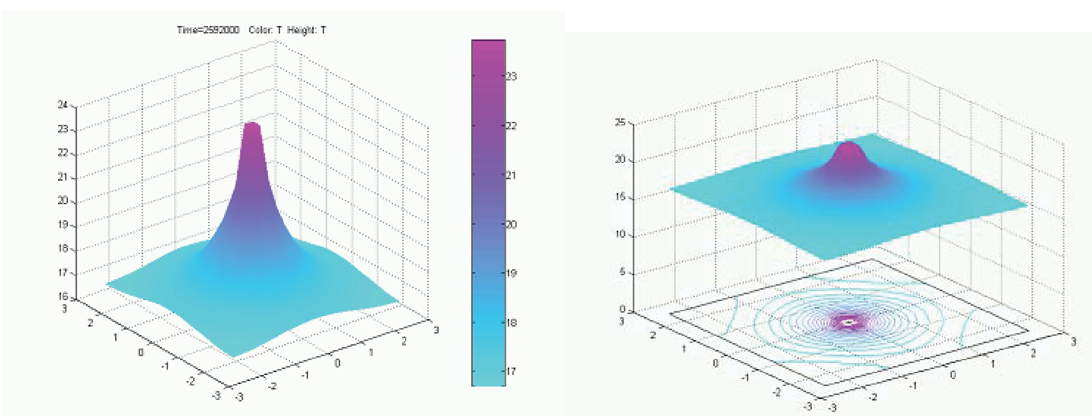


Figure.6: Temperature distribution in single borehole of group pipes after running for 90 days

Simulation of single season: GSHP system emitted heat through borehole to the ground in summer which was supposed to be 50w/m along borehole depth. Running conditions were that air-conditioning period was 90 days with 8 hours on every day, and starting temperature of next day was the last temperature it stopped yesterday. Temperature distribution after 30 days, 60 days and 90 days were respectively simulated, as above shown.

Figure 4 shows the temperature distribution in soil after running for 30 days, temperature near heat exchangers arrives at 21.5 ℃, temperature of the whole cross section rises from 16 ℃ to 18.5944 ℃, at this time ,heat affected radius is 1.8 m outside which the area is not influenced.

Figure 5 shows the temperature distribution in soil after running for 60 days, temperature near heat exchangers arrives at 23 ℃, temperature of the whole cross section rises to 19.50265 ℃. Heat affected radius slowly increase to

2 m, that's because distribution of inner heat source between adjacent boreholes are symmetrical so that the outer temperature rises slowly.

Figure 6 shows the temperature distribution after 90 days, temperature near heat exchangers arrives at 24 ℃, temperature of the whole cross section rises to 20.037 ℃, the heat affected radius is over 2 m, but no great difference compared with running for 60 days.

From figure 4 and figure 6, it is concluded that temperature near heat exchangers rises slower and slower because of less and less temperature difference between adjacent soils. At the same time, heat exchanging ability declines and rate of heat radius slows down, temperature of the whole cross section rises slow too.

3. SIMULATION ON MULTIPLE BOREHOLES

To validate accuracy of the single pipe model, multiple boreholes were simulated which were shown in figure 1. Mesh map of the whole area (16×16 m^2) is shown in figure 7, in which space between two pipe centers was 5 m. Boundary conditions of four fringes were constant temperature which value was the initial temperature of the soil. Other boundaries were the same as the single pipe model.

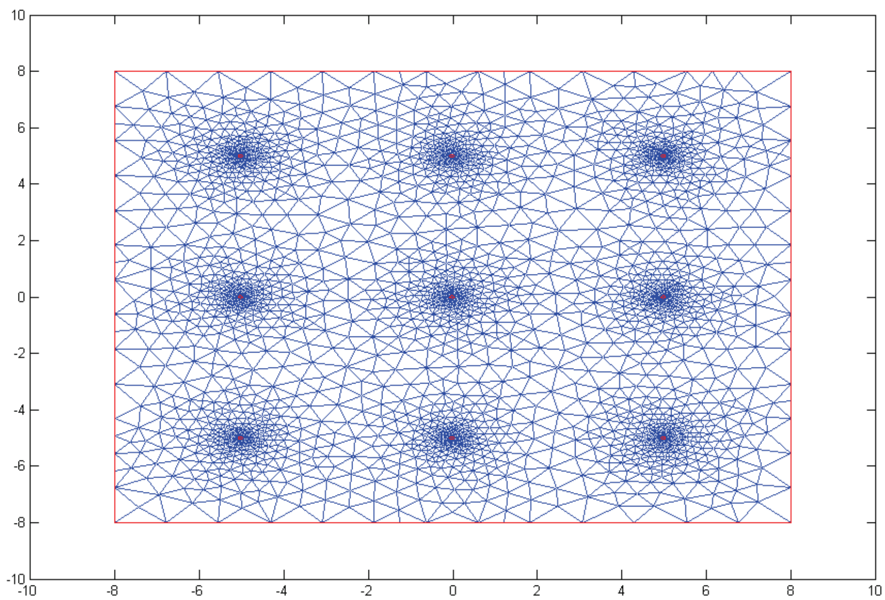


Figure.7: Grid setting in area of group pipes

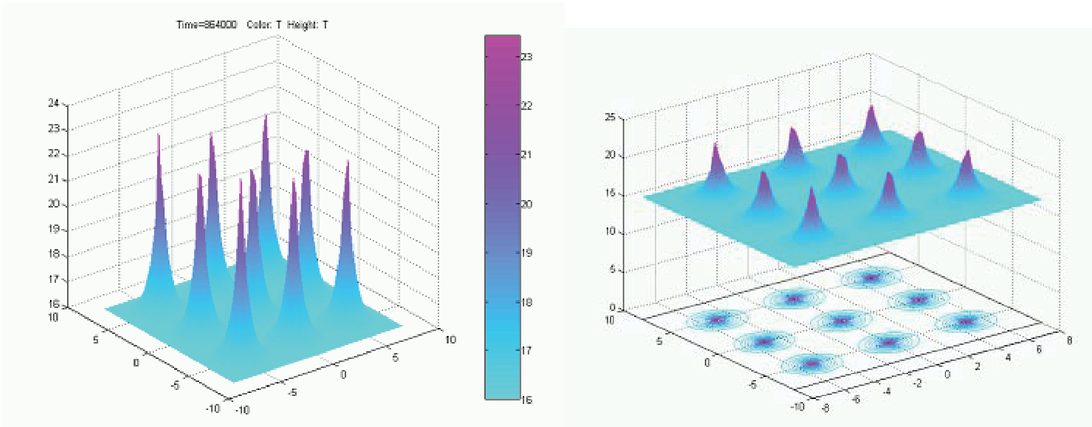


Figure.8: Temperature distribution after running for 30 days

Figure 8 showed the temperature distribution after running for 30 days in exothermic condition, at this time, interference between each borehole was not large, temperature near the heat exchangers rises to 22 ℃, the average cross section temperature is 18.9 ℃.

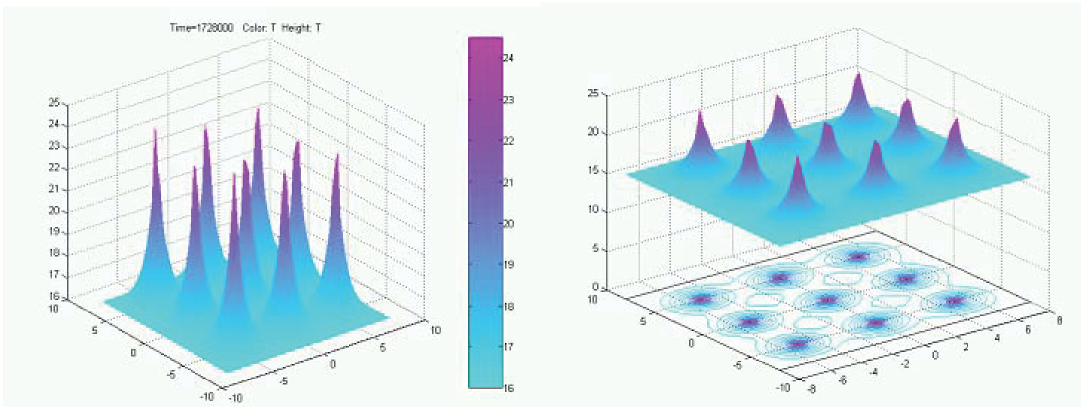


Figure.9: Temperature distribution after running for 60 days

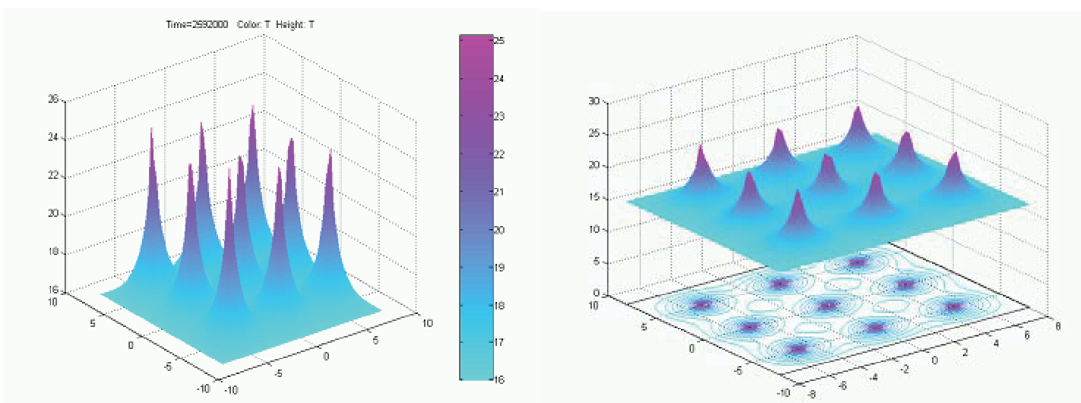


Figure.10: Temperature distribution after running for 90 days

Figure 9 showed temperature distribution after running for 60 days in exothermic condition, from which we can see that heat coupling between adjacent boreholes is obvious, a vacant area called heat affected public area appears where temperature is superposition caused by four boreholes around the area. Average temperature of the whole cross section is 19.7309 ℃.

Figure 10 showed temperature distribution after running for 90 days in exothermic condition, heat affected area changes little, temperature contours around boreholes are similar to that of single pipe model, and average temperature of the whole cross section is 20.30875 ℃.

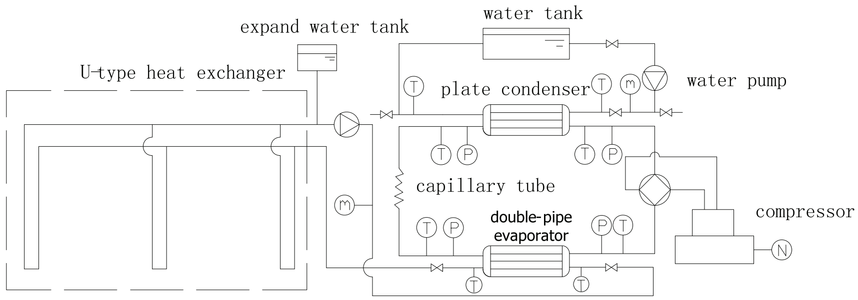
Table.1: Comparison of average temperature of whole area between group pipes and single borehole

Simulative time/d	**Temperature of simulative area/℃**		**Error %**
	Single borehole	**group boreholes**	
30	18.5944	18.9062	1.65
30	19.5026	19.731	1.16
90	20.037	20.3087	1.34

Seen from table 1, difference of average temperature contours of the cross section between single borehole model and multiple boreholes is little. Which proves that the supposed boundary conditions of single pipe are viable

4. EXPERIMENTAL STUDY ON GSHP HYBRID WITH WATER HEATER

To balance the contradiction of unbalanced heat absorbed and emitted to soil in winter and summer, water heater[6] is added to GSHP to use the additional heat as shown in figure 11.



T-temperature point； P-pressure point； N-power of compressor； m-flux of water

Figure 11: System of GSHP hybrid with water heater

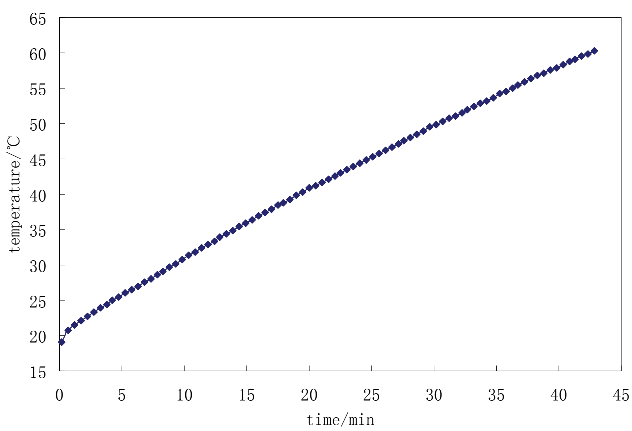


Figure 12 : Temperature of hot water changing with time

Figure 12 shows relation of hot water changing with time in storage-type GSHP water heater in November, initial temperature of heated water was 17℃， and temperature of buried-pipe outlet was 17.46℃. To heat water to 60℃ needs 45 minutes.

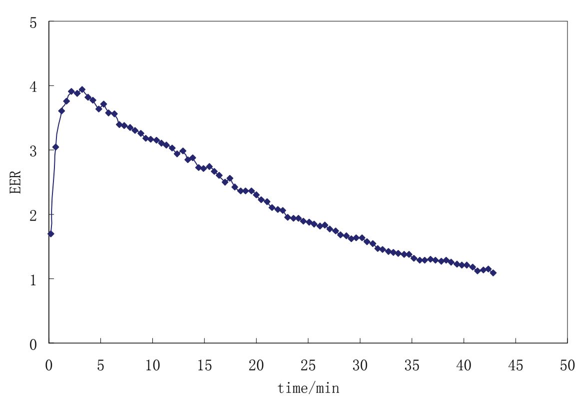


Figure 13: EER changing with time

As shown above, EER becomes less and less with running, average EER of whole heating process is 2.28. In this experiment, actual power of compressor was larger than rated power which deteriorated running conditions, in addition of low initial water temperature that results in low EER.

6. CONCLUSIONS

- Li Xinguo from Tianjin University adopted software Autough2 to simulate underground heat exchangers, which conclusion is that temperature of cc layer rises from 15 ℃ to 22 ℃ after running for 5 years and from 29 ℃ to 40 ℃ after running for 13 years[2]. Average temperature simulated in this paper of the cross section area rises from 16 ℃ to 20.3 ℃ after a running season in summer. Considering comeback of the soil, after 5 year's running of GSHP, temperature of the whole area will be likely to those of Li's.
- Two simplified models were put forward in this paper, through which models temperature distribution around heat exchangers and temperature of the whole cross section after running for several air-conditioning periods are obvious. Also the conclusion could be used as reference for studying heat exchange between fluid and soil.
- Disadvantage of the simulation is that it did not simulate temperature change in the condition of interval runs, except that it ignored layers of soil and comeback of soil when the system was off.
- In the experiment of GSHP hybrid with water heater, the highest EER could arrive at 4 at the start when experimented in winter but will decline with the running time.

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