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Simulation of Temperature Field around the Ground Source of Heat Pump

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Abstract: On the basis of model of buried heat exchanger with internal heat source, ICEM is used to model the grid, and then the model is simulated by ANSYS. Based on the simulation results of ambient temperature field of single U type heat exchanger, the influences of heat transfer performance of heat exchanger and soil recovery characteristics of single heat exchanger U type which were vertical buried under different heat exchange and soil.

Keywords: Ground source heat pump; Numerical simulation; U-tube ground heat exchanger; Ground temperature field

1. Introduction

Ground source heat pump system is a new energy saving and environmental protection air conditioning technology. Study on heat transfer of underground heat exchanger in soil is the core of the ground source heat pump technology. In previous studies, most of them are in the heat exchanger tube of single U and double U type buried, but little research on heat pipe group. In practical engineering applications, a large number of buildings seldom only use a single heat exchanger to meet the requirements of building heating and cooling. When the ground source heat pump system takes heat or heat in the rock and soil, it is necessary to arrange a large number of wells with a certain depth. Generally, the underground heat exchanger is dozens or even hundreds of sets of vertical pipe group heat exchanger. In order to ensure the heat transfer effect and the service life of the underground pipe heat exchanger, a reasonable layout should be designed, especially the depth of the vertical pipe, the number of vertical pipes and the design of the horizontal spacing. In this paper, the physical properties of the soil in Chongqing were collected. The ANSYS software was used to simulate the soil temperature field around the ground source heat pump U type vertical tube heat exchanger.

2. The Buried Pipe Group Model

Figure 1 is the distribution plane of the buried pipe ground model. There are nine U vertical buried pipe heat exchangers. The horizontal and vertical spacing of heat exchanger are 5 meters and the depth is about 100 meters. The simulation area is a square and the size is about 20*20 square meters.

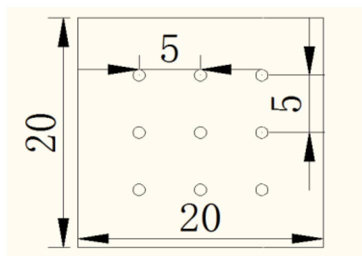


Figure 1. Distribution plane of heat exchanger

2.1. Simplifying assumptions of the model

In this section, the heat transfer condition of the ground source heat pump is simulated, and the heat flux density of the borehole wall is taken as the initial value, and the unsteady numerical simulation of the soil temperature field is carried out. In order to ensure the accuracy of the simulation and to consider the operation condition of computer, it's necessary to simplify the model. So the simulation chooses 9 ground heat exchangers and the simulation area of 20*20 square meters. In order to ensure the accuracy of the results meet the engineering requirements, the following assumptions are made on the model:

- Due to the relatively small changes of soil temperature caused by heat exchangers, we can assume that the thermal properties of the soil were identified and the thermal properties of the soil remained constant throughout the heat transfer process.
- The influence of surface temperature fluctuation and buried pipe depth on soil temperature is ignored, and the soil initial temperature is uniform.
- Without considering the effect of soil moisture transfer on heat transfer, and consider that the

transfer process between buried pipe and soil are pure heat transfer.

- The contact between backfill material and soil is good and no contact resistance.
- Without considering the convective heat transfer between soil and atmosphere.

2.2. Initial soil temperature: In Table 1

Table 1. Soil types and initial temperature

Layer number	Depth/m	Main soil types	Initial temperature/℃
aa	0~-20	Sandstone	12.2
bb	-20~-40	Mudstone	14.6
cc	-40~-60	Sandstone	15
dd	-60~-80	Mudstone	15.4

The above rock type and temperature are experimental results in a certain area of Chongqing and the temperature is the average temperature in each layer. It can be seen from the table that the rock stratum in Chongqing is mainly mudstone and sandstone.

2.3. Soil physical parameters

It is necessary to know the soil physical parameters of the soil in the setting of soil material, included the soil density, thermal conductivity, specific heat capacity and thermal diffusivity, etc. This paper mainly studies the situation of Chongqing, according to the results of the preliminary test of the soil thermal response to define the thermal properties of materials see table 2.

Table 2. Soil physical parameters table

Name	Density	Heat	Thermal conductivity	Thermal diffusivity
	Kg/m3	*kJ/Kg K*	*W/m.K*	*$10^{-6}m^2$ /s*
Mudstone	2720	0.8	1.77	0.8
Sandstone	2690	1.1	2.04	0.8

3. Heat Transfer Performance and Recovery Characteristics of Tube Group

3.1. Effect of initial temperature on soil temperature field

In order to study the effect of the initial soil temperature on the soil temperature field, three kinds of soil initial temperature were set up, which were 19℃,17℃,15.6℃. In order to analyze and compare the effect of the initial soil temperature on the temperature field, the concept of excess temperature was used. The temperature change of the most unfavorable point were choose, and make the excess temperature curve shown in Figure 2.

As can be seen from the excess temperature chart, three different initial temperature changes are basically same when the initial temperatures are 50W/m, 40W/m, 30 W/m. It can be seen that the initial soil temperature has little effect on the change of soil temperature field, which can be ignored. And this provides a basis for future research.

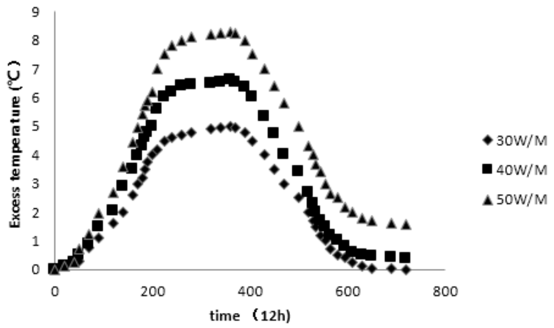


Figure 2. Excess temperature chart

3.2. Effect of heat exchange on soil temperature field

As can be seen from Figure 2, after a year of soil temperature rise is also different under different heat transfer conditions. As shown in table 3, the initial temperature of the soil, the different heat transfer, and the excess temperature of the soil are analyzed.

Table 3. Excess soil temperatures at different initial temperatures and heat transfer

Time(12h) \ Initial Temperature	19-50	17-50	15.6-50
1	0	0	0
109	2.68	2.68	2.68
209	6.94	6.94	6.94
319	8.18	8.18	8.18
419	7.53	7.53	7.53
519	4.31	4.31	4.31
609	2	2	2
719	1.61	1.61	1.61

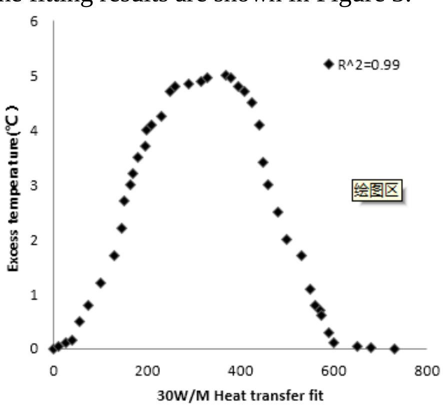
Time(12h) \ Initial Temperature	19-40	17-40	15.6-40
1	0	0	0
109	2.15	2.15	2.15
209	5.55	5.55	5.55
319	6.54	6.54	6.54
419	5.88	5.88	5.88
519	2.66	2.66	2.66
609	0.64	0.64	0.64
719	0.35	0.35	0.35

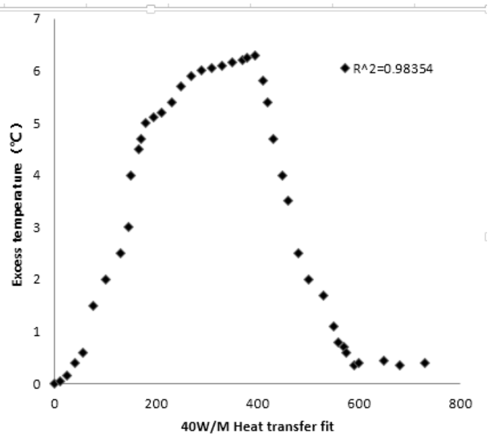
Time(12h) \ Initial Temperature	19-40	17-40	15.6-40
1	0	0	0
109	1.61	1.61	1.61
209	4.16	4.16	4.16
319	4.91	4.91	4.91
419	4.41	4.41	4.41
519	1.99	1.99	1.99
609	0.26	0.26	0.26
719	0.04	0.04	0.04

From the above table, we can see that the change of soil temperature rise is obvious. Soil temperature rise is 0.036℃ when the heat exchange is 30 W/m. Soil temperature rise is 0.35℃ when the heat exchange is 40 W/m. Soil temperature rise is 1.6℃ when the heat exchange is 50 W/m. It is not difficult to see from the table that the greater the heat transfer, the greater the soil temperature rise. In order to keep the balance of the soil temperature of the area of buried pipe, the heat transfer tubes shall have a maximum limit of a single buried. From the simulation, it is not appropriate for more than one 50W/m heat. The simulation results of the data in the form of synthetic function, so clearly expressed, the actual design of the project and the use of work to bring great convenience. In this paper, through the data processing software Origin, its own function library contains a number of linear and nonlinear functions were used. And according to the excess temperature of soil under different heat transfer conditions, function relations were fitted. As can be seen from figure 2, the excess temperature curve shows the trend of the two order equation. Using Origin internal gaussion fitting, the fitting formula is:

$$y = y_0 + \frac{A}{w\sqrt{\pi/2}} e^{-2\frac{(x-x_c)^2}{w^2}}$$

The fitting results are shown in Figure 3.





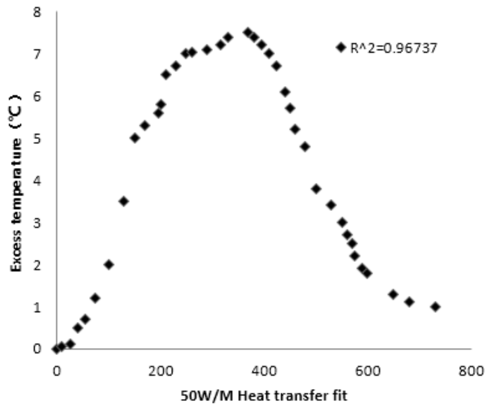


Figure 3. Three kinds of heat exchange excess temperature fitting curve

It can be seen from the fitting results in Figure 3 that the soil excess temperature curves of the three kinds of heat exchange are similar. The fitting function relation is shown in Figure 2, and the results of the fitting parameters are shown in table 4.

Table 4. Parameter values of different heat exchange fitting results

Heat exchange	30W/m	40W/m	50W/m
y_0	-0.77478	-0.65638	-0.7032
x_c	319.2528	319.5719	335.1865
W	314.8803	301.7627	332.4263
A	2382.9581	2914.1984	3890.1919

From the fitting results, the values of several fitting parameters in the formula are the same, the difference is small. For example, the value of y_0, x_c, w are basically same. Parameter A is the only parameter which has a big difference. When the initial temperature is 30W/m, parameter A is 2932.9581. When the initial temperature is 40W/m, parameter A is 2914.1984. When the initial temperature is 50W/m, parameter A is 3890.1919. As can be seen from figure 2.21, the peak value of the quadratic function is determined by the value of parameter A. It can be concluded that the function relation can be expressed as the form of quadratic function. The difference of heat transfer results in the difference of the peak value of the function curve. With the increase of heat transfer rate, the peak value of the function is larger.

4. Study on the Energy Saving and Economic Performance of Ground Source Heat pump

4.1. Determining the recovery time of soil temperature field

From the simulation results above, it can be seen that, after a year of operation, the change of soil temperature in the most unfavorable point has obvious rules. In the case of heat exchange 50W/m, the maximum temperature rise is about 1.5 ℃. In the case of heat exchange 30W/m, the maximum temperature rise is basically unchanged. If the heat is smaller, then the recovery effect is better. The results show that the heat transfer has a great influence on the recovery of soil, the smaller the heat exchange, the better the soil temperature recovery.

Based on the formula Q_L=K*F*(T_f-T_0), the change trend of underground effective heat transfer coefficient with time can be concluded. Formula K*F is defined as the effective heat transfer coefficient. The physical meaning of the fluid medium for heat exchanger for deep wells per meter and average temperature of the soil around the initial temperature of each difference of 1 degrees, the per meter well depth, the heat transferred per unit time. The determination of the index can provide the basis for the design of the underground heat exchanger system.

Q_L------heat exchange quantity per well depth W/m;

K------heat transfer coefficient W/($m^2 *$℃);

F------heat transfer area per well depth m^2/m;

T_f -----average temperature of fluid℃;

T_0------ Soil initial temperature （13℃）.

With the increase of heating time, the effective heat transfer coefficient gradually decreases and then tends to be stable. The results show that the heat transfer capacity of underground heat exchanger tends to be stable with time.

At the initial moment, the slope of the soil temperature rise curve is the largest, which is due to the effective heat transfer coefficient at the beginning of the maximum. After several years of operation, the effective heat transfer coefficient becomes smaller, and tends to stable which resulting in the slope of soil temperature rise curve becomes smaller, but also tends to stabilize. The turning point is about 5 a year or so for about 10 years. Therefore, it is necessary to simulate the change of soil temperature field in 10 years. The ground source heat pump system in the soil should be safe for more than 30 years. If the heat exchange is 30W/m, the temperature rise can be controlled after many years of operation. If the heat transfer increases, it is necessary to carry out specific simulation analysis to ensure that the soil temperature field can be restored.

4.2. Energy saving and economic performance of ground source heat pump

The size of underground energy storage can be measured by the excess temperature of the surrounding rock around the buried pipe. In summer, the higher the excess temperature of underground rock is, the higher the grade of underground energy storage. In winter, the higher the excess temperature of rock and soil is, the higher the underground heat storage is, and the better the heat transfer performance is.

Ground source heat pump system is suitable for use in the summer and cold winter area. If it is used only in winter or in summer, it will not only destroy the structure and heat transfer ability of rock and soil, but also give full play to the superiority of rock and soil energy storage. Two seasons are used, the summer use of the cold storage of cold storage, while storing heat, to prepare for winter. In winter, the heat stored in summer is used for heating, and the cold storage quantity is stored for summer use. Cold and warm load is basically equivalent where cooling and heating days are almost same in hot summer and cold winter area. And the same underground pipe heat exchanger can be used to achieve the construction of cold and warm for energy saving and also sustainable.

In the hot summer and cold winter area, taking Chongqing as an example, the summer cooling demand was significantly higher than that in winter. Cooling tower and ground source heat pump system can be used under this circumstance. Underground heat can be used to provide hot water in the transition season to ensure the heat balance of the soil and improve the service life and efficiency of the ground source heat pump.

5. Conclusions

The ground source heat pump system is relatively stable, and the soil has many advantages as a cold and heat source such as the soil temperature change is small and the temperature absorption ability is strong. Based on the simulation analysis of soil source heat pump system, the following conclusions can be drawn.

- The initial soil temperature has little effect on the change of soil temperature field around the ground source heat pump tube group and the impact of the initial temperature can be ignored.
- For the ground source heat pump tube group, when the heat transfer tube is 30M/m, the temperature rise of the soil temperature field is about 0.03℃. If increase the heat transfer, the heat transfer tube is 50W/m and the temperature rise of the soil temperature field is about 1.6℃. In the practical engineering application, in order to ensure the safe operation of the ground source heat pump, the ground source heat pump system should be used to simulate the soil temperature change for 30 years.
- The variation curves of soil excess temperature around the ground source heat pump tube group can be synthesized in the form of quadratic function: $y = y_0 + \frac{A}{w\sqrt{\pi/2}} e^{-2\frac{(x-x_c)^2}{w^2}}$ .The ef-

fect of different heat transfer on the parameter A is different, the greater the heat transfer, the greater the parameter value and the greater the peak value of the fitting curve.

- In order to realize the long-term use of soil heat source, the heat transfer and heat release rate of the ground heat exchanger should be balanced. When there is a big difference between cold and heat load, it is suggested to use "hybrid system", such as underground pipe and cooling tower or buried pipe and auxiliary heat source.
- At present, most of the research is to calculate the temperature field of the simulated tube group. But after a long run period, the simulation will have a greater error. Most of the models are simplified the heat transfer process into a simple thermal conduction process, ignoring the water migration and the different thermal properties of soil layers. These are the issues that need to be considered in future research.

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