

Simulation Study on Underground Heat Exchanger and the Underground Temperature Field

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Abstract: Based on inner heat source model of U-vertical ground coupled heat exchanger (UGCHE), the numerical simulation study on the performance of UGCHE and the underground temperature field was carried out by using computer code of AUTOUGH2 in this paper. First, the effects of soil properties on a single heat exchanger was analyzed, then, simulation on a group of heat exchangers under two operation modes was carried out: one was single season operation mode, which only extracted heat from ground in a heating season or emitted heat to ground in a cooling season in one year. The other was double season operation mode, which extracted heat from ground in heating season and emitted heat to ground in cooling season in the year.

Keywords: Inner heat source, U-vertical ground coupled heat exchanger (UGCHE), Underground temperature field

1. INTRODUCTION

Soil has different types, such as Sand, Clay, and Rock. The different buried types and different operation mode of UGCHE affects its performance and the underground temperature field.

In order to reach an optimum system design, all factors have to be taken into account when determining the size, number, and the life time of the UGCHE. Based on the inner heat source model^[1], the numerical simulation study on the heat transfer of UGCHE is carried out by using simulator of AUTOUGH2^[2, 3] for single and a group of UGCHEs.

2. NUMERICAL SIMULATION

2.1 The Influence of Different Soil Properties

Different soil types and properties have different effects on the performance of UGCHE and the underground temperature field. A UGCHE with depth of 90m is taken as example, with a heat exchanged rate of 40 W/(borehole) in extracted heat from ground and emitted heat to ground respectively.

2.1.1 Input Parameters

(1) Grid division: rectangular region with a area of $21 \times 21 \text{ m}^2$ is selected, and the length of the grid's side is 1m, as shown in Fig.1. The borehole heat exchanger has a diameter of borehole 300mm, and located at the centre (point O) of the area. The distances from points (A, B, C and D) to the heat exchanger (point O) are 1m, 2m, 3m and 4m respectively.

(2) Initial temperature: The soil initial temperature is given by 15°C .

(3) Input parameters used in the calculation given in the Table 1.

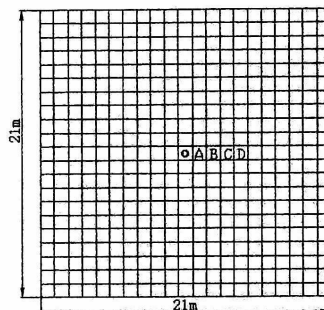


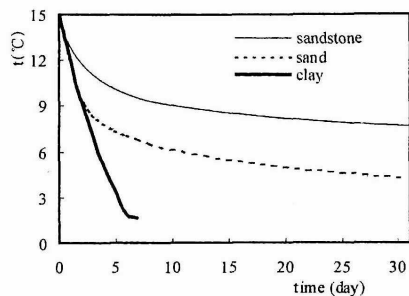
Fig 1: Numerical grid and location of the UGCHE

Table 1: Parameters used in the calculation

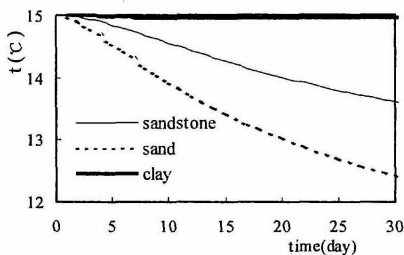
Items	Permeability (Darcy)	Porosity (%)	Density (kg/m^3)	C ($\text{J/kg} \cdot ^\circ\text{C}$)	λ ($\text{W/m} \cdot ^\circ\text{C}$)
Air	0.001	99	1	900	0.025
Clay	0.01	47	1500	2200	0.9
Sand	0.01	20	2000	700	1.9
Sandstone	0.01	10	2500	1430	3.0

2.1.2 Temperature Distribution in Different Types of Soil

To compare the temperature distributions in various types of soil, the numerical simulation are conducted for ideal type of soil, such as Clay, Sand and Sandstone representatively, given in Table 1. In the simulation, the extracting heat rate from ground and emitting heat rate to ground per unite depth are the both 40 W/m.



(a) Point O

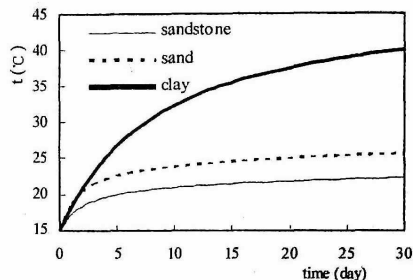


(b) Point A

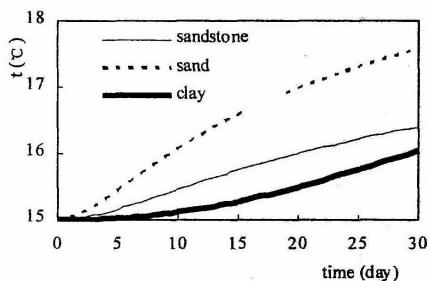
Fig 4: Temperature in various soil types in 30days continuous heat extracted

Fig.4 shows the temperature contours at points O and A under continuously extracting heat mode. According to Fig. 4a, the temperature decreased rate in clay is very fast, at 2.4 °C/day in the first 5days, and it drops down to 1.0 °C after 7-day continuous operation, which is out of the calculation data range. For the cases of sandstone and sand, the thermal conductivities are relatively higher so that the temperature decreased rate is lower. After 5 days, the soil temperature curves tend to be smooth. Fig. 4b shows clearly that the clay temperature keeps almost at the initial temperature, which is due to the poor thermal conductivity of clay that the heat in the soil far away from the heat exchanger cannot be transferred easily to the heat exchanger. Temperatures in the sandstone and sand have descended 10% and 16% respectively in 30days.

Similarly, we can get the results under the emitting heat mode as shown in Fig. 5. The clay temperature increases very fast, which is approximately about twice as fast as in sand. After 5days, the temperature in clay at point O reaches to 27 °C, while the temperatures in sand and sandstone are 23 and 20 °C respectively. However, the temperature in clay rises very slowly at point A because of the high heat capacity and low thermal conductivity in clay.



(a) Point O



(b) Point A

Fig 5: Temperature in various soil types in 30days continuous heat emitted

2.2 Simulation on a Group of Heat-exchangers

Fig.6 shows a group of heat exchangers, the total number is 21. The heat exchangers are located from left to right and from top to bottom numbered from 1 to 21. Each heat exchanger is 90 m in depth, buried in three rows with equal of 5 m. The rectangular simulation area is 42 m×21m, which is divided into 882 meshes.

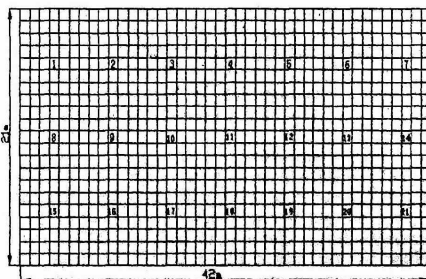


Fig 6: Location of borehole U-vertical Ground Coupled Heat Exchanger (UGCHE)

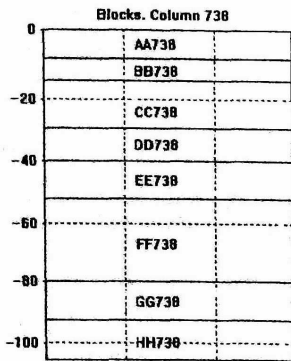


Fig 7: Cross section of layers

(1) Cross section of layers: Shown in Fig.7, in the vertical direction, the formation matrix is divided into 7 layers according to the soil types, which are shown in Table 2, and the soil properties of all layers are listed in Table 3. The soil properties and the initial condition can be set for each layer independently.

(2) The initial temperature given in Table 2.

(3) Inner source item: Based on the experimental data, the extracted heat per unite depth is 40 W in a heating season, and the emitting heat per unite depth is given by 60 W in a cooling season.

Table 2: Soil type and initial condition

Layer	Depth(m)	Soil type	Initial temperature(°C)
aa	0~-10	Powder clay	12.2 (a)
bb	-10~-15	Clay, Sub clay	14.6 (b)
cc	-15~-30	Sand	15 (b)
dd	-30~-40	Silt	15.4 (c)
ee	-40~-50	Clay, Sub clay	15.4 (c)
ff	-50~-80	First aquifer, Sand	16 (c)
gg	-80~-100	Second aquifer Sand clay	16~17 (c)

a- Annular average air temperature in Tianjin distract, b- Experimental data^[4], c- Calculated from experienced formula.

Table 3: Parameters used in the calculation

Items	Permeability (Darcy)	Porosity (%)	Density (kg/m ³)	C (J/kg · °C)	λ (W/m · °C)
atmosphere	0.001	99	1	900	0.025
powder clay	0.01	47.9	1350	2200	0.9
clay	0.01	47	1500	2200	0.9
sand	0.01	20	2000	700	1.9
silt	0.01	37	2000	1420	1.5
sand clay	0.01	20	2200	2000	1.2

2.3 Simulation in Double-Season Operation Mode

In the double-season operation mode, the GCHP system emits heat to ground in summer and extracts heat from ground in winter. In a cooling season, the heat emitted per unite depth is about 60 W/m, the air-conditioning period is 90 days, and the GCHP works about 8~10 hours a day, so the total heat emitted is about 2.94×10^6 kJ. In a heating season, the extracted heat per unite depth is about 40 W/m, the heating period is 120 days, so the total heat extracted is about 2.61×10^6 kJ.

Take No.11 UGCHE as an example to analyze the temperature variation. The temperatures in different distance from the centre of UGCHE in layer cc fluctuate up and down with the GCHP operation period (one year), shown in Fig.8. At $x=0$ m, the temperature's rising is almost equal to its dropping, and the annual average temperature has only slight rising trend, which means the total heat extracted and emitted in each operation period is nearly equilibrium at the centre of UGCHE. At $x=1$ m and $x=3$ m, the ground temperature increases obviously, and it will be increased 2~3°C after simulation goes to 30 years, indicating that the total heat absorbed by ground is

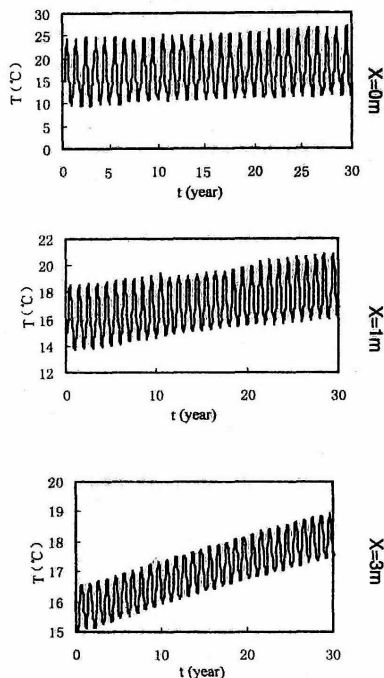


Fig 8: Temperature variation in different distance from the centre of UGCHE in layer cc-sandstone

more than its released heat where away from the centre of UGCHE. Consequently, the heat is accumulated gradually year-by-year where away from the centre of UGCHE that the temperature goes up.

Fig.9 shows the temperature contours of layer-cc in double season operation mode after 5, 20, 30 years. The initial temperature of layer-cc is 15°C. After 5 years, the temperature in part of the ground field will be 16°C. As operation time goes on, the temperature of whole layer-cc goes up, in other words, the radius of the influence range by the UGCHE increases more and more. After 30 years, the temperature increases to 18°C. The reason for this phenomenon is that the amount of heat emitted to ground in summer is more than heat extracted from ground in winter, which causes the temperature rise in ground. But this will be beneficial to the heat extracted from ground in winter.

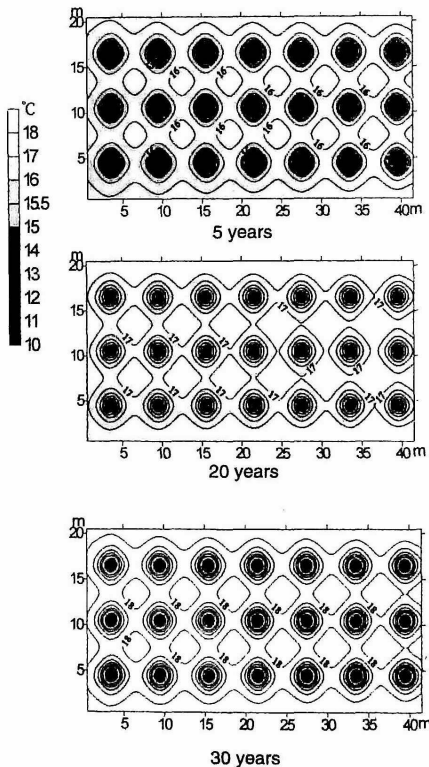


Fig 9: Temperature contours in layer-cc under Double season operation after 5, 20, 30 years

2.4 Simulation in Single Season Operation Mode

To explain the problem obviously, two extreme cases are studied: one is only extracting heat in winter in the year and the other is only emitting heat in summer in the year. The operation time and heat

exchanged for each case are equal to those in double-season mode discussed above.

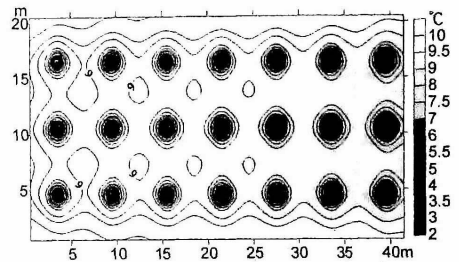


Fig 10: Temperature contours in layer cc only extracting heat from ground in winter after 5 years

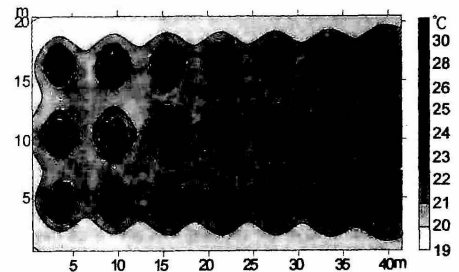


Fig 11: Temperature contours in layer cc only emitting heat to ground in summer after 5 years

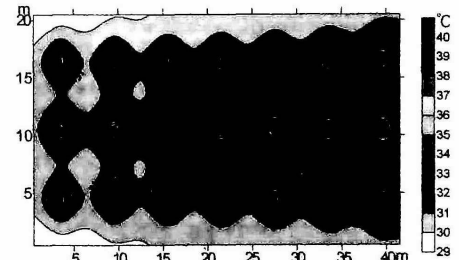


Fig 12: Temperature contours in layer cc only emitting heat to ground in summer after 13 years

Fig.10 shows the case of only extracting heat in winter after 5 years, the temperature is below 9°C in most of the ground field, and the temperature around the exchangers is only 6°C, which means the ability and efficiency to extract heat from ground declining gradually.

Fig.11 shows the temperature contours in the case of only emitting heat in summer for 5 years. The temperature in most of parts of layer-cc rises to 22°C, and the temperature reaches to 29, 30°C near the exchanger, which approaches the standard air-conditional temperature range.

Fig.12 shows the temperature contours after 13-year operation. The temperature of the whole layer-cc

reaches 29–40 °C, and it exceeds 35 °C near the exchanger, which exceeds the standard temperature range of cooling water. That is to say, after 13 years running, the ground temperature is no long suitable for the air-conditioning.

3. CONCLUSIONS

1. Different soil types and properties have different effects on the performance of UGCHE and the underground temperature field.

2. A group of 21 heat exchangers is studied in the paper. In 30 year simulation of double season operation mode, the temperature will almost remain the same if the total heat emitted in summer is equal to the heat extracted in winter that means the heat balanced, which will be beneficial to the GSHP operation as a sustainable source and sink.

3. In extracting heat only in winter, after 6 years, the ground temperature will be reduced to 1.8 °C in part of the ground field. In emitting heat only in summer, after 13 years, the ground temperature will

be over 35 °C, which no longer suitable for air-conditioning.

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