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Design and heat transfer characteristics of buried heat exchange tube group with vertical inlet and flat outlet

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ABSTRACT

In order to improve the heat transfer efficiency of ground source heat pump, a vertical inlet and flat outlet type buried tube group enhanced heat transfer system is designed by integrating the advantages of horizontal and vertical buried tube heat exchanger structures, and a shallow geothermal utilization system model is established in a laboratory in Chengdu as an example to study its heat transfer performance under load conditions, and three water circulation heat balance buried tube enhanced heat transfer structures are designed to study its enhanced heat transfer performance.The results show that: compared with the traditional buried tube structure, the heat transfer performance of the vertical inlet and flat outlet buried tube group can be improved by more than 65%; for the heat pump system, the heat transfer of rocky soil stratum is the largest, followed by sandy soil and the smallest clay; compared with the heat exchanger without reinforced structure, the cooling performance of the three water circulation heat balance buried tube heat exchangers are improved by 28.3%, 25.3%, 10.7%, and the heating performance are improved by 27.3% , 21.8%, 10.9%, and better stability.

1. INTRODUCTION

The use of shallow geothermal energy for heating and cooling is an important path to achieve the "double carbon" goal. Ground Source Heat Pump (GSHP) is recognized as one of the most efficient renewable energy systems, and the buried tube for heat exchange is one of its core components. It is important to explore a high-efficiency buried tube heat exchange system to promote ground source heat pump system.

More studies have been conducted at home and abroad on the heat transfer performance of buried tubes. For the nature of soil, Qi Chengying et al [1] found that coarse sand was used as backfill material compared to the original slurry of the borehole, and the denser the backfill material, the better it was for strengthening heat transfer; Yue Tao et al [2] found that the heat exchanger efficiency could be improved by about 21% after soil extrusion, and the U-tube thermal short circuit phenomenon was significantly improved.For buried tube structure, Xiao Yimin et al [3] found that the thermal resistance of a multi-inlet and single-outlet buried tube heat exchanger was reduced by 29%-34% compared to a single U-type structure and 10%-15% compared to a double U-type structure; Bezyan et al [4] compared W-type, U-type and spiral heat exchanger tubes and found that the heat transfer performance of spiral tubes was superior.For reinforced heat exchange with ribs, Reza et al [5] designed a shallow reinforced heat exchanger tube with horizontal aluminum rods (fins), and the heat transfer rate could be increased to 31%; Ma Jinghui et al [6] found that the heat transfer per unit burial depth of rectangular straight-ribbed buried tube heat exchanger was 19.12% higher than that of bare tube; Yoon et al [7] designed a threaded tube with 25% lower thermal resistance of vertical borehole than that of traditional polybutylene tube U-tube. Zhou et al [8] concluded that trench spacing and tube structure should be given priority in the case of limited soil through the analysis of heat pump system in chicken house.For groundwater seepage, Ma Fengfeng et al [9] concluded that the increase of soil porosity makes the overall heat transfer performance decrease; Yang Weibo et al [10] found that the increase of horizontal spiral type buried tube coil diameter is beneficial to enhance the total heat transfer but not to the heat transfer efficiency per unit tube length. For the influence of ground surface temperature, Si-Ru Li et al [11] concluded that the heat exchange of buried tubes is influenced by the annual cyclic temperature fluctuation of the ground surface.For horizontal tube structure, Duan Xinsheng et al [12] gave a theoretical calculation method for the initial temperature of horizontal shallow soil; Lin Yun et al [13] simulated and found that the design capacity of buried tube was negatively correlated with the volumetric heat capacity and thermal conductivity of soil; Yang Weibo et al [14] found that groundwater percolation made the rate of soil temperature rise around buried tube decrease, thus improving the overall heat transfer efficiency of the system; Kim et al [15] found that spiral tube heat transfer was better than horizontal slinky type through experiments; Chaofeng Li [16] et al considered that soil thermal conductivity and buried tube spacing were the main factors affecting heat transfer efficiency.

In summary, existing heat transfer performance studies mainly focus on individual vertical or horizontal buried tube systems, and less consideration is given to combining vertical and horizontal tube structures; the vertical system has a small footprint, high soil utilization and high heat transfer efficiency, but high cost, while the horizontal system has a small initial investment but low performance and is susceptible to environmental impact. Therefore, a new type of buried tube group system with vertical inlet and flat outlet is designed to ensure efficient soil utilization and reduce the initial cost. By studying its heat transfer performance and constraints, and optimizing and enhancing it, it can provide a basis for the design and operation and maintenance of buried tube group heat exchangers for ground source heat pumps.

2. GROUND SOURCE HEAT PUMP HEAT EXCHANGE SYSTEM DESIGN

2.1 Building year-round dynamic load calculation

Taking a laboratory load pattern of a university in Chengdu area as an example, this ground source heat pump system uses a heat pump unit to connect the underground heat exchange section and the building air conditioning end system, using the earth as a heat source (winter) or radiator (summer) to provide heat (winter) or cold (summer) to the building. The system operates to maintain a constant laboratory comfort temperature T_{ho}, and the outdoor temperature is the typical annual and monthly average temperature T_o in the Chengdu area. No consideration of building floor heat exchange and consider convective heat transfer between air and internal and external walls (or roof) and wall heat transfer. The heat flow model of the experimental building in summer and winter contains three parallel thermal resistances R_{ew}, R_{ns} and R_{ro}, which represent the heat transfer thermal resistance through the east and west walls, the north and south walls and the roof, respectively. The thermal resistance of each wall and roof consists of convective heat transfer on both sides and heat conduction in the solid [17].

$$R_{ew} = \frac{1}{h_o A_{ew}} + \frac{\delta_{ew}}{\lambda_{ro} A_{ew}} + \frac{1}{h_i A_{ew}} \tag{1}$$

$$R_{ns} = \frac{1}{h_o A_{ns}} + \frac{\delta ro}{\lambda_{ns} A_{ns}} + \frac{1}{h_i A_{ns}} \tag{2}$$

$$R_{ro} = \frac{1}{h_o A_{ro}} + \frac{\delta_{ro}}{\lambda_{ro} A_{ro}} + \frac{1}{h_i A_{ro}} \tag{3}$$

Where, h_i, h_o are the convective heat transfer coefficients of walls and roofs respectively; λ_{ew}, λ_{ns}, λ_{ro} are the thermal resistance of east-west walls, north-south walls and roofs respectively; δ_{ew}, δ_{ns}, δ_{ro} are the wall thicknesses of east-west walls, north-south walls and roofs respectively; A_{ew}, A_{ns}, A_{ro} are the areas of east-west walls, north-south walls and roofs respectively.The heat exchange (load) Q_t:

$$Q_t = \frac{T_{ho} - T_o}{R_t} \tag{4}$$

Among them:

$$\frac{1}{R_t} = \frac{1}{R_{ew}} + \frac{1}{R_{ns}} + \frac{1}{R_{ro}} \tag{5}$$

The laboratory is 35 m long, 15 m wide and 6 m high; the convective heat transfer coefficient is 15 W/(m^2·K) and the thermal conductivity is 0.15 W/(m·K) around and on the inner and outer walls of the roof, and the wall thickness is 0.2 m.The laboratory body shape factor is expressed as:

$$\text{Body size factor} = \frac{\text{Laboratory surface area}}{\text{Laboratory volume}} = 0.357 < 0.4 \tag{6}$$

Heat transfer coefficient of walls and roofs is expressed as:

$$K_{ew} = K_{ns} = K_{ro} = \frac{1}{\frac{1}{h_0} + \frac{\delta}{\lambda} + \frac{1}{h_i}} = 0.68 < 1 \tag{7}$$

The heat transfer coefficient satisfies the requirement of "Energy-saving Design Standard for Residential Buildings in Sichuan Province" less than 1. Keeping the indoor Tho at a comfortable temperature of 25 ℃, the typical annual temperature of Chengdu area is shown in Figure 1 [18], and the load of this laboratory by calculating the monthly load throughout the year. It can be seen that the maximum heat load is 16.83 kW at night in January, the maximum cold load is 5.36 kW during the day in August, and the heat load is above 15 kW in the coldest three months.

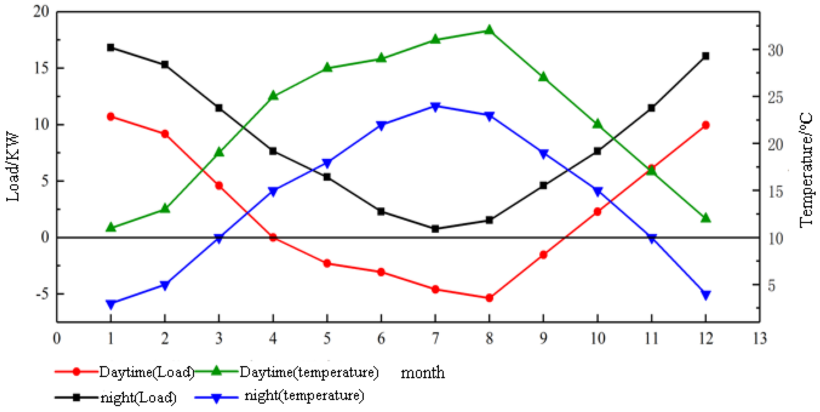


Figure 1： Annual temperature and monthly load

2.2 Vertical inlet and outlet type buried tube model

2.2.1 Physical model of vertical inlet and outlet type buried tube

The underground heat exchanger of the ground source heat pump system is shown in Figure 2, which is mainly composed of the circulating work substance (water) in the tube, the tube, the backfill soil and the earth soil. The soil is divided into three layers (clay layer, pebble layer, and mudstone layer) according to the geotechnical properties of Chengdu area [19], and the thickness of each layer as well as the physical parameters are shown in Table 1, where the temperature of the thermostatic layer is 18.5°C. Design buried tube group for shallow buried tube, the top of the soil set convective heat flux external temperature for the ambient temperature, in order to make the distant thermal boundary is not disturbed, the horizontal buried tube left and right each take the width of 5 m soil, the parameters are shown in Table 2.

The following assumptions are made about the model.

(1) A sufficiently large volume of soil was taken as the study area during the modelling process, assuming adiabatic heating at the most distal end.

(2) The geotechnical properties are isotropic and remain constant [20], and the physical properties of the geotechnical soils and backfills are identical.

(3) complete contact between the geotechnical soil and backfill, backfill and buried tube wall, neglecting the contact thermal resistance between them [21].

(4) Assuming that there is only heat transfer between the buried tube and the soil in the absence of groundwater infiltration.

(5) The bottom surface of the control body is the thermostatic surface, the top surface of the control body is the convective heat exchange surface with the atmosphere, and the control body is surrounded by the adiabatic surface.

(6) Solar radiation heat transfer is negligible [22].

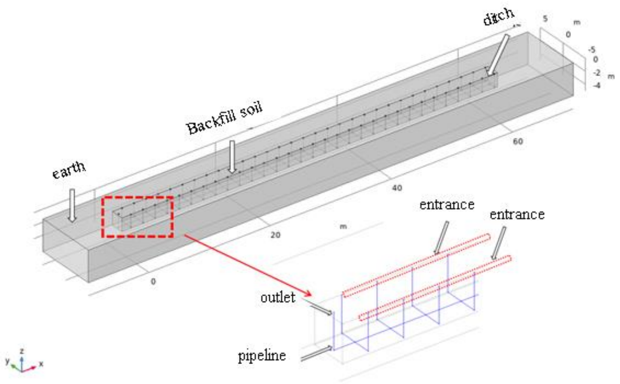


Figure 2： Model of buried tube group

Table 1 Geotechnical parameters in Chengdu area

Geology	Thickness m	Density kg/m^3	Thermal conductivity W/(m•°C)	Specific heat J/(kg•°C)

Clay layer	5	1600	1.2	1420
Pebble layer	20	1840	1.62	1180
Mudstone layer	75	2530	2.01	940

Table 2 Simulation parameters

参数	数值
3D model dimensions /m	80×10×5(length×width×depth)
Ditch size /m	60×2×2(length×width×depth)
Horizontal tube outer diameter /m	0.066
Horizontal tube inner diameter /m	0.06
Vertical tube outer diameter /m	0.032
Vertical tube inner diameter /m	0.026
Transverse spacing of buried tubes /m	2
Longitudinal spacing of buried tubes /m	2
Horizontal tube depth /m	2
Vertical tube length /m	2
Thermal conductivity of buried tubes /W•m^{-1}•K^{-1}	0.4
Soil initial temperature /℃	20
flow rate /L•s^{-1}	1.2
Ground convective heat transfer coefficient /W•m^{-2}•K^{-1}	15
Initial temperature /℃	20

2.2.2 Mathematical equation of vertical inlet and outlet type buried tube

The flow and heat transfer of the fluid in the tube is described by the following equation [23]:

$$\frac{\partial A_p \rho_f}{\partial t} + \nabla \cdot (A_p \rho_f \vec{u}) = 0 \tag{8}$$

$$\rho_f \frac{\partial \vec{u}}{\partial t} = -\nabla p - f_D \frac{\rho_f}{2d_p} \vec{u} \left| \vec{u} \right| \tag{9}$$

$$\rho_f A_p c_{pf} \frac{\partial T_f}{\partial t} + \rho_f A_p c_{pf} \vec{u} \cdot \nabla T_f = \nabla A_p \lambda_f \nabla T_f + f_D \frac{\rho_f A_p}{2d_p} \left| \vec{u} \right|^3 + q_p \tag{10}$$

where (8) is the mass equation, (9) is the momentum equation, and (10) is the energy equation; A_p is the cross-sectional area of the tube; ρ_f is the fluid density; u is the flow rate; p is the pressure; d_p is the inner diameter of the tube; f_D is the friction coefficient; c_{pf} is the specific heat capacity of the fluid volume; T_f is the fluid temperature; λ_f is the fluid thermal conductivity;q_p is the source term for heat transfer between the fluid and the external environment of the tube and is expressed as:

$$q_p = h_e Z_p (T_{ext} - T_f) \tag{11}$$

where he is the effective heat transfer coefficient between the fluid inside the tube and outside the tube; Text is the temperature outside the tube; and the fourth term in equation (10) represents the heat dissipation due to viscous shear, which can be calculated using the model [24] as:

$$f_D = 8\left[(\frac{8}{R_e})^{12} + (A+B)^{-1.5} \right]^{\frac{1}{12}} \tag{12}$$

$$A = \left[-2.457 \ln\left(\left(\frac{7}{R_e} \right)^{0.9} + 0.27\left(\frac{e}{d_p} \right) \right) \right]^{16} \tag{13}$$

$$B = \left(\frac{37350}{R_e} \right)^{16} \tag{14}$$

Where, *Re* is the Reynolds number. soil by thermal conductivity of solids in porous media and thermal conductivity and thermal convection of fluids in pores [25]. The thermal conductivity of solids is described by the following equation.

$$\rho_s c_{ps}\frac{\partial T}{\partial t}=\lambda_s\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+Q_s \tag{15}$$

where ρ_s is the density of the soil solid; c_{ps} is the volumetric specific heat capacity of the soil solid; T is the soil temperature; λ_s is the thermal conductivity of the soil solid; and Q_s is the heat source contained in the soil solid. For the liquid part in the soil pore, the heat transfer is convective heat transfer and fluid heat conduction, and the energy equation is :

$$\rho_f c_{pf}\frac{\partial T}{\partial t}+\rho_f c_{pf}\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\lambda_f\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+Q_f \tag{16}$$

Where, ρ_f is the density of the soil liquid; c_f is the volume specific heat capacity of the soil liquid; Q_f is the intensity of the heat source contained in the pore liquid; u, v are the groundwater seepage velocity in the x, y direction on the horizontal plane, respectively.

3. HEAT TRANSFER PERFORMANCE OF VERTICAL INLET AND FLAT OUTLET BURIED TUBE GROUP

3.1 Characteristics of vertical inlet and outlet buried tube groups under laboratory load

Intermittent operation mode was used i.e. 12 hours of daytime operation and 12 hours of nighttime stop for year-round simulation, January, February and December in winter and June, July and August in summer. Experimental building load year-round intermittent operation buried tube inlet and outlet water temperature as shown in Figure 3, except for the operating hours, the inlet and outlet temperatures are equal and subject to daily and seasonal temperature changes. Operating season, winter operation of the import and export temperature with the increase in operating time and decline, while the summer with the increase in operating time and rise, the vertical into the flat out of the tube group work minimum and maximum temperature of about 8.9 °C and 26.3 °C, applicable to most of the heat pump operating range, indicating that the vertical into the flat out of the buried tube group laboratory load has good operating performance. The system operating temperature under load conditions varied considerably in the initial phase of operation, such as about 6 °C and 3 °C in January and June, respectively, but only 1.3 °C and 2 °C in February and August when the load was greater. This is because the soil layer of the shallow trench buried tube is relatively shallow affected by the initial soil temperature, and the load is greater in winter leading to rapid temperature drop. However, as the system operates, the thermal recovery effect of intermittent operation makes the system temperature drop become smaller and stabilize, and overall the system stability is good.

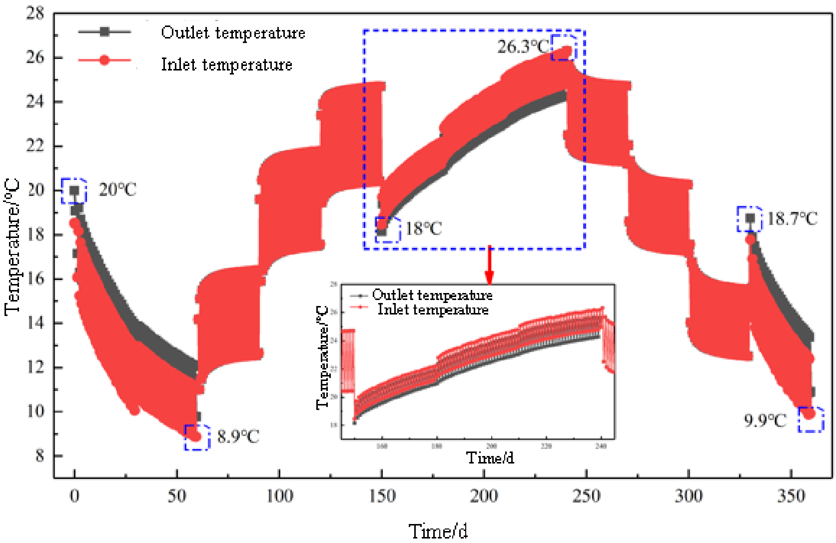


Figure 3: Laboratory load intermittent operation throughout the year, underground tube inlet and outlet water temperatu

3.2 Performance comparison with other buried tube structures

When the inlet temperature is 35 °C, the average ambient temperature of 28 °C, and three traditional types of horizontal ground buried heat exchanger (buried tube total length of the same) for comparison, the three arrangements are U-shaped tube vertical arrangement, serpentine tube horizontal arrangement, spiral tube horizontal arrangement as shown in Figure 4.

The variation of heat exchange with time for different structures of heat exchangers is shown in Fig. 5. For 30 days of continuous operation, the total heat exchange of each structure gradually decreases, but the rate of decrease gradually decreases and becomes stable. The average total heat exchange of the four structures at the end of the first day of operation was 15.2 kW, 9.2 kW, 7.1 kW, and 9.2 kW, respectively. the heat exchange efficiency of the vertical inlet and flat outlet buried tube increased by 65%, 114%, and 65% compared with the other three structures; after 30 days of continuous operation, the heat exchange efficiency of the vertical inlet and flat outlet buried tube decreased by 56%, the vertical inlet and outlet decreased by 57%, and the serpentine water and spiral tube decreased by 76% and 86% respectively, which shows that the vertical into the flat out type buried tube not only heat transfer performance and with the system running stability is better. There are two main reasons for this, the first is that the heat exchanger tube can affect the soil range is limited, serpentine tube and spiral tube type can use the soil is relatively small, this model soil use range is greater, heat dissipation surface is broader, heat dissipation is more dispersed so that heat dissipation as well as thermal recovery faster; and compare U-shaped tube and spiral tube, U-shaped tube than spiral tube performance is better, is due to the same tube length of vertical type The better performance of the U-shaped tube than the spiral tube is due to the larger volume of soil that can be utilized under the same tube length in the vertical type, which is a good indication that the incorporation of the vertical tube can improve the utilization of soil. On the other hand, because the distance between the inlet tube and the outlet tube is close to each other, there is a "thermal short circuit" phenomenon, which leads to the reduction of the heat transfer efficiency, and the other three tube types have a serious thermal short circuit phenomenon because of the close distance between the tubes. The above shows that increasing soil utilization and reducing thermal impact are the key factors to strengthen heat exchange.

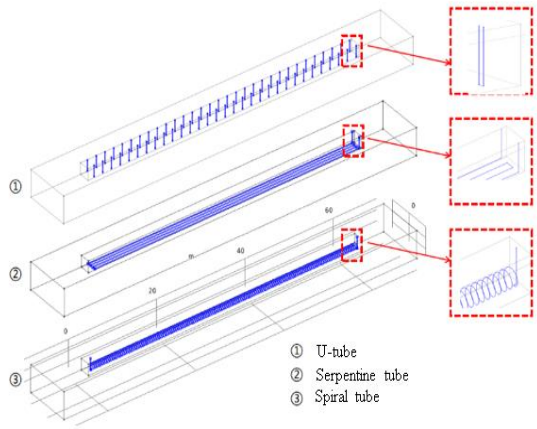


Figure 4: Three types of piping layout mode

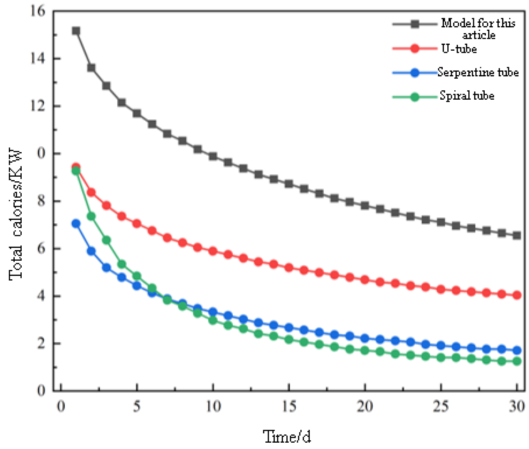


Figure 5: Heat exchange efficiency with different structures

3.3 Different soil types

Taking sandy soil, clay and rocky soil as examples, the physical parameters are shown in Table 3, and the system is operated for 180 h and stopped for 180 h. The calculation results are shown in Figures 6 and 7.

Table3 Physical property parameters of three typical soils

type	density kg/m^3	Thermal conductivity W/(m•K)	specific heat J/(kg•K)	Thermal diffusivity 10-6•m^2/s
sand	2000	2	700	1.430
clay	1500	0.9	1100	0.545
geotechnical	2500	3.2	1400	0.914

Figure 17 shows the heat exchange of different types of soil per linear meter of the system. The heat exchange per linear meter of the three types of soil is 287.3W/m, 213.3W/m and 407.4W/m respectively, which is because the thermal conductivity of the rocky soil is the largest, while the clay layer not only has the smallest thermal conductivity but also the smallest thermal diffusion coefficient which makes the heat gather around the heat exchanger tube, resulting in the deterioration of heat exchange and the smallest heat exchange.

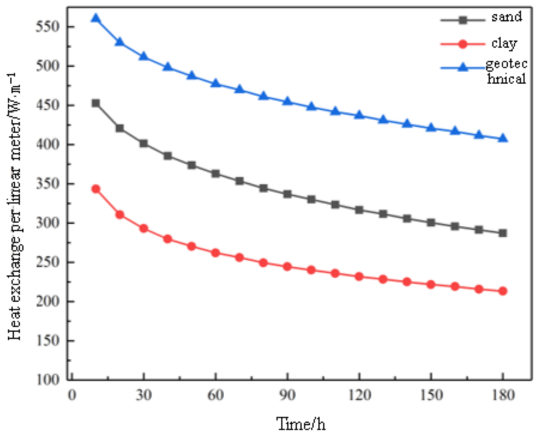


Figure 6: Heat exchange per linear meter of different soil types

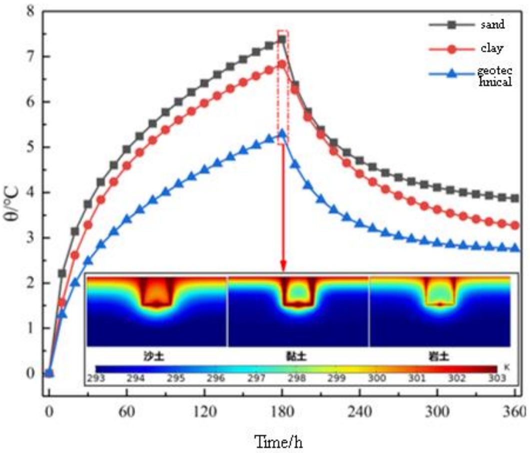


Figure 7: Excess temperature ofdifferent soil types

Figure 18 shows the excess temperature of different types of soils. The temperature rise of sandy soil is the largest and that of clay soil is the smallest in the operation section, and the excess temperature of sandy soil reaches 7.4 ℃, which is due to the small specific heat of sandy soil and the largest heat diffusion rate, resulting in the fastest temperature rise of soil and rapid diffusion to the surrounding area, causing large heat loss. The specific heat of clay soil is larger, and the heat exchange per linear meter is the lowest, resulting in the lowest soil temperature rise. And sandy soil, because of the smaller specific heat and large heat diffusion rate, the overall temperature is higher and widely spread, and the influence of ambient temperature is deeper; for clay soil, because of its higher specific heat and lowest heat diffusion rate, heat is gathered around the tube in a large amount, although the influence range is smaller but the heat exchange rate is lower, and rock soil has the largest specific heat capacity and larger heat diffusion rate, so the overall temperature rise is smaller and more uniform.

At the beginning of the outage section, the sandy soil temperature drops fastest and most, and the thermal recovery performance is the best. This is the greater the thermal diffusion coefficient, the faster the heat transfer rate to the surrounding area and the rapid decrease in soil temperature. In the later stage, because the clay soil has the lowest thermal diffusivity, it takes longer to reach stability therefore the decline is greater in the later stage.

4. WATER CIRCULATION HEAT BALANCE ENHANCED HEAT EXCHANGE

Most of the existing enhanced heat transfer studies focus on the structural arrangement and operation of the heat exchanger itself, with little consideration given to enhancing heat transfer by improving the heat accumulation in the soil around the heat exchanger. During the operation of the ground source heat pump system, the soil temperature will gradually approach the temperature of the buried tube heat exchanger, resulting in a continuous decline in the heat transfer efficiency of the buried tube heat exchanger and a relatively slow natural heat recovery, making it difficult to carry out efficient heat dissipation (cooling). Therefore, this paper designs a water circulation heat balance enhanced heat exchange system and three water circulation heat balance buried tube enhanced heat exchange structures, through water circulation to improve the heat accumulation around the heat exchanger and improve the heat transfer performance of the system; consider the year-round winter and summer heating and cooling to study its heat transfer performance, and explore the impact of key factors on its heat transfer performance and sensitivity analysis, which can be used to improve the buried tube group heat exchanger of ground source heat pump heat transfer It can provide a reference for improving the heat transfer performance of buried tube group heat exchangers of ground source heat pumps.

4.1 Enhanced heat exchange model

Circulating water heat balance buried tube reinforced heat exchange structure model is shown in Figure 8, including the initial structure (horizontal spiral tube heat exchanger) and water circulation heat balance system two parts. Three water circulation heat balance strengthening structures are designed as shown in Figure 9, including spiral structure, serpentine tube structure, upper serpentine lower spiral structure, the upper and lower layers of the three structures are buried at the same depth, the same tubes set up, inner diameter 0.013m, outer diameter 0.016m, where the serpentine tube structure and the spiral tube structure total tube length is equal, the water circulation structure and the initial structure horizontal distance of 0.05m, the average depth of the upper water circulation structure The average depth of the upper water circulation structure is 1m, and the average depth of the lower water circulation is 3.5m.

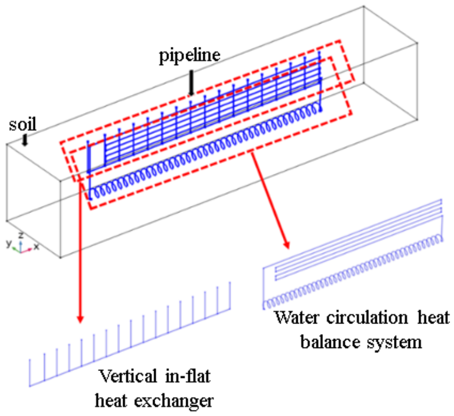


Figure 8: Water circulation heat balance buried tube reinforced heat transfer structure model

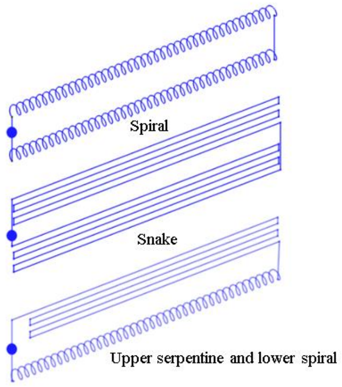


Figure 9: Water circulation heat balance heat exchange tube

4.2 Water circulation assisted into the flat-out buried tube group heat transfer performance

4.2.1 Comparison of cooling performance of circulating water heat balance underground control

The system is operated for 30 days, the inlet temperature is 35℃, and the heat transfer performance of the initial structure and the water circulation heat balance buried tube reinforced structure under the cooling condition is compared as shown in Figure 10. The heat exchange per linear meter of the three water circulation heat balance buried tube reinforced systems has a large improvement compared with the initial structure, and the improvement is more obvious as the system runs, and the heat exchange of the three reinforced structures and the initial structure are 148.9 W/m, 160.1 W/m, 159.3 W/m and 137.7 W/m respectively in 30 days of operation, and the heat exchange of the three reinforced structures compared with the initial structure is improved by 8.1%, 16.3% and 15.7% respectively compared with the initial structure. The heat exchange per linear meter decreases gradually with the operation of the system, and the initial structure decreases more and more rapidly. The heat exchange per linear meter of the initial structure decreases by 117.7 W/m in 30 days of operation, with a downward range of 46.1%, while the heat exchange of the reinforced spiral tube with the best heat exchange performance only decreases by 99.3 W/m, with a decrease of only 38.9%, indicating that the reinforced structure has better stability.

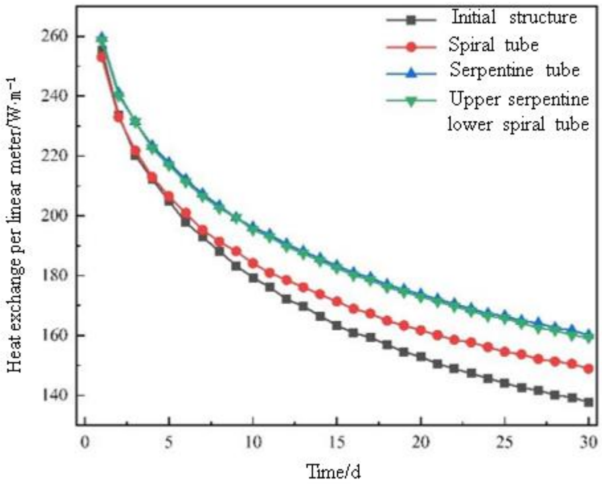
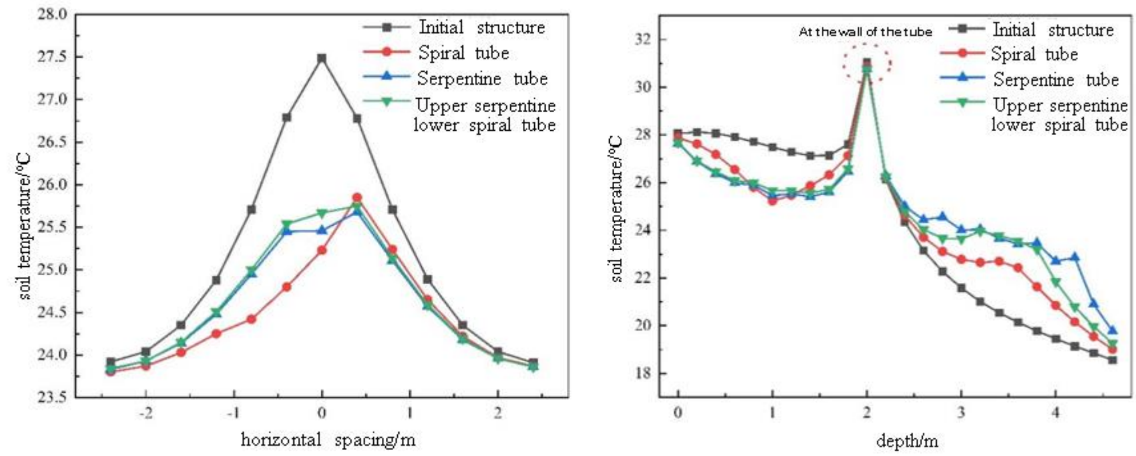


Figure 10： Comparison of heat transfer performance of different structures (Cooling)

Soil horizontal temperature comparison can be seen, the reinforced structure of the heat exchanger around the soil temperature compared to the initial structure has a significant decline in the serpentine tube and on the serpentine under the spiral structure of the overall drop in temperature is the largest, the spiral tube overall drop in temperature is the smallest, because the middle position is close to the tube wall at the center of the straight tube in the center of a high temperature point. Reinforced structure from the heat exchanger tube center horizontal spacing 0.8m range of the overall temperature drop of more than 0.5 ℃, from the center of the spacing 0.4m range of temperature drop is more than 1 ℃, the maximum drop in temperature reached 2 ℃, greatly reducing the heat buildup around the heat exchanger is an important reason to enhance the performance of the heat exchanger, compared to the left and right sides of the heat exchanger tube, it is clear to see that the side with a reinforced structure heat transfer temperature is lower, indicating that the heat exchanger structure effectively dissipates heat. The comparison of the soil depth direction temperature shows that the soil temperature around the heat exchanger with the reinforced structure also has a significant decrease compared to the initial structure. Compared to the spiral tube structure, the serpentine tube and the upper serpentine lower spiral structure have a lower soil temperature at the heat exchanger depth and a higher soil temperature at the deeper heat dissipation layer due to the narrower heat dissipation surface covered by the spiral tube in the vertical direction of the soil temperature and a smaller overall heat transfer. Contrast serpentine tube and upper serpentine lower spiral structure overall heat transfer performance is similar, but because the serpentine tube arrangement is deeper, which is not conducive to reducing the initial cost, so the upper serpentine lower spiral structure is more appropriate.

It can also be seen from the temperature diagrams of the initial and reinforced structures in Figure 12 that the large amount of heat accumulation around the heat exchanger in the initial structure leads to a larger temperature rise in the soil, resulting in a lower and larger drop in heat transfer; while the reinforced system continuously takes away the heat accumulated in the heat exchanger through the water circulation system and exchanges heat with the deeper soil, which strengthens the heat dissipation around the heat exchanger and plays a role in thermal balance, reducing the soil temperature around the heat exchanger and enhancing the heat transfer performance of the system.



(a)Horizontal direction from the center **(b)Depth direction**

Figure 11： Comparison of soil temperature of different structures (Cooling)

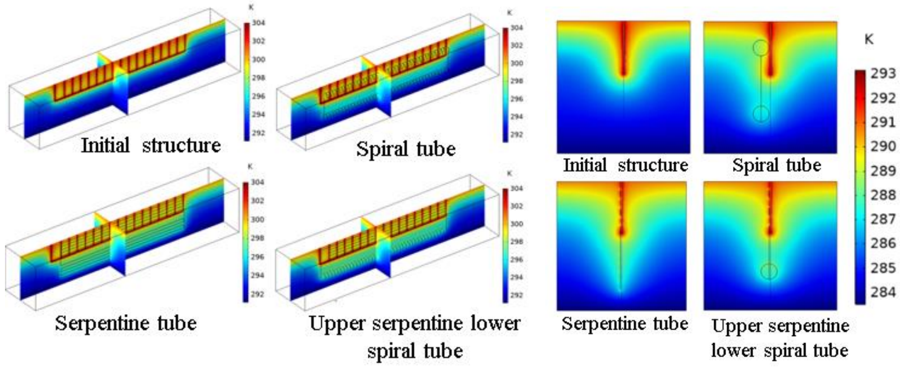


Figure 12： Temperature diagram of initial structure and intensified structure (Cooling)

4.2.2 Circulating water heat balance buried tube heating performance comparison

The system was operated for 30 days at an inlet temperature of 10℃, and the heat transfer performance of the initial structure and the water circulation heat balance buried tube reinforced structure under the heating condition is compared as shown in Figure 13. After 30 days of operation, the heat transfer of the three reinforced structures and the initial structure are 74.5 W/m, 80.1 W/m, 80.1 W/m and 66.4 W/m respectively, and the heat transfer of the three reinforced structures is increased by 12.2%, 20.6% and 20.6% respectively compared with the initial structure, which is more obvious with the operation of the system. The reinforced structure decreases less with the operation of the system and has better stability.

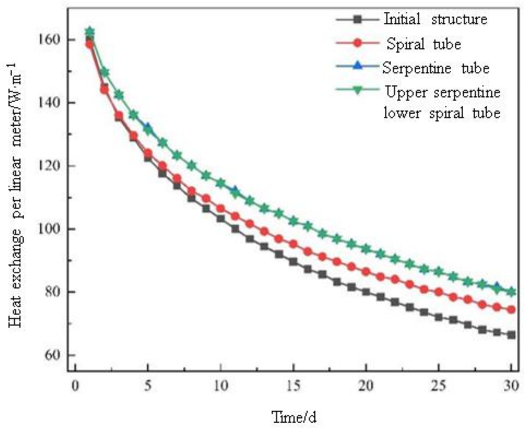
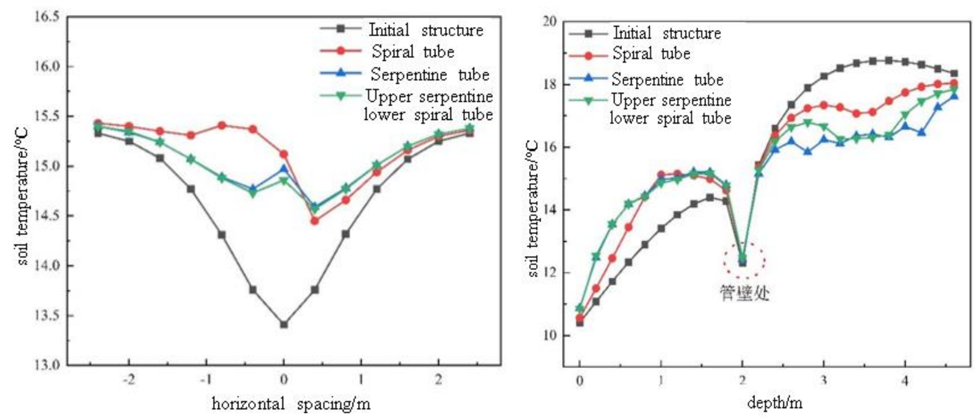


Fig. 13： Comparison of heat transfer performance of different structures (Heating)



(a)Horizontal direction from the center **(b)Depth direction**

Figure 14： Comparison of soil temperature of different structures (Heating)

Soil horizontal direction temperature comparison can be seen that the reinforced structure can effectively increase the soil temperature and greatly reduce the cold buildup around the heat exchanger is an important reason to improve the heating performance of the heat exchanger, as the middle position is near the wall of the tube so the straight tube has a high temperature point in the center. Soil depth direction temperature comparison can be seen, the spiral tube structure heat exchanger around the highest soil temperature, so the overall heat transfer performance is the best. In the lower part of the water circulation structure, the overall soil temperature is the lowest due to the greater heat transfer in the reinforced structure.

It can also be seen from the temperature plots of the initial and enhanced structures in Fig. 15 that the large amount of cold accumulated around the heat exchanger in the initial structure leads to a larger decrease in soil temperature, resulting in a lower and larger drop in heat transfer; while the enhanced system continuously takes away the cold accumulated in the heat exchanger through the water circulation system and exchanges heat with the deeper soil, which strengthens the cold dissipation around the heat exchanger and plays a role in thermal balance, increasing the soil temperature around the heat exchanger and enhancing the heat transfer performance of the system.

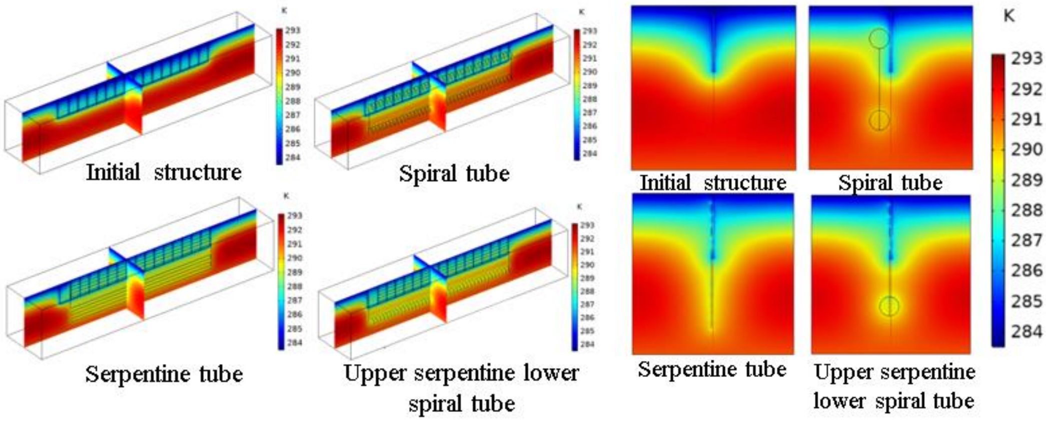


Figure 15： Temperature diagram of initial structure and intensified structure (Heating)

5. CONCLUSION

(1)A vertical inlet and flat outlet buried tube group is designed, and the structure has good stability and operation performance through load calculation and year-round simulation in an experimental building. The vertical inlet and outlet buried tube group has high heat transfer efficiency, compared with the vertical, horizontal and spiral tube structures of equal tube length, the heat transfer rate is increased by 65%, 114% and 65% respectively, and the stability of the system operation is better; the soil utilization range of the vertical inlet and flat tube group is larger, the heat dissipation surface is wider and the heat dissipation is more dispersed; the horizontal outlet tube reduces the thermal influence between the inlet and outlet tubes; increasing the soil utilization rate and reducing the thermal Increase soil utilization and reduce thermal impact are the key factors to strengthen heat exchange. The shallow heat pump system is influenced by the environment, and the heat exchange quantity decreases by about 20% when the ambient temperature increases by 5℃ in summer.

(2)For heat pump system, the heat exchange of rocky soil stratum is the largest, sandy soil is the second largest and clay soil is the smallest; the low heat diffusion coefficient of clay soil seriously affects heat exchange, sandy soil has small heat capacity and large heat diffusion rate, the rapid heat propagation leads to a larger range and higher soil temperature rise, thermal interference is the most serious, and the existence of large heat loss is not conducive to the long-term operation of the system.

(3)Three water circulation heat balance underground tube reinforced heat exchange structures were designed to improve the heat exchange performance of the system by adding a water circulation system to improve the heat accumulation around the heat exchanger. Compared with the traditional spiral tube underground heat exchanger, the three enhanced structures improved cooling heat exchange by 8.1%, 16.3% and 15.7%, and heating heat exchange by 12.2%, 20.6% and 20.6%, respectively.

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