Underground Thermal Engermal Energy Storage Storage Concrete Piples Around the Simulation and Analysis of Temperature Fileds

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Abstract: Based on the establishment of the concrete pile test-bed, the selection of concrete materials and the selection of insulation materials outside the concrete pile are compared, and the better materials are obtained. The heat exchanger is embedded in the concrete pile in advance, and the heat is stored in the concrete pile by using the heat source. By measuring the temperature and other parameters in different depths of concrete pile, the thermal storage effect of thermal storage pile is analyzed and the optimal thermal storage model is established. In this paper, through the study of the relevant data about the underground heat storage model of soil heat pump, the physical model and mathematical model used for the simulation and analysis of the temperature field around the buried pipe heat exchanger of underground concrete heat storage pile are obtained. In this paper, the single U vertical buried pipe is selected as the physical model, and the cylindrical heat source model is selected as the mathematical model, so as to simplify the heat exchanger around the buried pipe of underground concrete. The model of heat transfer is established. The mathematical model is analyzed with MATLAB. In this paper, the changes of concrete temperature with depth, radius, flow rate, specific heat and thermal conductivity are analyzed. The influence trend of these factors on the concrete temperature field around the buried pipe of the heat storage pile is summarized.

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1. Introduction
The solar energy received on the ground, affected by climate, day and night, season, is discontinuous and unstable. Therefore, solar storage is necessary, especially for large-scale use of solar energy. Solar energy can not be stored directly and must be converted into other forms of energy to be stored. At present, a new technology scheme of heat storage and heat recovery is put forward to store solar energy in underground concrete heat storage pile. In view of this method, the heat exchanger model is assumed in this paper. The heat conduction between underground concrete heat storage pile and heat exchanger is simulated and analyzed to consolidate the foundation for further research in this direction.

2. Brief introduction of underground concrete heat storage pile system
The underground concrete heat storage pile system includes heat storage pile, constant temperature water tank (simulated solar collector), automatic data acquisition and recording system and so on.
Concrete heat storage pile is to use concrete as heat storage medium, seal and heat preservation outside, form a closed heat storage space, and pass through the heat transfer pipeline, that is, buried pipe heat exchanger circulating heat medium, to achieve heat transfer. A carrier for the purpose of storing heat. The process of heat storage cycle is to draw constant temperature water from the lower end of the constant temperature water tank and return it to the water tank through the circulation pipeline\cite{1-3}.

### 3. Theoretical Analysis of Underground Concrete Heat Storage Pile

The underground concrete pile treated by grouting, heat preservation and sealing is actually a closed heat storage carrier, and the energy cannot be transferred out. The heat storage process is the internal heat transfer process with the buried pipe heat exchanger. Based on the theory of heat balance and thermal conductivity differential equation, the physical and mathematical models of heat transfer between underground concrete pile and heat exchanger are established.

#### 3.1. Physical Model of Heat Transfer between Underground Concrete Pile and Heat Exchanger

Assuming that the heat transfer temperature field of vertical single U heat exchanger is very complex, it is related to the type of concrete, thermal parameters, water content, heat pump running time, heat and cold load and so on. For the convenience of solving the model, the following assumptions are made: the concrete is uniform, the heat transfer mode between concrete and buried pipe is pure heat conduction; the heat transfer caused by water transfer in concrete; the contact between buried pipe and concrete is good and the contact thermal resistance is ignored; the concrete is stratified in depth direction, and the thermal conductivity of each layer is constant; The two branches of the U-shaped pipe are replaced by an equivalent pipe, and the equivalent radius \( r_e = \sqrt{2} r_p \), \( r_p \) is the radius of a single U-shaped pipe\cite{4}.

#### 3.2. Establishment of mathematical model of heat transfer between underground concrete pile and heat exchanger

Consider U tube an equivalent tube\cite{5-6}The heat transfer in the surrounding soil is a three-dimensional heat transfer problem. The heat conduction equation is as follows.

\[
\frac{\partial T}{\partial t} = \frac{\lambda}{\rho c_p} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + \frac{q_r}{\rho c_p} \tag{1}
\]

Considering that it is complicated to solve the temperature field directly by using the above three-dimensional heat transfer equation, the three-dimensional numerical solution is finally realized by coupling the heat transfer equation of different depths. In this paper, a two-dimensional heat transfer model around the equivalent buried pipe is established. The solution is carried out by numerical method.

### 4. Numerical Simulation of Heat Transfer Temperature Field

Through the above theory, the heat transfer model of underground concrete heat storage pile and heat exchanger is analyzed, and the temperature field around the heat exchanger is simulated and analyzed by means of mathematical method and numerical analysis software. The influence of heat exchanger on the temperature field of underground concrete heat storage pile can be accurately understood. The temperature field of heat exchanger and underground concrete heat storage pile is studied.

#### 4.1. Numerical solution of heat transfer model

Because the temperature distribution is mainly vertical and horizontal\cite{7}Therefore, the solution of temperature field mainly considers these two aspects. With the help of MATLAB software, different physical models are established and solved by PDE TOOL finite element method. The calculation flow is shown in figure 1.
4.2. Simulation Analysis of the Temperature Field of Concrete with Different Bored Radius

The radius of buried pipe can affect the flow rate and time of hot solution in concrete pile, and then affect the temperature distribution of concrete at a certain temperature. The distribution field of concrete temperature field under different radius of buried pipe is also different. The distribution model of concrete temperature field under different radius of buried pipe is studied. In this section, the temperature field of concrete under different buried pipe radius is analyzed. The parameters are as follows: \( h=1.5 \text{ m}, h=6 \text{ L/s}, \) specific heat capacity and heat flux of high temperature refractory Portland cement, respectively, and running time of 2400 h.

\[
V_f \ C_f = 4.2kJ/kg \cdot ^\circ C \quad \rho_f = 1.0 \times 10^3 kg/m^3 \quad 1.13J/(kg\cdot ^\circ C) \quad 1.28W/m\cdot ^\circ C
\]

Fig. 1 Block diagram of numerical simulation of temperature field around vertical U buried pipe

Temperature comparison table of concrete heat storage pile under different heat exchanger radius (Table 1).
Table 1. Temperature comparison of concrete heat storage piles during heat transfer with different radii heat exchangers

| Measuring distance | φ25 mm  | φ32 mm  | φ40 mm  |
|--------------------|---------|---------|---------|
| 0.09 m             | 54.13℃  | 58.94℃  | 60.75℃  |
| 0.5407 m           | 16℃     | 16.24℃  | 16.25℃  |
| 0.9997 m           | 6.877℃  | 6.882℃  | 6.895℃  |

According to table 1, under three different heat exchanger radii (φ25 mm, φ32 mm and φ40 mm), the larger the radius is, the higher the temperature of the pile near the heat exchanger is. However, the temperature at the edge of the pile has almost no change, which indicates that the larger the radius is, the easier the heat is to accumulate around the heat exchanger and is not easy to conduct, which is unfavorable to the long-term operation of the energy storage pile. The diameter of the concrete energy storage pile and the heat source flow should be combined. The results show that the diameter of the heat exchanger is φ25 mm and φ32 mm.

4.3. Analysis of the Temperature Field in Concrete Pile under Different Circulation Fluid Density

According to the formula, the heat transfer between underground pipe and soil is \( q = \frac{Q}{F} \) (where \( Q \) is the heat released from underground U-shaped pipe to soil in unit time and \( F \) is the surface product of equivalent underground pipe).

\[
Q = C_f \rho_f V_f (T_{f\text{in}} - T_{f\text{out}}) \tag{2}
\]

Where, \( C_f \), \( \rho_f \), \( V_f \), \( T_{f\text{in}} \), \( T_{f\text{out}} \) are specific heat of circulating fluid in buried pipe, \( \text{kJ/ (kg} \cdot \text{℃)} \); circulating fluid density, \( \text{kg / m}^3 \); circulating fluid flow, \( \text{m}^3 / \text{S} \); average temperature of fluid inlet in buried pipe, \( ℃ \); average temperature of fluid outlet in buried pipe, \( ℃ \). \( V_f \) from the above formula, it can be seen that the change can change the heat release from the underground U buried pipe to the soil per unit time, and at the same time change the fluid density in the buried pipe.

When the radius of buried pipe is 32 mm, the temperature field around the heat exchanger of underground concrete pile \( h=1.5\text{m} \) in concrete pile and the density of circulating fluid is 6 L/min, 9L/min, 12L/min respectively.

(1) When the circulating fluid density is 6L / min, the temperature field around the buried pipe of concrete pile is shown in Figure 3.

(2) When the circulating fluid density is 9L / min, the setting parameters are as follows: \( C_f = 4.2k\text{J/ (kg} \cdot ℃) \), \( \rho_f = 1.0 \times 10^3 \text{kg / m}^3 \), \( V_f = 1.5 \times 10^{-4} \text{m}^3 / \text{s} \), \( T_{f\text{in}} = 80℃ \), \( T_{f\text{out}} = 78℃ \), the specific heat capacity and heat flux of high temperature refractory Portland cement are \( 1.13J/ (\text{kg} \cdot ℃) \) and \( 1.28W / m \cdot ℃ \), and the operation time is 2400h.

Then

\[
Q = C_f \rho_f V_f (T_{f\text{in}} - T_{f\text{out}}) \tag{3}
\]

At the same time

\[
F = 2\pi r_{eq} \times l \tag{4}
\]

Heat flux density

\[
q = \frac{Q}{F} = 739J / S \cdot m^2 \tag{5}
\]

The temperature distribution of concrete pile and its plan are shown in Figure .2 below.
(3) When the circulating fluid density is 12 L/min, the temperature field distribution of underground concrete heat storage pile is shown in Figure 3.

Fig. 3 Temperature distribution of underground concrete piles at $V_f = 12$ L/min

Fig. 2 Temperature field distribution of underground concrete heat storage pile at $V_f = 9$ L/min
From the simulation analysis results Figure .2, Figure .3, the temperature comparison table of concrete heat storage pile with different heat exchanger flow rate can be obtained (Table 2).

Table 2. Temperature comparison of concrete heat storage piles with different heat exchanger flow rates

| Measuring distance | 6L/min | 9L/min | 12L/min |
|--------------------|--------|--------|---------|
| 0.09 m             | 57.94℃ | 83.46℃ | 105.5℃  |
| 0.5407 m           | 16.24℃ | 18.42℃ | 22.3℃   |
| 0.9997m            | 6.582℃ | 6.898℃ | 6.909℃  |

It can be seen from Table 2 that under the same circumstances, the temperature of concrete will rise greatly with the increase of heat exchanger flow in underground concrete pile, but it can also be obtained from the data. It can also be inferred that when the medium flow rate of heat exchanger reaches a certain limit, the temperature difference between concrete temperature and fluid medium is too small, which makes heat conduction difficult and unfavorable to heat transfer.

5. Concluding remarks

(1) Based on the theory of heat balance and the differential equation of heat conduction, the physical and mathematical models of heat transfer between underground concrete piles and heat exchangers are established to provide the basis for the simulation solution.

(2) The heat exchanger diameter and fluid medium parameters which affect the heat storage of underground concrete heat storage pile are simulated and analyzed.

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