Different surrounding ground buried pipes based on Fluent Simulation Analysis of temperature Field variation in Deep soil

Ma Kunru and Yu Ruijiao

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Ma Kunru, Yu Ruijiao
(School of Architecture and Engineering, Hebei University of Science and Technology, Shijiazhuang, Hebei, 050000)

Abstract:A simple buried pipe model is established by using Gambit modeling software, and its boundary conditions are defined.The numerical simulation software Fluent was used to simulate the temperature changes of the measured points at different distances from the buried pipe center, and the measured points at different depths were set at different distances.After six years of intermittent continuous simulation, it is concluded that when the distance from the center of the buried pipe is the same, the variation trend of soil temperature varies with the depth of the measuring point, and the greater the depth, the lower the temperature.When the depth of measuring point is the same, the temperature variation trend of each measuring point is different because of the distance from the measuring point to the center of the buried pipe, and the farther the distance, the lower the temperature.However, in either case, the temperature of each measuring point increases after the completion of heat collection every year, that is to say, the soil temperature increases after the system is completed normally every year.

Keywords: buried pipe; different depth; numerical simulation; temperature field; variation analysis

0 introduction

At this stage, especially in the rural areas of the north, there is still a large part of the traditional central heating system based on coal burning, but with the shortage of energy and the increasing demand for indoor comfort[1],The heating mode in various regions is changing to the direction of energy saving and emission reduction. The use of ground-source heat pump instead of the traditional heat source form has also been widely recognized in many regions.Heat pump, as a kind of special device, which can improve low grade heat into high grade heat by consuming a small amount of high grade energy, is favored by people[2].Ground-source heat pump is also called geothermal heat pump. It is a cooling source of heat pump in summer and a low-temperature heat source for heating in winter. It is also a system to realize heating, refrigeration and domestic water use[3].It is used to replace the traditional mode of air conditioning, heating and heating with refrigerators and boilers. It is an effective way to improve the urban atmospheric environment and save energy. It is also a new development direction of geothermal energy utilization in China[4].

There are some problems in the practical application of the device, mainly because the heating period is longer in the cold area of northern China[5].The heat extracted from underground in winter is greater than that of recharge in summer[6],that is, heat imbalance,If you use it for a long time,The underground temperature is lower and lower, and the heating effect is poor[7].The conventional solution is auxiliary heater heating, which to a large extent limits the ground source heat pump system to play the advantages of energy saving and environmental protection[8].Taking into account the rich solar energy resources of the North, so using solar energy as a renewable and clean energy source to replenish heat to underground soils in the non-heating season[9], That is to solve the imbalance of underground temperature field , effectively use clean energy to achieve energy saving and emission reduction and conform to the trend of the times[10]. Therefore, a comprehensive study of the underground temperature field will enable us to better grasp and apply the system.

1 Solar coupled ground source heat pump system

1.1 Composition of solar coupled ground-source heat pump system

In order to make full use of solar energy, the system stores the heat needed for building heating in spring, summer and autumn, and uses it in winter, and circulates this process every year. As can be seen from the figure, the system can be divided into three parts:

1.1.1 The collector part: the solar energy is collected through the plate heat exchanger 1 to heat the hot water in the water tank, that is, to reserve the hot water needed by the heating system.

1.1.2 The heat storage part: the water in the water tank is exchanged with the soil through buried pipes in the soil in an appropriate state, and the heat is stored in the soil for heating in winter.

1.1.3 The thermal user part: that is, heating the interior through different terminal devices in winter.

1.2 Operation of the solar coupled ground source heat pump system

1.2.1 Operation in non-heating season

In the non-heating season, the system collects hot water from solar heating tanks to raise the temperature. When a certain temperature is reached, the heat is transferred to the soil through the hot water in the buried pipe to raise the soil temperature. Soil is used as a heat reservoir to store heat for winter heating.

1.2.2 Operation during heating season

1.2.2.1 when the sun is good during the day,The heat collected by the collector is used to heat the hot water in the tank through the plate heat exchanger 1, and the heated hot water is heated directly through the plate heat exchanger 2 for the user. The heat stored in the soil can be heated by plate heat exchanger 3 when the user needs a heavy load.

1.2.2.2 when the light condition is poor during the day or there is no light at night, the heat stored in the buried tube is mainly used to heat the building through the plate heat exchanger 3, The insufficient part can use the auxiliary heat source to provide heat for the user through the plate heat exchanger 2.

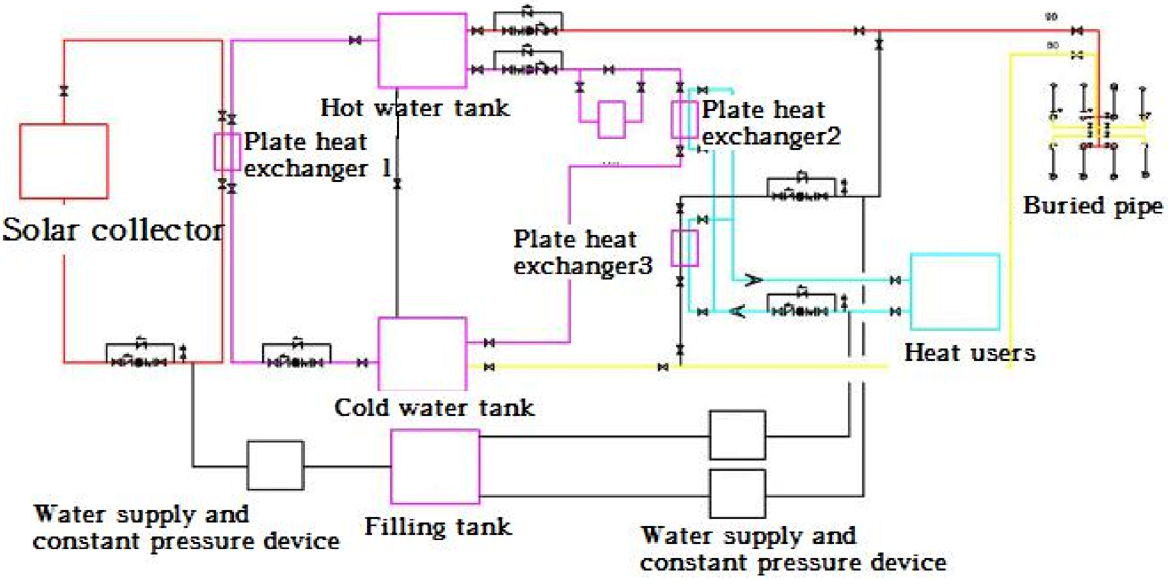

Fig. 1 Flow chart of solar coupled ground source heat pump system

2 Mathematical model of vertical U - tube heat transfer

2.1 Establishment of the model

The heat source model used in this paper is the line source model [11], which can treat the pipe buried vertically in the ground as a uniform line heat source and the soil outside the borehole as a whole [12]. Assuming that the heat loss per unit length along the depth direction of the line source is constant, that is, there is a constant heat flow, the earth around the pipe is regarded as an infinite entity[13]. The selection of parameters at the time of establishment of the buried pipe model is shown in Table 1 below:

Table 1 Model size of buried tube heat exchanger

Two U tube spacing	U-tube outer diameter	Backwater pipe spacing	U tube depth	Soil radius
3m	32mm	100mm	20m	10m

See figure 2 below for the specific model and grid division:

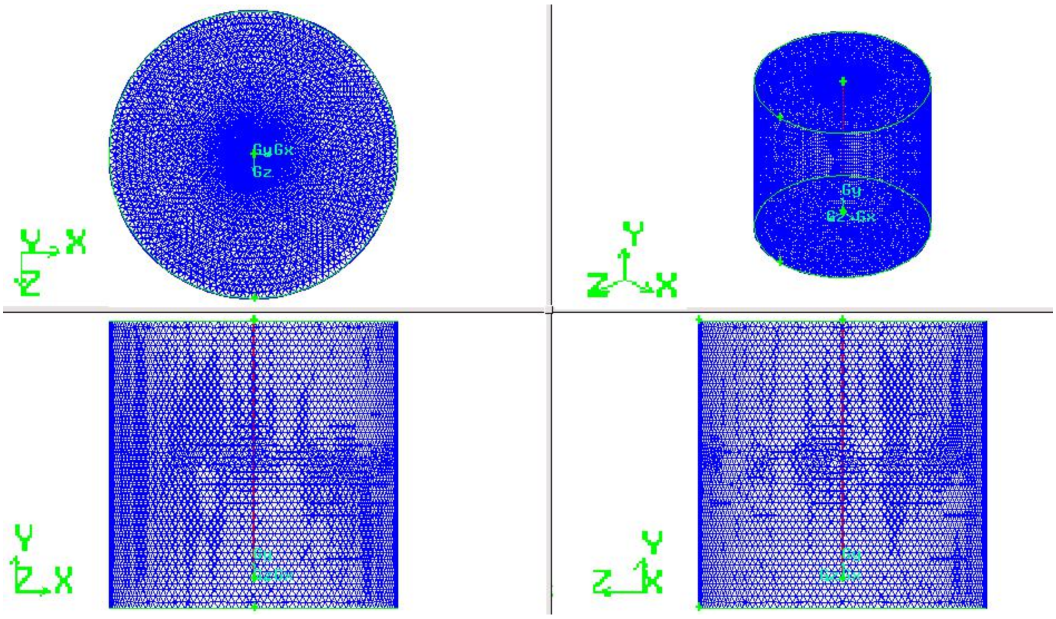

Fig. 2 Model and mesh generation

In this paper, the accumulator around the buried pipe is studied by taking clay as an example. In the course of calculation, the measuring points of different depth and distance from the buried pipe are set up in order to have a better understanding of the system. The physical properties of the material are shown in Table 2 below.

Table 2 Physical parameters of different regenerators

	Clay (moisture 15%)	water
Density $\left(kg/m^3\right)$	1925	998.2
Specific heat $\left(J/kg\cdot K\right)$	1298.7	4182
Thermal conductivity $\left(W/m\cdot K\right)$	1.5	0.6

2.2 Mathematical modelling

2.2.1 Mathematical model of fluid in pipe

The selection of K-ε mathematical model affects the accuracy of the calculation results. The mathematical model selected in the numerical simulation is the standard K- ε turbulence model. When the model is used to solve the convection heat transfer problem in turbulence, the governing equations include continuity equation, momentum equation, energy equation, K, ε equation and viscosity coefficient equation[14].

2.2.1.1 Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

2.2.1.2 Momentum equation:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial w}{\partial z}\right)=\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)-\frac{\partial p}{\partial x}$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)-\frac{\partial p}{\partial y}$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)-\frac{\partial p}{\partial z}$$

2.2.1.3 Energy equation:

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)$$

2.2.1.4 k, ε equation and viscosity coefficient equation:

$$\rho\frac{\partial k}{\partial t}+\rho u_j\frac{\partial k}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\eta+\frac{\eta_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_k}\right]+\eta_t\frac{\partial u}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\rho\varepsilon$$

$$\rho\frac{\partial k}{\partial t}+\rho u_k\frac{\partial k}{\partial x_k}=\frac{\partial}{\partial x_k}\left[\left(\eta+\frac{\eta_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_k}\right]+\frac{c_1\varepsilon}{k}\eta_t\frac{\partial u_i}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-c_2\rho\frac{\varepsilon^2}{k}$$

$$\eta_t=c_u{}'\rho k^{\frac{1}{2}}l=\left(c_u{}'c_D\right)\rho k^2\frac{1}{\dfrac{c_D k^{\frac{3}{2}}}{l}}=\frac{c_u\rho k^2}{\varepsilon}$$

$$c_u=c_u{}'c_Dc_u=c_u{}'c_D$$

The equation introduces three coefficients C_1,C_2,C_3 and three constants $\sigma_k,\sigma_\varepsilon,\sigma_T$, according to experience, the values of these six constants are generally 1.44，1.92，0.09 和 1.0，1.3，0.9，1.0。

In the form: x、y、z refer to the three coordinate directions in the coordinate system, m; u、v、w refer to the velocity in the three rectangular coordinate directions,m/s；t refer to the time,s; ρ refer to the density, kg/m3; μ refer to the dynamic viscosity, $N\cdot s/m^2$; p refer to the pressure, Pa; T refer to the Temperature, K; α refer to the thermal diffusion coefficient,m^2/s.

2.2.2 Temperature distribution in linear source model soil

$$t(r,\tau)=t_0+\frac{q_l}{4\pi\lambda}I\left(\frac{r^2}{4\alpha\tau}\right)$$

$$I(x)=\int_x^\infty\frac{e^{-s}}{s}ds$$

In the form:

$t(r,\tau)$——Temperature at any point in the soil，℃；

t_0——Geodetic initial temperature,℃；

q_l——Constant heat flux provided by line heat source，W/m；

λ——Soil thermal conductivity，$W/(m\cdot K)$；

α——Thermal diffusion coefficient of soil，m^2/s．

2.2.3 Determination of time required for underground temperature field to reach steady-state temperature

When the temperature of the unsteady heat transfer reaches 0.98 times of the steady state temperature, it is called that the unsteady heat transfer process there reaches the steady state.The time required for the system to reach the steady-state distribution was calculated by using the formula, and the variation of the underground temperature field during the simulation period was used to obtain the distribution of the internal temperature field of different regenerator at different times, and a relation of the time required for the system to reach the steady-state distribution was obtained by linear regression[15]:

$$F_o = 3.8R + 0.29\ (0.001 \le R \le 0.75)$$

In the form:

F_o——Dimensionless time, $F_o = \frac{\alpha_\tau}{H^2}$；

α——Thermal diffusion coefficient;

τ——The time it takes for the system to reach steady state, s;

H——Pipe range , m;

R——Relative radius, $R = \frac{r_0}{H}$, r_0——Pipe radius, m;

3 Analysis of simulation results

The system runs continuously for six years, during which the UDF program is loaded to control the solar energy illumination time, fluid flow rate and temperature.In order to obtain reasonable results and shorten the time required for simulation,the following assumptions were made when establishing the physical model of heat transfer: backfill, all parts of the soil were homogeneous and the thermal properties were the same [16]; Ignoring the contact thermal resistance between the buried pipe and the backfilling material, and between the backfilling material and the soil, and the heat conduction between the backfill material and the soil is considered as pure heat conduction[17]. The phenomenon of moisture transfer in soil caused by heat exchange between buried heat exchanger and surrounding soil is ignored [18]; The effect of heat transfer caused by groundwater flow is ignored [19]; The fluctuation of surface temperature and the influence of the temperature of rock and soil around the buried pipe are ignored [20], and it is considered that the initial soil temperature is the annual average soil temperature , and the final data will be analyzed[21].

In the course of simulation, different measuring points are set around the buried pipe. The distance from the transverse measuring point to the buried pipe center is 0.1m,1.1m,2.1m,3.1m,4.1m and 5.1m respectively, and then different depth is set at different center distance. Measurement points of different depths are set at different center distances, which are 5m,10m and 15m respectively.The temperature field is analyzed by the data generated in the process of comparison. Finally, the distribution of the temperature field is analyzed according to the soil temperature situation after the heat collection is completed every year. The detailed data are as follows:深度为 15m 的测点

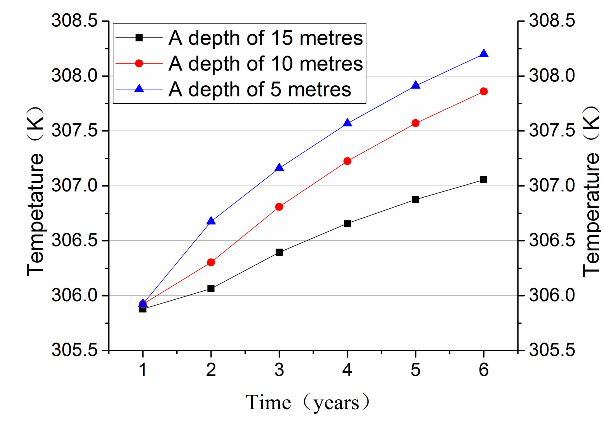

Fig.3 Temperature changes at different depth measuring points 0.1m away from the buried pipe center

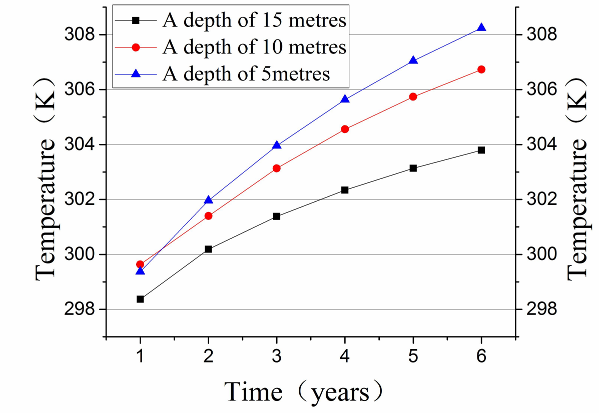

Fig.4 Temperature changes at different depth measuring points 1.1m away from the buried pipe center

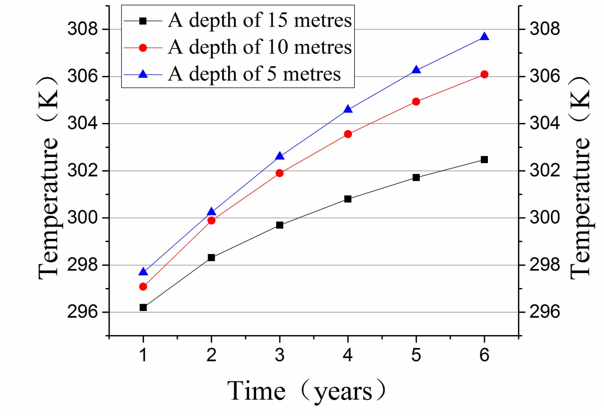

Fig.5 Temperature changes at different depth measuring points 2.1m away from the buried pipe center

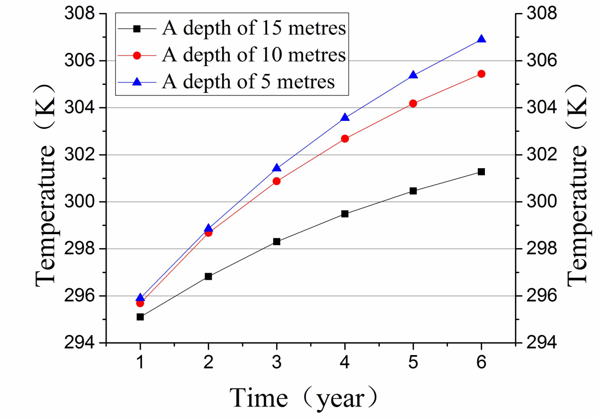

Fig.6 Temperature changes at different depth measuring points 3.1m away from the buried pipe center

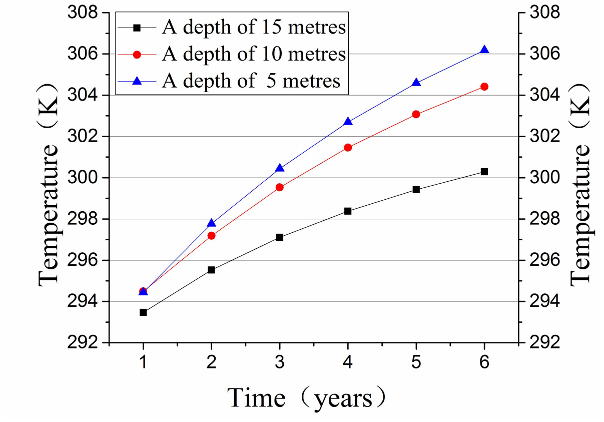

Fig.7 Temperature changes at different depth

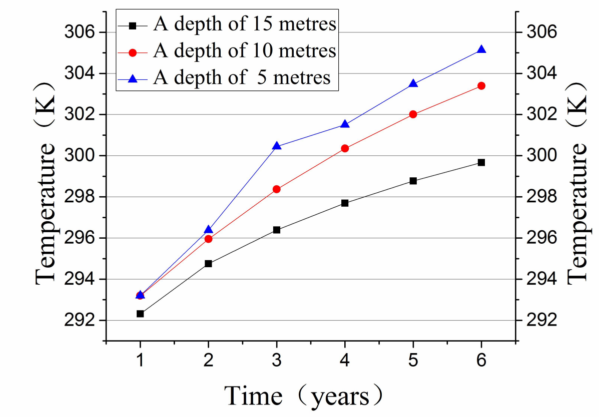

Fig.8 Temperature changes at different depth

measuring points 4.1m away from the buried pipe center

measuring points 5.1m away from the buried pipe center

From the above data, it can be seen that when the distance from the measuring point to the buried pipe center is the same, the temperature variation trend of the measuring points at different depths is roughly the same, but the specific values are different, and it also can be seen that the lower the temperature after the completion of heat collection each year, the deeper the depth is， the lower the depth, the higher the temperature, and with the increase of running time , the temperature of each point increases because the heat in the soil can not be taken out 100%.

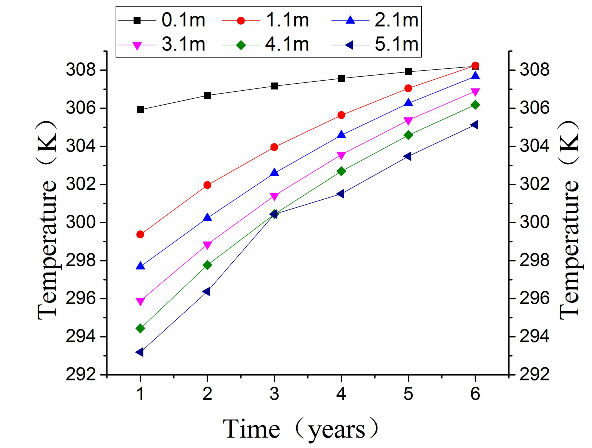

Fig. 9 Temperature change of measuring point when buried pipe depth is 5 m

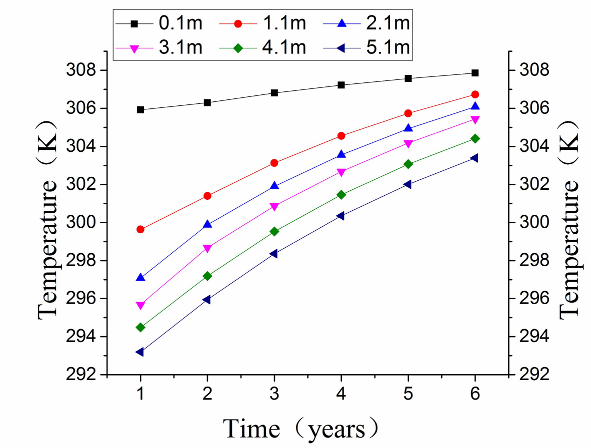

Fig. 10 Temperature change of measuring point when buried pipe depth is 10 m

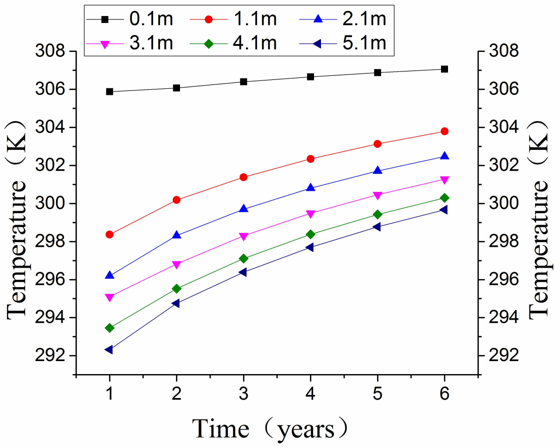

Fig. 11 Temperature change of measuring point when buried pipe depth is 15 m

From the data in the above figures, it can be seen that the temperature variation of different measuring points is different with different buried pipe depth, but the annual variation trend is basically the same. It can be observed that the closer the distance from buried pipe to the buried pipe, the higher the temperature after the end of the annual heating of the system,and the farther away it is, the lower the position is, and the temperature change of 0.1m measuring point is not as large as that of other measuring points after the end of heat collection every year, and the trend is different from that of other measuring points.

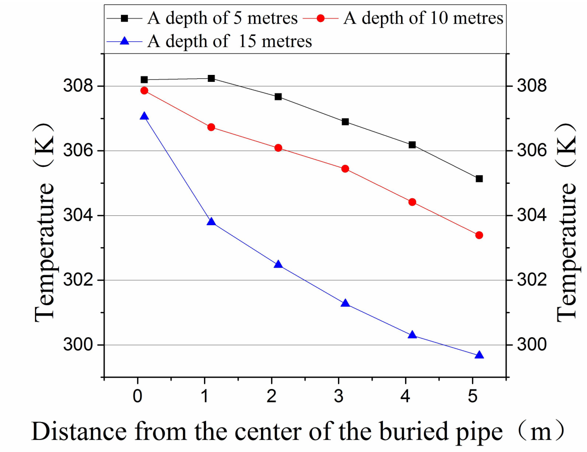

Fig. 12 Temperature of different measuring points after the sixth year of operation of the system

As can be seen from the above figure, the farther the distance from the buried pipe is at the same depth, the lower the soil temperature will be after the annual heat removal.

4 Conclusion

1) the temperature variation trend of the measuring points with different distance from the buried tube center is approximately the same after the completion of heat collection each year, and the temperature of the measuring point with greater depth is lower after the completion of the heat collection each year when the distance between the measuring points and the buried pipe center is the same.

2)When the depth is different, the variation trend of temperature is about the same after the completion of heat extraction, and the temperature change range of the point close to the center of buried pipe is smaller after the completion of heat collection each year. And the trend of change is basically the same as that of further observation points. And the longer the distance from the center of the buried pipe, the lower the soil temperature.

3)No matter which part of the soil, the temperature rises year by year after the heat is taken out, because the heat stored in the soil cannot be taken out 100%, and the buried pipe is only used for heat preservation at the top, without considering the heat preservation around and the bottom,which can actually cause energy loss.

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