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Research on Performance of Ground-Source Heat Pump Double U Underground Pipe Heat Exchange

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ABSTRACT

This paper uses FLUENT software building the three-dimensional unsteady state model of ground source heat pump single U and double U underground pipe to study on heat exchange of underground pipe system in the condition of unsteady state long-term continuous running, analyzes the change of soil temperature filed around underground pipe and performance of underground pipe heat exchange between single U and double U pipe system. The results show that double U pipe system is better than single U system, which can improve unit depth heat exchange efficiency, reduce the number of wells and reduce the initial investment.

Keywords: Ground-Source Heat Pump; Double U Underground Pipe Heat Exchange; Soil Temperature Field

1. Introduction

Ground source heat pump technology is a gradual rise of the energy saving technology along with global energy crisis and the emergence of environmental issues. Geothermal energy is a low grade energy, and a green renewable energy that human can use [1]. Conventional air conditioning high energy consumption and environmental pollution problem can be solved. The new geothermal energy could ease dependency of coal and oil in our country, and achieve the purpose of energy diversification. Currently some of residential districts, office buildings, hospitals and other kinds of buildings use the ground source heat pump system to heat and cool, and obtain good results. Ground source heat pump's characteristic is high initial investment, but low operating costs than conventional air conditioning system, so reducing the initial investment is very important to ground source heat pump. Double U pipe system can improve heat exchange performance, reduce the initial investment [2].

2. Introduction Model

2.1. The Theoretical Basis for Modeling

U-tube heat exchange process was divided into convective heat transfer between fluid and pipe wall, thermal conductivity between pipe wall and fill material, thermal conductivity of the fill layer, thermal conductivity be-

tween fill layer and the soil, thermal conductivity of the soil [3]. In this paper, the model was simplified in the allowable range, making the following assumptions:

- Thermal conductivity coefficient, density, specific heat capacity and other physical parameters of soil is uniform.
- When the system is running, ground water flow of soil around underground pipe lead to change of heat and moisture, the model ignore the change [4].
- Ignore the change of soil temperature with depth.

2.2. Physical Parameters

Parameters that affect the heat transfer include density, specific heat capacity, thermal conductivity of soil, fill layer, the fluid. In this model, pipes materials are high-density polyethylene pipe, backfill materials include 20% bentonite and 80% SiO_2 sand, the soil parameters is the weighted average of many local soil materials [5]. The material properties parameters of the model are shown in **Table 1**.

2.3. Geometric Model

This paper establishes the heat transfer model of the three-dimensional unsteady state of single U pipe and double U pipe, studies on the change of pipe outlet temperature, temperature difference of inlet to outlet, the mount of heat transfer and the change of soil temperature filed around underground pipe. U tube long for 100 m, tube diameter for 26 mm, tube wall thickness for 3 mm,

Table 1. Physical parameter table.

Materials	Density kg/m³	Specific heat capacity J/(kg·K)	Thermal conductivity coefficient W/(m·K)
Ter	998.2	4183	0.599
Pipe	950	2300	0.45
Backfill materials	1900	900	2.2
Soil	1600	1800	2

two tube feet spacing for 80 mm; double U model, two U tube parallel, four tube feet distribute square, edge long for 80 mm; drilling (filled layer) model is a cylindrical shape using two tube Center as circle, diameter for 140 mm, high for 101 m; soil model is also a cylindrical shape using the same circle, radius of 5 m, high for 105 m. The initial temperature of soil is 290 K, buried pipe inlet temperature is 310 K. The velocity is 0.4 m/s.

3. Numerical Simulation of Double U System and Single U System

3.1. Soil Temperature Distribution

Figures 1-**8** show soil temperature field of double U and single U pipe system run for 10 days, 30 days, 60 days, 90 days. In 30 m depth, intercept a square soil using tube centre as square centre, and side long is 2 m, research distribution of soil temperature field. Comparative analysis double U pipe and single U pipe effect on soil temperature field.

Figure 1 shows soil temperature field of double U and single U pipe system run 10 days. Compare **Figures 1** and **2**, it can be seen from the figure double U pipe impact on the surrounding soil temperature is slightly larger than the single U pipe system, after 10 days, soil temperature far from the pipe centre 1 m is 291.75 K, the temperature of the same locate in the single U system is 291.25 K. The soil temperature around the double U pipe growth rate is higher then the soil around the single U pipe. The soil temperature difference between double U system and single U system is 0.5 K in the radius 1 m.

Figure 2 shows soil temperature field of double U and single U pipe system runs for 30 days. System continuously runs for 30 days, soil temperature distance from the pipe centre 1m is 293.75 K, the temperature of the same locate in the single U system is 293.25 K. The soil temperature around the double U pipe growth rate is also higher then the soil around the single U pipe. The soil temperature difference between double U system and single U system is 0.5 K in the radius 1 m.

Figure 3 shows soil temperature field of double U and single U pipe system run 60 days. System continuously runs for 60 days, soil temperature distance from the pipe

centre 1m is 296.5 K, the temperature of the same locate in the single U system is 295.75 K. The soil temperature around the double U pipe growth rate is also higher then the soil around the single U pipe. The soil temperature difference between double U system and single U system is 0.75 K in the radius 1 m, slightly increase the temperature difference.

Figure 4 shows soil temperature field of double U and single U pipe system running 90 days. System continuously runs for 90 days, soil temperature distance from the pipe centre 1 m is 298.25 K, the temperature of the same locate in the single U system is 297.5 K. The soil temperature around the double U pipe growth rate is also higher than the soil around the single U pipe. The soil temperature difference between double U system and single U system is 0.75 K in the radius 1 m.

System continuously runs for 90 days in summer, to complete the summer cooling conditions. It can be seen from the figure, the two systems continuously run for 90 days, the double U system effects on soil temperature field is more than single U system. We can clearly see that there are two high temperature inlets and two relatively low temperature outlets in the double U plan. There is a high temperature inlet and a low temperature outlet in the single U plan. Double U system has two U shape pipes, four tube feet, influence on surrounding soil is bigger than single U system, with more heat transfer, so it can rapidly change surrounding soil temperature, with wide temperature range. But running after 3 months, surrounding soil temperature of double U pipe and single U pipe is little different, which is 0.75 K.

3.2. Comparison of Pipe Heat Exchange

Figures 5-**7** show that single U system and double U system outlet temperature changes with time. It can be seen from the figure, each U shape pipe outlet temperature basically same in double U pipe. Single U pipe outlet temperature and double U outlet temperature are same in the initial operation time; after that, double U pipe outlet temperature rise faster then single U pipe; run after 1 day, outlet temperature difference between single U pipe and double U pipe reach maximum value, and later gradually reduced. Running after 1 day outlet temperature of the single U pipe and the double U pipe are 302.31 K and 304.68 K, temperature difference is 2.37°C. Running after 90 day outlet temperature of the single U pipe and the double U pipe are 305.61 K and 307.03 K, temperature difference is 1.42 K.

Figures 8-**10** show that single U system and double U system change of temperature difference with time. It can be seen from the figure, two branch pipe temperature are basically the same in the double U system, temperature difference between inlet and outlet in the double U system is significantly lower than the temperature dif-
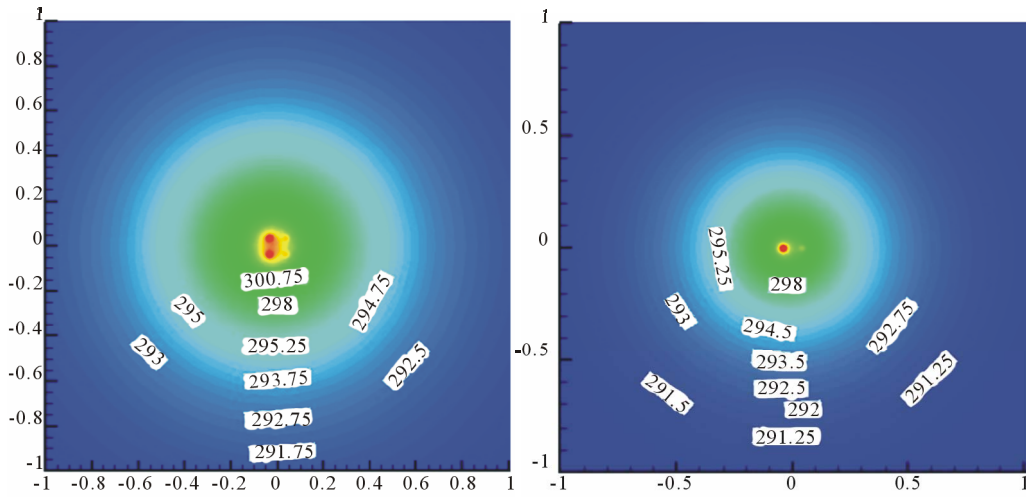
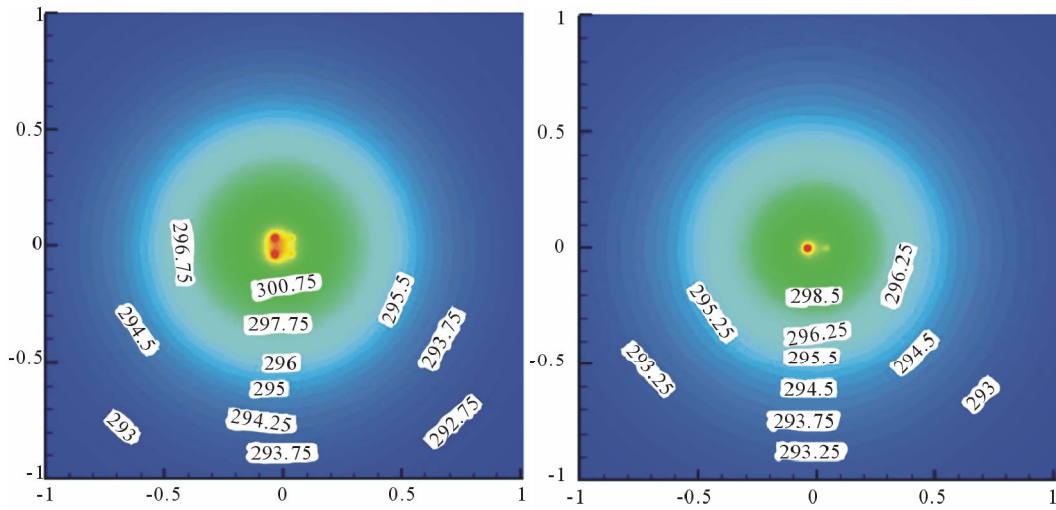**Figure 1. Soil temperature field of double U and single U pipe system run 10 days.**

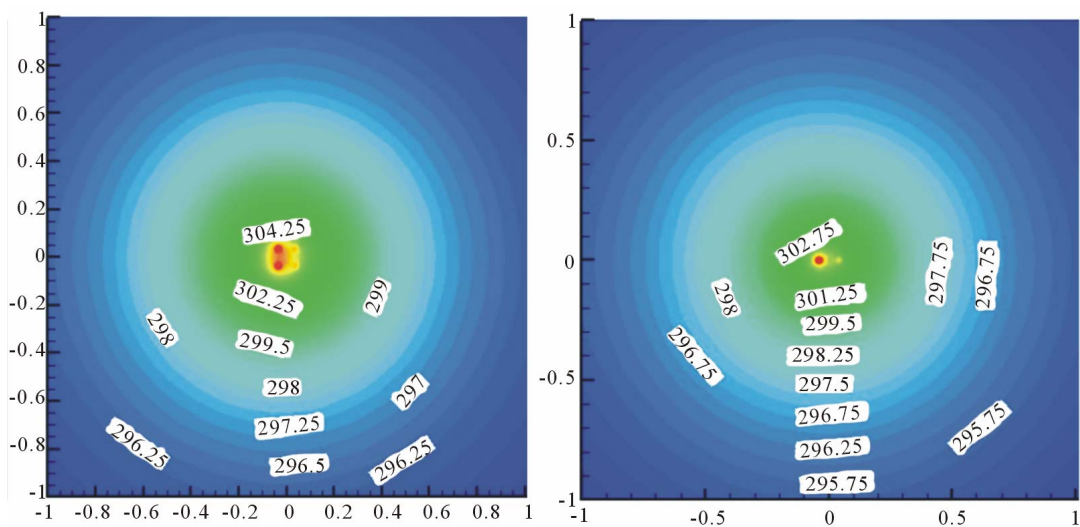**Figure 2. Soil temperature field of double U and single U pipe system run 30 days.**

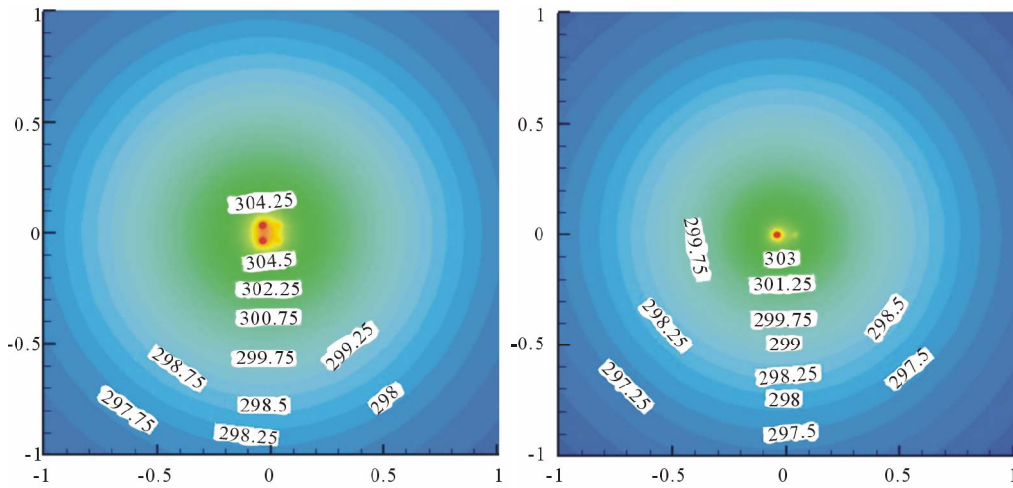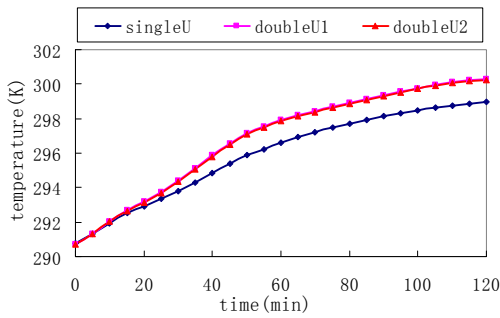**Figure 3. Soil temperature field of double U and single U pipe system run 60 days.**

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Figure 4. Soil temperature field of double U and single U pipe system run 90 days.

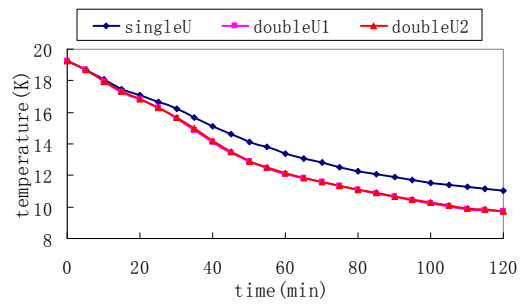
Figure 5. Run 2 h the change of pipe outlet temperature.
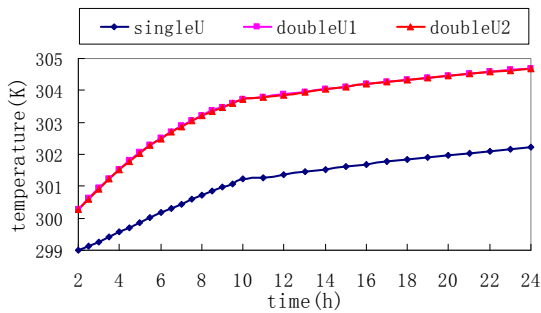

Figure 6. Run 2 h - 24 h the change of pipe outlet temperature.

Figure 7. Run 1 d - 90 d the change of pipe outlet temperature.

Figure 8. Run 2 h the change of pipe temperature difference.

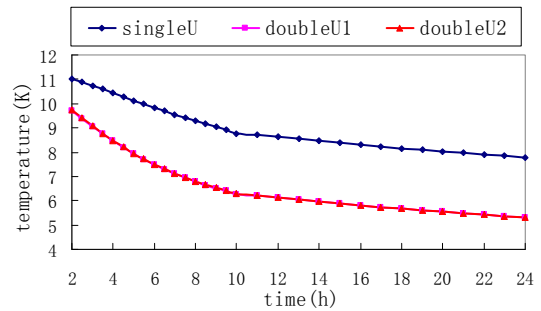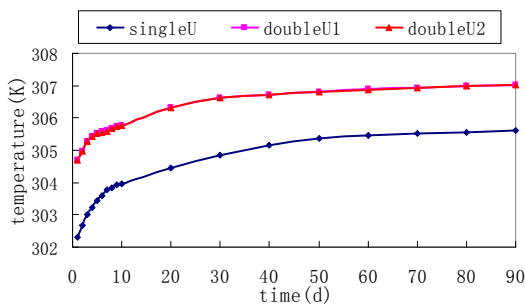**Figure 9. Run 2 h - 24 h the change of pipe temperature difference.**
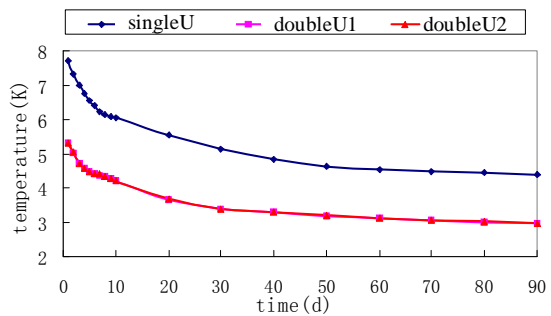

Figure 10. Run 2 h - 24 h the change of pipe temperature difference.

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ference between inlet and out in the single U system, because the number of tubes in the double U system every well is the number of tubes in the single U system every well, double U system have more heat transfer with surrounding soil, temperature of surrounding soil rapidly increases as time, temperature difference, heat transfer is small, so the temperature difference between inlet and outlet is small. However, heat transfer in the double U system is the sum of two U pipe heat transfer. Because the fluid flow in the double U pipe is twice of single U pipe.

Figures 11-**13** show that the change of unit depth heat exchange in the single U pipe and the double U pipe as time. **Figure 14** is comparison chart about unit depth heat exchange between single U pipe and double U pipe. U1 is one of the double U pipe, U2 is an another U shape pipe in the double U pipe, U1 parallel U2 form double U pipe, so double U pipe unit depth heat exchange is sum of U1 pipe heat exchange and U2 pipe heat exchange. We can see from figure that separate U1 and U2 pipe unit depth heat exchange is less than single U pipe heat exchange, but double U pipe unit depth heat exchange is the sum of U1 and U2 heat exchange, so heat exchange in the double U pipe is larger than the heat exchange in the single U pipe. Temperature difference between inlet and outlet is small, leading to heat exchange of each branch pipe is small, but double U pipe flow rate is single U pipe flow twice, or have two temperature difference, so the total heat exchange in the double U pipe is each branch heat exchange twice. Form **Figure 14** we can see that heat exchange of double U pipe is significantly higher than heat exchange of single U pipe. After system continuous operating 1 day, single U pipe unit depth heat exchange is 68.2 W/m, double U pipe unit depth amount of heat exchange is 94.3 W/m. After system continuously operating for 10 day, single U pipe and double U pipe unit depth amount of heat exchange are 53.6 W/m and 74.9 W/m. After system continuous operating for 1 month, single U pipe and double U pipe unit depth heat exchange are 45.6 W/m and 60.1 W/m. After system continuous running for 2 months, single U pipe
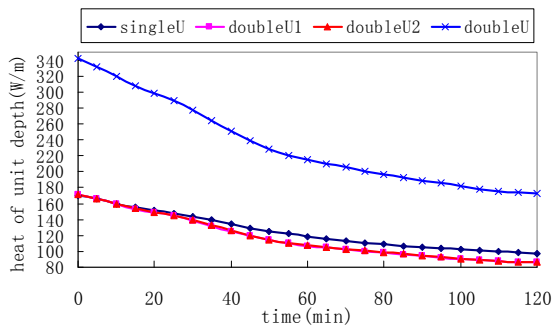

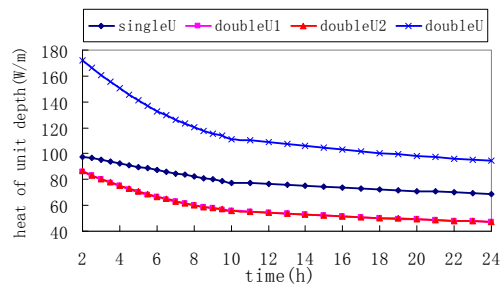**Figure 11. Run 2 h the change of pipe temperature difference.**

Figure 12. Run 2 h - 24 h the change of pipe temperature difference.
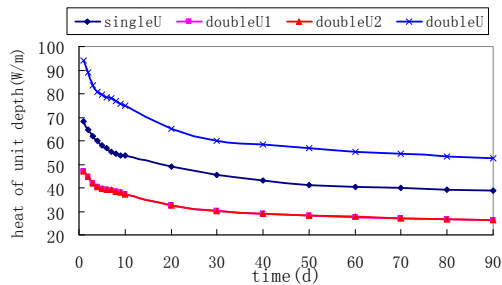

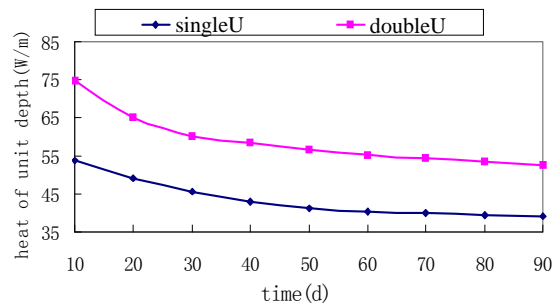**Figure 13. Run 2 h - 24 h the change of pipe temperature difference.**

Figure 14. Run 2 h - 24 h the change of pipe temperature difference.

and double U pipe unit depth heat exchange are 40.3 W/m, 55.3 W/m. After system continuous run 3 months, single U pipe and double U pipe unit depth heat exchange is 39.0 W/m, 52.6 W/m.

4. Conclusions

In this paper, using FLUENT software to simulate ground source heat pump single and double U-pipe system the long-term continuous operation in unsteady state conditions, the surrounding soil temperature changes and buried pipe heat exchange changes, get following conclusions though comparative study:

1) After the system running for 3 months, the soil temperature of double U system at the radius of 1 m rises to 298.25 K, the soil temperature of single U system at the radius of 1 m rises to 297.5 K. Double U system has more impact on the surrounding soil than single U sys-

tem, but not much difference.

2) After the system running for 3 months, temperature difference between inlet and outlet in the double U system is less than the temperature difference in the single U system, but the unit depth heat exchange is much larger than single U system, because the flow rate in the double U pipe is twice than the flow rate in the single U pipe, or we can say that double U system has two temperature differences, so unit depth heat exchange can greatly enhance, reduce the number of wells and reduce the initial investment.

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