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The Performance Simulation and Optimization of Ground Source Heat Pump Using TRNSYS

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Abstract

The dynamic performance of the whole year for Ground Source Heat Pump（GSHP） system is simulated using the software TRNSYS. The model of GSHP is built and economic performances are the object of optimization. The results show that: in the operation mode of using energy storage firstly, when the capacity of the heat pump is constant, the lager the storage water tank, the less the running cost. The payback period is increasing with the volume of the storage tank increases. When the storage proportion is less than or equal to 25%, the payback period of the coupled system is less than 5 years. As the storage proportion is varies from 10% to 100%, under the principle that meet the energy storage requirement and load requirement, when the storage proportion is 40%, the annual cost is the least, the economy of the coupled system is the optimal. When the storage proportion is less than or equal to 60%, the annual cost of the coupled system is all less than conventional ground source heat pump system.

Keywords: Ground source heat pump ; water storage tank; TRNSYS; running cost ; annual cost ; the payback period ; peak-valley price ratio

1. Introduction

Ground source heat pump (GSHP) system is now widely using in many areas of China as it can provide heat efficiently and economically with low emissions [1]. After introduction in the end of 20th century, GSHP system has achieved a rapid growth in China [2]. Ground-coupled heat pump (GCHP) system is a common type of GSHP system and has great advantage using in city or other area lacking of land space. In a GCHP system, BHE achieves the heat transfer between system and ground by extracting or rejecting heat through polyethylene tube with water or anti-freezing solution circulating in [3]. The cost of BHE installation may contribute to almost half of the total initial cost, so the parameters of BHE must be calculated properly to ensure an economic and efficient operation of GCHP system.

There are two kinds of heat transfer models that are commonly used for BHE design, including analytical solutions and numerical solutions [4]. Some analytical solutions, such as line source model [5] and cylindrical source model [6], have applied simplified computational model to increase compute speed but significantly reduce the accuracy. The BHE module of TRNSYS applies computational model based on temperature response function, which has advantage both in calculating speed and accuracy.

U-tube BHE with 32 mm outer diameter is most commonly used in practical application, while the thermal performance of U-tube BHE with other available standard diameters is relatively less studied. This paper investigated the thermal performance of U-tube BHE with four kinds of standard outer diameters, a case of GCHP system in Tianjin was simulated by TRNSYS and the influence of borehole depth and borehole diameter

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were discussed. To explain the simulation results, the effect of thermal resistance of U-tube wall was investigated by a single borehole simulation.

2. Case simulation

2.1. Simulation procedure

The object in the simulation case is an office building located in Tianjin with floor area of 1000 m2. The main parameters were shown below: soil thermal conductivity was 2.5 W/ (m K), soil specific heat was 1700 kJ/ (m3 K), soil surface temperature was 287.55 K, inlet temperature was 308.15 K and pipe thermal conductivity was 0.45 W/ (m K). A heat pump unit model (NLS-105.1) was chosen for the simulation. The cooling load of this case is more than the heating load so the simulation was conducted in the cooling season to meet the load demand, the simulation time is 90 days. In order to investigate the thermal performance particularly, the inlet temperature and the flow rate were considered to be constant during the simulation.

The standard U-tube outer diameters chosen for the simulation are 20 mm, 25 mm, 32 mm and 40 mm, as undersized U-tube does not has enough heat exchange area while oversized U-tube is not available for transportation. Borehole diameters include 3 values: 150 mm, 200 mm and 250 mm, borehole depths include 7 values: 60 m, 100 m, 120 m, 150 m, 200 m, 250 m and 300 m. Each kind of U-tube outer diameter was divided into single U-tube and double U-tube. In addition, the d istance between tube axis and borehole boundary was 25 mm in each group, i.e. different borehole diameters actually equals to different tube axis interval, which is also named as center-to-center half distance in TRNSYS.

BHEs number and heat exchange rate of each set were calculated in the simulation. At the beginning of the simulation, an initial heat exchange rate was set manually to calculate the initial BHEs number and initial flow rate, which is necessary for the following calculation. Then a new heat exchange rate will be calculated as well as a new BHEs number, if this number is equal to the in itia1 one then this set of simulation is completed, otherwise the iteration will be carried on.

2.2. Result and discussion

Fig.1 shows the heat exchange rate of each simulation set. Generally, heat exchange rate decreases when the borehole depth increases or the borehole diameter decreases, and the thermal performance of double U-tube is better than that of the single one. BHEs number varies inversely with heat exchange rate, so higher heat exchange rate means fewer BHEs and less installing cost. As the borehole depth increases, the influence of thermal interaction inside the BHE becomes significant and markedly reduces the heat exchange rate, which leads to longer total borehole length and higher initial cost.

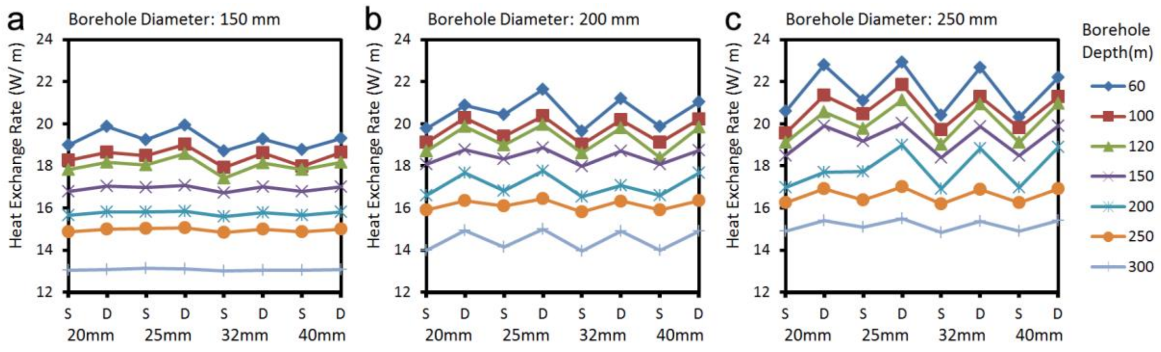

Fig.1 (a) Heat exchange rate of each set with borehole diameter of 150 mm, S stand for single and D stand for double; (b) Heat exchange rate of each set with borehole diameter of 200 mm; (c) Heat exchange rate of each set with borehole diameter of 250 mm.

The average relative heat exchange rate of each group is presented in Table 1. As it shows, the increase of borehole diameter improves the heat exchange rate and has more effect on 25 mm series against 32 mm series, which is considered to be the effect of wider interval between the tubes of BHE, which reduces the influence of thermal interaction, and this can also be used to explain the improvement of double U-tube, which increases the avenge heat exchange rate up to 7% when the borehole diameter is 250 mm, while the number is only 1.78% when the borehole diameter is 150 mm.

Table 1. Average relative heat exchange rate

Borehole diameter(m)	20 mm Single	20 mm Double	25 mm Single	25 mm Double	32 mm Single	32 mm Double	40 mm Single	40 mm Double
300	1.0100	1.0279	1.0209	1.0362	1	1.0221	1.0061	1.0230
400	1.0052	1.0588	1.0213	1.0687	1	1.0544	1.0035	1.0592
500	1.0033	1.0706	1.0333	1.0931	1	1.0807	1.0039	1.0790

It's worth noting that in each set of each group, the heat exchange rate is the highest when outer diameter is 25 mm, with improved ratio up to 4.85% compared with other d iameters. However, the Utube with outer diameter of 32 mm, which is normally applied in practical application in Ch ina, has the worst heat transfer performance among all kinds of diameters thus has the maximum boreholes number.

3. Single borehole simulation

A single borehole simulation was conducted to investigate the reason of relatively bad thermal performance of U-tube BHE with 32 mm outer diameter. Thermal resistance of the U-tube wall was considered to be a factor that may reduce the effect of heat transfer since the thermal conductivity of Utube wall is fairly small compare to that of soil and fluid, and the wall thickness of U-tube with 32 mm outer diameter is larger than that of 25 mm to ensure the structural strength, which leads to larger thermal resistance. Therefore, the heat exchange rate of U-tube with standard wall thickness was compared to that of 1 mm wall thickness, and the U-tube made by copper was used to verify the effect of thermal resistance. Simulation conditions were shown as follow: borehole depth was 100 m, borehole diameter was 250 mm and flow rate was 500 kg/ h, simulation results were presented in Fig. 2.

As the results shown, although the U-tube with 32 mm outer diameter has larger heat exchange area, it has bigger thermal resistance due to its bigger wall thickness which offsets the positive effect of larger heat exchange area and leads to a bad thermal performance. When the U-tubes with 4 kinds of diameter have the same wall thickness, the thermal resistance of each set becomes rather similar; when the material of the U-tube changes to copper which has relatively high thermal conductivity, the thermal resistance becomes quite small; in the above two situations U-tube with larger outer diameter exchanges more heat via bigger heat exchange area and has better thermal performance.

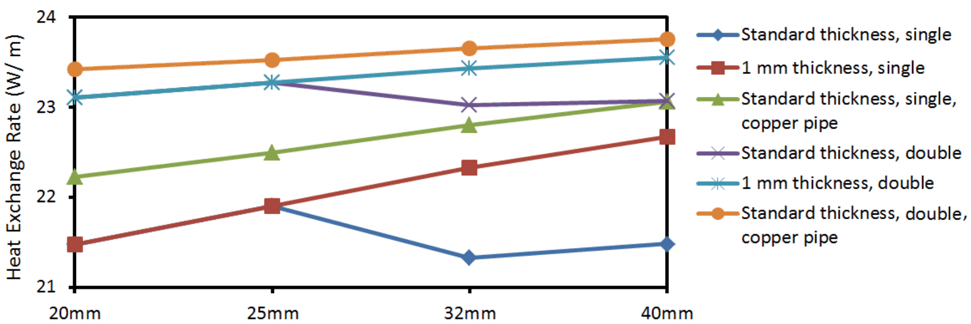

Fig.2 Heat exchange rate of U-tube BHE with 3 types of tube-wall

4. Conclusion

Thermal performances of U-tube BHE with different diameters were simulated by TRNSYS based on a GCHP case in Tianjin. The U-tube BHE with 25 mm outer diameter has the maximum heat exchange rate, however the U-tube BHE with 32 mm outer diameter, which is commonly used in practical application, has the worst thermal performance. As the borehole diameter increases or the borehole depth decreases, the influence of thermal interaction becomes less significant and increases the gap of heat exchange rate between 25 mm series and 32 mm series. Another single borehole simulation shows that thicker wall causes worse thermal performance of U-tube BHE with 32 mm outer diameter due to its larger thermal resistance, which offsets the positive effect of bigger heat exchange area.

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