Study on Optimization Design of Ground Source Heat Pump System with Horizontal Spiral Pipes

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Abstract. How to solve underground soil thermal balance problem is important for ground source heat pump system. Basing on the experiments of a ground source heat pump system with horizontal spiral pipes in Wuhan, the operation controlling strategies of intermittent operation and continuous operation in this system were studied in this paper. The temperatures of inlet and outlet water in the underground heat exchanger, and soil temperatures around the buried pipe were tested. And these temperature changes in the intermittent operation and continuous operation are compared and analyzed. The results show that soil temperatures around the buried pipe will recover quickly in the testing intervals of intermittent operation. Intermittent operation has advantages over continuous operation for this ground source heat pump system. It provided the designers of ground source heat pump system with beneficial information about underground soil heat accumulation.

1. Introduction

Ground-coupled heat pump systems are more frequently used as one of the most effective energy systems among renewable sources [1-3]. Heat is injected to the ground in cooling mode in summer and extracted in heating mode in winter in the same system. There are many factors that influence the heat transfer between underground soil and buried pipes, such as soil thermal-physical properties, dimension of ground heat exchangers and so on [4]. In winter cold and summer hot region, such as Wuhan in China, the heat extracted from underground soil in winter is greater than that injected in summer. How to solve the underground heat accumulation and improve the efficiency of ground source heat pump system is very important.

Majority of ground source heat pump systems use closed-loop ground heat exchangers installed horizontally or vertically [5, 6]. Basing on the experiments of a ground source heat pump system with horizontal spiral pipes in Wuhan, this study is focused on the analysis of ground source heat pump system performance optimization by proposing controlling strategies of intermittent operation and continuous operation of the ground source heat pump. It could help optimize the overall performance of the ground source heat pump system.

2. Experimental Test

The ground source heat pump system for experimentation was established in the campus of Wuhan University of Science and Technology in China. The buried ground heat exchangers consist of two horizontal spiral pipes, which respectively have a total length of 200m and 25mm diameter, 0.6m distance between two horizontal pipes, buried at the depth of 3m, with the working fluid flow flux of 8m\(^3\)/h.
The operation controlling strategies include intermittent operation and continuous operation of the ground source heat pump in heating conditions. The ground source heat pump system operated 10 hours a day for intermittent operation time and the testing time is 6 days. For continuous operation, the ground source heat pump system continuously operated 60 hours. The temperatures of inlet and outlet water in the buried pipe, together with the underground soil temperatures of selected three testing points are monitored efficiently. The experimental data for one horizontal spiral pipe were obtained from the ground source heat pump system respectively.

3. Results and Discussion

In the experiment, testing points 1-3 represent soil temperatures around the buried pipe. Testing point 1 is installed in the inlet of the buried horizontal pipe. The distance between testing point 1 and testing point 2 is 12m. Distance between testing point 2 and testing point 3 is also 12m. The data of temperatures of testing points and temperatures of inlet and outlet water were obtained under intermittent operation and continuous operation conditions of the ground source heat pump system. The experimental results are showing as Figure 1 to Figure 6.

3.1. Analysis of intermittent operation results

Figure 1 shows the changes of three testing soil temperatures around buried pipe in the first day of intermittent operation. The results show that the temperatures of testing point 1 and testing point 2 drop rapidly in the first three hours. And then the temperatures change stably. But the temperatures of testing point 3 are almost steady in the testing time. The reason is that testing point 1 and testing point 2 are close to the inlet of buried pipe. The inlet water with low temperature absorbs heat from around soil and leads soil temperature to drop rapidly. While the water temperature increases, it absorbs little heat and soil temperatures around the buried pipe will decrease slowly.

Figure 2 shows the changes of inlet and outlet water temperatures in buried pipe in the first day of intermittent operation. The results show that the temperature differences between inlet and outlet water are higher in the first three hours while the water absorbs heat from around soil rapidly. And then the temperature differences become lower while the water absorbs heat from around soil slowly. The temperatures of inlet and outlet water are all stable.

Figure 3 shows the changes of three testing soil temperatures around buried pipe after the end of the intermittent operation. The results show that the temperatures of testing point 1 and testing point 2 recover rapidly in the first 18 hours. And then the recovery of soil temperatures becomes slowly. Since testing point 3 suffers little influence from the buried heat exchanger, the temperature change of testing point 3 is not obvious.

In the experimentation of intermittent operation, the coefficient of performance (COP) of the ground source heat pump system is between 2.51 and 3.30. The energy efficiency ratio (EER) of heat pump unit is between 1.62 and 2.23.
3.2. Analysis of continuous operation results

Figure 4 shows the changes of three testing soil temperatures around buried pipe in 60 hours of continuous operation. The results show that three testing soil temperatures decrease in the experimental period in different degrees. The temperatures of testing point 1 and testing point 2 drop rapidly in the first 20 hours because they are close to the inlet of buried pipe. But the drop of the temperatures of testing point 3 is not very fast comparing with the temperature changes of testing point 1 and testing point 2.

Figure 5 shows the changes of inlet and outlet water temperatures in buried pipe in 60 hours of continuous operation. The results show that the temperatures of inlet and outlet water are decreasing through the experimental period. But the temperature differences between inlet and outlet water are almost stable.

Figure 6 shows the changes of three testing soil temperatures around buried pipe after the end of the continuous operation. The results show that the temperatures of testing point 1 and testing point 2 recover rapidly in the first 6 hours. And then the recovery of soil temperatures becomes slowly. The temperature change of testing point 3 is not obvious in the continuous operation period as Fig. 3 shows.

In the experimentation of continuous operation, the COP of the ground source heat pump system is between 2.38 and 3.22. The EER of heat pump unit is between 1.51 and 2.13.
4. Conclusion

The average temperature of outlet water in buried pipe for intermittent operation is higher than that of continuous operation. For heat pump system, the higher of outlet water temperature is, the bigger of its EER value will be.

In the testing intervals of intermittent operation, soil temperatures around the buried pipe will recover quickly. And in the total testing period, the dropping degree of soil temperature for continuous operation is higher than that of intermittent operation. In conclusion, intermittent operation has advantages over continuous operation for this ground source heat pump system.

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