Analysis of Selection of Single or Double U-bend Pipes in a Ground Source Heat Pump System

Haiwen Shu
Lecturer

Lin Duanmu
Associate Professor

Rongron Hua
Postgraduate Student

Civil and Hydraulic Engineering School of Dalian University of Technolog
Dalian, China 11602
shwshw313@sina.com

Abstract: The ground source heat pump (GSHP) system is widely used because of its energy-saving and environmental-friendly characteristics. The buried pipes heat exchangers play an important role in the whole GSHP system design. However, in most cases, single U-bend pipes are adopted only for their simplicity in design and construction instead of high efficiency and less operation cost of the whole system. In this paper, we make a comparison between single and double U-bend pipe heat exchangers in their heat exchange rate per depth, the number of boreholes needed for the same amount of cooling load, total lengths of pipes for the two different types of heat exchangers, and seasonal overall energy efficiency of the two GSHP systems. An economic analysis method is also presented. Finally, conclusions are made for the selection of single or double U-bend pipe heat exchangers in a GSHP system after a case study using TRNSYS simulation software is carried out.

Key words: Ground source heat pump, U-bend pipes, comparison, economic analysis

1. INTRODUCTION

The energy-saving and environment friendly characteristics of ground source heat pump(GSHP) system has been widely recognized.[1234] The GSHP system will be developed more rapidly in China especially under the background of constructing an energy efficiency society nowadays. The GSHP system with vertical buried pipes has relatively more application due to the fact that it is not restricted by underground water or surface water resources. Though many researchers believe that the cost of buried-pipe heat exchangers is one of the important reasons that slow the speed of the GSHP system's market penetration. [3][5] However, GSHP system with single U-bend buried pipes is often more adopted than the systems with double U-bend pipes in many projects. Then which one is the better solution? This paper will focus on the selection of single or double U-bend buried pipes in a GSHP system from engineering and economic perspectives.

2. METHOD

In a GSHP system, even only the buried pipes were changed from single U-bend type into double U-bend type, many other system characteristics will be changed consequently, such as the liquid flow rate in the buried pipes, the liquid temperature difference between flow in and out of buried pipes, heat exchange rate per borehole depth, electricity consumption of the heat pump and heat/cooling media circulation pump, and also the COP value of the whole system. So the problem will be overwhelmingly complicated if we try to analyze the system only from theory. Here a specialized software—TRNSYS—is used to simulate and help analyze the whole GSHP system.

As GSHP system with single or double U-bend buried pipes both have their own advantages and disadvantages, and investors usually pay more attention to the economic characteristics of the whole system in most projects, a technical economy analysis method is devised to evaluate the two different kinds of GSHP systems.

3. COMPARISON OF GSHP SYSTEMS

WITH SINGLE AND DOUBLE U-BEND BURIED-PIPE HEAT EXCHANGERS

3.1 Project Description and Heat/cooling Load Calculation Results

A four-storey office building in Shenyang, Liaoning province is selected as an example to demonstrate the method. The gross floor area of the building is 2100m^2. Other parameters for heat and cooling load calculation are as follows:

Heat transfer coefficient of exterior wall, window and ceiling are 0.5w/m^2·k, 2.83 w/m^2·k and 0.45 w/m^2·k respectively; 150 computers indoor altogether; average 13 w/m^2 of cooling load from illumination; average 200 persons in the building at the same time; the fresh air supply for each one is 30m^3/h·p.

The heating season of Shenyang is from November 1 to April 1 next year, and the cooling season is from June 1 to September 1. Figure 1,2 and 3 show the dynamic heat and cooling load calculation results, heat and cooling load duration profiles.

The maximum hourly heat and cooling load are 112kw and 130kw, and the annual total amount of heat and cooling supply are 88.9MWh and 70.5MWh respectively.

3.2 The Two GSHP Systems Simulation and Their Results Comparison

3.2.1 System parameters for simulation

For Shenyang locates in cold area, a glycol and water solution(with 25% glycol mass concentration and -10 freezing temperature) is used as the circulation liquid through buried pipes to prevent the system from freezing. The material of the buried pipes is the commonly used HDPE (high density polyethylene), whose thermal conduction is 0.46 w/m^2·k, with the inner/outer diameters of 25/32mm. As to the ground, its mean thermal conduction is 2.7 w/m^2·k, and its mean heat volume 2130KJ/m^3·k. All the borehole depths are set to be 100 meters. For a double U-bend buried-pipe heat exchanger has more thermal influence on the adjacent soil than a single U-bend one does, the distances between two boreholes for single and double U-bend pipes are set to be 5m and 7m correspondingly.

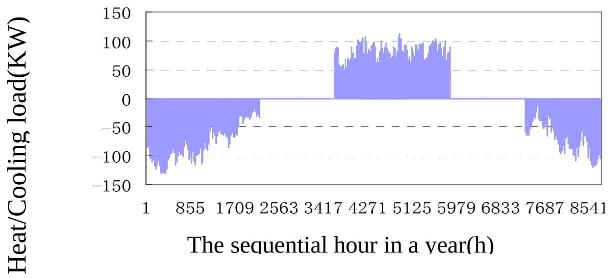

Fig.1 The dynamic heat and cooling load in a year

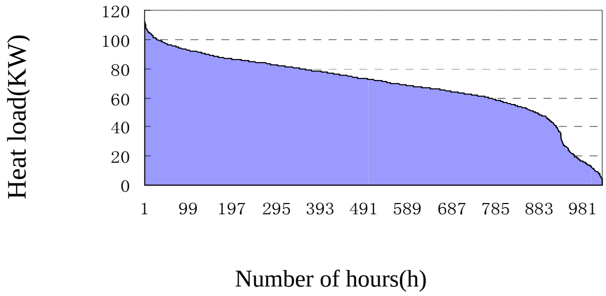

Fig.2 The heat load duration profile

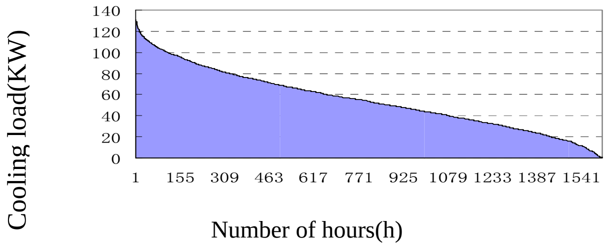

Fig.3 The cooling load duration profile

In addition, the two type of heat exchangers should be in basically the same operation conditions so as to compare their heat exchange capacities objectively. So the liquid temperatures flowing into the buried pipes of the two type of heat exchangers, and the liquid velocity in all the buried pipes are kept as the same as possible in system simulations.

3.2.2 System simulation results and analysis

After one year's simulation using TRNSYS software, results are obtained and listed in table 1 in which system 1 and 2 represent the GSHP systems with single and double U-bend buried-pipe heat exchangers.(Average COP value of the GSHP system here excludes the energy consumption of the heated/chilled water supply pumps.)

From table 1, it can be seen that the total pipe length and the total electricity consumption of the heat pump and the heating/cooling media circulation pump of system 2 are larger than those of system 1, however system 2 has its advantages in nearly all the other indexes. So a comprehensive economic index is

Tab. 1 The calculation results of the GSHP system

Items	Operation mode	System 1	System 2
Number of boreholes	Cooling/Heating	22	17
Total pipe length (m)	Cooling/Heating	4400	6800
Average heat exchange rate per borehole depth (w/m)	Cooling	78.1	98.9
	Heating	47.0	57.6
Average COP value of the heat pump	Cooling	5.6	5.24
	Heating	4.0	3.92
Total electricity consumption of the heat pump (MWh)	Cooling	22.3	24.1
	Heating	28	38.6
Total electricity consumption of the heating/cooling media circulation pump (MWh)	Cooling	2.4	4.9
	Heating	3.1	6.3
Average COP value of the GSHP system	Cooling	5.1	4.4
	Heating	3.7	3.4

Tab. 2 The economic indexes calculation results

The cost	Items	System 1	System 2
Initial cost (Yuan RMB)	Boreholes drilling	30.8×10^4	23.8×10^4
	Buried pipes	3.52×10^4	5.44×10^4
	Heat pump unit	11.7×10^4	11.7×10^4
	Heating/cooling media circulation pump	0.28×10^4	0.35×10^4
Operation cost (Yuan RMB)	Electricity consumption of heat pump unit	2.71×10^4	2.82×10^4
	Electricity consumption of circulation pump	0.25×10^4	0.50×10^4
Present Cost value (Yuan RMB)		71.50×10^4	69.51×10^4

needed to evaluate the two systems quantitatively, that is to make technical economy analysis

3.3 Technical Economy Analysis

Obviously, the outputs of the two GSHP systems are the same, that is, they both have the same effect of space heating and cooling, and also have the same lifecycle (Assume it to be 20 years here). According to literature [6], the Present Cost Method is adopted as the economic evaluation method. The method takes both initial and operation cost of a system into consideration. The system that has the least present cost is the optimal choice. On the basis of approximately the same installation cost, the economic analysis data is calculated in table 2.

The Present Cost (*PC*) values are calculated by:

$$PC=\sum_{t=0}^{n} CO_t (P/A, i_0, t) \qquad (1)$$

$$(P/A, i_0, t) = \frac{(1+i_0)^n - 1}{i_0 (1+i_0)^n} \qquad (2)$$

In which, *n*—Lifecycle of the system;

Co_t—Cash flow out in the t^{th} year;

P—Present value;

A—Annual value;

i_o—The basic interest rate, 10% here.

Since PC1＞PC2, it indicates that the second system is better than the first one, though the initial cost of the second system is higher than the first one. This reminds designers that the design scheme which can reduce the number of boreholes may have more economic advantages. We must point out that the *PC* values in table 2 are calculated on the basis of electricity price of 0.45 Yuan RMB/KWh (for civil use), and if the price was raised to 0.80 RMB/KWh (for industrial use), the *PC* values of the two systems would be 91.10×10^4 Yuan RMB and 91.50×10^4 Yuan RMB. Then the conclusion should be reversed.

4. CONCLUSIONS

(1) Specialized simulation software (e.g. TRNSYS) should be used so as to make quantitative analysis for the complicated GSHP system.

(2) Appropriate technical economy analysis method that takes both initial and operation cost into consideration should be adopted to help make decision on whether single or double U-bend buried-pipe GSHP system is a better choice.

(3)When the initial cost of borehole drilling is much higher, the GSHP system with double U-bend buried pipes is often a better solution from technical economy viewpoint.

REFERENCES

[1] Krishna C. Adivi. Simulation of a vertical ground-couple heat pump system with optimal ground loop design[D]. West Virginia: West Virginia University, 2003.

[2] Arif Hepbasli, Ozay Akdemir, Ebru Hancioglu. Experimental study of a closed loop veritical ground source heat pump system[J]. Energy Conversion and Management, 44,2003:527-548.

[3] Rybach L, Sanner B. Ground-source heat pump systems: the European experience [J]. Geo-heat center quarterly bulletin, 2000, 21(1):16-26.

[4] Chen Hongyong, Yin Kun, etc. The development of Geothermal heat pump technology [J]. World Geology, 2002, 21(2):203-207.(In Chinese)

[5] Yavazturk C, Chiasson. A D. Performance analysis of U-tube, concentric tube, and standing column well ground heat exchangers using a system simulation approach [J]. ASHRAE Trans., 2002, 108(1):925-938.

[6] Du Kui. Engineering Economics [M]. Chongqing: Chongqing University Press. 2000, 9-50.(In Chinese)