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Efficiency analysis of cross-season high-temperature energy storing in cold areas based on FLUENT simulation

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In this paper, by applying FLUENT simulation, a heat-storing and heat-removing system in cold areas was simulated, based on the interaction between the solar energy and the buried pipes. In spring, summer, and autumn, the soil is heated by the hot water produced from the solar energy, so the temperature of the soil is accordingly risen. This is the heat-storing stage. In winter, the cold water within the buried pipes is heated by the high-temperature soil, which can provide heat for the building. This is the heat-removing stage. According to this simulation process, the geometrical and mathematical models were established, the data when the system reaches balance were analyzed, the optimal distance for placing the buried pipes was obtained, and reference for actual projects was eventually provided.

Keywords: solar energy, buried pipe, heat-transfer simulation, heat storing, heat removing, heat providing

INTRODUCTION

Through combining with a heat-storing technology, the solar energy can be used more efficiently [1,2]. By virtue of certain storing media (such as heat storing based on hot water, heat storing based on gravel and water, heat storing based on soil with buried pipes, heat storing based on aquifer, etc.), Central Solar Heating Plants with Seasonal Storage (referred to as CSHPSS) can store solar energy (heat storing) in case of different demands for solar radiation and heat in different seasons. Through this process, the above-mentioned goal can be realized using solar energy more efficiently [3]. In this paper, among the various models of heat storing systems based on solar energy and buried pipes, the heat transfer model based on soil with buried pipes was chosen, taking the climate environment and soil environment of Shijiazhuang as an example, to simulate the long-term heat-storing and heat-removing process and analyze its energy efficiency.

In non-heating seasons, heat transfer between the water in the cold water tank and the hot water produced by the solar collectors will be conducted through the plate. When the water temperature rises, it will enter the hot water tank. When the water temperature of the hot water tank is higher, transfer between the hot water and the soil will take place.

The low-temperature water that flows out from those pipes will enter the cold water tank again, will be heated through the plate and will enter the hot water tank again. This process will circulate again and again.

EXPERIMENTAL

As shown in Figure 1, the main heat source of the whole heat providing system is the solar energy. The system can be divided into three parts [4-6]: (1) collector part, which mainly produces hot water, which is used to lift the temperature of the water tank through plate one; (2) the buried pipes part of the water tank, which is used to lift the temperature of the soil through the buried pipes; (3) the terminal of the heat users, which transfers the hot water heated by a variety of ways to the final heat users and provides heat for the building. In addition, the system is also equipped with an auxiliary heat source, pressurization through water refilling, and other devices [7].

At present, some technologies related to solar energy collectors are relatively mature, so in this paper, a simulation study on heat storing and heat removing of the soil, was conducted and its energy efficiency was analyzed.

Establishment of the geometrical model

The geometrical model consists of the following four parts: fluid (water), pipe wall, borehole backfill and ordinary soil [8,9]. In the FLUENT software, if a model is symmetrical, the symmetrical central plane can be set as a symmetrical plane, simplifying the calculation [10,11]. Because, in this paper, the buried pipes of the whole system take a cross form, so they are symmetrical in every direction. In order to reduce the time for calculation, a model based on a quarter of the whole one was established [12,13].

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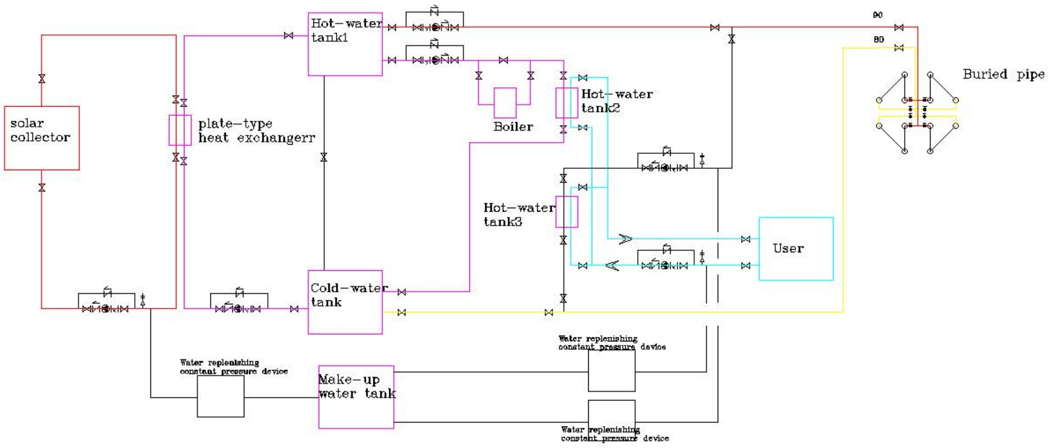


Fig. 1. System diagram on cross-season solar energy storage

The depth of the buried pipes is 20 m, which are composed of three U-pipes in a series. The outside diameter of the pipes is 25 mm. The three U-pipes are distributed in right-angle form. The size of the borehole is 150 mm. The structure is shown in Figure 2.

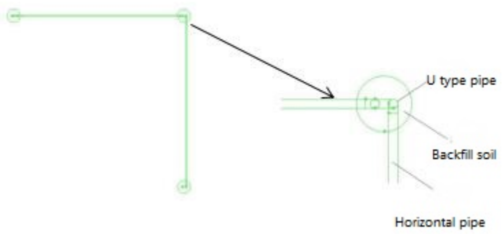


Fig. 2. Geometrical model of U-pipes and borehole backfill

In this model, the depth of the buried pipe is 20m. The distance from the farthest boundary of the soil to the outermost U-pipe is 20 m and it is divided into two parts. In the first part, the distance to the outermost pipe wall is 5m, while in the second part, the distance to the first part soil is 15 m, as shown in Fig. 3

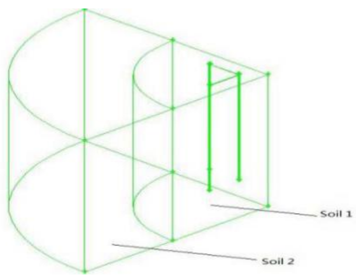
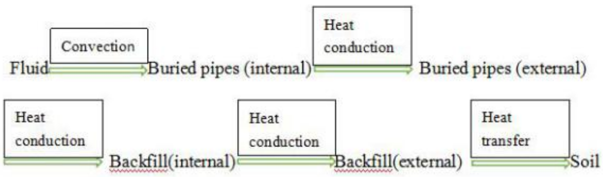


Fig. 3. Overall soil model

When the number of the drilling wells is determined, the interval among drilling wells has a great influence on heat storing and heat removing. In order to get the optimal interval, based on the above model, other specifications were left intact and only the interval among pipes was changed, establishing three models with different intervals (2m, 3m, 4m) to make comparison.

FLUENT numerical simulation

Heat transfer between the heat exchanger made by buried pipes consisting of U-pipes and the surrounding soil consisting of six processes



Boundary conditions and physical parameters: The soil temperature at the initial stage was set at 15ºC. Insulation layer was set at the upper surface, thus, taking it as the ideal situation, the upper surface was set as the insulation surface [14]. During heat storing, the inlet temperature was set at 90 ºC and the two right-angle surfaces were set as symmetrical surfaces.

RESULTS AND DISCUSSION

Determination of the thermal efficiency

For all models, during the heat storing process, the inlet temperature was 90 ºC; the flow velocity was 0.5 m/s; the time for heat storing was 5880 h (245 days); and the time for heat removing was 2880 h (120 days). Then, according to the different conditions related with the heat removing process, their influence on the results was analyzed. The specific types of heat removing are listed in Table 1.

Table. 1. Experimental models of different conditions

Material	Density	Specific heat	Thermal conductivity	Viscosity
Water	998.2	4182	0.6	0.001
Backfill	2082	837	0.8	
Soil	2082	837	0.8	

Because there are several models and the simulation time is relatively long, so, in order to reduce the time for simulation, two models with 3-4-meter intervals, respectively, were first chosen, and the inlet temperature during heat removing was set at 35ºC to conduct long-term simulation. The results from the preliminary simulation are shown in Figure 4.

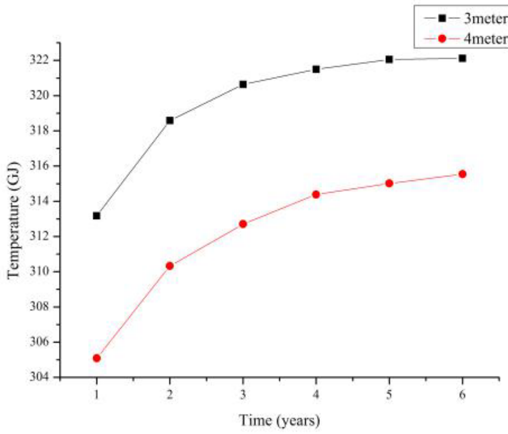


Fig. 4. Results of heat storage of soil under different conditions

According to the curve of soil temperature over time, it follows that 4 years later, when the heat storing ends, the change of the soil temperature tends to be smooth, and, at that time, the heat transfer rate reaches the highest level. So, the time for the system to reach balance is four years. Given it, each model can only simulate four years' time.

Efficiency of heat utilization under different conditions

Efficiency of heat utilization: it refers to the ratio between the heat removed from soil and the heat stored in it each year. Comparison of efficiencies of heat utilization over different intervals is shown in Figures 5-7. As can be seen, in the first year, the efficiency of heat utilization is generally low. The reason is that the soil temperature then is relatively low, so the heat stored in the soil is largely used to heat it. With the rise of the soil temperature, the efficiency of heat utilization also gradually increases. Among those models, the efficiency of heat utilization of the model with 2-meter interval begins to stabilize in the third year, with about 85% efficiency of heat utilization. However, the time for reaching stability for models with 3- and 4-meter interval was relatively long. In the actual situation, it is useless. So, from the view of practical application, the model with 2-meter interval is the best.

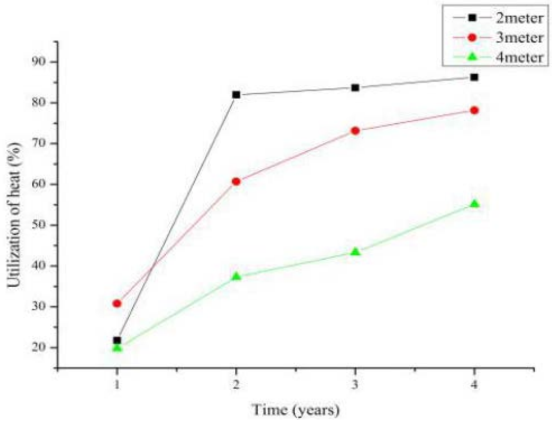


Fig. 5. Temperature of the return water during the heat removal process is 30 ºC

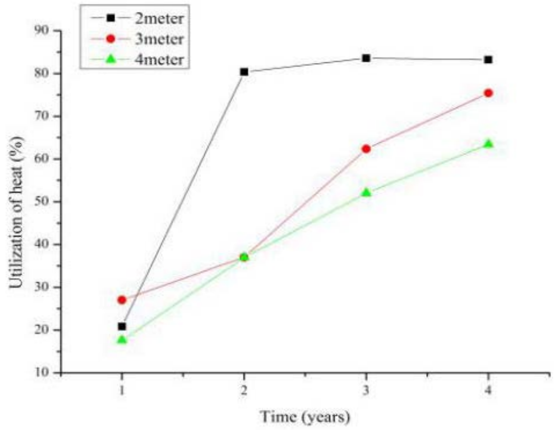


Fig. 6. Temperature of the return water during the heat removing process is 35 ºC

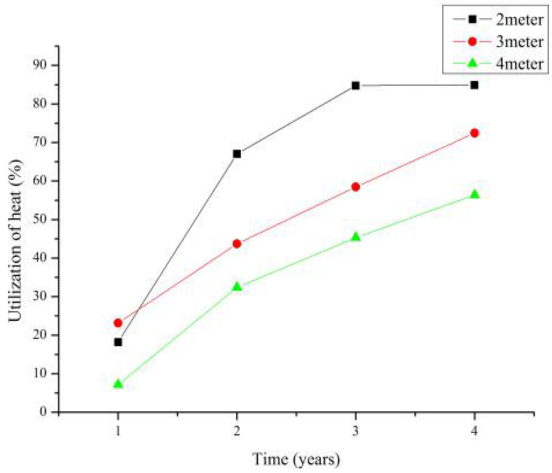


Fig. 7. Temperature of the return water during the heat removing process is 35 ºC

Calculation of the heat removing amount

The change of heat removing amount of the soil over time under different conditions is shown in Figures 8-10.

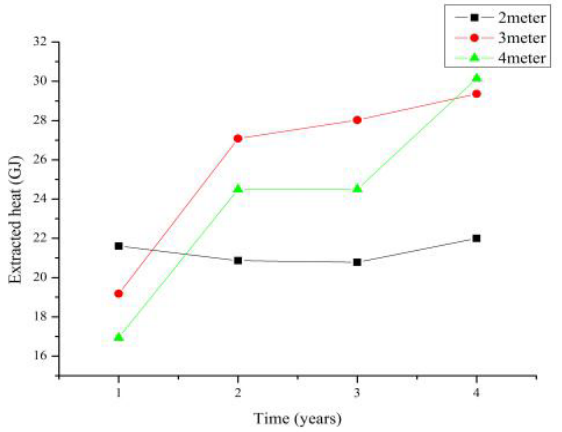


Fig. 8. Temperature of the return water during the heat removing process is 30 °C

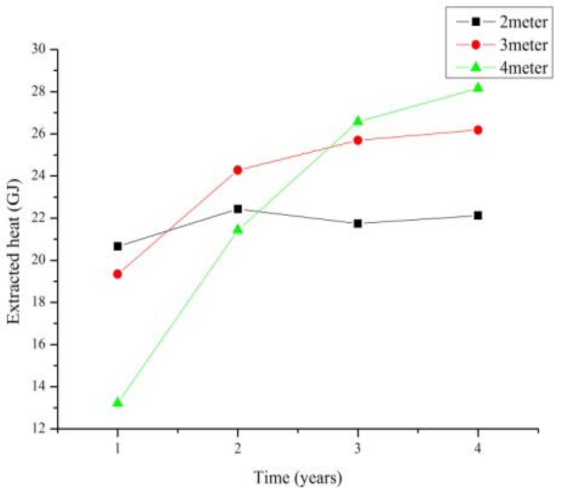


Fig. 9. Temperature of the return water during the heat removing process is 35 °C

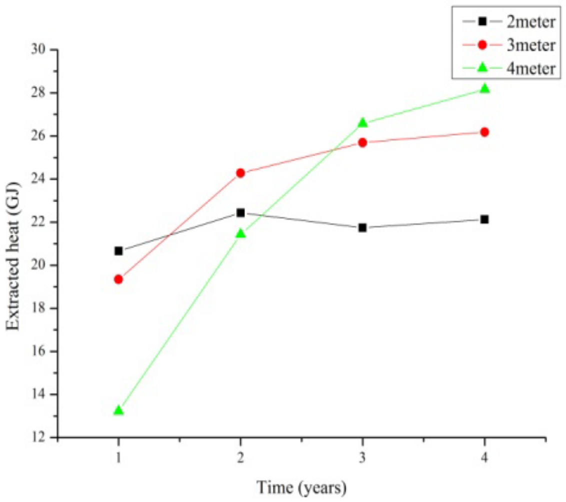


Fig. 10. Temperature of the return water during the heat removing process is 40 °C

According to the data above, when the temperature of the return water is 30°C, the final heat removing amount under 3-meter interval is almost the same as that under 4-meter interval; when the temperature of the return water is 35 °C, based on the same condition, the removing amount under 3-meter interval is by 2.2GJ lower than that under 4-meter interval; when the temperature of the return water is 40 °C, the final heat removing amount under 3-meter interval is by 0.48GJ higher than that under 4-meter interval. After comprehensive analysis, the 3-meter interval among buried pipes was considered as the best choice.

CONCLUSION

This paper simulates the cross-season energy storing of the solar energy with regard to the heat storing and heat removing of the soil. It was concluded that for Shijiazhuang, the heat storing and heat removing can reach balance after four years, and, at the same time, the ratio between the heat removing amount and the heat storing amount tends to be stable. After considering the efficiency of heat removing and the heat removing amount, the 3-meter interval was considered as most suitable for the actual project.

Table. 2. Specific values of the heat removing amount under different conditions

Values of the heat removing amount under different conditions in the fourth year (GJ)			
	Temperature of the return water		
	30 °C	35 °C	40 °C
2 m	21.99	22.12	20.48
3 m	29.44	26.17	23.2
4 m	30.18	28.37	22.72

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