Research of Aquifer Thermal Energy Storage System Integrated Underground Water Heat Pump

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Keywords

Aquifer thermal energy storage, energy storage efficiency, underground water source heat pump

ABSTRACT

Effect of aquifer thermal energy storage (ATES) of underground water heat pump system was researched. In winter, the heat pump extracted heat from underground water for space heating, at the same time, cold water was re-injected to underground and stored up around in-rejecting well, which would be used as the cool source of heat pump in summer. Similarly, in summer, underground water absorbed discharged heat of heat pump, and then temperature was raised and was re-injected to underground, which was stored up around the other in-rejecting well and would be supplied higher temperature water for the heat pump in winter. In this paper, the temperature and flux of production and re-injection wells had been tested in one year. Based on this datum, the ration of heat and cool energy storage was calculated; it indicated that the thermal and cool energy storage efficacy of the ATES system was 10.97% and 7.98% respectively.

1. Background

ATES is storing thermal energy or cool energy in the aquifer by re-injecting heated or cooled water into the underground, which using the characteristic of lower velocity and little temperature change of the water in the hole, crane and cavity of terrane of the underground[1]. Thermal energy storage (TES) applications around the world are known to provide economical and environmental solutions to the energy demand problem [2–6]. ATES systems, which help match energy supply and demand, contribute significantly to improving energy efficiency. Such systems increase the potential of utilizing renewable energy sources such as ambient cold air or waste heat. The use of fossil fuels and their release of carbon dioxide (CO_2) emissions into the atmosphere can be significantly reduced with TES systems.

Usually, the ATES Technology is combined with a heating and cooling system, and at present, most of which is combined with underground water heat pump system [7]. Underground water is used as heat source or heat sink of the heat pump. In winter, underground water is used as heat source of the heat pump, heat pump absorbs heat from underground water for space heating, at the same time, underground water temperature is falling, the cold water is re-injected to underground and stored up around in-rejecting well, which will be used as the cool source of heat pump in summer. Similarly, in summer, underground water is used as the heat sink of the heat pump, underground water absorbs heat of the heat pump system discharged and temperature rise, then the heated water is re-injected to underground and stored up around the in-rejecting well, which will be supplied as higher temperature water for the heat pump in winter.

In Turkey, the first application of HVAC system with integrated ATES was studied by H.O.Paksoy,Z. The results from the cooling mode in summer 2001 show that the ATES system uses 60% less electrical energy compared to a conventional system. The coefficient of performance (COP) of the system is expected to improve even more after completion of the heating mode in winter 2002. The total energy that can be stored with the ATES system is 0.4 MWh (3600000kJ) in the cooling demand months [8].

Before literatures about ATES I saw mainly pay attention to the application and the energy consuming decrease of the HVAC system. This paper is aimed to find a method of evaluating the energy storage effect of the ATES system quantificationally. Usually, underground water temperature of the aquifer is constant, but for the injection heated or cooled water to the underground, which will result in the underground water temperature around the injection wells rise or decrease. Then according to temperature change, the energy storage effect of the ATES system can be analyzed quantificationally.

2. System Descriptions

The aquifer thermal energy storage system integrated underground water heat pump is shown in Figure 1. This system was used to supply space heating and cooling for a hotel in Tianjin, using underground water as the heating and cooling resources for the heat pump; and at the same time, waste heating or cooling was re-injected into underground to gain seasonal energy storage. The total heating load is 366.6kW and cooling load is 488.4kW of this system. Two wells with depth of 210m were drilled. The distance between wells is 50m. Well number one (1) is the production well and Well number two (2) is injection well when heating, underground water is pumped into the evaporator from 1# well, in evaporator, cryogen R22 abstract heat from underground water and boils off, then the temperature of the underground water lowered and was re-injected into underground by 2# well, the cold water was stored around 2# well, which will be used in the summer. When cooling, the re-injected cold water was extracted from 2# well and entered into condenser, underground water absorb discharge heat in condenser and then temperature rise, then hot water outflow from condenser and was re-injected into underground by 1# well, the hot water was stored around 1# well, which will supply high temperature water for the heat pump in winter. In cooling mode, 2# well is the production well and 1# well is the re-injection well.

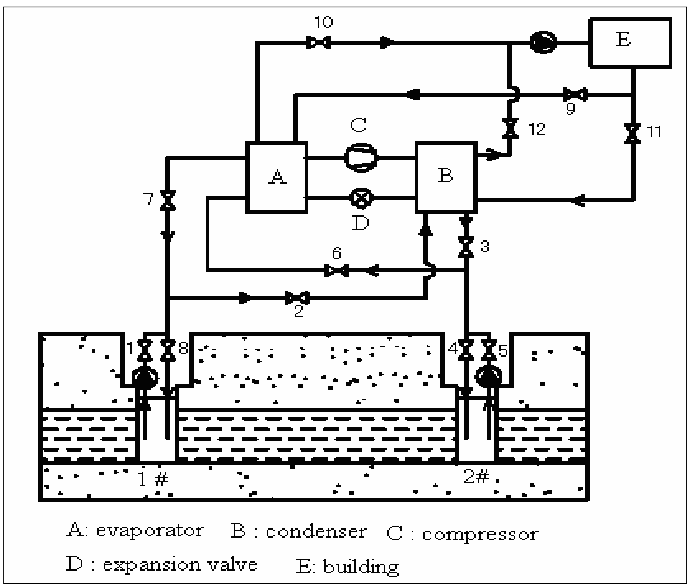

Figure 1. Diagram of Heat Pump Coupled Aquifer Thermal Energy Storage System.

3. Energy Storage Efficiency Definition

Energy storage effect of aquifer thermal energy storage (ATES) of underground water heat pump system was evaluated by energy storage efficiency. So Energy storage efficiency was defined, which is the ratio of storing energy and total energy abstracted from underground. The formula is

$$\eta = \frac{E_{st}}{E} \times 100\% \tag{1}$$

In the formula, E is the total energy of heat pump abstracted from underground, J, it is calculated by formula (2).

$$E = \int_0^n Gc\left|t_{ex} - t_{re}\right| d\tau = \sum_0^n Gc\left|t_{ex} - t_{re}\right| \tag{2}$$

G : Flux of underground water, m^3/d;
c : specific heat of water, J/(kg·°C);
t_{ex} : extract water temperature, °C
t_{re} : re-injected water temperature, °C
n : running time, day:

E_{st} is abstracted storing energy from underground, it is calculated by formula (3).

$$E_{st} = \int_0^m Gc\left|t_{ex} - t_0\right| d\tau = \sum_0^n Gc\left|t_{ex} - t_0\right| \tag{3}$$

t_0 : environment temperature of underground water °C;
m : running time when abstracted water temperature higher (or lower) than the environment temperature of underground water. When heating, m is the time of when abstracted water temperature higher than the environment temperature; when cooling, m is the time of when abstracted water temperature lower than the environment temperature environment temperature of underground water.

In winter, E_c is the heat energy storing in the water that temperature higher than the underground environment temperature, it can be considered as the heat energy stored in the aquifer, which is part of the re-injected heat energy in cooling mode.

In summer, E_c is the heat energy storing in the water that temperature lower than the underground environment temperature, it can be considered as the cold energy stored in the aquifer, which is part of the re-injected cold energy in heating mode.

4. Energy Storage Efficiency Analysis

4.1 Temperature of Extract and Re-Injection Water

In order to analyze the energy storage efficiency of the ATES system, temperature of extract water and re-inject water of one cooling and one heating periods were tested. The data were noted every two hours in all the cooling and heating days. Based on this data, the average temperature of every day was calculated, the temperature curves of extracted and re-injected water of cooling and heating periods were showed in Figure 2-Figure 5.

Figure 2 shows that in cooling days, extracted water temperature was lower than the underground environment temperature in 78 days. That is the result of re-inject cold water when heating. It indicates that the re-injected cold water to underground in winter can be stored in underground and supply lower temperature for the heat pump when cooling. This can improve the cop heat pump, saving energy consuming.

Figure 3 shows that in cooling mode, re-injected water temperature is much higher than the underground environment temperature. It indicates that heat energy was re-injected into underground in summer.

Figure 4 shows that in heating days, extracted water temperature was higher than the underground environment temperature in 75 days. That is the result of re-inject hot water when cooling. It indicates that the re-injected hot water to underground in winter can be stored in underground and supply higher temperature for the heat pump when heating. This can improve the cop heat pump, saving energy consuming.

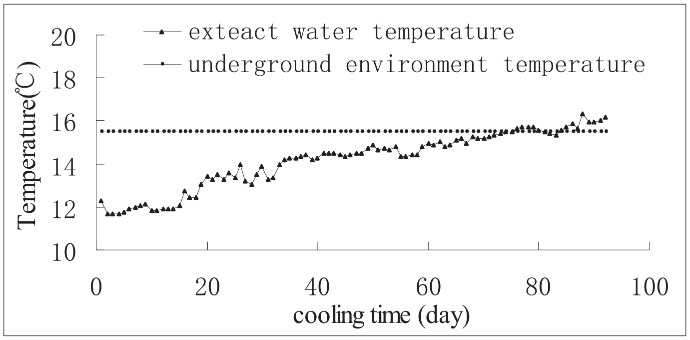

Figure 2. Temperature of Extract Water When Cooling.

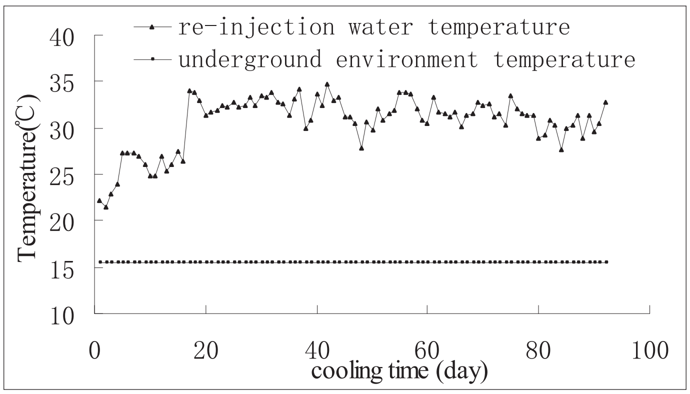

Figure 3. Temperature of Re-Injection Water When Cooling.

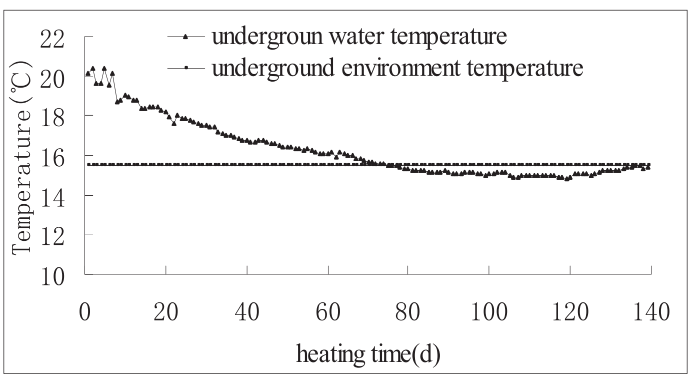

Figure 4. Temperature Of Production Well When Heating.

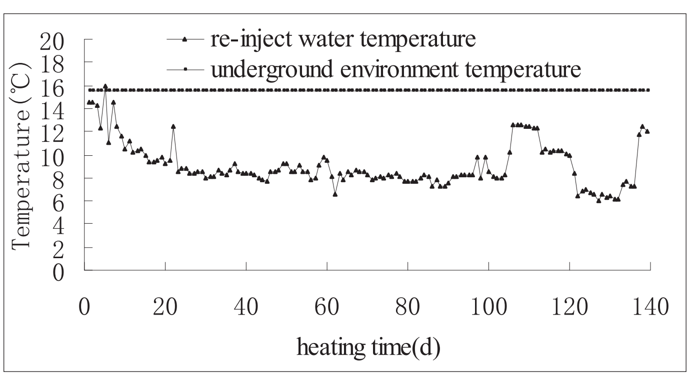

Figure 5. Temperature of Re-Injection Water When Heating.

Figure 5 shows that in heating mode, re-injected water temperature is lower than the underground environment temperature. It indicates that cold energy was re-injected into underground in winter.

4.2 Energy Storage Efficiency

Based on the tested temperature and flux of extract water and re-injection water, energy storage efficiency of the cooling and heating periods was calculated according to formula (1). Results of calculation are shown in table 1. In the calculation, the underground environment temperature was 15.5°C.

Table 1. Energy Storage Efficiency.

Running Mode	Cooling mode		Heating mode	
Temperature Range	T<15.5 °C	T>15.5°C	T>15.5°C	T<15.5°C
Running Time(d)	78	14	75	62
Efficiency	7.98%	0.37%	10.87%	2.34%

In Table 1, it can be seen that extracted water temperature was lower than the underground environment temperature in 78 days when cooling and the cool energy storage efficiency is 7.98%, and that extracted water temperature was higher than the underground environment temperature in 75 days when heating and the heat energy storage efficiency is 10.87%. It indicated that 7.98% cold energy when cooling was come from the re-injected cold in last winter and 10.87% heat energy when heating was come from the re-injected heat energy in last summer.

In Table 1, it also can be seen that extracted water temperature was higher than the underground environment temperature in 14 days, which energy and the total cold energy ratio is 0.37%. That is because the temperature of re-injection water is higher than the production well and the two wells are closer, the re-injection hot water flow into the production well, then caused the product well water temperature rise. That is disadvantage for energy storage. Similarly, when heating, in the 76th day, the re-injected lower temperature water flow into the product well and cause the temperature drop in the last 62days, which energy and the total cold energy ratio is 2.34%, which is disadvantage for energy storage. So in order to avoid the influence of re-injected water to production well, the distance of two wells should be large enough.

5. Conclusions

From the analysis of above, it can be concluded that the re-injected cold or hot water to underground in winter can be stored in underground. In cooling mode in summer, extracted water temperature was lower than the underground environment temperature in 78 days and the cool energy storage efficiency is 7.98%. In heating mode in winter, extracted water temperature was higher than the underground environment temperature in 75 days and the thermal energy storage efficiency is 10.87%. For the energy storage of ATES system, cop of heat pump was improved, and then energy consuming was saved.

But the re-injected water can be flow into product well in all cooling and heating mode, can resulted in the extract water temperature rise and lower in summer and winter respectively, which is disadvantage for energy storage. So the distance of two wells should be large enough to avoid the influence of re-injected water to production well.

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