Analysis of the influence of heat source well parameters on pumping temperature of groundwater source heat pump

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Abstract. In this paper, MATLAB software is used to simulate the influence of parameters of different heat source wells on pumping temperature in groundwater source heat pump system. The absolute value of horizontal permeability coefficient of aquifer will not affect its pumping temperature, but when the permeability coefficient ratio increases from 1 to 10, the pumping temperature decreases by 1.1 ℃; When the specific heat capacity increases from 2000 kJ / m³•℃ to 3000 kJ / m³•℃, the pumping temperature decreases by 0.8 ℃; When the degree of thermal dispersion increases from 1m to 3m, the pumping temperature decreases by 0.4 ℃.

Keywords: MATLAB; Ground water source heat pump; Parameters of heat source well; Pumping temperature.

1. Introduction
Due to the rich water resources in Tibet, and the groundwater source heat pump system uses almost constant temperature groundwater as the cold and heat source, and the energy consumption is only 70% - 80% of that of the conventional underground pipe system [1]. Therefore, it is feasible to popularize groundwater source heat pump system in Tibet. According to the different pumping and backwater modes, groundwater source heat pump system is mainly divided into two categories: different well recharge structure and pumping and irrigation same well structure [2]. The groundwater source heat pump system with pumping and irrigation in the same well reduces the number of wells drilled, and greatly reduces the construction cost and operation and maintenance costs compared with the system with different wells. In summer, the underground water source heat pump system discharges the excess heat in the room to the constant temperature underground water, which produces the indoor refrigeration function; in winter, the underground water source heat pump system extracts the heat higher than the outdoor in the groundwater and puts it into the room, thus producing the indoor heating effect. So as to achieve the purpose of seasonal energy storage and renewable energy recycling.

In this paper, based on the experimental data of the groundwater source heat pump system in the same well, the influence of the parameters of the heat source well on the pumping temperature of the groundwater source heat pump system is simulated by using MATLAB software.
2. Modeling

2.1. Establishment of model

The groundwater dynamic model of aquifer in the heat source well is [3]:

\[
\frac{1}{r} \frac{\partial}{\partial r} \left( K_r \frac{\partial s}{\partial r} \right) + \frac{\partial}{\partial z} \left( K_z \frac{\partial s}{\partial z} \right) = -v^2 s = \frac{\partial s}{\partial t}
\]  

Where: \( \nu \) is the groundwater overflow factor, \( s^{-1/2} \cdot m^{-1/2} \), \( \nu = \frac{\sqrt{K'}}{B} \). When it is connected with the underground aquifer as an aquiclude, \( \nu = 0 \); \( s \) is the drawdown of groundwater in aquifer, \( m_{H2O} \); \( t \) is the running time, \( s \); \( r, z \) is the component of cylindrical coordinates, \( m \); \( K_r \) is the horizontal permeability coefficient of aquifer, \( m/s \); \( K_z \) is the vertical permeability coefficient of aquifer, \( m/s \); \( B \) is the thickness of underground aquifer, \( m \); \( B' \) is the thickness of aquitard, \( m \).

The boundary conditions of outer shaft lining are as follows:

\[
\lim_{r=\infty} \frac{\partial s}{\partial r} = \begin{cases} 
0 & 0 \leq z < b_h \\
-\frac{Q_{w,p}}{2\pi k b_1} & b_h \leq z < b_h + b_0 \\
0 & b_h + b_0 \leq z < b_h + b_3 + b_0 \\
\frac{Q_{w,r}}{2\pi k b_2} & b_h + b_0 + b_3 \leq z \leq B - b_2 \\
0 & B - b_2 < z \leq B 
\end{cases}
\]  

Where: \( Q_{w,p} \) is the pumping flow of the heat source well, \( m^3/s \); \( Q_{w,r} \) is the reinjection water flow of heat source well, \( m^3/s \); \( K_h \) is the comprehensive permeability coefficient of heat source well, \( m/s \); \( b_1 \) is the distance between the bottom of the pumping filter section of the heat source well and the roof of the aquifer, \( m \); \( b_0 \) is the length of the pumping filter section in the heat source well, \( m \); \( b_3 \) is the distance between the pumping and return water filter sections in the heat source well, \( m \); \( b_2 \) is the length of filter section of return water in heat source well, \( m \); \( b_1 \) is the distance between the top of filter section of return water of heat source well and the roof of aquifer, \( m \).

2.2. Implementation of the model

In this paper, when using MATLAB software, its specific calculation parameters are set as follows: The aquifer thickness of the groundwater source heat pump system with pumping and irrigation in the same well is set as 40m, the radial flow range of groundwater in the heat source well is set as 200m, the unit water storage coefficient of aquifer in the heat source well is set as \( 1.0 \times 10^{-6} m^{-1} \), and the influence range of thermal dispersion caused by groundwater velocity fluctuation in aquifer is set as 1m. The whole model is uniformly set as non-uniform grid model. The impermeable layer thickness of the roof and bottom plate of the aquifer where the heat source well is located is set as 10m, the calculation range of the temperature field in the aquifer is set as 100m, the accuracy of the temperature field of the aquifer is set as \( 10^{-5} \), and the accuracy of the groundwater flow equation is set as \( 10^{-7} \). The number of grids is \( 152 \times 84 \) (horizontal \times vertical). Each time step is set as 3 hours, and the total calculation time is set as 72 hours (comparison test time). The physical and thermal parameters of the well are shown in Table 1.

| Subsoil               | Horizontal permeability coefficient \((10^{-3}m/s)\) | Permeability coefficient ratio (Horizontal / vertical) | Volume specific heat capacity \((kJ/m^3\cdot\degree C)\) | Thermal conductivity \((W/m\cdot\degree C)\) |
|----------------------|-----------------------------------------------|-----------------------------------------------------|-----------------------------|-----------------------------|
| Plain fill layer     | ---                                           | ---                                                 | 2607                        | 1.80                        |
| Clay layer           | 0.1                                           | 1                                                   | 2600                         | 1.80                        |
| Gravelly clay        | 15                                            | 1                                                   | 2600                         | 1.80                        |
| Coarse sand and gravel | 8                                               | 1                                                   | 2600                         | 1.80                        |
2.3. Model validation

Due to the different pumping flow of the groundwater source heat pump system in the test, the temperature difference between the pumping and return water of the heat source well will be different (the pumping flow will increase, and the temperature difference between the pumping and return water will decrease), as shown in Table 2.

| Table 2. 4 kinds of test conditions |
|------------------------------------|
| Pumping flow | Condition 1 | Condition 2 | Condition 3 | Condition 4 |
| Temperature difference between pumping and return water | 8m³/h | 10m³/h | 12m³/h | 14m³/h |
| | 2.5°C | 2.1°C | 1.8°C | 1.6°C |

Now in order to verify the correctness of the model established in this paper, the temperature difference between the pumping and return water of the heat source well in this paper is set as 2.5 °C, 2.1 °C, 1.8 °C and 1.6 °C respectively. The model calculation results are compared with the experimental results, as shown in Fig. 1-4.

![Fig. 1 Pumping flow is 8m³/h](image1)

![Fig. 2 Pumping flow is 10m³/h](image2)

![Fig. 3 Pumping flow is 12m³/h](image3)

![Fig. 4 Pumping flow is 14m³/h](image4)

It can be seen from figure 1-4 that under different working conditions (condition 1-condition 4) simulated in the established model, the simulated value of the groundwater source heat pump system is in good agreement with the experimental measured value. Taking the simulation condition 1 as an example, the measured value of pumping temperature is 17.9 °C, the simulated value is 18.7 °C, the absolute error is 0.8 °C, the error is only 4.5%, and the error range is less than 5%; The measured value of return water temperature is 20.4 °C, the simulated value is 21.3 °C, the absolute error is 0.9 °C, the error is only 4.4%, and the error range is less than 5%. Therefore, the correctness of the model is verified by the above data. The reason why the temperature of pumping and return water in the model is higher than that in the test is mainly because the influence of factors such as overflow and seepage between aquifers is ignored. The summary of the model and experimental measurements is shown in Table 3.
Table 3. Summary of testing and simulation

| Parameter                                              | Condition 1 | Condition 2 | Condition 3 | Condition 4 |
|--------------------------------------------------------|-------------|-------------|-------------|-------------|
| Pumping flow (m³/h)                                     | 8           | 10          | 12          | 14          |
| Temperature difference between pumping and return water (°C) | 2.5         | 2.1         | 1.8         | 1.6         |
| Average temperature of test pumping water (°C)          | 17.9        | 18.8        | 21.5        | 23.2        |
| Average temperature of test return water (°C)           | 20.4        | 20.9        | 23.3        | 24.8        |
| Simulated pumping average temperature (°C)              | 18.7        | 19.7        | 22.3        | 24.2        |
| Simulated average backwater temperature (°C)            | 21.3        | 21.8        | 24.1        | 25.8        |
| Error of average pumping temperature (°C)               | 0.8         | 0.9         | 0.8         | 1           |
| Error range (%)                                         | 4.5%        | 4.8%        | 3.7%        | 4.3%        |

3. Influence of parameters of heat source well

3.1. Influence of horizontal permeability coefficient
In this section, under condition 1, only the absolute value of the horizontal permeability coefficient in the aquifer of the heat source well is changed from $10^{-3}$ to $10^{-5}$ (that is, the soil structure of the aquifer is 100 times closer) to simulate the change of pumping temperature of the heat source well. The results are shown in Figure 5.

![Fig. 5 Relationship between pumping temperature and horizontal permeability coefficient](image)

It can be seen from Figure 5 that when the absolute value of horizontal permeability coefficient of aquifer in heat source well changes, its pumping temperature hardly changes. This is because in the same aquifer soil structure, under the condition that the permeability coefficient ratio (horizontal permeability coefficient / vertical permeability coefficient) is constant, simply reducing the absolute value of horizontal permeability coefficient will also reduce its vertical permeability coefficient. At the same time, the mixing ratio of raw water and reinjection water in the pumping area of heat source well will be reduced according to the same proportion. Therefore, the absolute value of horizontal permeability coefficient of aquifer in heat source well will not affect the pumping temperature of the well, but reducing its absolute value will only increase the difficulty of groundwater recharge.

3.2. Influence of permeability coefficient ratio
In this section, under condition 3, only the permeability coefficient ratio of aquifer in the heat source well is changed, that is, the value of horizontal permeability coefficient to vertical permeability coefficient is changed from 1 to 10 to simulate the change of pumping temperature of the heat source well. The results are shown in Figure 6.
Fig. 6 Relationship between pumping temperature and permeability coefficient

It can be seen from Fig. 6 that the pumping temperature of the heat source well will gradually decrease from 21.5 °C to 20.4 °C in the process of changing the permeability coefficient ratio from 1 to 10, and the drop range is about 1.1 °C. This is because when the horizontal permeability coefficient is much greater than the vertical permeability coefficient, it means that the underground water inflow of the aquifer is large and sufficient, which increases the proportion of the original water and return water. Therefore, for the ground water source heat pump system, it is better to select the place where the groundwater is sufficient and the horizontal permeability coefficient is far greater than the vertical permeability coefficient, or set the middle partition board in the recharge area of the heat source well to reduce the vertical permeability coefficient.

3.3. Influence of specific heat capacity of volume

Under the condition of condition 3, only the volumetric specific heat capacity of the aquifer in the heat source well is changed, that is, the heat extraction potential of the aquifer itself is changed, and it is gradually increased from 2000kJ/m$^3$·°C to 3000kJ/m$^3$·°C, so as to simulate the change of pumping temperature of the heat source well. The results are shown in Figure 7.

Fig. 7 Relationship between pumping temperature and specific heat capacity

It can be seen from Fig. 7 that the pumping temperature of the heat source well is almost inversely proportional to the volumetric specific heat capacity of the aquifer. When the volumetric specific heat capacity of the aquifer changes from 2000kJ/m$^3$·°C to 3000kJ/m$^3$·°C, the pumping temperature drops
by about 0.8 °C. This is due to the increase of the specific heat capacity of the aquifer, which enhances the heat storage capacity of the aquifer and improves the heat capacity of the aquifer where the heat source well is located. Therefore, the heat source well of groundwater source heat pump system should choose the place with high rock proportion as far as possible.

### 3.4. Influence of thermal dispersion

In view of the fact that the thermal dispersion of groundwater in the heat source well will directly reflect the mutual thermal influence phenomenon between heat source wells\(^\text{(4)}\), this section still chooses to change the thermal dispersion range of groundwater caused by velocity fluctuation from 1 m to 3 m, so as to simulate the change of pumping temperature of the heat source well. The results are shown in Figure 8.

![Fig. 8 Relationship between pumping temperature and thermal dispersion](image)

It can be seen from Fig. 8 that with the increase of thermal dispersion, the pumping temperature of the heat source well decreases in equal proportion. In the process of thermal dispersion from 1 m to 3 m, the pumping temperature drops by about 0.4 °C. This is due to the increase of thermal dispersion, which makes the disturbance of groundwater increase and the average of heat increase, which leads to the increase of effective heat transfer and the increase of heat influence range of recharge water. Therefore, the pumping area of the heat source well of the groundwater source heat pump system should be set at the place where the underground water flow rate is fast.

### 4. Conclusion

(a) The absolute value of horizontal permeability coefficient of aquifer does not affect the pumping temperature of heat source well, but the permeability coefficient ratio does. When the permeability coefficient ratio increases from 1 to 10, the pumping temperature drops by about 1.1 °C. Therefore, the place where the horizontal permeability coefficient is far greater than the vertical permeability coefficient should be selected as far as possible.

(b) The volume specific heat capacity of aquifer will affect the pumping temperature of the heat source well. When it increases from 2000 \(\text{kJ/m}^3\cdot\text{°C}\) to 3000 \(\text{kJ/m}^3\cdot\text{°C}\), the pumping temperature will decrease by about 0.8 °C. Therefore, the place with high rock proportion should be selected as far as possible.

(c) The increase of thermal dispersion of groundwater will reduce the pumping temperature of the heat source well. When the thermal dispersion changes from 1 m to 3 m, the pumping temperature will decrease by about 0.4 °C. Therefore, it is better to select the place where the groundwater velocity is fast.
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