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AQUIFER THERMAL TRANSPORT COMPUTER SIMULATION OF WINTER COMBINED SUMMER GROUNDWATER SOURCE HEAT PUMP SYSTEM

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ABSTRACT

Groundwater source heat pump technology is an energy-saving method to use the groundwater heat energy resources for heating in winter and cooling in summer. It is important to comprehensive study the process of groundwater thermal transport of winter combined summer GWSHP under the continuous running condition. In this paper the simulation models have been proposed using winter-only and winter combined summer GWSHP respectively, and computer simulations were carried out. The results show that the temperature will decrease year by year if using winter-only GWSHP. The groundwater temperature change is smaller using combined GWSHP than using winter-only GWSHP. In summer, the winter combined summer GWSHP can use the cooling storage recharged last winter and in the winter it can use the heat storage recharged last summer. The winter combined summer GWSHP can improve thermal efficiency in the winter and enhance the cooling effect in summer.

Keyword: *Groundwater Source Heat Pump , Winter Combined summer GWSHP, Temperature Field, Thermal Transport*

1. INTRODUCTION

Groundwater source heat pump (GWSHP) technology is an energy-saving method of using groundwater heat resources for winter heating and summer cooling. Its thermal efficiency is higher compared with the ground source air conditioning ， coal-fired centralized boiler, gas centralized boiler, etc. So it has been supported by most governments in China (Wei Yang, Jin Zhou,2010[1]). In recent years, with the advanced groundwater source heat pump technology widely used around the world, a large number of water source heat pump works are emerging(Gerald W H ， 1997[2] ， Sanner B ， 2003[3]). But most GWSHP works have been designed and used only for single-season (winter-only heating pump). Clearly, continuous recharging colder water to underground aquifers using winter-only GWSHP will drop the temperature of groundwater and reduce thermal efficiency of GWSHP year byyear. However this awareness is based on the experience for the most part. So it is important to study thetheory of the temperature change feature and how improves the thermal efficiency for winter and summer combined GWSHP.

For GWSHP woks, it is important to know the process of groundwater thermal transport and forecast the thermal efficiency, but now the studies [3-7] have concentrated on the single-season GWSHP. The temperature field how to change if use continuous winter and summer combined GWSHP? The researches on continuous winter and summer combined GWSHP is lack. The process of groundwater thermal transport hasnot been studied under the continuous running condition.

In the researches on groundwater source heat pump impacting on groundwater temperature field, Norio Tenma, Kasumi Yasukawa(2003[4]) have estimated the parameters of a typical underground system using the two-well model. Hu Ji-hua (2008[5]) studied groundwater flow through and its impact on the temperature field in the water source heat pump system, Wang Huiling (2009[6]) studied the different pumping and injection modes on flow field and temperature field on the ground source heat pump system. Wang Mingyu(2004[7]) researched the aquifer thermal energy storage heat

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transferring numerical model of two stage. Li Yue (2011[8]) used FlowHeat software to research the hydro-geological parameters of single well re-injection of underground water source heat pumping well which is influenced by the temperature field .

In this paper the groundwater thermal transport forecast computer simulation model of winter and summer combined GWSHP has been proposed, and the thermal transport process of groundwater have been simulated using computer.

2. COMPUTER SIMULATION MODEL OF GROUNDWATER AND THERMAL COUPLING

Considering convection and diffusion effect, assuming the aquifer medium as continuous medium, the three-dimensional unsteady water movement and thermal migration coupling equation of heterogeneous and anisotropic aquifer can be described as [5,6]

$$\begin{cases} n\rho_o\beta_p\dfrac{\partial P}{\partial t}+n\rho_o\beta_T\dfrac{\partial T}{\partial t}+\rho a_b\dfrac{\partial P}{\partial t}= \\ \nabla\cdot\rho\dfrac{k_p}{\mu}(\nabla P+\rho g)-q\rho* \\ n\rho_0\beta_p c_f T\dfrac{\partial P}{\partial t}+n\rho_0\beta_T c_f T\dfrac{\partial T}{\partial t}+\rho a_b c_f T\dfrac{\partial P}{\partial t}+ \\ n\rho c_f\dfrac{\partial T}{\partial t}-\rho_x c_x T a_b\dfrac{\partial P}{\partial t}+(1-n)\rho_x c_x\dfrac{\partial T}{\partial t}= \\ \nabla\cdot(nk_f+(1-n)k_s)\underline{\underline{I}}\nabla T+\nabla\cdot n\underline{\underline{D}}_H\nabla T- \\ \nabla\cdot n\rho c_f\underline{v}T+q\rho^* c_f T^* \end{cases}$$

Above, n is effective porosity; ρ_0 is reference pressure P_0 and the density of the fluid under the reference temperature T_0 , kg/m^3; β_p is compression coefficient of water, Pa^{-1} ; P is groundwater pressure, P_a ; T is water and porous medium temperature , C° ; β_T is coefficient of thermal expansion of the water , $C^{\circ\,-1}$; ρ is fluid density, kg/m^3; a_b is porous media compression factor, P_a^{-1} ; k_p is ability to penetrate tensor , m^2; μ is dynamic viscosity coefficient, kg/(m·s); g is acceleration of gravity , m/s^2; ρ^* is density of the fluid source term (source point) , kg/m^3; q is intensity of sources and sinks, inflows as positive and outflows as negative, m3/(m^3·s); t is time, s; P_0 is initial pressure distribution, Pa ; P_1 is pressure distribution known pressure boundary, Pa; c_f is Fluid specific heat capacity , J/kg·℃ ; c_x is porous media specific heat capacity, J/kg·℃; ρ_s is porous medium density , kg/m3; k_f is fluid thermal conductivity,W/m·℃ ; k_s is thermal conductivity of the porous medium,W/m· ℃; $\underline{\underline{D}}_H$ is Thermodynamic diffusion tensor, W/m· ℃; $\underline{\underline{I}}$ is 3-order unit matrix; $\underline{v}$ is Seepage velocity, m/s ; T^* is Temperature, fluid source term, ℃。

3. STUDY AREA HYDRO-GEOLOGICAL AND BOUNDARY CONDITIONS

In order to fully analyze the variation of the temperature field of the groundwater under the cold and heat load, a new constructed groundwater source heat pump project has been selected and research in Weifang City of ShanDong Province in China. This project has one pumping wells (a# well), pumping capacity of 900m3 / d, one injection wells (b# well), recharge capacity is 900 m3 / d, The distance between the two wells is 50m. Two observation wells were drilled along the direction of the hydraulic gradient also, the space from 1# observation well to recharge well, is 25m, 2 # observation well is 65m, seeing Figure 1. In verification test, to prevent groundwater from being exposed to the air and affecting the observation accuracy in the observation process, high-precision digital thermometer is used. Temperature Sensor is connected to the computer through data cable. The boreholes were covered always in observation process. Figure 2 is the finite element mesh map of study area

The study area range is 1000 × 1000m. The upper layer is gravel which mixed with clays, thickness is 20m; the second layer is coarse gravel, thickness 30m, and the third layer is impermeable clay layer, thickness 40m. Hydro-geological parameters and soil thermal physical parameters have been determined through field tests and laboratory experiments, The local hydro geological parameters are shown in Table 1.

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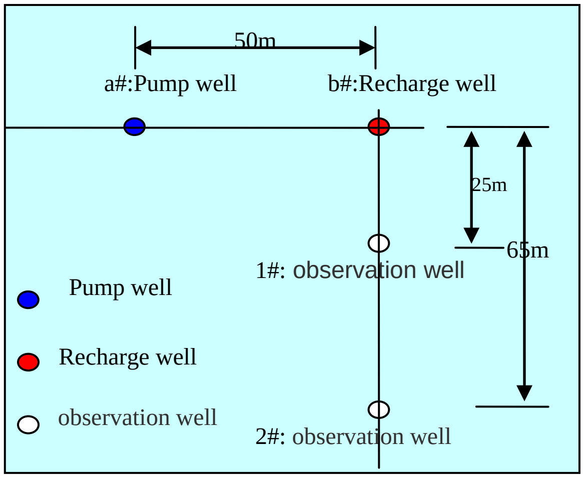

Figure 1: Layout of Wells

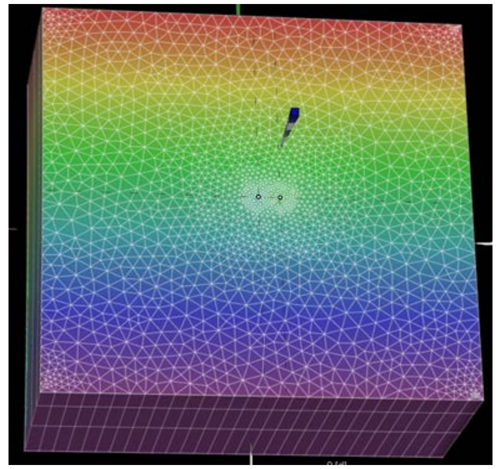

Figure 2: Finite Element Mesh Map Of Study Area

Table 1: Hydro-Geological And Soil Thermal Physical Parameters

Name of parameters	The first layer	The second layer	The third layer	Unit
Thickness of Aquifer	20	30	40m	m
KX/KY/KZ	6.14×10-7	2.6×10-3	1×10-9	m/s
Storage coefficient	0.005	0.2	0.025	
Porosity	0.4	0.3	0.45	
Initial temperature of groundwater	15.5	15.5	15.5	℃
Specific heat of groundwater	4200	4200	4200	J/（kg•K）
Bulk density of groundwater	1000	1000	1000	Kg/m^3
Thermal conductivity of groundwater	0.65	0.65	0.65	J/m/s/K
Volumetric specific heat of Soil skeleton	1.500×10E6	1.56×10E6	1.563×10E6	$J/m^3/K$
Thermal conductivity of Soil skeleton	1.10	1.82	1.05	J/m/s/K
Thermal Longitudinal diffusion coefficient	10^{-3}	5	10^{-4}	m
Thermal Lateral diffusion coefficient	10^{-4}	0.5	10^{-5}	m

Boundary conditions: boundary conditions are hydraulic boundary and temperature boundary. The local Coordinate system was used in this study. The roof elevation is set 0m, groundwater level, -15m. Then four direction side boundaries were set fixed water level and fixed temperature boundary. According to the pumping test and temperature measurement, local groundwater temperature is 15.5 ℃

4. COMPUTER SIMULATION OF CONTINUOUS WINTER-ONLY GWSHP MODE

Heating in winter is the most adopted form of GWSHP. It is a technique of extraction the heat of groundwater, and recharges the colder groundwater to aquifers. The temperature field how to changes if use continuous winter-only GWSHP? In this study case, the recharge water temperature is 7 ° C. The GWSHP run from November 15 to January 15 of next year (total running time of 120 days) and stop at the remaining time. We use professional groundwater simulation software Feflow to simulate the temperature field changes with continuous running three year and 120 days.

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Through simulation, the results have been attained. Figure 4 is the temperature change process lines at the points of pump well and recharge well. The results show that the temperature will decrease year by year if uses winter-only GWSHP. Figure 5 is the contour map of the temperature field after running 50d,120d, 365d,and 720d.

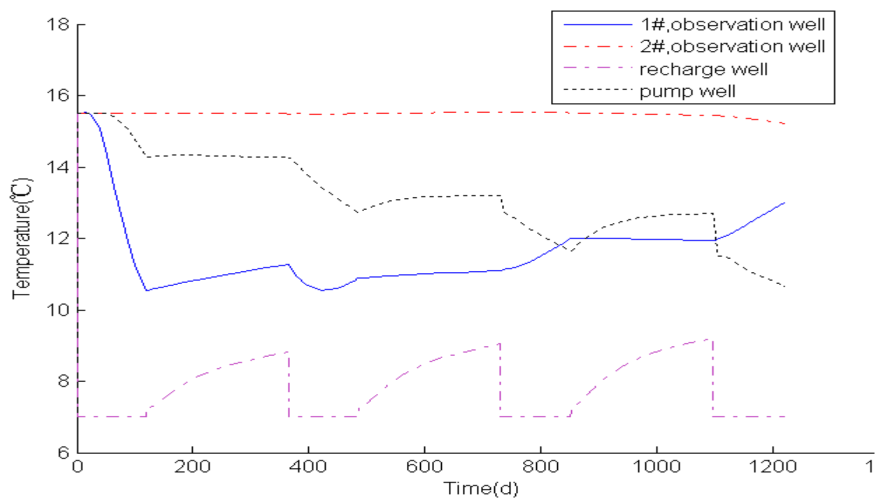
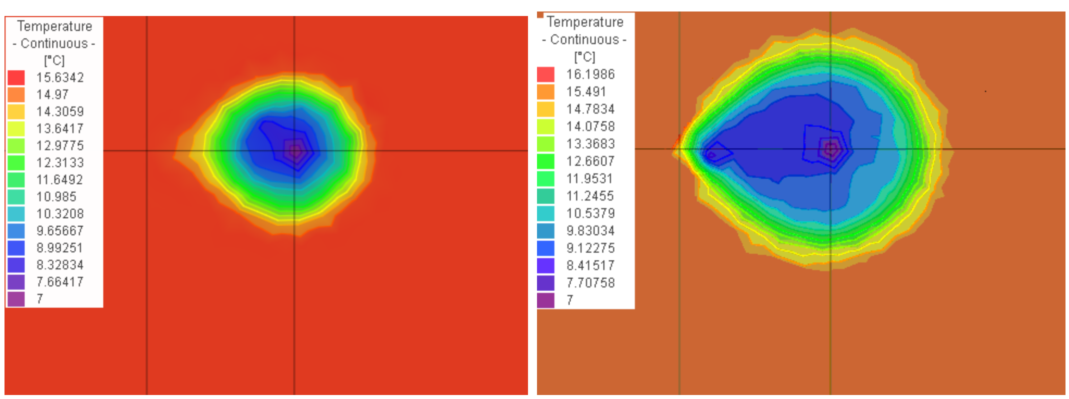
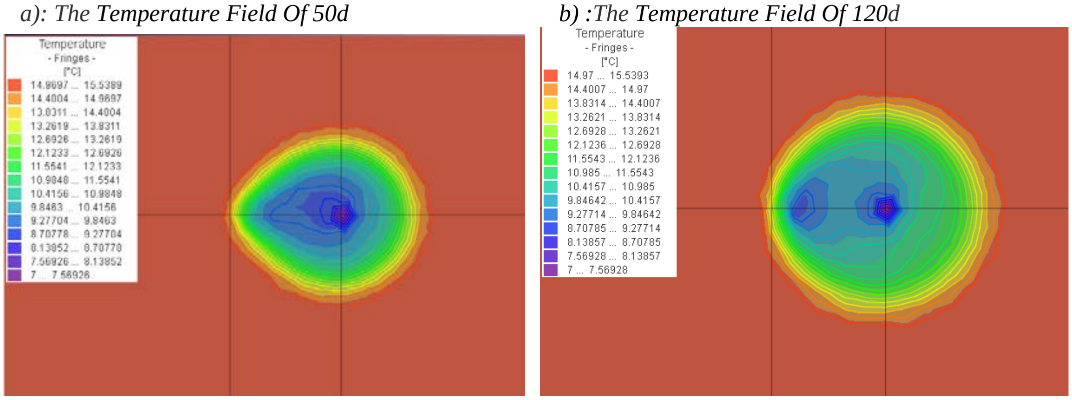


Figure 4: Temperature Change Process At The Points Of Pump,Recharge Well Using Winter-Only



a): The Temperature Field Of 50d *b) :The Temperature Field Of 120d*



c): The Temperature Field Of 365d *d): The Temperature Field Of 720d*

Figure 5: the temperature field change with winter-only mode

5. COMPUTER SIMULATION OF CONTINUOUS WINTER AND SUMMER COMBINED GWSHP

If we change the run mode, use the mode of winter and summer Combined. The running and

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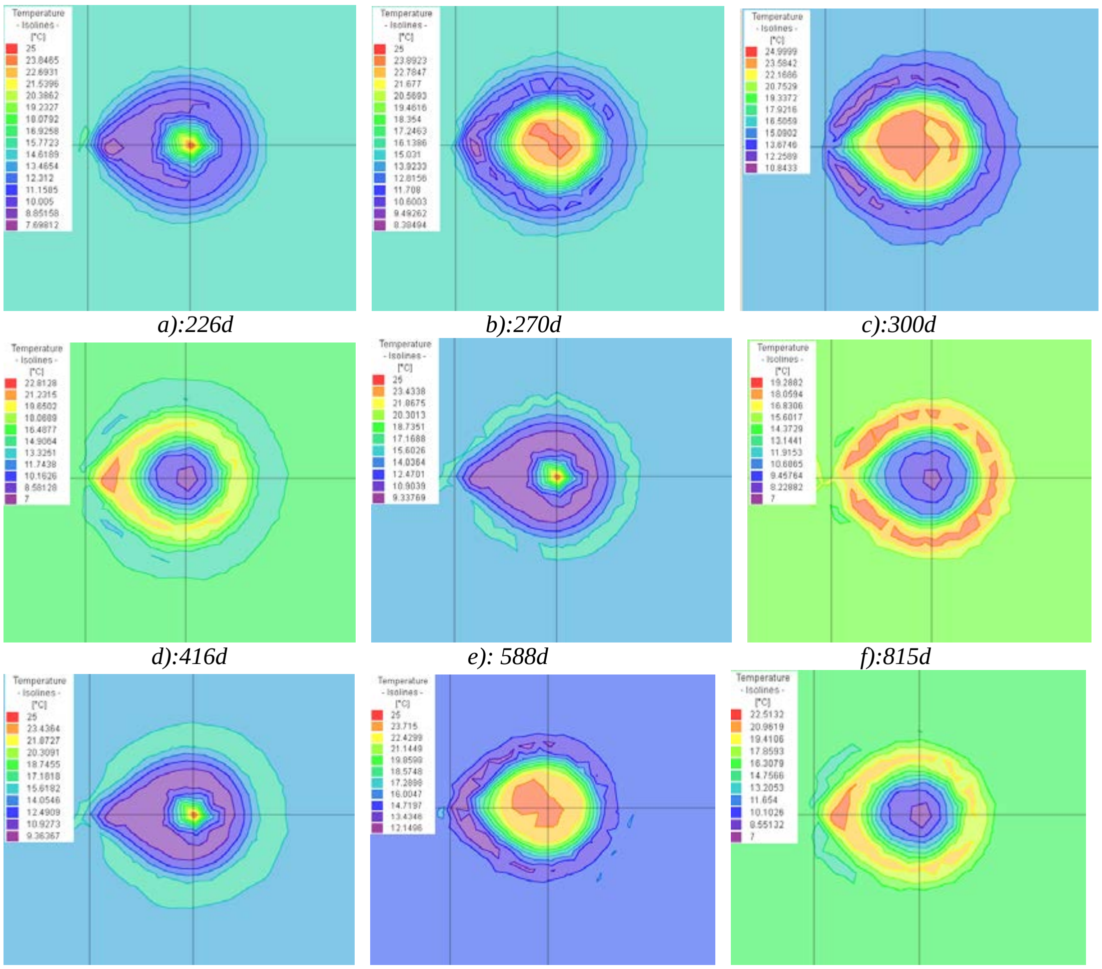
stop time scheme is set as table 2. Through simulation, the results have been attained. Figure 6 is the temperature field Contour map of different time. Figure 7 is the temperature change process at the places of pump and recharge well using winter and summer combined mode.



a):226d *b):270d* *c):300d*

d):416d *e): 588d* *f):815d*

g):953d *h): 1022d* *i):1148d*

Figure 6: The Temperature Field Change With Winter And Summer Combined Mode

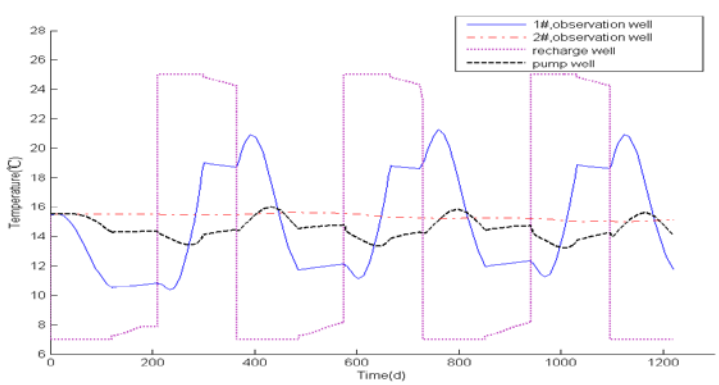


Figure 7: Temperature Change Process At The Points Of Pump, Recharge and Observation Well Using Winter And Summer Combined Mode

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6. THE COMPARISONS OF WINTER-ONLY GWSHP AND WINTER AND SUMMER COMBINED MODE

Figure 8 is the comparisons of temperature using winter-only GWSHP and winter and summer combined mode at the points of pump well. Results show that the temperature of groundwater is decreasing year by year using former mode. The max value is 15.5 ℃ and the min value but using the later, the min value is 13.5 ℃, the max value 16.03 ℃ and the temperature is fluctuated between 13.5 ℃ and 16.03 ℃. Obviously the later mode can improve the thermal efficiency in the winter and the Cooling effect in the summer.

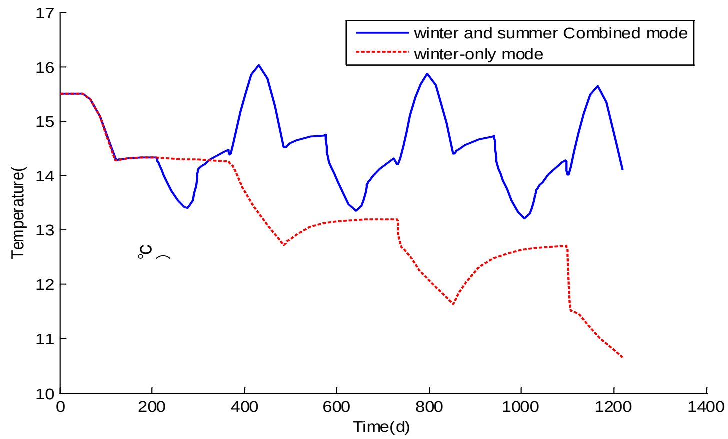

Figure 8: The Comparisons Of Winter-Only Mode And Winter And Summer Combined Mode

7. CONCLUSIONS

This paper established the computer simulation model of groundwater heat transfer of aquifer using winter-only mode and winter combined summer mode of GWSHP. The simulation results show that the temperature will decrease year by year if uses winter-only GWSHP at the place of flat slope. However, the average temperature of winter combined summer mode is higher than winter-only mode. The winter and summer combined mode can improve thermal efficiency in the winter and attain the goal of cooler effect in summer. Use winter and summer combined mode is better than winter-only mode, because in the summer we can use the cooling storage recharged last winter, in the winter can use the heat storage recharged last summer.

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