Plan of Research for Geothermal Reinjection in the Tianjin Bedrock Reservoir China

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ABSTRACT

Due to the massive exploitation of geothermal fluids during the 1990s in Tianjin, the water level in the main bedrock reservoir has dropped by 3 – 8 m per year. Reinjection has been carried out for ten years to maintain reservoir pressure. Reinjectivity and the effect of the low temperature fluid on the reservoir are of interest here. Research on the layout of main geothermal fields in bedrock reservoirs was carried out using a numerical model to simulate different scenarios and suggest the best reinjection well site, reinjection means, etc. It was intended that this be used as a foundation of geothermal management for sustaining development in this area.

1. INTRODUCTION

The low-moderate temperature Tianjin geothermal resource is located within a sedimentary basin. Since the 1980s, ten geothermal areas with the temperature gradients of 3.5°C/100 m have been found in unconsolidated layers. As of 2009, 8 geothermal fields have been exploited for a total production of about 2,604x0^{4}m^3/year. Most of the thermal fluid was charged from three reservoirs: two Neogne sandstone layers and one Pre-Cambrian bedrock reservoir. Due to higher temperatures and flow capacities, the Wumishan Group of the Pre-Cambrian Jixian System have produced up to 1,300x10^{4}m^3/ year. As the reinjection was only 300x10^{4}m^3/year, the reservoir pressure declined quickly, with water level declining 3 – 8 m/year. If this pressure decline were to continue, most of the wells would have to be abandoned after 20 years. The primary difficulty of reinjection in Tianjin is actually finding space to drill the injection wells. Many wells are located in an urban district. After a well location is chosen, the impacts of low temperature fluid injection must be considered thoroughly. Therefore, this reinjection plan has been carried out to find the best sites for new injection wells.

2. GEOLOGY, GEOTHERMAL AND REINJECTION CONDITION

2.1Geology and geothermal condition

Tianjin is located in the Huabei sedimentay Basin, which includes several sub-tectonic units. The research area is located in the middle of the Cangxian Upwarping shown in Figure 1, which contains the Wanglanzhuang, Sanlinzi, and Wanjiamatou Fields.

Most wells in the Wumishan Group are located in these three fields. The complex is further divided into tectonic formations by 3 – 4 faults. The Hangu fault forms the northern boundary.,The Tianjin fracture forms the western boundary that separates the field from the Wuqing concave and the Jinhai monocline. The Cangdong fault on the eastern boundary separates the fields from several concaves.

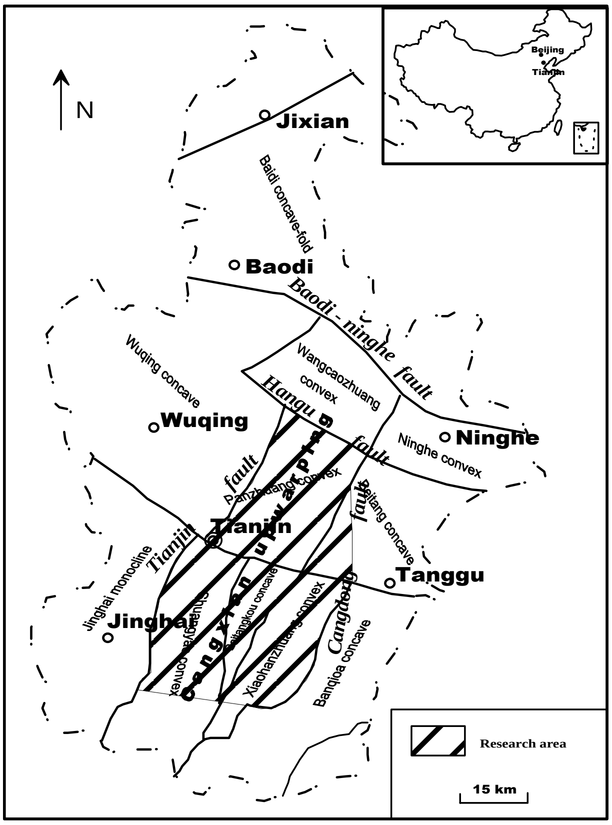

Figure 1: **The regional tectonic and location of research area**

The research area is composed of several layers, which are described in Table 1. The Quaternary, Neogene and Wumishan Group of the Jixian System of the Proterozoic are distributed over the entire area. Other layers are less widely distributed. The Wumishan Group bedrock is the bottom unit of drilled wells. The dominant lithology is rich in fissures and composed of dolomite and limestone-dolomite. The production temperature is 72 – 94°C, and the capacity of production wells is 80 – 150 m^3/h for each well.

2.2 Reinjection condition

By the end of 2008, there were 35 wells completed in the Wumishan Group for injection purposes. The dominant reinjection strategy is well doublet systems. After heat exchange, fluid discharged from production wells is injected into reinjection wells. Reinjection capacity varies from 80 – 100 m^3/h for each well.

Table 1: Simplified lithological structure of research area

Stratum	Thickness (m)	Lithology
Quaternary (Q)	300~450	Sandy cohesive soil, fine sand
Neogene (N)	500~800	Mudstone, sandstone and sandy conglomerate
Mesozoic (Mz)	~700	Sandstone, volcanic rock and mudstone
Carboniferous ~Permian (C-P)	~400	Mudstone and sandstone, coal
Ordovician (O)	~700	Limestone, shale and dolomitic limestone
Cambrian(Є)	~800	Limestone, mudstone, shale
Proterozoic (Pt)	>1000	Shale, sandstone, dolomitic limestone and dolomite

3. MODELING FOR REINJECTION PLAN

Reservoir modeling is an integral part of geothermal reservoir assessment and management. A conceptual model based on available geological data is presented in Figure 2. Consequently, the AQUA3D simulation programs were used to simulate monitoring data from production histories and determine the relationship between production and the historical pressure records. Consequently, the model can be used to manage future reinjection wells in the area.

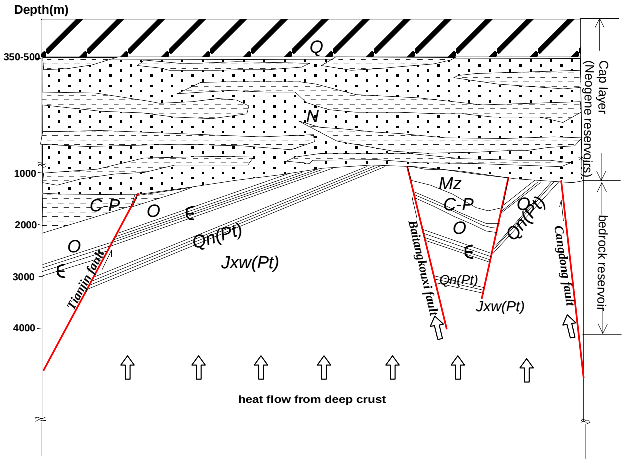

Figure 2: The conceptual model of the Tinjian research area

3.1 Conceptual model of the reservoir of the Wumianshan Group

A conceptual model is a descriptive or qualitative model of a system or section of a system that incorporates the essential physical features of the system and is capable of matching the salient behavior or characteristics of interest to the modeler.

The geothermal system modelling is based mainly on geological data. In the model, the structure of the geothermal system, the heat source, hot water flow paths, and the source of the recharge path are described, as shown in Figure 2.

Main elements of the conceptual model:

- The top of the reservoir of the Wumishan Group (Jxw) varies in depth from 900 – 3500 m. Based on current economics, the exploitable depth is limited to 4000 m.
- The thermal resource is characterized by conduction-dominated heat flow from the deep crust.
- The Quaternary and Tertiary formations have low thermal conductivity and permeability and act as a cap, which causes the permeable formations below to be heated.
- The main hot recharge fault in the system is considered to be the Cangdong fault.
- The geothermal water is believed to be of meteoritic origin and recharges from mountains in the northern Tianjin region.

3.2 Numerical distributed parameter model

Numerical distribution parameter modeling was carried out using the AQUA3D computer program. AQUA3D is a program developed to solve three-dimensional groundwater flow and transport problems using the Galerkin finite-element method.

AQUA3D simulates transient groundwater flow with nonhomogeneous and anisotropic flow conditions. Boundary conditions may be expressed in terms of prescribed nodal head and prescribed flow as a function of time or head-dependent flow. AQUA3D also solves problems of transient transport of contaminants and heat with convection, decay, adsorption and velocity-dependent dispersion. Boundary conditions may be expressed in terms of either prescribed nodal concentration (temperature) or prescribed dispersive mass (heat) flux.

The equation of invariable density groundwater flow has the following form:

$$\frac{\partial}{\partial x}\left(k_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_{zz}\frac{\partial h}{\partial z}\right)=S_s\frac{\partial h}{\partial t}-Q \quad (1)$$

where k_{xx}, k_{yy}, k_{zz} are permeability along the respective axes (m/s), h is pressure head (m), Q is unit flux ($m^3/s/m^3$), S_s is the storage coefficient , m^{-1}, and t is time (s).

The equation of solute or heat of the groundwater flow has the following form:

$$\frac{\partial}{\partial x}\left(D_{xx}\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_{yy}\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_{zz}\frac{\partial c}{\partial z}\right)+Q(c_w-c)-\left(V_x\frac{\partial c}{\partial x}+V_y\frac{\partial c}{\partial y}+V_z\frac{\partial c}{\partial z}\right)=\varphi Rd\frac{\partial c}{\partial t}+\varphi Rd\lambda c \quad (2)$$

where D_{xx}, D_{yy}, D_{zz} are the dispersion coefficients along the respective axes.

3.2.1 Creating the model mesh

The approximation is most readily described in terms of triangular-shaped elements. According to geological data, the Wumishan Group is divided into 232 nodes, as illustrated in Figure 3. Time is divided into 2 seasons per year: a heating season and a summer season of lower use.

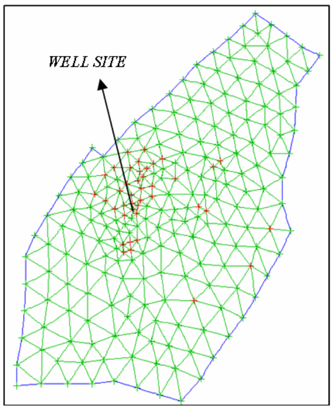

Figure 2: Mesh layout of the Wumishan Group geothermal system Aqua3D model

3.2.2 Disposal of the original condition and parameter

The starting time is November 2001, due to the availability of monitoring data. Due to different temperature fluids in the wells, the water level has changed to same well pressure head. The calibrated pressure head is 60 – 87 m.

Based on hydrogeological data and well logs, the parameters of the Wumishan Group are listed in Table 2.

The recharge comes from northern Dakoutun fault, eastern Cangdong fault, and southern fault according to water level contours. The recharge is $4.35\times10^6 m^3$/year.

Table 2 Parameter statistics of the Wumishan Group

Permeability coefficient (m/s)	$6.6\times10^{-6} – 2.1\times10^{-5}$
storage coefficient	$1.1\times10^{-5} – 4.2\times10^{-5}$
Porosity (%)	2.7 – 6.5
Anisotropism angle	60°
Diffusion coefficient (m^2/s)	1.0×10^{-6}

3.2.3 Model calibration

The parameters in the Aqua3D model were adjusted until a good match with the data observed in the wells was obtained. The adjustment of well pressure head in two wells is illustrated in Figure 4. Due to the good agreement of the simulated result with experimental data, the numerical model can be taken as characteristic of the Wumishan Group.

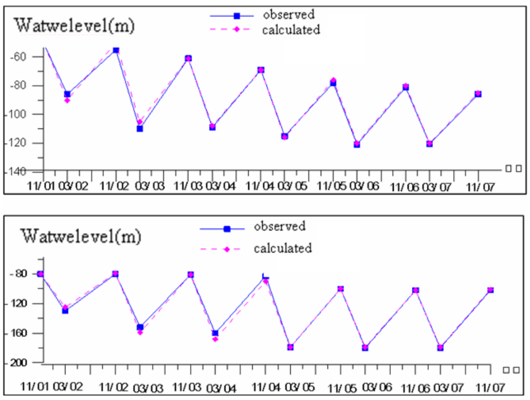

Figure 4: Variation of well pressure head simulated by Aqua3D in two wells.

3.3 Model application

3.3.1 Forecast of future pressure changes

Maintaining the existing production and reinjection strategy will result in fluid levels of 109 – 210.3 m after ten or more years of operation, with the largest decline occurring in the urban district, as shown in Figure 5.

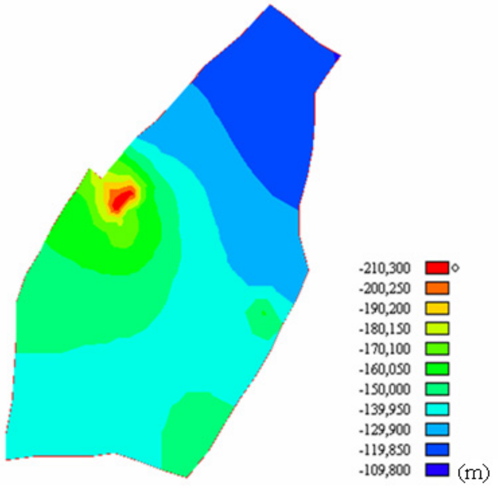

Figure 5: Well pressure head contour map after 10 more years of the existing injection strategy.

3.3.2 Scheme of reinjection for the Wumishanzu Group

Several reinjection cases, which place injection wells in different parts of the reservoir, have been performed, with a total increased reinjection of up to 400 x $10^4 m^3$/year.

- Case 1: 20 additional injection wells in the massive exploitation area.
- Case 2: 20 additional injection wells in the periphery of the massive exploitation area.
- Case 3: similar to Case 1 with an additional 4 reinjection wells in the north-eastern area near the recharge fault.

The predicted results are shown in Figures 6, 7, and 8, and indicate that pressure will be maintained better in Case 1 than in Case 2. Due to additional reinjection, the pressure drawdown is also effectively reduced in Case 3.

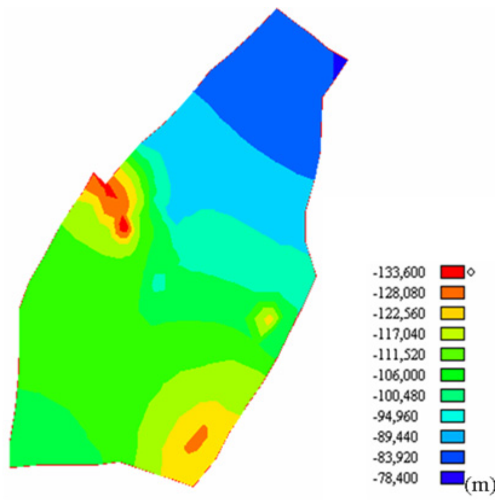

Figure 6: Well pressure head contour map for Case 1 after 10 years.

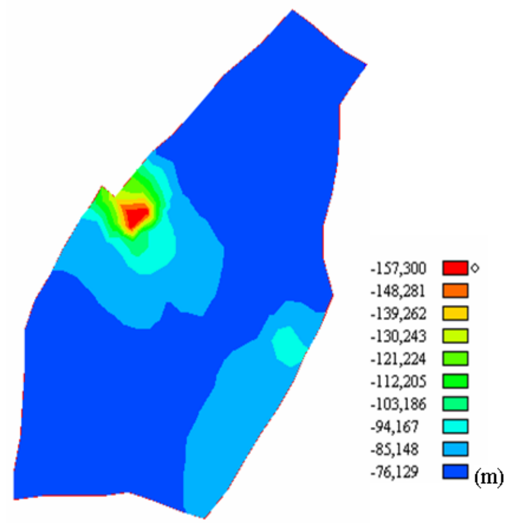

Figure 7: Well pressure head contour map for Case 2 after 10 years.

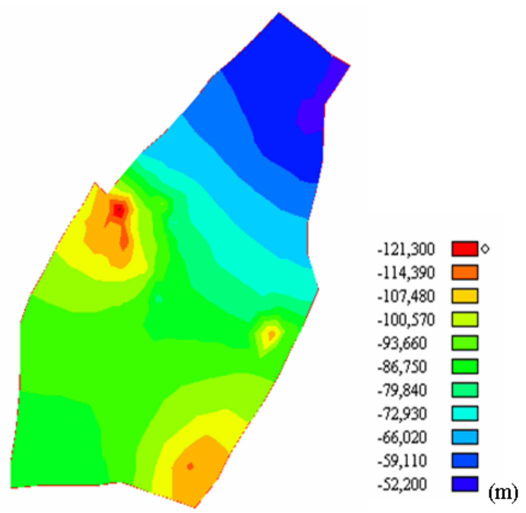

Figure 8: Well pressure head contour map for Case 3 after 10 years.

3.3.3 Reservoir temperature changes

Due to increased amounts of low-temperature fluid injected into the reservoir, the main negative effect is expected to be cooling. Therefore, it is important to predict the likely temperature changes.

A heat transport numerical model has been developed based on the conceptual model. Due to the lack of long-term temperature monitoring in the area, the original temperature conditions were assumed to be those measured in 2004. The reservoir temperature is 74 – 96°C and is 2 – 6°C higher than the wellhead temperature. A contour map of temperature is given in Figure 9. The coupling of the heat transport and fluid flow models in the Aqua3D program allows the forecast to be performed using the same model.

The Case 3 scenario was considered to be the best plan for reinjection, so the temperature modeling was based on Case 3. The forecasted reservoir temperature changes are shown in Figure 10. Some cooling was predicted to occur near the reinjection wells and along the faults. The overall temperature of reservoir shows only a small change, decreasing by only 1 – 3 °C.

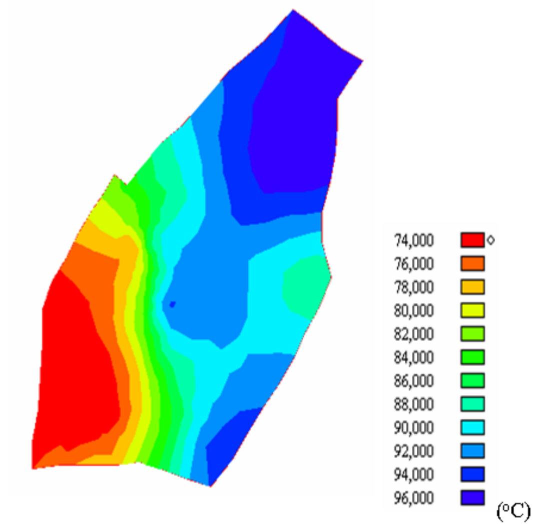

Figure 9: Reservoir temperature contour map in 2004.

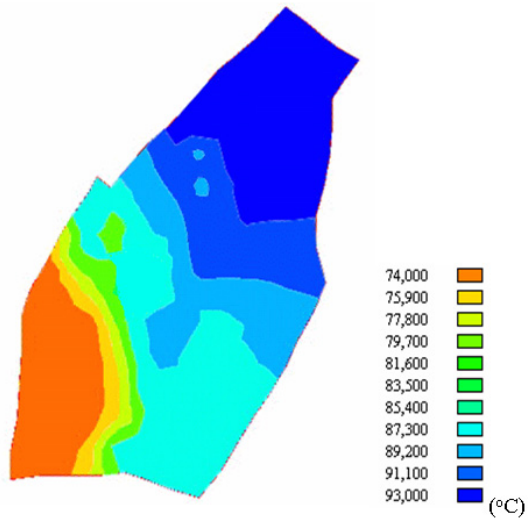

Figure 10: Reservoir temperature contour map after massive reinjection in 2020.

CONCLUSION

- Reinjection can effectively prevent pressure decline. If the reinjection is increased by 400×10^4 m^3/year, the water level drawdown would be about 80 m less than if increased injection does not occur.

- Increased reinjection is expected to result in a reservoir temperature decline of 1 – 3°C after ten years of operation.

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