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Reservoir Evaluationof the Zhouliangzhuang Geothermal Field, Tianjin, China

Li Jun, Li Dan

Tianjin Geothermal Exploration and Development-Designing Institute

No. 189 Weiguo Road, Hedong District, Tianjin 30050, P. R. China

tjlj829@hotmail.com

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ABSTRACT

The Zhouliangzhuang geothermal field is one of many geothermal fields in Tianjin, China. It is a conductive low temperature type system. At present, there is considerable interest in developing these geothermal resources further. The system is characterised by higher temperatures than most other fields in Tianjin, the highest temperature being more than 100°C. All geothermal wells drilled so far are artesian. Exploration of the field has been on going since 2001. Assessment of the production potential of the system is carried out by using lumped parameter models as well as a simple numerical model. Similar hydro-geological conditions control the two models, such as no recharge, and according to predictions of the two models, total allowable production of Zhouliangzhuang geothermal field is estimated to be about 7.8×10^6 m^3/year, with water level in production wells drawdown above 150 m for 20 years. Therefore, reinjection will be essential to maintain the reservoir pressure in order to enable sustainable utilization and increase the production potential of the system.

1. INTRODUCTION

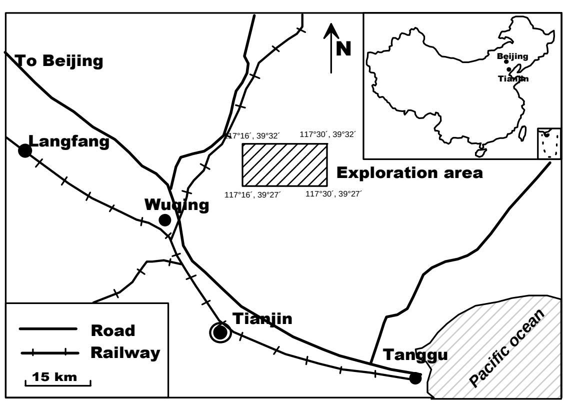

FIGURE 1: Location of the current exploration part of the Zhouliangzhuang field

The Zhouliangzhuang geothermal field is located in the northeastern part of the North China alluvial plain, about 35 km north of the city of Tianjin (see Figure 1). Utilization of the geothermal resources in the area, such as for space heating of villas, fish farming and greenhouse heating, has been planned by several companies because of the convenient location and the available land. The Zhouliangzhuang field is located about 20 km NE of Wuqing, where geothermal energy from a sandstone system has been utilized since 1994 (Wang, 1998), and about 60 km NW of Tanggu, where a comparable sandstone resource has been utilized since 1987 (Axelsson and Dong, 1998). In addition, the city of the Tianjin is the location in the P.R. of China with the most extensive and most advanced geothermal utilization in the whole country.

The Zhouliangzhuang field lies in a convex part of the sedimentary basin. Past investigations have indicated that thermal energy from the deep crust is conducted through high conductivity basement into shallower formations, while a low conductivity cap rock controls the surface heat flow (Chen M.X., 1988: Huabei Geothermal). Therefore, the field has high thermal gradient in the cap rock and a high reservoirs temperature. According to lithological data, the geothermal system can be divided into three formations or separate reservoirs, divided by impermeable layers. In early of 1980s, the geothermal resources were discovered through petroleum exploration drilling; three of these wells (W2, W3 and W4) have been used for geothermal utilisation at low discharge. These wells have been utilized for bathing and farming. Well W3 produces from an Ordovician system formation with a nearly constant flow rate of about 1.1 l/s since 1988, well W4 produces from a Cambrian system formation with a constant flow rate of about 4.2 l/s since 1987, and well W2 produces from a Proterozoic formation with constant pumping flow rate of about 8 l/s since 1990. A geothermal exploration well (ZL1) was drilled in 2002. The well was successful with a maximum pumping flow rate of about 83 l/s of 100 °C hot water. The thermal water from this well will be used for space heating, bathing and agriculture.

In this report, a brief outline of the geological characteristics of the geothermal system is given to clarify the reader about the nature of the field. The main emphasis of this report is on a reservoir evaluation through modelling. Lumped parameter models and simple numerical distributed parameter models are set up based on the system's conceptual model and available long-term monitoring data. Consequently an assessment of the production potential of the geothermal system is carried out. The utilization of reinjection as part of geothermal resource management in the field is also studied. It must be emphasised here that very limited data are available in the Zhouliangzhuang geothermal field, production response data, in particular, are limited. In such situations complex numerical modelling is generally not justified. The numerical model presented here, however, should be looked upon as the first step in model development for the field, which will be extensively revised and modified as more data become available.

2. THE ZHOULIANGZHUANG GEOTHERMAL FIELD

2.1 Geological background

The Zhouliangzhuang field is located in the so-called Wancaozhuang convex, in the northern part of Cangxian up-warping, which is located in the northern part of the

Huabei sedimentary basin (Li D., 2003). The convex is divided into further tectonic formations by three to four faults. The northern boundary of the field is the Baodi-ninghe fault (see Figure 2), and Dakoutun fracture is the southwest boundary separating the field from the Wuqing sedimentary basin and the Panzhuang convex. One fault on the eastern boundary of the Wangcaozhuang convex separates it from Ninghe convex.

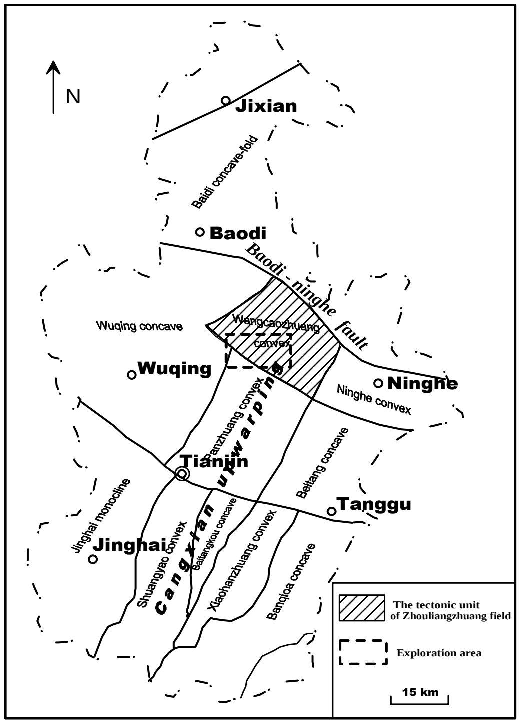

FIGURE 2: Tectonic map of the Tianjin region.

There are three main faults in the study area (see Figure 3) affecting the geothermal resources and the reservoirs distribution. These faults may be described as following:

- The Dakoutun fracture is a normal fault, striking NW-SE and dipping to the SW. formations on the downthrown side are part of the Wuqing sedimentary basin, which is characterised by very thick Tertiary formations, while the uplifted side belongs to the Wangcaozhuang convex. The fault is believed to provide path for hot water.

- The Wangcaozhuang fault is a normal fault, striking from NWW to SEE, dipping to the S with angle of 40°. The fault is about 30 km long and believed to connect different geothermal formations.

- The Niutihe fault is also a normal fault, more than 10 km in length, striking approximately from E to W, and dipping to the S, with an angle of about 30°. The fault is also believed to provide channels for thermal water migrating between different formations.

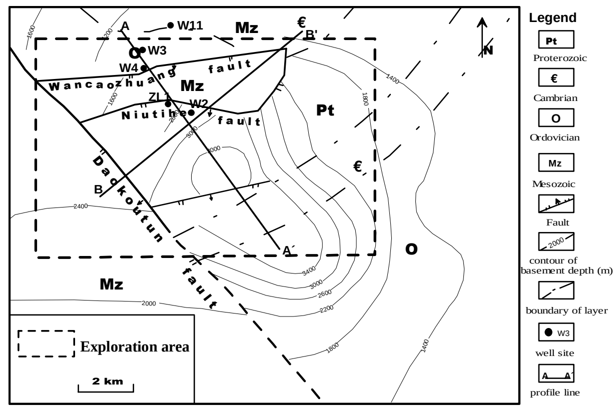

FIGURE 3: Geological map of the Zhouliangzhuang field

2.2 Lithological structure

The lithological information is summarised in Table 1 and Figure 4 show two cross-sections through the area.

In general, 7 layers or formations are found distributed over a 4000 m in the geothermal field, with varying thickness and lithological structure. Quaternary and Neogene formations cover the entire geothermal field, while Eogene, Mesozoic, Ordovician and Cambrian formations are appear to be missing in some areas. A thick Proterozoic formation is distributed over the whole field. According to analysis of properties of rocks, the Ordovician, Cambrian, and Proterozoic formations are main aquifers, with good permeability.

TABLE 1: Simplified lithological structure of the Zhouliangzhuang geothermal system

Stratum	**Thickness (m)**	Lithology
Quaternary (Q)	200-350	Sandy cohesive soil, fine sand
Neogene (N)	500-800	Mudstone, sandstone and sandy conglomerate
Eogene (E)	~2000	Mudstone and sandstone
Mesozoic (Mz)	~700	Sandstone, volcanic rock and mudstone
Ordovician (O)	~700	Limestone, shale and dolomitic limestone
Cambrian(Є)	~800	Limestone, mudstone, shale
Proterozoic (Pt)	>1000	Shale, sandstone, dolomitic limestone and dolomite

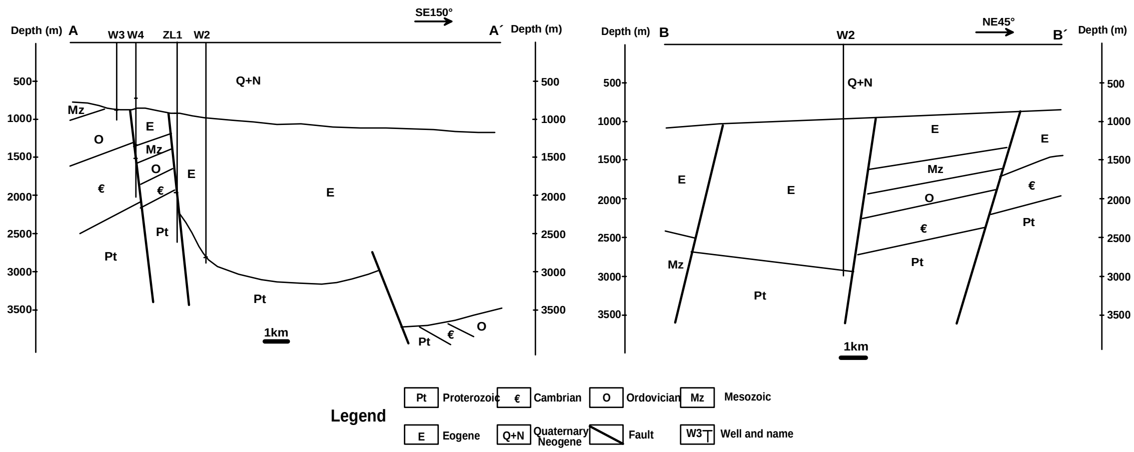

FIGURE 4: Geological cross sections through the Zhouliangzhang geothermal system (see Figure 3 for location)

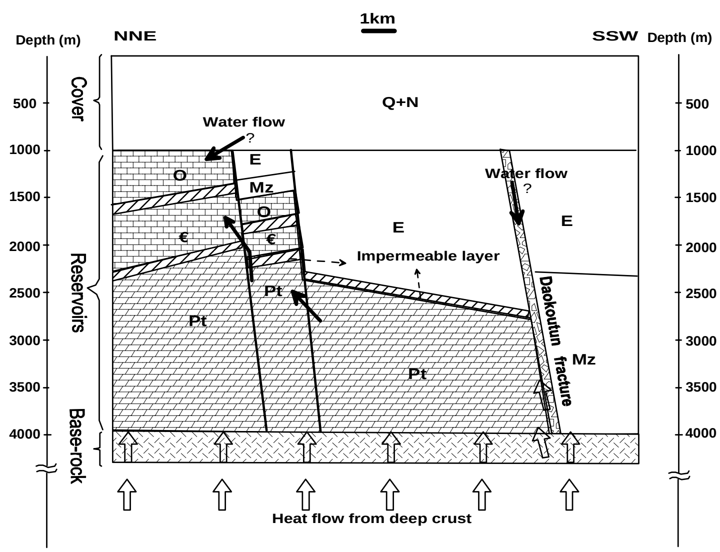

FIGURE 5: Conceptual model of Zhouliangzhuang geothermal system

2.3 The geothermal reservoirs

There are three separate productive geothermal formations or reservoirs, in the Zhouliangzhuang geothermal system, as already mentioned:

1. The Ordovician formation (O), which is mostly composed of limestone, has average temperature in the range of 60 to 82°C. This layer seems to be missing in the centre of the study area. Well W3 produces from this formation, and its wellhead pressure was 0.6-0.8 bars in 2001.

2. The Cambrian formation (€), which is mainly composed of limestone, has formation temperature higher than 80°C. Well W4 has produced from it since the 1980´s. The pressure of the wellhead was about 3.8 bars in 2001.

3. The Proterozoic formation (Pt) is mainly composed of dolomite and limestone-dolomite. This layer is widespread in the field. There are two wells (W2 and ZL1) producing from this formation. The temperature of the formation is about 100°C and wellhead pressure was about 6.0 bars in 2001.

3. MODELLING OF THE ZHOULIANGZHUANG GEOTHERMAL SYSTEM

Reservoir modelling is an integral part of geothermal reservoir assessment and management. In this report, a conceptual model based on available geological data is set up. Consequently, the LUMPFIT and TOUGH2 simulation programs are used to simulate monitoring data from two wells (W3 and W4) with production histories of nearly 15 years. The two models are set up to find the relationship between production and the historical pressure response to determine the production potential of the geothermal system. Consequently, these models should be involved in directing and managing the future geothermal development in the field.

3.1 Conceptual model of Zhouliangzhuang reservoir

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 behaviour or characteristics of interest to the modeller (Grant, Donaldson, and, Bixley, 1982). The conceptual model of Zhouliangzhuang geothermal system is mainly based on geological data. In the model, the structure of the geothermal system, the heat source, hot water flow paths and the source of recharge path are described. The conceptual model is shown in Figure 5.

The main elements of the conceptual model are as follow:

- The main reservoir formations vary in thickness. The Ordovician formation is 300-700 m, Cambrian formation is 300-800 m and Proterozoic formation is more than 1000 m. The Ordovician and Cambrian formations are not found in centre of the field.
- The thermal resource is characterised 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 heat up.
- Permeable faults connect the different formations and act as paths for the hot water.
- The main hot recharge fault of the system is considered to be the Daokoutun fault.
- The geothermal water is believed to be of meteoritic origin from mountains in the northern Tianjin region.

3.2 Lumped parameter modelling

The method of lumped parameter modelling has been used successfully for about two decades to simulate monitoring data from several low-temperature geothermal reservoirs in Iceland and elsewhere (Axelsson and Gunnlaugsson, 2000). The lumped simulators have been used to assess the production capacity of reservoirs by predicting future water level change for various production scenarios.

Lumped parameter models are set up by using the program LUMPFIT (Axelsson and Arason, 2002). The computer program automatically fits observed water-level or pressure change data with the model's production response by using a non-linear iterative least-squares technique for estimating the model parameters. The parameters characterize the response of the model to production. The two main properties of the model are the storage coefficients of a tank (κ_i) and flow conductance of a resistor (σ_i). The storage coefficient reflects the volumetric storage of different parts of the geothermal reservoirs depending on volume, porosity and storage mechanism. The following formula is used for the storage coefficient in the case of compressibility controlled storage:

$$\kappa = V \rho c_t \tag{1}$$

where V = Volume of the reservoir (m^3);

ρ = Liquid density (kg/m^3);

c_t = Total compressibility of the liquid-saturated formation (Pa^{-1}).

The total compressibility of the liquid-saturated formation is given by the equation:

$$c_t = \phi c_w + (1-\phi) c_r \tag{2}$$

where c_w and c_r are the compressibility of the water and rock, respectively and ϕ is the porosity of the formation.

The conductance parameter (σ_i) reflects the fluid conductivity of the reservoirs and depends on permeability, viscosity and geometry. The formula (assuming 2-D flow) is as follows:

$$\sigma_i = 2\pi k_i \frac{h}{\ln(\frac{r_{i+1}}{r_i})\nu} \tag{3}$$

where k_i is permeability (m^2), h is thickness of reservoir (m), ν is the kinematic viscosity of water (m^2/s) , and r_{i+1} and r_i are radiuses of different model parts.

Figure 6 shows the measured wellhead pressure of well W3, along with the pressure simulated by LUMPFIT, due to an almost constant 1.14 l/s production from 1989 to 2001. A two tanks closed model gave the best result. Figure 7 shows the observed wellhead pressure of well W4, along with pressure simulated by LUMFIT, due to an almost constant flow rate of 4.2 l/s from 1987 to 2001. A two tanks closed model gave the last fitting. This indicates that there is no recharge to the Zhouliangzhuang geothermal system. Although the two formations are simulated separately, there might be a connection between them through permeable faults, which might influence the simulation results. However, the effect of this possible connection is uncertain.

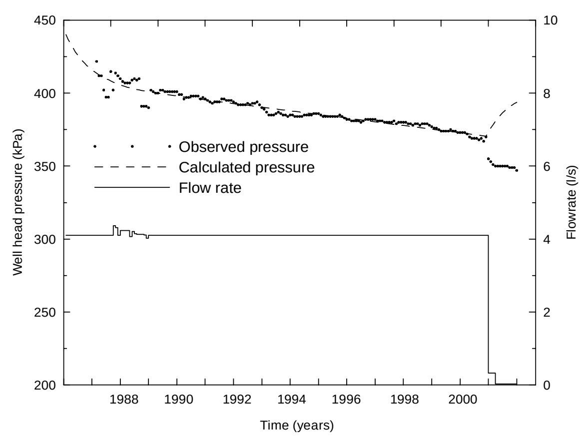

FIGURE 6: Wellhead pressure change and discharge history of well W3 simulated by LUMPFIT

3.3 Simple numerical distributed parameter model

In this report, the numerical distributed parameter modelling is carried out by the TOUGH2 computer program. TOUGH2 is a general-purpose numerical simulation program for non-isothermal flows of multi-component, multiphase fluids in one, two, and three-dimensional porous and fractured media (Pruess, Oldenburg and Moridis, 1999). The TOUGH2 program is now being used by over 150 organizations in more than 20 countries. The major application areas include geothermal simulation, environmental remediation, and nuclear waste isolation (Elmroth, Ding, Wu, and Pruess, 2002).

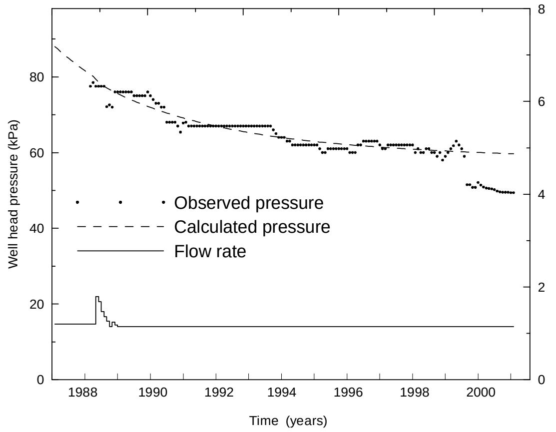

FIGURE 7: Wellhead pressure change and discharge history of well W4 simulated by LUMPFIT

3.3.1 Creating the model mesh

In general, a TOUGH model consists of a number of grid blocks (elements) connected to each other. Each element is assigned an appropriable rock type, which has certain permeability, porosity, and other properties partly based on the reservoir geology.

The Zhouliangzhuang model covers an area of 1050 km^2, which is approximately the area of Wancaozhuang convex (see Figure 8). The mesh was generated by the Meshmaker associated with TOUGH2. It consists of 640 elements, where 160 elements are "inactive" (For the inactive elements no mass and energy balance equations are set up, and their thermodynamic condition will remain unchanged in TOUGH2 model). The model consists of 8 layers.

3.3.2 Model calibration

In general, detailed data on geology, hydrogeology, temperature, pressure and long-term production and pressure response is needed for the development of a reliable detailed distributed numerical model of a geothermal system. In this case, however, only limited geological data is available and production histories are only for free discharge from wells, but not for large-scale mass production. The model developed here should, therefore, be considered as the first stage of model development data is needed to develop the model further before it becomes an integral part of future system management.

The fractures are considered as the most permeable flow channels which also connect different formations. Hence, the corresponding rock type has higher porosity and permeability.

It should be mentioned that when we simulate the observation data in the wells, well head pressures have been changed to formation pressure, so as to enable a comparison with the calculation by TOUGH2.

The parameters in the TOUGH2 model were adjusted until a good math with the observation data from the two wells was obtained as shown in Figure 9 and 10. The geothermal system model has no recharge from outside. However, the model characteristics are only based on a simulation with very low mass extraction rates, which can nearly be considered similar to natural discharge. The effect of production did possibly not reached the model to boundaries during the 15-years production histories.

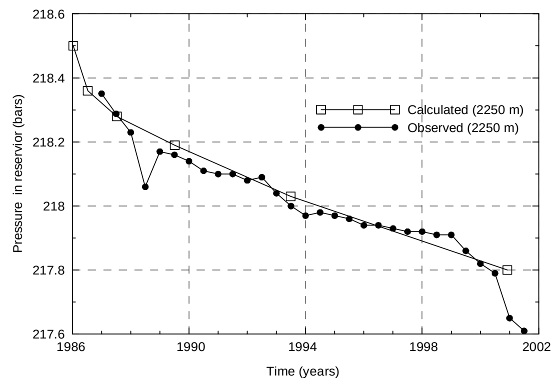

FIGURE 9: Observed and calculated pressure in well W3 at 1250m depth

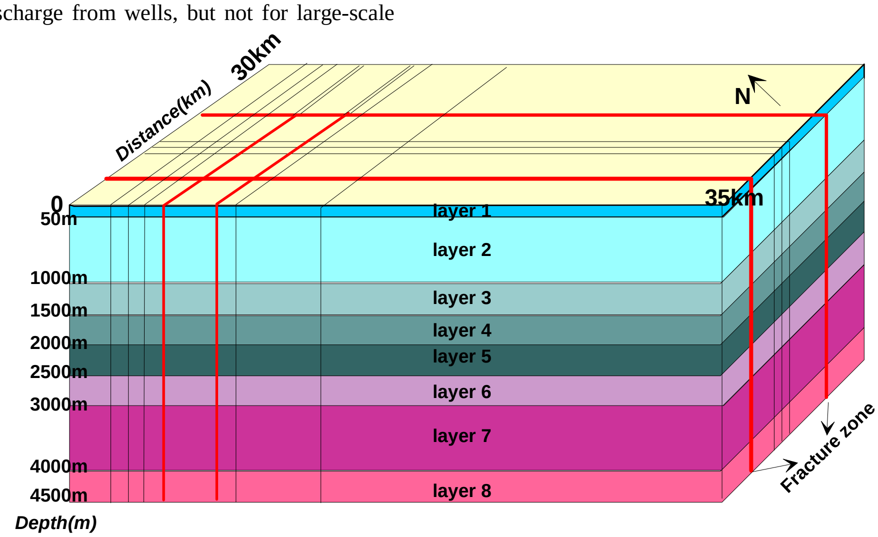

FIGURE 8: Mesh of the Zhouliangzhuang geothermal system of TOUGH2 model

TABLE 2: Future exploitation scenarios for LUMPFIT prediction

Formation	Scenarios			
	Scenario number	**Production in heating season (125 days), l/s**	**Production in non-heating season (240 days), l/s**	**Annual average production (m^3)**
Ordovician	1	30	5	430,000
	2	60	15	960,000
	3	120	20	1,700,000
	4	150	20	2,000,000
Cambrian	1	30	5	430,000
	2	100	15	1,400,000
	3	200	20	2,600,000
	4	250	20	3,100,000

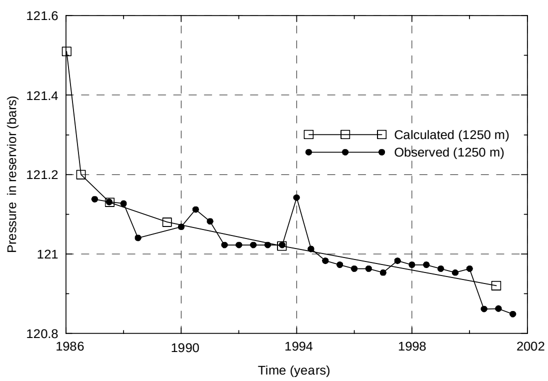

FIGURE 10: Observed and calculated pressure in well W4 at 2250m depth

4. ASSESSMENT OF THE PRODUCTION POTENTIAL

4.1 LUMPFIT predictions

In order to assess the production potential of the Zhouliangzhuang geothermal system, the lumped parameter models were used to predict the water level change due to long-term production. Four production scenarios were calculated for both the Ordovician and Cambrian formations, using the corresponding two tank closed models.

Table 2 presents these future production scenarios. The predictions are calculated to the year 2025, starting from 2004. The results are shown on the Figure 11 and 12. According to prediction results, the Ordovician formation should be able to sustain a production of 1,700,000 m^3/year until the year 2025, with a drawdown less than 150 m, which is the limit set by the down-hole pumps to be used. The Cambrian formation should, however, be able to sustain a production of 2,600,000 m^3/year during the same time period. Since the models are closed, no recharge is supplied to the reservoir, reflected in a constant drawdown with time in the second model. However, the first model is connected to outer part reservoir, with a very huge volume, which can supply relatively steady pressure to keep pressure of production formation.

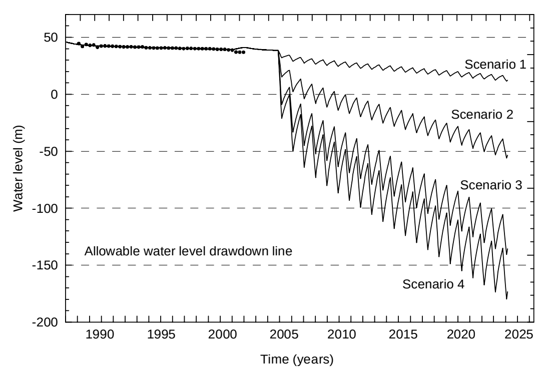

FIGURE 11: Predicted water level decline in the Ordovician formation (well W3) for production scenarios 1-4, calculated by the two-tank closed lumped model

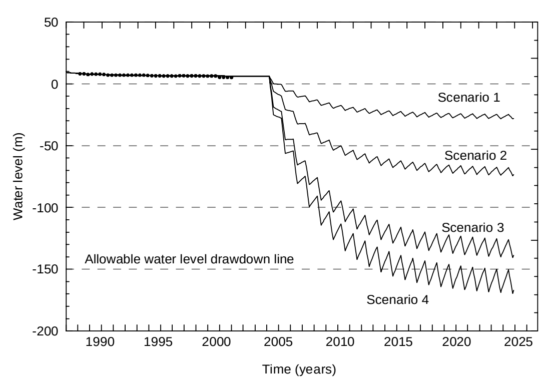

FIGURE 12: Predicted water level decline in the Cambrian formation (well W4) for production scenarios 1-4, calculated by the two-tank closed lumped model

4.2 TOUGH2 model prediction

Several production cases are considered for predicting with TOUGH2 model (see Table 3). Only constant-rate scenarios are considered here to simplify calculations. Here, the production of Proterozoic has no change with still constant flow rate of 8.3 l/s in case1.

TABLE 3: Future exploitation scenarios for TOUGH2 predictions

Average production (l/s) Formation	Case 1	Case 2	Case 3
Ordovician	65.0	65.0	70.0
Cambrian	80.0	80.0	90.0
Proterozoic	8.3	105.0	120.0

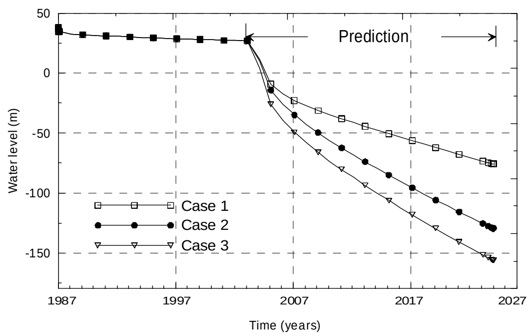

FIGURE 13: Predicted water level decline in the Ordovician formation (well W3) for production cases 1-3, calculated by TOUGH2 model

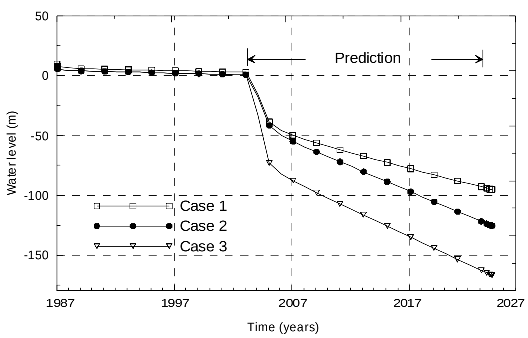

FIGURE 14: Predicted water level decline in the Cambrian formation (well W4) for production cases 1-3, calculated by TOUGH2 model

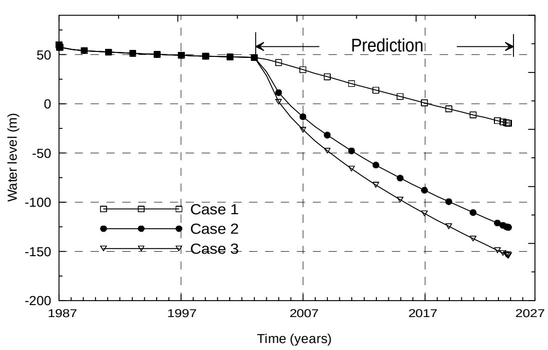

FIGURE 15: Predicted water level decline in the Proterozoic formation (well W2) for production cases 1-3, calculated by TOUGH2 model

Figure 13, 14 and 15 show the results of predictions by TOUGH2 in the three formations, which also are carried out to the year 2025.

It is interesting to note that even though only production from upper two formations (case1), the water level drawdown in Proterozoic formation is more than the past (see Figure 17), this result from the fact that the three formations are connected by faults in TOUGH2 model. Therefore, the production effect between the formations needs be comprehensively studied.

Based on the cases 2 and 3, the allowable production is the following:

- 65 l/s from the Ordovician formation;
- 85 l/s from the Cambrian formation;
- 110 l/s from the Proterozoic formation.

4.3 Production potential of the geothermal system

Based on current economic conditions (cost of extracting, etc.), the allowable maximum water level depth in production wells should be less then 150 m during the next 20 years. Based on the prediction result of LUMPFIT, the potential of the Ordovician formation is estimated to be about 1.7×10^6 m^3/year and that of the Cambrian formation is estimated to be about 2.6×10^6 m^3/year. Based on the TOUGH2 model, however, the production potential of the Ordovician formation is estimated to be about 2.0×10^6 m^3/year, and the production potential of Cambrian formation about 2.7×10^6 m^3/year. According to the TOUGH2 model the production potential of the Proterozoic formation is about 3.5×10^6 m^3/year. Therefore, the total allowable production of all three formations is estimated to be about 7.8×10^6 m^3/year.

5. REINJECTION IN THE ZHOULIANGZHUANG FIELD

Reinjection is currently used in many geothermal fields around the world. It's use started around the year 1970 as a method to dispose of wastewater from power plants for environment protection. Today, it is also used for pressure maintenance and to extracting more of the thermal energy in place in geothermal reservoirs (Stefánsson, 1997).

According to the results of the lumped parameter simulation, the Zhouliangzhuang geothermal system appears to be mostly closed, at least the deeper parts. The natural recharge to the system is, therefore, limited and the water-level drawdown will increase rapidly in the future with increased production. Reinjection is, consequently, essential to maintain the reservoir pressure in order to enable sustainable utilization and increase the production potential of the system.

Since 1996, reinjection experiments have been conducted in the karst-fissure basement reservoirs in Tianjin. The experiments have been verified that colder water can successfully be reinjected into this medium (Wang, 2003).

Therefore, both the lumped and numerical models were used to estimate the benefits of reinjection into the Zhouliangzhuang geothermal reservoir, as discussed in the following.

5.1 LUMPFIT reinjection simulations

In the future, geothermal production may be expected to increase as the local economy improves and consumption increases. Table 4 lists the production and reinjection scenarios studied. The predictions are carried out by using the LUMPFIT program and the models already developed for the two formations.

Figures 16 and 17 show the results of the lumped parameter predictions with and without reinjection. It is clear that reinjection can efficiently maintain the reservoir pressure. When the injected volume is about 50% of the production, the production potential will apparently increase quite drastically.

TABLE 4: Reinjection scenarios used for LUMPFIT prediction

Formation	Period (years)	Production in heating season (125 days), l/s	Production in non-heating season (240 days), l/s	Reinjection
Ordovician	2004-2005	30	5	--
	2005-2006	60	15	--
	2006-2008	100	15	50% injection
	2008-2012	150	20	50% injection
	2012-2017	200	20	50% injection
	2017-2022	250	20	50% injection
	2022-2025	300	20	50% injection
Cambrian	2004-2005	30	5	--
	2005-2006	60	15	--
	2006-2008	100	15	50% injection
	2008-2012	200	20	50% injection
	2012-2017	250	20	50% injection
	2017-2022	300	20	50% injection
	2022-2025	400	20	50% injection

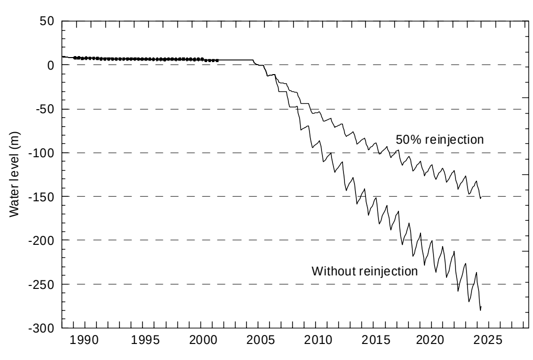

FIGURE 16: Benefit of reinjection into the Ordovician formation, according to the lumped parameter model

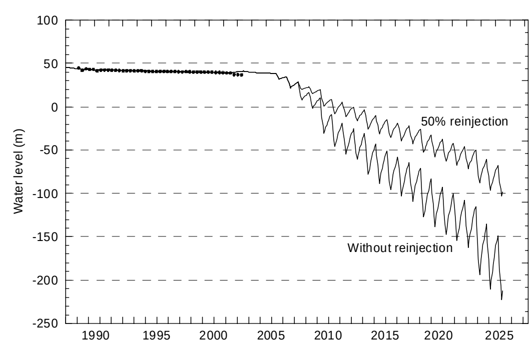

FIGURE 17: Benefit of reinjection into the Cambrian formation, according to the lumped parameter model

5.2 TOUGH2 reinjection calculations

In TOUGH model, the following case of average production and reinjection was considered:

Production:

- 100 l/s from Ordovician formation;
- 130 l/s from Cambrian formation;
- 160 l/s from Proterozoic formation.

Reinjection:

- 30 l/s into Ordovician formation;
- 40 l/s into Cambrian formation;
- 50 l/s into Proterozoic formation

This is minimum reinjection needed to keep the water level above 150 m depth.

Figures 18, 19 and 20 show the predicted water level changes with injection and without injection, in the three formations for the next 25 years, according to the TOUGH2 model.

According to these predictions by the two models, reinjection appears to be a good method of maintaining the reservoir pressure.

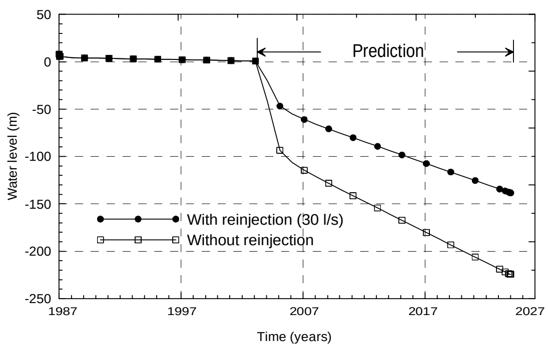

FIGURE 18: Benefit of reinjection into the Ordovician formation, according to the TOUGH model

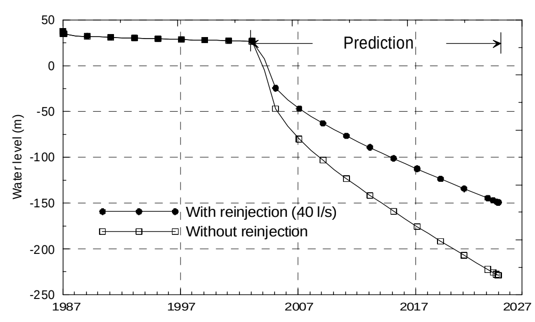

FIGURE 19: Benefit of reinjection into the Proterozoic formation, according to the TOUGH model

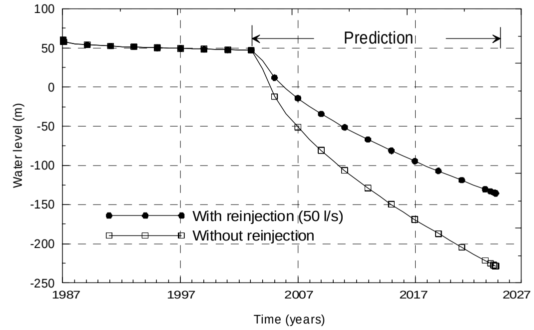

FIGURE 20: Benefit of reinjection into the Cambrian formation, according to the TOUGH model

5.3 Increased production potential

According to the reinjection simulation by the lumped parameter models, the production potential of the Ordovician formation is estimated to be about 3.6×10^6 m^3/year, and of the Cambrian formation to be about 4.7×10^6 m^3/year, both with 50% injection. Reinjection calculations by the TOUGH2 model, the production potential of the Ordovician formation is about 3.2×10^6 m^3/year, that the production potential of the Cambrian formation is about 4.1×10^6 m^3/year, and that the Proterozoic formation is about 5.0×10^6 m^3/year. This lead to a total allowable production of about 12.2×10^6 m^3/year, with average injection rates of about 30 l/s, 40 l/s and 50 l/s.

6. SUMMARY AND RECOMMENDATION

The main results of this report may be summarized as follows:

- The Zhouliangzhuang geothermal system is low temperature sedimentary geothermal system, with conduction dominated heat transfer. The system consists of three main reservoir formations associated with different formations (Ordovician, Cambrian and Proterozoic formation). The three aquifer formations are believed to be separated by impermeable layers and they are, hence, poorly connected hydrodynamically. The temperature of different parts of geothermal system ranges from 60 to102°C, and wellhead pressure is 0.6-6 bar.

- Three geothermal wells have been subject to long-term extraction at very low flow rates. Therefore, the geothermal system can be considered being close to the natural state. The only response data available are data on the well head pressure response to production for two wells, which discharge from the Ordovician and Cambrian formations.

- A lumped parameter model is set up, using the LUMPFIT program, base on the production and wellhead pressure histories of these two wells. The Ordovician and Cambrian formations are both simulated by closed two tank models, which are believed to conform with the nature of the formations, which are believed to have limited recharge. Closed models also lead to conservative predictions.

- Based on the conceptual model, a simple numerical distributed parameter model is also set up using the TOUGH2 program. It simulates the two production histories, and again the Zhouliangzhuang geothermal system is simulated as a closed system.

- According to predictions for various exploitation scenarios, calculated by both models, the production potential of the Ordovician formation is estimated to be 1.7-2.0×10^6 m^3/year for the next 20 years. The production potential of the Cambrian formation is estimated to be about 2.6-2.7×10^6 m^3/year. Based on the TOUGH2 model, the production potential of the Proterozoic formation is estimated to be about 3.5×10^6 m^3/year. The total allowable production is therefore about 7.8×10^6 m^3/year for the next 20 years.

- Through reinjection production from the geothermal system may be sustained for a longer period as well as increased.

The study presented in this report is limited by a lack of data on the geothermal system, which also affects the reliability of the results. Therefore, the author would like to make some suggestions, which may be helpful in the future, management of the geothermal resources in Zhouliangzhuang field.

- During the distributed parameter modelling, the complex geology of the geothermal system has been simplified drastically because of limited geometrical data. Therefore, the details of the numerical model should be increased as more and more data become available.

- Careful monitoring of production parameters for the Ordovician and Cambrian formations should be continued, and a comprehensive monitoring program set up that should involve production from the Proterozoic formation as well as other possible formations, such as the Neogene formation. The data collected will be an essential guide for future management of the geothermal resources.

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