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# Research and Progress of Geothermal Reinjection in Beijing, China

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## ABSTRACT

Since geothermal fields were found in the 1970's in urban areas of Beijing, a variety of tests on geothermal reinjection have been carried out in geothermal production wells drilled in urban and suburban areas. Tap water, shallow, cold groundwater, factory wastewater and geothermal backwater after heating have been used for the tests and a certain amount of experience has been accumulated. Productive reinjection has been gradually implemented and expanded in the Xiaotangshan geothermal field since the 21st century. At present, more than 36.5%[1] (up to 63%[2]) of geothermal water can be reinjected in this geothermal field. The pressure (water level) of geothermal reservoir has gradually risen since 2005, which was higher than that of 2004[3,4]. Geothermal reinjection can save costs for geothermal exploration and significant environmental benefits have been achieved. Research on the mechanism of geothermal reinjection has been carried out since the 1970's, but there was only a partial understanding at the early stages of the small-scale pilots. With the implementation of large-scale reinjection, progress has been made on water balance, heat balance and geochemical aspects. On this basis, recommendations have been made on geothermal reinjection in Beijing in the future.

## 1. EXPLORATORY ATTEMPTS IN GEOTHERMAL REINJECTION

Many tests of geothermal reinjection have been carried out in Beijing since the 1970's as geothermal development has continued. Tap water, waste hot water, shallow, cold groundwater, and waste geothermal water have been used for geothermal reinjection[4].

### 1.1 Tap Water Reinjection in the Urban

In 1971, the geothermal well JR-2 was drilled in the Temple of Heaven. A reinjection test was carried out for 12 days from November 27 to December 9, 1974 with tap water. Tap water at 10°C was cooled in the winter air and the total volume of water reinjected was 2041 $m^3$. Because the specific gravity of low temperature water is greater, it locally increased pressure in the reservoir and raised water head in surrounding geothermal wells. The spatial extent of the rise in pressure head was greater along the direction of the NE fault in the layered geothermal reservoir. Due to less reinjection, the downhole temperature recovered in about 15 days.

### 1.2 Waste Hot Water Reinjection

The geothermal well JR-13 was located at the No.3 Cotton Mill in Beijing for heating a textile workshop. In the summer, spray was used for cooling with cold groundwater in the workshop and the geothermal well was not used. Waste hot water in the factory was reinjected into the JR-13 in the test. It was expected to store thermal energy and to increase thermal efficiency for heating textile workshop in the winter. The reinjection test lasted 123 days from 17 June to 19 October, 1975 and the total volume of water reinjected amounted to 13,500 $m^3$. The hot water reinjected was 56~62°C. Because the specific gravity of hot water is lower, the pressure of geothermal reservoir decreased around the reinjection well causing a drawdown of water head. The underground heat storage was proven successful. There was an increase in heat when produced the following winter equal to about one third of the heat injected.

### 1.3 Cold Groundwater Reinjection

The tap water comes from groundwater in Beijing. In order to save costs and inject more groundwater, the geothermal well (JR-26), a temporarily idle well in the Chongwenmen Hotel, was used for the reinjection test. The auxiliary well was drilled 5m away from the JR-26 well. Quaternary cold groundwater in the auxiliary well was produced and then injected into the JR-26 well. This reinjection test lasted 89 days (from 4 June 1980 to 2 September 1980) and the total volume of water reinjected amounted to 59,400 $m^3$. The temperature of cold water reinjected was 15.5°C. And it had no influence on the temperature of production from the JR-8 geothermal well 250m away. The temperature in the reinjection well recovered slowly. Its temperature recovery was about two thirds after one year.

### 1.4 Waste Geothermal Water Reinjection

After the water from well JR-32 returned from circulation in the heating system, it was injected into the JRG-4 well in Metallurgical Industry Press. This reinjection test lasted 84 days for two time periods in the spring of 1982 and 1983. The total volume of water reinjected amounted to 30,200 $m^3$. The reinjection tests were carried out with different reinjection rates and data was obtained about the rise in water head and recovery temperature in the observation well.

## 2. THE IMPLEMENTATION OF PRODUCTIVE GEOTHERMAL REINJECTION

Geothermal reinjection in the Xiaotangshan geothermal field began in the winter of 2001. At that time, it was carried out in a couple of wells in Yutangquan Conference Center. Geothermal reinjection was carried out in TR11 after geothermal water was exploited from TR38 for heating. The volume of water reinjected during the winter heating period in 2001 and 2002 amounted to 70,000 $m^3$ and 100,000 $m^3$, respectively. Thereafter, reinjection was gradually expanded and the number of users and wells increased. The volume of water reinjected has greatly increased since the winter of 2004 (Table 1).

Figure 1 shows that exploitation quantity was large and reinjection quantity was very small before 2004. So the thermal water level declined, and in particular, there was a large decline in 2004. After the winter of 2004, there was a significant increase in reinjection quantity and a corresponding decrease in exploitation quantity each year.

Therefore, water level of geothermal water has risen since 2005 (monthly water level had risen after the reinjection in 2004) and water level still rose a little in the case of a significant increase in exploitation quantity in 2007.

## 3. MECHANISM OF GEOTHERMAL REINJECTION

The volume of water reinjected, water head, water temperature and well temperature are monitored during each geothermal reinjection. Meanwhile, water quality monitoring for reinjection water and pump water is carried out. Therefore, the mechanism of geothermal reinjection can be discussed on the basis of heat balance and change in water quality.

In 1979, there was casing damage in one geothermal well in Liangxiang geothermal field. It caused the incursion of shallow cold groundwater into the well to caused spontaneous reinjection of different water quality into the reservoir and reduced the temperature of geothermal water. This was the first discussion on the mechanism of geothermal reinjection from a geochemical point of view. The article *Preliminary discussion on the reinjection of different water quality* was presented at the national symposium on artificial groundwater recharge in Beijing in 1979.

### 3.1 Reinjection from TR38 to TR11

15 water samples were collected at intervals of a few minutes during the process of pumping water from TR11 after geothermal reinjection. Main cations, anions, $SiO_2$, F and pH were measured for each sample. Based on the content-time curve, the $SiO_2$ content and Total Dissolved Solids (TDS) were less than one-eighth of average level during the first 10 minutes of pumping. Changes in other indexes and time intervals were very small. As can be seen from the water quality measurements, $SiO_2$ content and TDS in TR38 were slightly lower than those in TR11. So the pumping showed that the TR38 water quality was only in less than 10 minutes in the process of pump water in TR11. After that, water was from original TR11.

**Table 1: Process of geothermal reinjection in Xiaotangshan Geothermal Field**

| Time | Geothermal reinjection | | | | | | | Total reinjected volume |
|---|---|---|---|---|---|---|---|---|
| | TR38 | TR22G | TR51 | TXR1 | TR35/TRG1 | TR41/TR7 | TR30 | Production well |
| | TR11 | TR22 | TR51G | TR3 | TR50 | TR37 | TR32 | Reinjection well |
| 2001 | blue | | | | | | | $0.070\times10^6$ m$^3$ |
| 2002 | blue | | | | | | | $0.100\times10^6$ m$^3$ |
| 2003 | blue | blue | | | | | | $0.248\times10^6$ m$^3$ |
| 2004 | blue | blue | blue | blue | blue | blue | | $1.027\times10^6$ m$^3$ |
| 2005 | blue | blue | blue | blue | blue | blue | | $1.323\times10^6$ m$^3$ |
| 2006 | blue | blue | blue | blue | blue | blue | blue | $1.270\times10^6$ m$^3$ |
| 2007 | blue | blue | blue | blue | blue | blue | blue | $1.232\times10^6$ m$^3$ |
| 2008 | blue | blue | blue | blue | blue | blue | blue | $1.220\times10^6$ m$^3$ |

* Blue in the table represents reinjection has been carried out.

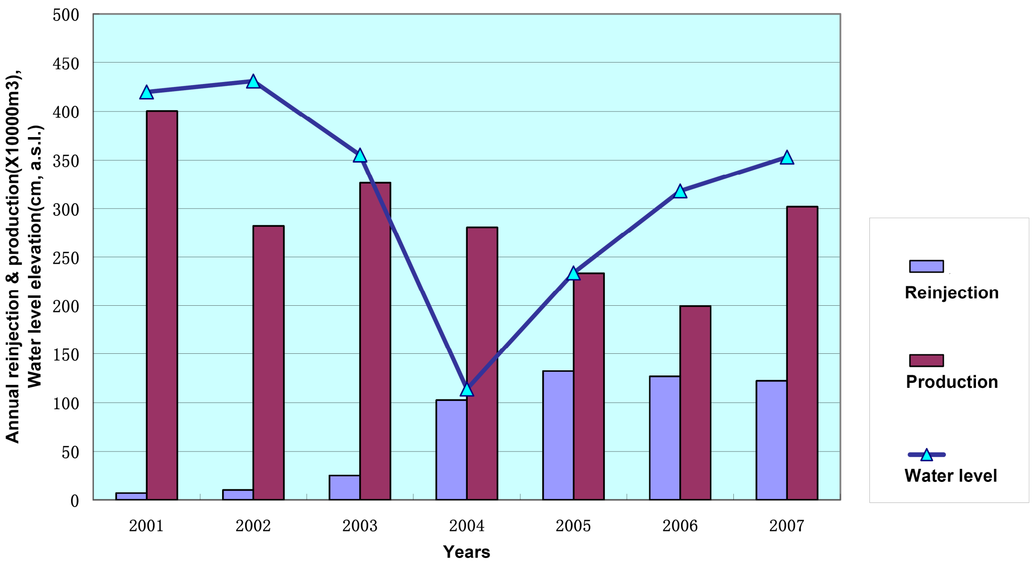


**Figure 1: Annual reinjection, production and water level in Xiaotangshan Geothermal Field**

In order to find the change in the water quality, a Langelier-Ludwig diagram was partly amplified to use (Fig.2) [2]. Water quality points in TR38 are concentrated in a small circle in lower right corner of the diagram and original ones in TR11 are concentrated in a big circle in the upper left part. Water quality of pump water from TR11 after reinjection is different from water quality in TR38 and is not exactly the same as the original quality in TR11. These points are concentrated in lower part of original water quality circle and close to the small circle of TR38. It shows subtle variation of water quality, but the mechanism of geothermal reinjection can be better understood. Geothermal backwater after heating is used for reinjection. Its temperature is lower, but its water quality is the same as geothermal water. Therefore, chemical reactions between different types of water quality cannot happen. Reinjection water sank to the bottom of the geothermal reservoir rather than staying in place because of its higher density and specific gravity after reinjection water comes into the geothermal reservoir from the reinjection well. In this process, water at the bottom of the geothermal reservoir, which is of higher temperature and closer to geothermal water, is driven into the top of the geothermal reservoir (open-hole section of the reinjection well). So when pumping back water, water in the casing is pumped (less than 10 minutes) and then water is pumped that is hotter than the water originally at the bottom of the reinjection well in the deep geothermal reservoir because it is neither water reinjected nor water originally in the reinjection well.

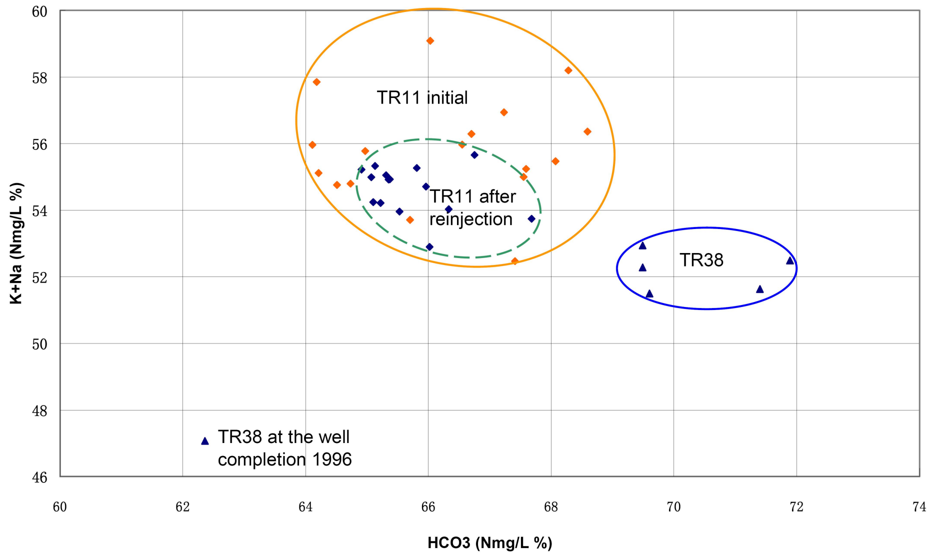


**Figure 2: Langelier-Ludwig diagram partly amplified**

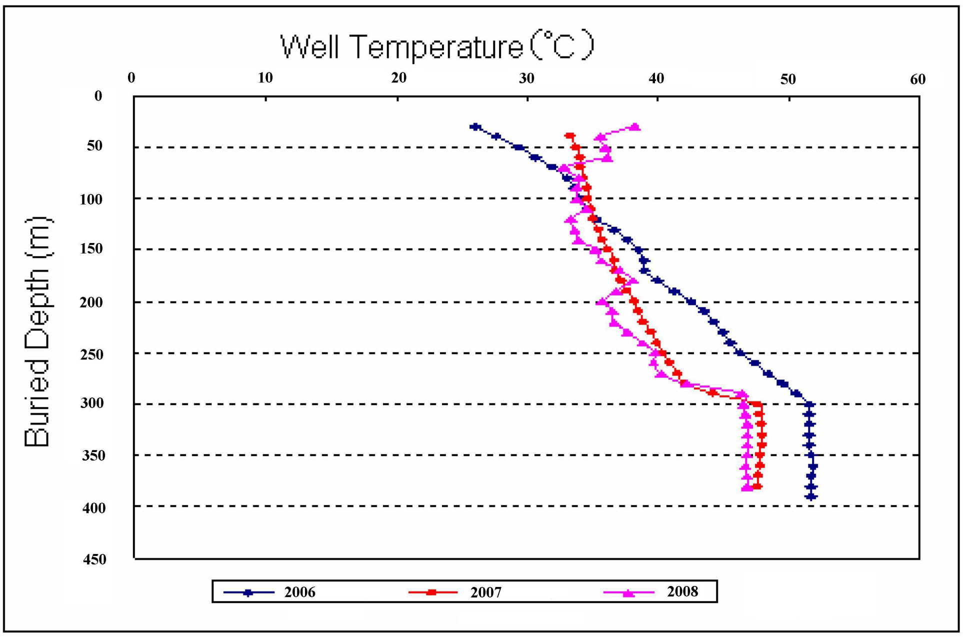

**Figure 3: Change in well temperature in TR22 in 2006, 2007, 2008**

### 3.2 Reinjection from TR22G to TR22

The wellhead water temperature was 68°C in TR22G and the temperature of backwater after heating dropped to 24~37°C and was 30°C on average. Backwater was injected into TR22. Original wellhead water temperature was 58°C in TR22, well temperature in TR22 no doubt dropped during reinjection. Figure 3 shows a comparison of the temperature curve during the spring of 2006, 2007, 2008 after reinjection. On the well section 120m~380m, the decline in well temperature from 2006 to 2008 becomes more obvious and regular[5].

Heat balance can be used for checking. The well was drilled to a depth of 557.18m and the intermediate casing was set at 380m. The cap rock was closed by well cementing. The well temperature at 380m represented the temperature on the top of the geothermal reservoir. The monitoring data respectively were 51.7°C on 27 October, 2006; 47.7°C on 10 November, 2007, which declined by 4.0°C; 46.8°C on 28 May, 2008, which declined by 0.9°C again. In accordance with 55,000 $m^2$ of heating area, 50W/$m^2$ of heating index and 35.06×$10^{12}$J of released heat, the water volume influenced by 4.0°C was 2,090,000$m^3$, which was 9.5 times of reinjection volume during 2006~2007 (220,500$m^3$). And then the water volume influenced by 0.9°C was 9,000,000$m^3$, which was 69 times of reinjection volume during 2007~2008 (134,800$m^3$) [5].

The decline of temperature during reinjection reached temperature equilibrium with the geothermal reservoir (including rock matrix), so for the siliceous dolomite of Formation Tieling Group of the Jixian System in TR22, the fractured rate was 1%, the formation density was 2700 kg/$m^3$, the specific heat of the formation was 920 J/kg.°C, the density of water was 1000 kg/$m^3$ and the specific heat of water was 4187 J/kg.°C. When the change in temperature was 1°C in 1$km^3$ of geothermal reservoir, changes in heat of rock and water was 4.19×$10^{13}$J and 2.46×$10^{15}$J, respectively. Hence, the change in temperature was 4°C during the reinjection period 2006~2007, that corresponded to 3,500,000$m^3$ of geothermal reservoir. The change in temperature was 0.9°C during the reinjection period 2007~2008, that correspond to 15,600,000$m^3$ of geothermal reservoir. Based on 300m of reservoir formation thickness, the volumes equal to cylinders, of which the reinjection well was the centre of the circle and 61m and 129m were the radius, respectively. The mechanism of this phenomenon may be explained by gradually expanding the volume of rock with reduced temperature and slowing the change in temperature by not quickly reducing the temperature of geothermal reservoir during continuous reinjection.

From a geochemical point of view, the overall change in water quality of geothermal water was analyzed. A simplified Langelier-Ludwig diagram was used (Fig.4). It can be seen that there is large difference in ion content between TR22 and TR22G, and it subtly affects the change in water quality. Water quality in TR22 gradually approaches water quality in TR22G. Thermal water exploited in TR22 is in the Tieling Group of the geothermal reservoir and thermal water exploited in TR22G is mixed from both reservoirs of the Tieling Group and the Wumishan Group. There is some difference in water quality between the two Groups. It is inevitable that water quality in the reinjection well approaches water quality in the production well (water source of reinjection) during long-term reinjection rather than the intrusion of much cold groundwater.

Therefore, the results show that:

(1) During continuous reinjection, the influence scope of temperature gradually expands, the change in temperature gradually slows, and the temperature of geothermal reservoir does not significantly drop.

(2) In the geothermal reservoir of Tieling Group, which has a thin thickness (300m) and less developed karst fissures, water quality in the reinjection well approaches water quality in the production well; in the geothermal reservoir of Wumishan Group, which has great thickness (3000m) and more developed of karst fissures, reinjection water of lower temperature sinks into the deep reservoir and then thermal water of higher temperature at the bottom of the geothermal reservoir rises up into the shallow reservoir[5,6].

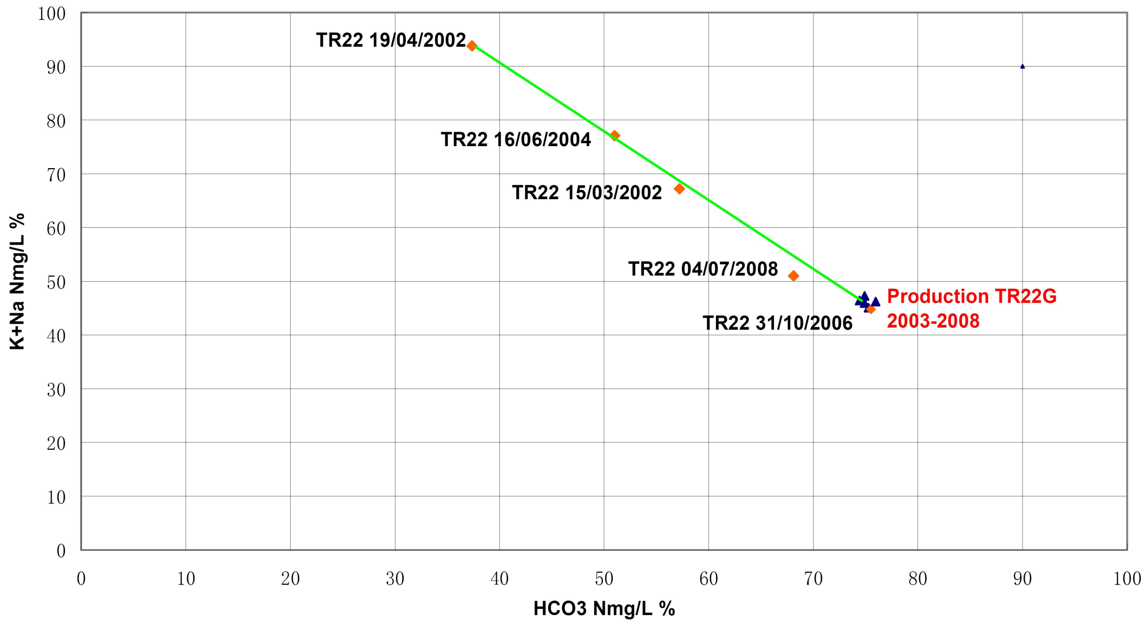

**Figure 4: Change in water quality between TR22 and TR22G**

## 4. RECOMMENDATIONS ON THE FUTURE OF GEOTHERMAL REINJECTION IN BEIJING

Geothermal reinjection offers very obvious and huge resource efficiency and economic and environmental benefits. Geothermal reinjection should be promoted and popularized for the appropriate users in the appropriate geothermal fields:

1. Geothermal backwater after heating is only thermal water of lower temperature and all the users of geothermal heating should and can carry out geothermal reinjection.

2. Users who are supplied with geothermal water should collect the water that cooled in pipelines and then release it for reinjection.

3. Besides the Xiaotangshan geothermal field, geothermal reinjection should be promoted and efficiency should be expanded in the geothermal fields in the urban and other geothermal fields.

4. Monitoring and research on geothermal reinjection should continue to be strengthened to further improve resource efficiency, economic and environmental benefits.

Geothermal reinjection is an important way to sustainably use geothermal resources and to achieve a “Circular Economy”. It is believed that under the premise of scientific concept of development, sustainable energy development, and a conservation-minded society, geothermal reinjection will play an increasingly significant role in the development of geothermal resources in the future.

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