

EXPERIENCE OF GEOTHERMAL REINJECTION IN BEIJING AND TIANJIN

Liu Jiurong

Beijing Institute of Geological Engineering

No.90, Beiwa Road

Beijing 100037

CHINA

jiu-rong@263.net

Wang Kun

Tianjin Bureau of Land, Resources and Real Estate Management

No.84, Qufu Road

Tianjin 300042

CHINA

kun1302@sina.com

ABSTRACT

Beijing and Tianjin are two very big cities with abundant low-temperature geothermal, using it mostly for space heating, bathing, health spas and recreation, fish farming, greenhouses and domestic hot water etc. With the improving living conditions of the citizens, the need for geothermal water is ever increasing in the cities. Large-scale abstraction of geothermal water caused a rapid declining of the water level of the geothermal wells in both Beijing and Tianjin, and how to ensure the sustainability of geothermal utilization has been taken as the most important task. Apart from the limitation of geothermal water production, reinjection is also taken as an important aspect of geothermal management.

Reinjection has been widely applied in the management of geothermal resources, and is becoming a kind of routine in a lot of geothermal fields. In China, reinjection tests started in 1974 in the City of Beijing. But reinjection of used geothermal water from heating systems in scale was started in the City of Tianjin in the 1990's. Since 2000, reinjection has been taken as a more and more important aspect of geothermal resources management in the two cities.

At present, a number of reinjection projects have been in operation in Beijing and Tianjin. As a result, the water level declining of the geothermal wells has been greatly mitigated. In Xiaotangshan geothermal field in Beijing, the water level has even stopped declining since 2006, owing to the reinjection and controlling of the production of geothermal water.

In the paper, the reinjection history in both Beijing and Tianjin will be summarized, and the experiences and problems of reinjection, including the distance between the production and reinjection wells, tracer test and monitoring of geothermal fields with reinjection will be discussed.

1. INTRODUCTION

Geothermal is a kind of green energy, widely used in a lot of countries for power generation and direct purpose, such as space heating, bathing, swimming pools, fish farming, greenhouses, health spas and recreation etc., creating significant economical and environmental effects. Geothermal is a kind of renewable energy, but it should not be over-exploited; otherwise, the resources will be depleted, or will need a rather long time to recover from the improper management. Therefore, it is mandatory to implement proper management for the sustainable use of geothermal resources.

Reinjection has been widely used in the management of geothermal fields, and is becoming a kind of routine in a lot of geothermal fields, since the first such project was implemented in the famous Geysers in 1969 (Axelsson & Stefansson, 1999). The purpose of geothermal reinjection is for (1) the disposal of the waste geothermal fluid that may cause thermal and chemical pollution to the environment; (2) the improvement of the heat mining, because over 90% of the heat in the geothermal reservoirs is stored in the hot rock matrix; (3) the stabilization of the production capacity of the geothermal field through the maintenance of the reservoir pressure (Liu, 1999).

Geothermal reinjection started out as a method of disposing of wastewater from power plants in order to protect the surrounding environment. It started as early as 1969 and 1970 at the Geysers in California and Ahuachapan field in El Salvador, respectively. Presently there are a number of geothermal fields worldwide where injection is already a part of the field operation, including the Geysers field in USA, Larderello field in Italy, Berlin field in El Salvador, Paris in France, Laugaland field, N-Iceland etc. There are a number of other geothermal fields where reinjection experiments have been carried out, and some of them may start production-scale reinjection soon.

There are abundant low enthalpy geothermal resources in China (high enthalpy geothermal only exists in Tibet). It is mostly used for health spas and recreation in southern China because it is not very cold even in the winters; and it is used for various direct purposes in northern China where it is very cold in the winters. For over 30 years, geothermal utilization has been ever increasing, especially in the past 10 years and in some northern big cities such as Beijing, Tianjin and Xi'an etc. With the expansion of geothermal utilization, some problems have been found, for example, the rapid declining of the reservoir pressure in the geothermal fields where the production is of a large-scale. Therefore, reinjection is considered as a kind of measure for the sustainable use of geothermal energy.

In China, the earliest geothermal reinjection experiments were started in the urban area of Beijing in 1974 and 1975. In 1980, larger scale reinjection experiments were carried out in the geothermal area: cold ground water and return geothermal water was injected into a geothermal well as deep as 1275m. At the end of the 1980's, reinjection tests were carried out in the Tertiary sandstone reservoir in Tianjin. Since 1996, reinjection experiments have been implemented in the dolomite reservoir in Tianjin. Till now, there have been 13 production-reinjection doublets running in Tianjin. In 2004 and 2005, reinjection experiments into the sandstone reservoir were carried out in Tianjin again. In 2001, reinjection experiments were implemented in the Xiaotangshan geothermal field north of Beijing, and the Urban geothermal field, Beijing. Since then, production scale reinjection started in Xiaotangshan Geothermal field. Experiments in both Tianjin and Beijing showed that reinjection is a feasible measure to ensure the sustainable use of geothermal resources in the two cities.

2. THE IMPORTANCE OF GEOTHERMAL REINJECTION

Beijing is rich with low-temperature geothermal stored in limestone or dolomite reservoirs, and the areas that have been identified with geothermal potential are over 2760km², divided into 10 geothermal fields, such as the ones in the southeast urban area and Xiaotangshan (about 30km north of the city centre). The temperature of geothermal water in Beijing is 38-89°C. The geothermal water

contains SiO_2 and other components that are good for human health. In the history, hot spring water was used for bathing and spas in Beijing. Large-scale geothermal use only started in 1971 in Beijing, with the completion of the first geothermal well. After that, the number of geothermal wells increased very fast, and the amount of geothermal water production increased in the mean time. By 1985, the geothermal production increased to over 10 million m^3 annually, causing a rapid declining of reservoir pressure (water level). Therefore, strict measures were taken to control the amount of geothermal water abstraction since 1985. As a result, the water level decline has slowed down since then (Figure 1). At present, it is often 1 to 2.5m annually, and still threatens the sustainability of geothermal utilization in Beijing.

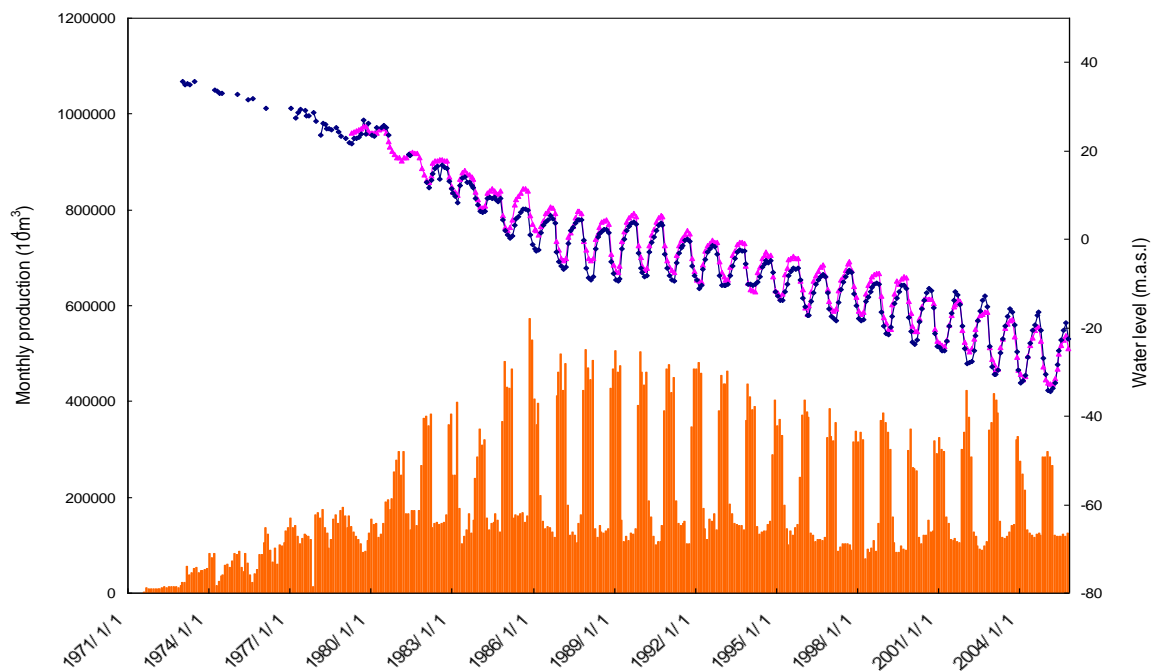


FIGURE 1: Historical water level change and monthly geothermal water production in southeast urban area, Beijing

This means that the net discharge of geothermal water, that is, the gap between production and reinjection, of the geothermal systems should be less than a certain limit. Otherwise, the water level of the geothermal wells will decline, and threatens the sustainability of geothermal use. It also means that if reinjection is not carried out, the production will have to be decreased by a large amount. Therefore, it is essential to reinject the used geothermal water back to the geothermal reservoir properly.

The geothermal resources in Tianjin are of a typical low-enthalpy geothermal in sedimentary basin. The area with geothermal potential is about 8700km^2 , accounting for about 77% of the total area of the city. Geothermal is stored in Tertiary sandstone and the karst/fractured dolomite reservoirs. The temperature of the geothermal water ranges from 55 to 103°C . Geothermal is widely used for space heating, domestic hot water, fish farming and greenhouses, and recreation etc. By the end of 2007, 294 geothermal wells (including 38 reinjection wells) have been drilled in Tianjin, of which the deepest is close to 4000m. The production capacity of each well is 100 to $200\text{m}^3/\text{h}$. The annual production of geothermal water was 24.50Mm^3 .

Due to the large-scale development of the geothermal resources, the reservoir pressure decreases quickly in Tianjin, especially in the dolomite reservoir. Since 1997, the annual water level drawdown

has been over 3m. Currently the depth to the static water level in the geothermal wells varies between -40m and -90m, with an annual drawdown of 6-9m (Figure 2). This suggests that the recharge to the reservoirs is rather limited. Therefore, it is necessary to implement reinjection for maintaining the reservoir pressure and prolonging the life time of the geothermal wells.

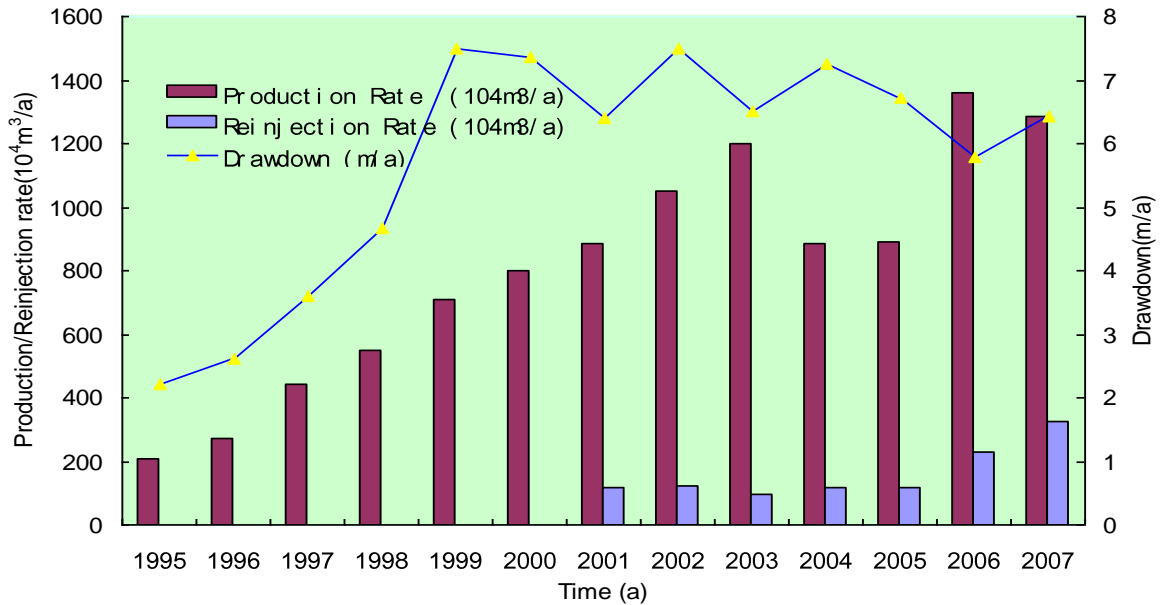


FIGURE 2: The history curve of water level drawdown v. geothermal water production and reinjection of the dolomite reservoir in the Tianjin urban area in 1995-2007.

3. APPLICATION IN BEIJING

3.1 History of Reinjection in Beijing

In China, the earliest geothermal reinjection experiments were started in the urban area of Beijing in 1974 and 1975. In 1980, larger scale reinjection experiments were carried out in the geothermal area: cold ground water and return geothermal water was injected into a geothermal well as deep as 1275m. After then, reinjection stopped in Beijing for a rather long time. Until 2001, reinjection experiment and demonstration projects started again. Recently, reinjection has been implemented in rather large scales and got significant achievements in Beijing. The geothermal reinjection history can be divided into 4 periods:

3.1.1 1974-1983

Because of the increase of geothermal water production in early 1970's, the water level of the geothermal wells declined rather fast. It was considered that reinjection would be an important measure to prolong the lifetime of the geothermal wells. In 1974, a short reinjection test was conducted in the famous Park of Temple of Heaven in the southeast urban area. And in 1975, a short reinjection test was conducted again in the southeast urban area.

To 1980, there have been over 30 geothermal wells in the southeast part of Beijing, and the geothermal water production has been about 3 million m³/a, and the water level decline became more serious. Therefore, a larger scale injection test was carried out from June 4 to September 2, 1980. Cold

groundwater of 15.5°C was injected into a 1060m deep geothermal well in the southeast urban area. In the 89 days of injection test, about 60,000 m³ of cold water was injected, and the temperature change inside the injection well was observed (Liu et al., 1981). After that, 40°C return geothermal water from a heating system was reinjected into a 1274.65m deep geothermal well in the same area (Bai and Gong, 1984). In that period, reinjection tests focused on after how much time the injected colder water could be heated again in the same wells.

3.1.2 1983-2000

Geothermal reinjection activity stopped mostly because of financial problems, although the water level continued to decline in this period.

3.1.3 2001-2002

After 1999, with the fast development of geothermal utilization in Beijing, and a wide acceptance of the idea of sustainable development, reinjection was considered again to counter the decline of the water level. In 2001, a demonstration project of geothermal reinjection was carried out in the Xiaotangshan area. Return water from geothermal heating was injected back to the same geothermal reservoir through a well about 200m away from the production well. This reinjection project operated smoothly in 2001 and 2002, and did not show any cooling of the production temperature (Liu, 2003).

In 2001, a reinjection test was also conducted in the southeast urban area in Beijing. Return water from a heating system was injected into a well that struck a shallower geothermal reservoir through a well 80m away from the production well. And reinjection experiments also started in 2002 in the southeast boarder of the same geothermal field (Liu, 2003).

3.1.4 2003-present

Since 2003, reinjection in Beijing expanded rapidly, after the experiments in 2001 and 2002. In the Xiaotangshan area, there have been 6 reinjection wells in operation in 2006, and the amount of water reinjection has been about 60% of the production. ReInjection also expanded in other parts of Beijing in this period, and the role of reinjection on sustainable utilization of geothermal resources has been well presented.

3.2 ReInjection in the Xiaotangshan area

The reinjection in Xiaotangshan was started in 2001 in a hotel in the centre part of the geothermal field. One of the two production wells of the hotel was converted into an injection well. The wells of the hotel were drilled in 1984 and 1996, respectively. The distance between the wells is about 200m. The geothermal reservoir is in the limestone of Cambrian System and the Dolomite of the Jixian System. The wells encountered the same fault that is very important to the occurrence of geothermal around the area of the hotel. The reinjection was carried out from 30 November 2001 to 27 March 2002, totalling 117 days. The temperature of the reinjected return geothermal water was 30-44°C. The flow rate of reinjection changed with the atmospheric temperature. It was around 800m³/d in the coldest days from 8 to 20 January, 2002, and was under 800m³/d on the rest of the days. The injectivity of the well did not decrease during the injection (Figure 3). The total amount of water injected was 73,331 m³ in that heating season (Liu and Yan, 2006).

A tracer test was conducted during the reinjection. On 8 January 2002, 50kg KI was applied to the reinjection well instantaneously, 39 days after the injection started. 165 water samples from the production well were collected till the space heating stopped. Some samples were also collected from

the surrounding wells. But there was not any iodine found in the samples. This indicates that there is not a direct pass between the reinjection and production wells, and premature thermal breakthrough is not likely to happen in the production well (Liu, 2002).

After the injection stopped, a submersible pump was installed in the injection well, intended to restore the injectivity of the well, if there was any reduction. On 15 April 2002, the pump was started. At the beginning, the temperature of the water was around 30°C, and in an hour, the water became 63.5°C, nearly restored to its normal production temperature that is 64°C. The reinjection experiment shows that the injectivity of the geothermal reservoir is rather good, and the reservoir also has a good capacity to heat the reinjected colder water (Liu, 2006).

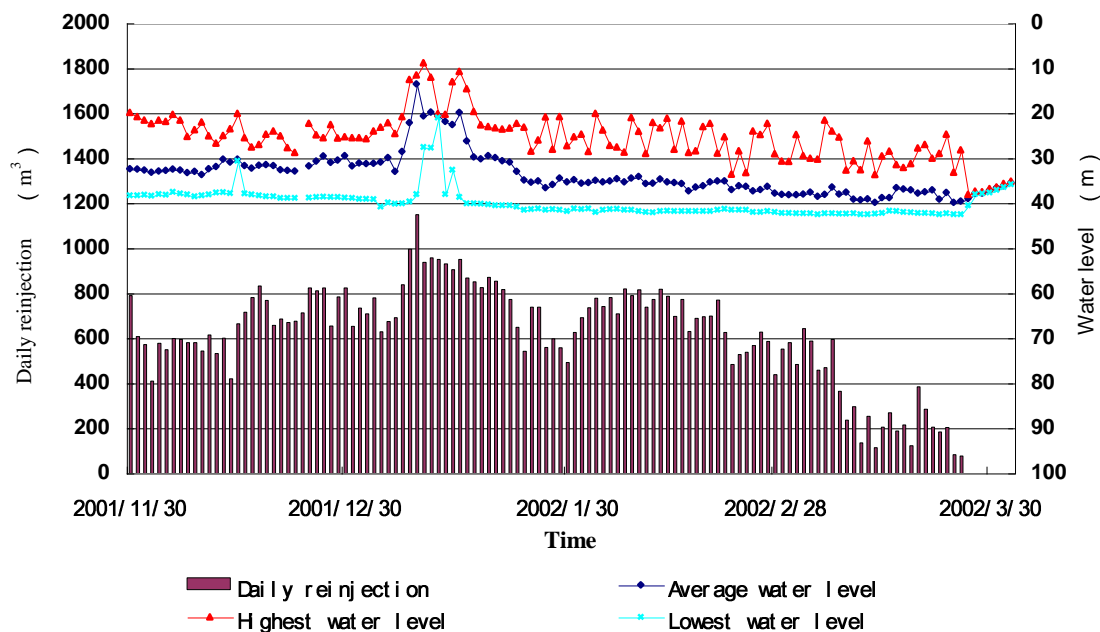


FIGURE.3: The amount of reinjection and water level change of a reinjection well in Xiaotangshan Geothermal Field in 2001-2002 heating season

In the 2003-2004 heating period, a reinjection test was carried out in another hotel very close to the first one. In 150 days, $1.48 \times 10^5 \text{ m}^3$ of return geothermal water from the heating system was injected into a well drilled for injection purpose. The total amount of reinjection reached $2.48 \times 10^5 \text{ m}^3$ in that heating season.

In the 2004-2005 heating period, four production-reinjection doublet systems were set up, by converting old production wells into injection wells, or by drilling new injection wells in the geothermal field. From November, 2004 to April, 2005, $10.2 \times 10^5 \text{ m}^3$ of return geothermal water was injected into the geothermal reservoir, accounting for 36.5% of the total production (Liu and Yan, 2006).

In the 2005-2006 heating period, there have been 6 reinjection wells for injecting the return water of 8 production wells. There are two production-reinjection assemblages that each involves 2 production wells and 1 reinjection well. The total quantity of reinjection was $1,322,778 \text{ m}^3$, accounting for 56.6% of the annual production in the field.

In the 2001-2002, the effect of the reinjection on the stabilization of the reservoir pressure was very little, because the amount of reinjection was little. With the increase of reinjection, the effect became more and more significant. In the 5 months from December, 2004 to April, 2005, the water level of the monitoring well (has been monitored for about 30 years) was higher than that in the same period in 2003 and 2004 (Figure 4), it rose 2.5m. Considering that the water level decreased 1 to 1.5 meter every year before the large scale reinjection, the effect was very significant.

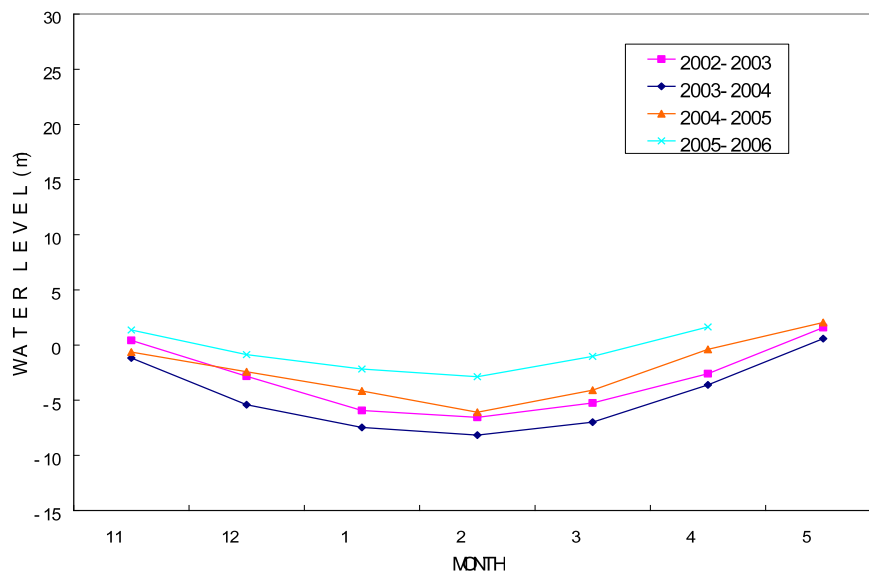


FIGURE 4: The water level of a monitoring well in Xiaotangshan geothermal field from 2002 to 2006

The reinjection in the Xiaotangshan geothermal field does not have observable influence on the temperature of production wells, although the distance between some of the production and reinjection wells is as short as 200m. It has also been found out that the chemical composition of the geothermal water from the production wells did not change apparently. But the content of HCO_3^{2-} of the water pumped from one of the reinjection wells decreased, and the content of SO_4^{2-} increased. This may indicate that the reinjected colder water flows to the deeper part of the geothermal reservoir and the hotter water from a greater depth flows to the top of the reservoir.

3.3 Reinjection in Other Areas in Beijing

Although geothermal reinjection tests have been carried out as early as 1974 in the urban area in Beijing, long term reinjection only started in early 2002 in an apartment building district about 5km south of the Tiananmen Square. There are two geothermal reservoirs at different depths, both made of dolomite, and separated by a shale layer about 100m thick. Two wells, 90m apart from each other, were drilled in 2001 for the space heating of the 28,000m² floor area (with the help of a heat pump system) and the reinjection of the tail water from the heating system. The reinjection well is 1900m deep, striking the upper reservoir; the production well is 2054m deep, completed for producing from the lower reservoir. The water temperature from the reinjection well and the production well is 54°C and 59°C respectively. Both wells have a rather good production capacity. The average flow rate of geothermal water in the heating system was 35m³/h, and all of the tail water was reinjected into the upper reservoir. The water level in the injection well rose approximately 4m on average. The experiment shows that the injectivity of the well is close to its productivity. This geothermal heating

system, incorporating reinjection and heat pumps, has been running for more than 6 years, and did not meet any difficulties. It is also a good example for the cascaded use of geothermal resources (Liu, 2006).

After that, a few other reinjection wells were put into use in the southeast urban area and other geothermal fields in Beijing. Because the government encourages reinjection by deducting a geothermal resources fee, more and more users are planning to start reinjection.

4. APPLICATION IN TIANJIN

4.1 History of ReInjection in Tianjin

Reinjection activity started in the early 1980's in Tianjin, and the history may be divided into 4 periods:

4.1.1 1980 ~ 1995

With the increase of geothermal water production, it was realized that reinjection might be useful to control the declining water level. At the beginning of the 1980's, studies on geothermal production-reinjection doublets or production-reinjection well groups were carried out, and related numerical modelling on sandstone reinjection was conducted. According to the results, reinjection tests were carried out in Dagang and Tanggu District in 1987-1989 and 1995, focused on reinjection in the sandstone geothermal reservoir of the Tertiary System.

4.1.2 1995 ~ 1998

With the increase of geothermal water use from the dolomite reservoir, more attention was paid on reinjection into the dolomite reservoir in Tianjin. In 1995, the first such production-reinjection doublet was drilled, and a reinjection test was carried out in 1996-1997. The result showed that reinjection is technically feasible in the dolomite geothermal reservoir in Tianjin (Wang et al, 2001).

4.1.3 1998-present

Based on the results of the reinjection tests for the dolomite reservoir, a few production and reinjection doublets were installed and operated in this period in Tianjin. In the same time, tracer tests were carried out for understanding the movement and heating process of the reinjected colder water. Monitoring of the doublets has become routine, including the flow rate, water level, temperature, chemical contents. And numerical modelling was carried out for predicting the effect of reinjection. A technical standard about the design and operation of geothermal reinjection was compiled, by summarizing the experiences of geothermal reinjection in Tianjin.

Since 2004, a test on reinjection into the sandstone geothermal reservoir was started again in Tianjin, due to the rapid decline of the geothermal water level in the sandstone reservoir.

4.2 Dolomite reservoir reinjection

Most of the geothermal production-reinjection doublet systems in Tianjin are inside the urban area. Both of the production and reinjection wells were drilled into the dolomite reservoir which spreads widely in the area of Tianjin (Wang et al., 2001).

Since the first geothermal production-reinjection doublet was put into operation in the winter (during the space-heating period) in 1999, there have been 27 reinjection wells and 77 production wells in this reservoir in Tianjin. All the doublet systems carry on reinjection under free flow condition. All the used geothermal water from the doublets was reinjected into the reservoir after the heating cycle. The amount of reinjection was $2.89 \times 10^6 \text{ m}^3$ in 2007, accounting for about 24% of the total production from the geothermal reservoir. Although there are more geothermal production wells used for space heating, and the adjacent production wells also influence the reservoir pressure around the reinjection wells, it can be observed that the water level close to reinjection wells declines much slower than other parts. The average annual drawdown has been decreasing with the increasing reinjection. On the other hand, there has not been an observable temperature change happen in the surrounding production wells till now.

According to the geological condition, a numerical model was set up for the geothermal system in the urban area in Tianjin, using the software package TOUGH2, according to the past 20 years production and reinjection history. The model was used to predict the changes of reservoir pressure of the geothermal system in the future, assuming that (1) all the geothermal wells will keep the average production rate in 2002 ($80\text{-}120 \text{ m}^3/\text{h}$ in winter, and 5-10% of the winter production rate in the summer); (2) all the 10 reinjection wells are put into use with a reinjection rate of $50\text{-}100 \text{ m}^3/\text{h}$ for each well, and the annual amount of production is $1.3716 \times 10^7 \text{ m}^3$ (deducting the amount of reinjection $1.7 \times 10^6 \text{ m}^3$). It was predicted that the deepest water level in the reservoir will be 193m below sea level. This means that the sustainability of the geothermal production could not be realized if the present production and reinjection will be maintained into the future. If the present amount of reinjection increases 150%, it was predicted that the deepest water level will be 138m below sea level in 2013 (Figure 5). This means that reinjection makes an effective measure to counteract the decline of the reservoir pressure (Wang, 2005).

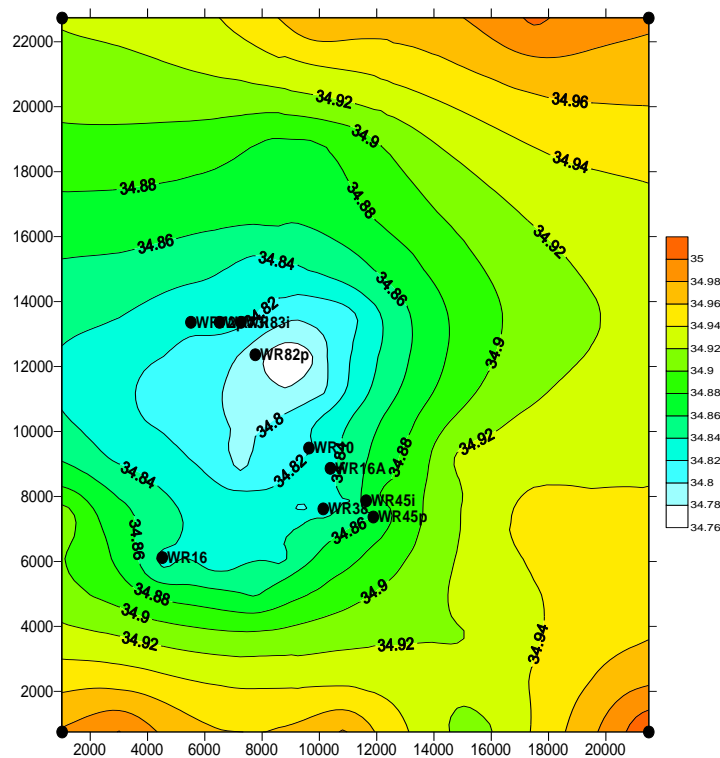


FIGURE 5: Contour map of calculated water level of the dolomite reservoir in Tianjin in Sept. 2013, assuming the reinjection will increase 150%.

The reinjected cold water will extract more thermal energy from the rock matrix and improve the heat mining from the geothermal reservoir. But it is not a simple decision to increase the amount of reinjection, because of the possible cooling of the production water. It is proposed that a tracer test be carried out to study the connections between the production and reinjection wells and to predict the cooling effect by the increase of reinjection.

In the winter of 1999 and 2001, tracer tests in the dolomite reservoir were carried out and the tracers used including chemical tracer (I, Br⁻) and radioactive isotopic tracer (¹²⁵I, ³⁵S). The distance between the production and the reinjection well is 850m. The amount of tracer is 10kg. The entire tracer was applied instantaneously. The tracer break through time was about 3 days, and the peak time was at about 52 days (Figure 6). According to the deduction from the tracer tests, there will not be a premature thermal break through.

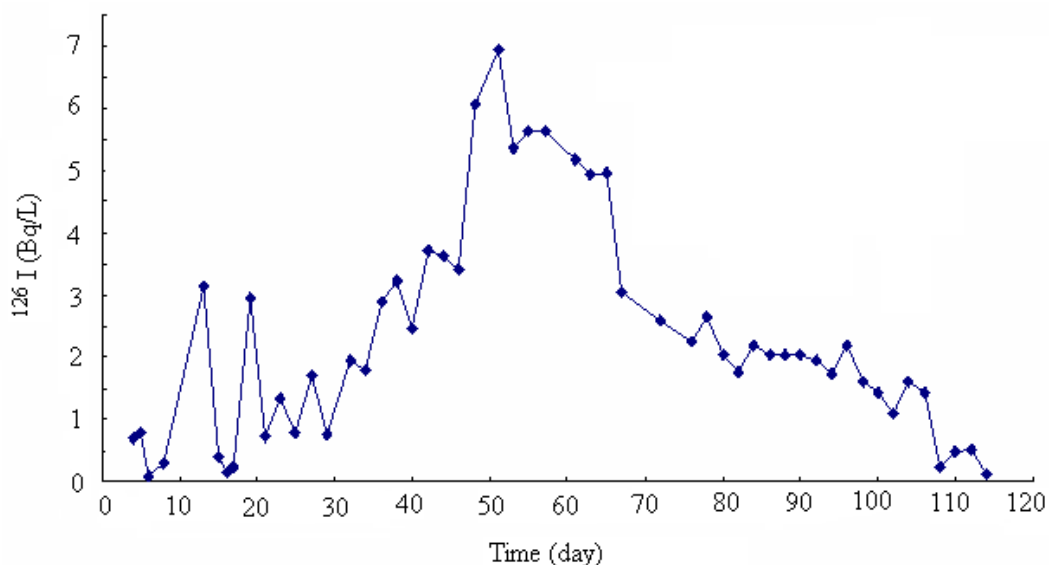


FIGURE 6: Curve of tracer (¹²⁵I) recovery of a tracer test

4.3 Sandstone Reinjection

By the end of the 1980's, the reinjection tests had been carried out in the Tertiary sandstone reservoir in Tianjin. During the tests, about 30-50m³/h waste water were injected into the reservoir. But along with the going on of reinjection, the injectivity decreased quickly. Tests of sandstone reinjection were carried out again in the winter of 2004-2005, and the results were similar to that of the previous tests. The main problems of sandstone reinjection in Tianjin are:

- (1) Injectivity decreases fast with time, or injectivity changes too much with time during the reinjection process;
- (2) the clogging of the reinjection wells, attributed to physical, chemical and biological factors.

It is proposed that further tests on sandstone reinjection be carried out, considering the experiences in the oil fields in China and the experiences in the world.

Now some tests and research jobs are progressing steadily, on the aspect of the wellhead facilities, drilling and casing techniques of reinjection wells in sandstone reservoirs.

5. DISCUSSIONS

5.1 Distance of Production and Reinjection

The cooling of produced geothermal fluid caused by injection of colder fluid has been reported in a few high-enthalpy geothermal fields. For low-enthalpy geothermal fields, there has not been any such report, even in the cases where the distance between the production well and injection well is rather small. Therefore, it may be concluded that for production/reinjection doublets in low-enthalpy geothermal fields, one does not have to fear about the cooling of the production water, if the distance between production and injection well is greater than a few hundred meters, and the amount of reinjection is not very huge.

In designing the distance of reinjection and production wells of a doublet system, a few factors should be considered, including the type of geothermal reservoir, the geological structure of the geothermal field, the permeability and thickness of the reservoir, the direction of fluid flow, the temperature difference between the reservoir and reinjection water, the flow rate of reinjection etc.

But in the cases that a large number of reinjection wells and production wells will be placed among a rather small area, care has to be taken, and proper tests have to be carried out and proper modelling has to be done before any such injection project is started, so as to avoid premature thermal breakthrough.

5.2 Tracer test

Tracer breakthrough can be a very good precaution for thermal breakthrough. Tracer testing is one of the most important aspects of geothermal reinjection, which has become a routine for reinjection experiments. Tracer tests can provide information about the flow paths and the flow velocity of the geothermal fluids between the injection and production wells. For fractured reservoirs, the volume of the aperture can be deduced from the tests. This information can be used to predict the cooling due to reinjection (Axelsson and Stefánsson, 1999). For reinjection projects that are large-scale or a number of production and reinjection wells in a relatively small area, it is strongly proposed that a tracer test be carried out.

5.3 Monitoring

Monitoring is one of the most important elements for geothermal management. For a geothermal field with reinjection, a proper monitoring program is even more important. Besides the monitoring of reservoir pressure, temperature, amount of production, chemical composition of geothermal fluid etc., the water level in the injection wells, temperature of injection water, amount of injection and chemical composition of injection water should also be monitored. The purpose is to find out the changes of the geothermal system caused by reinjection, especially the cooling of the produced geothermal water.

6. CONCLUDING REMARKS

Reinjection is one of the most important aspects for the sustainable management of geothermal resources. Reinjection tests were started as early as 1974 in Beijing. Scaled reinjection of return geothermal water from heating systems has been applied in Tianjin since 1996 and in Beijing since 2001. The reinjection experiences show that it is significant in controlling the lowering of reservoir pressure, and improves the heat mining of the geothermal field. In the Xiaotangshan area in Beijing, the amount of reinjection has to be about 60% of the geothermal water production. As a result, the

water level of the geothermal field has stopped declining. This is a very good example of sustainable use of geothermal resources. It is proposed that reinjection can be expanded in Beijing and Tianjin, as well as other geothermal fields in the world. On the other hand, reinjection is the most complicated technique of reservoir engineering, and pre-mature thermal break through should be avoided, and tracer tests and proper monitoring program should be carried out.

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