GEOTHERMAL REINJECTION IN CHINA

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ABSTRACT

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 and some other places. But reinjection of used geothermal water from heating systems in scale was started in the City of Tianjin in 1990's. Since 2000, reinjection has been taken as a more and more important aspect of geothermal resources management in China. At present, a number of reinjection projects have been in operation in Beijing and Tianjin, while in other provinces reinjection is still very little. But recently, it has been decided that geothermal will be used for district heating in a few geothermal areas such as the City of Xanyang in Shaanxi province, and Xiongxian County in Hebei province. It is certain that geothermal reinjection will be widely operated in China in the near future. In the paper, the reinjection history in China will be summarized, and the experiences and problems of reinjection in Beijing and Tianjin will be presented.

Keywords: Reinjection, geothermal resources, reservoir pressure, tracer test, thermal breakthrough

1. INTRODUCTION

Geothermal is a kind of green energy, and it is widely used in a lot of countries for power generation and direct purpose, such as space heating, bathing, swimming pool, fish farming, greenhouse and health spa 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 need a rather long time to recover from the improper management. Therefore, it is mandatory to carry out reinjection for the sustainable use of geothermal resources**.**

Reinjection has been widely used in the management of geothermal field, 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 dispose 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).

There are abundant low enthalpy geothermal resources in China (high enthalpy geothermal only exists in Tibet). It is mostly used for health spa in southern China because it is not very cold even in winters; and it is used for various direct purposes in northern China where it is very cold in winters. In the past 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 Xian etc. With the expansion of geothermal utilization, some problems have been found out, for example, the rapid declining of the reservoir pressure in the geothermal fields where the production is of large-scale. Therefore, reinjection is considered as a kind of measure for the sustainable use of geothermal energy. In Tianjin and Beijing, reinjection experiments have been carried out and reinjection of the return geothermal water from heating systems has been in production scale.

2. GEOTHERMAL REINJECTION HISTORY

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 about 30 geothermal fields worldwide where injection is already a part of the field operation, including The Geysers field in USA, Larderrello field in Italy, Berlin field in El Salvador Paris in France, Laugaland field, N-Iceland etc. There are more than 30 other geothermal fields where reinjection experiments have been carried out. Some of these fields may start production-scale reinjection soon.

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 . in 1985 a small scale reinjection experiment was also carried out in Sanlifan geothermal field in Hubei Province, southern China. At the end of 1980's, the 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 Xiaotanshan 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.

3. APPLICATION IN TIANJIN

3.1 Geothermal Resources and Its Utilization

The geothermal resources in Tianjin are of 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 is often higher than 80℃, and is widely used on space heating, domestic hot water, fish farming and greenhouse etc. The annual production of geothermal water reached 25 million m^3 in 2005, and the amount of annual reinjection was 3.6 million m^3, accounting for about 14% of the total production. The floor area of space heating using geothermal is about 9 million m^2, almost half of the total geothermal heating area in China.

3.2 The Importance of Reinjection

Due to the large scale development of the geothermal resources, the reservoir pressure decreases quickly, especially in the dolomite reservoir. Since 1997, the annual water level drawdown has been over 3m, and even got to 10m in 2002 (Figure 1). 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.

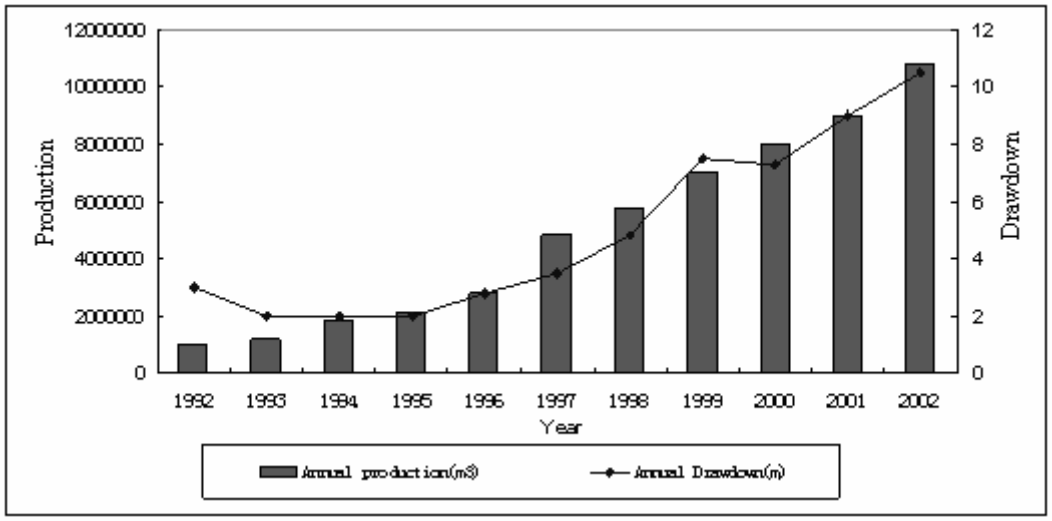

Figure 1.The history curve of water level drawdown and geothermal water production of the dolomite reservoir in the urban area in 1992-2002.

3.3 Reinjection Practice in Tianjin

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 spreading widely in the area of Tianjin (Wang et al., 2001). The reservoir is buried 988m to about 3000m below ground surface. Its porosity reaches 5%-7%. The production capacity of a single geothermal well is mostly 100-200m^3/h, and can reach 380m^3/h close to the fracture zones. The wellhead temperature is 79-103℃. The karst fractures developed well in the reservoir and formed strong storage capacity.

Since the winter (during the space-heating period) in 1999, the doublet systems in Tianjin has carried on reinjection

under free flow condition, without using any pressure pump. All the used geothermal water from the doublets was reinjected into the reservoir after the heat cycling. 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 still be observed that the water level close to the reinjection wells declines much slower than other parts of the geothermal area. On the other hand, there have not been any observable water temperature changes in the geothermal area 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 (80-120m^3/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 50-100m^3/h for each well, and the annual amount of production is $1.3716\times10^7 m^3$ (deducting the amount of reinjection $1.7\times10^6 m^3$). It was predicted that the deepest water level in the reservoir will be 193m below see level. This means that the sustainability of the geothermal production could not be realized if the present production and reinjection will be maintained in the future. If the present amount of reinjection increases 150%, it was predicted that the deepest water level will be 138m below see level in 2013 (Figure 2). This means that reinjection makes an effective measure to counteract the declining of the reservoir pressure, and ensure the sustainable management of geothermal resources (Wang, 2005).

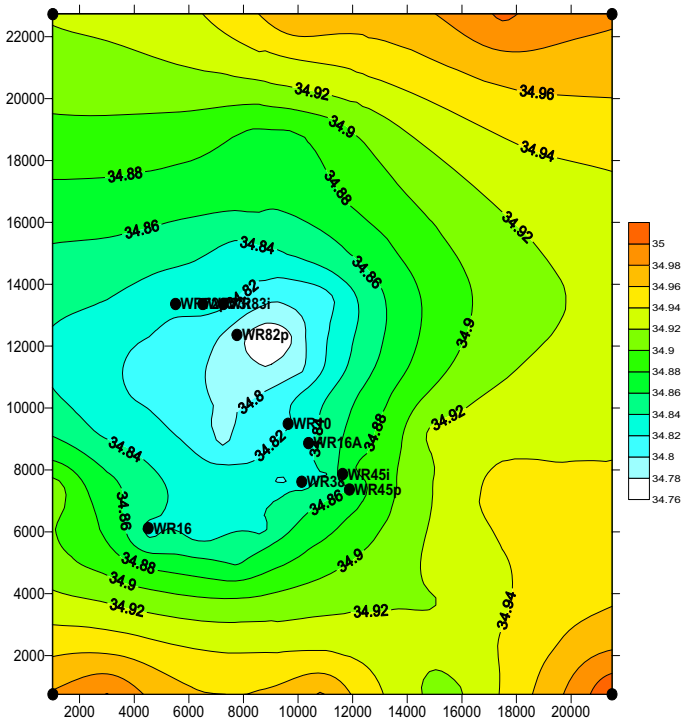

Figure 4. Contour map of calculated water level of the dolomite reservoir in Tianjin in Sept.2013, assuming the reinjection will increased 150%.

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 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.

4. APPLICATION IN BEIJING

4.1 Geothermal Resource and Its Utilization

Beijing is rich with low-temperature geothermal stored in limestone or dolomite reservoirs, and the areas identified with geothermal potential have been over 2800km^2, including 10 geothermal fields, such as the ones in the urban area and Xiaotangshan (about 30km north of the city). The temperature of geothermal water in Beijing is 38-89□. 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 spa in Beijing. Large-scale geothermal use only started in 1971 in Beijing, with the completion of the first geothermal well. After then, 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 about 15million m^3 annually, causing 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 declining has slowed down since then (Figure 3). In the recent years, the annual geothermal water production was about $10^7 m^3/a$, in which about $4\times10^6 m^3/a$ each from Urban geothermal field and Xiaotangshan geothermal field.

4.2 The Importance of Reinjection

The development of geothermal in Beijing is creating great economic effect, environmental and social effect. But the water level in the most developed geothermal fields, for example, the Urban geothermal field and Xiaotangshan geothermal field, still lowers 1.5 to 2 m annually, threatening the sustainability of the precious resources (Liu, 2004). To realize sustainable management of geothermal, it is essential to have a proper monitoring system, to set up simulation models, and to conduct reinjection of used geothermal water (Rybach, 2003; Stefansson and Axelsson, 2003; Axelsson, 2003). Of all the above elements of sustainable management of geothermal resources, reinjection is the most important when the amount of production from the geothermal system is more than the water recharge of the system.

4.3 Reinjection in Xiaotangshan Area

The reinjection in Xiaotansgan was started in 2001 in a hotel in the center part of the geothermal field. One of the two production wells of the hotel was converted to a injection well. The wells of the hotel were drilled in 1984 and 1996, respectively. The distance of the wells is about 200m. The geothermal reservoir is the limestone of Cambrian System and the Dolomite of 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, totally 117 days. The temperature of the reinjected return geothermal water was 30-44℃. The flow rate of reinjection changed with the atmospheric temperature. It was around 800 m^3/d in the coldest days from 8 to 20 January 2002, and was under 800 m^3/d on the rest days. The injectivity of the well did not decrease during the injection (Fig.3). The total amount of water injected was 73331 m^3.

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, although the amount of tracer applied was a little not enough.

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, the pump was started. At the beginning, the temperature of the water was around 30℃, and in an hour, the water became 63.5℃, nearly restored to its normal production temperature that is 64℃.The reinjection experiment shows that the injectivity of the geothermal reservoir is rather good, and the reservoir also has good capacity to heat the reinjected colder water.

In the period from the winter of 2003 to the spring of 2004, reinjection test was carried out in another hotel vary close to the first one. In 150 days, $1.48\times10^5 m^3$ of return geothermal water from the heating system was injected into a well drilled for injection purpose. The total amount of reinjection reached $2.48\times10^5 m^3$ in that heating season.

In 2004 and 2005, 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, $10.2\times10^5 m^3$ of reture geothermal water was injected into the geothermal reservoir, accounting for 36.5% of the total production.

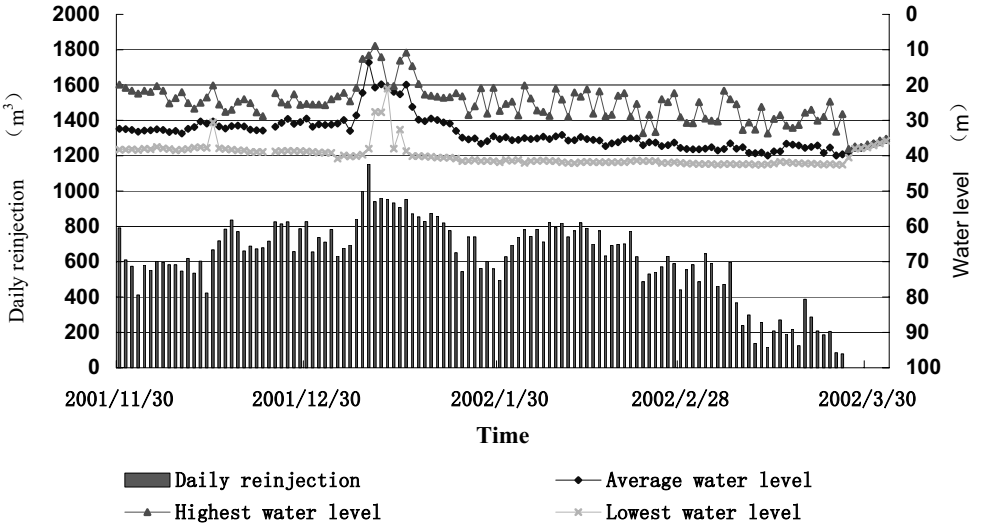

Figure.3 The amount of reinjection and water level change of the reinjection well in Xiaotangshan Geothermal Field

In 2001-2002, the effect of the reinjection on the stabilization of the reservoir pressure was very little, because that 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), 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.

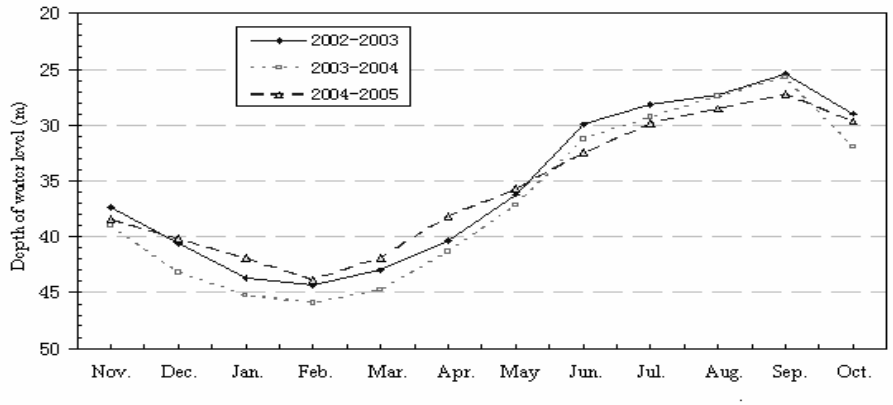

Figure.4 The water level of a monitoring well in Xiaotangshan geothermal field from 2002 to 2005

The reinjection in Xiaotangshan geothermal field does not have observable influence on the temperature of production well, although the distance between some of the production and reinjection wells is as short as 200m. It is also fund 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 greater depth flows to the top of the reservoir.

4.4 Reinjection in the Urban Area

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 in different depth, both made of dolomite, and separated by a shale layer about 100m thick. Two wells, 90m to each other, were drilled in 2001 for the space heating of the 28,000m^2 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℃ and 59℃ respectively. Both wells have rather good production capacity.

The average flow rate of geothermal water in the heating system was 35m^3/h, and all the tail water (26-34℃) was reinjected into the upper reservoir. The water level in the injection well rose 4m averagely. The experiment shows that the injectivity of the well is close to its productivity.

This geothermal heating system, incorporated reinjection and heat pump, has been running for more than 5 years, and did not meet any difficulties. It is a good example for the cascaded use of geothermal resources.

5. SOME POTENTIAL AREAS OF GEOTHERMAL REINJECTION

With the continuous rise of oil and gas price, geothermal heating is becoming more and more popular in northern China, because of its low cost and less negative impact to the environment. A few geothermal heating projects have been proposed to build "no smoke city" by substitute boiler burning coal, such as Yanqing County in Beijing, the City of Xianyang in Shaanxi Province, Xiongxian County in Hebei Province.

Yanqing County is about 70km northwest of Beijing central area, and it is rich with low temperature geothermal. It have been planned that 28 gerthermal production and reinjection doublets will be build, to meet the heating needs of buildings with 3 million m^2 floor area, by incorporating heat pumps in the system.

The City of Xianyang is one of the old capital cities in China. There are 4 geothermal reservoirs in different depth, and the reservoir temperature ranges from lower than 50□ to 118□. It has recently been approved of "a China Hot Spring Village", and It has been planned that district heating using geothermal will be greatly expanded, and 30 reinjection wells will be drilled for injecting 5.8 million m^3/a return geothermal water from the heating system.

Xiongxian County is about 130km south of Beijing. The geothermal reservoirs, buried only a few hundred meters below surface, are made of sandstone and dolomite that are very permeable. Geothermal utilization there started before 1990, has created significant economical and environmental effects. It was also approved of "a China Hot Spring Village" in early 2006. It has been decided that geothermal will be used for all the district heating of the capital town (plus ground source heat pumps), and to construct a "no smoke city". The water recharge of the geothermal system is rather limited, while there is abundant heat stored in the rock matrix. Therefore, it is proposed that all the return water from the heating system be reinjected back to the reservoir, so as to ensure the sustainability of the geothermal utilization.

A common feature for the above three geothermal projects is that it is essential to reinject the used geothermal fluid from the heating system, and the reinjection will be in large scale (a large number of reinjection wells in a comparatively small area and huge amount of colder water will be reinjected). There is still not much experience on this kind of reinjection project in the world. Therefore, cares have to be taken in the designing of the reinjection scheme, so as to avoid the possible cooling of the water form the production wells.

6. DISCUSSIONS

6.1. Possible Cooling Caused by 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 that 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 in not very huge. But in the cases that a large number of reinjection wells and production wells will be placed among a rather small area, cares have to be taken, and proper tests have to be carried out and proper modeling has to be done before any such injection project started, so as to avoid premature thermal breakthrough.

6.2 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 tracer test be carried out.

6.3 Monitoring

Monitoring is one of the most important elements for geothermal management. For 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.

7. CONCLUSIONS

Reinjection is one of the most important aspects for the sustainable management of geothermal resources. Reinjection tests have been started as early as 1974 in Beijing. Scaled reinjection of return geothermal water form heating system has been applied in Tianjin in 1996, and in Beijing since 2001. The reinjection experiences shows that it is significant in controlling the lowering of reservoir pressure, and improve the heat mining of the geothermal field. Although the amount of water reinjection has been fairly big, and the cooling of the produced geothermal water has not been reported. In a few geothermal area, such as Yanqing County in Beijing, Xianyang in Shaaxi Province, and Xiongxian County in Hebei Province, intense reinjection has been proposed. For this kind reinjection projects, cares must be taken in the placing of the production and reinjection wells, and tracer tests have to be carried out to study the connections between injection and production wells, in order to avoid premature thermal breakthrough. It is also essential to have a proper monitoring program to detect the possible cooling of the produced geothermal water.

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