Geothermal Reinjection Experience
in Beijing and Tianjin

Liu Jiurong
Beijing Institute of Geological Engineering

Wang Kun
Tianjin Bureau of Planning and Land and Resources

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Introduction

- 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.
- 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
The purpose of geothermal reinjection

- Disposal of the waste geothermal fluid that may cause thermal and chemical pollution to the environment;
- Improvement of the heat mining, because over 90% of the heat in the geothermal reservoirs is stored in the hot rock matrix;
- Stabilization of the production capacity of the geothermal field through the maintenance of the reservoir pressure
The importance of reinjection

- In Beijing, 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.
- At present, it is often 1 to 2.5m annually, and still threatens the sustainability of geothermal utilization in Beijing.
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.

This suggests that the recharge to the reservoirs is rather limited.

It is necessary to implement reinjection for maintaining the reservoir pressure and prolonging the life time of the geothermal wells.
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
In China, the earliest geothermal reinjection experiments were started in the urban area of Beijing in 1974 and 1975.

The geothermal reinjection history can be divided into 4 periods:

- 1974-1983
- 1983-2000
- 2001-2002
- 2003-present
1974-1983

in 1974 and 1975 short reinjection tests was conducted in SE urban area

In 1981, A larger scale injection test was carried out

Cold groundwater of 15.5°C was injected into a 1060m deep well in the SE urban area

After that, 40°C return geothermal water from a heating system was reinjected into a 1274.65m deep geothermal well in the same area

In that period, the tests focused on after how much time the injected colder water could be heated again in the same wells.
1983-2000

- Geothermal reinjection activity stopped
- Because of financial problems
- Although the water level continued to decline
2001-2002

- Demonstration projects of geothermal reinjection was carried out in the Xiaotangshan area and SE urban area.
- It showed that reinjection is feasible technically.
2003-present

- Since 2003, reinjection expanded rapidly in Xiaotangshan area and other parts of Beijing.
- The role of reinjection on sustainable utilization of geothermal resources has been well presented.
Reinjection in the Xiaotangshan area

- Started in 2001 in a hotel in the centre part of the geothermal field
- The distance between the wells is about 200m
- The geothermal reservoir is in the limestone and dolomite
- The wells encountered the same fault that is very important to the occurrence of geothermal around the area of the hotel
Reinjection in the Xiaotangshan area

- The reinjection lasted 117 days
- The temperature of the reinjected return water was 30-44°C
- The flow rate of reinjection was around 800 m³/d in the coldest days, and was under 800 m³/d on the rest of the days
- The injectivity of the well did not decrease during the injection
- The total amount of water injected was 73,331 m³ in that heating season
The amount of reinjection and water level change of the reinjection well in Xiaotangshan Geothermal Field in 2001-2002 heating season.
A tracer test was conducted during the reinjection. 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. 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.
After the injection stopped, a pump was installed in the injection well.
At the beginning of the pumping, the temperature of the water was around 30°C.
In an hour, the water became 63.5°C, nearly restored to its normal production temperature (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.
In the 2003-2004 heating period, another production-reinjection was put into operation in Xiaotangshan.

In the 2004-2005 heating period, 4 production-reinjection doublet systems were set up.

In the 2005-2006 heating period, there have been 6 reinjection wells for injecting the return water of 8 production wells. The total quantity of reinjection was 1,322,778 m³, accounting for 56.6% of the annual production in the field.

In 2006-2007, the amount of reinjection has been over 60% of the annual production.
Reinjection wells in Xiaotangshan area
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 was higher than that in the same period in 2003 and 2004 (2.5m rise).

Considering that the water level decreased 1 to 1.5 meter every year before the large scale reinjection, the effect was very significant.
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.

The chemical composition of the geothermal water from the production wells did not change apparently.

But the content of $\text{HCO}_3^-$ of the water pumped from one of the reinjection wells decreased, and the content of $\text{SO}_4^{2-}$ 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.
Reinjection in Other Areas in Beijing

- In the urban area of Beijing, reinjection 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, separated by a shale layer about 100m thick.
- Two wells, 90m apart from each other, were drilled for the space heating of the 28,000m$^2$ floor area (with the help of a heat pump 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.
Reinjection in Other Areas in Beijing

- The average flow rate in the heating system was $35m^3/h$, and all of the tail water was reinjected into the upper reservoir.
- The water level in the injection well rose 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.
- After that, a few other reinjection wells were put into use in the SE urban area and other geothermal fields in Beijing.
- Because the government encourages reinjection by deducting geothermal resources fee, more and more users are planning to start reinjection.
Application in Tianjin

- Reinjection activity started in the early 1980’s in Tianjin, and the history may be divided into 3 periods:
  - 1980 ~ 1995
  - 1995 ~ 1998
  - 1998-present
1980 ~ 1995

- Studies on geothermal production-reinjection doublets were carried out
- 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
1995 ~ 1998

- In 1995, the first 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
1998-present

- A number of production and reinjection doublets were installed and operated
- Tracer tests were carried out
- Monitoring of the doublets has become routine
- Numerical modelling was carried out
- A technical standard about the design and operation of geothermal reinjection was compiled
- Since 2004, a test on reinjection into the sandstone geothermal reservoir was started again in Tianjin
Dolomite reservoir reinjection

- Most of the geothermal production-reinjection doublet systems in Tianjin are inside the urban area.
- The wells were drilled into the dolomite reservoir.
- Since the first geothermal doublet was put into operation in the winter 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.
- The amount of reinjection was 2.89 million m$^3$ in 2007, accounting for about 24% of the total production.
- The water level close to reinjection wells declines much slower than other parts.
- There has not been observable temperature change in the surrounding production wells till now.
A numerical model was set up to predict the water level in the urban area in Tianjin.

It was predicted that reinjection makes an effective measure to counteract the decline of the reservoir pressure.

Contour map of calculated water level of the dolomite reservoir in Tianjin in Sept.2013, assuming the reinjection will increase 150%.
In the winter of 1999 and 2001, tracer tests in the dolomite reservoir were carried out.

- 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 (¹²⁵I) is 10kg.
- All the tracer was applied instantaneously.
- The tracer break through time was about 3 days.
- The peak time was at about 52 days.
- According to the deduction from the tracer tests, there will not be a premature thermal break through.
Curve of tracer ($^{125}$I) recovery of a tracer test
Sandstone Reinjection

- At the end of the 1980’s, the reinjection tests had been carried out in sandstone reservoir in Tianjin
- During the tests, about 30-50m$^3$/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:

- Injectivity decreases fast with time
- The clogging of the reinjection wells
- 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
**Discussions**

- **Distance of Production and Reinjection wells**
  - For low-enthalpy geothermal fields, there has not been any report of obvious cooling of production water, 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.
  - But in the cases that a large number of reinjection wells and production wells will be placed among a small area, care has to be taken.
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
- This information can be used to predict the cooling due to reinjection
Monitoring

- For a geothermal field with reinjection, a proper monitoring program is even more important.

- The purpose is to find out the changes of the geothermal system caused by reinjection, especially the cooling of the produced geothermal water.
The Geysers

Thank you for your attention