Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Geothermal Reinjection in Tianjin, China

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Keywords: Geothermal Reinjection, Dolomite reservoir, Sandstone reservoir, Tianjin

ABSTRACT

Tianjin is a big city with abundant low- and midgrade-temperature geothermal resources used for space heating, greenhouses, spas, and domestics hot water. Large-scale extraction of geothermal water has caused a rapid decline of water level in the geothermal wells. In order to protect geothermal resources, geothermal reinjection has been required during the development of geothermal resources in Tianjin since 1999. At present, 53 reinjection wells have been drilled, and the annual reinjection amount is 5.62 million m^3/yr. This accounts for 22.5% of total production from the reservoir in 2008. As indicated by temperature and pressure monitoring in geothermal reservoirs, the water level close to reinjection wells declines much slower than in other parts, and no temperature changes have been observed in the surrounding production wells yet. The experiences and problems related to reinjection in Tianjin are discussed.

1. INTRODUCTION

Geothermal reinjection began as a method to dispose of wastewater from power plants in order to protect the surrounding environment. It started as early as 1969 at the Geysers in California and 1970 in the Ahuachapan field in El Salvador. Presently, there are a number of geothermal fields worldwide where injection is already a part of the field operation, including the Geysers field in the USA, the Larderrello field in Italy, the Berlin field in El Salvador, Paris in France, the Laugaland field in 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.

Reinjection has been widely used in geothermal management, and its use is becoming routine in many geothermal fields (Axelsson & Stefansson, 1999). Geothermal reinjection has multiple purposes: (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).

There are abundant low enthalpy geothermal resources in China. These resources are mostly used for health spas and recreation in southern China and for various direct purposes in northern China. For over 30 years, geothermal utilization has been ever increasing, especially in the past 10 years and in some large northern cities such as Beijing, Tianjin, and Xi’an. With the expansion of geothermal utilization, some problems have been found, such as the rapid decline of the reservoir pressure in the geothermal used for large-scale production. Therefore, reinjection is considered as a measure for the sustainable use of geothermal energy.

In China, the earliest geothermal reinjection experiments began in the urban area of Beijing in 1974 and 1975. In 1980, larger scale reinjection experiments were carried out in the geothermal area, in which cold ground water and return geothermal water were injected into a geothermal well with a depth of 1275 m. At the end of the 1980s, 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. In 2004 and 2005, reinjection experiments into the sandstone reservoir were again carried out in Tianjin. In 2001, reinjection experiments were implemented in the Xiaotanshan geothermal field north of Beijing and the urban geothermal field in Beijing. Since then, production scale reinjection has been initiated in the 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 Tianjin.

2. THE IMPORTANCE OF GEOTHERMAL REINJECTION

The geothermal resources in Tianjin are of typical low-enthalpy reservoirs in the sedimentary basin. The area with geothermal potential is about 8700km^2, accounting for about 77% of the total area of the city. Geothermal heat is stored in Tertiary sandstone and the karst/fractured dolomite reservoirs. The temperature of this geothermal water ranges from 55 – 103°C. Geothermal energy is widely used for space heating, domestic hot water, recreation, fish farming, greenhouses, etc. By the end of 2008, 294 geothermal wells (including 53 reinjection wells) had been drilled in Tianjin, the deepest of which is nearly 4000 m deep. The production capacity of each well is 100 – 200 m^3/h. The annual production of geothermal water was 5.858 million m^3/yr.

Due to the large-scale development of geothermal resources, reservoir pressure decreases quickly in Tianjin, especially in the dolomite reservoirs. Since 1997, the annual water level drawdown has been over 3 m. Currently, the depth to the static water level in the geothermal wells varies between 40 m and 90 m, with an annual drawdown of 6-9 m. The drawdown and water production and reinjection values from 1995 – 2008 are illustrated in Figure 1. This suggests that the recharge to the reservoirs is rather limited. Therefore, it is necessary to implement reinjection to maintain the reservoir pressure and prolong the lifetimes of the geothermal wells.

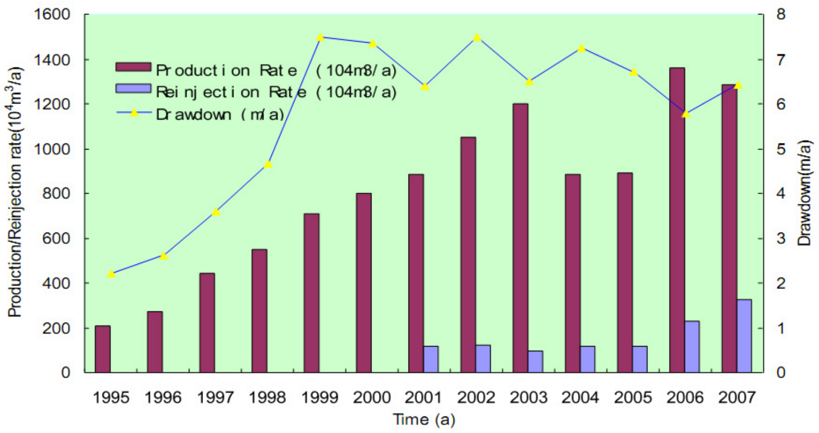

Figure 1: The history of water level drawdown and geothermal water production and reinjection in the dolomite reservoir in the Tianjin urban area from 1995-2008.

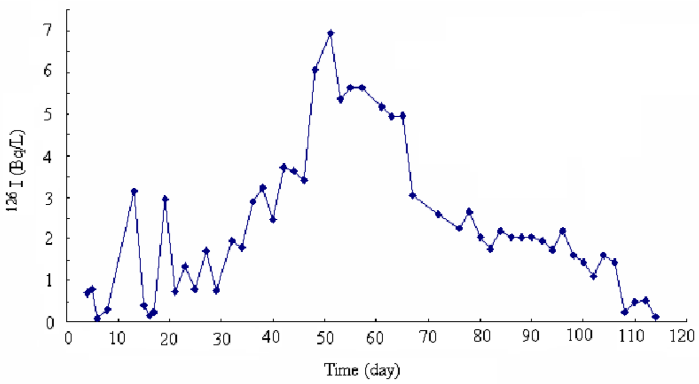

Figure 2: Curve of tracer (^{125}I) recovery of a tracer test

3. DOLOMITE RESERVOIR REINJECTION

Most geothermal production-reinjection doublet systems in Tianjin are inside the urban area. Both production and reinjection wells were drilled into the dolomite reservoir, which spreads widely in the Tianjin area (Wang et al., 2001). Since the first geothermal production-reinjection doublet was put into operation in the winter of 1999 (during the space-heating period), 43 reinjection wells and 127 production wells have been drilled in this reservoir in Tianjin. All these doublet systems carry out reinjection under free flow conditions. All used geothermal water from the doublets is reinjected into the reservoir after the heating cycle. The amount of reinjection was 5.62×10^6 m^3/yr in 2008, accounting for about 22.5% of the total production from the geothermal reservoir.

3.1 Distance of Production and Reinjection

The cooling of produced geothermal fluid caused by the injection of colder fluid has been reported in a few high-enthalpy geothermal fields. For low-enthalpy geothermal fields, there have been no such reports, even in 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, the cooling of the production water is not a concern if the distance between the production well and injection well is greater than a few hundred meters and the amount of reinjection is not excessively large.

When designing the distance between 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, and the flow rate of reinjection.

However, care must be taken in cases where a large number of reinjection wells and production wells are placed among a rather small area: proper tests must be carried out and proper modeling must be performed before any such injection project is started, so as to avoid premature thermal breakthrough.

3.2 Tracer test

Tracer breakthrough can be a very good indicator of thermal breakthrough. Tracer testing is one of the most important aspects of geothermal reinjection and 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 injection and production wells. In fractured reservoirs, the volume of the apertures can be deduced from these tests. This information can be used to predict the cooling due to reinjection (Axelsson and Stefánsson, 1999). In cases of large-scale reinjection projects or those with a large number of production and reinjection wells in a relatively small area, it is strongly proposed that tracer tests be carried out.

In the winters of 1999 and 2001, tracer tests were carried out in the dolomite reservoir, and the tracers used included chemical (I, Br-) and radioactive isotopic tracers (^{125}I, ^{35}S). The distance between the production and the reinjection well is 850 m, and 10 kg of tracer were used. The entire tracer mass was applied instantaneously. The tracer breakthrough time was about 3 days, and the peak time was about 52 days, as can be seen in the tracer return curve in Figure 2. After analysis of the tracer tests, it was deduced that there will not be premature thermal breakthrough in this reservoir.

3.3 The effect of reinjection

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 in other areas. The average annual drawdown has decreased with increasing reinjection. Production well HX-25 and reinjection well HX-25B were the earliest doublet wells in Tianjin. There are 4 production wells around them, as illustrated in Figure 3. It has been confirmed that HX-14 is connected to HX-25B through tracer test. The water level drawdown in HX-14 is slower than that in HX-25, as shown in Figure 4. On the other hand, no observable temperature changes have occurred in the reinjection well yet (Figure 5).

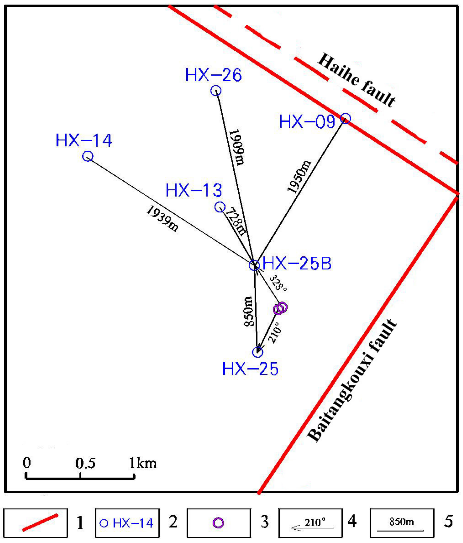

Figure 3: The locations of geothermal wells 1. fault 2. location of wells bottom 3. location of well head 4. azimuth angle 5. distance

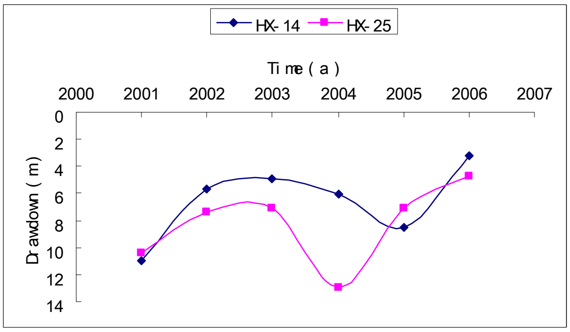

Figure 4: The water level of monitoring wells from 2001 to 2007

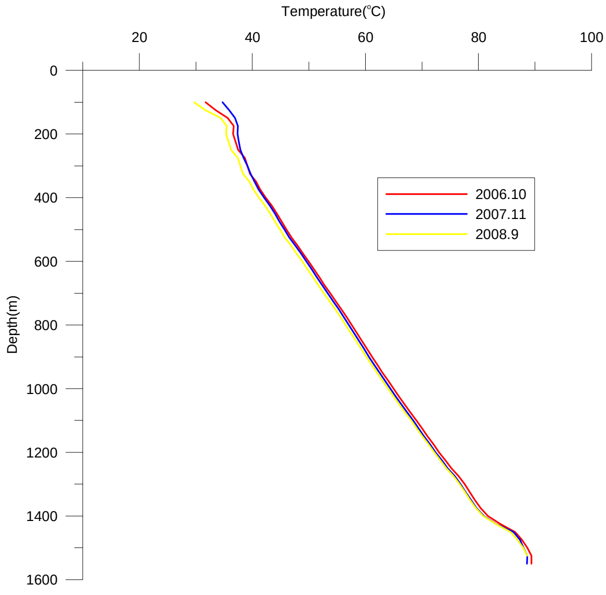

Figure 5: The monitoring data of temperature in reinjection well (HX-25B)

3.4 Testing geothermal aquifers

Hydraulic tests serve to characterize geothermal aquifers, and are commonly performed as pumping tests. Wells intended to be used for injection are investigated by means of pumping tests. The tests are performed stepwise, and the flow rates of the mostly three steps are determined by the planned production flow rates and the technical limitations of the pumping tests. The time-dependent determination of the flow rates and the determination of the pressures and temperatures in the aquifer zone are required to determine the productivity of the well and the transmissivity of the aquifer around the well. Additional pressure measurements in observation wells create a better understanding of the aquifer between the point of measurement and the production well. The test duration depends on the flow rates and the pressure behavior. For proper evaluation, the pressure should stay relatively constant at a consistent flow rate. According to years of experience of geothermal well construction, acid-fracturing technology can be used in geothermal wells in carbonate bedrock fractures as an effective stimulation measure if the transmissivity of the aquifer is low.

4. SANDSTONE RESERVOIR REINJECTION

By the end of the 1980s, reinjection tests had been carried out in the Tertiary sandstone reservoir in Tianjin. During these tests, about 30-50m^3/h of waste water were injected into the reservoir. However, the injectivity decreased quickly during reinjection. 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.

Through many years of research, the problems of reinjection in dolomite reservoirs have basically been solved. Reinjection problems in sandstone reservoirs mainly occur at low reinjection rates and short duration times, as shown in Figure 6.

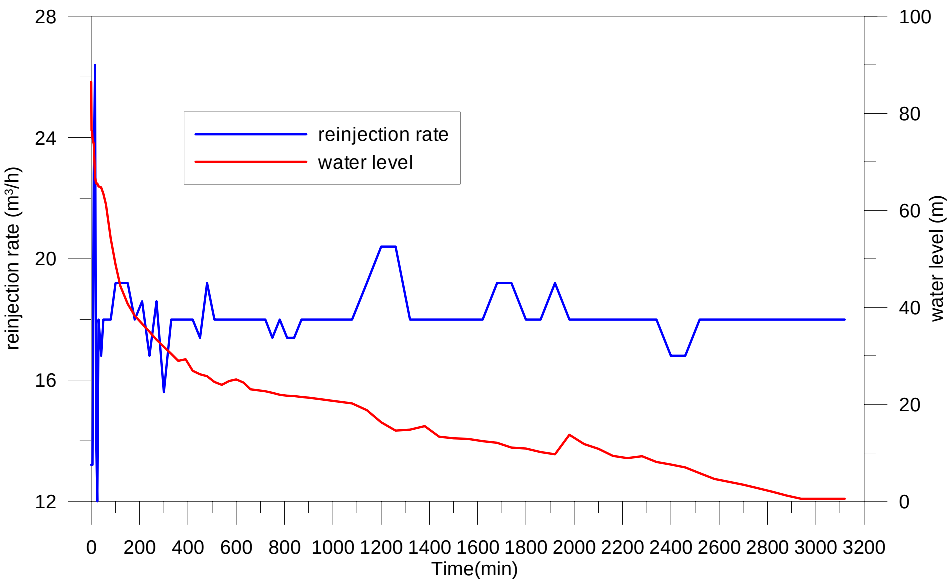

Figure 6: The data of reinjection test in Dagang district

Filtered particles with a diameter of >0.45 µm carried in suspension by the fluid in most of the wells has been analyzed using SEM (Scanning Electronic Microprobe). The results indicate that Plagioglase, quartz, K-feldspar, FeS and ZnS seem to be the most common components carried by the fluid, in addition to other possible components, such as NaCl, $CaCO_3$, and others.

The activities of anions, cations, and several intermediate compounds in geothermal solutions, as well as the saturation index of the most significant minerals in the Tianjin geothermal wells, have been computed using the PHREEQC-2.11 simulation code. There seem to be three types of minerals that may potentially precipitate during reinjection around the bottom of the Tianjin wells: 1) quartz (chalcedony), 2) calcite, and 3) Fe-Zn oxides (hydroxides) and sulfides. Among them, the Fe-Zn oxides and the sulfides were found in the most sample wells. The discovery of large amounts of similar solid components in matter collected by filtration proved that the water is saturated in these components in these exploitation wells. This aspect of the reservoir's hydrogeochemistry leads to the assumption that iron and zinc originates from oxidation of the well tube and the water pipeline.

In order to prevent physical and chemical jam, secondary filtrating equipment was used in the reinjection system. The primary filtration was rough, with a precision of 50µm, whereas the secondary filtration was extractive, with a precision of 3-5µm. There were pressure cabins at the ends of the filtration pot. If there was a pressure difference in the cabins, the finer particles resorted in the filter pack. In practice, the precision of secondary filtration is high, and its effect is good. To prevent gas blockage, a vent was installed at the head of the reinjection well.

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

Currently, some tests and research jobs are progressing steadily, including wellhead facilities, drilling, and casing techniques of reinjection wells in sandstone reservoirs.

5. CONCLUSION

Reinjection is one of the most important aspects of the sustainable management of geothermal resources. Scaled reinjection of return geothermal water heating systems has been applied in Tianjin since 1996. Reinjection experiences show that it is significant in controlling the lowering of reservoir pressure and improves the heat mining of the geothermal field.

Reinjection is the most complicated technique in reservoir engineering, as it involves issues such as premature thermal breakthrough. To avoid such breakthrough, tracer tests and proper monitoring programs should be carried out.

REFERENCES

Axelsson, G., 2003: Essence of geothermal resource management. Edited by Ffidleifsson I.B. and Gunnarsson M. Lectures on the sustainable use and operating policy for geothermal resources--Short course prior to the International Conference IGC2003. United Nations University Geothermal Training Programme, pp.249.

Axelsson, G. and V. Stefansson., 1999: Reinjection and geothermal reservoir management -associated benefits. Proceedings of the International Workshop on Direct Use of Geothermal Energy . Ljubjana, Slovenia, pp21.

Liu, J., 1999: Reinjection and tracer tests in the Laugaland Geothermal field, N-Iceland, UNU G.T.P., Iceland, 141-164.

Liu, J. and Y.Yan., 2004: Gothermal resources and direct use in the area of Beijing. Proceedings of the 6th Asian Geothermal Symposium. KIGAM, Daejeon, Korea. 25-31.

Liu, J., X. Pan, W. Ran, X. Wang and W. Xu., 2002: A few aspects of geothermal reinjection in Beijing. Proceedings, 2002 Beijing International Geothermal Symposium, China Geological Publishing House.373-380.

Rybach, L., 2003: Sustainable use of geothermal resources: renewability aspects. Edited by Ffidleifsson I.B. and Gunnarsson M. Lectutes on the sustainable use and operating policy for geothermal resources--Short course prior to the International Conference IGC2003. United Nations University Geothermal Training Programme. pp.249.

Stefansson, V. and G.Axelsson., 2003: Sustainable utilization of geothermal energy resources. Edited by Ffidleifsson I.B. and Gunnarsson M. Lectutes on the sustainable use and operating policy for geothermal resources--Short course prior to the International Conference IGC2003. United Nations University Geothermal Training Programme. pp.249.

Wang K. et al., 2001: The modeling Research about the deep basement geothermal reservoir in Tianjin (in Chinese). Tianjin Geothermal Exploration and Development Institute, Report 20-30pp.

Wang K., 2005: The Sustainable Development and Utilization of Geothermal Resources in Tianjin, CHINA, Proceedings World Geothermal Congress 2005.