Recent Advances in China-Australia Managed Aquifer Recharge

中国－澳大利亚含水层补给管理新进展

主编 王维平
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·郑州·

内 容 提 要

本书精选了中国-澳大利亚含水层补给管理研讨会论文，其主要内容包括可管理含水层补给的地址的选择、设计，有关水力学知识，地球化学特征及水质变化，风险评估，数学模型及模拟、指南，中国和澳大利亚有关可管理含水层补给的案例研究等。

本书适合从事地下水科研、教学、管理及相关部门人员参考使用。

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《中国–澳大利亚含水层补给管理新进展》

编 委 会

Preface

Managed aquifer recharge (MAR) is the intentional recharge of water to aquifers for subsequent recovery or environmental benefit. Aquifers may be recharged by a range of methods using wells and infiltration systems, to increase groundwater supplies and improve their quality or to redress saline ingress or land subsidence.

To date in China the major applications of MAR have been in infiltration basins established in the 1990s, such as the groundwater dams, infiltration wells and trenches in Shandong province, with a total recharge capacity exceeding 200 million m^3/a. River bank filtration projects have been established in South China to improve the quality of water for industry and agriculture. Injection wells are now in routine operational use for sustainable management of geothermal reservoirs in North East China with reinjection of 4 million m^3/a. In addition, there are recharge projects to reduce land subsidence in Shanghai. A demonstration project in Beijing is exploring wastewater treatment processes to precede recharge for sustainable projects that protect human health. New research in Jinan is starting to explore recharge of roof rainwater to replenish a karst aquifer that feeds historically important springs.

In Australia infiltration basins have been used, for 50 million m^3/a of agricultural supplies, since the late 1970s, commencing in the Burdekin Delta, Queensland. More recently urban stormwater and reclaimed water resources have been used in MAR, via injection wells in South Australia and infiltration projects utilising soil aquifer treatment in Western Australia and Northern Territory.

The China-Australia Managed Aquifer Recharge (MAR) Training Workshop held in Jinan October 27 ~ 31, 2008, was supported by the AusAID Public Sector Linkages Program, the National Natural Science Foundation of China, Shandong Institute of Geological Survey and Jinan Water Resources Bureau in order to facilitate the exchange of information and experience on MAR among Australian researchers and Chinese researchers and water resource managers. In large parts of both countries groundwater is a resource under stress, and in urban areas the possibilities of urban runoff and treated sewage for augmenting groundwater supplies are being trialled or used. This workshop proceedings documents the way MAR is being used or could be developed to address some of China's water resource management challenges. It provides a guide to developing MAR schemes based on Australian and Chinese experience. The material presented takes account of technical, health or environmental risks and the methods used to manage those risks. Consequently MAR operations can be confidently sited, designed, constructed and operated to be successful for a range of purposes.

As an outcome of the workshop research collaborations are intended to emerge among Chinese researchers, and between them and Australian counterparts. Progress on developing and communicating the outcomes of demonstration projects, providing unified national guidance and policies for MAR, and developing maps of the potential opportunities for MAR are recommendations emerging from this workshop. In addition, and to support this progress, a MAR Network was formed to facilitate ongoing communication between researchers and exponents of MAR. Dr Wang Weiping and University of Jinan will provide the hub of this network as part of an international UNESCO network. Workshop attendees hope this will spread quickly throughout China where MAR has a valuable role to play in water supply development and protection particularly where access to safe drinking water supplies is limited.

Peter Dillon Wang Weiping
January 2009

前 言

中国北方地区水资源缺乏，供需矛盾尖锐，地下水严重超采，并带来一系列生态环境问题，例如大面积地下水漏斗、地面沉降、岩溶塌陷、泉水停喷、海水入侵以及地下水水质恶化等。可管理的含水层补给技术采用雨洪水或者再生水人工回灌地下水，将含水层作为地下库容，既可在时间和空间上调节水资源、增加水资源可利用量、改善水质，又可以预防和修复由于地下水超采带来的生态环境问题，是保证城市用水安全的最经济的方法，对北方缺水城市具有重大的经济效益、社会效益和生态环境效益。

澳大利亚联邦科学与工业研究组织(CSIRO)、清华大学、济南大学、中国科学院广州地球化学研究所、中国地质调查局于 2008 年 10 月 27～31 日在济南大学主办了中国-澳大利亚含水层补给管理研讨会。国际水文地质学家协会含水层补给管理专业委员会主席 Peter Dillon 博士，出席了研讨会，并进行了讲座。经过十多年的研究和推广，目前澳大利亚 MAR(Managed Aquifer Recharge)技术每年供水 300 万 m^3，计划每年利用城市雨水和再生水回灌含水层开发 25 000 万 m^3 补充供水。研讨会的目的是将澳大利亚在含水层补给管理方面的技术和经验介绍到中国，促进 MAR 在中国的发展；同时交流中国在人工回灌地下水的案例和经验。

研讨会上中澳双方的专家和教授从不同的方面，多角度地对人工回灌地下水的有关问题进行了讲座和研讨，澳方研讨的内容涉及 MAR 地址的选择、设计和建设，水力学知识，地球化学特征及水质的变化，风险评估、指南与模拟和澳大利亚有关可管理含水层补给的案例；中方研讨的内容有地热水回灌深层含水层、城市污水处理后的再生水回灌浅层孔隙含水层、城市屋顶雨水回灌岩溶含水层、滨海地区建地下坝拦蓄地下径流并利用汛期雨洪水、地表水回灌浅层含水层等，并组织编辑成论文集。

研讨会得到了澳大利亚政府澳大利亚国际开发署(Australian Government AusAID)、澳大利亚联邦科学与工业研究组织(CSIRO)、中国国家自然科学基金委员会(National Natural Science Foundation of China(40810162))、济南大学、济南市水利局、山东省地质调查院资助。

本书的出版得到了中国国家自然科学基金委员会(National Natural Science Foundation of China(40742014、40810162))、山东省重点学科(实验室)基金项目、山东省自然科学基金(Y2008E18)、济南市科技发展计划(企业自主创新计划 200807125)项目、澳大利亚联邦科学与工业研究组织(CSIRO)等的资助。

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作 者

2008 年 12 月

目 录

Reinjection of Geothermal Water in Beijing and Tianjin Areas of China

Han Zaisheng[1], Liu Jiurong[2], Wang Kun[3]

(1 China Geological Survey, No.45 Fuwai Street, Beijing, 100037; 2 Beijing Institute of Geological Engineering, No.8 Beiwa Road, Balizhuang, Haidian District, Beijing, 100037; 3 Tianjin Bureau of Land Resources and Real Estate Management, No.84 Qufu Road, Heping District, Tianjin, 300042)

Abstract: Beijing and Tianjin are two very big cities with abundant low-temperature geothermal in China, 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 of Beijing, the water level has even stopped declining since 2006, owing to the reinjection and controlling of the production of geothermal water. 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.

Keyword: Geothermal reinjection; management

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 and Stefansson, 1999). The purpose of geothermal reinjection is for ①the disposal of the waste geothermal fluid that may cause thermal and chemical pollution to the environment; ②the improvement of the heat mining, because over 90% of the heat in the geothermal reservoirs is stored in the hot rock matrix; ③the 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, Larderrello field in Italy, Berlin field in El Salvador, Paris in France, Laugaland field in 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 (Han, 2002). 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 groundwater and return geothermal water was injected into a geothermal well as deep as 1 275 m. 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. 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 2 760 km^2, divided into 10 geothermal fields, such as the ones in the southeast urban area and Xiaotangshan (about 30 km 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 10×10^6 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. At present, it is often 1~2.5 m annually, and still threatens the sustainability of geothermal utilization in 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 8 700 km^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 °C to103 °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 4 000 m. The production capacity of each well is 100~200 m^3/h. The annual production of geothermal water was 24.50×10^6 m^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 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 (see Figure1). 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.

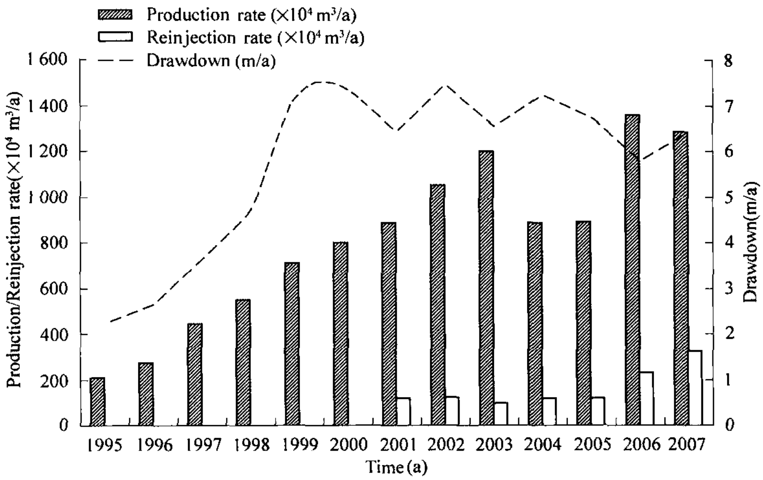

Figure 1　The history curve of water level drawdown vs geothermal water production and reinjection of the dolomite reservoir in the Tianjin urban area in 1995 ~ 2007

3　Reinjection of geothermal water in Beijing

3.1　History

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 groundwater and return geothermal water was injected into a geothermal well as deep as 1 275 m. 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:

(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 m^3/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 ℃ was injected into a 1 060 m deep geothermal well in the southeast urban area. In the 89 d of injection test, about 60 000 m^3 of cold water was injected, and the temperature change inside the injection well was observed (Liu *et al.*, 1981). After that, 40 ℃ return geothermal water from a heating system was reinjected into a 1 274.65 m 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.

(2)1983 ~ 2000. Geothermal reinjection activity stopped mostly because of financial problems, although the water level continued to decline in this period (Han, 2002).

(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 200 m 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 80 m away from the production well. And reinjection experiments also started in 2002 in the southeast boarder of the same geothermal field (Liu, 2003).

(4)2003 to 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 200 m. 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 November 30, 2001 to March 27, 2002, totaling 117 d. 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 800 m^3/d in the coldest days from 8 to 20, January, 2002, and was under 800 m^3/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 m^3 in that heating season (Liu and Yan, 2006).

A tracer test was conducted during the reinjection. On January 8, 2002, 50 kg KI was applied to the reinjection well instantaneously, 39 d 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 April 15, 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).

In the 2003 ~ 2004 heating period, a reinjection test was carried out in another hotel very close to the first one. In 150 d, 1.48×10^5 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 2.48×10^5 m^3 in that heating season. In the 2004 ~ 2005 heating period, 4 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, 10.2×10^5 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 2 production-reinjection assemblages that each involves 2 production wells and 1 reinjection well. The total quantity of reinjection was 1 322 778 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(See Figure2), it rose 2.5 m. Considering that the water level decreased 1 ~ 1.5 m every year before the large-scale reinjection, the effect was very significant.

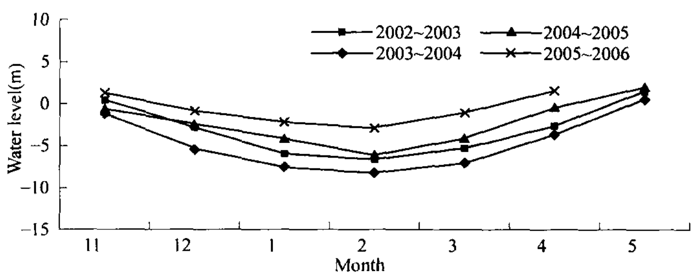

Figure 2 The water level in Xiaotangshan geothermal field from 2002 to 2006

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 200 m. 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^- 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 5 km south of the Tiananmen Square. There are two geothermal reservoirs at different depths, both made of dolomite, and separated by a shale layer about 100 m thick. Two wells, 90 m apart from each other, were drilled in 2001 for the space heating of the 28 000 m^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 1 900 m deep, striking the upper reservoir; the production well is 2 054 m 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 35 m^3/h, and all of the tail water was reinjected into the upper reservoir. The water level rose approximately 4 m on average in the injection well. 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 Reinjection of geothermal water in Tianjin

4.1 History

Reinjection activity started in the early 1980's in Tianjin, and the history may be divided into 3 periods:

(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 modeling on sandstone reinjection was conducted. According to the results, reinjection tests were carried out in Dagang District and Tanggu District in 1987~1989 and 1995, focused on reinjection in the sandstone geothermal reservoir of the Tertiary System.

(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).

(3)1998 to 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 modeling 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 2.89×10^6 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 (80~120 m^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 50~100 m^3/h for each well, and the annual amount of production is $1.371\ 6\times10^7$ m^3 (deducting the amount of reinjection 1.7×10^6 m^3). It was predicted that the deepest water level in the reservoir will be 193 m 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 138 m below see level in 2013. This means that reinjection makes an effective measure to counteract the decline of the reservoir pressure (Wang, 2005).

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 (^{125}I, ^{35}S). The distance between the production well and the reinjection well is 850 m. The amount of tracer is 10 kg. The entire tracer was applied instantaneously. The tracer breakthrough time was about 3 d, and the peek time was at about 52 d(See Figure 3). According to the deduction from the tracer tests, there will not be a premature thermal breakthrough.

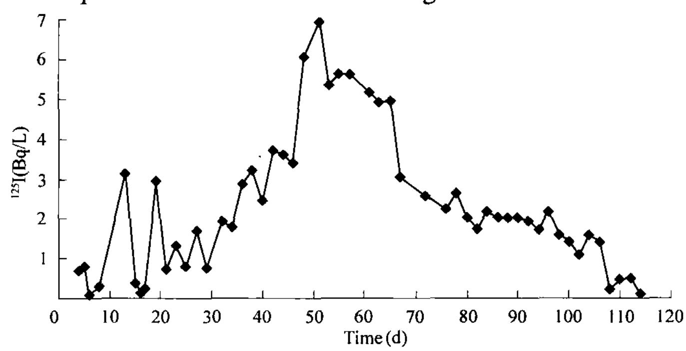

Figure 3 Curve of tracer (^{125}I) recovery of a tracer test

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 30~50 m^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: ①Injectivity decreases fast with time or injectivity changes too much with time during the reinjection process; ②The 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