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Management of Geothermal Resources in Beijing

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ABSTRACT

For most geothermal fields, the sustainability is limited by lack of liquid recharge, rather than lack of heat content. The extraction of geothermal fluid often causes continuous lowering of the pressure of the production wells. It is necessary to keep good balance between the geothermal fluid production and recharge. This is often a very difficult task, because the changes, on the fluid pressure of the production wells and the surrounding area, caused by production of geothermal fluid is often difficult to foresee. On the other hand, the recharge of a geothermal system is also difficult to predict, and it may change along with the amount of geothermal fluid production and the distribution of the production.

Technical measures are very important for keeping the balance between fluid production and the recharge of a geothermal field, including monitoring, reinjection and modelling. And administration measures are equally important, for limiting the amount of production and enhancing reinjection, especially for geothermal fields that have many users.

Beijing has abundant low-temperature geothermal, and it has had a nearly 40 year history of scaled geothermal utilization, including space heating, bathing, swimming pools, health spas and recreation, greenhouses, fish farming etc. Owing to over extraction of geothermal water, the pressure of the geothermal wells has started to decline rather fast in the most important geothermal fields since the early 1980's. To realize sustainable use of geothermal resources, a lot of measures, both administrational and technical, have been applied in Beijing. As a result, the water level decline of the most important geothermal fields, such as southeast Urban and Xiaotangshan areas, have been greatly reduced, even stopped recently in the later one.

1. INTRODUCTION

Geothermal is a kind of green energy, and it is renewable to a certain degree. Sustainable use has been the endeavored objective of any resource, including geothermal. A lot of scientists have worked on geothermal sustainable use and have made important achievements (Axelsson et al.,2005; Axelsson et al., 2002; Rybach and Mongillo, 2006; Rybach,2003; Lin et al., 2006; Wang et al., 2006). For most geothermal fields, the sustainability is limited by a lack of liquid recharge, rather than a lack of heat content. Because of this, the extraction of geothermal fluid often causes a lowering of the pressure of the production wells, threatening the sustainability of geothermal utilization. Therefore, it is necessary to keep the balance between the geothermal fluid production and recharge, so that the water level of the geothermal reservoir will stop declining or decline in a controlled manner.

A geothermal system is often very complicated, with many factors controlling the fluctuation of the water level or pressure, such as the geological structure, the size and permeability of the reservoir, the distance and amount of the recharge sources etc. Therefore, it is very difficult to keep balance between production and recharge of the geothermal fluid. On the one hand, the changes of fluid pressure of the production wells and the surrounding area, caused by the production of geothermal fluid is difficult to foresee. On the other hand, the recharge of a geothermal system is also difficult to predict, and it may change along with the amount of geothermal fluid production and the distribution of the production.

For the management of geothermal resources, there are two kinds of measures: administrational and technical measures, both equally important. Administration measures focus on limiting the amount of production and enhancing reinjection. It is especially important for geothermal fields where there are many users. Technical measures include monitoring, reinjection and modelling etc.

Beijing has abundant low-temperature geothermal, and the area identified with geothermal is over 2760 km^2, accounting for over 40% of its plain area. It has had an almost 40 year history of large-scale direct utilization, including space heating, bathing, swimming pools, health spas and recreation, greenhouses, fish farming etc. Owing to the ever-expanding needs for geothermal in Beijing, the geothermal water has long been over extracted, causing the pressure of the geothermal wells to decline 1-2.5m every year in most of the geothermal fields since the early 1980's. To realize the sustainable use of geothermal resources, a lot of measures, both administrational and technical, have been applied in Beijing. As a result, the water level decline of the geothermal fields, such as southeast Urban area and Xiaotangshan, has been greatly reduced, even stopped recently for the later one.

In the paper, the geothermal resources in Beijing and the utilization will be briefly introduced. The administration of geothermal exploration and utilization will be presented, including the related laws and regulations, institutions, permit processes, the controlling of geothermal water production, the encouragements of reinjection by the government, the funding of research projects, planning of geothermal development etc.; the technical measures, including monitoring, reinjection and modelling of the geothermal fields, will also be presented.

2. GEOTHERMAL AND ITS UTILIZATION

Geothermal in Beijing is often stored in limestone or dolomite reservoirs, and the areas identified with geothermal potential are over 2760 km^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°C. The geothermal water contains

SiO_2 and other components that are good for human health (Liu, 2008).

In the past, 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 had increased to over 10 million m^3 annually, causing a rapid decline of the reservoir pressure (water level). Therefore, strict measures were taken to control the amount of geothermal water extraction since 1985. As a result, the water level decline has slowed down since then.

In recent years, the annual geothermal water production was 7-10 million m^3/year, and the geothermal fields in the southeast Urban and Xiaotangshan have the most production. In Beijing, geothermal is used for space heating, bathing, swimming pools, health spas and recreation, greenhouses, fish farming etc., creating significant social, economical and environmental benefits. With the improvement of the living conditions, geothermal is playing a more and more important role in combating the air pollution and reducing the CO_2 emission in Beijing.

3. ADMINISTRATIONAL ASPECTS

3.1 Laws and Regulations

Geothermal is defined as a kind of mineral resource according to the Act of Mineral Resources of the People's Republic of China. It is also defined that the geology and mineral resources department of the national government is responsible for the over-all management of geothermal exploration and development, including (1) organization of regional geothermal geological exploration; (2) management of geothermal exploration rights and mining rights; (3) supervisory and management of geothermal utilization; (4) approval and registration of geothermal reserve and data collection.

The Beijing Geothermal Management Regulation was approved in 1999 and put into operation in 2001 by the municipal government. It is clearly defined that the governmental institution in charge of geology and mineral resources should be responsible for the administration and management of geothermal in the city. In the regulation, some details of geothermal administration measures are also defined, including (1) the procedure of tariff submission for geothermal exploration and utilization; (2) permit process for geothermal exploration and utilization; (3) the requirements for geothermal well drilling and related data and document acceptance; (4) the limitation of geothermal water extraction of each user and monthly reporting of temperature, water level and amount of geothermal water extraction; (5) measuring of production temperature and amount; (6) deduction of geothermal resources tariff for reinjection of return water from heating use; (7) the lower limit of return water temperature; (8) the punishment for activities breaking rules etc.

3.2 Institutions

In the City of Beijing, the department responsible for geology and mineral resources is the Bureau of Land and Resources of Beijing (BLRB). Within the Bureau, there are three divisions related to geothermal: (1) Geothermal Division, for the all-around management of geothermal; (2) Mineral Resource Development Division, for the geothermal exploration and mining right administration; (3) Mineral Resource Exploration and Reserve Division, for the approval and management of geothermal reserve documents.

The Beijing Bureau of Geology and Mineral Exploration and Development (BBGMED) is responsible for technical support to the management and development of geothermal. There are a few institutes under BBGMED related to geothermal activities in Beijing, such as the Beijing Institute of Geological Engineering (BIGE). Those institutes are responsible for the planning, feasibility studies, drilling, reinjection and geothermal water treatment etc.

Beijing Geothermal Association (BGA) is a non-governmental and non-profit institution, with experienced geothermal expertise. It plays a very important role in the geothermal planning, exploration, development, and utilization. It is in charge of the assessment of feasibility report of geothermal utilization and well drilling projects, and supervision of geothermal drilling activities, entrusted by BLRB.

3.3 Permit Processes

The process of getting a geothermal utilization permit in Beijing includes the following steps:

(1) Feasibility study: a feasibility study should be carried out, including the background information of the project, geothermal geology conditions, preliminary design of the geothermal well(s) etc. The report should be ready before applying for the drilling permit.

(2) Registration for geothermal exploration right: a geothermal user has to register at BLRB, for checking if the geothermal exploration right of the project area has been given to other users.

(3) Application for geothermal exploration right and well drilling permit: the user has to submit the application to BLRB, with the design of geothermal well(s), a contract of drilling, assigning an advisory institution, a preliminary plan of geothermal utilization.

(4) Drilling of geothermal well(s): after getting the geothermal well drilling permit, the drilling can only be started.

(5) Application for geothermal utilization right: After the drilling of the well(s), and the installation of geothermal utilization facilities, BLRB will have a field inspection, and approve the geothermal utilization right.

3.4 Production Control

Because the fluid recharge of the geothermal system in Beijing limits its production capacity, the amount of geothermal water production has to be controlled, so as to realize the balance between the recharge and production. Every year, the Geothermal Division of BLRB will set an upper limit of geothermal water production for each geothermal user according to (1) the total production potential of each geothermal field; (2) the capacity of each geothermal use facilities; (3) the profit made by geothermal utilization of each user etc. All the users will be informed of their limit beforehand every year. If a user's geothermal production is more than the upper limit, it will be fined according to the geothermal resources management regulation in Beijing.

Another measure to control the amount of geothermal production is the use of a price lever. Geothermal water was used freely before 1985. In 1985, the first geothermal water

pricing system was put into operation, although the price was very low (Table 1). After 1997, the price for geothermal water use was raised gradually in seven steps. The present price system was stipulated in 2004 (Table 2).

Table 1: Standard of geothermal water tariff in 1985 (unit: Yuan/m^3) (From Beijing Bureau of Land and Resources, 2006)

Classification of use	<50˚C	50-70˚C	>70˚C
Farmer users	No charge, according to national policy		
Agricultural, forestry, fishery, spa and bathing	0.02	0.04	
Other uses	0.04	0.06	0.08

Table 2: Standard of geothermal water tariff revised in 2004 (unit: Yuan/m^3) (From Beijing Bureau of Land and Resources, 2006)

Utilization	<50˚C	50-60˚C	60-70˚C	>70˚C
Space heating and greenhouse	3.5	4	4.5	5
Governmental institution	5	6	7	8
Industry, hotel and commercial	9	10	11	12
Spa and recreation	55	57	59	61

3.5 Encouragements of Reinjection

Reinjection of return water from the space heating systems and greenhouses is also believed to be an important measure to keep the balance between the recharge and discharge of geothermal reservoirs in Beijing. It is strongly encouraged by the government. It is stressed in the geothermal resources management regulation that users should reinject return water of geothermal heating systems if the condition allows for it. And the geothermal resources fee should be deducted according to the temperature and amount of reinjection. For example, if a user takes 49˚C geothermal water for space heating and reinjects all the pumped geothermal water back to the geothermal reservoir, the user will use the water freely. This makes reinjection economically reasonable for the users, and has played a significant role in the geothermal management in Beijing.

For example, in the Xiaotangshan, there are 6 reinjection wells in operation at present, and the total amount of geothermal resources fee deduction has been over 10 million Yuan from 2001 to 2006 (Pan, 2006).

3.6 Research Projects

It is essential to have technical support for the sustainable use of geothermal, because the geothermal systems are very complicated, with many factors influence the responses to the production. On the one hand, there are growing needs for geothermal in Beijing, and new areas have to be studied. On the other hand, the geological condition and the occurrence of geothermal in Beijing are very complicated. This made the geothermal exploration in Beijing very risky. Therefore, research projects are badly needed in Beijing. BLRB funds a few research projects every year, focused on geothermal exploration techniques, utilization techniques, resource assessment, and information systems etc. The achievements of those projects has greatly supported the geothermal development in turn.

3.7 Planning

Geothermal planning is carried out every 5 years in Beijing, corresponding to the Five Year Plan of Social and Economical Development of the city. In the planning, the status of geothermal exploration and utilization will be summarized, and the problems and future needs will be analyzed. According to this, the planning will tackle aspects related to: (1) the measures for insuring the sustainable use of geothermal; (2) the total amount of geothermal water consumption in each geothermal field; (3) division of areas where production should be strictly controlled; (4) measures encouraging geothermal exploration in new areas or areas with few geothermal wells. The most recent geothermal planning was started in late 2005 and completed in 2006.

4 TECHNICAL ASPECTS

4.1 Monitoring

Monitoring of geothermal field is a very important component for sustainable use of geothermal (Axelsson, 2003), especially for field with reinjection. In Beijing, monitoring has started since the beginning of modern geothermal utilization in early 1970's.

At present, there are 12 wells dedicated for water level monitoring in Beijing, mostly in the important geothermal fields, such as the one in southeast Urban area and Xiaotangshan, as well as other less developed geothermal fields. At the early days, the water level was measured manually, but has been automatic since the 1990's. Recently, electronic devices are used for water level monitoring and the records can be downloaded by a computer. The monitoring data shows that the water level has been declining since the production started (Figure 1).

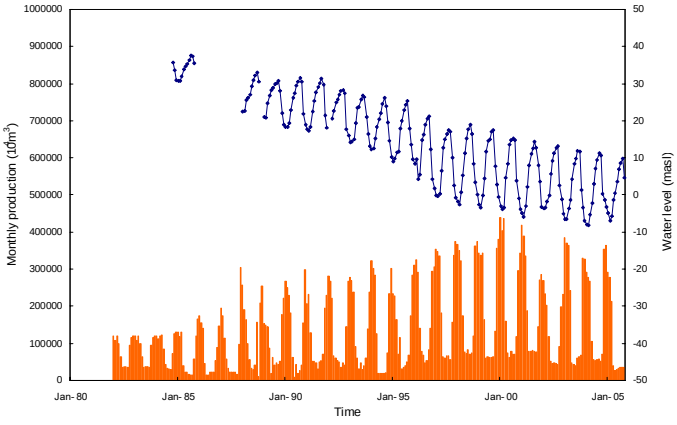

Figure 1: Water level monitoring data in Xiaotangshan geothermal field

Chemical and temperature monitoring of geothermal fields was also started in early 1970's in Beijing. There are around 20 such wells sampled twice every year in Beijing. The results showed that there were not much changes of chemical composition and temperature of the geothermal water.

4.2 Reinjection

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 that, reinjection stopped in Beijing for a rather long time. Until 2001, reinjection experiments and demonstration projects started again. Recently, reinjection has been implemented on a rather large scale resulting in significant achievements in Beijing (Liu and Wang, 2008).

In 2005-2006 heating period, there have been 6 reinjection wells for injecting return water of 8 production wells in Xiaotangshan area,. 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 m^3, accounting for 56.6 % of the annual production in the field. As a result, the water level in the geothermal field not only stopped declining, but started rising since 2005, and in the winter of 2005-2006, the water level was about 5m higher that in the winter of 2003-2004. This shows that reinjection is effective for the sustainable use of geothermal in Beijing (Liu and Wang, 2008). In 2007 and 2008, although the reinjection is a little less than that of 2005-2006 heating season, the water level of the geothermal reservoir is still rising somewhat.

In 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 2), 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.

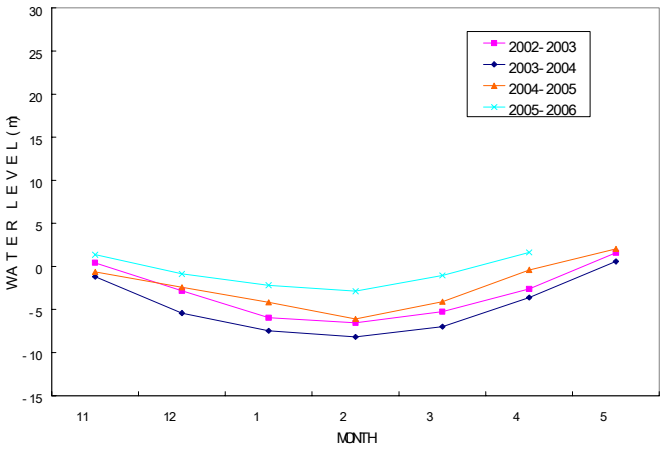

Figure 2: The water level of a monitoring well in Xiaotangshan geothermal field from 2002 to 2006

In southeast Urban area in Beijing, reinjection has also been conducted for a rather long time, but the effect on maintaining the water level was not very obvious. In other geothermal fields, a few reinjection wells have also been drilled, and reinjection will start very soon. With the encouragement for reinjection by the municipal government, reinjection will soon become more popular in Beijingresulting in greater achievements.

4.3 Potential Assessment and Modelling

It is important to know how many geothermal resources in the geothermal fields are under production especially how much geothermal fluid could be produced in a certain time (for example 1 year), without causing obvious reservoir pressure, or water level decline, so as to realize the sustainable use of geothermal. In Beijing, geothermal potential assessment will be carried out every 5 years, along with the geothermal planning. And for the most important geothermal fields, projects of potential assessment are often funded by the government for renewing the assessments if more detailed results are needed, or when the production scale expanded.

In the processes of geothermal potential assessments, monitoring data, including the amount of production and reinjection, the water level, as well as chemical composition and so on, is very useful. These data are used to set up models for calculating the geothermal potential and to predict the responses to the production in the future. Until now, the models used in Beijing were mostly statistical models and mathematical models. Lumped parameter models (Liu et al., 2001; Sun et al., 2005) were also set up for the southeast Urban area and Xiaotangshan area. But there is still not a numerical model for the geothermal fields in Beijing.

5. CONCLUSIONS AND RECOMMENDATIONS

Geothermal is a kind of green energy and it is renewable to a certain degree. The sustainability of geothermal use is often limited by the lack of fluid recharge, rather than the heat recharge. It is important to keep a balance between the fluid production and fluid recharge so that the geothermal can be used in a sustainable manor. To realize this, there are two categories of measures, administrational and technical, aiming to control the production and enhance reinjection. In Beijing, there are proper institutions, laws and regulations for geothermal management. On the other hand, proper technical measures have also been taken, including monitoring, reinjection and potential assessment and modelling. As a result, the water level decline of most of the geothermal fields is under control. Especially, the water level decline has stopped in the Xiaotangshan area, owing to the strict control of production and effective promotion of reinjection. This can be a model for other geothermal fields in Beijing and China.

However, the water level of most of the geothermal fields in Beijing is still declining, except in the Xiaotangshan area, although the amount of production has been strictly controlled. This means that reinjection should be expanded. On the other hand, the effect of reinjection should be observed and the possible cooling of production wells should be studied. This is still a tough task for the geothermal development in Beijing.

There are still a lot to do in the modelling of the geothermal fields and potential assessment in Beijing, especially numerical modelling. In the mean time, the historical data for the most developed geothermal fields, such as Xiaotangshan and southeast urban area has been rather good for numerical modelling.

The pricing system for the geothermal resource fee should be revised, because the present pricing standard can not well act as a factor for encouraging the effective ways and limiting the ineffective ways of geothermal direct use in Beijing.

The geological conditions are the controlling factors of the geothermal occurrence in Beijing. But in some areas, the deep geology is still not clear, making the geothermal drilling very risky. It is proposed that some projects on geological exploration and related techniques be funded by the government.

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