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Exploration and Research of Geothermal Resources in Beijing, China

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ABSTRACT

The earliest geothermal exploration in Beijing begain in 1956 for the purpose of exploration and resource assessment for Xiaotangshan Hot Spring Sanatorium. In 1970, geothermal was recognized as a new form of energy in China. Geothermal exploration was carried out in Beijing urban area at that time. The Beijing Urban Geothermal Field was confirmed by three successful geothermal wells in the ensuing year. Following this success, continuous geothermal exploration extended range and depth of the field and the identified reserves were enlarged progressively. Up to now four geothermal zones have been recognized. Ten geothermal fields were divided with a total area of 2,760 km^2. The temperature ranges between 36°C and 118.5°C. The type of the geothermal water is mainly HCO_3-Na. The contents for SiO_2, F and some Rn and Ra have reached the index of mineral water.

Give consideration to both exploitation and protection, geothermal resources were controlled to exploit 10 million m^3 per year in Beijing. It was used for district heating, greenhouse planting, aquaculture feeding, bath and medical treatment, and tourism relax and resort. Geothermal water was realized integrated use, especially in Nangong village where it has created a conversion from traditional agricultural cultivation economy to modern geothermal economy.

Since the 1950s, Beijing has carried out geothermal monitoring. Geothermal reinjection tests started in the 1970s. Beijing started to implement the geothermal resources management in 1984. Since the 2000s, Beijing has realized a beneficial geothermal reinjection program, with highest record over 60% of reinjection/production rate in Xiaotangshan geothermal field. All these measures have ensured a sustainable development for the renewable geothermal energy. Beijing pays attention to international cooperation and exchange in geothermal works. We have learned advanced technology and experiences from the world, which has directed and enhanced our work and research.

1. INTRODUCTION

There is long history for use of geothermal hot springs in Beijing. Since 1,500 years ago, the “Commentary on the Waterways Classic”, which was written by Li Daoyuan at Beiwei Dynasty, had recorded a hot spring used in Foyukou of Beijing. However the earliest geothermal exploration started in 1956 in Beijing. At that time, the Ministry of Health and Ministry of Geology jointly selected 15 hot spring sanatoria to carry out geothermal exploration. The purpose is to ensure the supply of hot spring water. Beijing Xiaotangshan hot spring was selected for this purpose.

2. GEOTHERMAL EXPLORATION AND RESOURCE ASSESSMENT

The hot spring exploration in Xiaotangshan carried out in 1956-1958 is the earliest geothermal exploration in Beijing. Geological survey, hydrogeological investigation, water chemical sampling and analyzing were implemented. Geothermal drilling includes 26 exploration holes with total length of 4,281.33 m. The deepest hole is 534 m in depth. Whole work was carried out there under guidance of Russian experts. The exploration report trapped the geothermal area of 0.6 km^2 with temperature over 37°C. Exploitable reserves of geothermal water were assessed.

In 1964 the Thermal Mineral Water Group was created in the First Team of Hydrogeology and Engineering Geology of Ministry of Geology. It carried out well temperature measurement and found an anomaly in Wali area, where the groundwater temperature was 3-5°C higher than other areas. Exploration drilling was carried out there in 1966 and 1967. The deepest drilling had reached 760 m. Two drillholes found abandoned karst groundwater. But the temperature gradient is very small. The temperature in bottom hole is less than 22°C with total increase less than 2°C. These projects marked the early stages of geothermal work in Beijing.

At the beginning of 1970, the world’s first crisis of petroleum price triggered national governments to seek and develop new energy in order to replace conventional energy source of fossil fuel. The Minister Prof. J. S. Lee of the Ministry of Geology was called upon to develop geothermal energy in addition to coal and oil energy resources in the country. Since that time geothermal was recognized as an energy source that should be explored and developed in China. The Xiaotangshan hot spring is located 30 km north of the urban area. It was not convenient for public bus traffic at that time. Therefore, the Beijing urban area was determined to be the main target. The first exploration drilling started in 1970. Positive results were harvested in 1971, when three geothermal wells were completed with temperature of 39-53°C. The total drilled length was 3,817 m at that time. Beijing urban geothermal field was trapped for 30 km^2. The geothermal reconnaissance stage was completed. Following the success, exploration drilling accompanied with geophysical survey as resistivity sounding, gravity and magnetic survey etc. was extended. Thus the detailed survey and exploration stages were passed in 1978 and 1982, respectively. The corresponding geothermal resource assessment reports were submitted associated with the enlargement of the geothermal field. Finally, we had reached the exploitation stage in Beijing urban geothermal field (Table 1) (Pan and Zheng, 2010).

Table 1: Exploration Progress in Beijing Urban Geothermal Field

Exploration stage / year	Area of the geothermal field	Wells completed / unsuccessful	Total drilled length	Degree of resources assessment
Reconnaissance /1971	30 km^2	3 / 1	3817 m	D
Detailed survey /1978	60 km^2	19 / 3	18.4 km	C+D
Exploration /1982	100 km^2	35 / 3	38.4 km	B+C
Exploitation /1989	120 km^2	44 / 3	50.8 km	A+B

Since that time, drilling for geothermal injection and production wells has continued. Beijing urban geothermal field has extended into 240 km^2 in area. There are total 207 wells drilled in the field.

The successful progress of geothermal exploration in Beijing urban geothermal field affected wide surrounding areas. By local requirement, the combined exploitation and exploration drilling was carried out in Xiaotangshan hot spring area. Higher temperatures were observed, and the range of the geothermal field was extended. Meanwhile, geothermal exploration was implemented in other areas where similar geothermal geological conditions to the Urban and Xiaotangshan geothermal fields existed. Since the 1980s, China transferred from a planned economy into a market economy. The national budget for geothermal exploration decreased greatly. Developers found that running geothermal business can make more profits. So they invest money to explore geothermal. Hot spring resort became popular projects for earning more money, which attracted more developers to invest in geothermal projects. However this is favorable for geothermal exploration and research in Beijing. To date, we have divided four geothermal zones with 10 geothermal fields in Beijing. The total area has covered 2,760 km^2. In total, 496 geothermal wells have been drilled. Geothermal resource assessment showed total reserved energy of 500.772×10^{18} J. The reserved geothermal water is 17.973 billion m^3. The annual exploitable rate is 80.85 million m^3. It contains total heat of $16{,}969.67\times10^{12}$ J. This is equivalent to 964,900 tons of standard coal.

Beijing geothermal fields originally yielded thermal water a maximum temperature of 89°C. They all belonged to low temperature geothermal field. In 2010-2012 in Caiyu of Daxing District 3, geothermal wells drilled 3,300-3,600 m depth yielded steam-water two phase flow of 103-118.5°C. The well No.3 yielded 2,302 t/d of total flow rate with 0.8 MPa of shut well pressure（Fig.1). It made the Fengheying geothermal field become a medium temperature geothermal field.

Figure 1: Well testing of 118.5°C geothermal in Caiyu, Beijing

3. GEOTHERMAL RESOURCES DEVELOPMENT AND UTILIZATION

Geothermal wells with exploration purpose that were drilled in Beijing urban area were located in large enterprises. Earlier utilization was mainly geothermal space heating and hot spring bath. At that time winter heating was supplied by each user (enterprise) itself. Geothermal water of 50-60°C circulating 24 hours is better than boiler heating supplying water twice per day during morning and evening. It provides stable and comfortable effect for space heating. Geothermal air-conditioning (heating with moisture) for cotton spinning workshops could decrease cost and increase the product's quality. Then the tail water with suitable temperature was used for staff bath. Geothermal wells located in suburban area were used for geothermal green houses for growing top grade vegetables and flowers. It promotes higher economic benefit. Geothermal aquaculture breeding is also popular to get high yield and new variety. It added beautiful features for the market in the capital, Beijing.

When China entered the market economy, in order to fit various consumer groups privately operated business invest a multitude of hot spring resorts. They run hot spring bath, medical care, tourism and relaxation. The initial developers gained high benefit, and then it attracted later investors. In addition, in real estate projects villa with "hot spring entering your home" and domestic hot water supplies were welcome.

A comprehensive survey that was carried out in 2013 showed the status of geothermal development and utilization. Geothermal utilization is mainly for district heating (Fig. 2), although the running cost has increased due to the resource fee that was collected under geothermal resource management. It has affected the growth of geothermal district heating. However, the policy of deduction for reinjection wells improved geothermal district heating (Pan et al, 2014). Especially at present, in order to govern the fog haze, the "Beijing Action Plan of Clean Air for 2013-2017" has stipulated to create the clean energy system with electricity and natural gas mainly and with geothermal and solar energy as assistant. A concrete implementation method has been issued. Reforming the project for district heating from conventional to geothermal will gain subsidy of 50% fund.

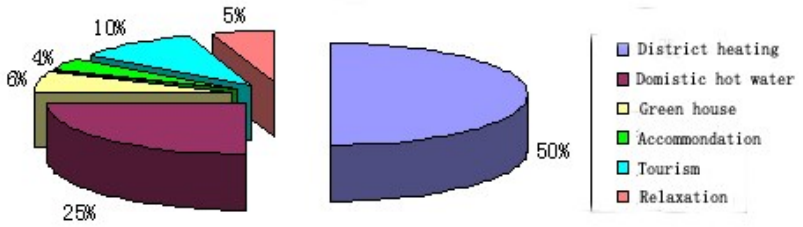

Figure 2: Proportion of geothermal use in Beijing

4. GEOTHERMAL MONITORING, REINJECTION, AND MANAGEMENT

4.1 Longest History of Geothermal Monitoring in China

Along with the geothermal prospecting carried out in Xiaotangshan in 1956, corresponding geothermal monitoring had been implemented for both the hot spring and geothermal well. Monitoring frequency is several times per month for water level and temperature, and twice per year for water chemistry.

Geothermal monitoring had a gap for a few years during the cultural revolution. Since the 1970s, it was carried out continuously by a professional geothermal section. Monitoring measurement by man power had lower frequency as before. However, the automatic recording by instrument is once per hour usually. Maximum record for single well has over 0.3 million data. Longest monitoring of water chemistry for single well has experienced for 58 years with over 80 samples.

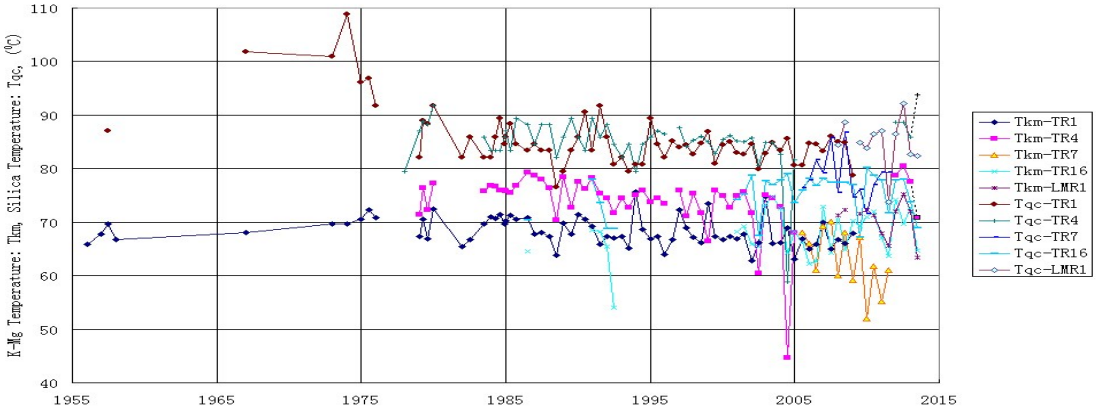

Figure 3: Behavior of geothermometry temperature of T_{KM} and T_{SiO2} in Xiaotangshan

4.2 From Testing to Productive Geothermal Reinjection

Geothermal reinjection tests started in 1974 in Beijing. Tap water was injected into an unused geothermal well in Temple of Heaven Park. It lasted for 12 days and injected 2,041 m^3 of tap water. Due to higher specific weight for cold water, it made pressure increasing locally, so geothermal water level rose up in surrounding wells. Afterwards geothermal reinjection was tested in several locations using waste hot water, shallow cold groundwater, and geothermal tail water.

Productive geothermal reinjection was carried out and enlarged progressively since 2001 in Xiaotangshan geothermal field. Geothermal water was exploited from production wells and used for geothermal district heating. Then the tail water was collected and injected into reinjection wells. It was started from a couple of wells, and then grew into 10 pairs, for a total of 22 wells. The reinjection rate was enlarged year by year. The maximum reinjection/production ratio is more than 60%. It appeared wonderful result that water level rose in every month compared with previous year (Pan, 2006). A tracer test was also performed (Pan, 2010). In 2013 the sum of reinjection was 2.38 million m^3, while the whole production was 4.04 million m^3 in the geothermal field. Therefore the reinjection/production ratio equals 58.9%.

The sum of geothermal reinjection rate in all of the geothermal fields in Beijing in 2013 was 5.46 million m^3, while the total production was 12.96 million m^3. So the average reinjection/production ratio is 42.1% in Beijing. The effect of reinjection has controlled the speed of water level drawdown to be more or less stable. Reinjection didn't appear to cause a drop in temperature of the production wells.

4.3 The Earliest Geothermal Resources Management in China

The implementation of geothermal resources management was started in 1984 in Beijing. There were 45 geothermal wells completed in Beijing Urban geothermal field at that time. In addition, 30 more wells were drilled in Xiaotangshan and Liangxiang geothermal fields. The sum of geothermal wells in Beijing was about 80 at that time. The total annual production rate was about 10 million m^3. The annual water level drawdown was 2-3 meters. In order to control well drilling, to restrain production, to encourage reinjection and enhance research, the mayor's working meeting decided to compile geothermal resources management method and establish the geothermal administration to implement the management. This is the earliest city for implementation of geothermal resources management in China (Liu and Zheng, 1993). Geothermal resources management of 30 years has gained outstanding effect. There are 496 geothermal wells in Beijing now. They yield 13 million m^3 of geothermal water annually meanwhile inject 5.5 million m^3. The net consumption is 7.5 million m^3. Water level drawdown is controlled within 0.5-2.0 meters annually.

5. GEOTHERMAL INTERNATIONAL COOPERATION AND EXCHANGE

Chinese geothermal development with typical example of Beijing got attention from the world. UNDP sent international geothermal experts to investigate in Beijing. Then the Beijing Geothermal Resources Exploration as UN aided CPR.80/065 project was established. During the implementation, we got overall guidance by eight international experts, including geothermal geology, geophysics, geochemistry, reservoir engineering, and corrosion and scaling aspects. We also obtained the most advanced instruments in our laboratory for water chemical and isotopic detection. Because of this, we became the top laboratory in China. A pilot application for geothermal space heating and reinjection was installed, too. All of these greatly enhanced our exploration and research in Beijing.

In 2002, the Beijing International Geothermal Symposium with the theme of "Geothermal contributes to the 2008 Olympic Games" received 15 foreign guests to attend the symposium. Except a few honorable guests, including the IGA President, most of foreign guests came by admiration. At that time LIU Qi, the Beijing Secretary of CPC hoped to hear comments from international geothermal experts on how to serve for green Olympics. This was a successful symposium. Beijing followed foreign experts' comments and hosted successful green Olympics.

In 2005, the 39th Board Meeting of International Geothermal Association was held in Beijing. The IGA President brought 22 board members to attend the meeting. We invited them to attend the opening ceremony of nationwide geothermal industry sustainable development symposium, and five foreign experts reported their research presentation. Foreign experts visited in Nangong village, the "first geothermal village of China" for cascade geothermal utilization. The IGA President wrote respectful words for the village.

Beijing received a lot of geothermal delegations from France, Germany, United States, New Zealand, Japan, Hungary, Thailand, Indonesia, and other countries. The Ministers of Environment from Germany and Hungary requested a visit in Nangong geothermal village. Geothermal development in Beijing has won the attention of foreign friends. They gave us valuable comments.

Beijing geothermal delegation attended World Geothermal Congress and visited many advanced geothermal countries, too. Foreign exchange helped us to learn from the rest of the world , and enabled us to gain new technology, new methods, and new ideas.

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