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BACKGROUND, HISTORY AND STATUS OF GEOTHERMAL USE IN BEIJING

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ABSTRACT

The City of Beijing is rich with low-temperature geothermal resources, and the area identified with geothermal potential is 2,760km^2, divided into 10 geothermal fields, including the one in the south-eastern part of the urban area and the one at Xiaotangshan. The geothermal reservoir is made of limestone or dolomite that is karsted. The production temperature is 38-89°C.

Geothermal explorations started in the 1950's and large-scale geothermal development started in the early 1970's in Beijing. After that, the number of geothermal wells has been ever increasing, and in 1985 the annual production of geothermal water has increased to more than 10 million m^3, causing a fast decline of the water level in the geothermal wells. Although the amount of geothermal water production was decreased, and the annual drawdown of the water level became smaller, the water level continued to decline. At present, there have been about 400 geothermal wells, and the annual geothermal water production is 7-9 million m^3.

The geothermal water, containing components good for human health, is used for various direct purposes, including space heating, bathing, greenhouses, fish farming, health spa and recreation, bringing great economical, environmental and social benefits. In 2005, the geothermal water production was 7.7 million m^3. The related economical profit was about 1.1 billion YUAN (about 110 million EURO); the energy used accounts for 85.8 thousand tons of coal; the CO_2 emission reduction is about 204.7 thousand tons.

The water level of most geothermal wells is still declining often 1-2m annually, because of the production of geothermal water is still more than the recharge of the geothermal systems, while reinjection is still not very much. Therefore, it is essential to control the production and expand the scale of reinjection. It is also very important to strengthen the monitoring and modelling of the geothermal system, especially to set up detailed numerical models in the most developed geothermal fields.

1. INTRODUCTION

The City of Beijing is the political, scientific, cultural and foreign exchange center of China. It is one of the six ancient cities of China, having over 800 years of history as a capital city. It covers an area of about 16,800km^2, including about 10800km^2 of mountain area in the north and west part, and about 6000km^2 of plain area in the southeast part, which is the northern end of the North China Plain (Figure 1). It has a population of about 14.56 million at the end of 2003, and over 60% is inside the central area that is about 1000km^2. Since 1980, the city has been developing tremendously in an all-round way and its GDP growth rate was steadily over 10% recently. In 2007, its GDP has increased to about 900 billion Yuan, 12.5% increase compared to that in 2006. Beijing has now become a modern metropolis with the charm of an ancient oriental city.

FIGURE 1: A satellite image of the City of Beijing

Beijing is rich with low-temperature geothermal stored in limestone or dolomite reservoirs, and the area identified with geothermal potential is over 2,760km^2 (according to the area where the temperature is over 50°C at the depth of 3500m), divided into 10 geothermal fields. 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 history, water from hot springs was used for bathing and health spa (Liu et al., 2001). The geothermal exploration in Beijing started in the 1950's, lead by Dr. Li Siguang who is a well-known geologist. Large-scale geothermal development commenced in the early 1970's. Since the late 1990's, geothermal direct use in Beijing has developed tremendously, and 20 to 30 geothermal wells were drilled every year. Recently, to mitigate the air pollution in the city, the utilization of clean energy, including geothermal, is encouraged by the government. To the end of 2007, about 400 geothermal wells have been drilled in the city, and the deepest is over 4,000m. Geothermal water is used for space heating, bathing, greenhouses, fish farming, spa and recreation, bringing great economical, environmental and social benefits. Geothermal has been widely accepted by the society, with the

increase of geothermal utilization in Beijing. In the planning of a lot of construction projects, geothermal was often considered for space heating and health spas at present.

In the paper, the geological background, the characteristics of the geothermal reservoirs, the features of the geothermal water in Beijing will be described, and the history of geothermal explorations will be introduced, the situation of the geothermal direct use and the problems threatening the sustainability of geothermal development in Beijing will be analyzed.

2. GEOTHERMAL EXPLORATIONS

There were a few natural hot springs in the area of Beijing, including the one in Xiaotangshan. In the early 1950's, the hot springs were investigated, and in the late 1950's, during the geological explorations for cold water purpose, warm water of about 30°C was found in a 70m deep well in the area of Liangxiang, about 30 km southwest of the city centre (Bin, et al., 2002).

In late 1960's, preliminary geothermal explorations were carried out in the Plains area in Beijing. In 1971, the first geothermal well was completed in the south-eastern part of the urban area in Beijing, Thereafter, large-scale geothermal exploration and development started in Beijing. In the past 37 years, great achievements have been made: 10 geothermal fields were prospected or discovered; over 400 boreholes have been drilled for geothermal explorations, production and reinjection; and areas identified with geothermal potential (over 50°C at the depth of 3500m) are greater than 2,760km^2.

The history of geothermal exploration may be divided into three periods:

Before 1985, most of the geothermal activities in Beijing were for exploration purposes, and the producing geothermal wells were the by-products of geothermal exploration. Less than 100 boreholes for geothermal exploration were drilled in this period. Funding for geothermal explorations was supplied by the government.

In 1986-1995, the geothermal exploration in Beijing slowed down, and only 5 to 6 geothermal boreholes were drilled each year (in 1991, only one well was drilled). The funding for geological exploration from the government reduced greatly in that period, because of the economical reform of the country. On the other hand, investment on geothermal development from enterprises was still rather rare.

From 1996 to the present, geothermal exploration increased tremendously in Beijing. Although the government has almost stopped funding of geothermal drilling, investment from enterprises increased greatly. The number of geothermal wells drilled each year increased. Especially, 20 to 35 geothermal wells were drilled annually since 1999 (Table.1).

TABLE 1: Record of geothermal drilling before the end of 2005
(From Beijing Bureau of Land and resources, 2006)

Years	No. of boreholes	Drilling footage (m)	Percentage of boreholes	Average depth (m)
1971-1975	25	23943.96	3.62	957.76
1976-1980	24	22341.21	3.38	930.90
1981-1985	35	42040.62	6.36	1201.16
1986-1990	29	31328.78	4.74	1080.31
1991-1995	22	31159.45	4.71	1416.34
1996-2000	75	151384.34	22.89	2108.5
2001-2005	152	359191.94	54.30	2363.10
Total	362	661390.30	100.00	1827.05

3. GEOTHERMAL RESOURCES

3.1 Geological Background

Geologically, the area of Beijing is featured by a series of grabens and horsts bounded by a series of faults that formed since early Jurassic Period, running from SW to NE in parallel. These faults spreading in the same direction with the primary stress of the current tectonics, are mostly conduits of underground water, and are closely related to geothermal (Fang and Zhu, 2002). There are also lots of faults running from NW to SE in Beijing. The geological formations in Beijing include:

- Quaternary System (Q): unconsolidated sediments
- Tertiary System(R): shale, mudstone and basalt
- Cretaceous System (K): mudstone and conglomerate
- Jurassic System (J): andesite, tuff and mudstone
- Carboniferous-Permian System (C-P): sandstone and shale
- Ordovician-Cambrian System (O-$\in$): -C): limestone
- Qingbaikou System (Q_n): shale, sandstone and marlstone
- Jixian System (J_x): Tieling Group (J_{xt}), dolomite; Hongshuizhuang Group (J_{xh}), shale; Wumishan Group (J_{xw}), dolomite
- Changcheng System (Ch): Complicated sediment rock
- Archaeozoic basement (Ar): Old crystalline rock

The Tertiary, Cretaceous and Jurassic Systems are often very thick in the grabens and do not exist on the horsts in Beijing. This is closely related to the occurrence of geothermal in the area of Beijing. The limestone and dolomite beds in Ordovician-Cambrian System and Jixian System are often karsted and permeable, and may constitute aquifers for cold ground water and geothermal water (Liu and Yan, 2004).

3.2 Geothermal Reservoirs and Caprock

The most important geothermal reservoir is the dolomite of Jixian System that is much fractured as a result of the long history of tectonic activity. As it is listed above, the Jixian System consist of three groups: (1) the Tieling Group is made of dolomite, and its thickness is about 350m; (2) the Hongshuizhuang Group is made of shale of about 80m thick and (3) the Wumishan Group is made of dolomite, and its total thickness is over 2000m in the areas where it is not eroded. Most of the geothermal wells in Beijing are producing from this geothermal reservoir.

Other geothermal reservoirs are limestone of the Ordovician-Cambrian System and sandstone of the Tertiary System. The former often has good aquifers for cold water, and is of great importance to the cold water supply in Beijing. Geothermal water can only be found in this aquifer in local areas at great depth. The later is only found in the southern most area in Beijing. Although the Tertiary System exists everywhere inside the grabens, it is mostly aquifuge in Beijing. Other formations are often serving as caprock for the geothermal systems in Beijing (Liu and Yan, 2004).

3.3 Temperature of Geothermal Reservoir

Geothermal in Beijing is of a sediment-basin type, and the temperature of the geothermal reservoirs is closely related to the depths at which they are buried, that is, the thickness of the caprock. On the horsts, the caprock is often constituted by the Quaternary and lower Jurassic System. Because the caprock is very thin, the temperature of the geothermal reservoirs is generally less than 55°C on the horsts; While, in the grabens, the caprock can be as thick as over 3000m, composed of the Tertiary, the Cretaceous and the Jurassic Systems. The reservoir temperature is also influenced by geological structures. Some of the fractures, or faults, reach into the deep underground, making hot water flow upwards creating local geothermal anomalies in places. The average temperature of geothermal water in Beijing is 40-70°C, with a high of 89°C, till now.

The geothermal gradient in the geothermal fields in Beijing decreases with depth of the caprock. For wells where the caprock is located at a depth less than 1000m, the average geothermal gradient is 2.45-4.98°C/100m; when the caprock is located at a greater depth than 2500m, the geothermal gradient is only 1.76-2.24 °C/100m (Table 2). On the boundary of the plain and mountain area, the geothermal gradient may be as low as 1.11°C/100m, because of the cold water recharge from the mountain area.

TABLE 2: The geothermal gradient for wells of different caprock thickness in Beijing (From Bin et al., 2002)

Thickness of caprock (m)		<1000	1000-1500	1500-2000	2000-2500	>2500
No. of wells		23	21	13	5	6
geothermal gradient (°C/100m)	Average	3.44	2.91	2.40	2.40	2.09
	Range	2.45-4.98	1.89-4.1	1.59-2.9	2.28-2.62	1.76-2.24

3.4 Chemical Characteristics of Geothermal Water

The geothermal water in Beijing is generally of low mineral content, and the TDS is often lower than 1000mg/l (Table 3). It contains components that are good for human health, such as SiO_2, F^-, Sr^+, Li^+ etc.

TABLE 3: Typical chemical compositions of geothermal water from a well in Beijing

Item	**Content (mg/L)**	**Item**	**Content (mg/L)**
K^+	15.6	CO_3^{2-}	0.0
Na^+	86.7	Fe_2^++Fe_3^+	1.58
Mg_2^+	14.2	F^-	6.5
Ca_2^+	41.5	Br^-	0.05
Cl^-	30.3	I^-	<0.02
SO_4^{2-}	68.2	H_2SiO_3	63.6
HCO_3^-	278	DTS	543

3.5 Geothermal Fields

According to the geothermal planning in 2006 (Beijing Bureau of Land and Resources), there are 10 geothermal fields in the area of Beijing, based on the distribution of the geothermal reservoirs, mostly taken important faults as their boundaries (Figure 2 and Table 4). The most important are the ones in the urban areas, Xiaotangshan, Liangxiang and Tianzhu. There are also a few wells outside of these geothermal fields in Beijing, although the production temperature is very low compared to the great depth of the wells.

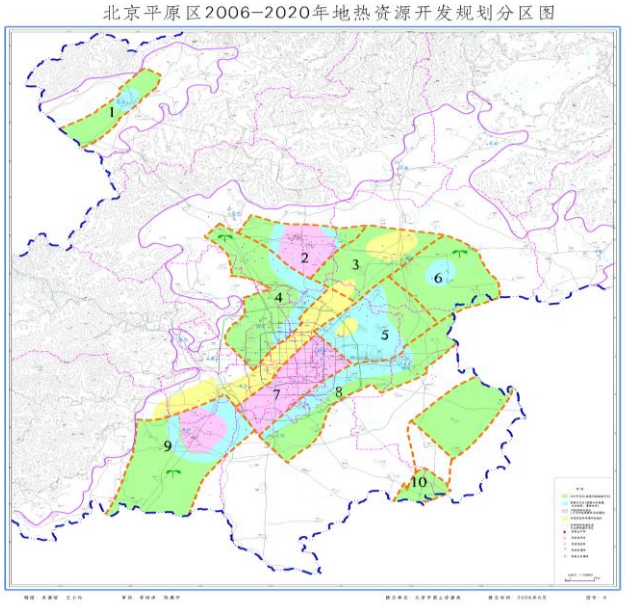

FIGURE 2: Map of geothermal fields in Beijing

TABLE 4: List of geothermal fields in Beijing
(From Beijing Bureau of Land and resources, 2006)

No.	Geothermal field	Area (km^2)	Max. temperature (°C)	Max. well depth (m)
1	Yaqing	121.88	70	2500
2	Xiaotangshan	186.42	70	1905
3	Houshayu	239.85	75	2920
4	Northwest urban	363.21	76	2603
5	Tianzhu	290.75	75	3688
6	Lishui	273.04	55	1300
7	Southeast urban	207.44	88	3610
8	Shuangqiao	339	58	2509
9	Liangxiang	475.77	70	2950
10	Fengheying	262.51	83	2000
Total		2759.87	——	——

4. GEOTHERMAL UTILIZATION

4.1 Geothermal Water Production

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. Since then, the number and depth of geothermal wells have increased gradually, as has the geothermal water production. After 1980, the geothermal water production increased abruptly; and by 1985, it surpassed 10 million m^3 annually, causing rapid decline in reservoir pressure (water level), threatening the sustainability of geothermal use. Therefore, strict measures have been taken to control the amount of geothermal water abstraction since 1985 (Figure 3). As a result, the lowering of the water table has slowed down since then.

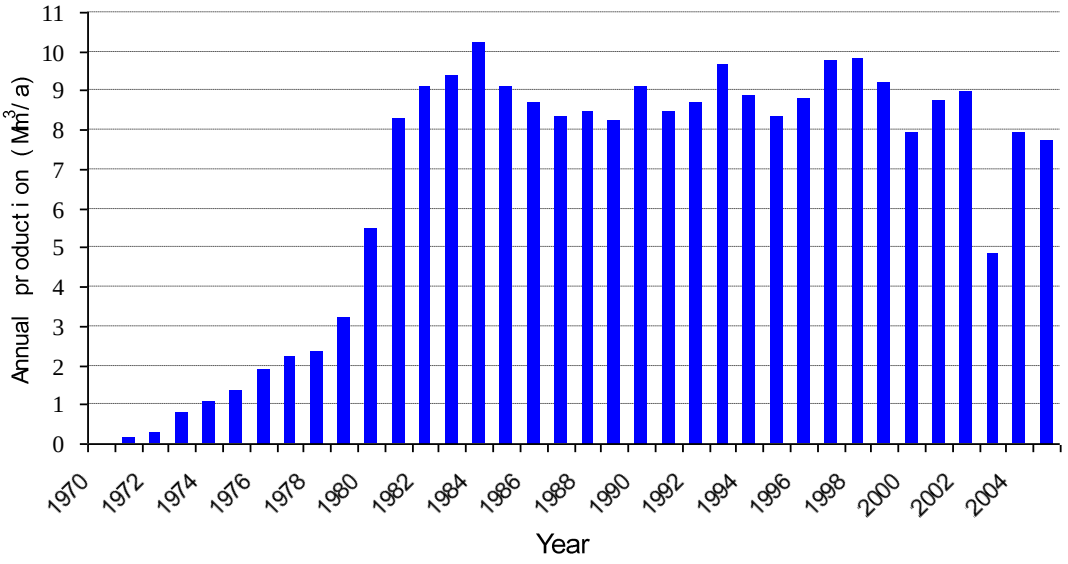

FIGURE 3: Historical record of geothermal water production in Beijing
(From Beijing Bureau of Land and resources, 2006)

In 2005, there were a total of 315 geothermal wells in use, of which 161 wells were for production, 13 for reinjection, 12 for monitoring and 124 to be used. In recent years, the annual geothermal water production was 0.79 to 0.92 million m^3/a, and Xiaotangshan and the south-eastern urban area have the most production (Table 5).

TABLE 5: Geothermal water production from each geothermal field in 1999-2004. Units in $10^4 m^3$/a

Field	1999	2000	2001	2002	2003	2004	Total	Average
Yaqing	9.10	10.25	10.33	13.20	15.60	10.35	68.83	11.47
Xiaotangshan	400.86	336.41	338.13	267.93	286.91	265.72	1895.96	316.00
Houshayu	0	0	3.60	3.00	0.60	0.60	7.80	1.95
Northwest urban	0	0	27.37	57.32	89.55	77.84	252.08	63.02
Tianzhu	29.35	45.89	69.13	88.12	81.36	115.93	429.78	71.63
Lishui	12.89	9.94	11.40	9.13	10.99	10.35	64.7	10.78
Southeast urban	369.68	305.09	312.72	347.67	283.59	218.60	1837.35	306.23
Shuangqiao	0	8.51	9.39	7.58	7.12	9.60	42.20	8.44
Liangxiang	97.92	75.25	82.19	91.96	102.05	74.78	524.15	87.36
Fengheying	0	0	3.60	3.60	3.60	3.60	14.40	3.60
Total	919.80	791.34	872.66	895.35	885.50	790.98	5155.63	880.48

4.2 Water Level Change

The water level (or the well head pressure) of geothermal wells is still declining, although the production has been strictly controlled. According to the statistics of the annual geothermal water level decline of all monitoring wells from 1999 to 2005 in Beijing, the maximum was 2.36m/a in Liangxiang Geothermal field, and the minimum was 0.83m/a in the Xiaotangshan area. While in Xiaotangshan geothermal field, tail water from 6 space heating systems is reinjected through 6 reinjection wells, and the amount of reinjection is about 1.7 million m^3/a, accounting for about 60% of the total water production from the geothermal field. As a result of the reinjection, the water level of the monitoring wells has stopped declining in 2006 (Zhang and Liu, 2004; Beijing Bureau of Land and Resources, 2006).

4.3 Geothermal Use

Geothermal is used for various direct purposes in Beijing, including space heating, domestic hot water hotel, greenhouse, health spa and recreation, as well as fish farming (Figure 4). Multi-purpose use is very common, often it is a combination of space heating and domestic hot water supply. In 2005, there were 91 geothermal users in Beijing, in which 20 were for space heating (heating floor area 1.2 million m^2); 68 for domestic hot water supply; 33 for hotels, 38 for recreation, 14 for greenhouses (totally 0.38 million m^2 of floor area) and fish farming (0.15 million m^2 of ponds).

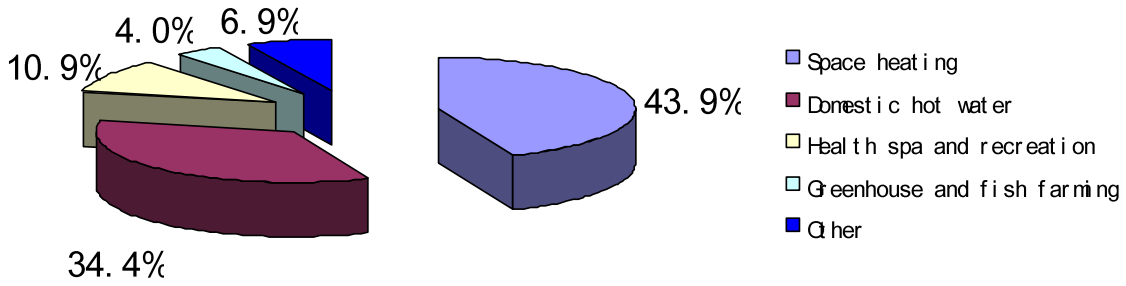

FIGURE 4: Percentage of each kind of geothermal utilization in Beijing
Revised from Beijing Bureau of Land and resources (2006)

In 2005, the geothermal water production was 7.7 million m^3. The related economical profit was about 1.1 billion YUAN (about 110 million EURO); the energy used accounts for 85.8 thousand tons of coal; the CO_2 emission reduction is about 204.7 thousand tons. Furthermore, about 6 million m^3 of the geothermal tail water was used for scenery creation, considering that the water resources are not sufficient in Beijing.

A model project for geothermal cascaded use in Beijing is the one in Nangong Village (in Liangxiang geothermal field), southwest of the city. In 2000, a 2,950m deep geothermal well was completed there, producing 72°C hot geothermal water. Geothermal has been used for space heating, domestic hot water for the residents, swimming pool and recreation, greenhouses and fish farming. And an exhibition hall for geothermal knowledge spreading was built there and was put into operation in 2002. This geothermal direct use project, together with the exhibition hall, was named Nangong International Geothermal Natural Garden, has become a tourist attraction in Beijing (Liu and Yan, 2004). A reinjection well has been drilled in Nangong I 2006, and reinjection may start very soon.

5. PROBLEMS

Geothermal reservoirs are located at great depth in Beijing, in close relation to the geological structure of the pre-Quaternary System. But, the in depth understanding of the geology is still not good enough. Because of this, some drilling projects failed to strike the geothermal reservoirs at the anticipated depth, or cannot strike the geothermal reservoir at all, causing remarkable economical loses. Therefore, geological structure study and other fundamental geological research should be funded to avoid the economical risks of geothermal development as much as possible.

Hot water supply for bathing in neighbourhoods used to be a very important aspect of geothermal utilization in Beijing; this is because the geothermal water was believed to be good for the human health. Experience showed, however, that keeping the geothermal water warm for 24 hours a day is rather expensive, for the reason that the temperature of the raw water in often rather low and the heat loss in the pipeline system is high.

The water level of most geothermal wells is still declining, since the production of geothermal water is still greater than the water recharge of the geothermal systems, while reinjection is still insufficient. Therefore, it is essential to control the production and expand the scale of reinjection. It is also very important to strengthen monitoring and modelling of geothermal systems, especially to set up detailed numerical models.

6. CONCLUSSIONS

There is abundant low-temperature geothermal water stored in dolomite and limestone reservoirs in Beijing. About 400 geothermal wells have been drilled in the city since the first geothermal well created in 1971. The area identified with geothermal potential is over 2,760km^2, and is made up of 10 geothermal fields. Geothermal water is used for space heating, bathing, greenhouses, fish farming, spa and recreation, bringing great economical, environmental and social benefits. In 2005, the geothermal water production was 7.7 million m^3. The related economical profit was about 1.1 billion YUAN (about 110 million EURO); the energy used accounts for 85.8 thousand tons of coal; the CO_2 emission reduction is about 204.7 thousand tons. Reinjection has been carried out in the most important geothermal fields, and has showed remarkable results on mitigating the water level decline of the geothermal systems. To realize sustainable use of geothermal, it is essential to control the production and expand the scale of reinjection, to strengthen monitoring and modelling of the geothermal system.

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