Geothermal development scheme for the Olympic Park in Beijing

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Abstract

The City of Beijing has won the bid for the 2008 Summer Olympic Games, and Green Olympics will be one of the most important features of the event. The geothermal potential of the area around the Olympic Green (Olympic Park) is promising and the Beijing Municipal Government is committed to using geothermal energy for space heating and hot water supply for the facilities of the Olympic Green. Buried at more than 2000 m depth, the geothermal reservoir in the area consists of limestone and dolomite, and its temperature is expected to be about 70°C. Till now, no geothermal wells have been drilled inside the area, but according to nearby geothermal wells, the reservoir is more likely to behave like an almost closed system. Therefore, reinjection will be essential for the sustainable management of the geothermal resource. About 10 geothermal wells are planned for production and reinjection, and three of the wells will be drilled soon. In the paper, the geological background, the result of geological exploration and the behaviour of the geothermal reservoir around the area is presented. Furthermore, some suggestions on the geothermal development of the Olympic Green are put forward.

***Keywords**: Olympic Games, geothermal, geological structure, reinjection, Beijing.*

1 Introduction

Beijing, the capital of the P.R. of China, is rich in low-temperature geothermal resources, and the area identified as having geothermal potential is over 2000 km^2. The geothermal water in Beijing, which has temperature ranging from about 40 to 88°C, is used for various direct purposes includeing space heating, bathing, greenhouse heating, fish farming, for swimming pools, other recreation, etc. With the rapid growth of the city, the geothermal development has been rather fast and in recent years 20-40 geothermal wells have been drilled each year. At present, there are about 200 geothermal wells in the city producing around 10 million m^3/a of geothermal water.

The City of Beijing will hold the 2008 Summer Olympic Games. The Olympic Park area, which will be called Olympic Green, will be built in the northern part of Beijing, about 10 km from the centre of the city (Fig. 1). It will include a few stadiums and gymnasiums, the Olympic Village, some forest areas and other related facilities.

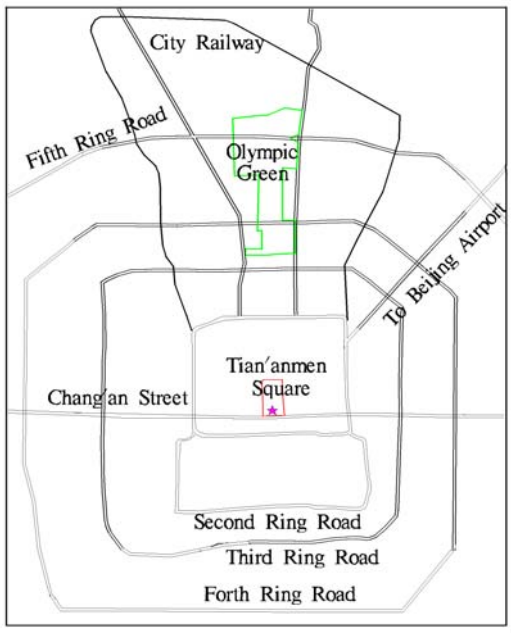

Figure 1: Map of Beijing showing the location of the Olympic Green.

Coal is the dominant energy source used in Beijing, causing serious air pollution. In the past several years, measures intended to curb the air pollution, including the promotion of geothermal utilization, have been implemented. The

Olympic Games in Beijing will be featured as Green Olympics, and geothermal energy has been planned as the energy source for space heating and domestic hot water, for part of the facilities.

Based on the results of geological exploration in the area, and some successful geothermal wells drilled nearby, the Olympic Green is believed to have considerable geothermal potential. The target geothermal reservoirs are limestone and dolomite aquifers buried at depth of more than 2000 m. Some internationally known geothermal scientists have put forward a wealth of suggestions concerning geothermal development for the Olympic Green (Cappetti, 2002; Fridleifsson, 2002; Lund, 2002; Rybach, 2002; Axelsson et al., 2002; Erlingsson et al., 2002).

2 Geological Background

The Beijing area is characterised by a series of grabens and horsts, bounded by faults that run SW-NE. The distribution of these faults corresponds with the primary stress field of the current tectonics. The faults are mostly conduits of underground water, and are closely related to the geothermal activity (Fang and Zhu, 2002).

The Olympic Green is located near one of the faults mentioned above, the H-G fault (F1 in Fig. 2). This fault is a regional fault, reaching to about 35 km depth in the crust. There are also a few other faults (F2 and F3), passing through the region. These faults all play an important role in the occurrence of geothermal energy. The area of the Olympic Green is inside the Beijing Plain Area, which is located in a sedimentation basin, and the main formations in the area include:

- Quaternary (Q): unconsolidated sediments
- Tertiary (R): shale, mudstone and basalt
- Cretaceous (K): mudstone and conglomerate
- Jurassic (J): andesite, tuff and mudstone
- Carboniferous-Permian (C-P): sandstone and shale
- Ordovician-Cambrian (O-ε): limestone
- Qingbaikou (Qn): shale, sandstone and marlstone
- Jixian (Jx): Tieling Group (Jxt), dolomite, Hongshuizhuang Group (Jxh), shale Wumishan Group (Jxw), dolomite.

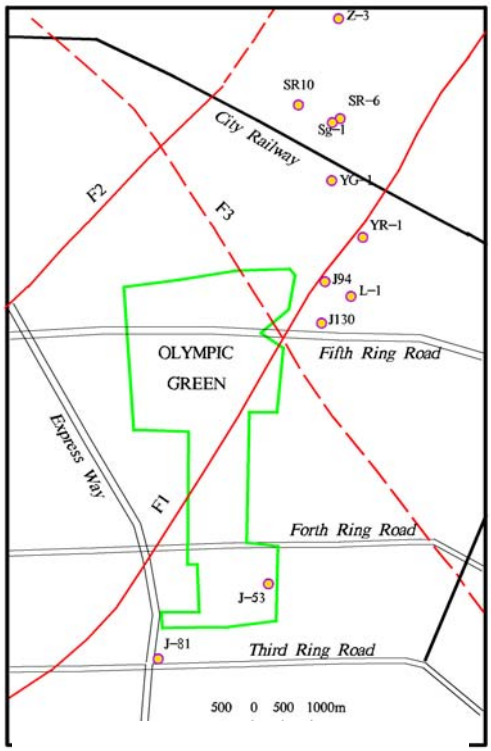

Figure 2: A sketch map of geological structures in the area of the Olympic Green.

3 Geological Exploration

Geological exploration in the Olympic Green area started in the 1950's, as part of regional groundwater exploration. Since then, numerous geological studies have been conducted in the area, such as groundwater studies, oil exploration and earthquake research. This exploration activity has included regional gravitational surveys, magnetic surveys, electrical soundings and drilling. The depth of the drilling has mostly been less than 1000 m. The geothermal exploration in the area started in the 1980's (Li et al., 1983; Zhang et al., 1990). The first geothermal exploration borehole (L-1) was drilled in 1984-1985 at Beiyuan, which is about 1200 m east of the north

end of the Olympic Green. The borehole was drilled to 2101 m, less than the depth to the geothermal reservoir. Another geothermal borehole (J-53) was drilled to 2501 m depth in 1989-1990 at the Beijing Olympic Centre, which is a part of the Olympic Green. This borehole also didn't reach the geothermal reservoir, which may be at more than 3000 m depth. With advances in drilling techniques, and the improving economy of the city, some successful geothermal wells were recently completed nearby (Fig. 2 and Table 1), although there are still no successful geothermal wells inside the Olympic Green.

Table 1: Geothermal wells in the vicinity of the Olympic Green.

Well	J-94	YR-1	Yg-1	SR-6	Sg-1	SR-10	J-130	J-81
Depth (m)	3600	3648	3349	2418	2898	2750	3701	3766
Yield (m^3d^{-1})	1500	2460	1829	4000	1650	1143	1506	2000
Water Temperature (°C)	70	74	68	70	59	62	76	69
Reservoir depth (m)	2902	2676	2341	1250	-	2605	3133	2900
Reservoir rock	L	L	L	L	L	L	L&D	D

Note: L = limestone; D = dolomite

Zheng (2002) conducted a hydro-geochemical study in the area of the Olympic Green, which indicated that the prospects for success of geothermal drilling in the area were quite good, but that wells would need to be more than 3000 m in depth. The results also showed that the water near the H-G fault is different chemically from water further away from the fault. This indicates that the fault zone is most likely an up-flow zone for geothermal water.

The drilling of about 10 geothermal wells is planned for the Olympic Green, and three of the wells will be drilled soon. To locate the geothermal wells, all the available geophysical exploration data (gravity, magnetic and electrical) were collected, and some new geophysical exploration surveys conducted (MT and micro-seismicity) in the area (Xu, 2002a).

4 The Geothermal System

According to results of geological exploration, in the area of the Olympic Green in Beijing, a model of the geological structure is put forward (Fig. 3), although there are still not sufficient geological exploration data available, considering the complexity of the geological structures in the area. There are two geothermal reservoirs in the area, i.e. the limestone aquifer of Ordovician and Cambrian Systems in the northwest part of the area and the dolomite aquifer of the Wumishan Group in the southeast part.

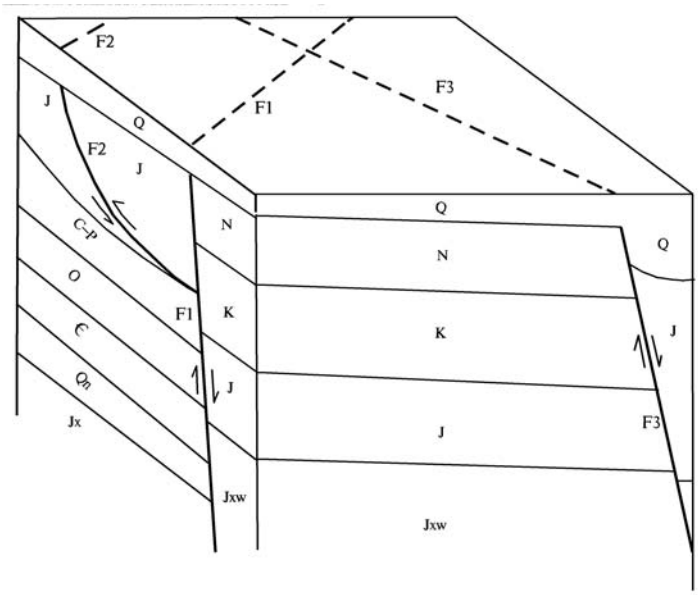

Figure 3: Geological structure model in the area of the Olympic Green.

The depth to the top of

the geothermal reservoir (limestone formation) in the northwest part of the Olympic Green is from 2000 to 3000 m, while the depth of the geothermal reservoir (dolomite formation) in the southeast part of the Olympic Green is about 3000 m. The permeable nature of the reservoirs is closely related to the karstification of the limestone and dolomite. Generally, the formations are more fractured and permeable near the main faults.

The geothermal gradient of the caprock in the area is mostly as low as 1.4°C/100m, only being higher in areas close to faults, such as near well SR-6, which is about 2700 m north of the Olympic Green (Bin et al., 2002). The reservoir temperature in the area is around 70°C.

The geothermal water in the Beijing area originates as infiltrated precipitation. Generally, the recharge area is in the mountains in the north and west of the Beijing Plains. The faults play a very important role in the transmission of water from the mountain area to the geothermal fields (Liu et al., 2001). The H-G fault is a key element of the geothermal system in the area of the Olympic Green, both concerning heat- and water transfer.

5 The response of the reservoir to production

As mentioned above, no successful geothermal well has still been drilled inside the Olympic Green area. But a few wells have been drilled outside the area (see Table 1). The characteristics of these wells may give important information on the reservoir engineering properties of the geothermal system.

Well SR-6 is the well with the longest production history in the area. It is located about 2700 m from the northeast tip of the Olympic Green. The well has been used for space heating since November 2000, and in addition for swimming pool use and recreation since the end of 2002. Before production started, the wellhead pressure of the well was 0.27 MPa. After production during the 2000-2001 heating season, which averaged about 47 m^3/h, the wellhead pressure declined to 0.11 MPa. The production in the 2001-2002 heating season was 30 m^3/h on the average, causing the wellhead pressure to decline from 0.12 MPa on November 17, 2001 to 0.07 MPa on March 21, 2002. This rapid decline of wellhead pressure may indicate that the recharge to the geothermal reservoir is very limited.

Based on production and monitoring data for Well SR-6, a lumped parameter model has been set up for the area (Xu, 2002b; Axelsson et al., 2002). The simulation result shows clearly that the geothermal reservoir is an almost closed system (with limited recharge). According to the model the surface area of the reservoir is of the order of 110 km^2. The model also indicates an average permeability-thickness of about 19 Darcy-m ($19 \cdot 10^{-12} m^2$). This corresponds to an average permeability of about 0.04 Darcy, assuming a reservoir thickness of 500 m. Water level predictions for well SR-6 were calculated using the model for an 8-year period, based on an average yearly production of 20 l/s. They show that reinjection will be essential for sustainable utilization of this reservoir. If 80-90 percent of the water produced is reinjected into a nearby well after use, the water level will not decline very rapidly, according to the predictions. Otherwise, without reinjection, the water level will decline very fast. The geothermal reservoir suffers, in fact, from a lack of water. More than sufficient thermal energy is in-place in the geothermal reservoir, however, and reinjection will, therefore, provide a kind of artificial recharge (Axelsson et al., 2002).

At present, the reservoir pressure is declining rapidly in the area, although the production is not great. Yet, it is also possible that the reservoir pressure decline will slow down after a few years of production, as was the experience in the Urban

geothermal field in Beijing, which is the most heavily utilized geothermal field in Beijing. The geothermal water level in the Urban field was close to the ground level when the production started, and it declined rather fast, a few meters per year, at the beginning of production in the early 1970's. In recent years the decline is slower, or 1.5-2 m/a (Liu et al., 2002). This is believed to be because recharge to the reservoir from the outside increased as the water level declined. It is hoped that the same will apply for the reservoir in the area of the Olympic Green.

A seismic observation well (Z-3), which is about 300 m deep, is located about 1500 m north of well SR-6, intersecting the same aquifer as well SR-6. The water level in the well has fluctuated in phase with production from well SR-6 during the past two years. Testing of wells YR-1 and YG-1 (Fig. 2) also has shown active interference between the wells. This indicates that the hydraulic connection between different parts of the geothermal reservoir is rather direct.

6 Suggestions for the geothermal development

Based on the expected temperature (around 70°C) of the geothermal water from the reservoir below the Olympic Green, and the purpose of the Olympic Green, current plans assume that the geothermal water will be used for space heating and domestic hot water for living quarters, which will be located in the middle part of the Olympic Green. The drilling of 10 geothermal wells has been planned in the area, and the Beijing government will fund the first two wells. An additional well (about 3600 m deep) will be drilled soon at the Olympic Centre (constructed for the 1990 Asian Games), located in the southeast part of the Olympic Green.

Considering the abundant heat in-place in the geothermal reservoir, while the water recharge is very limited, it is essential to reinject the return water from the space heating system so as to support the reservoir pressure and use the geothermal energy in a sustainable manner. Of course, reinjection is a complicated aspect of the management of the geothermal reservoir, and careful experiments have to be carried out before applying this technique. This includes using tracer tests to study the danger of premature thermal breakthrough. Axelsson et al. (2002) propose that the spacing between reinjection- and production wells should be more than 1 km in the Olympic Green area. Considering the rather good connection between geothermal wells in the area, this should be kept in mind when locating the wells.

It has been suggested to use heat pumps, which extract energy from shallow groundwater, for the peak load of the space heating system, as well as for cooling of the Olympic facilities and apartments, because extensive cooling will be needed during the event (Rybach, 2002; Lund, 2002).

Considering the limited time left for the construction of the geothermal project for the Olympic Green (less than 5 years), a complete plan should be put forward as soon as possible. Since the geological structure, and geothermal potential, of the area is still not very well known, the geothermal development should be in a step-wise manner. Geophysical exploration, using different methods, should be employed in locating the wells.

It is essential to conduct proper management of the geothermal reservoir to enable sustainable use of this precious resource. This calls for careful reservoir engineering research from the beginning of the geothermal development, taking all the geothermal wells around the area into consideration. Especially, a proper monitoring program should be set up for the geothermal reservoir in the area of the Olympic Green.

7 Conclusions

The City of Beijing will hold the 2008 Summer Olympic Games, and plans to change its energy policy in order to control air pollution and contribute to the reduction of greenhouse gas emissions. The Olympic village will be built in the northern part of the city, where geothermal potential is known to exist. The geothermal reservoir consists of limestone or dolomite about 2000-3500 m underground. There are a few large-scale faults that play an important role in the geothermal activity in the area. The geothermal energy can be used for space heating and domestic hot water supply for the Olympic Green. The drilling of 10 geothermal wells, including reinjection wells, has been planned for the project, and the drilling of 3 wells will start soon. Using heat pumps, which extract energy from shallow groundwater, for the peak load of the space heating, and also for the cooling of the Olympic facilities and apartments, has been proposed. It is essential to reinject the return geothermal water for the sustainable use of the geothermal energy in the Olympic Green, because the water recharge of the geothermal system is rather limited. Owing to the complexity of the geological structure in the area, step-wised development is suggested.

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