

Geothermal Rational Exploration and Exploitation Strategy Research in Beijing

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ABSTRACT

Based on the analysis of geothermal research and utilization, this paper lists the most main challenges of geothermal exploration and exploitation at present in Beijing which is including the lack of regional reconnaissance, the undeveloped of prospecting techniques, the shortened of service life in those geothermal fields which are exploited unreasonably, the unsystematic of dynamic monitoring, and etc. Therefore, for making rational utilization and effective protection of geothermal resources finally come true, the paper suggests a strategy research, namely to set up large scale geothermal investigation which will be carried out in the whole Beijing for making clear all the geothermal conditions; to point out geothermal exploitation target areas; to assess exploration methods for reducing drilling risks; to study reinjection techniques and to establish critical mode making the equilibrium between extraction and reinjection in typical geothermal field; to build structural models and matching numerical simulation models for predicting utilization effect of geothermal system; and to construct geothermal data base and management information system for managing the exploration and utilization of geothermal field timely and effectively.

1. INTRODUCTION

Beijing is one of the few capitals in the world which have geothermal resources, and geothermal exploration and utilization also began early, namely starting in the early 1970s. As increasing understanding of the geothermal resources, with growing application of exploration and exploitation technology, a series of planning studies was done in the late 1990s and early 21st century, e.g. "Regionalization Study of Geothermal Exploration and Utilization in Beijing" 1996, "Sustainable Utilization Planning of Geothermal Resource in the Early 21st Century, Beijing" 1999, "Resources Investigation and assessment in Beijing Urban Geothermal Field" 2000, "Geothermal Resource Potential Survey and Evaluation of Beijing" 2007, and etc. These studies provided guidelines for reasonable investigating and using geothermal resources at that time. Strictly speaking, strategic research of geothermal rational exploitation, however, used to be hardly done before in Beijing. In addition, current exploration technologies let information about geothermal resources has been far beyond beforetime. Therefore, there is necessary to carry out a strategy research about geothermal development and protection. This paper is basis on deeply studying of those challenges of geothermal exploration and utilization in Beijing then give out targeted proposals or measures, in order to realize rational utilization and protection of the geothermal.

2. GEOTHERMAL EXPLORATION AND UTILIZATION IN BEIJING

Most of geothermal resources in Beijing are contained in hot water reservoirs lying in sedimentary plain. Geothermal study, which has been lasting for 40 years in Beijing, suggests that the Jixianian system carbonate is the most primary reservoir which's status is attributed to the Wumishan formation and the Tieling formation, while Ordovician limestone, Tertiary conglomerate and Cambrian carbonate are the second important reservoirs. Temperatures in the reservoirs are mostly in range of 40-70 °C and geothermal gradients are in range of 0.8-4.0 °C/100m generally, so geothermal resources can be defined as typical low-temperature resources. According to laboratory testing, geothermal water quality is fine in Beijing. Fluorine, metasilicic acid and metaboric acid are measured up to medical mineral water standard respectively, and these elements are advantaged for medical care and recreation.

Geothermal exploitation can be traced back to the 6th century in Beijing, but real large-scale exploration and utilization has just begun in a few decades ago and was closely related to the oil crisis in 1970s. At that time, geothermal showed up as an important alternative energy for the first time and its exploration and utilization has become a global issue, so do the same in Beijing.

2.1 Geothermal Exploration

The first exploration was started in Xiaotangshan area, since there is a famous hot spring which used to serve the Qing dynasty's royal. The exploration was set up from 1956 to 1958 and the field was named "the homeland of hot spring in China" in October 2005. Although the first exploration began at Xiaotangshan area, but the first successful thermal well was drilled in March 1971 at Beijing downtown. So to speak, geothermal productive exploration actually began at downtown with continuously growing attention to geothermal. According to incomplete statistics, geothermal boreholes were about 480 and total footage was great than 800km by 2008. Some typical thermal well having significant influence on geothermal exploration will be listed below.

Table 1: typical boreholes having significant influence on geothermal exploration in Beijing

Area	Borehole No.	Completion time	Capacity	Significant influence on geothermal exploration
Xiaotangshan	T 5-2	1974	Discharge 968m ³ /d Water temp 42 °C	Broke through the previous distribution range of low-temperature geothermal.
	TR 7	1981	Discharge 1380m ³ /d Water temp 59.4 °C	Confirmed that there are good geothermal conditions in the south of Xiaotangshan field.

Downtown	JR 3	1971	Discharge 1144m ³ /d Water temp 39.2°C	The first successful thermal well in downtown.
	JR 120	2003	Discharge 1019m ³ /d Water temp 89°C	The thermal well having the highest water temperature in downtown.
Yanqing	New-YR 1	1993	Discharge 1850m ³ /d Water temp 52.5°C	The first successful thermal well in Yanqing field.
Liangxiang	Bi 1	1995	Discharge 2163m ³ /d Water temp 54.6°C	The first successful thermal well in Liangxiang field.
Northwest urban	SR 5	2000	Discharge 887m ³ /d Water temp 69°C	The first successful thermal well in Shahe field.
	JR 167	2006	Discharge 2324m ³ /d Water temp 64°C	The deepest successful thermal well in Beijing, and its depth is 4088.88m.
Shunyi	ShR 1	1983	Discharge 2900m ³ /d Water temp 48°C	The first geothermal well in Tianzhu field.
	208-4	1985	Discharge 1143m ³ /d Water temp 43°C	The first geothermal well in Lisui field.
	Rear-ShR 2	2002	Discharge 1965m ³ /d Water temp 75°C	The first Jurassic geothermal well in Beijing.
Tongzhou-Nanyuan	Shuangshen 1	1989	Discharge 1965m ³ /d Water temp 75°C	Confirmed successful drilling procedure in the area.
Tongzhou-Daxing	XR 12	2012	Discharge 3002m ³ /d Water temp 117°C	The thermal well having the highest water temperature in Beijing so far.
	XR 9	2011	Discharge 1500m ³ /d Water temp 103°C	The thermal well having the second high water temperature in Beijing so far.

All of the exploration shows that area, in which most borehole depths are less than 3500m and temperatures of thermal water are great than 50°C, is calculated about 2760km² and could be divided into 10 geothermal fields in Beijing plain. These fields are relatively independent and having certain hydraulic connection. Field dividing is shown in Figure 1 and each field's area is shown in table 2.

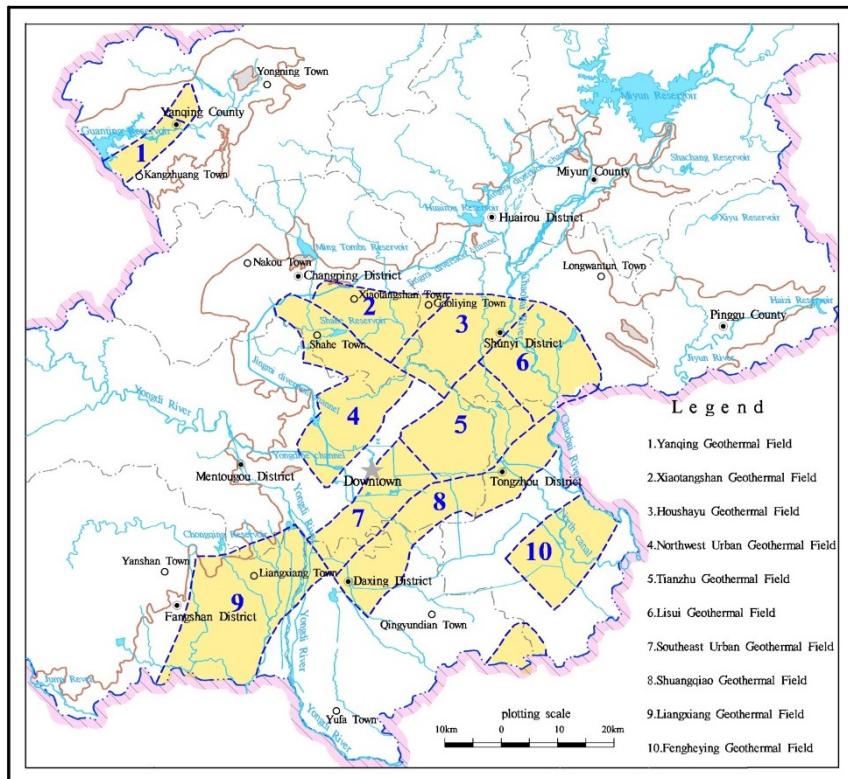


Figure 1: Geothermal Field distribution in Beijing Plain.

Table 2 areas schedule of 10 geothermal fields

No.	Geothermal field	Area/km ²	No.	Geothermal field	Area/km ²
1	Yanqing	121.88	6	Lisui	273.04

2	Xiaotangshan	186.42	7	Southeast urban	207.44
3	Houshayu	239.85	8	Shuangqiao	339.00
4	Northwest urban	363.21	9	Liangxiang	475.77
5	Tianzhu	290.75	10	Fenghying	262.51

Geothermal exploration in Beijing so far tells that 2 successful thermal wells having water temperature great than 100 °C are located in Fenghying geothermal field which is belong to Tongzhou-Daxing area, so the Fenghying field would be exploration and utilization target in the future.

2.2 Geothermal Utilization

Geothermal resources are multipurpose in Beijing, including space heating, medical health, recreation, agriculture, and etc. Space heating is primary type of geothermal utilization and the Xiaotangshan field is in the pride of place of geothermal exploitation.

According to statistics, in 2011, total exploitation quantity of geothermal water is $937 \times 10^4 \text{ m}^3$ in Beijing, 43% for space heating, 34% for domestic hot water, 11% for medical health and recreation, 4% for greenhouse and fish farming, 8% for other use, as shown in figure 2.

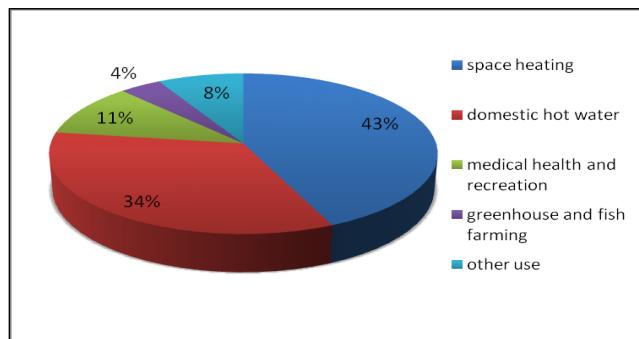


Figure 2: Beijing geothermal water utilization pie chart in 2011

2.2.1 Space Heating

Geothermal heating started in winter 1976 at People's Fine Arts Publishing House. The 59°C thermal water was mainly used for $1.55 \times 10^4 \text{ m}^2$ building heating system. Until 2007, 50 geothermal wells were involved in space heating in Beijing, they supplied total hot water $300 \times 10^4 \text{ m}^3$ per a year and to heat $180 \times 10^4 \text{ m}^2$ building. The 2008 Olympic game brought an opportunity for geothermal utilization, and some gymnasiums using geothermal heating are typical utilization example. There are usually 3 kinds of geothermal heating styles in Beijing: straight forward geothermal heating, using GHEX, and using geothermal heat pump system.

2.2.2 Medical Health and Recreation

Based on the famous Xiaotangshan hot spring, a convalescent hospital was set up in 1958. In the hospital, combined with physiotherapy, acupuncture, massage, medicine and etc, the hot spring is used in treatment of skin disease, digestive system disease, respiratory disease, disease of cardiovascular system, nervous system disease, and nervous system disease. According to medical record from 1981 to 1989, spa treatment effectiveness reached to 89% in Xiaotangshan convalescent hospital. For the record, health care by using geothermal spa has to depend on other type of therapy for getting fine effectiveness.

Compared with medical health applications, geothermal mineral water is more used in recreation in Beijing. Several hot spring hotels have been built since 1990s, and they are located in each of geothermal fields. The Fengshan Hot Springs Resort, the Huqing Spa Hotel, the Shengshiyuan Hot Springs Hotel, the Longmai Spa Resort, the Hot Spring Leisure City, and the Badaling Spa Resort, are the representations of geothermal application in leisure activities.

2.2.3 Agriculture and Aquaculture

Beijing weather belongs to temperate continental monsoon climate, and biota growth is limited by cold and dry weather in the winter. Via artificial ecological environment made of geothermal, not only types of planting and breeding would increase, benefits of regular agriculture and aquaculture also would grow.

Greenhouse is the mainstream style about geothermal utilization at agriculture. It can apply to planting of anti-season vegetable or rare flower. The earliest greenhouses applied to agriculture planting were constructed in middle of 1980s at Xiaotangshan field for cultivation of special vegetation. Beijing geothermal aquaculture has begun in 1980s as well, and aquaculture water has already increased to about $13 \times 10^4 \text{ m}^2$ now. Geothermal water can makes it easier to fish for overwintering, makes fish fry rearing time shorter, so geothermal has exactly push forward development of industrial fish breeding in Beijing.

There are some classic case of geothermal application in agriculture and aquaculture, including the Xiaotangshan National Agricultural Science and Technology Demonstration Garden, the World Geothermal Natural Science Park, the Hot Spring Leisure City etc.

3 GEOTHERMAL EXPLORATION AND UTILIZATION CHANLLENGES

Geothermal exploration and utilization have been lasting for almost 50 years and lots of achievement had been gained, but a lot of problem also had been exposed during the process of geothermal exploitations.

3.1 Lack of Government Investment in Geothermal Investigation

Government was dominating the geothermal investigation in Beijing before the 1990s, while after that the sources of investment mainly turned to the market, and it caused that investment is shrinking and systemic research is weak.

3.1.1 Insufficiency of Systemic Research

Although there are more than 480 geothermal wells in Beijing plain, but the most of geothermal exploitation just focus on exploration benefits within the scope of small-scale around the geothermal well under the heavy market pressure. Therefore, first of all, there is no detailed prospecting covering the whole Beijing plain, because almost all detailed investigation is so limited to the local scope, that the whole geothermal resources evaluation could not be finished; the second, all gained investigation materials, such as geological data, hydrogeological data, and geophysical prospecting data, etc., does not make the comprehensive analysis; the third, hardly knowing about features and parameters each of reservoirs, reservoir parameters even is calculated just relying on pumping test sometimes; and the last, geothermal exploitation degrees are not equal in all geothermal fields, and exploitation risk is still higher and successful wells are still few in some field.

3.1.2 Lack of Long-term Monitoring

There are not enough Long-term monitoring wells and their distribution is also not reasonable at each of geothermal fields, thus existing monitoring wells could not reveal dynamic changes of the fields. Although results has been piled up a lot for more than 40 years, but they usually are in the hands of the different management organizations and companies, so as to the results could not be synthetically used, not to mention informatization management.

3.2 Backward Technology and Equipment

The majority of geothermal field does not have enough surface features except for some famous hot springs, so to confirm distribution of reservoir and cap rocks, several explorations would be carried out in whole exploration process.

3.2.1 Misapplication of Reconnaissance Methods

During the reconnaissance, on the premise of unknown about fracture's structure and reservoir's thickness, geophysical and geochemical exploration methods are usually used to prove features in work area. But current geophysical and geochemical methods had problems such as anti-interference and the multiple solutions, so there is no way to infer deep geological conditions in detail, to make drilling easier either, especially in relative strange area.

3.2.2 Out-dated Drilling Equipment and Technology

The deepest geothermal wells have already been drilled into underground more than 4000m in Beijing, so we could say that drilling capacity in geothermal exploitation is top in China. But for deeper than 4000m of drilling, equipment cannot meet needs of construction, and it is manually operated in general, namely the degree of automation and mechanization is lower compare with some foreign similar equipment.

Some steps in progress of completing geothermal well should be optimized, such as the plugging, casing installation, cementing, screen pipe installation, well flushing and pumping test, etc.. Particularly in process of completing well deeper than 3000m, the steps need to be paid even more attention.

3.2.3 Lagging Rejection Compared with Exploitation

Rejection is an efficient method to slow down groundwater drawdown caused by geothermal resources exploitation. In fact, rejection has been lagging behind the geothermal water exploitation in Beijing plain. For instance, groundwater drawdown is continuous at the Southeast urban geothermal field, the Xiaotangshan geothermal field, and the Liangxiang geothermal field due to large quantity of groundwater pumping. Although rejection has been carried out now, but the drawdown does not be stopped, because rejection rate is confined by injection facilities and sedimentary strata.

Some critical parameters which would control rejection rate are still not totally understood, including lithology and structure of reservoir rock, pressure changes in reservoir, and so on; rejection running procedures and ground facility standard should be refined, especially what effect rejection put on the temperature of the geothermal field needs to be long-term observed.

3.3 Low-level Intensive Exploitation and Management

The exploitation quantity of geothermal resources at the Xiaotangshan field and the downtown is about 60% of annual whole exploitation quantity in Beijing, while the exploitation quantity are about 10% respectively at the Liangxiang field, the Tianshu field and the northwest field. For the rest of geothermal fields, there are less than 5% in the whole exploitation quantity.

3.3.1 Problems in Intensive Exploitation and Management

Based on survey, nearly 80% geothermal water is used in space heating and resident supply, in turn, the uses in other application are not enough. A part of thermal water was not cascade use at all, and some utilization still keeps going with the way of direct feed and drain, so that geothermal resources get wasted unnecessarily. Besides, management of thermal water use is unordered, namely each takes what he needs and each does things in his own way, since locations of well usually are dispersive and ownerships of well belong to different organizations.

3.3.2 Problems about Idle Wells

There are many idle wells in Beijing plain, not only have wasted social resources, also limited other unit to exploit geothermal. By the end of 2013, there were about 160 idle wells, nearly a third of the total number of geothermal Wells in Beijing.

4 COUNTERMEASURES OF RATIONAL GEOTHERMAL EXPLOITATION

"Beijing geothermal resources sustainable utilization planning in 2006-2020" proposes that exploitation quantity of geothermal water will be limited in about 20 million m^3/a , while the reinjection quantity will amount to 10 million m^3/a , to make actual geothermal water consumption within the 10 million m^3/a . Given target mentioned in the planning, several measures should be improved in the future.

4.1 Enhancing Government Investment to Promote the Systemic Study Level

Geothermal systemic study is a career which is more like public welfare due to needs for large amount of money and researcher. Enhancing government investment is a powerful way to put geothermal systemic study forward, because only the government can put all social resources together to guarantee the study running smoothly. Main aspects should be invested and imporved will list below:

4.1.1 To Further Reinforce Basic Study

First of all, geothermal geological survey throughout whole Beijing plain (1:100000 scale) should be carried out, and serial maps will be modified accordingly such as main reservoir exploitation conditions partition map, geothermal temperature contour map in Beijing plain, and etc.; the second, reconnaissance has to be practiced in some areas containing geothermal resource, for example a few geothermal borehole was successful drilled in west piedmont and next step exploration is going to be done; the third, to integrate all data of high exploration degree field, comprehensive study will be able to begin, and it's results can be used in building numerical simulation model of typical geothermal like the Xiaotangshan and Southeast urban geothermal fields.

4.1.2 To Promote Long-term Monitoring and Resources Assessment

Among 10 geothermal fields, different grade of geothermal resources assessment was finished at the Xiaotangshan, Southeast urban, Lisui and Liangxiang fields, while resources assessment reached to D grade at other fields before 2003. With the increase of geothermal well numbers in recent years, cognition about geothermal features has been extended, so resources assessment should be continuously maintain as a regular work.

For the relatively mature fields in geothermal exploitation, long-term monitoring system ought to be perfected and automatic monitoring system needs to be set up early; for other geothermal fields, the long-term monitoring system should be established as soon as possible. In this way, key parameters such as discharge, pressure and temperature fields, porosity, permeability coefficient and so on can be comprehensively grasped, so that dynamic assessment of geothermal resources in each of the fields can be realized.

4.2 Devoting to Technology of Exploration and Exploitation

Methods and technologies of exploration and exploitation adapting geological conditions in Beijing have to be screened out and adopted from reconnaissance to the productive exploration.

4.2.1 Choosing the Proper Geophysical Exploration Methods

There are many geophysical exploration methods in geothermal reconnaissance, some methods are thought to be more effect, through in-depth study and comparison of various methods. They are the controlled source audio-frequency magnetotelluric sounding (CSAMT), the telluric electromagnetic sounding (MT, CEMP), the Rayleigh wave method, the Distributed passive source electromagnetic method (DPREM), and numerous electrotelluric lithology sounding methods. If the best result was gained, multiple methods should be integrated to interpret data due to multiple solutions of geophysical and geochemical methods.

4.2.2 Strengthening Study abut Drilling Procedure and Technology

It is necessary to synthetically analyze geothermal drilling technologies, in order to find out the most suitable technologies for drilling in Beijing. For improving well's quality, some drilling technologies, such as reverse circulation drilling, directional drilling, cementing, perforating and well flushing, and etc, will be emphases to enhance. Meanwhile, drilling technology and procedure applied in petroleum and coal industry would be used for reference, so further cooperation with those industry will be imperative.

4.2.3 Developing Research of Reinjection

Geothermal reinjection in Beijing has begun in the early 1970s. Injection water usually is consisted of tap water, waste heat water, groundwater, and geothermal heating tail water. As an effective measure to ensure sustainable utilization of geothermal, reinjection has to face a big challenge that is how to determine the impact injection would put on reservoir temperature and groundwater quality, so corresponding research must be continuously pushed ahead. In particular, water treatment technology aiming at different injection water has to be paid a lot of hardly work before constructing a set of successful reinjection work mode.

4.3 Promoting Research of Sustainable Development

Sustainable development thought of geothermal exploration and exploitation is supposed to be practiced into prospect planning of each of the geothermal fields in Beijing.

4.3.1 Sustainable Development Planning in High-degree Exploitation Field

High-degree geothermal exploitation fields include the Southeast urban field, the Xiaotangshan field, and the Liangxiang field. Due to fine geothermal conditions, exploitation risks are lower in those fields, so thermal wells distribution is more dense, more than $10/km^2$, and groundwater table is going down constantly. For those fields, a rigid rule should be set up in the future, that is no longer increase production but only reinjection. To limit exploitation mode of single well single-family, integrated utilization mode

will be wildly spread out to protect geothermal resources. A uniform monitoring net should be set up as soon as possible to monitor discharge, water temperature, and groundwater level. In some conditional area, it is necessary to do interference well test and reservoir engineering study to provide basic materials for higher level reserves calculation.

4.3.2 Sustainable Development Planning in Low-degree Exploitation Field

The Lisui field, the Shuangqiao field, the Yanqing field, the Houshayu field, the Northwest urban field, the Tianzhu field, and the Fengheying field need to enhance geothermal exploitation degree. For the areas, in which thermal well distribution are between $1/100\text{km}^2$ and $1/10\text{km}^2$, exploited wells can be built appropriately, at the same time injection wells have to be done.; for the areas, in which thermal well distribution is less than $1/100\text{km}^2$ and blank area, geothermal exploration should be encouraged to carry out, so that geothermal resources assessment would be conducted quickly.

5 CONCLUSIONS

In Beijing, main challenges of geothermal exploration and exploitation are summed up into 3 aspects: the top one is that government investment is far from sufficient to carry out high-quality synthetical geothermal research and to set up long-term monitoring system; the second problem is that technology and equipment in geothermal exploration has already fallen behind the developed counties and the most typical problems are the multiple solutions of geophysical-geochemical methods and injection clogging in sedimentary strata; the last one is low level geothermal exploitation and management, such as unequal exploitation degree in those geothermal fields and applications, lack of the cascade use, and decentralized management of geothermal wells. For instance, the geothermal exploitation quantity at the Xiaotangshan field and the downtown is about 60% of annual whole exploitation quantity in Beijing, nearly 80% geothermal water is used in space heating and domestic hot water, and about 160 thermal wells were being idle by the end of 2013.

For the above challenges, the paper proposes corresponding countermeasures one by one. The principle one is to enhance government investment in order to increase systemic study level and set up long-term monitoring system: Geothermal geological survey in whole Beijing plain (1:100000 scale) should be carried out. Reconnaissance has to be practiced in some areas such as west piedmont, while comprehensive study is going to be done in high exploration degree field and geothermal numerical simulation model of typical geothermal, like the Xiaotangshan and the Southeast urban fields, will be built. Long-term monitoring system ought to be perfected by improving automatic monitoring level in mature fields of geothermal exploitation, while the long-term monitoring system should be established as soon as possible in other fields. Dynamic assessment of geothermal resources in each of the fields can be realized due to comprehensively grasping key parameters in reservoir, e.g. discharge, pressure and temperature fields, porosity, permeability, etc; the second, exploration and exploitation technology will be further enhanced by choosing proper geophysical methods, drilling procedure and technology, and reinjection mode. Some geophysical methods, including CSAMT, MT, CEMP, DPEM, the Rayleigh wave method, and etc., some drilling technology, including reverse circulation drilling, directional drilling, cementing, perforating and well flushing, and some reinjection problems will be emphases to deeply research; the last is to point out sustainable route of geothermal exploitation in different areas of geothermal exploitation degree. In High-degree Exploitation Field, namely the Southeast urban, the Xiaotangshan and the Liangxiang fields, no wells will be drilled, integrated utilization mode will be wildly carried out, a uniform monitoring net should be set up soon. In Low-degree Exploitation Field, namely the Lisui, the Shuangqiao, the Yanqing, the Houshayu, the Northwest urban, the Tianzhu, and the Fengheying fields, exploited wells can be built appropriately, at the same time injection wells have to be done, accordingly geothermal exploration will be increased to carry out.

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