

THE LATEST PROGRESS IN EXPLORATION AND UTILIZATION OF GEOTHERMAL RESOURCES IN CHINA

Shangyao Huang¹ and Kcyan Zheng²

¹ Institute of Geomechanics, Chinese Academy of Geol. Sci. Beijing 100081, China

² Dept. of Science and Technology, Ministry of Geology. Beijing 100812, China

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ABSTRACT

China is rich in geothermal resources. According to the latest statistical data, the number of hot springs with $t > 25^{\circ}\text{C}$ in the country is over 2 700. If the hot water wells in basins and hot water outlets in mines were included, it would be well over 4 000. In recent years, the progress in geothermal exploration and utilization has been made. Geothermal resources of different types are successfully utilized for different purposes. The high temperature geothermal resources formed on the boundary of the plates are mainly used for power generation. At the same time, the low and medium temperature geothermal resources formed in widespread interplate uplifted and subsided regions are favorable for direct uses. This paper deals with the basic types of geothermal resources in China and the latest progress regarding the exploration and utilization.

1. INTRODUCTION

China is rich in geothermal resources, which are widely distributed. There are not only hot springs occurring at the surface, but also a lot of thermal water and thermal brine resources in basins at depth which have been discovered by host of drillholes. According to the latest statistical data, the number of hot springs with temperature exceeding 25°C is over 2 700 (S. Huang et al. 1993). If thermal water wells and thermal outlets in mines are taken into consideration, this number will be increased well over 4 000.

Depending on the geothermo-geological setting the geothermal resources can be divided into 3 basic types and 6 subtypes. Below are some examples given in this paper. Also described are formation characteristics of geothermal resources of different types in China and the latest progress in their exploration and utilization.

2. BASIC TYPE OF GEOTHERMAL RESOURCES

The geothermal resources in China can be divided into 3 types and 6 subtypes as follows (S. Huang et al.,

1986, 1993):

I. Magmatic Activity Type

I a. Recent Volcano Subtype

I h. Recent Magma Subtype

II. Uplifted Fault Type

II a. Intermountain Basin Subtype (Inland and Coastal)

II b. Piedmont Transition Subtype

III. Subsided Basin Type

III a. Sedimentary Faulted Basin Subtype

III h. Sedimentary Depressional Basin Subtype

In accordance with this division, examples include Tengchong of Yunnan (I a), Qingshui of Yilan County in Taiwan (I a), Yangbajain of Xizang (Tibet) (I b), Daiyun of Fujian (II a), Tangshan of Nanjing (II b), Shanlingzi of Tianjin (III a), Junlian (III b) and Huashuiwan (III b) of Sichuan. Because of the different geothermo-geological background, the type of geothermal manifestations at the surface, intensity of hydrothermal activity, water temperature, discharges and chemical composition also show obvious differences.

Tengchong of Yunnan and Yangbajain of Xizang are located in the central and western section of the Zang-Dian High-Temperature Geothermal Zone, respectively (S. Huang et al. 1981, 1986), and belong to the Recent Volcano Subtype (I a) and the Recent Magma Subtype (I b), respectively. Located in the northern section of the Taiwan High-Temperature Geothermal Zone, Qingshui of Yilan County falls under Subtype I a. They appear on the plate boundary in the Pliocene and Quaternary Volcanic Zone and the Cenozoic tectonic mobile zone - the young orogenic zone. The heat sources are closely related to the recent volcanic eruption and recent magmatic intrusion.

Daiyun of Fujian is located on the northeastern end of Ming-Yue-Qiong Lower and Medium Temperature Geothermal Zone (Southeastern Coastal Geothermal Zone). Tangshan of Nanjing is situated on the eastern branch of Ningzhen Arc. They belong to Coastal Intermountain Basin Subtype (II a) and Piedmont Transition Subtype (II b), respectively. The heat source conditions are related to deep circulating convection of underground water.

Shanlingzi of Tianjin, located on the northern edge of the North China Basin falls into the Sedimentary Fault-

ed Basin Subtype (III a). Bath Junlian and Huashuiwan, located in southern and western parts of Sichuan Basin, respectively, belong to the Sedimentary Depressional Basin Subtype (IIIb).

The geothermal resources of the II and III types are widely distributed in the interplate uplifted and subsided areas of the Earth's Crust, respectively. It is suggested that the heat sources of the II a, II b subtypes and IIIa subtype be related to the deep circulating convection of underground water. The heat source of the IIIb subtype depends mainly on heat conduction under the influence of normal geothermic gradient.

3. EXPLORATION RESULTS

The typical examples of the geothermal resources of different types and their exploration results are as follows (Table 1)

3.1. Yangbajain Geothermal Field of Xizang (Tibet) (I b)

Yangbajain Geothermal Field is located in Yangbajain Area of Damxung County in the Xirang Autonomous Region. The Field is about 90 km Lhasa, the capital of Xirang. It is the first exploratory high temperature geothermal field belonging to a water-dominated hydrothermal system. Among the high temperature geothermal fields this field is one of most famous fields at home and abroad due to its distinctive geological background (Cirenda et al., 1988). Whether there is a higher temperature geothermal reservoir is present at depth of Yangbajain Field or not, constitutes one of the problems which has attracted good deal of attention from geothermal circle in China and overseas. On the basis of analyses of geophysical and geochemical data the locations of 3 deep wells in northern part of the field were selected (X. Ren, 1994). One deep well ZK4002 has discovered a geothermal fluid with a temperature of 329.81° at depth of 2 007m. It is the first borehole with a temperature over 300°C in China. Encouraging progress has been made, thus, enabling China to rank among the countries the world over which have a hydrothermal system with a temperature in excess of 300°C

3.2. Qingshui Geothermal Field of Yilan County, Taiwan (I a)

Located in the westsouthern part of Yilan County, Qingshui Geothermal Field has the temperature ranging from 60°C to 991°. It abounds in fumaroles. The largest one is in riverbed, discharges 150 t/h of geothermal fluid. Chemical composition is $\text{HCO}_3\text{-Na}$ type with pH 9.7 (C. H., Chen, 1975). In the spring area, the reservoir rock consists of the epimetamorphic slates and quartzites in the Early Miocene. The 7 productive boreholes have been made. They produce 500 t/h of thermal water, of which about 75 t/h can be transformed into steam. The maximum well depth reaches up to 3 000m. The thermal water of 2291° was hit. In 1981 an experimental power plant was built, with a power capacity of 3 000 kw (C. H., Chen, 1994).

3.3. Daiyun Geothermal Field of Lianjiang County, Fujian (II a)

This field is located in northeastern suburbs of Lianjiang County. The exploratory work in the field included geophysical and geochemical exploration. In order to determine whether the geothermal anomaly is present in the study area, temperature measurements, geochemical anomalies of Helium (He), Mercury (Hg) and Polonium (Po) at shallow depth, geophysical methods of gravimetric, seismic, electric and hydrochemical analyses, have been carried out (Y. You, 1993). On the basis of analyses of the geostructural, hydrogeological, geophysical and geochemical data determination of the location of the first geothermal well was made. The exploratory work has achieved good results. In the place where the geothermal wells was under way, the rock is fractured, fissures and fractures are developed. There are center of geothermal anomalies ($t=24^\circ\text{C}$) and low resistivity (10–30Ωm) in the intersections of 2 or 3 groups of fissures and fractures. As a result, both the first geothermal well (ZKL01) at the depth of 156.11m and the second one encountered thermal water with the temperature of 62.1°C and 64.0°C and artesian discharges of 3 281 t/d and 4 000 t/d, respectively. The pressures at both wellheads reached 300 kPa. The hydrochemical type of thermal water of the well (ZKL01) is $\text{Cl-SO}_4\text{-Na}$. The mineralization is of 663.92 mg/l. Its pH is 018.84.

The water contains Br, I, Sr, B, etc.,

3.4. Tangshan Hot Spring of Nanjin, Jiangsu (II b)

Tangshan Hot Spring is located in the eastern part of Nanjing, 28 km away from the city proper.

The hot spring area occurs in the eastern top of the Ningrhen Arc—Eastern Flank Reflect Arc of the Huaiyang Epsilon Tectonic System. The reservoir rock is fissure limestone of the Lower and Middle Ordovician, consisting the axis of Tangshan Anticline to the east of the Tanglun Anticlinorium. There are silicified limestone and breccia in the area. At present, about 8 spring-shallow wells, are being exploited. Temperatures of the water are from 50.0 to 62.0°C and discharges are between 18–58 l/s. The hydrochemical composition is calcium sulphate ($\text{SO}_4\text{-Ca}$) and the mineralization is 1.71 g/l. Several sanatoria, hospitals, bathrooms and a villa have been built. In recent years, the further exploration in application of geological, geochemical and geophysical methods has been carried out. According to the results of geothermal exploration, the first well met the thermal water of more than 1 000 t/d of 57°C at depth of 200 m.

3.5. Shanlingzi Geothermal Field of Tianjin (III a)

Shanlingzi Geothermal Field of Tianjin (III a), located in the eastern part of Tianjin. It is one of the largest lower and medium temperature geothermal fields ever discovered in the country for the present. The geothermal reservoirs have the following characteristics: several productive layers, relatively shallow depth and rather wide distribution. After detailed

Table 1. Several Examples of Geothermal Exploration and Uses in China

no.	Location	Geol. Type	T°C	Q, l/s	pH	M, g/l	Hydrochemical Type	Use Type
1	Yangbajain (Xizang)	Ib	171-330	981	7.9	1.6-2.4	Cl-Na Cl-HCO ₃ -Na	P 25 MW G 2 000 m ²
2	Langjiu (Xizang)	Ib	78-112	5-10	7.8	2.04	Cl-HCO ₃ -SO ₄ -Na	P 1 MW
3	Naqu (Xizang)	Ib	62-116	5	7.5	2.82	HCO ₃ -Cl-Na	P 1 MW
4	Qingshui (Taiwan)	Ia	99-299	28	9.7	2.5	HCO ₃ -Na	P 3 MW
5	Xiaotangshan (Beijing)	IIb	35-65	95	7.2-7.9	0.3-0.7	HCO ₃ -SO ₄ -Na-Ca	S 1 D 30 000 m ² G 100 000 m ² F 650 000 m ²
6	Tangshan (Nanjing)	IIb	50-62	58	7.2	1.7	SO ₄ -Ca	S 2 B 3 F 60 000 m ² (Guquan)
7	Yingshan (Hubei)	IIa	46-69	50		0.3-0.5	SO ₄ -Na	I Textile, Ditto etc. G F B
8	Tanggu (Tianjin)	IIIa	69-75		8.5	1.5-2.0	Cl-HCO ₃ -Na	D 620 000 m ²
9	Shanlingzi (Tianjin)	IIIa	30-50 75-96	12-58	8.0-8.8	1.6-1.8	Cl-SO ₄ -Na Cl-HCO ₃ -Na HCO ₃ -Cl-Na	D 30 000 m ² I Wool Textile etc G F
10	Junlian (Sichuan)	IIIb	52-56	40	7.7	4.4	Cl-Na	B T

P. Power Generation; G. Greenhouses; S. Sanatorium; D. District Heating;
F. Fish Farming; I. Industrial Uses; B. Bathing and Swimming.

geothermo-geological exploration (Z. Chen, 1993), the geothermal reservoir consists of Minghuazhen Formation (Nm) and Guantao Formation (Ng) of the Upper Tertiary System and the geothermal reservoirs of the Cambrian and Middle and Upper Proterozoic basement rock. The geothermal reservoirs in the rock of Fm. Nm and Fm. Ng have temperatures of 30–50°C. The temperature of geothermal reservoirs in the carbonate rock of the Middle and Upper Proterozoic ranges from 75°C to 96°C. The mineralization of thermal water is generally 1.6–1.8 g/l, which is similar to that of the deep and shallow geothermal reservoirs. The types of the chemical composition of the water are mainly Cl-SO₄-Na, Cl-HCO₃-Na and HCO₃-Cl-Na. The geothermal reservoir in the Fujunshan Formation of the Cambrian carbonate rock was discovered for the first time in this area. Its buried depth is 1 440–1 670m. The maximum temperature of the water reaches 96°C. The pressure at the wellhead is 23–28 m above ground. The artesian discharging rates of the wells are 44–207 t/h (12–58 l/s). It is of important significance for Tianjin and even the North China as a whole.

3.6. Junlian Hot Spring of Junlian County, Sichuan (IIIa)

Junlian Hot Spring, also referred to as Xunsi Hot Spring, is located in Xunsi Xiang of Junlian County. On the end of submerged Xungsi Nose Anticline, it occurs in the Maokou-Qixia lumpy limestone of the Lower Permian (P₁m+q). Water temperatures range from 52 to 56°C and the discharge is about 40 l/s. The chemical composition type is sodium chlorite (Cl-Na) with a mineralization of 4.33–4.88g/l. One of the hot springs in Sichuan Basin, Junlian has the highest temperature and largest discharge. Some coal-exploratory wells, of at least 2 were drilled by the Sichuan Coal Team no. 141, and thermal water pinpointed. In recent years, by the Sichuan Tourism-Geological Association with the help from the Scientific Commission and the Urban Construction Bureau and other units, the characteristics and significance of Junlian Hot Spring and karst-geological landscape have been evaluated. A reliable geological basis for the development and utilization of resources mentioned above was provided (W. Ge et al, 1989). The practice indicates that the tourist development and sanatorium construction began to

take shape and the economic, social and environmental benefit is obvious.

3.1. Huashuiwan of Dayi County, Chengdu of Sichuan (IIIb)

Huashuiwan is located in Dayi County, west of Chengdu, Sichuan Province. There was an exploratory well, whose original object was to seek after oil and gas in the early 70s, but it turned out to have hit thermal water with no oil and gas round, and then the well was in a standing shut state.

In 1986, Sichuan Bureau of Geology and Mineral Resources maintained, that those oil and gas exploratory wells which did not come to anything should be put to use again in terms of exploitation of thermal water. The feasibility of the suggestion was proved by Sichuan Tourism-Geological Association together with the Planning Commission of Dayi County in 1992. After opening the well, geothermal water of over 72°C up to 10 000 t/d at the depth of 1 800-2 000 m was successfully obtained in 1994. The reservoir rock is karstified fissured limestone of the Middle Triassic (M. Chen, et al., 1993).

4. PROGRESS IN UTILIZATION

To sum up, the geothermal resources of the Type I are mainly suited for power generation; the geothermal resources of Types II and III are suited for developing direct uses, including district heating, industrial and agricultural uses, medical treatment and tourism and drinking, etc. Typical examples are as follows (Table 1).

4.1. Power Generation

As shown in Table 1, Yangbajain Geothermal Power Plant has a total generating capacity of 25 MW, having produced more than 5×10^8 kWh electricity since 1979. By the end of 1993 the annual electricity production reached over 1×10^8 kWh, indicating that Yangbajain Geothermal Power Plant had contributed a great deal to the Lhasa electrified wire network. Besides, Langjiu and Naqu of Xirang have the generating capacity 1 MW, respectively, Qingshui of Taiwan has 3 MW (Table 1). A part from the above mentioned geothermal fields, there are lots of boiling springs in China, where the high-temperature geothermal systems are very developed. They are rich in power resources. However, in several areas, such as Tatun of Taiwan because lower pH value (pH 2-4), so corrosion problem is very serious, whereas in other areas temperature is relatively lower, the power generation was not effective or economical.

4.2. District Heating

There are many successful experience in connection with district heating in Beijing, Tianjin and many other locations in North China. The geothermal district heating system established in Tanggu district of Tianjin serves an area of 620 000 m². The geothermal resources of Shanlingzi Geothermal Field are utilized for

district heating in an area of about 30 000 m² as well. Although the scale is still small, it saves conventional fuels and decreases pollution.

4.3. Industrial and Agricultural Uses

The thermal water of Shanlingzi Geothermal Field made use of as hot water sources for boiler and a wool-textile mill. It can save 7 000 t of coal, 4 000 t of industry salt and 8 000 kWh of electricity annually (Z. Chen, 1993). In recent years, a great progress in agricultural uses of geothermal resources has been made. Rich experience was accumulated (B. Chu, 1991).

4.4. Medical Treatment and Tourism

In recent years, the uses of hot spring resources in the medical treatment and tourism have rapidly been developed. The number of sanatoria in China is over 200. In many locations like Xiaotangshan of Beijing, Tangshan of Nanjing (Table 1), Haikou, Xinglong Sanya, Qionghai of Hainan Province, aim is at building hot spring hospital, sanatoria, hotels, holiday houses and recreational centre for entertainment etc. Besides, Tengchong of Yunnan and Tatun of Taiwan are famous for their volcanic hot spring in the country. Dagejia, Qab and Gulu of Xizang anti Rekeng (Calu) of Western Sichuan are well known for their geyser and spouting boiling springs. Marvellous geothermal landscapes are abundant in these areas. They are valuable for developing tourism and sight-seeing having an enormous potentiality.

5. CONCLUSION

As mentioned above, geothermal resources of Type I belong to volcano type, the heat source of which is usually favorable for formation of geothermal resources with temperatures over 150-180°C. The geothermal resources of the types II and III belong to nonvolcano type. There are no special heat sources and the temperature of geothermal systems is below 150°C.

According to statistics by S. Huang et al. (1993), hot springs with temperatures of over 80°C make up only 7-8% of the total number of hot springs in China as a whole. Besides, hot springs with temperatures from $> 25^\circ\text{C}$ to $< 80^\circ\text{C}$ make up 92-93% of the total. The former are principally distributed in Zang-Dian and Taiwan, the two High-Temperature Zones are located on the boundaries of the plates belonging to Type I. The latter are in the widespread interplate uplifted and subsided areas as in Dian Chuan, Ming-Yue-Qiong Lower and Medium Temperature Zones and others. Most of the geothermal wells in the Meso-Cenozoic sedimentary basins have the same temperatures to those of the latter. They belong to Type II and III.

Application of various geological, geophysical and geochemical methods, in conjunction with structural analyses, shallow temperature measurements, Helium,

Mercury and Polonium measurement and gravimetric, seismic and electric exploration have achieved good results. Shanlingzi of Tianjin and Daiyun of Fujian have rendered successful experience which is of important significance for geothermal exploration in future.

Several examples indicate that geothermal power generation using high temperature geothermal resources, plays an active role in developing new energy sources of the country. The low and medium temperature geothermal resources are favorable for multipurpose utilization (Table 1).

Many information and statistical data of geothermal uses are available from the papers of Chinese Geothermal Association.

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