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Sustainable Development of Geothermal Resource in China and Future Projects

Tingshan Tian[1]and Shangyao Huang[2]

[1] Chinese Institute of Geo-Environmental Monitoring, Beijing, China, 100081

[2] Institute of Geomechanics, CAGS, Beijing, China, 100081

huangshangyao@btamail.net.cn

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ABSTRACT

Since the early 1990's of 20th Century, the commercial geothermal development in China predominated gradually and the funds through different channels for the geothermal exploration and exploitation increased continuously. An unprecedented great progress in geothermal development in China has been made. Especially, there exist the favorable geothermo-geological conditions and there are broad users, the large- and middle scale cities, new villages and towns of the oil-gas fields, developing the geothermal resources, are numerous and distributed widely. In recent years, the utilization of high-temperature geothermal resources in Xizang Autonomous Region and Taiwan Province for power generation was progressing slowly because of several technology problems and funds shortage. At present, the low-medium temperature geothermal resources in many places of the country are successfully utilized for space heating, greenhouses, aquaculture, irrigation and thermal water supplying, medical treatment and tourism, public bathing, drinking, extraction of chemicals and others. At present, the long-term project of the future geothermal development in China is compiling. In this paper the development and utilization status of geothermal resources in China are presented. Several tables are given in the paper.

1. INTRODUCTION

Since the early 70s of 20 Century, with the attention paid by the related state ministries and commissions and the organizations of the Government of China and at the vigorous suggestion of the famous late scientist, Prof. J.S. Lee and under his direct guidance, the good results have been obtained for geothermal investigation, exploration and multipurpose utilization in more than 20 Provinces, Cities and Autonomous Regions of China. In 70~80s of 20 Century, great deal of funds are invested by the State to develop the geothermal resources, mainly concentrated in Xizang (Tibet), North China and Southeast Coastal Zone. In the Yangbajain, Naqu and Lanjiu Geothermal fields, the high-temperature geothermal resources have been explored and developed for power generation, and the geothermal experimental power stations have been successfully built. In Beijing , Tianjin, Central Hebei of North China, and Fuzhou, Zhangzhou, Fengshun, Zhanjiang, Haikou and others of Southeast Coastal Zone, the geothermal research, exploration, development and utilization have been carried out for direct uses of lower and medium geothermal resources early and late. And the abundant geothermal waters are discovered successively.

Since the early 1990s of 20 Century, with the quickening of urbanization processes and increase of the level people's life, the commercial geothermal development in China predominated gradually and the funds through different channels for the geothermal exploration and exploitation increased continuously, the geothermal markets are greatly broadened. An unprecedented great progress in geothermal development in China has been made. Especially, there exist the favorable geothermo-geological conditions and there are broad users, the large- and middle scale cities, new villages and towns of the oil-gas fields, developing the geothermal resources, are numerous and distributed widely. An area of geothermal field is spread and the exploration depth is increased. At present, the long-term project of the future geothermal development in China is compiling. In order to realize sustainable geothermal development, especially for the geothermal fields in several cities and oil-gas fields with over-exploitation of geothermal water the strengthening the development management and the carrying out the regime observation and the reinjection test are very important.

2. OUTLINE OF GEOTHERMAL RESOURCES

China is rich in geothermal resources According to incomplete statistics, there are 2,796 localities stating hot springs with water temperature ≥25□ in China (Huang *et al*., 1993). The geothermal wells drilled in the geothermal fields of the cities and the oil-gas regions, industrial and mining enterprises are over 5000 (Huang, 2000). Up to now, according to approximate statistics, it can be in excess of 5200. From a global tectonic point of view, the high temperature hot springs are concentrated in the suture lines both between the Eurasian and Indian Plates in southeastern part of China (mainly in South Xizang, West Ynnan and West Sichuan) and between the Eurasian and Pacific Plates in eastern part of China (Taiwan). And the medium and lower temperature hot springs are distributed widespread in the interior of Eurasian Plate. The boiling springs, geysers, fumaroles and other strong hydrothermal manifestations occur all in above-mentioned intraplate regions. It is clear that there exist the favorable geological conditions for forming the geothermal resources of recent magmatic type in the bounder lines of plates and the geothermal resources of the uplifted fracture type and the depressed basin types are formed in the interior of the plate.

It indicates that they are distributed widely. There are not only the high-temperature geothermal resources in the intraplate geothermal belts, which can be utilized for generating an electricity, and also there are the rich lower and medium geothermal resources in the interplate uplifted regions, the most parts of hot spring areas, and in the interplate depressed regions—the spread distributed Meso-Cenozoic sedimentary basins.

3. CURRENT STATUS OF DEVELOPMENT AND UTILIZATION

In recent years, the utilization of high-temperature geothermal resources in Xizang Autonomous Region and Taiwan Province for power generation was progressing slowly because of several technology problems and funds shortage. But the low-medium temperature geothermal resources in many places of the country are successfully utilized for space heating,

greenhouses, aquaculture, irrigation and thermal water supplying, medical treatment and tourism, public bathing, drinking, recovery of useful minerals and others. According to Freeston (1995) and Lund and Freeston (2000) the capacities of the installed thermal power of China in 1995 and 2000 for direct uses are 1915MWt and 2814MWt, respectively. It is indicated that China stands still at the head of the World.

Several examples indicating an outline of the geothermal resources in China and the current status of their multipurpose utilization are shown in Table 1. The famous geothermal fields, such as Beijing, Tianjin, Chongqing, Xi'an, Kunming, Yangbajain, Tengchong and others are included.

3.1 Geothermal Power Generation

The famous Yangbajain Geothermal Plant in Xizang Autonomous Region (Tibet) is the first one in the country, which was built in September 1979. Its installed capacity is still of 25.18MW and accounts for 41.5% of a total capacity of Lhasa electrified wire netting, and it can reach up to 60.0% during the winter time. In order to increase the capacity of geothermal power generation the two wells were completed in northern part of Yanbajain Geothermal Field in 1993 and 1996, respectively, and the high temperature geothermal fluids have been successfully revealed, but they are not still utilized up to now. The second and the third ones in the country were built in Lanjiu and Naqu Geothermal fields of Xizang Autonomous Region in 1987 and 1993 with installed capacity of 2.0MW and 1.0MW, respectively. At present, these two power plants are interruptedly operating (Liu Shibin, 2003). In 80s of 20 Century the Tuchang and Qingshui geothermal power plants were built in Taiwan Province of our country with installed capacity of 0.3 MW and 3.0MW, respectively, at present, they are already closed.

3.2 Space Heating

In recent years, the development of medium and lower geothermal resources for direct uses has been very fast, the space heating has a great growth. Especially, in several cities such as Beijing, Tianjin, Dagang, Renqiu, Daqing, Kaifeng, Xi'an, Xianyang and others, the good results are obtained and both the conventional energy sources were saved and the environmental pollutions were decreased. For example, an area of district heating in Tianjin City totals over 860,000m² and it constitutes over 80% the total heating area of the country. At present, an area of geothermal space heating of the country is estimated in excess of 1,300,000m². In recent 10 years, in Xi'an City, the geothermal exploration works were continuously strengthened. And over 120 wells were completed. An area of space heating totals 1,000,000m²□Xue Huafeng and others, 2001□. In Kaifeng City, more than 60 geothermal wells were completed and heating area is up to 600000m²(Zhang Dezhen, 2003).

3.3 Geothermal Agriculture Uses

Most of the regions having geothermal resources in China belong to agriculture ones. Recently, the geothermal resources are effectively utilized for agriculture uses including the greenhouses, aquaculture, hatchery, irrigation *etc.* An area of geothermal greenhouses has also a great growth as that of geothermal space heating. According to incomplete statistics an area of geothermal greenhouses in the country reached up to 1,000,000m². It is known that in the greenhouses of Yangbajain Geothermal field over 20 kinds of vegetables such as tomato, cucumber, green pepper and others are planted more than 20 years. In Yingshan Geothermal Field of Hubei Province the geothermal waters are successively utilized for breeding good strains of rice and the seed rate has been raised from 13.5% to 98.6%. Besides, the natural rich waters of several hot spring areas in the country are successfully utilized for field irrigation. For example, both geothermal natural rich waters in Wuwang Hot Spring of Linyi County, Shanxi Province, and Fenquan Hot Spring of Heyang County, Shaanxi Province, contain higher ammonium nitrate, a content of which is 0.34g/L for the former.

3.4 Medical Treatment and Tourism

China is a country not only rich in thermo-mineral resources, but also with a long history of their research and utilization as well. The medical uses of thermo-mineral water may be dated back to long ago, when the thermo-mineral water for medicinal purposes were already documented in ancient books of China as published as early as during a period of several hundred years BC, illustrating that the ancient people knew quite well how to make good use of thermo-mineral water for medical treatment purpose. In recent years, with national economy progressed and people's living level enhanced, the medical thermo-mineral water has witnessed increasingly widespread application. Besides the recuperation and convalescence they are also utilized for tourism, vacation, entertainment, *etc.* The markets in the development and utilization in this respect become broadened and the use functions increased (Huang and Petrova, 2002).

There are many regions in the country having both the medical thermo-mineral water resources and the tourism sightseeing resources. At present, more than 200 hot spring resorts of certain scale have been built. Such as, Huaqingchi of Lintong, Shanxi Province, Ruzhou of Henan Province, Arshan of Neimenggu Autonomous Region, Nan-Wenquan and Bei-Wenquan of Chongqin City, Shuimogou of Urumqi, Xinjiang Uygur Autonomous Region, Tengchong, Yunnan Province, Tanggangzi, Liaoning Province and others, became the famous hot spring sanatorium and tourism resorts. For example, the Arshan, being a town with population of less than 8000, has more than 40 both hot and cool mineral spring vents, and a wonderful natural sight. It is reported that the tourist person-time in 2003 has reached up to 300000. Besides, in Rehai, there still exist both abundant and quite valuable medicinal thermo-mineral water and geothermal steam resources characteristic of having varied types and many uses, which can be utilized to the treatment over 40 diseases and illnesses caused by motor system, nervous system, digestive system, respiratory system, gynecology, dermatoses, *etc.*

In recent years, because of many users and funds from entrepreneurs the great progresses in geothermal development and utilization for convalescence, tourism, vacation and entertainment in China have been made. In Nangong Village of Fengtai District, Beijing, the geothermal multipurpose utilization achieved a good result (Pan, X., and others, 2003), and here everyday near 1000 person-time are accepted for convalescence, tourism, vacation and entertainment. This is the first of characteristic is to utilizing the medium and lower geothermal resources in China. The second one is to developing and utilizing vigorously the geothermal convalescence and tourism resources combined with real estate development that gives especially obvious beneficial results, because the prices of apartment houses built in the places with geothermal resources can be increased several times over (Zheng, K. and others, 2001; Huang, S. and Yang, Y., 2002). Besides, in several places such as in the valley or on the river bank or the shore of a lake, with a scenic beauty and pleasant environment, where the geothermal resources were not yet discovered. The geothermal waters are transported over long-distance to here and the landscape style apartment houses are built, named after Hot Spring Garden, Hot Spring Vacation Village, *etc.* For example, in Emei Hot Spring Town of Sichuan Province, the transport distance of

geothermal waters is about 12km. In the Town there are many swimming pools including out- and indoor, and the Chinese traditional medicinal crops such as Chinese angelica, Chinese wolfberry, aloes, *etc*. are put into the pools for swimming or bathing in order to strengthen people's health more vigorously, gracefully and beautifully. As a results, the good social, economical and environmental effect are obtained. Besides, the geothermal brines are also utilized as a tourism resource for swimming pool, such as in Penglaizhen Geothermal Brine Field of Sichuan Province. In these cases, the geothermal brine and the cold bittern are mixed with a mineralization over 220g/L and transported into the swimming pool. It is reported that the people can be floating on the water surface and reading because of the buoyant force. Therefore, this special kind of the tourism uses promoted greatly the development of the local economics.

3.5 Recovery of Useful Minerals

There are many minor elements such as, boron, lithium, strontium, potassium and other compounds in geothermal brine of China. To date, they are utilized successfully for extracting useful minerals by salt-chemical plants in several provinces of the country. In the end 50s of 20 Century, a stratigraphic well was completed in the central part of Sichuan Oil-Gas-Bearing Basin and the geothermal brines with a temperature of 79□ and a total mineralization of 200g/L was revealed at depth of about 2200m of the basin. The latest results investigated in April of 2004 indicate that up to now, although the geothermal brines have been exploited for 40 years, but the production regime is quite stable. At present, the geothermal brines from this well are mainly utilized for extraction of salt and recovery of bromine and iodine.

4. REALIZING SUSTAINABLE DEVELOPMENT OF GEOTHERMAL RESOURCES

It is known that there are many factors, influencing sustainable development of geothermal resources, such as development scale, distribution areas of reservoir, excessive exploitation, distance between production well and reinjection well and others. Among them an excessive exploitation is one of the principle factors influencing sustainability of geothermal development. If geothermal waters exploited at several times more than the natural supplied one the rate of temperature and pressure should be declined. In order to realize sustainable development of geothermal resources, especially for the geothermal fields in several cities and oil-gas fields with over-exploitation of geothermal water, the strengthening of the development management and the carrying out the regime observation and the reinjection test are very important. In recent years, the good results have been obtained in several geothermal fields of Beijing and Tianjin, such as Xiaotangshan, Southeastern City Area, *etc*. (Liu and Others, 2002; He, M. and Xu, N., 2002).

The geothermal resource is a renewable energy resource and it is also the limited resource. Its supplying processes are very slow. In several geothermal fields of the country such as Beijing, Tianjin, Yangbajain, Xi'an, Kunming, Zhengzhou and others, because of over-exploitation the water lever continuously decreased, and as a result in several areas the source can be dried up influencing seriously the life of geothermal fields (Huang Shangyao, Yang Yutong, 2002). As above-mentioned, it is necessary firstly to strengthen management and take measures for limiting quantity of wells and geothermal waters and for rational exploitation and effective protection. Besides, it is also necessary to carry out the experimental reinjection research repeatedly, as a result the reliable parameters are obtained in order the to ensure that sustainable development of geothermal resources shall be realized.

5. FUTURE PROJECT OF DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES IN CHINA

At present, the future project of geothermal resource development during the period of 11th Five-Year Plan in China is compiling. Now, the basic principles and part of contents in the report about project of geothermal resource in China (Ministry of Land and Resources of the People's Republic of China, 2000) are presented briefly as follows.

5.1.1 Exploration Project (2000~2005)

On the basis of systematic investigating the status of exploring, developing, predicting and assessing the geothermal resources throughout the country the database of geothermal resources for all the country should be set up. For the regions where there exists great potential of geothernal development and utilization such as North China, Songliao Plains the geothermal investigation and assessment should be carried out. In the central cities and towns, and the places near oil fields where the geothermal resources are abundant and there is a market requirement in these regions, the exploration will be carry out in order to prepare the resource conditions and establishing the development exemplary area. For the regions where the development and utilization have been carried out for a long time, the applied technology should be studied for realizing modernization management and preparing the technological reserves in order to develop the new areas.

5.1.2 Exploration Project (2005~2010)

According to the investigating the basic status of exploration, development and utilization during a period of the 10th Five-Year's Plan in China, and predicting and assessing the geothermal resources throughout the country the database of geothermal resources and their development and utilization for all the country should be set up. In the selected key regions, the recoverable number should be predicted and assessed. In the regions where the geothermal resources are abundant and there is certain basis of development, it is necessary to carry out the exploration combined with development in order to assess the recoverable number and to provide basis for establishing exemplary area. In the main exploited geothermal regions by applying the advancement technology the modernization management should be realized.

5.2 Project of Development and Utilization (2000~2010)

As above-mentioned there are 2796 localities of hot springs in China, among them there are 2114 localities with a temperature between 25~60□(Huang and others, 1993), which account for 76.6% of total amount and are already in excess of 3/4. Besides, according to statistics of temperature data for 760 geothermal fields an average temperature is only 54.8□ (from "Project Report of Geothermal Resources in China", Ministry of Land and Resources of the People's Republic of China, 2000). These figures indicate that most of the geothermal resources in China are the medium and lower temperature ones. Therefore, in the development and utilization of geothermal resources in China the direct utilization of medium and lower temperature geothermal resources should be developed principally. To date, the medium and lower temperature geothermal resources are principally utilized for space heating, thermal water supplying, sanatorium and tourism, greenhouses, aquaculture, *etc.* (Table 2~6).

6. CONCLUSION

China is rich in geothermal resources. The high temperature geothermal resources are distributed mainly in South Xizang, West Yunnan, West Sichuan and Taiwan. The medium and low temperature geothermal resources are distributed widespread in the mountainous and the plain regions of the country. According to the geological setting, the resource conditions of the country and the local demand the exploration and the utilization of the medium and low temperature geothermal resources for direct use should be energetically developed. Of course, the power generation is an important use way for high temperature geothermal resources, but it is not unique one.

It is known that in many high-temperature geothermal areas there are much wonderful natural sight and very beautiful manifestations such as geysers, fumaroles, boiling springs and various forms of sinters *etc.* These types of hydrothermal activities should be firstly developed as the geothermal tourism resources, in these regions such as Rehai Boiling Spring Area of Tengchong the exploration and development will certainly cause great damage to the valuable geothermal tourism and natural medical resources. Many examples indicate that the geothermal direct use is in conformity with the principle of sustainable development and becomes gradually one of the new increase points in the economic development of the country. It is expected that the direct use of the geothermal resources have more broad market and more rapid development in the future.

It is clear that an over-exploitation is the most important factor influencing sustainability of geothermal development. It can involve usually many serious consequences such as the temperature and pressure decline, the resource dried up, the earth subsidence, the collapse *etc.* It is expected that for the realizing of the sustainable development of geothermal resources in several cities and oil-gas fields with over-exploitation the development management strengthened, and the regime monitoring of geothermal water and the reinjection test should be carried out for a long time.

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Table 1 Outline of Geothermal Resources in China and Current Status of Their development and Utilization

1. Power Generation; 2 Space Heating; 3. Greenhouse; 4. Aquaculture; 5. Hatchery; Agriculture; 7. Industry Use;

8. Sanatorium, Tourism ; 9. Water Supplying; 10. Bathing; 11. Swimming Pool; 12. Mineral Water

13. Sci. Experimen1; 14. Earthquake Obs

Geographic Distribution	**Reservoir**	**Temperature** □	**Depth m**	**Geothermal Utilization**
Beijing	Pt	35~73, max. 88	max. 3600	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14
Tianjin	N, Pz, Pt	60~90, max. 98	2000~3000 max 4000	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14
Shanghai	Pz	28~31	300~700	12
Chongqing	T, Pz	25~62	500~2000	8, 9, 10, 11, 12
Jinan, Shandong Province	P	41	600	8, 10
Tangshan, Jiangsu Province	O	60		6, 8, 9, 10□
Fuzhou, Fujian Province	γ	70~98	141~530	3, 4, 5, 6, 7, 8, 9, 10, 11, 13
Zhengzhou, Henan Province	N	40~47	~1000	8, 10, 12
Sanyuanli, Guangzhou		32		8, 9, 10, 11
Haikou, Haonan Province	N	42	700	6, 9, 10
Xi'an, Shaanxi Province	N, E	56~70, max.113	1300~1600, max. 4005	□□□□□□□□□□□□□□□
Kunming, Yunnan Province	Pz, Pt	37~73	1000~1500, ,max 4000	4□□□9□ 10
Xiongxian, Hebei Province	Pz, Pt	58~86	500~1200	□□□□□□□□□□□□□□□□□□□□□□□□□□□□
An'shan, Liaoning Province	γ	72		□□□□□□□□□
Lindian, Daqing Oil Field	K	40~70	1200~2400	□□□□□□□□
Yingshan, Hubei	A	46~73		□□□□□□□□□□□□□
Kangding, Sichuan Province	γ	88~94		□□□□□□□□
Tengchong, Yunnan Province	N	96 (local boiling point)		□□□□□□11
Yangbajain, Xizang Autonomous. Region	Q γ	150~165 251~257	180~280 950~1459	□□□, 11

Table 2 Project of Space Heating Use

Year	Yield of Geothermal Water □10000m³□	Heating Area by Using Waste Water of 40□□10000m²□	Heating Area by Using Waste Water of 15□□10000m²□
2005	11686	1412.7	3629.1
2010	19438	2259.7	5944.4

Table 3 Project of Water Supplying (Bathing) Use

Year	Yield of Geothermal Water□10000m³/a□	Water Consumption (Bathing) for one time□1000m³/each person□	Man-time □Hundred Million□	Average Consumption Per Year□1000m³/each household□	Number of Users□ households□
2005	26378	0.20	13.20	60	440
2010	41887	0.20	20.94	60	700

Table 4 Project of Sanatorium and Tourism Use

Year	Yield of Geothermal Water□10000m³/a□	Water Consumption □m³/bed□	A Total Amount of Beds □1000beds□	Number of Hospitals □500bed/each hospital□
2005	4148	100	24.0	840
2010	6437	100	64.4	1288

Table 5 Project of Greenhouse Use

Year	Yield of geothermal water□ 10000m³□	Water Consumption Per Mu □10000m³□	A Total of Mu □10000mu□	A Total of Square Meters □1000m²□
2005	2660	0.25	1.064	700
2010	3902	0.25	1.560	1030

Note: Mu = 667 **m²**

Table 6 Project for Aquaculture Use

Year	Yield of geothermal water □10000m³/a□	Water Consumption Per Mu□10000m³□	A Total of Mu □mu□	A Total of Square Meters□ 1000m²□
2005	2370	0.50	4740	316
2010	3859	0.50	7720	515

Note: Mu = 667 **m²**