

The Geothermal Resource and Its Sustainable Development in China

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Abstract: China is rich in geothermal resources. With 2,300 MW of geothermal power and annual thermal energy of 10,600 GWh, China nowadays is the largest user of non-electric geothermal energy in the world, whereas with about 28 MW installed capacity power plant, China is still laggard, compared with some countries, and with her owned resources. Geothermal Sources Heat Pump is the most promising area of geothermal energy, to which more and more attentions are being paid in China, and its market is being developed rapidly. Geothermal is generally renewable, however its sustainable development for a geothermal project must be studied. This paper introduced the geothermal resource and its Utilization, combined Yangbajing geothermal field and geothermal source heat pump, the sustainability of geothermal resources was discussed, at last some suggestions were presented to keep the sustainable utilization of geothermal resources in China.

Keywords: geothermal resources, high temperature, low medium temperature, geothermal sources heat pump, sustainability

1. THE GEOTHERMAL RESOURCES AND THE UTILIZATION IN THE WORLD

The development of economy and environment have changed the energy structure rapidly, the renewable energy will be up to 50% of the whole exhausted energy in 2005, even 60% in some countries. Solar, biomass, geothermal and wind energy is becoming more important for the people.

Geothermal energy is theoretically renewable. The total heat in the earth's interior can be estimated to be around 10^{31} J. Considering the surface area of continents (some $2 \times 10^{14} \text{ m}^2$) and the continental crust to 1 km depth only, the heat content of this shell is still considerable with $3.9 \times 10^6 \text{ EJ}$. Taking into account the world's primary energy consumption, 400 EJ in 2000, this geothermal energy would be sufficient for a million years. Would this heat be extracted, it would need 1000 years to replenish the store by the terrestrial heat flow (Rybach et al., 2000). In 2002 there are about 8,000 MW geothermal electric power installed in 22

countries, producing about 50,000 GWh/yr. Direct-Use was reported in 58 countries, with an estimated installed capacity of 15,200 MW and annual production 53,000 GWh (Lund, 2002).

During the first oil crisis Los Alamos Scientific Laboratory (New Mexico) proposed Hot Dry Rock (HDR), since several HDR Projects have been performed in USA, Japan, Australia and some countries in Europe. The first HDR was experimented at Fenton Hill on the east-side of the Valles-Caldera near Los Alamos, in 1986 the second HDR circulation system was completed and now the U.S. Department of Energy had the enhanced Geothermal systems to the geothermal electric power generation industry.

Table 1. Leading countries using ground-source heat pumps

Country	Capacity (MWth)	Generation (GWh/year)	Number Installed
Austria	275	370	23,000
Canada	435	300	36,000
Germany	560	840	40,000
Sweden	2000	8000	200,000
Switzerland	440	660	25,000
USA	3730	3720	500,000

The European HDR research project started at Soultz-sous-Forêts, Alsace in 1987, and now is being executed with the goal to construct a HDR-pilot-plant with a thermal power of 30 MW. Germany is working at generating power with different geothermal concepts. Huengels E (2002) is working at Stimulations- und Testarbeiten in der Tiefbohrung E Groß Schönebeck, and Wolff H. (2003) is doing his UGGW project "Der

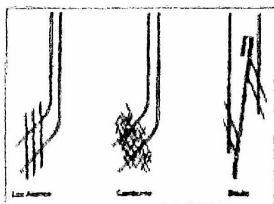


Fig.1 Conceptual Models of HDR systems (H. Tenzer)

Untertägig Geschlossene Geothermische Wärmetauscher”.

Geothermal Sources Heat Pump technologies, as a new quite promising area in direct use shallow geothermal energy, have been rapidly developed. table 1 lists the countries with the highest use of ground-source heat pumps.

2.GEOTHERMAL RESOURCES AND ITS UTILIZATION IN CHINA

China is rich in geothermal resources, of which with high temperature ($>150^{\circ}\text{C}$) are concentrated in Tibet, Tengchong in Yunnan Province and Taiwan and used for power generation. At present, a geothermal power plant with installed capacity of 25.18 MW is in operation at Yangbajing, and two other geothermal power stations with capacities of 2 MW in Langju and 1 MW in Naqu respectively (Wang, 2002).

Low-medium temperature ($<90^{\circ}\text{C}$ and $90-150^{\circ}\text{C}$) geothermal resources are widely used for space heating, industrial processing, agriculture, aquaculture, bathing and spas. There are two types of low-medium temperature geothermal resources in China. One is the thermal water from the low-medium temperature systems of convective type, such as Zhangzhou and Fuzhou geothermal systems in the Southeast coast of China. Another is the thermal fluid connected with the low-medium temperature geothermal systems of conductive type in large-scale sedimentary basins, such as North China Basin, Songliao Basin and Sichuan Basin, etc.. China nowadays is the largest user of non-electric geothermal energy in the world. In 2002 the directly used geothermal power in China was 2,300 MW and thermal energy 10,600 GWh/yr (Lund, 2002).

With the development and application of heat pump technique, low-medium temperature thermal waters are widely used for space heating and air-conditioning throughout in China.

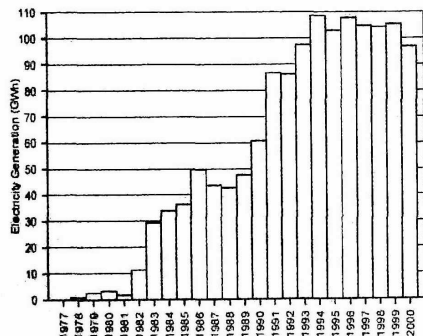


Fig. 2 Electricity generation output of the Yangbajing geothermal power plant in the years 1977-2000, the amount in 1977 was 49.4 MWh (Fan Xiaoping 2002)

3.THE SUSTAINABLE DEVELOPMENT OF GEOTHERMAL RESOURCES IN CHINA

3.1 Promote geothermal power generation in western area, especially in Tibet

3.1.1 Electricity generation output of the Yangbajing geothermal power plant

China is developing its western areas. With the completion and operation of the Qing-Zang railway, the rapid development of Tibet demands more energy. Tibet is rich in high temperature geothermal resources, Yangbajing geothermal field supplies 41% (more than 60% in the winter time) of the electricity to Lhasa city, the capital of Tibet Autonomous Region. The initial electricity generation of the Yangbajing geothermal pilot power plant began in 1977 with a one MW turbine generator. The total capacity reached 25 MW when the last 3 MW turbine generator joined the electricity net in 1991. The amount of electricity generation increased along with an increase of the installed capacity and reached a peak in 1994, but has since been on a small but gradual decline. This behaviour has to do with the massive production out of the shallow reservoir (Fig. 2).

3.1.2 Conceptual Model of the Yangbajing Geothermal Field in Tibet

The non-volcanic high-temperature Yangbajing Geothermal Field is located close to the convergent collision zone between the Indian and Eurasia plates. The Yangbajing convective system consists of shallow and deep reservoirs, Fig.2. The shallow reservoir is in unconsolidated Quaternary alluvium and altered Himalayan granite. Its temperature ranges from 150 to 165 $^{\circ}\text{C}$ at depths between 180 and 280 m. The shallow sodium chloride thermal water is a mixture of deep thermal water and cold groundwater. The deep reservoir is in a slip-fault zone of the Nyainqentanglha core complex and fractured Himalayan granite. The deep reservoir can be subdivided into two parts: the upper part, with a temperature of 251 $^{\circ}\text{C}$, is between depths of 950 and 1350 m, while the lower part, below a depth of 1850 m, has temperatures as high as 329 $^{\circ}\text{C}$. No significant permeability has yet been encountered in the lower part. The shallow reservoir is assumed to have an area extent of 15 km² while the deep one covers less than 4 km². The geothermal fluid may originate as glacial melt at high elevations, but when heated at depth it becomes saline (2.8 g/l chloride). Mixing with fresh water occurs in the shallow system, resulting in a salinity of 1.5 g/l. Considerable land subsidence has followed production and pressure decline in the shallow and sedimentary reservoir. Subsequently, some of the wells to the south now show reservoir cooling due to colder boundary recharge while wells to the north have become slightly hotter as a result of increased recharge from the deep system.

3.1.3 The sustainable development of geothermal resources in Tibet

So far, only the shallow reservoir has been exploited for power generation, a swimming pool and greenhouses. The pressure in the production wells has declined sharply due to limited recharge. There is now insufficient steam available to run the turbines at full load. The surface geothermal manifestations have disappeared except for a few fumaroles in the northern

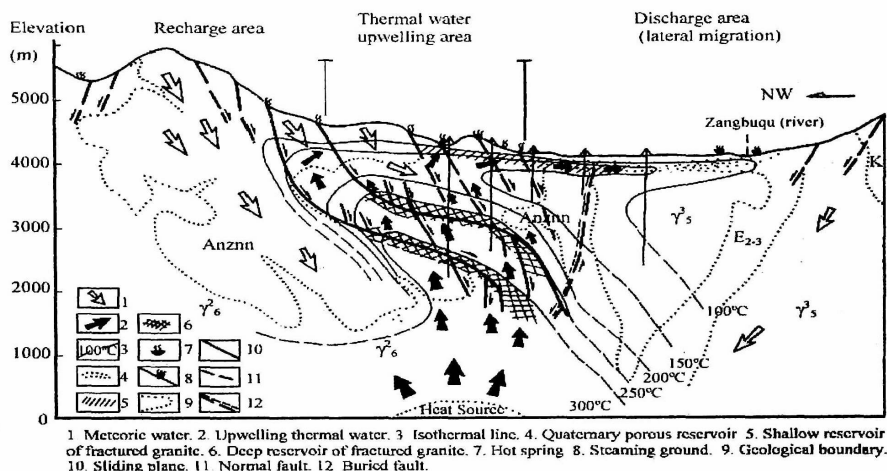


Fig. 3 Conceptual Model of the Yangbajing Geothermal Field, Tibet-(Dor Ji, 2000)

part of the field. Two deep exploration wells were drilled in the northern part of the field in 1993 and 1996 for new deep geothermal resources. This drilling discovered a high enthalpy fluid. Well ZK4001 was drilled to a depth of 1450m in 1996. The two phase flowing wellhead conditions were 200°C and 1.5 MPa at a rate of 84 kg/s. This well is expected to support 12 MW of electricity. Well ZK4002 was completed at 2006.8 m depth of 329.8 °C in December 1993, but it has no stable flow rate due to low permeability. To apply this geothermal resource, the technologies like HDR can be introduced, e.g., fractures can be generated by hydraulic stimulation.

3.2 The development of Geothermal Source Heat Pump and the Shallow Geothermal Resources in China and (Zheng, 2003)

Geothermal resource heat pump system is a relatively new technology in application for geothermal space heating and/or air-conditioning. It represents the fastest growing segment of geothermal energy utilization, and is quite a promising area in direct use of geothermal energy nationwide in China.

3.2.1 The Feasibility or Incentives to Develop GSHP system in China

The economic, environmental and technical factors that affect the utilization of GSHP in China can be described as follows:

- GSHP systems can provide heating and cooling with higher efficiency. The temperature below 5~10 m depth in most areas of China is stable at that level with average temperature (5 ~ 25°C) during the year, with which GSHP systems can provide from 3.3 to 4.5 seasonal performance factor, i.e., for each kWh of heating output, only 0.22~0.30 kWh of electricity are required to operate the system. This is higher than air source heat pump systems by up to 40%, and the

operation cost, is only about 50~60% of that of central air conditioner system.

- GSHP systems come in different types and sizes, and are installed in a decentralized manner, providing flexible needs for heating. The size of individual units can vary from a few to over a hundred kW, which are more suitable for China, where different types and sizes of GSHP systems provide different demands in different regions. To satisfy Beijing's needs for heating, cooling and domestic hot water, GSHP can be installed for both residential and commercial uses. One of the most important advantages of GSHP systems is that these systems can contribute more environment protection than fossil energy conventionally consumed in Beijing, which is significant also to for the 2008 Olympic venue. The western regions of China have many different characteristics from the eastern regions, e.g. relatively undeveloped and undisturbed environment, with a shortage of energy. As environment friendly systems, GSHP will play an increasing important role in the development of the western regions.

- GSHP systems require small areas to install with low operating and maintenance costs, and geothermal energy has no transportation risks.

- GSHP systems are more environmental friendly. The GSHP systems operate emission free and help to reduce greenhouse gas emissions like CO₂.

- In terms of cost analysis of lifecycle, GSHP systems are relatively cost-effective.

3.2.2 The Technologies to Promote the Development of GSHP Systems in China

GSHP is quite new in China. To promote the GSHP market in China, there are still a number of technological problems to be solved.

- In some regions, installation of open or groundwater systems should have the priority to be considered. These sites with suitable aquifers, which

has sufficient permeability to allow production of the desired amount of ground water, and the quality of the groundwater is good, e.g. low iron content, and to avoid problems with scaling, clogging and corrosion. Open systems tend to be used for larger installations and the cost is comparably low depending upon well costs. But the local regulations to water resources must be strictly followed and the affect of the installations must be observed.

- The horizontal ground heat exchangers, with different type of pipe patterns, in series, in parallel and slinky as closed systems, are easiest to install. These systems need relatively larger surface areas.

- The vertical ground heat exchanger can provide sufficient heat exchange capacity under a confined surface area. Thus, it is more widely favored. The design of a vertical ground heat exchanger is depended on the type of underground (soil, rock and water). The thermal properties of the underground are the key to the design of the vertical ground heat exchanger. For small systems the design is relatively simple. In Europe, below 30 kW, a table of values and a nomogram is proposed, and there are also rules of thumb that can often be used for the initial planning and cost estimate in the U.S.. Larger installations are typically more complex and require more sophisticated methods like computer simulation. Now there are some programs, such as "EED"—Earth Energy Designer, developed and used mainly in Europe, "GchpCalc"—Geothermal Heat Pump Design Software for Commercial Buildings, from Stephen Kavanaugh in the U.S..

- One unusual systems with geostructures such as foundation piles or supporting walls equipped with heat exchanger tubes can be taken as a special case of vertical closed systems. Additionally, the water from mines and tunnels, hybrid system, standing column well and underground thermal energy storage, can also be considered as efficient systems suitable to different regions or sites to provide heating or cooling in China.

- To install GSHP efficiently the design of the GSHP should be studied thoroughly, including the research of local basic conditions and the thermal conductivity between borehole heat exchanger and surrounding formations. Good local basic research is important, to include climate, topography, geology, as well as the distribution of a) subsurface temperature, b) geothermal gradients, c) soil thermal conductivity, and d) groundwater flow conditions. All this kind of research has been done in Europe or in the USA, whereas in China the technologies and instruments to determine the local basic conditions should be conducted. The variety of geological formations and properties that affect thermal performance must be investigated, and a database of the formations built. Meanwhile the thermal conductivity model of the thermal properties should be established, and with the aids of a computer the conduction of heat between the fluids flowing in the tubes of the heat exchanger can be calculated more exactly.

- In the market investigation, including economical, environmental and potential comparison, the most important factor is the cost of GSHPs. Cost performance evaluation should be the first step to introduce GSHPs in China. Only when GSHPs are

cost-effective and competitive to other heating systems, can GSHPs be accepted, especially when used for the decentralized individual needs in China. Results from Europe, USA, and Japan indicate that GSHPs are cost-effective and competitive compared to other heating systems. It is more important to do cost performance evaluation based on the conditions of China.

- Heat pump selection, loop design and pumping are also a new technology in China. The material of the heat exchanger (U-tube), circulating fluids and grouting material to fill the void between the U-tube and the borehole etc should also be studied.

- For widespread utilization, standardization of GSHP systems and preparation of manuals are important to understand this system for designers, system builders, and the users.

3.2.3 The international collaboration will be the most efficient way to develop GSHP systems in China.

The USA and some European Countries have developed GSHPs for many years. Thus, they have a mature technique and rich experience which can help China to develop the GSHPs market. This can benefit the world environment because of reduction of greenhouse gas emission like CO₂. The international collaboration will promote the widespread utilization of GSHP in China.

4. CONCLUSIONS AND SUGGESTIONS

- Geothermal energy will be one important component in the energy structure in China;

- Geothermal resources are renewable, but must be researched and planed for the sustainable utilization.

- To develop deep resources of Yangbajing geothermal field, HDR technologies can be applied, with water circulating men in made fractures by hydraulic stimulation, heat can be extracted from deep formation.

- Geothermal source heat pump will be one of the most suitable air-conditioning methods, and some research based on condition of China should be adopted.

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