Research status of geothermal resources in China

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Abstract. As the representative of the new green energy, geothermal resources are characterized by large reserve, wide distribution, cleanness and environmental protection, good stability, high utilization factor and other advantages. According to the characteristics of exploitation and utilization, they can be divided into high-temperature, medium-temperature and low-temperature geothermal resources. The abundant and widely distributed geothermal resources in China have a broad prospect for development. The medium and low temperature geothermal resources are broadly distributed in the continental crustal uplift and subsidence areas inside the plate, represented by the geothermal belt on the southeast coast, while the high temperature geothermal resources concentrate on Southern Tibet-Western Sichuan-Western Yunnan Geothermal Belt and Taiwan Geothermal Belt. Currently, the geothermal resources in China are mainly used for bathing, recuperation, heating and power generation. It is a country that directly makes maximum use of geothermal energy in the world. However, China’s geothermal power generation, including installed generating capacity and power generation capacity, are far behind those of Western European countries and the USA. Studies on exploitation and development of geothermal resources are still weak.

1. Introduction

Energy shortage and environmental pollution have become important issues restricting sustainable global development[1]. The exploitation and development of new green energy represented by non-fossil energy such as wind energy, solar energy, water energy, biomass energy, geothermal energy and ocean energy, has become the hot topic of energy studies in the world. Geothermal energy is featured by large reserve, wide distribution, cleanness and environmental protection, good stability, high utilization factor and other advantages. Not only are geothermal resources important renewable energy and mineral resources, they are applicable to medical treatment, tourism, and industrial and agricultural purposes. Geothermal resources are inexhaustible clean energy if they are rationally exploited and developed, which are highly recognized and valued in various countries. The abundant and widely distributed geothermal resources in China show a broad prospect for development. The exploitation of geothermal resources has boomed since the 1990s. In recent year, the quantity of direct geothermal utilization in China has taken first place in the world, steadily increasing by nearly 10% every year and making a great contribution to the low carbon economy development in China. Nevertheless, the geothermal industry in China is still in its infancy, with a low degree of development and utilization of geothermal resources.
2. Classification and Distribution Characteristics of Geothermal Resources

2.1 Classification of Geothermal Resources
Geothermal resources refer to geothermal energy, geothermal fluid and their useful constituents in the interior of the earth that can be economically utilized by human beings\(^2\). Geothermal resources can be divided into four types, namely, hydrothermal, geo-compressed, hot dry rock and magma resources\(^3\). So far, only the geothermal resources of hydrothermal type are by and large developed and utilized on a large scale throughout the world. In terms of temperature, it can be divided into high temperature, medium temperature and low temperature geothermal resources.

2.2 Distribution Characteristics of Geothermal Resources in China
The formation and distribution of geothermal resources in China are subject to the characteristics of geologic structure of China and their locations in the global tectonic plates. The global Mediterranean-Himalayan Geothermal Belt and Circum Pacific Geothermal Belt run through southwest region and southeast coast of China. For these reasons, the high temperature geothermal belt mainly centers on two regions: Tibet-Western Sichuan-Western Yunnan and Taiwan. Tibet-Western Sichuan-Western Yunnan Geothermal Belt is the eastern branch of the global Mediterranean-Himalayan Geothermal Belt. The thermal flow value of this regional background is 80–100 mW/m\(^2\), and the highest value is about 364 mW/m\(^2\). Taiwan Geothermal Belt is located in the boundary between the Pacific Plate and the Eurasian Plate, which is a part of the West Pacific Island Arc Geothermal Sub-belt. With active earth crustal motion, including violent quaternary volcanic activities and frequent earthquakes, Taiwan Island is the zone with the strongest geothermal activities among the southeast islands of China. The medium and low temperature geothermal resources in China are broadly distributed in the continental crustal uplift and subsidence areas inside the plate. The crustal uplift area has developed the fault belt formations in different geological time, most of which could act as favorable channels for ground water movement and rising after multiperiod geological activities. Seeping into deep crust and being heated under normal geothermal gradient through deep cycling, atmospheric precipitation gushes out of the earth surface along the active fault and forms hot spring. The southeastern coastal geothermal belt is the zone with the most intensive hot springs in the crustal uplift area, including Eastern Jiangxi, Southern Hunan, Fujian, Guangdong and Hainan. In the crustal subsidence area inside the plate, Mesozoic and Cenozoic sedimentary basins were broadly developed in China, e.g. North China Basin, Songliao Basin, Sichuan Basin, Ordos Basin, Weihe Basin, North Jiangsu Basin, Junggar Basin, Tarim Basin, and Qaidam Basin. These basins contain abundant medium and low temperature geothermal resources which are often in the same basins together with oil and gas or other mineral resources such as coal\(^4-6\).

According to the statistics of China's geothermal resources assessment results\(^7\), the amount of geothermal resources of the 12 major basins (plains) in China is 24 964.4×10\(^18\) J, which can be converted into standard coal of 8.531.9×10\(^8\) t. It is expected that the annual amount of minable geothermal resources can be converted into standard coal of 6.4×10\(^8\) t and the annual reducibly emitted CO\(_2\) of 13×10\(^8\) t. The annual heat release of hot springs in China is 1.32×10\(^17\) J, which is equivalent to the heat generated by burning 451.83×10\(^4\) t standard coal. If the mineable coefficient of 5.0 is taken, the amount of mineable convective geothermal resources in China is 6.6×10\(^17\) J/a, which is converted into standard coal of 2.259.1×10\(^4\) t/a.

3. Utilization Status of Geothermal Resources
The utilization of geothermal resources can be divided into direct utilization and power generation. The geothermal resources are principally used for heating, cooling, medical care, hot spring bathing, tourism, aquaculture, greenhouse cultivation and so on in a direct way. Currently, among the geothermal utilization modes, China has formed the development and utilization patterns consisting of geothermal power generation represented by Yambajan in Tibet, geothermal heating represented by Tianjin, Shaanxi and Hebei, shadow water source heat pump heating and cooling represented by
Shenyang, seawater source heat pump heating and cooling represented by Dalian, recuperation and tourism represented by Beijing and southeastern coastal region as well as geothermal cultivation and breeding represented by North China Plain.

Figure 1. Conventional geothermal resources distribution in China\cite{1}.

3.1 Direct Utilization of Geothermal Resources
China has developed and utilized geothermal resources and hot springs for more than 2000 years, which is one of the oldest countries using geothermal resources. The direct utilization amount of geothermal resources in China has ranked the first for many years. According to the report of the World Geothermal Conference 2010, the direct utilization amount of geothermal resources in the world was 121,696 GWh in 2010, and China's direct utilization amount of geothermal resources is 20,932 GWh, accounting for 17.2% of the global utilization amount. Among all countries, the direct utilization amount of 15 countries is more than 2,000 GWh/a. According to incomplete statistics, of the direct utilization of geothermal resources in China, bathing and recuperation accounts for 47.55%, heating 30.77% and others 21.68%.

3.2 Geothermal Power Generation
At present, the geothermal power generation technologies mainly consist of dry steam power generation, flash evaporation (expansion) power generation and dual working medium cycle power generation (including organic Rankine cycle and Kalina cycle). Dry steam power generation is the primary method for high temperature geothermal field power generation; while flash evaporation method and dual working medium cycle power generation method are two major methods for medium and low temperature geothermal power generation. Yambajan Geothermal Power Station in Tibet also adopts the two-stage flash evaporation power generation technology.

Geothermal power generation has a history of more than a century. In 1904, Italians built the first geothermal power station in the world, and 24 countries have utilized geothermal power generation up to date. In 1970, China became the eighth country that took advantage of geothermal resources for power generation. Nevertheless, during the 30 years afterwards, geothermal power generation has always lagged behind without improvement in China. But nowadays, among 24 countries using geothermal power generation, China's installed capacity just ranked 18th. According to the report of
the World Geothermal Conference 2010, the installed capacity of global geothermal power generation was up to 10 716.7 MW. China's installed capacity was only 24 MW, ranking 18th and accounting for 0.22% of the world's total installed capacity.

Whereas, from the perspectives of domestic and foreign circumstances, the development of geothermal industry in China is still facing great challenges. In term of international circumstance, although China has become the country that directly utilizes maximum geothermal energy in recent years, its geothermal power generation, including installed generating capacity and power generation capacity, is far behind those of Western European countries and the USA. In term of domestic circumstance, new energy resources such as wind energy, solar energy, nuclear energy and biological energy have rapidly boomed in recent years under the favorable conditions of national preferential policies, government subsidies and access to preferred loans. In comparison, geothermal power generation is still in a weak position and ranks last among the new energy resources under the restriction of technologies, resources, policies and conditions. The geothermal industry remains stagnant and has not yet formed a certain scale of industrial structure. The utilization level of geothermal resources accounts for a small proportion in the entire energy structure.

Meanwhile, with the accelerated pace of geothermal resources commercialization, industrialization and scalarization, the economic assessment on exploitation and utilization of geothermal resources becomes more and more important in China. Nevertheless, studies on the economic assessment of exploitation and utilization of geothermal resources are still in their infancy. The studies of the academic circle on exploitation and development of geothermal resources are still weak. In the economic assessment on exploitation and utilization of geothermal resources, factors such as technologies, economy, environment and resources or the composite relation between the factors are separately taken into consideration, hence the comprehensive assessment on the system of resource-economy-environment. The input and output of geothermal development and utilization are principally used for financial calculation, with the lack of performance studies in the input and output of geothermal development and utilization.

4. Conclusion
(1) According to the characteristics of exploitation and utilization, China's geothermal resources can be divided into high-temperature, medium-temperature and low-temperature geothermal resources.

(2) The medium and low temperature geothermal resources are widely distributed in the continental crustal uplift and subsidence areas inside the plate, represented by the geothermal belt on the southeast coast; while the high temperature geothermal resources concentrate on Southern Tibet-Western Sichuan-Western Yunnan Geothermal Belt and Taiwan Geothermal Belt.

(3) The geothermal resources in China are mainly used for bathing, recuperation, heating and power generation. It is the country that directly makes maximum use of geothermal energy in the world. However, China's geothermal power generation, including installed generating capacity and power generation capacity, is far behind those of Western European countries and the USA. The studies on exploitation and development of geothermal resources are still weak.

The Feimo Cu-Mo polymetallic deposit is situated within the Ailaoshan Copper-Gold metallogenic belt and provides excellent metallogenic conditions.

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