Current Situation, Challenges and Prospects of Geothermal Energy Development in China

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Abstract. Based on the geothermal resource conditions, the current situation of China's geothermal energy utilization in heating (cooling), power generation, hot spring bathing, high-end seed breeding, and hot dry rock exploration and development are explained. The development trend of geothermal energy in the fields of resource discovery, exploration, development and utilization technology, utilization scale, macro policies, and market participants are predicted in the context of the goal of "carbon peak and carbon neutral". Finally, suggestions on the management of China's geothermal industry is proposed.

Keywords: Geothermal power; hot dry rock; carbon peaking; carbon neutrality.

1. Introduction

Geothermal energy is a kind of renewable energy which has characteristics of abundant reserves, wide distribution, reliability, stability and high utilization coefficient, which makes it quite competitive among the clean energy available today [1-3]. In order to implement the objective of "carbon peaking and carbon neutrality", it is important to vigorously develop and utilize geothermal energy. From a worldwide perspective, power generation and direct usage of geothermal energy are its principal uses. (1.072 1×107 kW for global geothermal power generation and 5.059 1×107 kW for direct utilization in 2010), with a total of 27 countries worldwide using geothermal power (mostly in the Americas and Asia, accounting for 39.9% and 35.1% of the world's total installed capacity, respectively [4-7]. By the end of 2021, more than 100 million m2 of geothermal heating (cooling) area will be added nationwide, which shows the good development of geothermal industry. The development of geothermal energy according to local conditions and the construction of comprehensive geothermal energy will occupy an important position in the clean heating in the north, heating and cooling in the south, energy-saving renovation of buildings and rural revitalization. This article gives an overview of the utilization of geothermal resources and the current status of geothermal development technology in China and looks forward to geothermal energy. The current problems that need to be tackled and suggestions have been listed.

2. Overview of Chinese geothermal resources

According to the differences in geological structure characteristics, heat flow transmission mode, temperature range and exploitation mode, geothermal energy is divided into three types such as shallow geothermal energy, hydrothermal geothermal energy, and hot dry rock as shown in Fig. 1. Shallow geothermal energy is distributed throughout the country, and shallow geothermal energy resources are distributed underground in the shallow part of the mainland. Hydrothermal high-temperature geothermal resources are primarily distributed in southern Tibet, western Yunnan, western Sichuan, Taiwan,etc.. Other areas are dominated by geothermal resources of medium and low-temperature. Their genesis and storage conditions are mainly influenced by the shallow geothermal field and the depth of bedrock burial. The shallow geothermal field is related to the earth's heat flow and the average annual temperature, which vary from region to region, but the temperature of the stratum at a depth of 200 m is mostly lower than 25℃. The depth of bedrock determines the difficulty of establishing and making use of shallow geothermal energy, and the loose rocks of the Fourth Series deposited in the vast plain area are easy to drill into and generally have certain waterrichness, which is more conducive to the application of buried pipes and water source heat pumps in relatively shallow buried bedrock. Influenced by various factors such as tectonics, magmatic activity, formation lithology, and hydrogeological conditions, the distribution of hydrothermal geothermal resources has a certain regularity. According to their distribution and genesis differences, they can be divided into two categories: sedimentary basin type and hoisted mountain type. Sedimentary basin type geothermal resources are primarily distributed in Songliao Basin, Bohai Bay Basin, North and South China Basin, Ordos Basin, etc. Hoisted mountain type geothermal resources are generally smaller in scale and mainly distributed in uplift and orogenic belt areas. According to the genesis, hot dry rock resources can be broadly classified into four types: strongly tectonic activity belt type, sedimentary basin type, modern volcanic type and high radioactivity heat production type. The Qinghai-Tibet Plateau, the Tengchong, Changbai Mountain and the Five Great Lotus Ponds in the area of strong tectonic activity, the southeast coast where large Mesozoic acidic granite bodies are developed, and the lower part of the Cenozoic basin have good exploration potential. The survey results of China Geological Survey show that the annual recoverable resources in 336 major Chinese cities, shallow geothermal energy is comparable to 700 million tons of standard coal, and the annual recoverable resources of medium and deep geothermal energy are equal to 1.865 billion tons of standard coal. The amount of hot dry rock geothermal energy resources in the depth range of 3.0-10.0 km in mainland China is equivalent to 856 trillion tons of standard coal, of which 106 trillion tons of standard coal is equivalent to the depth of 5,500 m [8-9].

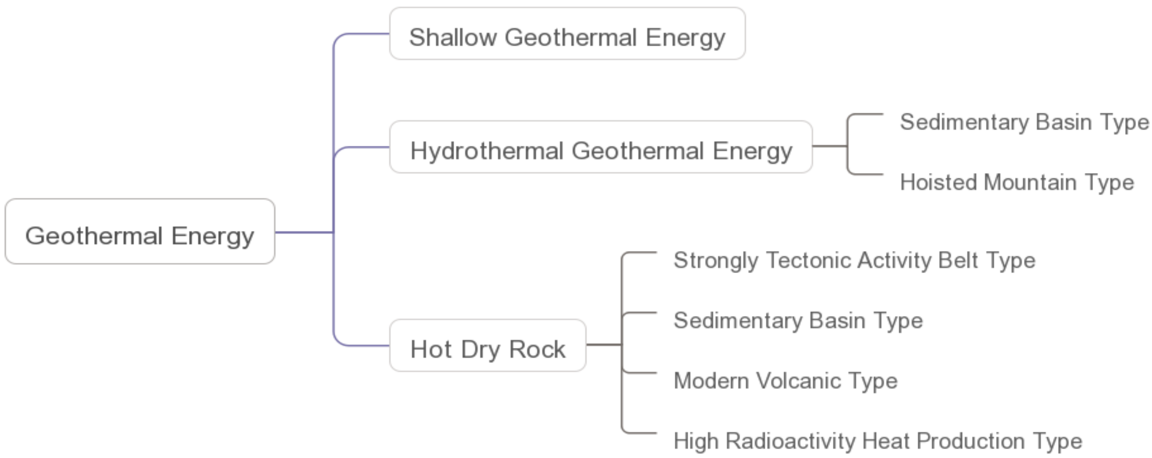

Fig.1 Classification of Geothermal Energy

3. Chinese Geothermal Energy Development and Utilization Status

3.1. Shallow geothermal energy for heating (cooling)

The rapid development of shallow geothermal energy utilization in China mainly relies on the continuous progress of heat pump technology, with an annual average growth rate of 15.6% from 2016 to 2020. To the end of 2020, the shallow geothermal energy heating (cooling) floor area in China reaches 810 million m2 as shown in Fig. 2. The areas where shallow geothermal energy utilization has been distributed on a large scale are mainly concentrated in the southern northeast, northern China and the middle and lower reaches of the Yangtze River, and the scale of heating (cooling) in provinces such as Liaoning, Hebei and Beijing exceed 50 million square meters. In terms of project utilization, shallow geothermal energy utilization is mainly concentrated in buildings such as offices, hospitals, malls, schools and other public structures, and is primarily used for both heating and cooling. Water source heat pump systems are relatively widely used before 2016. Between 2016 and 2020, shallow geothermal energy is mainly utilized by buried pipes due to shallow geothermal water extraction policy and environmental protection requirements.

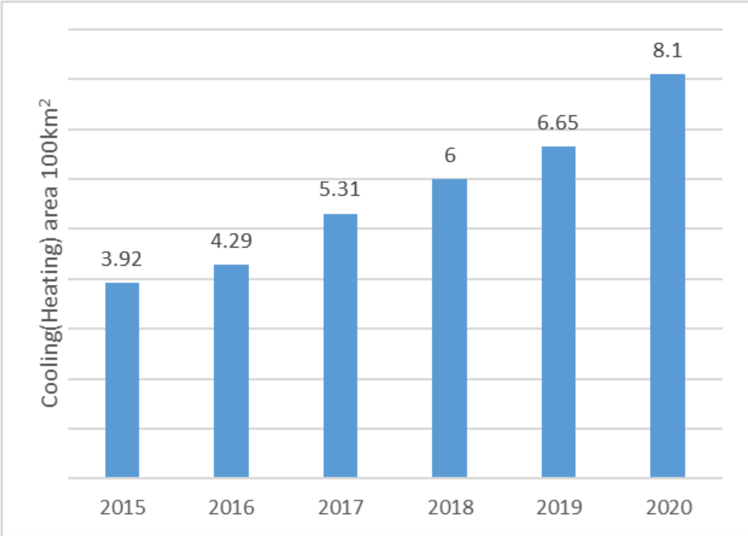

Fig.2 Shallow Geothermal Energy Growth in China from 2015-2020

3.2. Medium-deep geothermal heating

Under the background of the country winning the Blue Sky Defense War and clean heating in the north, medium-deep geothermal clean heating is developing rapidly with an annual average growth rate of 10%. At the end of 2020, the total area of medium and deep geothermal heating will reach 5.82 1×10^9 m^2. In terms of the types and characteristics of geothermal resource utilization, medium-deep geothermal heating is mainly concentrated in the Bohai Bay Basin, the South China North Basin and the Fenwei graben system where geothermal resource conditions are favorable, with the development of three sets of thermal reservoirs mainly in the Jixian System, the Ordovician karst and the Neoproterozoic sandstone. Local areas develop the thermal reservoirs in the Paleoproterozoic System, and the exploitation temperature is mostly between 45~80℃. From the administrative division and the scale of geothermal heating utilization in each province, the areas with the large scale of geothermal heating area are mainly concentrated in the northern provinces and cities such as Hebei, Henan, Shandong, Shanxi, Shaanxi and Tianjin where the demand for clean heating is strong. Among them, the scale of medium-deep geothermal heating in Hebei is the largest, with an area of 160 million square meters. The area of medium-deep geothermal heating in Henan and Shandong both reaches over 50 million square meters as shown in Fig. 3. In terms of the development of geothermal heating project, geothermal heating has gradually developed from distributed single heating projects to centralized heating utilization in cities and towns.

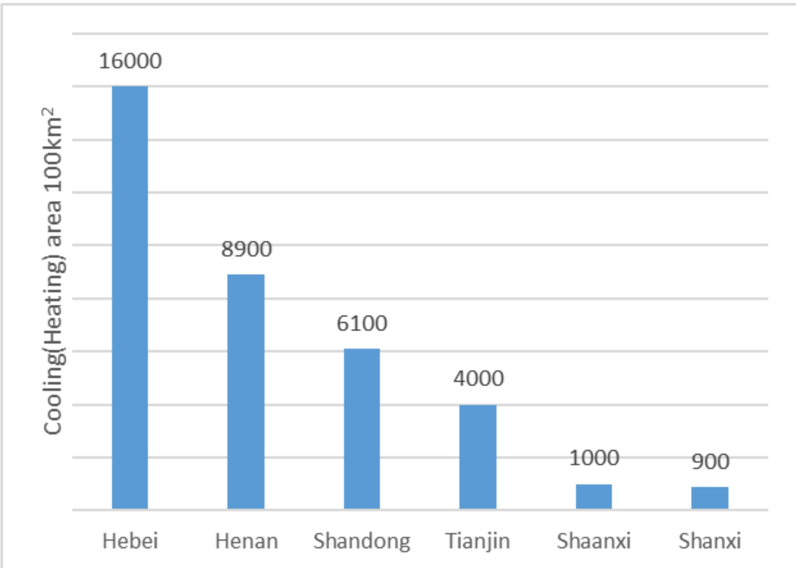

Fig.3 Area of Medium and Deep Geothermal Heating in Major Norther Provinces of China

3.3. Utilization of geothermal energy production

Due to the influence of geothermal resource taste and electricity price, Chinese geothermal power generation started early, however, the development was relatively slow. In December 1970, the first geothermal power generation unit in China was successfully generated in Dengwu, Fengshun County, Guangdong Province. In September 1977, the first MW high temperature geothermal energy generation unit was successfully generated in Yambajing, Tibet. In 1991, Yambajing geothermal energy power plant in Tibet was successfully installed with an installed capacity of 25.18 MW. After that, the total installed capacity of geothermal power generation in China has not increased significantly until 2015. Between 2016 and 2020, China added 18.08 MW of geothermal power generation capacity, achieving a cumulative installed capacity of 45.36 MW. In 2018 the Tibet Yang Yi 16 MW geothermal power plant was connected to the grid, becoming the largest single project of geothermal power generation after the Yang Bajing geothermal power plant.

3.4. Other uses such as hot spring bathing

The use of hot spring bathing, greenhouse and aquaculture is the most direct way to utilize geothermal resources. Geothermal water with medical value is the main object of development, and Chinese scale of the utilization of hot springs has consistently rated top in the globe for many years, almost all over the country. In 2019, the utilization scale equals to 6,608 MW. About 20 provinces in China use geothermal energy for greenhouse planting and aquaculture, among which greenhouse planting is mainly for anti-seasonal vegetables and flowers while aquaculture is mainly for tilapia, prawns and other aquatic products. In 2019, the equivalent installed capacity of geothermal energy development and utilization in the greenhouse cultivation and aquaculture territories in China was 346 MW and 482 MW, respectively, which increased by 55.4% and 55% compared with 2015.

3.5. Hot dry rock exploration and development and utilization

Compared with the United States, Germany, France and Japan, China was late in exploring, developing, and using hot dry rock, and hot dry rock development and exploitation has not been carried out for the time being. Since the establishment of 863 project by the Ministry of Science and Technology in 2012 to start special research on hot dry rock in China, the China Geological Survey, Sinopec, and provincial geological units have finished a lot of exploration work. In 2017, the China Geological Survey made a breakthrough in hot dry rock exploration in China by drilling and encountering a 236°C high temperature hot dry rock body at a depth of 3,705 m in the Republican Basin of Qinghai [10], and at this stage, it focuses on gearing up the construction of electricity generation demonstration projects.

4. Current Status of Geothermal Resource Development and Utilization Technology

Geothermal resource development and utilization is a multidisciplinary and comprehensive technology, involving such technologies as resource exploration and evaluation, drilling and formation process, tailwater recharge, gradient utilization, high-efficiency operation, heat insulation and heat exchange, anti-corrosion and scale prevention, and power generation. After years of research and development, geothermal workers in China have initially established a set of technology systems that are compatible with the characteristics of Chinese geothermal resources and have guided the practice of discovery and exploitation of geothermal resources.

4.1. Geothermal resource exploration and resource evaluation technology

Geothermal resource exploration technology mainly includes the geophysical exploration method, geochemical exploration method, and remote sensing method. At present, the geothermal resource exploration technology in China is mainly electric and geomagnetic method, and the exploration depth does not exceed 2000 m. The geothermal resource evaluation methods and technologies mainly include the surface heat flow method, magma heat balance method, analogy method, thermal storage method, statistical analysis method, and numerical model method. Among them, the thermal storage method is the most mature and has been widely used.

4.2. Geothermal drilling and formation process technology

For different depths, stratigraphic and lithological characteristics, China has basically developed drilling for geothermal well at moderate and low temperatures and formation technologies such as the optimized design of a good structure, low-density fluid drilling, logging of physical and chemical properties of thermal reservoirs, and effective reservoir evaluation, which are suitable for different thermal reservoir types. In terms of geothermal well formation technology, a variety of well body structures suitable for efficient development have been formed based on different reservoir properties such as sandstone pore type and bedrock fracture type, and the deepest geothermal well in China (People's Bank of Xianyang well with a depth of 4,250m) has been drilled, with water coming out of the wellhead reaching 126°C.

4.3. Geothermal tailwater recharge technology

A strategy to prevent thermal and chemical contamination brought on by the direct discharge of geothermal wastewater is geothermal recharge, and it is crucial for maintaining the thermal reservoir’s pressure as well as for ensuring the technical requirements of geothermal field exploitation, reducing the resources waste, expanding the lifespan of production wells and minimizing environmental pollution. To avoid cooling of the thermal reservoir due to recharge, recharge tests and tracer tests need to be conducted and comprehensive monitoring of the recharge process needs to be carried out.

4.4. Geothermal resource gradient utilization technology

According to the idea of "Grade Matching, Gradient Utilization", the gradient utilization technology of geothermal resources can realize the gradient utilization of geothermal power generation, efficient heating and cooling of buildings, industrial and agricultural production, and hot spring bathing, and significantly promote the conversion and utilization of geothermal energy.

4.5. Geothermal development and utilization system high-efficiency operation technology

Geothermal resources have obvious geographic distribution characteristics, so a set of information management platform with geographic location as the platform, including resource development process management, dynamic monitoring of operation of each development project, analysis of dynamic changes in thermal storage and sustainable utilization of geothermal, and information network release of each project, etc. is built. Automatic control and other technologies are used to optimize system operation and establish an automatic monitoring system. The network of monitoring stations could be built to achieve real-time understanding, comprehensive maintenance, and unified management of geothermal project operation conditions. After basic remote control is realized, the number of on-site operation personnel is reduced. The early warning of abnormal working conditions of the system can be made to avoid abnormalities or accidents of the whole geothermal site and make the whole system run safely, stably and efficiently.

4.6. Geothermal water insulation and heat exchange technology

Conducted technical research on double-layer insulation pipe, double-layer heat insulation casing, foam cement slurry, polymer anticorrosive insulation coating, etc. The thermal conductivity of the insulation pipe is less than 0.05W/(m·°C). The insulation technology has been mastered the in the process of geothermal water transmission to reduce the heat loss in transmission. For different areas of geothermal water quality, different heat exchanger design and material selection are used to effectively improve the heat transfer efficiency.

4.7. Anti-corrosion and anti-scaling technology

The mineralization of geothermal water is generally high, especially the hardness and alkalinity are high, and the stratum water contains a large number of cations such as Ca^{2+} and Mg^{2+}, and also contains a certain concentration of hydrogen sulfide, carbon dioxide, and other acidic substances, so the scaling and corrosiveness of water quality are strong, which easily causes the corrosion and scaling of geothermal mining and utilization systems, such as power generation equipment and heating systems, and seriously affects the service life of the equipment and normal operation. A lot of work has been done in China to solve the corrosion and scaling problem of water system equipment, and preliminary research has been carried out on the anti-corrosion and anti-scaling technology of heat pumps in the geothermal development process, and there are mature technical solutions for the treatment of wastewater with high acidic gases such as CO_2 and H_2S.

4.8. Energy-saving transformation technology of geothermal heating terminal

The heat dissipation performance of the end of geothermal heating directly affects the efficiency of geothermal application and development. Through the energy-saving transformation of the end, lowering the heating water supply temperature, and widening the temperature difference between supply and return water, the heating capacity can be effectively improved and the comfort of users can be increased at the same time. At present, the heating end is dominated by radiators, radiant floor, and fan coils. Develop high-efficiency radiators for geothermal heating and target the end with adaptive energy-saving transformation to improve heat utilization efficiency. The technology is mainly applied to older buildings to improve heating efficiency by developing new radiators to retrofit old radiators.

4.9. Expansion flash steam energy generation technology

The process of expansion flash steam energy generation equipment is simple, but the thermal efficiency and economic benefits of the generator set are greatly affected by the temperature level of the heat source and the temperature of the circulating water, and the overall thermal efficiency and economic benefits of the unit are not high. Among them, the basic situation of Tibet Yangpaijing Geothermal Power Station is as follows: geothermal fluid temperature 140-160℃, wet steam, installed 24MW (8 sets of units); annual power generation capacity of more than 100 million kWh, supplying more than 40% of the electricity of Lhasa city.

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6. Existing Problems and Countermeasures

Although China's geothermal energy has made important progress, due to its dual attributes of geological minerals and energy, compared with other new energy sources, there are still large gaps in the management process, institutional mechanisms, financial and taxation policies, etc., which need to be further improved and perfected. At present, China is facing problems such as a low degree of geothermal resource exploration, difficulty in discovering deep hidden geothermal resources, lack of unified development and utilization planning, irregular management of resource development and utilization, low precision in evaluating recoverable geothermal resources, immature high-temperature drilling technology, etc. It also faces problems. In view of these problems, the following suggestions are made.

(1) Geothermal resources exploration and research could be strengthened, and the number of geothermal resources could be found out which can be developed and utilized in the region and its development and utilization conditions.

(2) According to the regional resource conditions, formulate regional unified development and utilization planning.

(3) The management process could be straightened out and the regulation of exploitation need to be strengthened, a unified mining right system need to be established, and the development of industry could be promoted orderly.

(4) Optimize the allocation of resources and implement comprehensive, graded and recycled utilization of geothermal resources in terms of heat, minerals and water, reflecting their optimal economic, resource and environmental benefits.

(5) Implement differentiated treatment of hot springs in mountainous areas and deep geothermal wells in plains, as well as differentiated management of geothermal fields and single-well mining in cities and towns, and focus on supporting the construction of geothermal central heating projects in cities and towns with balanced mining and irrigation and large-scale development [11].

(6) Strengthen scientific and technological research on geothermal energy generation at medium or low temperature, hot dry rock utilization, and economic recharge of sandstone.

(7) Carrying out standardized management of geothermal projects, strict project review and supervision, and guiding the healthy and sustainable development of the geothermal market through integrated planning, legal control, localization, classification, government guidance, market promotion, ecological protection, and efficient energy conservation [12].

7. Conclusion

At present, the use of different depths of the soil (or groundwater) heat transfer and storage characteristics and heat pump technology combined with shallow low-grade geothermal (heat) energy to high-grade energy for building cooling or heating in the economy, environmental protection, and other aspects have obvious advantages. The energy saving and emission reduction effect is obvious, thus making the use of shallow geothermal (heat) energy heat pump technology has been widely promoted and used. Utilization of heat pump technology is still in the initial stage in China, so it is necessary to effectuate extensive research on some common concerns, especially on the issues of close concern to the two major disciplines of geology and HVAC. Under the double pressure of energy shortage and environmental pollution, this clean and renewable new energy source is increasingly valued by administer. A series of supportive and encouraging policies and management regulations have been introduced, and some local governments also subsidize the development and utilization of shallow geothermal energy with financial subsidies, which has laid an important technical and material foundation for the development of this technology. Energy is the basis of human development, and mankind needs clean geothermal energy. More efforts should be put in geothermal development including investing and application of this technology.

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