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Research on the Development Trend of Global Geothermal Industry Based on Patent Analysis

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ABSTRACT

Geothermal energy, as an efficient and clean "local" energy derived from deep part of the earth, has the advantages of large resource scale, sustainable stability and environmental friendliness while utilizing. It has a wide range of application scenarios under the background of carbon peak and carbon neutralization, and is recognized by majority countries to play a pivotal role in the process of energy evolution. At present, the world has entered the digital, intelligent era, means that information access channels and transmission speed more convenient and fast and accurate. With the arrival of the post-epidemic era and gradual recovery of the oil market, energy market competition becomes more fierce, new energy and traditional energy go hand in hand, therefore, the crucial technologies and their advantages in the global competition showed unprecedented importance. In today's increasingly strengthened awareness of property rights, patent analysis is an effective shortcut for tracking the technology trend and the updated studies on certain technical field, and carrying out targeted technology and product research and development. This paper studies the technology trend of the global geothermal industry from the perspective of patent analysis. The study found that since 2001, there are 66 countries, regions or organizations in the world applied geothermal patents, mainly distributed in China, the United States, the World Intellectual Property Organization and other countries or organizations. In particular, China and the United States are intensive patents in this technology field, far ahead in Chinese mainland and in the United States, with 761 and 378 geothermal technology patents, accounting for 30% and 15% of the total patents. On the whole, geothermal technology patent literature mainly distributed in the countries and regions owning abundant geothermal resources, large-scale oil companies and advanced science and technology, such as Chinese mainland, the United States, Germany, Australia and Japan. The main sources of geothermal technological patents applied in Chinese mainland are European countries, the United States and Canada. Since 2000, the development of worldwide geothermal technology can be divided into three stages, for instance, early slow development period of 2000-2006, rapid development period of 2007-2009, stable development period from 2010 to present, however, the global COVID-19 epidemic in 2020 has a certain negative impact on the development of geothermal industry that the number of geothermal patent applications has a downward trend. To sum up, geothermal development scheme optimization technology, geothermal power generation and geothermal dynamic monitoring technology are the current most important study fields, and underground thermal exchanging and hot dry rock power generation are the future crucial technologies. China has certain advantages technologies in geothermal direct use, resources evaluation, play evaluation, geothermal drilling and completion, although geothermal exploration, development and utilization were concerned less than that in developed countries. Meanwhile, China pay little attention to technologies of geothermal power generation and underground thermal exchanging, which patents are concentrated almost in China without overseas layout.

1.INTRODUCTION

Since June 2014, when the international crude oil price continued to decline, the world's energy structure and consumption composition have undergone significant changes. A number of renewable energy sources, including solar energy, wind energy, geothermal energy and biomass energy, have received extensive attention and strong support from countries around the world (Hiroshi, et al., 2015; Ingrid, et al., 2015; Ingrid, et al., 2015; John, et al., 2015; Ruggero, 2015). At present, oil accounts for about 33% of the global energy consumption structure, while renewable energy only accounts for about 2%. There is still a huge space for development and utilization. From the perspective of sustainable development and environmental protection, renewable energy has better conditions for development and utilization than conventional fossil energy(Barbier, et al., 2002; Barbacki, et al., 2003;.Gwen, et al., 2006; Doug, et al., 2013; Julio, et al., 2013; Patric, et al., 2013; Zigos, et al., 2013; Betina, et al., 2014).

Geothermal energy has attracted wide attention due to its huge scale of resources, wide distribution, stable operation, clean and environmental protection. More and more countries are developing and utilizing geothermal energy, and the depth of development is gradually expanding deeper and deeper. Geothermal is widely used, but it is mainly used for power generation abroad. In recent years, the scale of geothermal power generation in foreign countries has been expanding. The installed capacity of geothermal power generation in the world increased from 8,594 MWe in 2000 to 14,600 MWe in 2018. The installed capacity of geothermal power generation in the United States, Indonesia, the Philippines, Turkey and New Zealand all exceeded 1,000 MWe.Turkey, Indonesia, the United States and Kenya have all increased their installed geothermal power capacity by more than 500 MWe in the last decade.

At present, the world has entered the digital and intelligent era, which means that the access channels and transmission speed of information are more diverse, convenient, rapid and accurate than before. With the advent of the post-pandemic era and the gradual recovery of the oil market, the market competition in the energy field is fiercer than before, and new energy and traditional energy go hand in hand. Under this background, the core technology and technological advantage of enterprises have shown unprecedented importance in the global competition. In the final analysis, the competition between countries and enterprises is actually the competition of core technological strength. Whoever has mastered and possessed key and core technologies in a certain field will have a dominant position in the competition in this field.Nowadays, with the increasing awareness of property rights, one of the most efficient and effective ways to understand and track the technology development trend and the latest research and development trend of a technology field, and conduct targeted technology and product research and development is to make full use of patent information for analysis and research.This paper studies the development trend of global geothermal industry from the perspective of patent analysis.

2 STATISTICAL ANALYSIS OF PATENT DATA

2.1 Major countries of geothermal patent literature distribution

Figure 1 and Figure 2 show the distribution of thermal technology patent documents in major countries and regions worldwide since 2001.There are 66 countries, regions or organizations with patented technologies in this field, mainly distributed in China, the United States, the World Intellectual Property Organization and other countries or organizations.In particular, China and the United States are concentrated areas of patent distribution in this field of technology. The number of patents applied in mainland China and the number of patents applied in the United States is far ahead, with 761 and 378 patents respectively, accounting for 30% and 15% of the total number of patents in this field.The World Intellectual Property Organization, the European Patent Office, Germany and Canada have

more than 100 geothermal technology patents, which is the leader in this field.Australia, Japan, South Korea, Mexico, Brazil, Russia, New Zealand, Eurasian Patent Office, India, Austria, Norway all have more than 20 geothermal technology patents, are relatively strong participants in this field;There are also 10 or more patents distributed in the Philippines, Spain, Argentina, Poland, Denmark, Czech Republic, Israel, Taiwan Province of China, Colombia and Chile.In addition, France, Singapore, Iceland, Italy, Peru, Switzerland, Slovakia and other countries also have sporadic patent distribution, the number of no more than 10.On the whole, geothermal technology patent documents are mainly distributed in countries and regions with abundant geothermal resources, more large oil companies and strong scientific and technological strength, such as mainland China, the United States, Germany, Australia and Japan. In addition to abundant geothermal resources, these countries also have relatively developed economy and advanced science and technology, which effectively promote the development of geothermal industry. The main technology source countries for patent applications in mainland China are European countries, the United States and Canada (Figure 3).

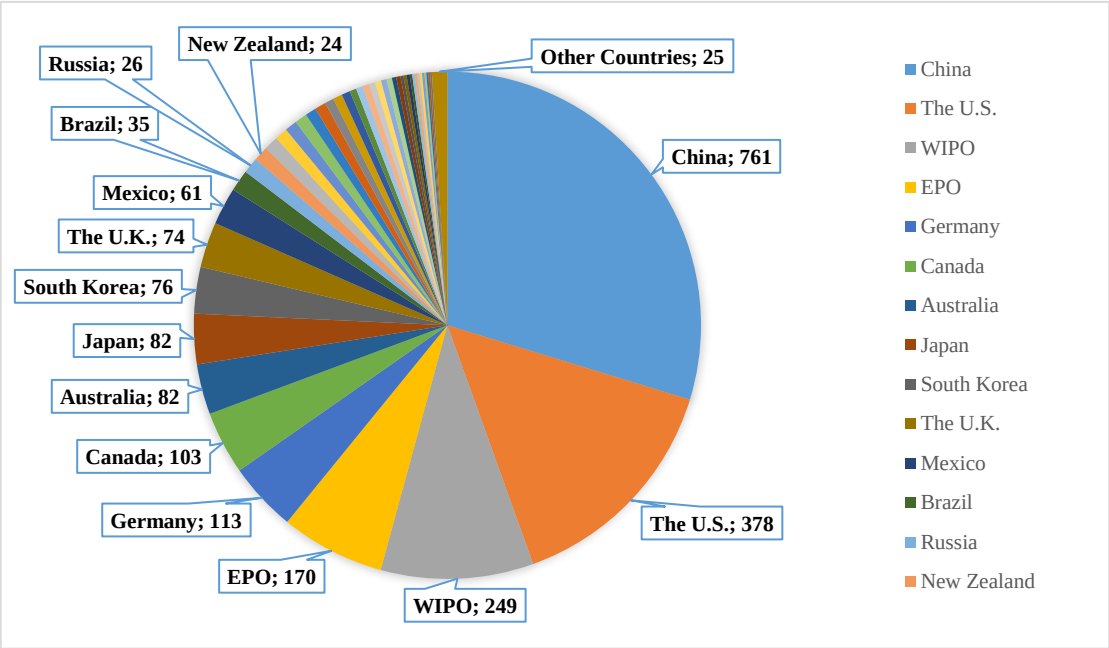

Figure 1: Pie chart of distribution of worldwide geothermal patent documents by country and region

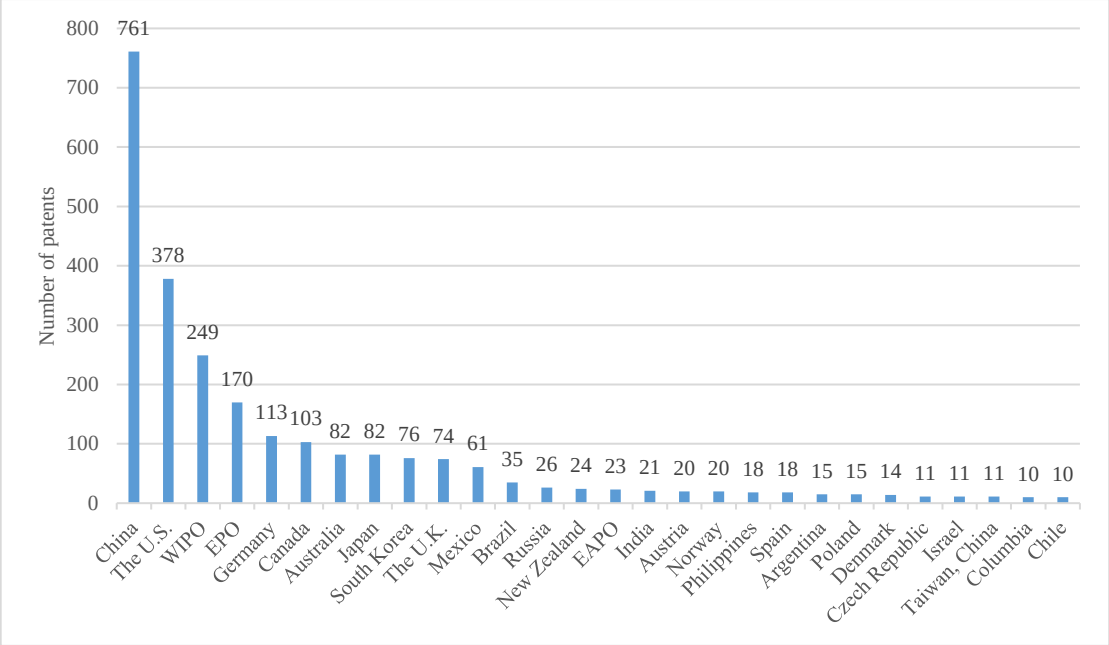

Figure 2: Bar chart of distribution of major countries or regions with more than 10 patents worldwide

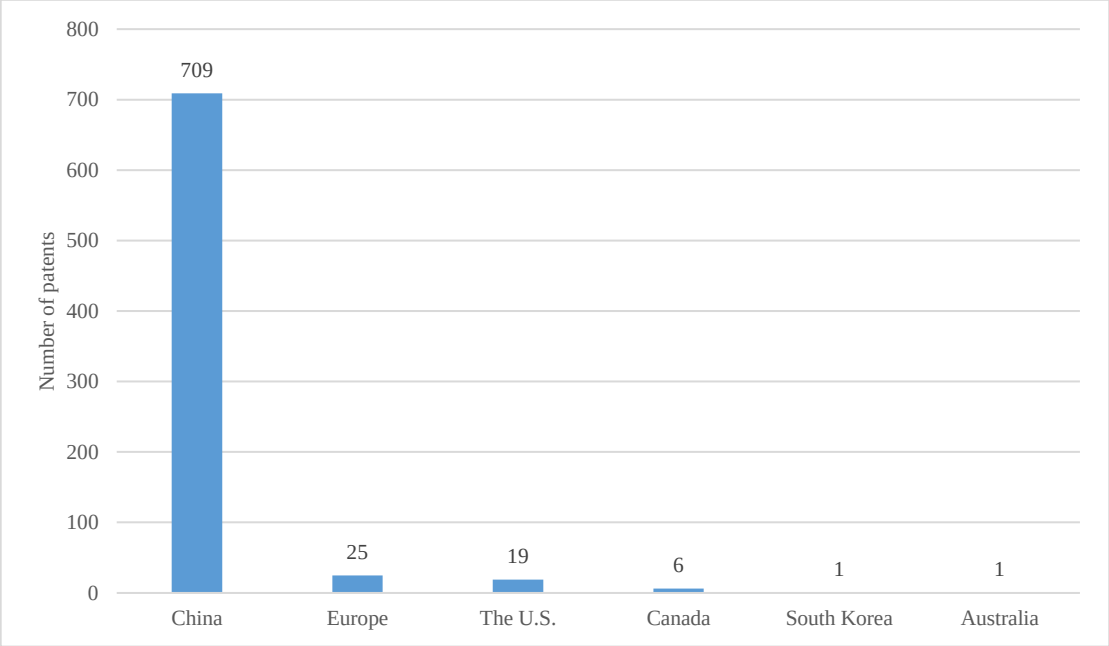

Figure 3: A bar chart of geothermal patents applied in mainland China

2.2 The relationship of geothermal patents over time

In view of the lag time of 18 months from application to publication of an invention patent, and the retrieval of geothermal patent strategy research in this project is up to September 1, 2021, the number of invention patent applications in 2021, 2020 and even 2019 used in this statistical analysis is only a part of the total number of invention patent applications.In particular, far from all invention patents filed in 2020 and 2021 are included in the current statistics.Therefore, the decreasing trend of patent number in 2020 and 2021 in the graph of patent literature changes over time is caused by incomplete data.

Figure 4 shows the changes of the number of domestic thermal technology patent applications and the number of patents published worldwide over time since 2000.The development trend can be divided into three stages: (1) the

early slow development period (2000-2006), which reached a peak in 2003, when there were 61 patent applications;(2) Rapid development period (2007-2009) : international economic recovery had a positive effect on the development of geothermal industry to a certain extent, and the average annual number of patent applications during this period exceeded 100;(3) Stable development period (2010 -- present) :With the plummeting oil price, the rapid decline of conventional oil and gas production, and the increasing difficulty of exploration and development, many oil companies began to consider energy transformation and business restructuring, and have resumed or established internal new energy research teams, which to some extent promoted the development of geothermal technology. During this period, the average number of patents applied was more than 150, and the number of patent applications reached 261 in 2019.However, the global epidemic of COVID-19 in 2020 had a negative impact on the development of geothermal, and the number of geothermal patent applications showed a downward trend.

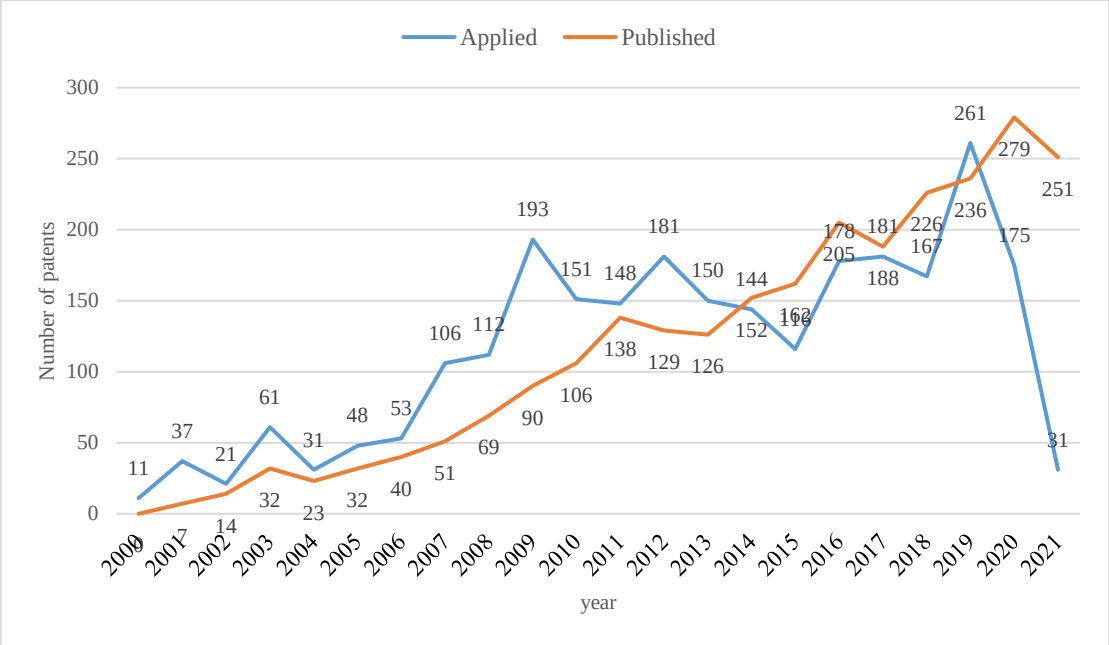

Figure 4: A graph of the volume of thermal technology patents worldwide over time

Although there are some twists and turns, on the whole, the number of geothermal patents worldwide has shown an obvious upward trend since 2001, revealing that technological R&D and innovation efforts have been increasing amid twists and turns, and are in a positive development stage.

In order to further analyze the development history of the technology, taking every two years as a counting unit and comprehensively considering the number of patent applications and the number of patents, the distribution of geothermal patent literature over time since 2000 was studied (Figure 5).The horizontal axis shows the number of patent applications, and the vertical axis shows the number of patents.Through the analysis of the increase and decrease of the number of patents and the number of applicants in each period, the stages of technology are investigated: start-up stage, development stage, technology maturity stage, decline stage and redevelopment stage, which is completely consistent with the trend of patent number over time shown in Figure 4.Due to the delay of patent publication time, the data from 2020 to 2021 are incomplete. In order to more accurately reflect the changing trend of technology, the data of these two years are excluded from Figure 5. As can be seen from Figure 5, 2000-2001 was a stage of technological development, and the number of patent applications in that year was considerable. From 2002 to 2005, it experienced a slow growth stage.Since 2006, geothermal technology has entered a stage of rapid development, and both the number of patent applications and the number of patent applicants have seen a

leapfrog development. Since 2008, the number of patents has reached 300 every two years, and from 2018 to 2019, it has reached 428, with more than 170 applicants participating in the competition, indicating that this technology is currently in a stage of rapid development. Generally speaking, the development phase of a technology's life cycle allows for increased investment in research and development. Therefore, we should attach importance to the research and development of this technology at the present stage. When the technology enters the rapid development stage, we should further increase the investment in research and development, expand our technical advantages, and maximize the occupation of the technical market.

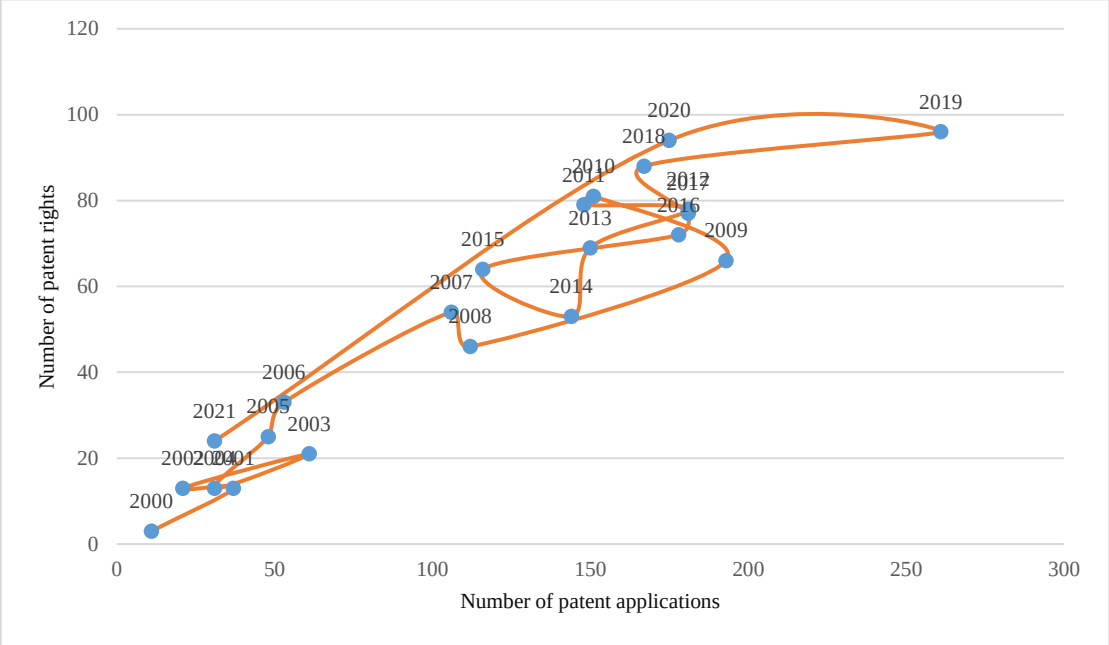

Figure 5: Worldwide thermal technology patent life cycle map

2.3 Geothermal patent layout

The distribution of geothermal patent area and technology is analyzed, and the key protection area and technology in this field are studied.

The key protected areas and technologies are analyzed through two channels.The first is the manual analysis of all patent literature, through the manual statistical method to analyze the patent distribution of countries and have more patents technology;The second is through the database software analysis, mainly through the program calculation to obtain the patent citation information and the same family information, to determine the influential important technology and key protection technology.

2.3.1 Geothermal patent layout of technology

The overall layout of geothermal patented technology is studied by manual statistical method. From the technical perspective, in the field of geothermal research, there are four parts: "geothermal resources and selection evaluation technology", "geothermal exploration technology", "geothermal drilling and completion technology" and "geothermal efficient development and utilization technology". In the part of "geothermal resources and constituency evaluation Technology", the key protection technology is "geothermal resources evaluation", which mainly includes geothermal geological modeling technology and geothermal resources evaluation technology, including the dry-heat type and hydrothermal type modeling evaluation technology.The remaining three parts cover 10 specific

technologies and methods, with a total of 2,455 patents. The key technical indicators to be protected are geothermal thermal storage engineering technology, high-temperature geothermal drilling and completion technology, medium-low temperature geothermal drilling and completion technology and geothermal direct utilization technology (Table 1, Figure 6). In addition, they also include geothermal power generation technology, geothermal anti-fouling technology and geothermal geophysical exploration technology.

Table 1: Technical and methodological indexes of key protection in the field of geothermal research（Number of patents≥100）

Technical and methodological names	Number of patents
High temperature geothermal drilling and completion technology	492
Medium and low temperature geothermal drilling and completion technology	322
Geothermal geophysical exploration technology	102
Geothermal power generation technology	270
Geothermal anticorrosion and scale inhibition technology	260
Geothermal rservoir engineering technology	651
Geothermal direct utilization technology	304

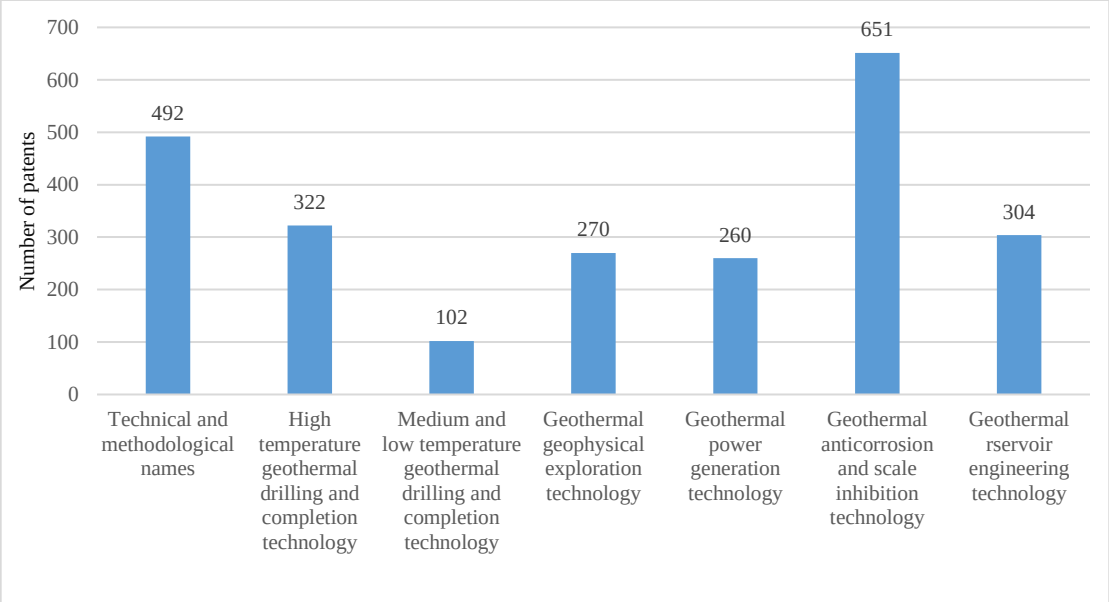

Figure 6: Bar chart of key conservation techniques and methods in the field of geothermal research（Number of patents≥100）

2.3.2 Geothermal patent layout of geography

The constitution of geothermal patent protection network is analyzed, and the geographical distribution of patent literature is investigated in two ways.Firstly, from the perspective of manual statistical analysis of geothermal patent database since 2000, the geographical distribution of patents in the field of geothermal research to technology is investigated as a whole, and the main countries where the patents in the whole field are distributed are understood.The second is to select the key patents in the field of geothermal research for analysis, to study how specific institutions to protect their own advantageous technology in the regional aspect to achieve, mainly through the analysis of the number and distribution of patent family members.The number of patents reflects the potential technological market and economic reach of an invention, and patent applicants will only file a patent application in

a country if they have an expectation of the market.Therefore, by analyzing the countries in which the applicant applied for a patent for a certain invention, it is helpful to understand the construction of the applicant's patent network, management strategy, market development direction and so on.

As can be seen from the distribution analysis results of major countries with hot patents in the mainland worldwide, patent applications in this field are concentrated in China and the United States, and the two countries' patent applications account for 45% of the total number of patents. In addition, Germany, Canada, Australia, Japan, South Korea, the United Kingdom and Mexico are also key geothermal technology protection countries/regions.

According to 2559 geothermal patent literature retrieved by this project, the geographical distribution of domestic and foreign patent literature was analyzed.In addition to the domestic patents applied in mainland China, some institutions of the United States, Germany, Canada, the United Kingdom and other countries were also found;Patent documents applied abroad involve a total of 18 countries/regions, such as the United States, Russia, Japan, Europe and other countries and regions have a lot of geothermal technology patents distribution, but only Guangzhou Energy Institute of the Chinese Academy of Sciences system has applied for geothermal patents abroad.

3 CONCLUSIONS

(1) Since 2001, there have been 66 countries, regions or organizations with patented technologies in the hot fields in the world, mainly distributed in China, the United States, the World Intellectual Property Organization and other countries or organizations. In particular, China and the United States are the concentrated areas of patent distribution in this field of technology, with the number of patents filed in mainland China and the number of patents filed in the United States far ahead.

(2) Geothermal technology patent documents are mainly distributed in countries and regions with abundant geothermal resources, more large oil companies and strong scientific and technological strength. The main sources of technology applied for patents in mainland China are European countries, the United States and Canada.

(3) Worldwide thermal technology development since 2000 can be divided into three stages: In the early period of 2000-2006, the period of rapid development from 2007 to 2009, and the period of stable development from 2010 to now. However, the global epidemic of COVID-19 in 2020 has had a certain negative impact on the development of geothermal, and the number of geothermal patent applications has a downward trend.

(4) The optimization technology of geothermal development scheme, geothermal power generation and geothermal dynamic monitoring technology are the hot areas of progress at present, and the development trend is the research and development of underground heat recovery and dry hot rock power generation technology;China started late in geothermal exploration, development and utilization, but it has certain advantages in geothermal direct utilization, resource and selection evaluation technology, geothermal drilling and completion technology and other fields. It has few involvement in geothermal power generation and underground heat recovery technology, and its patents are all concentrated in China, without overseas layout.

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