Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Exploration and Research of Geothermal Resources in Fujian, China

Qingxiang ZHUANG

Fujian Energy Research Society, Fuzhou 350001, China

E-mail: zqx1944@gmail.com

Keywords: geothermal resources, exploration, research, Fujian, China

ABSTRACT

Fujian province is located in southeastern coastal region of China. It is close to the Pacific Rim Geothermal Zone. There are 215 hot springs in Fujian province. The density of hot spring is the third place in China. Since 1970s, Fujian province has paid attention to the exploration and utilization of geothermal resources. Geothermal well achieves 121.5°C within 100 m depth in Zhangzhou. This is the highest temperature in Eastern China. Fuzhou city installed the earliest geothermal water supply in the country. Fuzhou created geothermal administration earlier as well. There is no demand for space heating in Fujian due to its warm climate. But geothermal cooling was firstly used in Fujian. Sea eel feeding by hot springs was advanced in Fujian. Geothermal geological condition is complicated in Fujian due to rock fractured reservoir. However, higher temperature and water yield are found in many geothermal fields in Fujian in recent years. It is considered as one of targets for EGS research in China. China is accelerating the replacement of renewable energy from conventional fossil fuel energy. Fujian is lack of conventional energy resources. The provincial governor has advised to draw up an industry planning of geothermal resources development in Fujian province. It will show the targets for short-term, mid-term and long-term respectively. It could be expected to have a wonderful prospective in Fujian in future.

1. INTRODUCTION

1.1 Major Cities Exploration in the Planned Economy Era

Geothermal resources exploration of Fujian province began in the 1950s. The major works were data collection, field reconnaissance and indoor data compilation. Field drilling started in 1960s, but the major exploration was carried out in 1970s in major cities like Fuzhou, Zhangzhou and Xiamen.

Hot springs in Fuzhou were documented since Tang Dynasty. Comprehensive geological surveys of 1:50,000 scale began in 1958. To solve the problem of hot water supply for Fuzhou senior cadre rest house, a preliminary warm spring area survey was started in 1960. Accordingly, there were 1040m/16 drill-holes with the deepest hole of 151.69m. In 1972, Fuzhou started geothermal reconnaissance. At the end of 1976, 900m/20 drill-holes were drilled and the mid-term survey report was submitted to the local government. Until 1985, another 9000m/34 holes were drilled with the deepest hole of 939.82m. The area of delineated geothermal field was 9km^2. The average temperature was 72°C, and the evaluated exploitable geothermal resource was 9800m^3/d. Final survey report was submitted at the same time (Fuzhou Hot Spring Editorial Committee, 2001).

In 1970s, the early geothermal reconnaissance in Zhangzhou delineated 1km^2 geothermal field. From 1984 to 1987, Zhangzhou carried out detailed survey of geothermal resources. More than 4000m drilling was completed, and 7.9km^2 delineated geothermal field was expanded. The highest temperature of geothermal water was 121.5°C in a hundred meter depth. According to the evaluation of geothermal resources, the exploitable resource in Quaternary loose reservoir was 5,410m^3/d and in fractured reservoir was 7,598m^3/d respectively (Zhuang, 1987, Zhuang, 2010).

Several geothermal springs were found in Xiamen. Xinlinwan geothermal field completed reconnaissance of 1:10,000 scale in 1976 and geothermal geophysical survey in 1981 respectively. In 1986, they carried out specialized geothermal reconnaissance and completed 1,099.49m/5 drill-holes, two of which revealed the thermal anomaly fractured zone in 200m depth. Besides, 430 shallow holes about 5m deep were used for shallow temperature measurement. Pumping tests, water quality sampling and analysis, geophysical and geochemical work and groundwater dynamic monitoring of one year were conducted as well. According to the submitted geothermal and geological report, exploitable geothermal water resource was 4,336m^3/d, and the temperature was 72°C.

1.2 Enterprise Development in the Market Economy Era

Fuzhou built geothermal water plant early, and did geothermal resources administration simultaneously. There is no demand for space heating in Fujian due to its warm climate, but geothermal cooling was firstly used in Fujian. Sea eel feeding by hot springs was also advanced in Fujian. Since 21th century, geothermal exploration has shown a blowout trend. Cities with hot springs set up many geothermal companies successively. Private enterprises employed geothermal water to support resort, retirement home, bath center, swimming poor, medical care and aquaculture industry, while state-owned enterprises applied central urban geothermal water supply. To get enough hot water and expand their business, some private enterprises asked drilling team to drill geothermal wells near the companies. When the geological condition was more complex than their estimation, they asked the local hydrogeological team carried out feasibility studies and design drilling plans. Those commercial projects are relatively small; usually one or two geothermal wells were drilled at one time. However, the adjacent developers and users rarely communicated their geothermal wells projects, so the geothermal field development was lack of comprehensive consideration based on the small scale. In 2005, Land Development Corporation developed a large geothermal field of Xinlinwan in Xiamen. The corporation drilled 3 wells with 500m depth each with one reinjection well. The highest water yield of a single well was 5,200m^3/d, and the water temperature was 90°C.

2. EXPLORATION STATUS AND EXISTING PROBLEMS OF GEOTHERMAL RESOURCES IN FUJIAN

2.1 Fujian Geothermal Resource Exploration Status

Tectonic unit of Fujian province belongs to the syneclise of the South China, but its geothermal geological background belongs to China southeast coastal geothermal belt in contact with zones among Eurasian Plate, Pacific plate and Philippine plate. Geological structure features of Fujian province are profoundly affected by Yanshanian movement, like north-north-east strong fault, fold and magma intrusion and volcanic eruption. It forms a series of fault basin along the north-north-east and north-west-west direction (figure 1).

Provincial magmatic rock distribution area is about 80,000 km^2, which accounts for two-thirds of the province's land area (123000 km^2). The provincial hot springs and geothermal resources basically originate from the faults and fractures related to Yanshanian granite, which belongs to fractured reservoir.

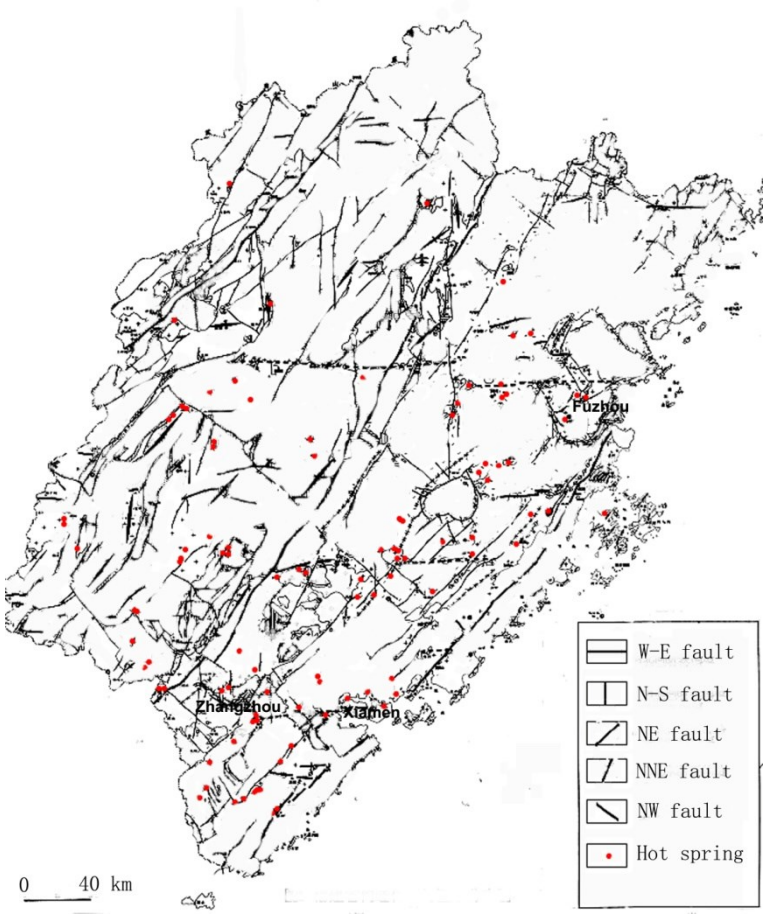

Figure 1: Tectonic system and hot spring distribution

The preliminary geothermal exploration in the province found out 215 natural hot springs with the highest temperature of 89°C. The hot spring distribution density ranks the third in China. Hot springs exist in 48 cities (referred as hot springs county) among 84 cities of the entire province (excluding Kinmen county). The hot springs counties in the southern Fujian accounts for 54.2%, while the middle part of Fujian accounts for 37.5%, and the north Fujian accounts for only 8.3%. In the east of Fujian hot springs distribute in 32 counties, which account for 66.7% of the total number of the provincial hot springs countries. The west Fujian has 16 hot springs counties which account for 33.3% of the total number. The temperature of two geothermal wells is higher than 100°C during geothermal exploration. Zhangzhou worker's sanatorium well is 87m deep. Its bottom temperature is 121.5°C, while the wellhead temperature is 105°C with steam overflow intermittently. The well in Zhangzhou fifth middle school is 200m deep. The wellhead temperature is 122°C with continuous steam and hot water overflowing, and the borehole temperature cannot be measured. The average temperature of Provincial hot springs is 53.12°C. The highest temperature of Nancheng hot spring in Quanzhou Dehua is 89°C. There are 16 hot springs with their temperature range of 80-100°C, 56 springs with temperature range of 60-80°C, 106 springs with temperature range of 40-60°C and 51 low-temperature springs with temperature range of 30-40°C. The provincial total flow of hot springs is 136,500 m^3/d. The maximum flow rate of natural hot spring is 10,340 m^3/d for the exits of geothermal karst river in downtown Yongan. The maximum water yield of geothermal well is 10,450 m^3/d.

The deepest geothermal well of the province is 1200m in Fuzhou. The wellhead temperature is 95°C and the highest temperature in well is 107°C. The water yield exceeds 1,000 m^3/d. Zhangzhou geothermal resources account for about 40% of the total province. The geothermal field of Zhangzhou has the highest temperature, the most abundant geothermal resources, the shallowest buried and accessible conditions in eastern China. It is the area which offers very high potential for geothermal exploitation. The whole province's geothermal energy within depth of 5000m is estimated to be the same as the energy of 5 trillion tons of standard coal.

Fujian province lies in the southeast China coastal active crust belt, but the present author noticed that the areas with intensive hot springs like Zhangzhou, Xiamen, Fuzhou never happened earthquake in the history. Quanzhou in south Fujian without any hot springs and geothermal wells had an earthquake greater than magnitude 7. Quanzhou also had earthquakes of magnitude 6-7 many times, and earthquakes of magnitude 5 more than 10 times in recent years. Small earthquakes often occur. These phenomena may illustrate that the geothermal development can release geothermal energy, not only could protect environment, save energy, create a green and low-carbon economy, but also can convert seismic energy accumulation and mitigate earthquake disasters (Zhuang, 2013).

2.2 Existing Problems of Geothermal Resources in Fujian

(1) The geothermal professional technical group is weak. There is no major geothermal project in the province. The old experts are retired, and no new technical staff involved in. These make the geothermal exploration difficult.

(2) The research's degree of survey achievement is still low in the province, except the Fuzhou and Zhangzhou's geothermal fields. A huge fund was invested to Fuzhou geothermal field for nearly 20 years. Zhangzhou geothermal basin survey took more than three years, and Zhangzhou geothermal field's research had a relative high precision. However, the area which achieves mining exploration accuracy is only 7.89km^2. The assessment of these two geothermal field's resources is limited to a few hundred meters depth, and the research on deep geothermal resources is still blank. Professor Chen Zongji from Chinese Academy of Sciences did a lot of work on deep geophysical exploration, and came up with the ideas that magma chamber might exist in Zhangzhou, Xiamen and Quanzhou, and no other related research or exploration hole could be found to support this hypothesis.

(3) The range of geothermal exploration is very small. It is only limited to a few individual geothermal fields of Fuzhou, Xiamen, Zhangzhou, three economy developed coastal cities. The exploration is not implemented within whole scope of the province.

(4) The equipment of geothermal exploration is behind. Most of provincial geothermal drilling rigs are 100 (m) type. Only a few drilling rigs are 300 (m) and 1000 (m). Deeper drilling rigs are barely used and no anti-blowout devices are equipped. In case of a blowout with high temperature, the drilling well had to be closed in advance. Geochemical analysis is backward, only general water quality analysis could be done in the laboratory due to the lack of advanced detection equipment.

(5) The cooperation between relevant departments is not enough. The lack of data sharing and information communication among geothermal exploration units, other geology, earthquake departments and universities, it would impair further analysis and understanding of local geothermal research.

3. SPECIALIZED PLAN OF GEOTHERMAL RESOURCES DEVELOPMENT IN FUJIAN

Nowadays, China is accelerating the pace of renewable energy to replace conventional fossil fuel energy. Fujian is lack of conventional fossil energy, and the governor of Fujian province intends to improve the specialized plan, exploration and exploitation of geothermal resources, according to short, mid and long-term planning.

Specialized Plan of Geothermal Resource Development is an event for Fujian Province, which is timely and needs to carry out carefully. The whole plan fully considers the geothermal resources of Fujian, and effectively deploys future development. The Fujian Bureau of Geology and Mineral Exploration and Development is now working on the preparation of this specialized plan, which contains the following four parts.

(1) Development Situation and Trend: Specialized plan should include current situation sorting, basic condition identification and development trend analysis.

(2) General Requirements: Proposing guideline of Fujian geothermal development; identifying basic principles of geothermal development; setting development goals.

(3) Primary Mission: This is the key point of Fujian geothermal development, including geothermal recourses exploration, utilization and protection. It also needs a comprehensive geothermal industry development goal.

(4) Supporting Measures: Preferential policies and effective supervision from local government guarantee the completion of established goals.

4. FUTURE WORK

4.1 Geothermal Geological Work

Past surveys just focused on finding the geothermal distribution. We also need to relate the survey results with local geological structure to have a foreseeingly perception, which might reveal the potential geothermal conditions that are not exposed as hot springs by geophysical and geochemical exploration (Zhao et al, 2009).

4.2 Geochemical Exploration

Geochemical exploration has a weak link in China. Many projects seldom utilize geochemical methods to find geothermal anomaly and validate geothermal geological conditions. Geochemical methods could provide useful information to locate potential geothermal resources where no hot springs exist. Geochemical methods could also be applied to the reconnaissance, detailed survey and exploration.

4.3 Geophysical Exploration

Geophysical exploration is inadequate on Fujian geothermal resources in the past. Firstly, previous geophysical exploration methods (including instruments and methods) are relative backward. For example, resistivity method could detect only about 1000m depth, and interpretation accuracy is also limited. Now controllable source audio magnetotelluric method (CSAMT) can

detect the depth of 3000m, which is suitable for drilling geothermal wells. With the advanced interpretation software, we could acquire more information to complete a success exploration from geophysical surveys. In addition, Chen Zongji et al from Institute of Geophysics, Chinese Academy of Sciences conducted seismic, gravity, artificial seismic and other geophysical survey at Quanzhou-Shantou section in 1985. They explained that Zhangzhou, Xiamen coastal areas might exist high temperature molten rock within the crust about 5km depth (Chen, 1992). However, there was no other evidence to support the explanation. Magnetotelluric method (MT) was used to verify the potential geothermal resources in this area.

4.4 Comprehensive Analysis of Geology, Geochemistry and Geophysics

The comprehensive analysis on previous geological, geochemical and geophysical survey data gives a complete understanding of the geothermal geological conditions in Fujian. It is basically a conceptual model about geothermal field or geothermal anomaly zone. Thus, we could deploy further drilling exploration with confidence.

4.5 Drilling Exploration

Geothermal exploration drilling could be deployed on the basis of preliminary geothermal conceptual model, so we can basically locate (less risky) potential geothermal resources. This could purposefully expand the distribution of geothermal resources, and also discover and validate new geothermal fields.

4.6 A Prospective Study on Dry Hot Rock Technology Development

Hot dry rock (also known as Enhanced Geothermal System, EGS) geothermal resources have been described as the 21st century geothermal energy due to its large potential. Developed countries around the world are stepping up relative research, and China also arranges the 12th Five-Year Plan on this subject. Fujian has the highest temperature geothermal wells in southeast coastal areas of China, and Zhangzhou, Xiamen coastal areas might exist high temperature molten rock within the crust about 5km depth. Fujian is selected as one of the alternative target zones for China enhanced geothermal system study. Deep geophysical survey is on schedule, and the result would determine the necessity of drilling. This is a big event in Fujian geothermal development history.

5. CONCLUSION

The high-temperature geothermal potential in China's southeastern coastal region is only behind the Tibetan Himalayas geothermal zone. Fujian has the highest temperature geothermal wells in China's southeastern coastal region. However, the past geothermal surveys were only focused on Fuzhou, Zhengzhou and Xiamen, while the exploration depth and accuracy were not enough. According to the governor's instructions, provincial government should schedule the "Fujian geothermal resources development plan" and conduct purposeful resources exploration. These efforts would not only help to discover more potential geothermal resources, but also make a significant contribution to energy saving and emission reduction in Fujian Province.

ACKNOWLEDGMENTS

The authors appreciate the support and investment on geothermal exploration from Fujian Geology and Mineral Exploration and Development Bureau. Special thanks to Geothermal Council of China Energy Society for helping Fujian geothermal exploration developing and me personally.

REFERENCES

Wang, C.T., and Horne, R.N.: Boiling Flow in a Horizontal Fracture, *Geothermics*, **29**, (1999), 759-772.

Fuzhou hot spring Editorial Committee: Fuzhou spring document, (2001).

Zhuang Q.X.: Fujian province Zhangzhou basin geothermal survey report (1:25,000), Bureau of Geology and mineral resources of Fujian Province, (1987).

Zhuang Q.X.: Research and practice of Fujian geothermal, *Geological Publishing House*, (2010).

Zhuang Q.X.: The development of geothermal energy could converse earthquake negative energy to prevent earthquake disaster, *Energy and environment*, **5**, (2013).

Zhao Y.H. et al.: Geothermal energy development report of Fujian, *Channel science*, **1**, (2009), 30-33.

Chen Z.J.: Fujian geothermal geophysical research, 1992.