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Geothermal Space Heating Has a Promising Role to Play in the Reduction of Air Pollution in North China: a Success Story of the Xiongxian Geothermal Project

Zhonghe Pang and Jumei Pang

Institute of Geology and Geophysics, Chinese Academy of Sciences. No.19, Beituchengxilu, Chaoyang district, Beijing, 100029, China.

z.pang@mail.iggcas.ac.cn

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ABSTRACT

Over the past 10 years, China has become the world leader in direct use of geothermal resources. Among the space heating applications, Xiongxian County has been a model project. The project has turned the region smoke-free. A comparison has shown that, with 6.7 million square meters of houses serviced, Xiongxian is the largest geothermal heating project in the world in terms of total area heated by geothermal if the fact that heat supply is from a single geothermal field is considered. Efficient and rational development in Xiongxian Geothermal Field has set high technological standards for the rest of China and the world in terms of 100% waste water reinjection. The project has led and promoted the exploitation and utilization of geothermal resources in China, especially in the population-concentrated and economic focus. It is of great significance for the energy structure transition of the country as well as the reduction of air pollution because of the fact that more than half of the smog days are in the winter time when coal-burning heating is on. This paper will review the resources potential estimate at greater depth, the response of the geothermal field to large scale utilization, and technological achievements made during the project implementation. The great potential of geothermal resources in the region and the success of Xiongxian project have shed light on the future of geothermal development in the Xiong'an New Area and the rest of North China.

1. INTRODUCTION

Geothermal energy is a clean, low-carbon, widely distributed, and stable high-quality renewable energy source. The development and utilization of geothermal resources in Xiongxian geothermal field began in the 1980s. Before the 1980s, there were few geothermal wells and a small amount of production. Many geothermal wells were artesian wells. In early 2014, the demonstration project of geothermal heating in Xiongxian County were began to promote to the northern region of China. In 2016, Xiongxian County has a population of 90,000, with 68 geothermal wells, 24 of which are recharged wells, forming a heating capacity of 4.5 million square meters, basically realizing the full coverage of geothermal central heating. Xiongxian adopted the combination of harvesting and irrigation, and nearly 100% of the recharge was realized, so that heat was taken and water was not taken.

The highlights of Xiongxian geothermal heating demonstration project include: full coverage of the geothermal heating urban area, the largest project in the world (heating capacity 4.5 million square meters, current operation 2.8 million square meters, benefiting 90,000 people), the average heating capacity of a single well is as high as 100,000-150,000 square meters. The heat depleted geothermal water is fully recharged in the same layer. The recharge of Xiongxian geothermal field started in 2010. By the end of 2017, the total recharge of Xiongxian geothermal field has reached 23.9 million cubic meters. The recharge of geothermal tail water avoids the pollution caused by surface discharge, and effectively slows down the decline of thermal storage pressure

Geothermal resources are abundant in China, and its development and utilization has great significance for energy saving, emission reduction and reducing of regional fog and haze. Large scale karstic geothermal reservoirs are developed widely in the carbonate reservoirs in North China, and they could be large-scale exploitation and utilization in balance of mining and reinjection. The Niutuozhen geothermal field is one of the most advantageous areas of large scale karstic geothermal reservoirs in North China. The exploitation and utilization of geothermal resources in Niutuozhen geothermal field adopt the method of combination of mining and reinjection, and only heat is produced without loss of geothermal water. In particular, Xiongxian, located in the southern part of the Niutuozhen geothermal field, built the first "smokeless city" to replace coal by geothermal energy, and realized the use of high efficiency and close to zero emission for the use of clean energy. Hence monitoring of the characteristics of water level and heat response of karst thermal reservoir under large-scale exploration and recharging are necessary. It could provide a basis for the study of sustainable development and utilization mechanism of karstic geothermal reservoir in the Niutuozhen geothermal field, and in practice, it has important practical value for supporting the scientific and rational development of the geothermal resources and ensuring the sustainable utilization of geothermal resources in the Xiong'an new area.

2. GEOLOGICAL SETTING

2.1 Geographic Location of the Xiongxian Geothermal Field

Xiongxian geothermal field is located in the eastern of the northern Taihang Mountains, and is located in the western part of the central Hebei Plain. The whole geothermal field is distributed in the Northeast direction (Figure 1). The geothermal resources of the geothermal field have the characteristics of large distribution area, large reserves, shallow burial, high temperature and excellent water quality. The basic feature of the terrain in this area is plain. The general trend of change is high in Northwest and low in southeast. The difference of terrain height is small, and the altitude in this area is 7-14 m.

Xiongxian geothermal field belongs to a semi-humid and semi-arid continental monsoon climate. The precipitation is mainly concentrated in summer, with an average annual precipitation of 525.8 mm. The main water system in this area is Haihe River system, which is located in the middle and upper reaches of Daqing River system in Haihe River Basin. It collects the atmospheric precipitation in Taihang Mountains, Yanshan Mountains and plain areas, and forms a fan-like water system. The plain in the geothermal field is mainly composed of Quaternary alluvial deposits.

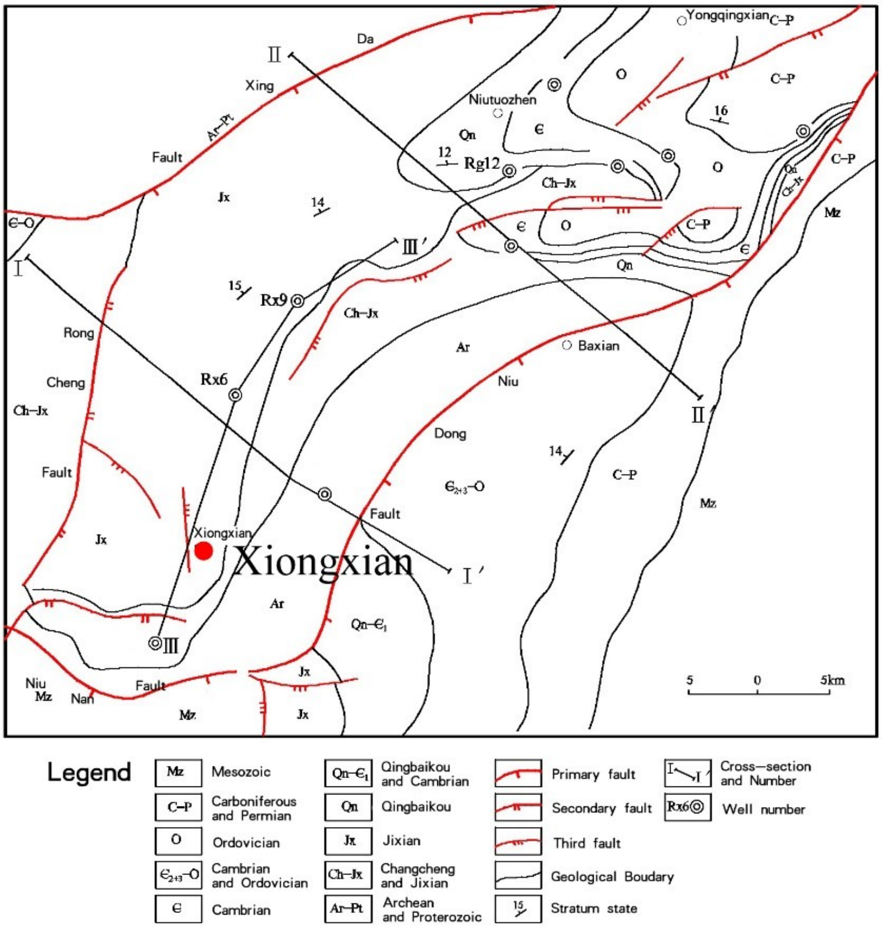

Figure 1: The geographic location of the Xiongxian geothermal field.

2.2 Regional Geological Background

The Xiongxian geothermal field is located in the northern part of the Jizhong garben in the Bohai Bay Basin in North China, belongs to eastern tectonic unit of Chinese continent (Pang, 2018). In the late Mesozoic Triassic period, the Bohai Bay Basin in North China began developing by crustal movement, and NE-SW trending horsts and garbens formed and alternately distributed from west to east along the fractures' extended direction. The crustal extension formed a series of deep and persistent faults, NE-SW striking (Xu et al, 1995). The boundary of the Xiongxian geothermal field is separated by four normal faults, which are Rongcheng, Niunan, Xushui and Daxing faults, respectively (Figure 1). These local faults are long-term active faults formed in the mid- and late Yanshan movement period, and fault activities increased in the early Himalayan movement. These fractures provide pathways for diffusive or convection escape of the fluids from deep sources.

The geological tectonic conditions of formation of geothermal resources are superior in the Niutuozhen geothermal field. The geothermal gradient of the Cenozoic formation is significantly higher than the gradient in the depressions on either side of the geothermal field, due to the basement uplift of the middle and Upper Proterozoic formations. The geothermal gradient of the Quaternary and Neogene caprock in the southern part of the geothermal field is between 4.86-7.64 ℃/100m, with an average of 5.6 ℃/100m, has the characteristics of conduction type geothermal field. The geothermal gradient of the Jxw reservoir is much lower than that of the upper caprock, with an average temperature of 0.62 /100m, showing obviously convective heat transfer characteristics. The high geothermal gradient value of the Cenozoic caprock in the geothermal field is distributed in the direction of NEE, and the general trend is that the gradient of southwest region is high and that of northeast region is low. (Pang, 2018)

The geothermal system can also be divided into several groups, and the Wumishan group is the most productive group. It is widespread around the Xiongxian geothermal system with a depth range of 950 m to 1050 m. The formation in the Jixian reservoir largely consists of dolomite and alternating dolomite and flint belts. The faults and secondary fractures through the bedrock are the main flow channels of the geothermal water. The lithological structure is shown in Figure 2.

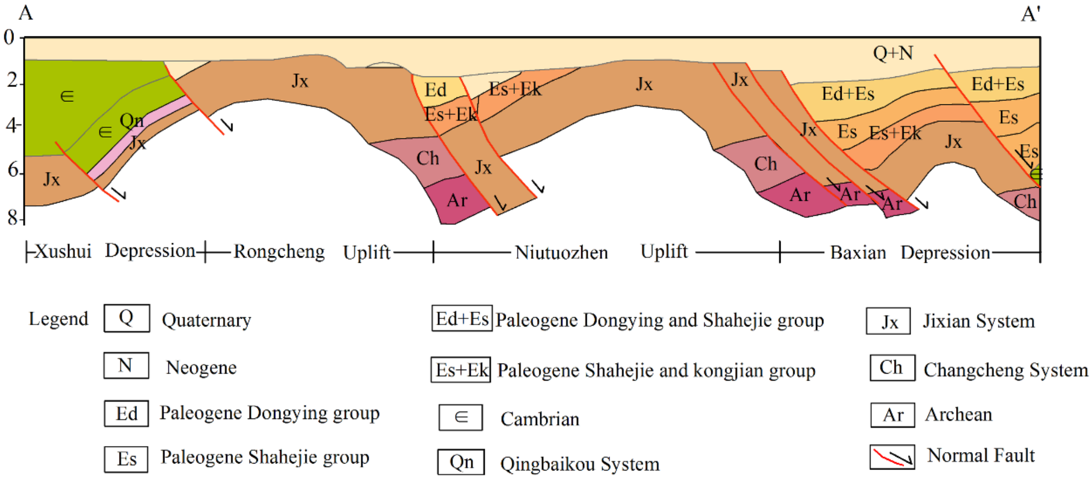

Figure 2: Geological cross-section A-A' of the NTZ geothermal field (Revised based on Zhou et al. 1989).

The geothermal water cycle in the Neogene reservoir and the Jixianian Wumishan (Jxw) reservoir belongs to a relatively independent system, respectively, and the geothermal water originates from meteoric water. There is a good connectivity between the Neogene Minghua formation and Guantao formation. The karstic geothermal water mainly accepts the lateral runoff recharge of the groundwater from western Taihang Mountain and Northern Yanshan Mountain, and is deposited in the bedrock reservoirs after deep circulation heating. The supply of geothermal water in the Neogene and Jxw reservoirs is relatively slow. According to the 14C dating data, the geothermal water is generally more than 20 thousand years old. The fractures and secondary fractures in the bedrock reservoir constitute the upward migration channels of geothermal fluid from deep reservoirs, and the karstic fissures are the main channel for the lateral migration of geothermal water. According to the results of the chemical-thermodynamic simulation of water-rock reaction, the temperature of Jxw reservoir is in the range of 60-108℃: it is 60-72℃ in the Rongcheng area in the west of the field; it is 85-95℃ in the Xiongxian area in the south of the field; and it is 90-108℃ in the Bazhou area in the east of the field. According to the carbon isotopic characteristics of geothermal gases, thermogenic CH_4 and carbonate metamorphic originated CO_2 are commonly found in the geothermal water of Jxw reservoir. The deep reservoir temperatures were evaluated based on carbonate isotope geothermometry between CH_4-CO_2 gases to be in the range from 141 to 165℃, with an average value of 153℃ (Pang, 2018).

3. RESPONSE OF GEOTHERMAL RESERVOIR TO LARGE-SCALE EXPLOITATION

3.1 Water Level Response

The exploitation and utilization of geothermal resources in the Xiongxian geothermal field began in the 1980s. Before the 1980s, there were few geothermal wells and little exploitation. Many geothermal wells were artesian wells, and the initial pressure head was more than 10 meters above the surface. From 1988 to 2017, due to the increasing demand for geothermal energy, the exploitation of geothermal water gradually increased. The annual exploitation of geothermal water in Xiongxian geothermal area in the south of the geothermal field increased from $50.29\times10^4 m^3$ to $767.53\times10^4 m^3$. With the increase of production, the water level of geothermal wells also decreases significantly (Figure 3). In order to prevent the pressure of thermal storage from declining continuously, at the end of 2009, the large-scale development and utilization of geothermal water in Wumishan Formation of Jixian System most has adopted the mode of pair-wells exploitation and recharge.

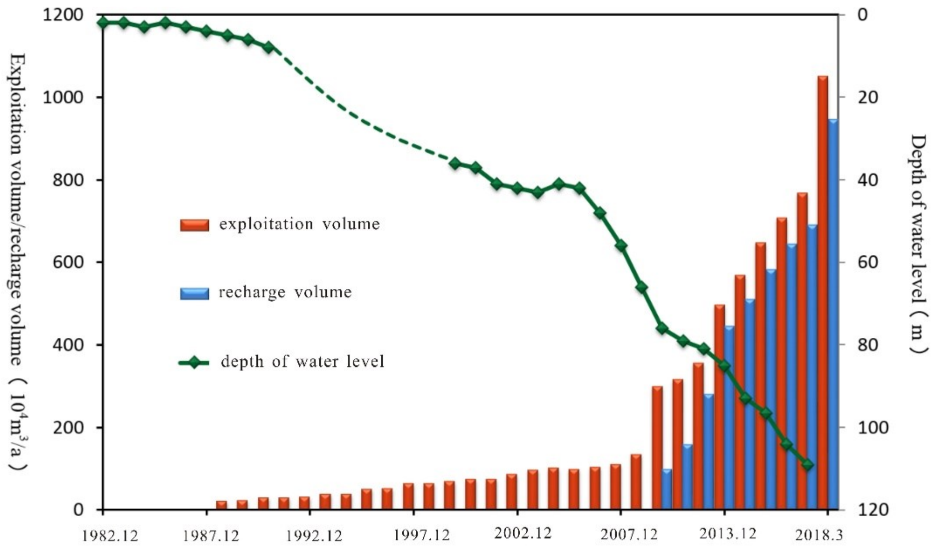

Figure 3: Annual geothermal water exploitation and recharge volume and static water level change of geothermal Wells in xiongxian country (revised from Pang, 2017).

Figure 3 shows the curves of exploitation, recharge and water level of monitoring well change from 1982 to 2018 in the Xiongxian geothermal field. As can be seen from the figure, the rate of water level decline in geothermal well has slowed down since 2012 due to recharge of heat-deleted water to the geothermal system.

3.2 Temperature Response of Geothermal Wells

The main development and utilization of Xiongxian geothermal field is the geothermal energy of Wumishan Formation in Jixian System. The fluid in the thermal reservoir is mainly liquid phase. In order to understand the response characteristics and changing trend of the two major factors of reservoir pressure and temperature under the conditions of large-scale exploitation and recharge, systematic temperature measurements have been carried out for many years to evaluate the long-term exploitation potential of geothermal fields. Temperature profile of geothermal wells were measured after six months of reservoir recovery period after the end of annual heating season, because steady-state temperature measurement method could achieve a full balance between well temperature and surrounding rock geotemperature. Temperature measurement data can directly reflect the variation of water level and temperature of geothermal wells with depth. In order to study the recovery of thermal reservoir temperature in boreholes in different time periods, the temperature measurement results from 2013 to 2017 are compared, as shown in Figure 4-5.

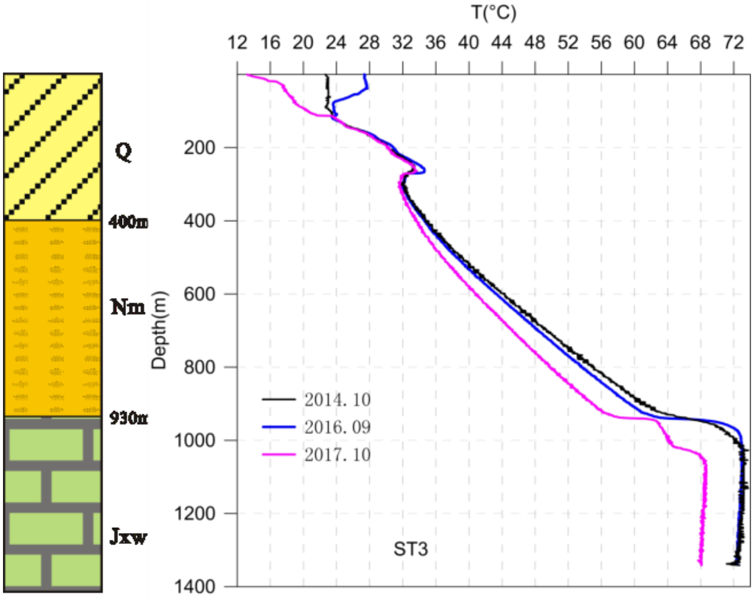

Figure 4: Steady-state temperature-depth curve of ST3 exploitation well from 2014 to 2017.

According to the temperature measurement curve, the reservoir temperature of ST3 well in 2017 is lower than that in 2014 and 2016, and the geothermal gradient of 300-900m shows a downward trend. Compared with the previous two years, the temperature of bedrock reservoir in well ST3 decreased by 5 degrees in 2017, and the geothermal gradient of Neogene caprock also showed a downward trend. Combining with the exploitation conditions of well ST3, there is no obvious change in the wellhead outlet water temperature of the well, and the production volume increases almost 1% annually. It is believed that the decrease of geothermal reservoir temperature of bedrock is mainly due to the influence of shallow groundwater downward flow, which results in the decrease of geothermal reservoir temperature. The decrease of geothermal gradient of Neogene caprock is mainly due to the fact that the geothermal gradient of Neogene caprock mainly comes from the heat transmitted upward from the basic reservoir, and the temperature of bedrock reservoir decreases, which results in the decrease of geothermal gradient of Neogene caprock.

Based on the monitoring temperature response data of exploitation well, the temperature response of thermal reservoir of exploitation well to large-scale production-recharge is mainly reflected in two parts: the upper Neogene caprock and the lower Wumishan formation thermal reservoir. Due to the influence of heterogeneity and anisotropy, low temperature recharge water may flow into production wells along the direction of good connectivity, resulting in the reduction of reservoir temperature in production wells. In addition, the main source of heat in Neogene caprock is the heat conducting upward from the underlying bedrock thermal reservoir. Therefore, the temperature of bedrock reservoir decreases, resulting in a decrease in the heat acceptance of the upper Neogene caprock, showing a decrease in the geothermal gradient.

The temperature-depth curve of recharge well ST2 reflects the temperature change after entering the thermal reservoir. The temperature of thermal reservoir decreases by 4 degrees in 2014 compared with that in 2013. In 2015, the temperature of thermal reservoir recovers by 2 degrees compared with that in 2014. The reservoir temperature in 2016 and 2017 is between the two years. It shows that the thermal reservoir temperature around well ST2 is greatly affected by the temperature of recharge water which injected into reservoir. Moreover, in 2017, the geothermal gradient of the 700-900m section of the Neogene caprock overlying the well also decreased slightly.

Based on the systematic temperature measurement data of recharge wells, the response of reservoir temperature of recharge wells is mainly influenced by the temperature of injected recharge water. Recovery period of 8 months per year is not enough for recharge wells that restore the reservoir temperature to the rock temperature of the non-recharge state. Hence， compared with the production wells of the same depth, the reservoir temperature is lower.

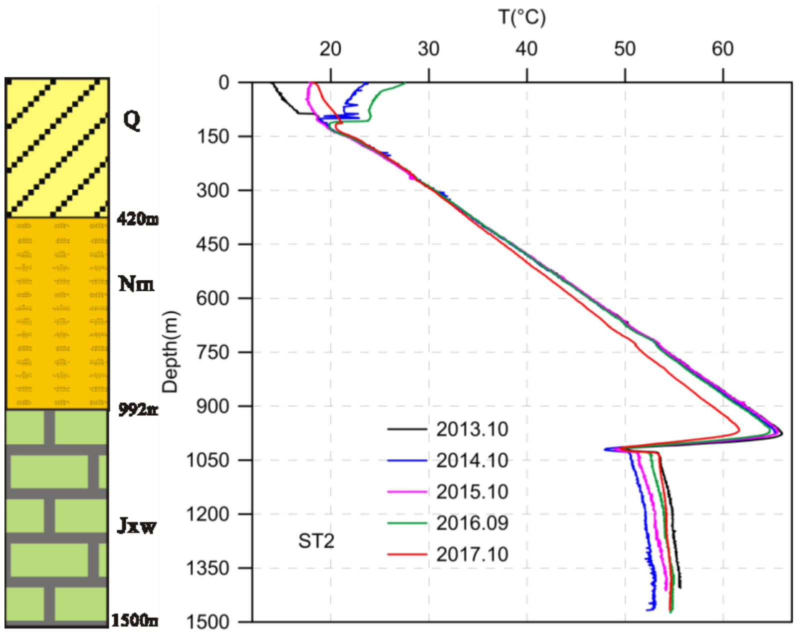

Figure 5: Steady-state temperature-depth curve of ST2 recharge well from 2013 to 2017.

3.3 Results and Discussions

The pressure of the geothermal system decreases with large-scale exploitation. The average decline rate of the hydrostatic water level of geothermal water is 6 m/year, and the dynamic recharge of geothermal water is less than that of exploitation. By method of steady-state temperature measurement of borehole system, it is revealed that the geothermal gradient of Neogene caprock is affected by the temperature change of bedrock thermal reservoir, and the temperature of thermal reservoir in exploitation wells is affected by the temperature of recharge water. However, the large thickness and wide distribution of karst thermal reservoirs can strongly support the dynamic recharge of reservoir flow and heat, make the geothermal system establish a new balance and maintain the stability of reservoir pressure and temperature. It is necessary to carry out long-term observation and simulation study on temperature field and water flow field of thermal system, reveal the response mechanism of large-scale exploitation and recharge, in order to maintain the sustainable utilization of geothermal energy.

4. CONCLUSIONS

Xiongxian geothermal heating demonstration project has been running smoothly for 8 years. The project is the largest in the world (heating capacity 4.5 million square meters, current operation 2.8 million square meters, benefiting 90,000 people). The average heating capacity of a single well is as high as 100,000-150,000 square meters. The raw heating-depleted water is fully recharged in the same layer. The reinjection of raw heating-depleted water avoids the pollution caused by surface discharge and effectively, and slows down the decline of thermal reservoir pressure. It is necessary to carry out long-term observation and simulation study on temperature field and water flow field of thermal system, reveal the response mechanism of large-scale exploitation, and maintain the sustainable utilization of geothermal energy.

REFERENCES

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

Kong Y., Pang Z., Shao H., Hu S., Kolditz O.: Recent studies on hydrothermal systems in China: a review, *Geothermal Energy* , **2**, (2014),19.

Lv M.: Methods for calculating reservoir temperature of the Niutuozhen geothermal field. Dissertation, the Chinese Academy of Sciences University (in Chinese), (2013).

Pang J., Pang Z., Lv M.: Geochemical and isotopic characteristics of fluids in the Niutuozhen geothermal field, North China, *Environmental Earth Sciences*, **77**, (2018), 1-21.

Pang Z., Hu S., Wang S., Xu P., Wang G., Yang F.: Geothermal systems and resources. In: Wang J (ed) Geothermic and its applications. Science Press, Beijing (in Chinese), (2015).

Pang Z., Pang J., Kong Y., Luo L., Duan Z., Yang F.: Large karstic geothermal reservoirs in sedimentary basins in China: genesis, energy potential and optimal exploitation, *Proceedings world geothermal congress 2015*, Melbourne, Australia, (2015), 19-25 April.

Pang Z., Reed M.: Theoretical chemical thermometry on geothermal waters: problems and methods, *Geochimica et Cosmochimica Acta,* **62**, (1998), 1083-1091.

Zhou R., Liu Q., Zhang J., Yang L.: The geological features and exploitive prospects of the geothermal field of salient type of bed rock of Niutuozhen in the fault basin of north China, *Bulletin of the 562 comprehensive geological brigade Chinese academy of geological sciences,* **7**, (1989), 21-35 (in Chinese).