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Geothermal Resources Sustainable Production-Reinjection Mode:

A Case Study of Xiongxian in the Niutuozhen Geothermal Field in North China

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ABSTRACT

Geothermal reinjection is one of necessary measures for the sustainable development of geothermal resources. A three dimensional numerical model was built based on Xiongxian geothermal reservoir in the Niutuozhen geothermal field in North China to study the advantage and disadvantage under different production-reinjection schemes. Simulation results indicated that geothermal field service time would be reduced due to cooling of reservoir resulting from long term reinjection, even though this scheme could help maintain reservoir pressure in the short term. In contrast, concentrated production-reinjection mode would only cool the reservoir temperature within the reinjection area without affecting reservoir temperature in production area to guarantee sustainable thermal supply capacity of the geothermal field. Therefore, concentrated production-reinjection mode can have the advantage of maintaining sustainable development of geothermal resources in which reinjection is possible.

1. INTRODUCTION

China is rich in medium and low- temperature geothermal energy resources, most of which are hydrothermal resources. Geothermal water is the major medium for exploiting geothermal energy resources. Because a large amount of geothermal water has been produced, geothermal reservoir pressure has significantly declined and caused gradually increased energy consumption in exploitation(Wang et al. 2005). Geothermal reinjection is one of the necessary measures for maintaining geothermal reservoir pressure, but geothermal reinjection is very complex. If the reinjection well is too close to the production well, the production well may be cooled by the reinjected water and consequently cause the well's productivity to decline or fall off completely. If the reinjection well is too far away from the production well, it may fail to provide sufficient pressure support to the geothermal reservoir. Therefore, research on the well layout is necessary for developing a geothermal reinjection scheme. At present, the most common exploitation reinjection mode is the distributed mode, i.e. arranging the production well and reinjection wells in a distributed layout. Some of production and reinjection wells are arranged in parallel. Another mode is concentrated mode, i.e. arrange the production and reinjection wells in separate parts of the geothermal field. These two modes have different impacts on the pressure field and temperature field of the geothermal field. This paper describes a case study of comparing these two reinjection modes in the geothermal field in the Niutuo Town, Xiongxian County.

2. OVERVIEW OF THE RESEARCH AREA

2.1 Geology of this area

Niutuo geothermal field covers an area of about 1500km^2, which is located in partial areas of Xiongxian County, Rongcheng County, Yongqing County, Xushui County, Gu'an County, and Baxian County. This geothermal field was discovered in the oil exploration in 1970s. The Niutuo geothermal field is located in the bulge belt of the depressed central basement in the North China Basin, which was composed of bulges in Niutuo Town and Rongcheng County, presenting a north-east distribution. Stratigraphic sequence from old to new includes Cenozoic quaternary System, Neogene System, and Palaeogene, Mesozoic Cretaceous System and Jurassic System, Paleozoic Permian System, Carboniferous System, Ordovician and Cambrian System, Middle-upper Proterozoic Qingbaikou System, Jixian System, Changcheng System and Archaeozoic (Figure 1). Xiongxian County lies in the south of the Niutuo geothermal field, which is the earliest area in exploiting and utilizing the geothermal resources in the geothermal field and the area with highest development level.

2.2 Geothermal resources condition

Geothermal exploitation in the Niutuo geothermal field is mainly in the south area of Xiongxian County. The general thickness of the quaternary System is 400m, with a geothermal gradient of 4.57-12.61° C/100m, reaching the highest value in North China. The average geothermal gradient in the geothermal reservoir of Neogene System is 3.85 ° C/100m, and that of the Jixian System is 1.21 ° C/100m(Chen 1988). The production capacity of the single geothermal well in the Jixian System of the Niutuo geothermal field reached to 120-180m^3/h, with hot water temperatures of 64-83° C(Wang 2011).

The first reinjection experiment on the Niutuo geothermal field was conducted in 2009. In this experiment, the geothermal water in the first production well was reinjected to another well after heat transfer. The second reinjection experiment was conducted during from 2010-2011. In this experiment, the geothermal water in the second production well was reinjected into the same reinjection well after heat transfer. The experiment results showed that under non-pressurized conditions, the reinjection capacity of the single geothermal well reached 180m^3/h(Wang et al. 2011), and the reinjection water was still below the mouth of the well. The two

experiments showed that the geothermal well had great reinjection capacity and could completely realize “clean exploitation and clean reinjection” mode.

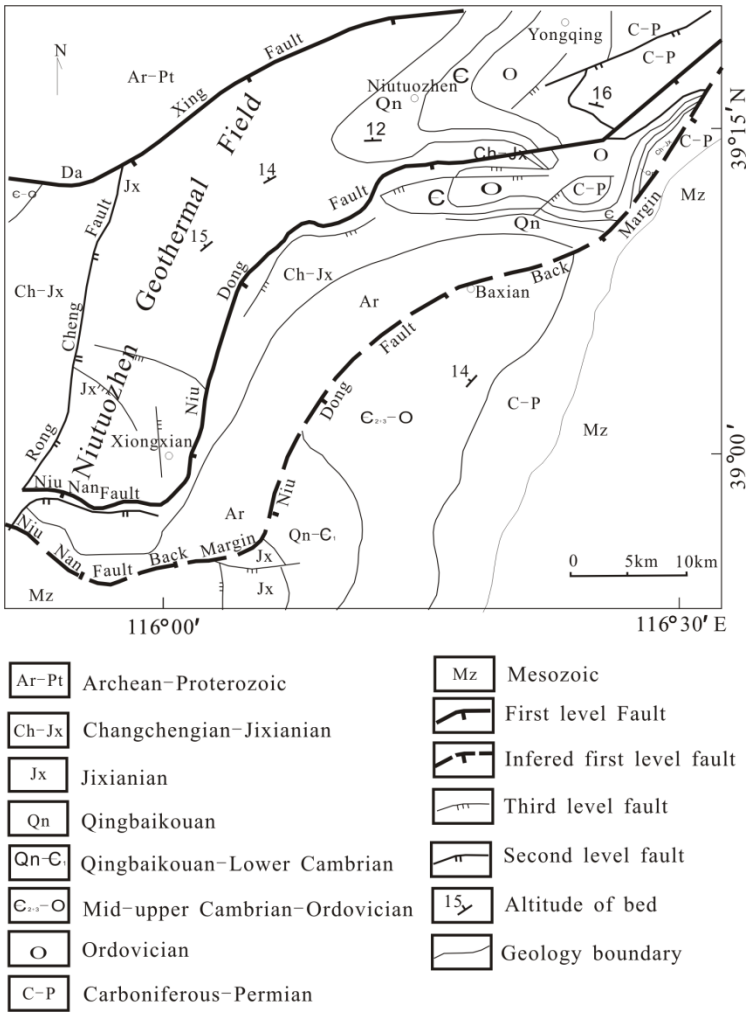

Figure 1: Pre-cenozoic geological map the Niutuozhen geothermal field

3. EXPLOITATION AND REINJECTION MODE OF THE GEOTHERMAL FIELD

3.1 Exploitation and reinjection mode

Generally, it can be called in-field reinjection if the production well is close to the reinjection well, and both lie in the heat source area of the geothermal field. Conversely, it can be called out-field reinjection if the production well is far away from the reinjection well and the reinjection well lies in the marginal area of the geothermal field (Kaya et al. 2011). In-field reinjection is generally adopted in the preliminary reinjection stage, so as to reduce the pipeline laying and reduce cost and discover the impact of reinjection on the geothermal field as soon as possible. However, with the increasingly expanded reinjection scale, especially in the thermal water-based geothermal field, the reinjection often causes thermal breakthrough and cools the geothermal reservoir.

Numerical modelling plays an important role in forecasting the change of geothermal reservoir temperature and pressure. Many large-scale geothermal fields in the world, such as Wairakei, Larderello adopted numerical modelling to simulate and forecast the changes of geothermal reservoir pressure, production and enthalpy (Zarrouk et al. 2006). In addition, with the improvement of the exploitation and utilization of the geothermal fields, the model was gradually updated to accurately simulate the geothermal reservoir.

3.2 Conceptual model of geothermal field

The geothermal reservoir in the Niutuo geothermal field includes Neogene System sandstone geothermal reservoir and Jixian System wumishan formation dolomite geothermal reservoir. The Neogene System sandstone geothermal reservoir and the Jixian System wumishan formation (Jxw) are separated by the lower part of the Neogene System and Palaeogene System dense mudstone, forming two geothermal reservoirs with poor hydraulic connection and mutual independence. The Jxw geothermal reservoir is the most important geothermal reservoir of the Niutuo geothermal field, so it was chosen as the main target.

For three-dimensional simulation of the geothermal field, the numerical model was vertically divided into 17 layers and horizontally divided into polygons. As a result, the places with higher computational accuracy requirements (such as geothermal well area) can be partially densified, so as to avoid inflexible densifying in the rectangular subdivision. In addition, polygon subdivision can flexibly deal with irregular edges of the geothermal field

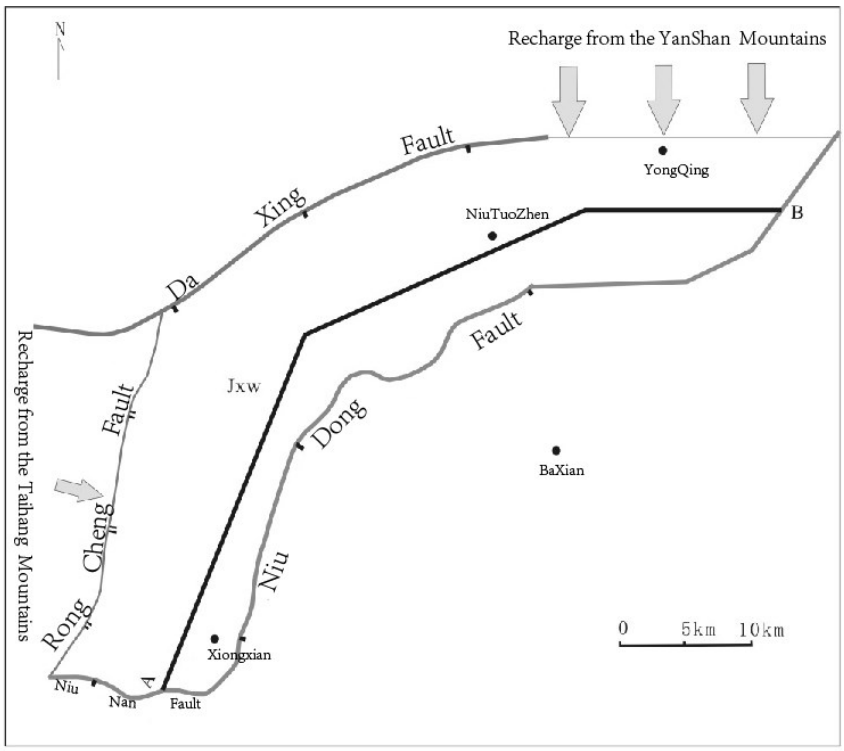

Figure 2: Conceptual model of the Niutuozhen geothermal field

3.3 Numerical model of the geothermal field

Wang Shufang utilized the geothermal system modeling software (TOUGH2-based PETRASIM) to established a three-dimensional hydro-thermal coupling numerical model in Niutuo geothermal field. Both the centralized and parallel exploitation and reinjection modes were simulated for the Niutuo field, and the impact of each mode on reservoir temperature and pressure was forecasted. In a broad sense, exploitation and reinjection mode is composed of two kinds of modes: one is the distributed mode, where the production and reinjection wells are alternatively distributed. This model has the benefits of lower waterline cost and timely pressure support, but may cause geothermal reservoir cooling. Another mode is the concentrated mode, where the production and injection wells are concentrated in separate areas of the field. The wells are far away from each other and mutually independent. This mode can reduce the risk of geothermal reservoir cooling, but cannot supply geothermal reservoir pressure rapidly. Therefore, this paper simulated these two modes, analyzed the geothermal reservoir response of these two modes, so as to evaluate the effectiveness of these two modes (Figure 3).

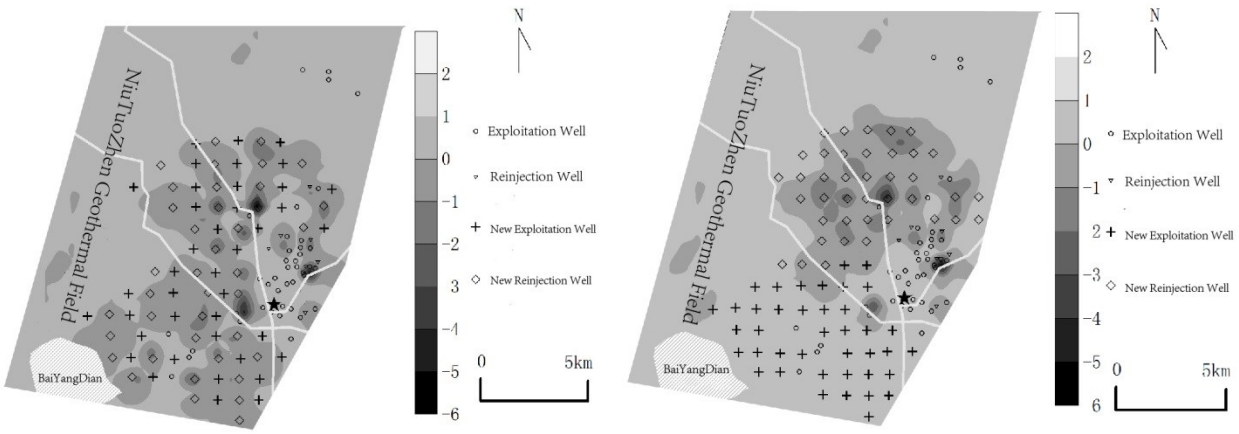

Figure 3: Temperature change of the Jixianian geothermal reservoir under distributed production-reinjection mode and concentrated production-reinjection mode

Note: the right symbol in Figure 3 represents temperature. Symbol with "-" means temperature reduction, while symbol without "-" means temperature increasing. Unit is ° C. Because the geothermal wells are mainly centralized in the south part of Niutuo geothermal field, the temperature of the south part of the geothermal reservoir changes significantly.

4. RESULTS AND DISCUSSION

The simulation results showed that for the the parallel exploitation and reinjection mode, the entire well field in the 1000m-2000m range was impacted by cooling. It also reduced the temperature of the geothermal water in the production wells, and impacted the heating capacity of the production wells to a certain degree. If the exploited thermal energy of the production wells under this mode is the minimum limit of heating requirements, the heating capacity of the geothermal reservoir cooling caused by reinjection will

decrease and no longer meet the basic needs for heating. However, under the centralized exploitation and reinjection mode, the geothermal reservoir temperature of the exploitation area did not decrease, and the heating capacity of the geothermal well did not change. If the decreasing range of the centralized exploitation pressure is acceptable, and the exploitation quantity is not impacted by improving the water exploiting capacity of the water exploiting device, it can continue to meet the total heating needs. In addition, in the centralized exploitation and reinjection mode, after the pressure field reached a stable state, the impact of running time was gradually reduced, and the decreasing degree of the pressure was gradually decreased as well, which is in favor of exploiting geothermal water. The results of numerical simulation on peripheral well reinjection in Tianjin geothermal field conducted by Zhu Jailing, etc. also showed that peripheral reinjection has slight impact on the temperature field of the exploitation area, and has obvious practicality in maintaining the geothermal pressure of the geothermal field. Peripheral reinjection is of great long-term benefits for controlling the geothermal reservoir pressure in the whole exploitation area.

In the parallel exploitation and reinjection mode, the partial flow field caused by parallel exploitation and reinjection mode improved the flow of reinjected water in geothermal reservoir to some extent and increased the spreading rate of the cooling range of the geothermal reservoir, which is very unfavorable for maintaining the temperature of geothermal reservoir and the heating capacity of the geothermal well. In the centralized exploitation and reinjection mode, the reinjected water gradually increased the pressure of geothermal reservoir, which limited the flow rate of the reinjected water in the geothermal reservoir to a certain extent and delayed the spreading rate of the geothermal reservoir cooling range.

5. CONCLUSION

The karst geothermal reservoir has great reinjection capacity. In the geothermal field with the capacity of total reinjection of geothermal water, the parallel exploitation and reinjection mode caused the entire well field in the 1000m-2000m range to be impacted by cooling. It also reduced the temperature of the geothermal water in the production well, and impacted the heating capacity of the production well to a certain degree. However, under the centralized exploitation and reinjection mode, the geothermal reservoir temperature of the exploitation area did not decrease, and the heating capacity of the geothermal well did not change. In addition, under the centralized exploitation and reinjection mode, after the pressure field reached to a stable state, the impact of exploitation was gradually reduced. In conclusion, the centralized exploitation and reinjection mode is superior to the parallel exploitation and reinjection mode in maintaining the sustainable exploitation of the Niutuo geothermal field.

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