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Study on the Reinjection Experiment in Xiongxian of the Niutuozhen Geothermal Field, North China

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ABSTRACT

Reservoir pressure at the Niutuozhen geothermal field decreased dramatically due to extreme pumping. Geothermal reinjection is necessary to maintain reservoir pressure in the development of sustainable geothermal resources. Reinjection experiments were first carried out in Xiongxian of the Niutuozhen Geothermal Field in 2009. The first reinjection experiment with one reinjection well and one production well indicated that reinjection capacity of the geothermal well is 150 m^3/h. The second reinjection experiment indicated that reinjection capacity of well is 180 m^3/h with an injection index of 8.72(L/s)/bar at zero pressure in the well head. Tracer tests demonstrated that there are small-scale hydraulic channels between reinjection and production geothermal wells.

1. INTRODUCTION

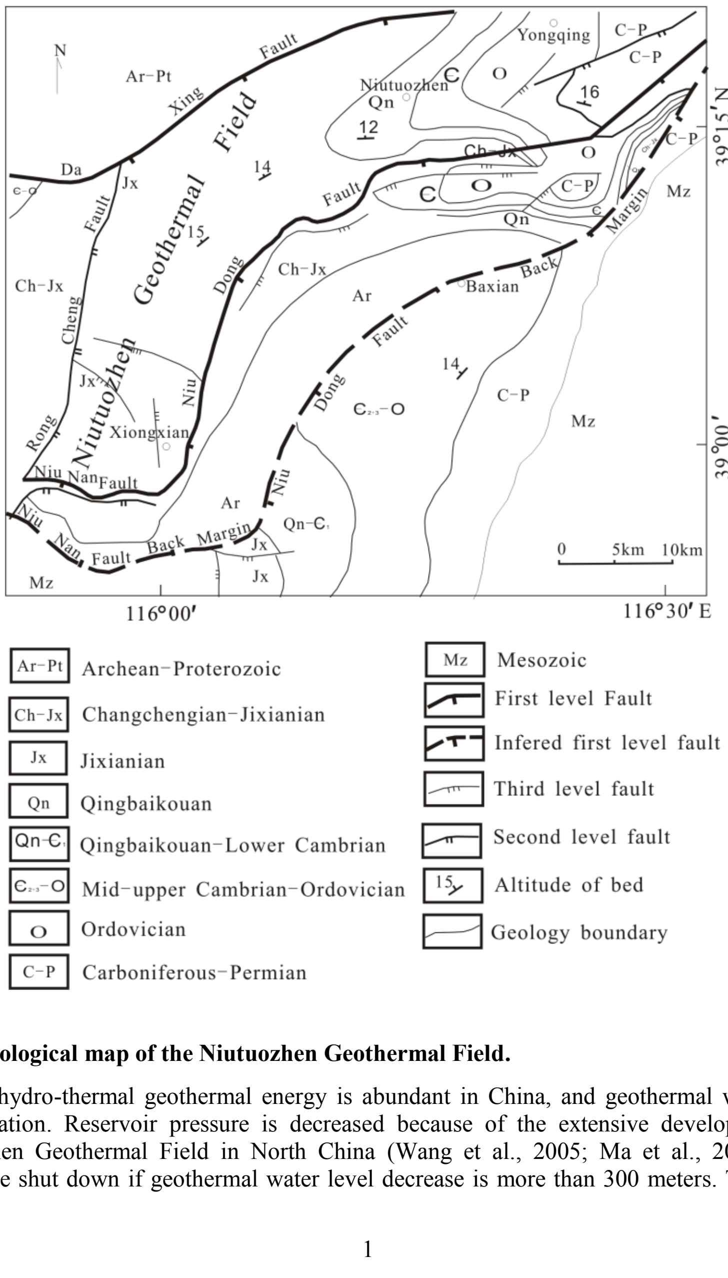

Figure 1: Pre-Cenozoic geological map of the Niutuozhen Geothermal Field.

Low-medium temperature hydro-thermal geothermal energy is abundant in China, and geothermal water is the main media for geothermal energy exploitation. Reservoir pressure is decreased because of the extensive development of geothermal water extraction in the Niutuozhen Geothermal Field in North China (Wang et al., 2005; Ma et al., 2006; Liu et al., 2010). The geothermal wells have to be shut down if geothermal water level decrease is more than 300 meters. Therefore, geothermal water reinjection is necessary to maintain reservoir pressure. The first reinjection experiment and tracer test were carried out to calculate reinjection ability of wells and identify hydraulic connection between production and reinjection wells.

2. GEOLOGICAL SETTINGS AND GEOTHERMAL RESOURCES CONDITIONS

2.1 Geological Settings

The Niutuozhen geothermal field, located in the Niutuozhen uplift, is the northern part of the Jizhong graben in the North China Basin, which was formed by vertical tectonic movement before the Late Triassic period. The alternatively distributed uplifts and grabens striking from northeast to southwest were formed by mountain building movement between Jurassic and early Tertiary and the subsidence during Late Miocene. As one of these uplifts, the Niutuozhen uplift was bordered by the Niudong Fault, Niunan Fault, Rongcheng Fault and Daxing Fault. The uplift started to be covered by the Minghuazhen and Quaternary sediment from the Late Miocene (Fig. 1).

2.2 Geothermal Resources Conditions

The Minghuazhen Formation sandstone of the Neogene with an average effective thickness of 225 m and Wumishanian dolomite of the Jixianian with a thickness of more than 1000 m are the main reservoirs in the Niutuozhen geothermal field. The Quaternary clay and the mudstone of the Minghuazhen Formation which is more than 493 m thick are the caprock of the geothermal reservoirs.

The thermal gradient of the cap rock is in the range of 3.0-11.5 ℃/100m (Chen, 1988). The thermal gradient of the Wumishanian reservoir is within 1.65-2.55 ℃/100m (Chen, 1988; Geothermal Group, 1983). The maximum well bottom pressure was 3.74×10^5 Pa in 1970s (Chen, 1988) and decreased to 1.01×10^5 Pa because of drastic development without reinjection. The well head temperature varies from 59 to 84 ℃, without any changes after 40 years development. The permeability of the Minghuazhen Formation reservoir is within 3.36×10^{-14}-2.39×10^{-12} m^{-2} and the Wumishanian reservoir is within 2.10×10^{-11}-$6.15\times10^{-10} m^{-2}$.

3. GEOTHERMAL REINJECTION EXPERIMENT

3.1 Reinjection Experiment

Geothermal water reinjection is one of the effective methods to achieve sustainable development of geothermal resources. To prevent reservoir cooling caused by large scale reinjection, reinjection experiment is one of the effective methods to identify hydraulic connection between production and reinjection wells and calculate injection capacity of the wells (Einarsson, 1975; Stefansson, 1997; Liu, 2003).

The first reinjection experiment was carried out in 2009 with one production well and one reinjection well (Fig. 2 and Fig.3). The injection rate was increased from 50 m^3/h to 150 m^3/h during the experiment. The second experiment was carried out from 2010 to 2011 with two production wells and one reinjection well. The injection capacity of one injection well was 180 m^3/h (Wang, 2011) which indicated that all the geothermal water after using for space heating could be reinjected into the dolomite reservoir.

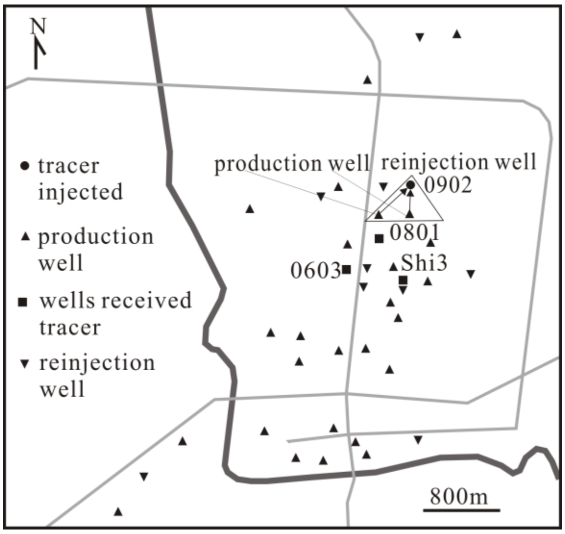

Figure 2: Distribution of geothermal wells.

The injection index could be calculated based on the second reinjection experiment as

$$II = \left|\frac{\Delta Q}{\Delta p}\right| \tag{1}$$

where *II, ΔQ, Δp,* are injection index, injection rate difference and pressure difference, respectively.

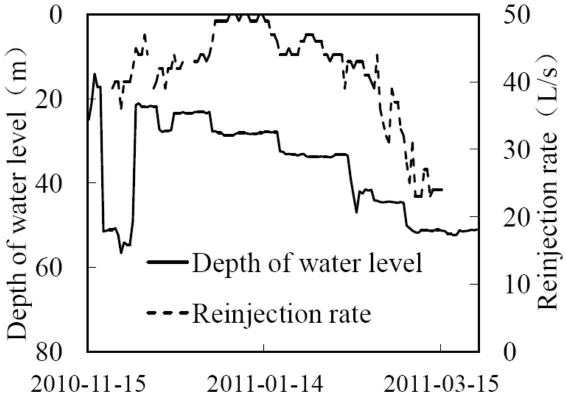

Figure 3: Water level above sea level and reinjection rate of reinjection well.

The slope of the line in figure 4 is 0.1146 (Fig.4), and the injection index is calculated to be 8.72(L/s)/bar, which indicates that well bottom pressure increases 1 bar when the increase in injection rate is 8.72 L/s.

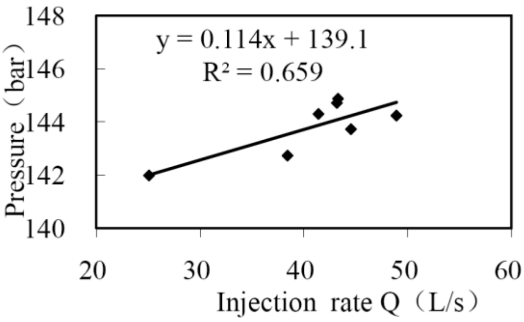

Figure 4: Relationship between well bottom pressure and reinjection rate.

3.2 Tracer Test

To identify hydraulic connections between production and reinjection wells, tracer test was carried out using sodium fluorescein as tracer. Amongst 20 production wells, only three production wells received tracer. The distance between reinjection well and these three wells is ranged from 816 to 1477 meters. The nearest production well 0901 did not receive tracer. The first concentration peak was found in well 0603 (Fig. 5) with a distance of 1477 meters from reinjection well, indicating anisotropy of the karstic geothermal reservoir.

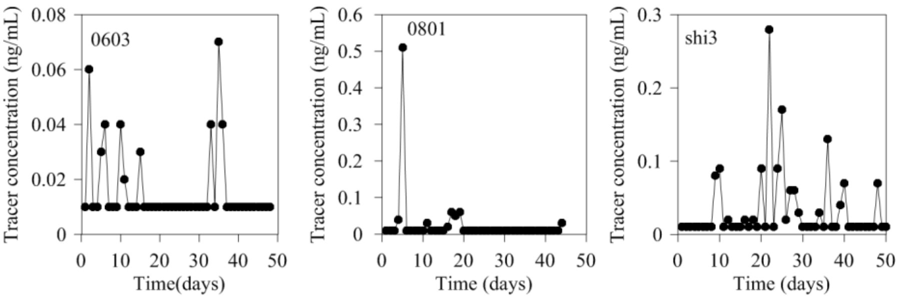

Figure 5: Tracer concentration in well 0603, 0801 and shi3.

The highest velocity of tracer in channels between production well and reinjection well is calculated to be 370m/d (well 0603). Well 0603 received 0.057 kg tracer which is approximately 0.19% of the total tracer injected, indicating that around 260 m^3 injected geothermal water was received by well 0603 in one year. Approximate 0.00048 kg tracer was received by well 0801 which is about 0.0016% of the total tracer. Temperature change was not detected, indicating that reservoir cooling did not occur during the experiment.

According to origin and evolution of geothermal water in the Niutuozhen Geothermal Field, flow direction of geothermal water is from north-east to south-west, which is in accordance with the tracer flow direction (Wang et al., 2013).

4. CONCLUSIONS

Based on the results of the reinjection experiment and tracer test, following conclusions could be drawn:

(1) The injection rate of 180 m^3/h has been realized during reinjection experiment and injection index was calculated to be 8.72(L/s)/bar, indicating that balance between production and reinjection could be realized in the future.

(2) The flow direction of reinjection geothermal water is from north-east to south-west, which is influenced by regional natural flow field and production induced flow field.

(3) The low recovery rate of tracer test implies that the scale of channels between production wells and reinjection wells are quite small, which could not result in reservoir cooling during a short period.

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