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Analysis on Geothermal Field Dynamic Characteristics of Low – Medium Temperature Geothermal Reservoir Under Exploitation and Reinjection

Tian Guanghui, Liu Donglin, Zeng Meixiang, Zhao Sumin, Zong Zhenhai, Cai Yun

Tianjin, China, Wei guo Road He dong District No. 189, 300250

tjdrytgh08@126.com

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ABSTRACT

There is high geothermal temperature background value in Tianjin, one of the four municipalities of China. In Tianjin geothermal resources have been exploited with large scale for a long time and convert to recycling exploitation mode by reinjection. The continuous steady wellhead temperature monitoring data of geothermal well shows that the temperature of geothermal fluid has no apparent fluctuate for long-term exploitation. The temperature is measured in a reinjection well during and after reinjection. The result shows that while recharge in low temperature original water, the bottom temperature of borehole decreased by 0.1～0.76℃/a; But after reinjection the temperature of extraction reservoir recovers month by month. It also indicates that after reinjection the geothermal temperature of reinjection region gradually recovers to the original temperature of last year before the next reinjection stage.

1. INTRODUCTION

There are abundant sedimentary basin type low-medium temperature geothermal resources in Tianjin. Geothermal resources have been commercially exploited on a large scale since 1980s and by now there have been 474 geothermal wells of different geothermal reservoir and different depth. Its exploitation scale, direct use technology, geothermal research level ranked the first in China and well known worldwide. The large scale exploitation causes the decrease of geothermal reservoir pressure. For this, reinjection research begun in 1982 and by 2013 there has been 53 reinjection wells. In 2013 the production is $3706\times10^4m^3$, and reinjection is $1553\times10^4m^3$. Under exploitation and reinjection, the dynamic variations of geothermal reservoir pressure (water level）, hydrochemistry and temperature are complicate. Based on the well head temperature and borehole bottom serial temperature measurement data of these years, the dynamic characteristics of geothermal reservoir under exploitation and reinjection are analyzed.

2. GEOTHERMAL FIELD OF TIANJIN GEOTHERMAL RESERVOIR

The ground temperature research degree of North China basin is the highest among Chinese geothermal anomaly area. There has been a large amount of data of geothermal well bottom/head temperature, steady state temperature measurement and ground temperature. These data shows that due to the effect of cold water in the Beijing-Baoding-Shijiazhuang depression and the Baodi depression there are two low-temperature zones about 30～60km width where geothermal gradient is lower than 2.0℃/100m. Besides, the geothermal gradient of most area of North China plain is higher than 2℃/ 100 m. And in southeast of Beijing, Tianjin area and the area bounded by Jinan to the south, Shijiazhuang to the west and Bohai to the east there is a high ground temperature region where the geothermal gradient is higher than 3.0℃/100m, the average geothermal gradient 3～4℃/100m of cap rock accounts for 27.6% of and average geothermal gradient higher than 4℃/100m accounts for 17.3%. The structural feature of deep bedrock controls the regional geothermal field, usually the bulge of bedrock is the geothermal anomalous region.

Tianjin locates in the northeast of North China basin. Baodi depression, to the north of Baodi-Ninghe fault, has a lower geothermal gradient because the unconsolidation cap rock is very thin or bedrock directly reaches out of the ground. The geothermal field to the south of the fault is as the same as North China basin horizontally and vertically. The average geothermal gradient is higher in the middle region(Cangxian uplift) and lower on both sides(Jizhong depression and Huanghua depression).Taken the 3.5℃ / 100m as the lower limit value of geothermal anomalous region, there are 10 geothermal anomalous regions in Tianjin area and 7 of these regions, located in Cangxian uplift. The geothermal temperature distribution shows a low- high- low pattern horizontally, which is coincident with the depression- uplift- depression pattern of geological structure. Geothermal drilling achievements show that in Tianjin area the well head steady fluid temperature of Neogene system porous type geothermal reservoir that is terrestrial clastic sediment is 40～82℃; the temperature of karst fracture type bedrock geothermal reservoir that is mainly marine sediments is 60～102℃, and the highest temperature can be 113℃.

3. DYNAMIC CHARACTERISTICS OF GEOTHERMAL RESERVOIR TEMPERATURE FIELD UNDER EXPLOITIATION

Naturally, geothermal reservoir maintains dynamic equilibrium of the recharge, runoff and discharge, the dynamic factors like pressure（water level）, hydrochemistry and temperature fluctuate a little. The exploitation of geothermal fluid breaks this dynamic equilibrium. Besides the reservoir pressure, we should also pay attention to the change of reservoir fluid temperature.

Taken the capacity of pumping equipment, economy and technical level into consideration, 7 geothermal reservoirs can be exploited in Tianjin area currently including Porous type geothermal reservoir in Neogene system Minghuazhen formation(Nm）, Guantao formation（Ng）and Paleogene system Dongying formation(Ed）; bedrock type geothermal reservoir in Paleozoic group Ordovician system（O）, Cambrian system（Є）and Mesoproterozoic group Jixian system Wumishan formation（Jxw）and

Changcheng system Gaoyuzhuang formation (Chg). Large scale exploitation of geothermal resource has been a long time in Tianjin. The exploitation reservoir, exploitation region and the exploitation/ reinjection period are quite concentrative. 90% of the geothermal wells of Tianjin targets at Minghuazhen formation, Guantao formation and Wumishan formation. The exploitation/ reinjection period is mainly 15 November to 15 March of the next year, about 120 days. According to " Dynamic monitoring annals of geothermal resource exploitation of Tianjin in 2013", the production of these three main geothermal reservoir is $3159.8\times10^4m^3$ and is about 85.3% of the total production in Tianjin($3706\times10^4m^3$）.

We choose several typical production wells of the main geothermal reservoir and analyze their multiyear well head steady fluid temperature (Fig 1). In order to reflect the true dynamic characteristics of the geothermal fluid temperature in one well under multiyear production, we choose the fluid temperature data at the same period of different years. To avoid the influence of other factors, these temperature data are in steady state and measured with the same method and under the same production condition. These multiyear temperature curves indicate that comparing with the fluid temperature when the well completed, the geothermal fluid temperature has no obvious change for long-term exploitation.

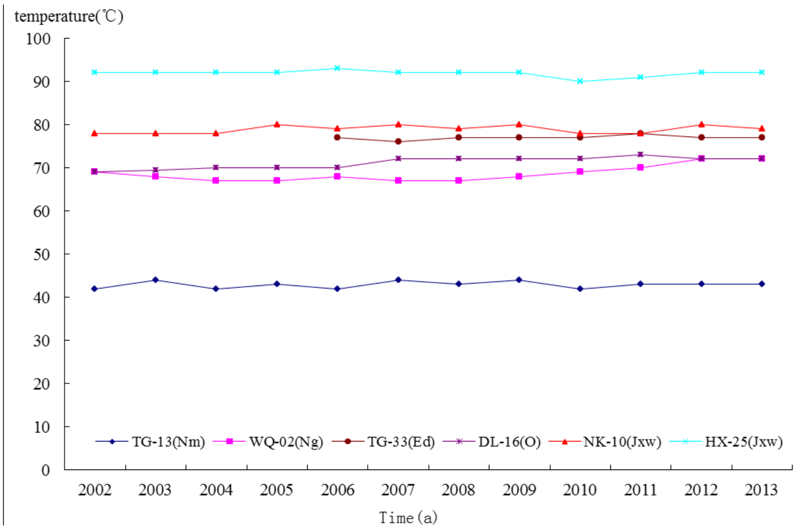

Fig. 1 multiyear steady fluid temperature

4. ECONOMIC BENEFITS AND DEVELOPMENT PLAN

Now geothermal resource is developed under exploitation/reinjection in Tianjin. When reinjection experiments put into practice in 1982, there have been 53 reinjection wells and the ratio of reinjection wells to production has exceeded 15%. Reinjection increase year by year and in 2008 the total reinjection rate is 22.5%. This has reached the aim (rejection rate reaches 20%) ahead of 2 years in "Survey and development and utilization plan of geothermal resources in Tianjin "（2006 - 2010）. It is a great achievement for Tianjin, because geothermal resource has been developed using single well in extensive mode since 1936 and it is only about 10 years using circulating exploitation mode by reinjection.

In Tianjin except Dongying formation and Gaoyuzhuang formation, The other geothermal reservoirs are all have reinjection wells now. We have carried out many technical research including vacuum reinjection, pressurized reinjection and tracer test etc.. Most reinjection wells have operated for several years and reinjection water is original geothermal water after heat exchange. In Tianjin most reinjection wells are Jixian system Wumishan formation, Ordovician system and Neogene system Guantao formation, and of which 30 reinjection wells are Wumishan formation. These years reinjection increases dramatically from less than $100\times10^4m^3$ in 2000 to $1553\times10^4m^3$ in 2013, and the reinjection rate increases from 7% in 2001 to 41.9% in 2013.

Base on the large-scale reinjection situation, the impact to ground temperature field is the first thing that should be taken into consideration. Owing to the fluid temperature cannot reflect the temperature of the deep geothermal reservoir, we selected several typical reinjection wells and use borehole steady thermometric method. Though it is more expensive and difficult, it can eliminate the influence of heat loss that causes by many factors like flow velocity, flow rate and borehole wall resistance etc. when geothermal fluid move to the well top. We measure the temperature of the same reinjection well before and after reinjection. HX-25B is a key study well.

Reinjection well HX-25B located on Cangxian Uplift in the North China Fault Sag, to the south of Baodi-Ninghe fault, on the northern margin of the North China Platform, with a high temperature background. The region is well known as Wang Lan zhuang geothermal field, having a geothermal anomaly area of 534km2, and the maximum geothermal gradient is 8.0℃ / 100m. The depth of well HX-25B is 1658m (slant depth); the geothermal reservoir is WuMishan formation of Mesoproterozoic Jixian System. Thickness of the water intake section is 156m, and the wellhead temperature is 91℃. Since constructed in 1995, productive reinjection experiments (reinjection of geothermal water after heat exchange into the same production layer through the other well of the doublet wells, forming a closed loop) have been carried out on this well during winter. The annual reinjection rate is $20\times10^4m^3\sim28\times10^4m^3$. Measurement of the well temperature has been made from 2006 year. The well temperature curve (Fig.2) shows a fast increase in temperature within 100～200m depth, geothermal gradient changes significantly near 200m depth, form 400m depth to 1454.46m (top of the bedrock), the temperature increases steadily; While in the bedrock, there is a high temperature geothermal fluid upwelling in the lower part, as there is a large difference of the heat conductivity between the cap rock and the underlying formations, temperature of the geothermal reservoir increased significantly. Analysis of the significant change in the lower part of the curve suggests that temperature increase only occurs at the contact region of the cap rock and the bedrock reservoir(1425～1450m depth), due to high heat conductivity of the bedrock, strong conductivity of the fluid and a good runoff condition, geothermal gradient decreased significantly in the reservoir. Combined with the well completion data, it is found that drilling fluid leakage mainly occurred at 1546.3～1654.3m depth. Take the temperature curve of year 2006 as an example, the annual reinjection rate is $23.6\times10^4m^3$,the temperature is 44℃, the curve shows temperature increase is minor below 1550m depth, and can be inferred that the reinjection fluid mainly flowed into the reservoir below 1550m depth, and formed a low temperature (92℃) region at 1575m depth in the reservoir, while the maximum flow rate is $101m^3/h$ and the temperature is 90.5℃ during steady flow pumping test just after well completion. Considering the borehole effect in Tianjin (cause heat loss of 2～3℃), the reservoir temperature should be 92.5～93.5℃, so using the reinjection water of 44℃ the reservoir can recover to its original temperature at the same year, which accounting for the fast recovery of the reservoir temperature after reinjection.

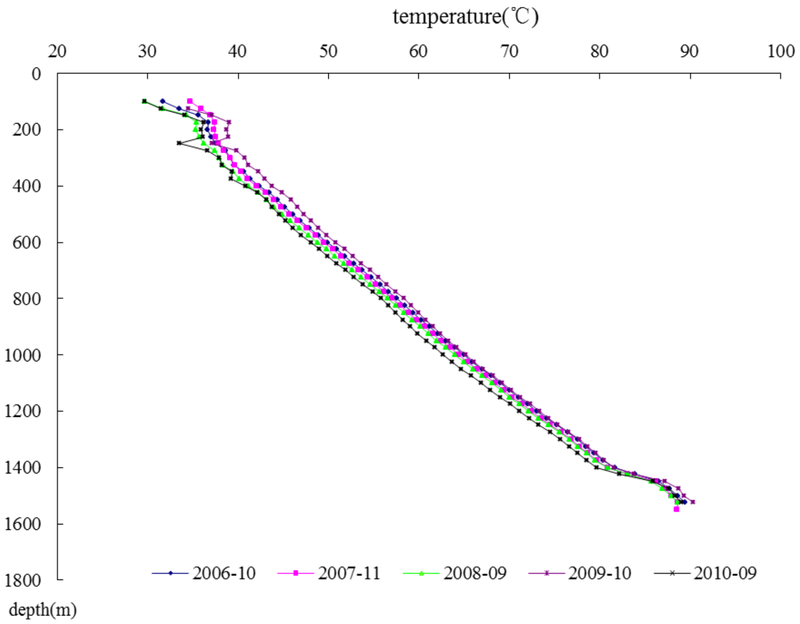

Fig. 2 multiyear temperature curve of reinjection well HX-25B

Table 1 presents a series of temperature data around the top of the bedrock of the reinjection well HX-25B for five years, the borehole temperature vary compare the series temperature data on the same section at different time. Take the temperature data collected from September to November before reinjection period each year as an example, well temperatures at 1450m depth(contact part of cap rock and bed rock) were 83.88℃, 83.12℃,83.2,83.82 and 83.31℃ respectively, fluctuated a little in five years; While well temperature at 1525m depth(bed rock part) were 88.36℃,88.64℃, 88.63℃,88.29and88.67,with no significant variation. Since 1454.46m depth is the very location where the bottom of the technical casing area, implying fluid temperature in the well pipe of the reinjection well decreases slightly year by year, the amplitude for 1425m,1450m and 1475m depth were 0.1～0.76℃/a、0.27～0.51℃/a、0.35～0.42℃/a, but the phenomenon only occurs in the well pipe and at the contact section of the cap rock and the bedrock; While on the main water intake section of the open hole (1500m and 1525m depth), the well temperature barely fluctuated, which can be ascribed to the continuous heating to the low temperature reinjection fluid by the high enthalpy host rock.

Existing data shows that multiyear continuous reinjection did not cause obvious temperature decrease in the geothermal reservoir, which is also supported by dynamic monitoring data. Steady fluid temperature of the production well HX-25 of the doublet system and the adjacent well HX-14(the two wells has been proved to have a hydrodynamic connection by pumping test) fluctuated slightly (fig.1), or can be said to have no influence to the fluid temperature of the production well yet. However, the influence of the large amount of low temperature fluid recharge to the temperature of the reservoir and the fluid of the production well still needs further verification by long term monitoring.

Table 1 well temperature data series of the bedrock reservoir well HX-25B

depth(m) \ time		2006-10-19	2007-11-12	2008-4-14	2008-7-29	2008-9-22	2009-03-25	2009-06-23	2009-10-27	2010-5-7	2010-9-06
1425		83.88	83.12	82.97	83.2	83.08	82.77	82.94	83.82	83.31	82.18
1450	Top of bedrock	86.49	86.22	85.91	85.76	85.71	85.56	85.71	87.2	86.08	85.89
1475		87.68	87.33	86.97	86.93	86.91	86.69	86.82	88.73	87.2	87.65
1500		87．92	87.96	87.56	87.88	87.89	87.47	87.60	89.3	87.89	88.29
1525	main leakage section	88．63	88.64	87.96	88.45	88.63	88.17	88.29	90.3	88.67	89.01

In order to further study the response of reservoir temperature to reinjection, and find the dynamics characteristic of the ground temperature, three continuous temperature measurements were performed to well HX-25B in April, July and September in 2008. The measured data and the well temperature curve shows that even the well temperature decreased slightly in the upper part of the well (above 1475m depth), on the main water intake sections at 1500m and 1525m depth the well temperature shows an increase pattern (table 1 and table 3), for instance, the temperature were 87.96℃,88.45℃ and 88.63℃ at 1525m depth, the temperature had almost recovered to the level of October, 2006 (88.63℃) and November, 2007 (88.64℃). If the temperature were measured in October or November, 2008, the period before reinjection the well temperature would recover to the previous one. This trend implies that the reservoir temperature recovers monthly during the period with no reinjection. It can be inferred that the reservoir temperature can recover to the same level of the contemporaneous period of the previous year.

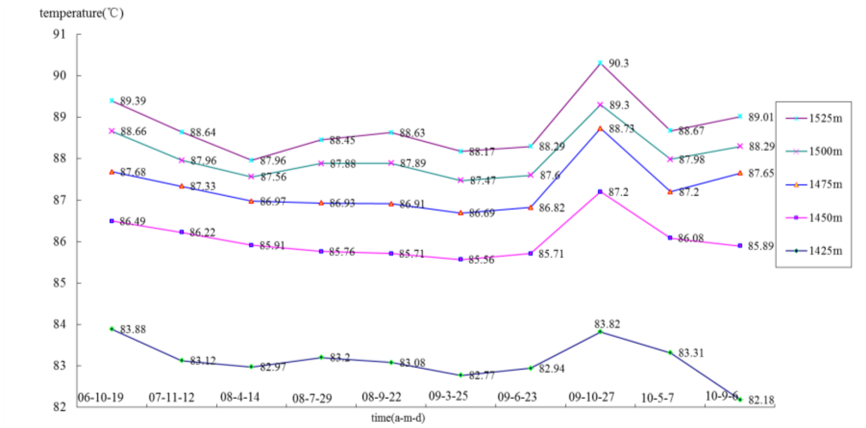

Fig.3 multiyear temperature data of bedrock reservoir well HX-25B

5. CONCLUSIONS

Tianjin area situated in the northeast of the North China plain is located in a region characterized of high thermal temperature background, with large geothermal anomaly area, high reservoir temperature, large scale exploitation and high research level. Geothermal reinjection work has been strengthened in recent year; development of the valuable geothermal resources has stepped into the circulation mode. Based on the fluid temperature monitoring data of a bunch of geothermal wells and the multiple well temperature measurement of typical geothermal wells, steady well head fluid temperature of all the geothermal wells and the reservoir temperature show no significant decrease, and can be concluded that either development of geothermal resources or geothermal reinjection that last for more than half a century, has no significant impact on the ground temperature field of the reservoir. However, further works are still needed to explore the dynamic characteristics and the temperature field trend of geothermal reservoir under exploitation and reinjection.

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