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Reinjection Research of Neogene Porous Geothermal Reservoir

SUN Baocheng, JIA Zhi, YANG Zhongyan, PENG Hongjing, YANG Yongjiang

Mailing address, No.189, Wei Guo Dao Road, Hedong District, Tianjin City, China.

E-mail address, tjdryjz@sina.com

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ABSTRACT

Recently, porous geothermal reservoir of Neogene as an important mining geothermal reservoir, have been the increasingly exploited. The geothermal reservoir pressure shows trend of declining yearly at tremendous speed and therefore how to achieve its sustainable development has become an urgent issue. General consideration of the reinjection is the primary measurement of exploitation and protection of the geothermal resources and it also can solve many problems brought with the development and utilization of geothermal development in an effective way. The study of Neogene reinjection had not made a breakthrough since 1970s. In this paper, we set Tianjin geothermal reinjection an example, with the combination of the successful experience and technology from domestic and overseas to analyze lithological and tectonic features of Neogene geothermal reservoir sandstones; uses natural reinjection test methods to explore the permeability of Neogene geothermal reservoir under reinjection condition; and compares the reinjection test results of several wells with different technology, in purpose of figuring out appropriate reinjection parameters. Consequently, it is important for the sustainable development and utilization of Neogene geothermal resources.

1. INTRODUCTION

In the process of geothermal development and utilization, the main problem is the decreasing of geothermal reservoir temperature and pressure during exploitation, and the environment thermal pollution induced by discharge of geothermal water. At present, reinjection is the best measure to solve the decline of geothermal reservoir pressure and the adverse impact on environment caused by geothermal water. The geothermal reinjection mining and geothermal reinjection are widely used in the global scope and doublet wells exploiting geothermal energy are increasing rapidly. This paper takes geothermal reinjection of Guantao formation from Tianjin area as an example to analyze the reinjection technology of Neogene porous geothermal reservoir.

2. DOMESTIC AND FOREIGN REINJECTION STATUS

In USA, New Zealand, Iceland and other countries, at the initial exploiting stage of geothermal resources, without a reasonable plan of development and utilization, with the direct discharge of geothermal water, lead to a rapid decline of geothermal reservoir pressure and serious resources waste. Therefore, reinjection technology has become an important topic in development and utilization of geothermal resources. In 1969, the Geyser geothermal field in America and Melunl Almont in France had been carried out the earliest reinjection of geothermal reservoir. Reinjection was intended to deal with geothermal water in order to prevent the pollution of the surrounding environment [1]. However, in the past 20 years, the main purpose of geothermal reservoir reinjection has been focusing on maintain reservoir pressure and improving the geothermal mining rate [2].

At present, reinjection has become an important way to maintain the development and utilization of geothermal resource [3] of the geothermal resource management. The reinjection research of porous geothermal reservoir of Neogene in Tianjin area began in 1970's, mainly aimed at the reinjection of porous geothermal reservoir, water absorbing capacity of reservoir and factor of influence, attenuation state of reinjection, reinjection mechanism , the causes and solutions of reinjection clogging, etc[4~5].

3. THE FEATURES OF GUANTAO FORMATION RESERVOIR (NG)

The reservoir including of alluvial fan and fluvial deposits like sand and grave intercalated with variegated mud rock was formed in fluvial clastic sedimentary environment , The lithology varying coarse to fine to coarse features shows obvious sedimentary cycles and mainly contain grayish-white, light gray medium sandstone, fine sandstone interbedded with brown-red, grayish-green mudstone, the bottom is rock with sand and gravel in the ascending order . The thickness of geothermal reservoir is 80~400m in which sandstone accounts for 23% ~ 62%. The porosity of sandstone and glutenite is 20%~38% and the permeability is $805\sim1884\times10^{-3}\mu m^2$ representing a good water-retaining property. Single well yield is 40～120m^3/h, wellhead stable flow temperature is 60~80 ℃, water type is mainly of HCO_3-Na and $HCO_3\cdot$Cl-Na, salinity is 800 ~ 1900mg/l[6].

4. WELL DRILLING TECHNOLOGY COMPARISON

In Tianjin area, the well completion technology of shallow geothermal reservoir mainly uses the supply water well completion method, This method is aimed to put wrapping wires filter pipe into the corresponding reservoir and at the same time drop annularly gravel material to stop a further fine sand using mud ball to pack and seal water. Dropping gravel is difficult for the deep geothermal wells, directly put wrapping wires filter pipe on usual, packing appropriate copper mesh or not depends on reservoir sand size, use cements to cement and seal water[7]. The effect is very promising. In recent years, perforating completion technology of oil and gas wells is gradually applied in geothermal wells, achieved accurate results especially in the reinjection. For current, relatively more mature and perfect well completion method at home, filter pipe and perforating, are the best illustration .

4.1 Filter pipe completion

Filter pipe is installed in aquifer of the well and the water in aquifer can flow into the well through the pore of filter pipe whose function is to prevent the aquifer wall from collapsing due to a large number of pumping and from the fine sand pouring into the well. According to the structure, the common types of filter pipe are as follows: wrapping wires filter pipe and wrapping wires filter pipe with packet mesh.

(1) geothermal wells within 1200m depth, fine-grain sandstone, no cementation or poor cementation, to prevent formation sand flow, generally using the traditional water well completion technology, applying wrapping wires filter pipe with 1mm spacing, dropping 2~4mm gravel material from pipe outer , sealing water by clay ball , backfilling casing and borehole annularly by clay .

(2) wells of 1200~1500m depth, the formation drill-ability worse than the shallow, large aperture drilling cost is high, and it is more difficult to drop gravel, cementation and grain of sandstone are better than the shallow, using wrapping wires filter pipe with trapezoid section, wrapping wire spacing is usual 0.5~0.7mm determined by thermal reservoir sandstone grain, coated 40 mesh copper mesh to prevent sand flow.

(3) wells of 1500~3000m depth, using winding wires filter pipe with 0.5~1mm spacing.

4.2 Perforating completion

Perforating is a process technology which is used to transport the perforator by special instrument to a scheduled depth of downhole, detonate the perforator aim to the target layer, penetrate the casing and cement annulus and form pore passage from target layer to the casing. The pore geothermal wells were drilled by cable to transport shaped charge perforator. When the shaped charge jet hit the layer, high temperature, high pressure and high strain-rate region rapidly formed in rock contact surface, and make the rock quickly disintegrated even broken, subsequent jet then pushes the broken materials into the stratum, thus form perforation channel, at the same time compact the rock around perforation channel. According to the structure of perforating bullet, layer properties, the length of channel ranges from few centimeters to tens centimeters as usual. Pore diameter is few millimeter to ten millimeter in general.

5. ANALYSIS OF THE TESTS IN THE POROUS GEOTHERMAL RESERVOIR

In order to study the influence of Neogene reservoir reinjection through different well completion technology, we choose two geothermal wells with different well completion technology in Tianjin, comparing them from two aspects: step-down test and reinjection test.

5.1 The basic situation of geothermal wells

DR-1, DR-2 well are located in the southeast of Tianjin Dongjiang harbor, 56km away from Tianjin downtown,. The Cangdong fault, the Haihe fault and the Hangu fault have much influence on the geological conditions of the study area (Figure 1). The Neogene Guantao formation are perfectly produced in these wells, the distance of the two wellhead is about 550m, the specific circumstances shows in table 1.

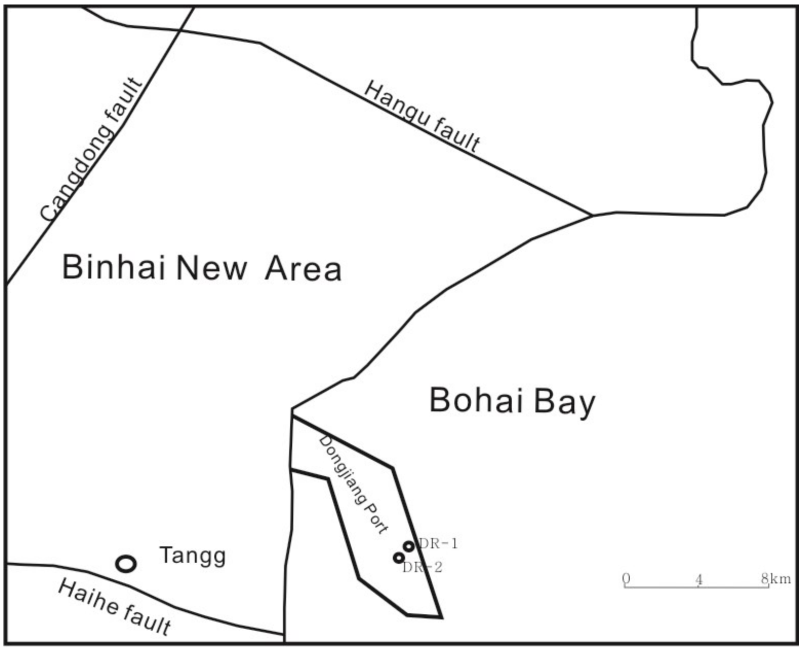

Figure1: Location of the well

Table 1 Parameters of geothermal wells

Parameter	DR-1	DR-2
Geothermal reservoir	Guantao formation	Guantao formation
Lithology	Medium-coarse grain sandstone, gravel-bearing rock	Medium-coarse grain sandstone, gravel-bearing rock
Water yield(m^3/h)	120.63	120.63
Temperature(℃)	70	70
Water quality type	HCO_3·Cl-Na	Cl·HCO_3-Na
Salinity （mg/l）	1256.8	1458.6
Porosity（%）	24.37～32.79	27.08～32.53
Permeability（$\times 10^{-3}\mu m^2$）	424.13～990.72	559～1002
Water section (m)	1631.41~1649.52、1663.12~1681.17 1704.44~1719.45、1723.95~1741.46 1764.36~1775.34、1792.68~1804.01 1808.46~1820.03	1739.7~1759.7、779.5~1787.5 1827~1832、1851.7~1879.7 1956.2~1962.2、2012.3~2018.3 2021.3~2028.3、2032.3~2043.3
Aquifer thickness（m）	89.4	91
Well radius（m）	0.113	0.113
Well completion technology	Filter pipe	Perforating

5.2 Analysis of the pumping test

During the exploitation of geothermal wells, especially in the initial stage, the wellhead temperature is not constant, but increasing with the continuation of time, while the changes of water density and temperature is in inverse proportion, cause the observed water level cannot reflect the actual level changes of geothermal wells (geothermal reservoir pressure) . At this time, although the water level rises or remains unchanged, the geothermal reservoir pressure decrease. This phenomenon is called "wellbore effect", and therefore in the process of data collection, it need to uniformly correct the temperature to eliminate" wellbore effect". According to the wellhead temperature and the experience value of temperature loss , this paper takes 70℃ of geothermal reservoir as the uniform temperature to correct the observed data collected from the DR-1, DR-2 well step-down test and reinjection experiment .

5.2.1 Test process

In March 19~22 of 2011, DR-1 well performed three times step-down test (NO.1, NO.2 and NO.3), duration curves are shown in Figure 2, test results are shown in table 2.

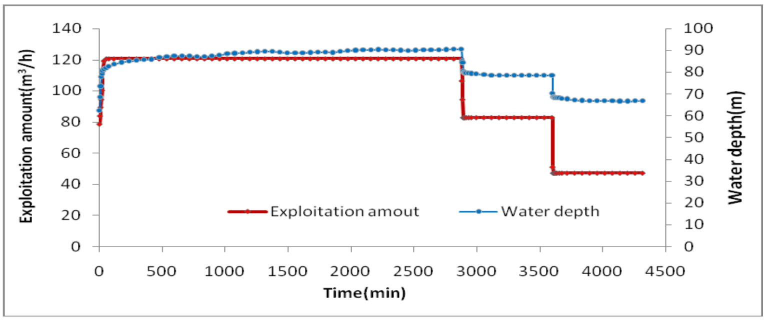

Fig.2 Pumping test curve of DR-1

Table 2 Pumping test result of DR-1

Parameter	NO.1	NO.2	NO.3
Exploitation amount（m^3/h）	120.63	82.95	47.33
Water depth（m）	90.2	78.4	66.24
Static water level（m）	49.61		

In June 1~4 of 2012, DR-2 well performed three times step-down test (NO.1, NO.2and NO.3), duration curves are shown in Figure 3, test results are shown in table 3.

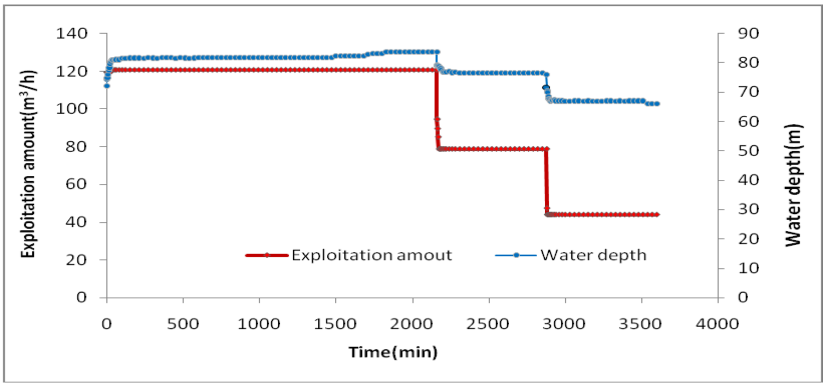

Fig.3 Pumping test curve of DR-2

Table 3 Pumping test result of DR-2

parameter	NO.1	NO.2	NO.3
Exploitation amount（m^3/h）	120.63	78.74	43.92
Water depth（m）	84.5	77.45	69.31
Static water level（m）	56.11		

5.2.2 Calculation of pressure test heat storage of hydrogeological parameters

Combined with the geothermal reservoir characteristics in this area, we use Dupuit formula and hope he formula to analyze and calculate the test data, to determine the hydrogeological thermal reservoir parameters of DR-1 and DR-2 well.

（1）specific yield

Calculation formula of specific yield is

$$q = \frac{Q}{s_w} \tag{1}$$

Where q, Q, s_w are specific yield（m^3/h·m）, amount of pumping water(m^3/h) and steady drawdown(m).

（2）permeability coefficient and influence radius

$$K = \frac{0.366Q}{M \times s_w} \lg \frac{R}{r_w} \tag{2}$$

$$R = 10 s_w \sqrt{K} \tag{3}$$

Where Q, R, r_w, s_w, M are amount of pumping water（m^3/d）, influence radius of pumping（m）, well radius of water section（m）, stable down depth（m） and effective thickness of geothermal reservoir（m）.

（3）permeability

Calculation formula of permeability is

$$k = \frac{\eta_t}{g} K_t \tag{4}$$

Where *k*, η_t, K_t, *g*, are permeability of geothermal reservoir（m^2）, kinematic viscosity coefficient of t℃ geothermal fluid（m^2/s）, permeability coefficient of t℃ geothermal reservoir（m/s） and acceleration of gravity（$9.8m/s^2$）。

The calculation results shows in table 4.

Table 4 Calculated results of hydrological parameters

parameter	DR-1	DR-1
specific yield(m^3/h·m)	3.03	4.42
The influence radius of pumping water(m)	418.5	336.03
permeability coefficient(m/d)	1.11	1.51

By comparing the two wells' hydrogeological parameters, it concludes that at the same stratigraphic parameters, geothermal well completed by perforating (DR-1) in the specific yield and permeability coefficient are better than the geothermal well completed by filter pipe (DR-2), but its influence radius of pumping water is smaller. Internal and external wrapping wire spacing and gravel diameter is relatively large in size, will be a little better in effluent efficiency, which size of the diameter can achieve the best effluent efficiency needs to be further studied.

5.3 Analysis of the reinjection test

5.3.1 Reinjection test of DR-1

In August 5~15 of 2011, DR-1well has performed reinjection test, duration time was 183.6 hours, the cumulative reinjection was 11029 m^3, the maximum instantaneous reinjection was 87 m^3/h. Duration curves are shown in Figure 4.

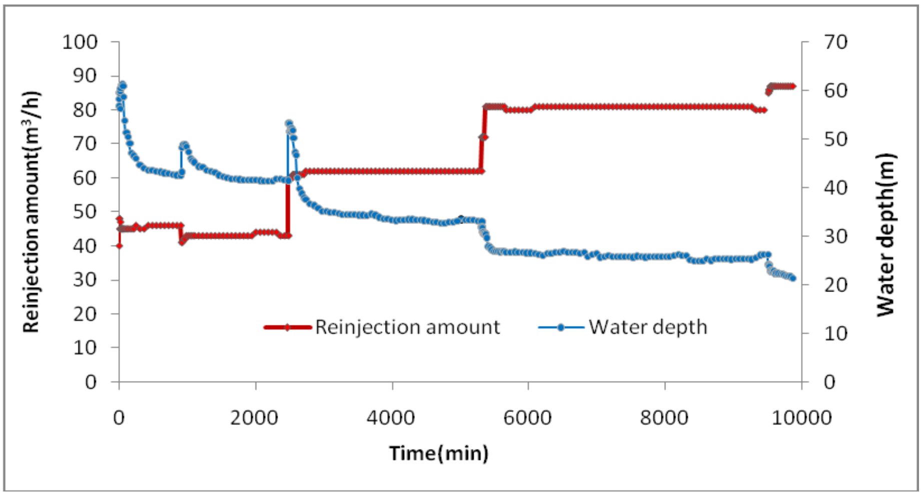

Fig.4 Reinjection test curve of DR-1

From figure 4, it can conclude that reinjection and dynamic water level of the three stages 1165～2485min, 2705～5315min and 5395～9515min are stable, the results are shown in table 5.

Table 5 The result of DR-1 reinjection test

parameter	NO.1	NO.2	NO.3
Water depth（m）	45.2	35.3	27.5
Reinjection amount（m^3/h）	43	62	81
Stabilization time（h）	22	43.5	68.7

5.3.2 Reinjection test of DR-2

In June 24~28 of 2013, DR-2well has performed reinjection test, duration time was 98.5 hours, the maximum instantaneous reinjection was 101 m^3/h. Duration curves are shown in Figure4.

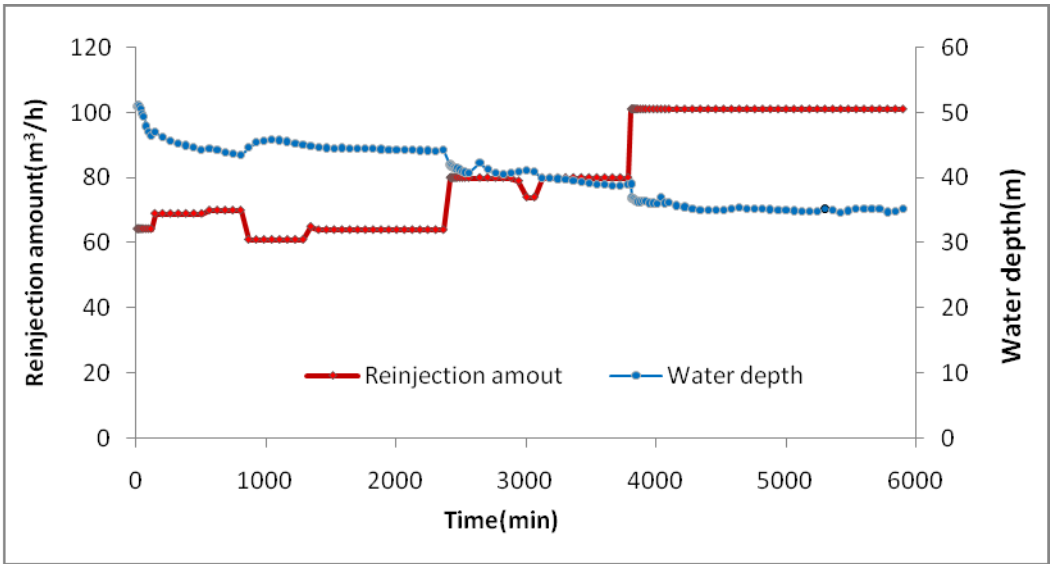

Fig.5 Reinjection test curve of DR-2

From figure5, it can conclude that reinjection and dynamic water level of the three stages 1410～2370min, 2434～3790min and 3818～5905min are stable, the results are shown in table 6.

Table 6 The result of DR-2 reinjection test

parameter	NO.1	NO.2	NO.3
Water depth（m）	48.42	42.08	37.9
Reinjection amount（m^3/h）	64	80	101
Stabilization time（h）	18	18	20

5.3.3 Calculation of geothermal reservoir hydrogeological parameters of reinjection test

This paper uses formula (5), (6) and (7) to calculate water injection permeability coefficient K_{inj}。

$$K_{inj} = \frac{0.366Q_{inj}}{M \times s_r} \lg \frac{R}{r_w} \quad (5)$$

$$R = 10 s_r \sqrt{K} \quad (6)$$

$$P = Q_{inj} / M s_r \quad (7)$$

Where K_{inj}, P, Q_{inj}, s_r are water injection permeability coefficient（m/d）, absorption rate of geothermal reservoir（$m^3/d \cdot m^2$）, water injection（m^3/d）and water level recovery（m）.

The calculation results shows in table 7.

Table 7 Calculate result

Calculate parameter	DR-1	DR-2
Kcp（m/d）	0.75	3.07
Pcp（$m^3/d \cdot m^2$）	0.59	2.62
Tcp（m^2/d）	67.05	273.65

Suppose the reinjection temperature of the two wells are 70℃,and the fluid field of geothermal reservoir is stable, s_r assigned 50m, according to formula(7), DR-1 and DR-2 allowing reinjection amount are 109.89m^3/h and 496.71m^3/h.

The test results show that, in the same geological and reinjection water source conditions, reinjection effect of perforating completion well is better than the filter pipe completion well. In theory, allowing reinjection amount is large, but the well actual operation is influenced by Jiamin effect, high quality water, water rock interaction and clogging by solid particles or microbial, the actual sustainable reinjection amount may be smaller than the theoretical value.

6. ANALYZE

By the end of 2013, there are 135 geothermal wells of Neogene in Tianjin area, including 66 geothermal wells of Minghuazhen formation and 79 geothermal wells of Guantao formation. There are 6 reinjection wells of Minghuazhen formation, reinjection amount is only 0.89×10^{4}m^3 each year, reinjection rate is less than 1%. The annual exploitation of Guantao formation geothermal reservoir is 628.28×10^{4}m^3 in total, 119.38 ×10^{4}m^3 less than 747.66×10^{4}m^3 in 2012; There are 26 reinjection wells of Guantao formation, but only 12 wells still have reinjection, the annual reinjection amount is 62.17×10^{4}m^3, 35.65×10^{4}m^3 more than the 2012 year's 26.52×10^{4}m^3. Reinjection rate is 9.90%, has much more increase than 3.55% of 2012 (Table 8).

Table 8 Years' exploitation and reinjection amount of Neogene

Guantao formation geothermal reservoir

Time（year）	2006	2007	2008	2009	2010	2011	2012	2013
Exploitation amount（×10^{4}m^3/year）	759.8	764.4	811	802.5	784.2	608.1	747.66	628.28
Reinjection amount（×10^{4}m^3/year）	12.8	17	9.7	37	20	12.6	26.52	62.17
Reinjection rate (%)	1.68	2.22	1.20	4.61	2.55	2.07	3.55	9.90

From the data in table 8, it can conclude that the whole reinjection rate of Neogene reservoir is low, the maximum is only 9.90%, most less than 5%. As you see from Figure 6, the reinjection amount and rate in 2009 is obviously larger than the previous years, this is mainly because from the beginning of 2009, the perforating well completion technology started to large-scale use in porous geothermal well, part of the wells' reinjection capacity reached 100%. Because some original geothermal wells' reinjection effect is not good, the whole number of reinjection wells is decreasing and consequently the whole reinjection amount is less either. But in the recent years, with attention to the porous geothermal reservoir reinjection, more than 10 eyes geothermal wells of Guantao formation has drilled with the perforating completion technology In this way, both reinjection amount and rate have significantly improved.

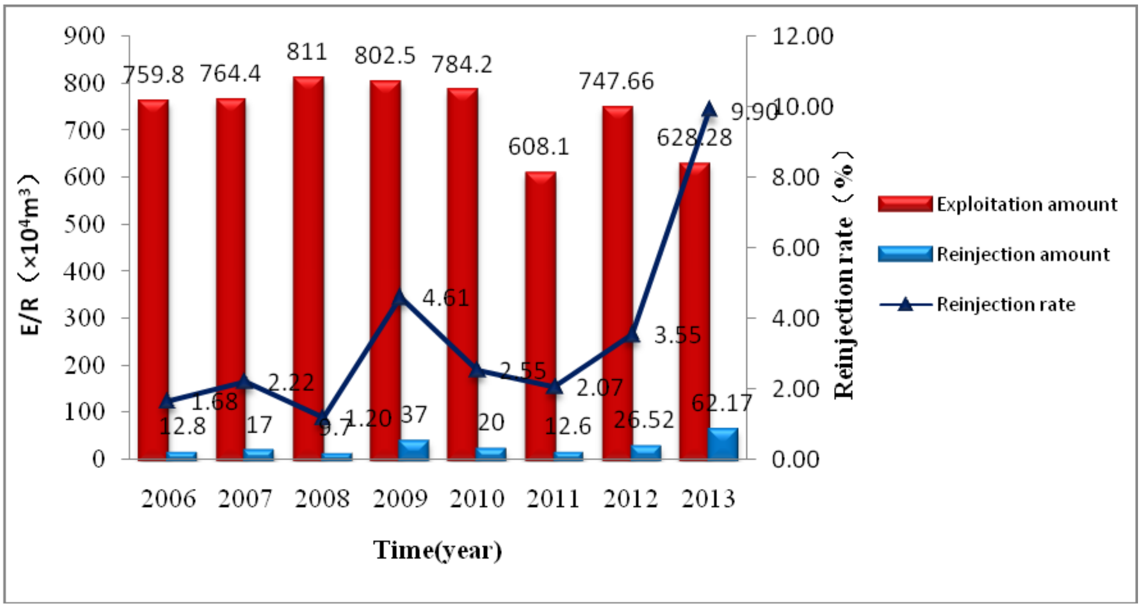

Figure 6 statistics of years' exploitation amount, reinjection amount and rate of Guantao geothermal reservoir of Neogene in Tianjin area

In the process of reinjection, water sensitivity and velocity sensitivity effect is easily happened to the reservoir and can cause physical changes of reservoir. With the increase of fluid migration distance and the decrease of the pressure, the solid particles gradually deposit or being captured, that make pores clogged, seepageresistance increases, permeability reduces and the geothermal fluid reinjection ability weakened. At present, there are only 12 eyes porous geothermal reinjection wells still have normal reinjection in Tianjin area, including 9 eyes with perforating completion, 3 eyes with filter pipe completion, the maximum of reinjection amount is 100 m^3/h, and reinjection amount of perforating is significantly higher than that of filter pipe (Table 9).

Table 9 Porous geothermal reinjection wells in Tianjin area

Well completion	Well number	Reinjection method	Reinjection amount （m^3/h）	Reinjection temperature（℃）
Perforating	JN-17B	Natural reinjection	61.3	21
	TG-36B		60	32
	TG-39B		60	36
	TG-20B		42	32
	TG-47B		73.8	36
	TG-26		91	36
	TG-32B		24	29
	WQ-23B		126	38
	BCR-09		100	56
Filter pipe	YR-9	Natural reinjection	21.32	40
	DG-49B		25	40
	DL-25B		20	50

7. CONCLUSION

The perforating technology is a mature technology in petroleum industry, but applying it to geothermal development is just primary, It still provides a new method for development of geothermal resources, especially when the reinjection effect is not suitable for conventional drilling process. The successful application of perforation technology provides some well perforation experience, but the test is only constrained to the Guantao formation and for other formations, such as Minghuazhen formation, need to do more research. At the same time, many theories in perforating technology still belongs to exploring perfection stage, such as the mechanism of pore inrush, how to optimize the distribution parameter in perforating technology, how to conduct sand control effectively, etc.

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