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Practical Experience and Research in the Reinjection into Sandstone Reservoirs in Tianjin, China

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ABSTRACT

As a renewable resource, geothermal energy is very important for the development of the economy of China. Re-injection of the geothermal fluids after use is an effective means for maintaining reservoir pressure, which is the key to sustainable utilization of geothermal resources. Re-injection of the geothermal fluid is also an important environmentally way of preventing surface disposal and pollution of surface waters. In the Tianjin area, research regarding re-injection into sandstone reservoirs has been carried out from the 1980s to now. Due to chemical scaling in wells and formation, plugging of aquifers, and corrosion of casings, the re-injection rates into the sandstone reservoirs decreased dramatically with time. During the re-injection evaluation and research of the drilling techniques, filtering techniques, and re-injection regulations. Up to recent years, we have made great progress in re-injecting return geothermal water into sandstone reservoirs in several different areas. Five demonstration projects were set up, and the re-injection rates acquired great progress, up to 100-120m^3/h into a single sandstone re-injection well. In this report, we describe re-injection issues from different perspectives, including reservoir configuration, aquifer characteristics, drilling techniques, filtering techniques as well as re-pumping at the interval of re-injection. We also describe the reinjection experience during the past decades in Tianjin, China.

1. INTRODUCTION

As a clean energy source, geothermal energy has important effects on improving the social energy framework and protecting the environment. Tianjin has abundant low-medium temperature geothermal resources, which covers about 8700 km^2. The resource exists in two geological environments: sedimentary reservoirs and basement reservoirs. The sedimentary reservoirs closed clastic rock subsurface systems that belong to low enthalpy geothermal systems. The geothermal fluids have good quality and low temperature of 40～80℃. The geothermal water has been utilized directly in Tianjin for space heating, bathing, swimming pool, greenhouses, industry, physiotherapy spa. Furthermore, geothermal exploitation is making important progress throughout the whole country. From the monitor data up to 2018, there were 721 geothermal wells in Tianjin, therein 248 geothermal wells were drilled into sedimentary reservoirs (Fig.1). The annual exploitation quantity in 2018 was about 1843×10^4 m^3, and the annual re-injection quantity is about 620×10^4 m^3.

With the rapid economic development in Tianjin, geothermal utilization increased very quickly. The increased production from the geothermal resources has only been followed by limited re-injection. Lowering of water level in the geothermal reservoirs is therefore pronounced, and the water level sinks deeper and deeper ranging from 1.8 to 5.5 m/a. Up to now, the water level is found 80 m or deeper.

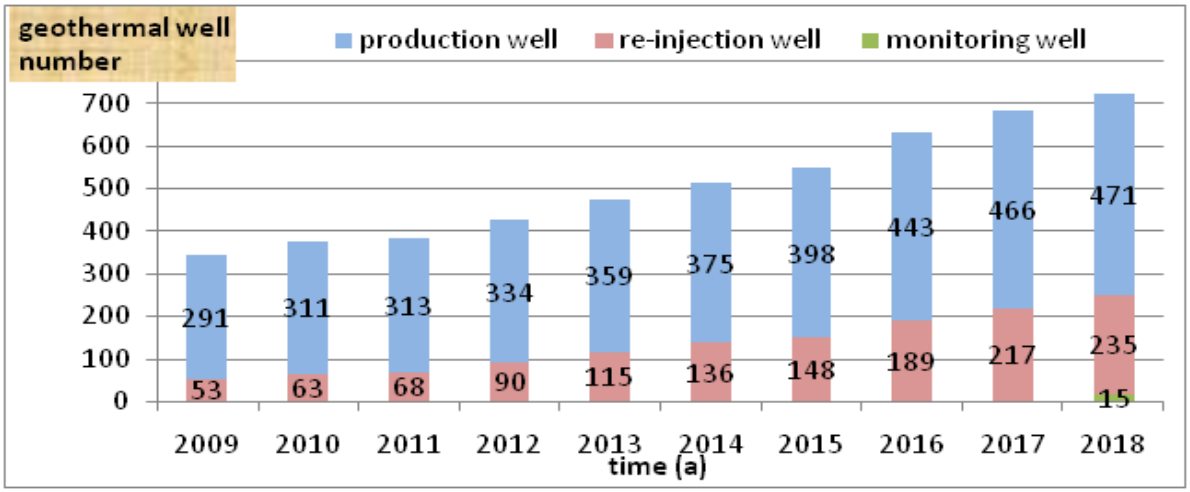

Fig.1 Number of production & re-injection wells in Tianjin in the last ten years

2. GEOTHERMAL RE-INJECTION EXPERIENCE INTO SANDSTONE RESERVOIRS IN TIANJIN

Geothermal re-injection is injecting the produced geothermal fluids after utilization back into the reservoir by gravity (natural free flow) or by pumping (pressured mode). Reinjection is the best method to stop the continuous drawdown of the water level in the reservoir and also to avoid surface disposal and pollution of surface water. Reinjection is, therefore, both important pursuing sustainable utilization and also important environmental management.

In the Tianjin area, the geothermal re-injection testing and research have been ongoing since the 1980s. It has, therefore, history for more than 30 years. In recent years, the Tianjin government has paid increasing attention to the sustainable development of the geothermal resource. Up to the end of 2018, since the 1980s, there were 721 geothermal wells, including 235 re-injection wells, of which 82 are basement re-injection wells and 33weresandstone re-injection wells (Table 1). The re-injection quantity is about 2881.05 $\times 10^4$ m^3， occupied 56.75% of production, while re-injection quantity in the sandstone reservoir was about 198×10^4 m^3/a. There is, therefore, a large gap between production and re-injection volumes in the sandstone reservoir. The reason for the limited reinjection is the clogging of reinjection wells, which have not been resolved, especially in porous sandstone geothermal reservoirs.

Table 1 Number of re-injection wells in Tianjin

	Sandstone re-injection well	Basement re-injection well	Total
2012	27	63	90
2013	33	82	115
2014	38	98	136
2015	43	105	148
2016	60	123	189
2017	69	148	217
2018	72	163	235

3. SANDSTONE GEOTHERMAL RE-INJECTION EXPERIMENTATION IN TIANJIN

Re-injection into sandstone reservoirs has been the subject of extensive investigations in Tianjin during the last three decades, and four large-scale re-injection tests have been carried out. (Shibin, Baoshan, & Keyan, 2005)（Table 2).

Table 2 Basic Information of the Previous Test

Test phase	Time(year)	Test site
Ⅰ	1987-1989	Dagang district water and electricity factory
Ⅱ	1995-1996	Tanggu district Xinkai Area
Ⅲ	2003-2004	Dongli district & Wuqing district
Ⅳ	2008-2018	Binhai New Area & Beichen district

In the last re-injection tests, aquifer parameters and well casings and diameter of the re-injection wells were different. A detail data list is seen in Table 3:

Table 3 Basic parameters for Re-injection Test

Re-injection well	Dagang district	Tanggu district	Dongli district	Wuqing district
Stratigraphy	Ng	Ng	Ng	Ng
Lithology granule	Silty sandstone, sandstone	Sandstone, with gravel	Sandstone, with gravel	sandstone, Silty sandstone
Cementation grade	Bad-good	bad	bad	good
Granuledia.(mm)	2-4	5-10	5-10	0.5-1
porosity (%)	29.9	20	27-32	20.1-31.6
Permeability（md）	500-600	740-1270	690-1085	171.8-874.5
Depth (m)	1900	2025.26	1360.19	2346.8
water sieve type	Monolayer sieve	Monolayer sieve	doublet sieve	doublet sieve
space between sieve (mm)	0.4～0.6	0.5-0.7	1.5(inner); 1.2(outer)	0.7(inner); 0.5(outer)
well diameter (mm）	Φ219	Φ219	Φ177.8	Φ177.8
water sieve total length (m)	58.58	60.99	57.52	93.87
Fluids temperature (℃)	69.5	69.5	81.5（70）	73℃
Flow rate (m^3/h)	55	90～120	100	94

3.1 First periodical re-injection test

From 1987-1989, four re-injection tests were carried out in the Dagang district. The Fluid was injected into Guantao formation through wells R2 & R12, for a total testing time of 4728 hours (197 days)， and a cumulative quantity of 77943m^3 (Table 4).

Table 4 Basic date of the re-injection test in the Dagang district

Well No.	Accumulative time(d)	Accumulative Quantity(m^3)	Re-injection Temperature(℃)	Re-injection mode
R2	54	23000	55	Single well
R12	16	8889	38	Doublet well
R12	68	23819	36.8	Single well
	31	9867	36.8	Single well
R12	6	2465	36.8	Doublet well
	15	12503	36.8	Doublet well
	7	7400	32.5	Doublet well

During re-injection, the injectivity of injection wells decreased rapidly, but even an increase of the wellhead pressure from 0.1 to 0.2 MPs during the 54 days test does not compensate for the decrease of the reinjection capacity (Fig.2). The re-injection capacity has a positive correlation with re-injection temperature (Table 4).

3.2 Second periodical re-injection test

From 1995-1996, the second periodical re-injection test was carried in the Guantao group in Tanggu district. The test persisted 79 days and resulted in three useful data sets. Idiographic data is list in table 5.

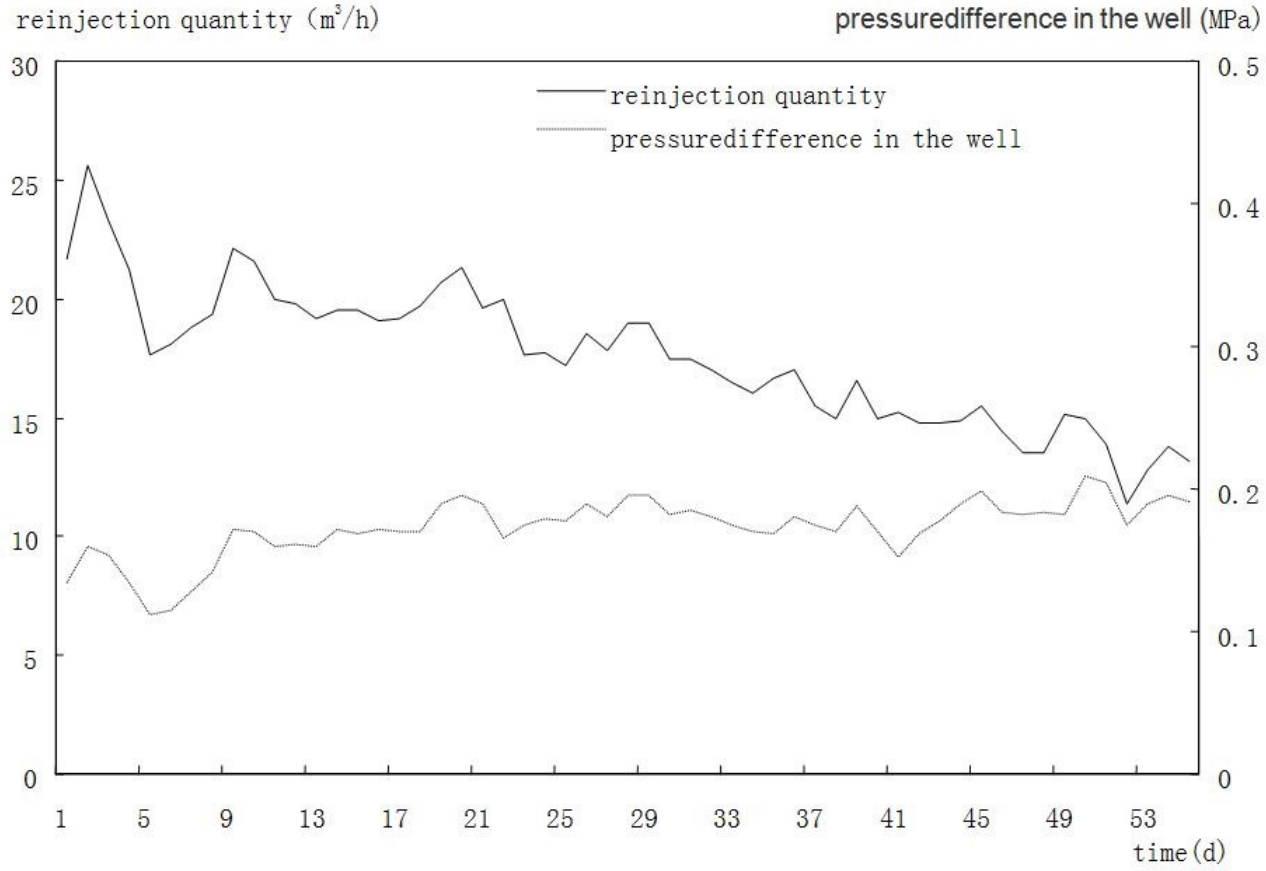

Fig.2 Relationship capacity and wellhead pressure of well R2 during 54 days reinjection test

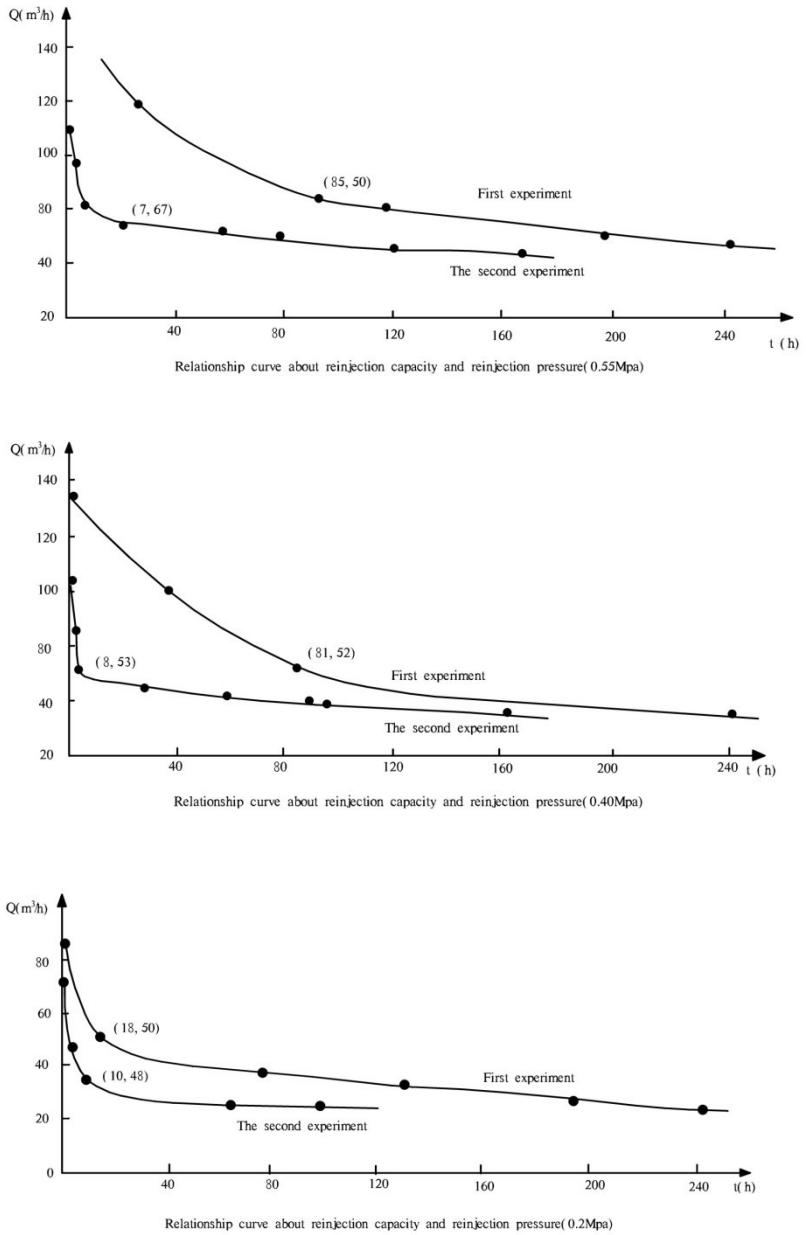

Fig.3 Relationship curves of water level and temperature in Tanggu

From this test, we can see a positive correlation between injectivity and pressure, and at a given re-injection pressure, the re-injection capacity decreases with time. (Fig.3)

3.3 Third periodical re-injection tests

In 2004, two re-injection wells were drilled in an agricultural science and technology section in the Doli district, and Wuqing Guohuan Inc, to finish the re-injection tests. In order to solve the physical and chemical clogging of aquifers and wells, secondary filtrating equipment was installed in the system, the primary filtration was to filter particles larger than 50μm. Meanwhile, the secondary filtration was extensive, with a precision of 3-5μm. The test lasted 138 days, and basic information of the tests is listed in table 5.

Table 5 Basic Information of the Re-injection Test in Doli

sequence	Test No.	Quantity (m^3/h)	Temperature(℃)	**Accumulative Quantity(m^3)**
1	1st	49	45	863.4
2	2nd	48	46	4167.1
3	3rd	41	47	1795.9
4	4th	43	48	10163.6
5	5th	41	48	5087.2
	total			22077.2

3.4 Fourth periodical re-injection tests

From 2010-2018, three demonstration projects were set up and three re-injection wells were drilled in the Dongle and Tanggu district. In these tests, the re-injection rates acquired great progress, up to 100-120m^3/h into a single sandstone re-injection well. For example, the re-injection rates were up to 120m^3/h into TGR-28. The test lasted 138 hours. The basic information of the test is listed in table 6.

Table 6 Basic Information of the Re-injection Test in TGR-28

sequence	cumulative time (h)	Re-injection rate (m^3/h)	Temperature(℃)	**Accumulative Quantity(m^3)**
1	23	40	60	920
2	42	53.7	64	2255
3	73	75	66	5475
4	72	100	66.5	7200
5	94	120	67	11280
total	304			27130

4. ANALYSIS ON THE RE-INJECTION IMPACT FACTOR IN SANDSTONE

Analysis of the results of different tests and the factors impacting the re-injection capacity:

(1) Stratum lithology, hydrogeology condition

The lithology, bulk of rockgranule, intersect between the granule, porosity, and permeabilities of the stratum impact re-injection. In the Tanggu and Dongli districts, the lithology is sandstone with gravel, the granularity is bigger (5-10 mm), the osmosis is better (permeability 690-1270 md), the re-injection capacity in this area is much higher than in other areas.

For these years of research, we get the conclusion: re-injection capacity has a closed relationship with the characters of the reservoir, such as porosity, permeability, and density. Otherwise, suitable drilling technique in different areas is very important for increasing the re-injection capacity, some basic information is listed in table 7.

Table7 Characters of Reservoir in Different areas and drilling technique

Re-jection well	Dagang	Tangu	Wuqing	Dongle	Tanggu	Tanggu
Grain (mm)	2-4	5-10	0.5-1	5-10	5-10	1-4
Porosity(%)	29.9	20	20.1-31.6	24-32	26-31	24-32
Permeability (mD)	500-600	740-1270	171-874	421-1077	450-950	347-937
Depth(m)	1900	2025.26	2346.8	1362.39	1950	2105
Drilling process	single	single	double	single	gun perforation	gun perforation
Tie wire spacing (mm)	0.4-0.6	0.5-0.7	0.7(in); 0.5(out)	0.8-0.85	Φ244.5mm casing, 75.2m	Φ244.5mm casing, 96m
Casing Diameter (mm)	Φ219	Φ219	Φ177.8	Φ219		
Length	58.58	60.99	93.87	95.11		
Re-injection tempreture(℃)	32-55	25-30	47-52	19-48	30.7	18-36
rate (m^3/h)	15-20	20-50	21-49	30-66	63.79	102

(2) Re-injection fluids temperature

During the previous decades, the re-injection capacity has had a positive correlation with the re-injection temperature. In all the re-injection test, we draw the same conclusion.

(3) Re-injection pressure

Commonly, the capability of the re-injection in the porosity stratum is about 20-30 m^3/h, the subjoin pressure can increase the capability to a certain extent.

5. CONCLUSIONS

The geothermal re-injection has very important practical significance. From the re-injection test research of the Casing program, the main factors affecting geothermal re-injection include hydro-geologic characteristics, the distance between the production and re-injection well, and re-injection mode. Re-injection in sandstone is a very complicated, systems engineering, and advanced studies is an important and necessary part to achieve sustainable exploration & development.

Advancing studies confirm that the practical results obtained from the operation of the geothermal plants in Tianjin Binhai New District can well be transferred to many other sites in China with analogous geological conditions.

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