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

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ABSTRACT

Reinjection of the geothermal fluids after use is effective means for maintaining reservoir pressure which is the key to sustainable utilization of geothermal resources, which is also important environmentally way preventing surface disposal and pollution of surface waters. In Tianjin area, research regarding reinjection into geothermal reservoirs have been carried out since 1980s. Due to chemical scaling in wells and formation, plugging of aquifers and corrosion of casings, the reinjection rates into the sandstone reservoirs decreased dramatically with time. During the reinjection evaluation and research of the drilling techniques, filtering techniques and reinjection regulations. With the rapid economic development in Tianjin, geothermal utilization increased very quickly. As guarantee geothermal resources re-circulation of sustainable development of important means, great progress had been made in reinjecting return geothermal water into reservoirs in several different areas. Up to the end of 2024, there were 745 geothermal wells in Tianjin, therein 321 reinjection wells were drilled. Several demonstration projects of injecting into sandstone & basement reservoir were set up and the reinjection rates acquired great progress, up to 100-120m^3/h into a single sandstone re-injection well, and the re-injection effect is much more better in the basement reinjection well. In this report, we describes reinjection issues from different perspectives including: reservoir configuration, aquifer characteristics, drilling techniques, filtering techniques, analysis combined with geothermal monitoring data, analyzes the conveyance speed as well as re-pumping at the interval of reinjection. 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 in improving the social energy framework and protecting the environment. Tianjin has abundant low-medium temperature geothermal resources, which covers about 8700 km^2. Resource exist in two geological environments : sedimentary reservoirs and basement reservoirs. The sedimentary reservoirs closed clastic rock subsurface systems which belongs to low enthalpy geothermal systems. The geothermal fluids has good quality, low temperature of 40-80℃, and geothermal water has been utilized directly in Tianjin for space heating, bathing, swimming pool, green houses, industry, physiotherapy spa. The area of geothermal space heating up to 4760×10^4 m^2, account for 8% of the city's heating area. Furthermore, geothermal exploitation is making an important progress throughout the whole country. Up to the end of 2024, there were 745 geothermal wells in Tianjin, therein 321 reinjection wells were drilled (Fig.1). The annual exploitation quantity in 2024 was about 4598×10^4 m^3, it exhibited a year-on-year increase of 157.69×10^4 m^3. the annual re-injection quantity reached 4431.90×10^4 m^3, marking a year-on-year rise of 203.33×10^4 m^3, the overall Re-injection rate stood at 96.39%, indicating a year-on-year growth of 1.16%. With the rapid economic development in Tianjin, geothermal utilization increased very quickly. In the early stages, the increased production from the geothermal resources have only been followed by limited re-injection, and lowering of water level in the geothermal reservoirs is therefore pronounced and the water level sinks deeper and deeper at rate sranging from 1.8 to 5.5m/a. In recent years，With the continuous increase in the re-injection rate(Fig.2)， the annual water level is on the rise.

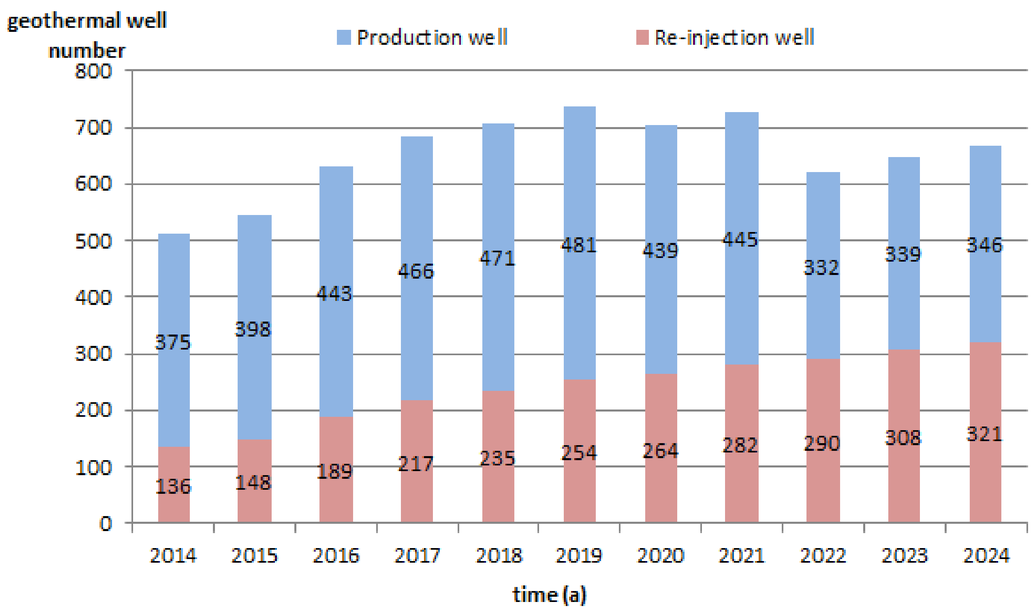


Fig.1 Number of production & re-injection wells in Tianjin in last decade years

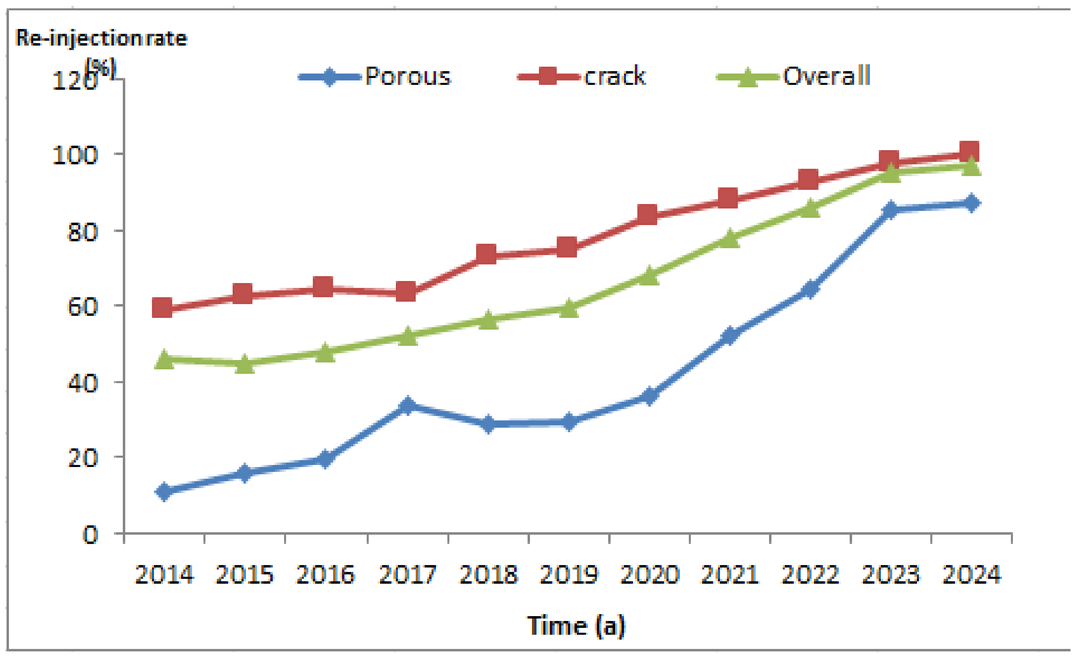


Fig.2 Re-injection rates for different types of thermal reservoirs over multiple years

2. Re-injection Experience into sandstone reservior

2.1 Re-injection Test in different district

Reinjection is the best method to stop the continuous draw down of the water level in the reservoir and also to avoid surface disposal and pollution of surface water. Pursuing sustainable utilization and environmental management. In recent years, Tianjin government has paid increasing attention on the sustainable development of the geothermal resource.

In the last re-injection tests and reseach, aquifer parameters and well casings and diameter of the re-injection wells were different. A detail data list is seen in Table 1:

Table 1 Characters of Reservoir in Different area and drilling technique

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

2.2 Analysis on the re-injection Impact Factor in Sandston

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, interstice between the granule, porosity and permeabilities of the stratum impact re-injection. In Tanggu and Dongli district, the lithology is sandstone with gravel, granularity is bigger (5-10mm), osmosis is better(permeability 690-1270 md), the re-injection capacity in this area is much higher than in other areas. For these years research, we get the conclusion: re-injection capacity has closed relationship with the characters of reservoir, such asporosity, permeability, density. Otherwise, suitable drilling technique in different area is very important for increasing the re-injection capacity.

(2)Re-injection fluids temperature: During the previous decades, Re-injection capacity has positive correlation with re-injection temperature. In all the re-injection test, we draw the same conclusion.

(3) Re-injection pressure: Commonly, the capability re-injection in porosity stratum is about 20-30m3/h, subjoin pressure can increase the capability in a certain extent.

3. Historical Trends of MajorIon Component Concentrations

A comparison of water quality monitoring results over multiple years reveals that the chemical properties of geothermal fluids in major thermal reservoirs are relatively stable. Apart from certain fluctuations, the contents of major ion components have not undergone significant changes due to artificial exploitation or recharge, example for DG-49 (Fig.3).

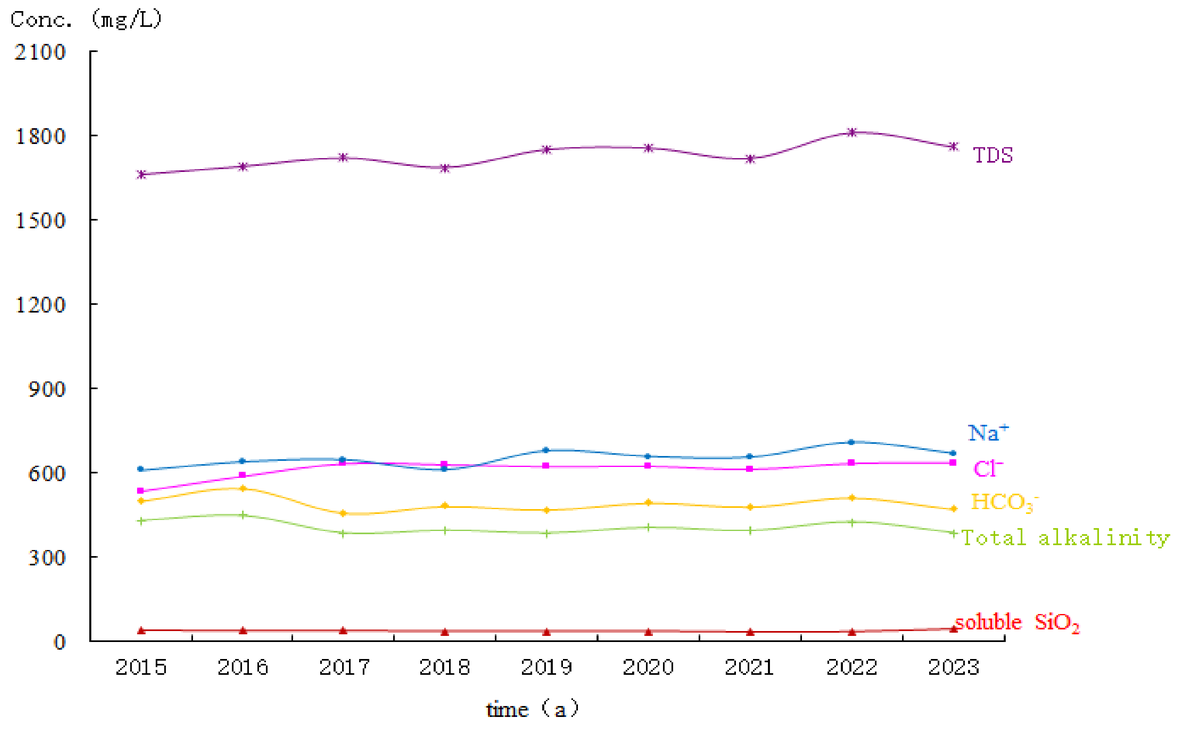


Fig.3 Historical Trends of MajorIon Component Concentrations in DG-49

4. Historical Trends of Water level in different reservoir

Following years of monitoring and in-depth research, within both the sandstone reservoir and rock reservoir environments, an enhancement in the re-injection rate has been observed. Concurrently, there has been a reduction in consumption, leading to a transition in the water level trend from decline to recovery.

Since 2018, the general decline in water levels in major geothermal reservoirs has been diminishing. By 2019, the buried depth of water levels had generally reached historical lows. In 2021, water levels in all major geothermal reservoirs began to rebound, with the rebound range further expanding in 2022, reaching historical maximums in some areas.

From 2023 to 2024, water levels have generally continued to rise, albeit with a decreasing annual increase.

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4.1 Historical Trends of Water level in Guantao formation

Over the past five years, the water level fluctuations in the Guantao Formation thermal reservoir have followed a trajectory of gradual decline reduction, punctuated by localized minor rebounds, culminating in a broad-based rebound across the entire region by 2023. This year, with the exception of the area south of Jinghai urban district, where water levels continued their downward trend, all other regions have generally maintained a rebound trend, albeit with a diminished magnitude. In recent years, the central areas of the two districts have undergone the most notable transformation in water level patterns, shifting from experiencing the largest declines to witnessing the most significant rebounds. The water level funnel zone reached its maximum extent in 2019, subsequently contracting annually until it diminished to 44.56 km^2 by 2024(**Table 2**).

Table 2 Statistical Table of Water Level of Guantao Formation Reservoir in the Past Five Years

Year	Water Level （m）	Annual Water Level Change (m)	Area of funnel area with water level depth greater than 120m (km^2)
2020	66.45～141.30	-4.52～8.67	544.22
2021	67.57～131.51	-1.64～8.42	294.28
2022	67.47～129.32	-1.25～7.59	254.10
2023	66.50～123.95	0.08～5.80	78.36
2024	64～121.65	-3.22～3.44	44.56

4.2 Historical Trends of Water level in Wumishan formation

Prior to 2022, the thermal reservoir water level fluctuations in the Wumishan Formation exhibited a pattern of gradually diminishing annual declines, accompanied by localized minor rebounds, followed by rapid rises across most regions, reaching their peak levels in 2022. In 2023, the rebound amplitude began to wane across most areas, except for the southern thermal reservoir fringe, where water levels continued to decline slightly, while localized declines also occurred in Xiqing District and Dongli District. Although the maximum rebound amplitude in 2024 matched that of 2023, the recovery rate further diminished in most regions. The water level funnel zone, which peaked in 2019, underwent a sharp contraction in 2022, and by 2024, funnel zones with water levels exceeding 160 meters had vanished. (**Table 3**).

Table 3 Statistical Table of Water Level of Wumishan Formation Reservoir in the Past Five Years

Year	Water Level （m）	Annual Water Level Change (m)	Area of funnel area with water level depth greater than 120m (km^2)
2020	82.63～174.74	-3.84～3.87	181.14
2021	83.27～173.90	-2.82～6.17	142.23
2022	84.65～165.61	-1.38～9.40	28.52
2023	86.82～163.43	-3.92～8.74	1.70
2024	86.89～158.93	-1.98～8.86	0

Wumishan Formation's thermal reservoir has seen a consistent increase in both reinjection volume and re-injection rate. In 2024, the re-injection rate reached 93.22%, marking a 1.70% year-on-year increase, which has significantly curtailed water consumption. A comparative chart (Figure 4) illustrating water level and consumption trends from representative observation wells in recent years reveals that as consumption decreases, water levels in multiple geothermal wells initially plummet to their lowest point before rebounding. Both the trend patterns and turning points in water levels align precisely with consumption fluctuations. This underscores that the rising re-injection rate in the Wumishan Formation is the primary driver behind the water level recovery.

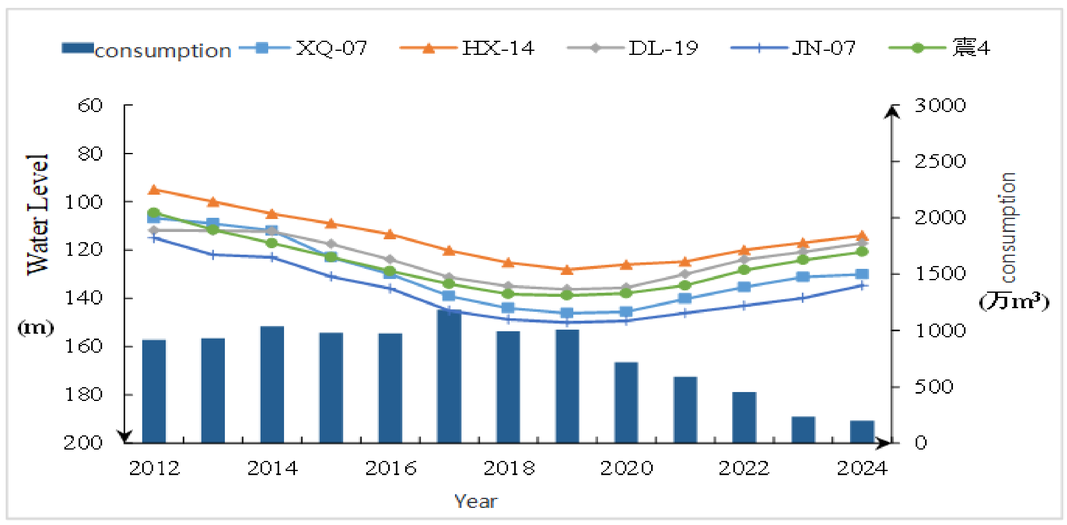


Fig.4 Curves of fluid consumption and water level depth in Wumishan Formation

5. CONCLUSION

I. Geothermal re-injection has very important practical significance. From the re-injection test research of Casing program, the main factor saffecting geothermal re-injection includes: hydrogeologic characteristics, 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.

II. 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..

III. The dynamic changes in geothermal reservoir water levels are predominantly influenced by a multitude of factors, including the reservoir's dynamic environment, development and utilization, as well as resource protection and management. In recent years, through a series of research endeavors and the implementation of protective policies, the re-injection rate of geothermal resources has markedly improved, while consumption has decreased. This has resulted in a shift in the water level trend from decline to recovery, and the orderliness of geothermal resource development has been enhanced.

IV. Through comparison of multi-year water quality data, it is observed that the chemical composition of geothermal fluid undergoes minor alterations following exploitation and utilization. However, the concentrations of the principal ions remain highly similar, indicating that such exploitation and utilization activities do not impact the overall hydrochemical environment of the geothermal reser-

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