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Study on Tianjin Tertiary Sandstone Aquifer Reinjection Plugging Mechanics

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ABSTRACT

Since the 1970's, Tianjin has exploited Tertiary geothermal water. The amount produced has increased with time. Up until now, the amount exploited from the tertiary sandstone aquifer has been larger than the amount of from basement aquifer. However, long term reinjection to Tertiary sandstone is not possible. This paper discusses the mechanics of reinjection plugging based on reinjection testing carried out in Tianjin sandstone aquifer in 2004 and in 2005. Rock porosity, water quality analysis, water graininess and bacteria analyses have been performed. The Phreeqc software is used for water/rock interaction calculations (Spycher and Reed, 1976). It's considered that the strata characteristics of loose, clay-cemented, fines and tight fissures in the Tertiary sandstone aquifer are the major internal reason for plugging. The combined action of deposition of suspended sediments, precipitation of secondary minerals, and bacteria growth in reinjection fluid are external causes. Suspended sediments deposition is the main reason for Tianjin Tertiary sandstone aquifer reinjection plugging. Reinjection temperature and volume are also influences on the reinjection. Prevention and cure measurements to reinjection plugging have been raised accordingly.

1. INTRODUCTION

Tianjin has exploited geothermal water since the 1970's. From the early 1980's, reinjection studies and testing have been conducted to examine the drop in reservoir pressure. Single well, doublet and multi-wells reinjection tests have been done in Minghuazhen group and Guantao group. Changing regulation of the hot water force field, water chemistry field and temperature field under the condition of reinjection have been studied. Based on these tests, conclusions have been drawn. Reinjection with low temperature waste water is feasible under the condition of non-pressure. Although the reinjection tests and theoretical studies have had some achievements, the reinjection results have not been satisfactory. In 2005, the total production of geothermal water was $2500 x 10^4 m^3$/a, from which the production from Tertiary sandstone reservoir is 1400 $x10^4 m^3$/a (Lin et al., 2006). But there was not any reinjection in the Tertiary reservoir, according to the Annual report of underground water dynamic monitoring for 2005 (Tianjin Geothermal exploration and development Institute, 2005). The plugging problem is the key obstacle for effective reinjection.

From Aug. 2 till Sept. 6, 2004 and from Dec. 9, 2004 till March 21, 2005, two reinjection tests were conducted focusing on studying the plugging mechanics of the Tertiary reservoir. From the series of tests, the plugging mechanics have been analyzed and countermeasures have been proposed.

2. HYDROGEOLOGICAL BACKGROUND

The major geothermal aquifers of the Tianjin Tertiary reservoir are the Minghuazhen group and Guantao group. Lithologically, the Minghuazhen group can be divided in two parts. The upper part is mainly composed of silt, fine grain sand and varicolored clay rock. The lower part is clay rock interbedded by silt and fine grain sand. The bottom is mainly clay rock. Sand belts can be seen locally. The Guantao group is below the Minghuazhen group. It is made of three parts. The upper is sandstone, the middle is clay rock, and the lower part is gravel and sandstone. So the Guantao group can been divided into the Guan I sandstone reservoir and the Guan III reservoir. This group has experienced little diagenesis and is loose with high porosity.

The hydrological parameters have been calculated during pumping testing after the doublet has finished. Conductivity is 534m/d. The permeability coefficient is 7.11m/d. The elasticity coefficient is $1.60x10^{-4}$.

3. REINJECTION TESTING

3.1 Water Sample Analysis Results

Water chemical components, bacteria and granularity have been analyzed.

Two geothermal water samples were taken from production well (H-Well 1) (73°C) and reinjection well (H-Well 2) (78°C) in Huatai area separately. Two reinjection water samples were taken from different sources. Reinjection water sample 1 (R-1) is geothermal water after space heating (41°C). Reinjection water sample 2 (R-2) is a combination of geothermal water from H-Well 1 and shallow ground water (44°C). R-2 is the reinjection water for summer reinjection testing in 2004. R-1 is the waste water of H-Well 1 after space heating. Thus it has similar characteristics as the reinjection water from the second reinjection testing in the early 2005. Water chemical analysis results are shown in Table 1. Granularity analysis results are shown in Table 2. Bacteria analysis results are shown in Table 3.

3.2 Aquifer Porous Characteristics

Three rock samples of the Guantao group had been taken from Well YR9 in the Wuqing area. Rock aperture was tested. Table 4 shows the results.

3.3 Reinjection Testing

2 Reinjection testing have been performed. The first test was in summer 2004 using R-2 as reinjecton water. The second test was conducted in a space heating period in the Wuqing area.

Table 1 water chemical analysis results

contents	H-Well 1	R-1	R-2	H-Well 2
Al^{3+}	1.7007	-	-	-
Ca^{2+}	27.0386	30.8319	26.1	35.43
Fe^{2+} , Fe^{3+}	0.1415	4.9807	<0.08	-
K^{+}	53.1987	68.8115	28	*1443.03
Mg^{2+}	10.0916	11.3265	6.1	9.08
Mn^{2+}	0.0205	0.2499	-	-
Na^{+}	456.719	628.852	381.6	-
H_2SiO_3	27.462x	31.004x	-	-
Zn^{2+}	0.5147	0.2212	-	-
Br^{--}	1.228	0.668	-	-
CO_3^{2-}	-	-	0.00	164.86
HCO_3^{-}	963.30	954.4	457.6	131.43
Cl^{-}	573.96	406.0	276.5	402.98
F^{-}	9.762	4.628	-	-
NO_3^{-}	-	0.010	-	-
SO_4^{-}	411.28	289.40	211.3	2220.88
Soluble SiO_2	40.73	37.35	33.8	-
Free CO_2	14.087	22.539	17.6	-
Corrosive CO_2	27.278	9.628	-	-
Solids	2014	1912	1153	4333

Note: - is below detective limit or this item is not analyzed. * represent K^{+} plus Na^{+}.

Table 2 particle diameter test results

Samp.	T(℃)	10%(μ m)	90%(μ m)	Medium(μ m)	Average(μ m)
H-Well 1	73	1.104	2.306	1.352	1.579
R-1	41	1.079	1.345	1.151	1.204
R-2	44	1.098	1.629	1.281	1.353
H-Well 2	78	1.091	1.910	1.261	1.431

Table 3 Bacteria test results

Contents (CFU/ml)	H-Well 1	R-1	R-2	H-Well 2
Iron bacteria	-	100	0	0
Sulfate reducting bacteria	-	1,000	0	0
Metatrophic bacteria	-	100	1	0.6

Note:- is below detective limit

Table 4 Rock aperture of Guantao group in YR9

Sample No.	Average pore diameter (nm)
DR-03	14.87
DR-02	13.02
DR-01	12.53

Because of an electricity problem, the summer reinjection test was disturbed and broken it into five periods. The following series of graphs (Figure 1) are the summer test results and Figure 2 is the winter test results. They show the relationship between water level, reinjection temperature and reinjection flow rate. The y-axis is the water level, temperature of reinjected water and flow rate in m^3/h and x-axis is time. The red line is water level. The black line is reinjection temperature. The green line is flow rate in m^3/h.

3.4 Reinjection Possibilities and Characteristics

The reinjection test results show that the Tertiary sandstone aquifer is rechargeable. But the reinjection volume is limited. Water level has an inversely proportion relationship with reinjection flow rate. Water level goes back to its original position after a short pause but rises quickly when reinjection restarts. For long term reinjection, the flow rate is smaller than that for short time reinjection.

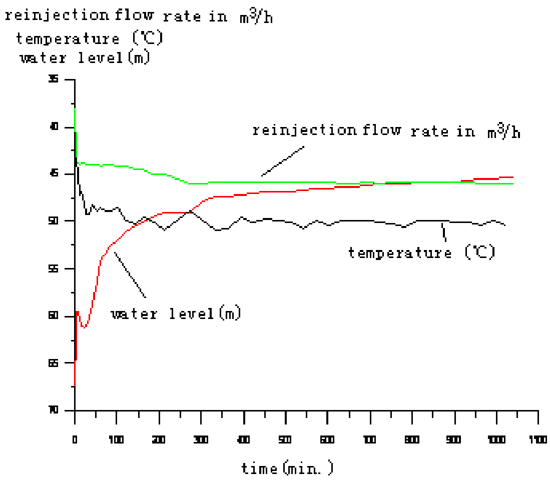

Figure 1-1. The reinjection flow rate, water level and temperature of reinjected water curves at the first period of the first reinjection-test term.

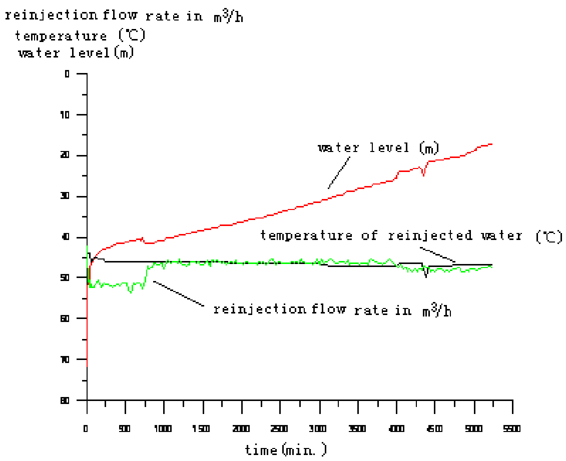

Figure 1-2. The reinjection flow rate, water level and temperature of reinjected water curves at the second period of the first reinjection-test term.

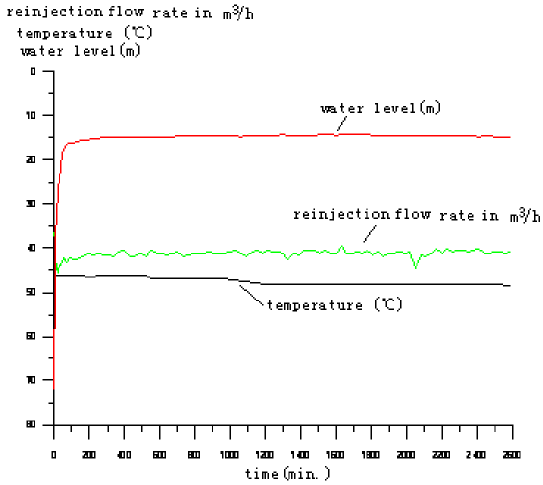

Figure 1-3. The reinjection flow rate, water level and temperature of reinjected water curves at the third period of the first reinjection-test term.

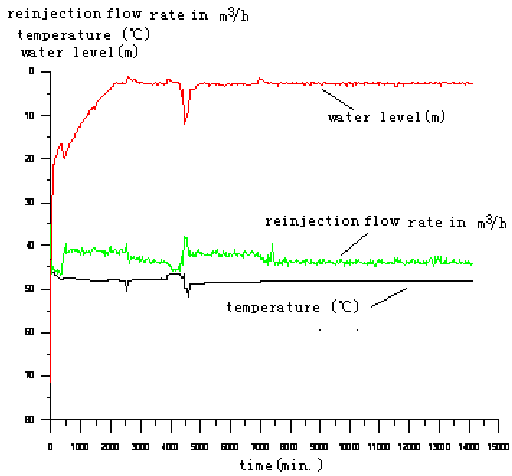

Figure 1-4. The reinjection flow rate, water level and temperature of reinjected water curves at the fourth period of the first reinjection-test term.

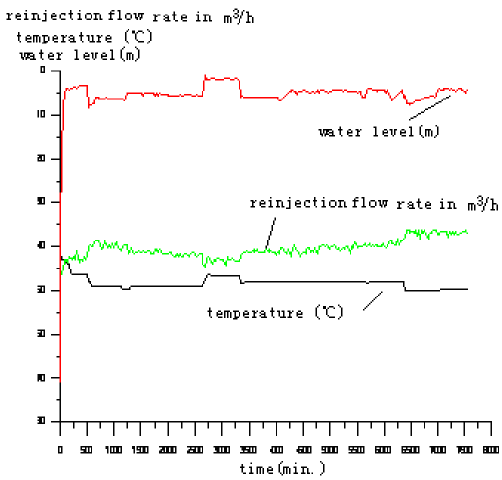

Figure 1-5. The reinjection flow rate, water level and temperature of reinjected water curves at the fifth period of the first reinjection-test term.

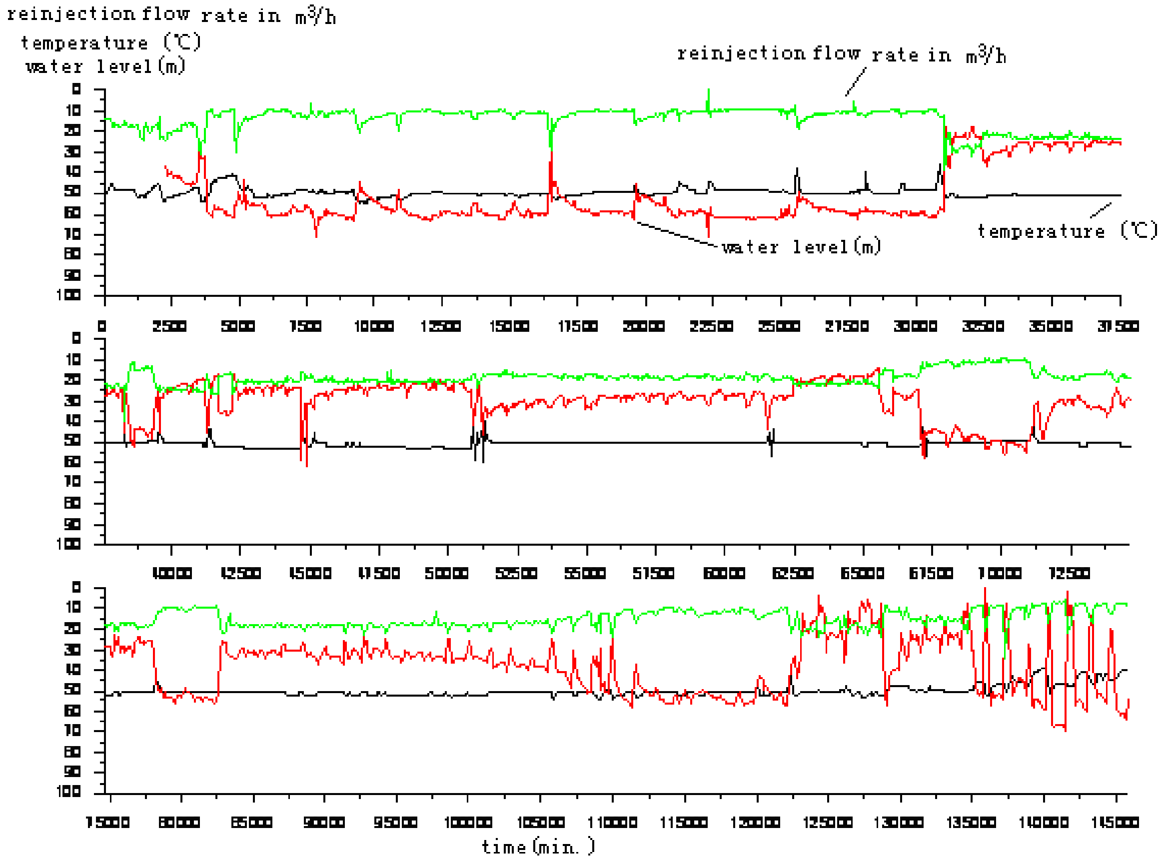

Figure 2. The reinjection flow rate, water level and temperature of reinjected water curves at the second reinjection-test term

4. REINJECTION PLUGGING MECHANICS ANALYSIS

4.1 Chemical Plugging Analysis

Phreeqc software (Spycher and Reed, 1976) has been used to understand the water/rock interaction in the reinjection well. R-2 and R-1 are used for modeling. R-2 was used for the first reinjection test. The reinjection water for the second reinjection is geothermal water from H-Well 1 after space heating. It has similar chemical characteristics to R-1. We used R-1 water chemical analysis results to model the second reinjection test.

Table 5 and 6 show that Ca^{2+}, Fe^{3+}, Mg^{2+}, CO_3^{2-} and SiO_2 are major causes of chemical plugging. Secondary minerals are mainly made of them. Water/rock interaction products play an important role for reinjection plugging.

4.2 Physical Plugging Analysis

Reinjection water contains a certain amount of suspended solid material. The granularity of solid grains is much larger than the aperture of the aquifer. So solid grain deposition within the reinjection well or in the rock around the reinjection well is the major reason for plugging.

4.3 Bacteria Plugging Analysis

R-1 reinjection water contains three major bacteria: iron bacteria, sulfate reducing bacteria and metatrophic bacteria. For flowing water, the number of bacteria cannot cause plugging. But for relatively slow rates of flow, bacteria may become one of the plugging causes.

Table 5 Supersaturated Secondary Minerals of R-2

Secondary minerals	Supersaturation index
Aragonite	0.20
Calcite	0.33
Dolominte	0.5
$Fe(OH)_3$(a)	0.66
Goethite	7.19
Hematite	16.46
Quartz	0.14

Table 6 Supersaturated Secondary Minerals of R-1

Secondary minerals	Supersaturation index
Aragonite	0.30
Calcite	0.43
Dolominte	0.90
$Fe(OH)_3$(a)	2.58
Goethite	9.02
Hematite	20.11
Jarosite-k	1.99
Quartz	0.03
Rhodochrosite	0.45
Siderite	0.29

4.4 Temperature Influence Analysis

Reinjection temperature influences the pH value of reinjection water and the saturation index of minerals. Modeling of different reinjection temperatures of R-1 has been performed. Table 7 shows the results.

It shows that minerals composed of Fe^{3+} and Ca^{2+} form in different amounts at different temperatures. So if most of the iron can be gotten rid of, the most important thing is to prevent carbonate deposition.

4.5 Lithological Characteristics

The tertiary sandstone aquifer is lithologically loose and clay-cemented. Compared with the baserock aquifer, sandstone's fractures and effective pore volume are tight. This is the internal reason for reinjection plugging.

Table 7 Supersaturation Index of R-1 at 30 °C and 50°C

T(°C)	30	50
pH	7.443	7.379
Aragonite	0.2	0.39
Calcite	0.34	0.51
Dolominte	0.65	1.09
$Fe(OH)_3$(a)	1.97	0.89
Goethite	8.03	7.61
Hematite	18.1	17.33
Quartz	0.18	-0.09
Rhodochrosite	0.4	0.49

5. COUNTERMEASURES

Based on the plugging mechanics analysis, the following countermeasures have been proposed.

① Control the instantaneous flow rate to a suitable amount during reinjection.

② Get rid of Fe^{3+} and solid suspended materials before reinjection water goes to the well. Periodic backwashing is needed to remove solid deposits and bacteria blockage.

③ Lower the reinjection temperature if the Fe^{3+} can be effectively gotten rid of.

④ For high production wells, two or three reinjection wells may be needed to achieve full reinjection.

6. CONCLUSIONS

① The Tianjin Tertiary sandstone reservoir could be used for reinjection. But the reinjection flow rate is less than 50m^3/h under the condition of free pressure.

② Internal and external reasons cause the reinjection plugging. Internal rock characteristics are the reasons for the difference between the Tertiary sandstone aquifer and the basement aquifer. The external factors include deposition of suspended solids, precipitation of secondary minerals caused by water/rock interaction, and bacterial activities. Physical plugging is the major reason for plugging, and chemical plugging plays an important role.

③ Key measures for Tianjin Tertiary aquifer reinjection are removal of iron and suspended solids, periodic backwashing, and the use of a multi-reinjection well system.

REFERENCES

Spycher N. F. and Reed m. H.: A computer program for computing aqueous –minerals-gas equilibria, User's guide for SOLVEQ, University of Oregon, 1990.

Lin J.W., Liu X.M., and Gao B.Z., et al.:Tianjin geothermal reinjection testing analysis and its problem, Journal of Henan Polytechnic University, vol.25, No.3, Jun. 2006

Tianjin Geothermal exploration and development Institute: Underground hot water dynamic monitoring Annual Report for the Year of 2005.