

Reinjection Tests in Different Geothermal Fields in China

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ABSTRACT

Reinjection is significantly important for sustainable development of geothermal resources which is regarded as a difficult subject worldwide. Reinjection tests have been implemented in China for many years in different geothermal fields. This report presents the work performed in three fields both for sandstone and limestone reservoirs. Significant achievement has obtained through the sophisticated design and operation during the tests. Limestone reinjection work in Xiong County of Hebei province has been implemented since 2009, the water level drop has been extraordinarily controlled. Sandstone reinjection in Shaanxi and Shandong has achieved periodical success during the last two heating season.

1. INTRODUCTION

China is the largest geothermal direct use country in the world in terms of district heating capacity and other diverse direct uses. Sinopec Green Energy Geothermal Development Co., Ltd (SGEG) as a Sino-Icelandic joint venture is the largest geothermal district heating company in the country mainly developing geothermal in three regions in Xianyang, Hebei and Shandong presently.



Figure 1: Reinjection locations in China

This paper presents the reinjection work of the company during these years both in limestone geothermal field and sandstone geothermal field. Reinjection work has been successfully implemented in limestone area in its Hebei project. Up to the last heating season in 2012, there has been a total of 9,073,620 m³ of geothermal water reinjected into the reservoir since 2009. Tracer tests have been conducted twice (??) in continuously during two years, from 2010 to 2012. The water level drop has been controlled to be 2-3 meter per year in the contrast of 10 meters per year in the past years. The first reinjection test was conducted in Xianyang sandstone geothermal field in 2012 which was the first test in the history of this region. It also has achieved some promising results. The average reinjection flow rate is 50 m³/h, and the maximum value reached 90 m³/h. Reinjection in sandstone is known as the main difficult subject worldwide, this first test in Xianyang is seen as the milestone for sandstone reinjection implementation in this region. Meanwhile, the reinjection test in Shandong project has also been conducted since the beginning of its development in 2011. The reservoir is relatively shallow compare to Xianyang and quite similar as the Tianjin sandstone reservoir field. After two years of experiments, initial success was also achieved and accumulated experience in sandstone reinjection. Based on all these tests and experiments in different regions, the geothermal exploration and exploitation are more secured and sustainable in long term development. There are still lots of difficulties to be solved, and this reinjection work and research will be continued to be improve performance.

2. REINJECTION TEST IN HEBEI

Hebei province is rich in low and medium enthalpy geothermal resources. SGEG has started to develop geothermal energy in this province since 2009 with the first project in Xiong county of Baoding municipality. The main utilization is geothermal district heating which has already covered more than 90% of the total construction area up to now. 100% reinjection has been conducted

since then. The exploited reservoir in Xiong County is limestone layers, which is much easier to reinject after use. The average productive flow rate is about 120m³/h, and the temperature is 60-80°C.

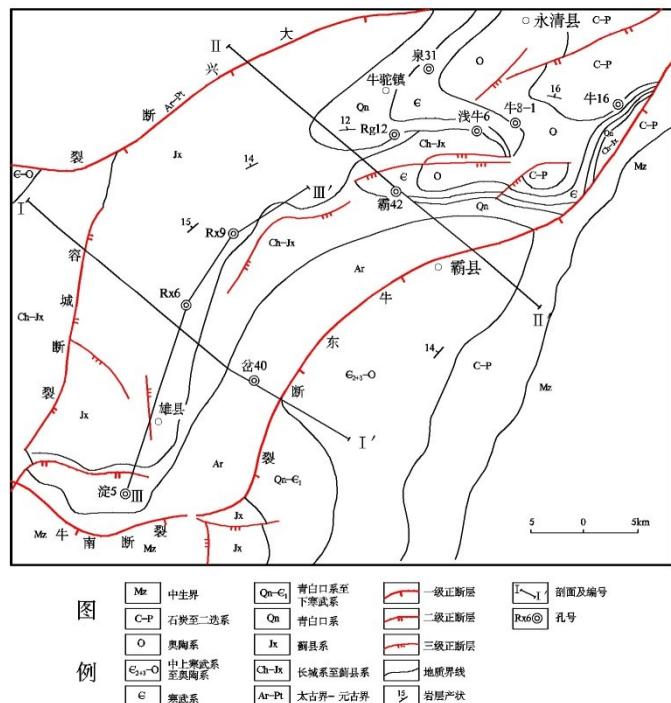


Figure 2: Geological map of Niutuzhen geothermal field

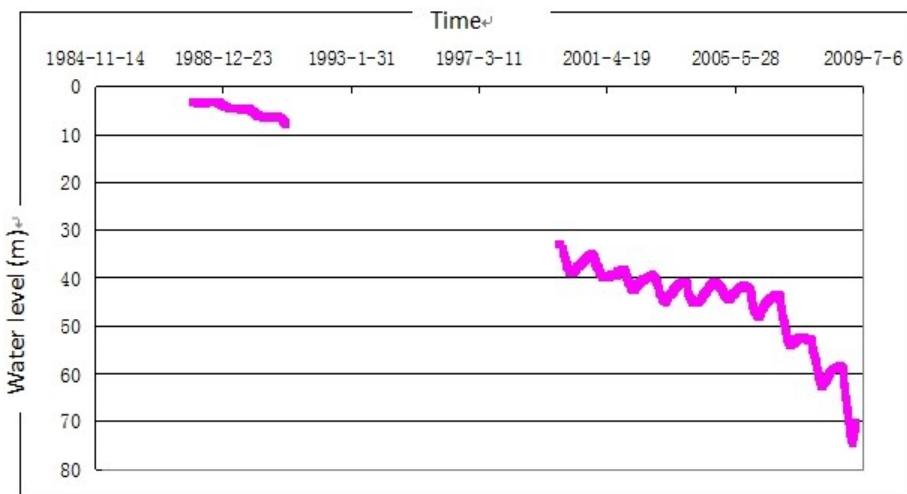


Figure 3: Water level duration curve 1984-2009 in Xiong County

The development of geothermal in Xiong County started in the 1970's, during the past 30 years, there has been only production without any reinjection. The main use for geothermal is district heating and bathing. The geothermal area covers 50% of Niutuzhen geothermal field in Xiong County. The reinjection test has started since 2009 when SGEG signed exclusive agreement with the local government to develop geothermal, and meanwhile the tracer test also has been conducted. The results showed that the reinjection flow rate can maintain 150 m³/h without any pumping. There's no direct thermal exchange between production well and reinjection well. The temperature and flow rate of production well has not been affected by reinjection. Tracer tests have been conducted for twice for the same well during two heating seasons. For the first one, no tracer was detected. For the second one, there's a little small amount of tracer detected from in nearby wells.

There are more than 20 reinjection wells in total in Xiong County since the start of reinjection in 2009. conducted since Before then the water level was dropped very steeply which as is shown in Figure 3. According to the water level monitoring data for during these years, the water level has been recovered slowly. The Figure 4 below indicates the reinjection schematic chart in the limestone reservoir in Xiong County. It is relatively simply compare to the sandstone reinjection system. The geothermal system should be 100% oxygen free to avoid scaling and corrosion. The geothermal water is pumped out by a submersible pump in the production well and goes to the reinjection well after releasing the heat to the secondary loop for heating system. The reinjection pipe should be submerged below the water level in the well. Meanwhile, the reinjection temperature is also important to maintain

the proper level to guarantee not affect productive temperature and also realize full use of energy. The average reinjection temperature in the project is maintained at be 32-38°C.

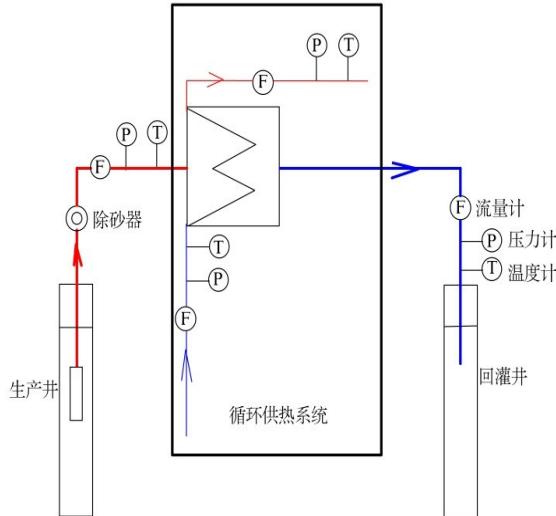


Figure 4: Limestone reservoir reinjection schematic chart



Figure 5: Distribution of wells in Xiong County

Tracer tests have been conducted twice for the same reinjection well in Xiong County. The principle of tracer tests is to add a tracer into reinjection well during the reinjection test, according to the sampling scheme, (7) to get samples in sounding production wells. Then through analysis of tracer sample to research path and velocity of migrant water as well as effective area, etc. During the heating season 2009-2010, there was no tracer sample fetched from any production well. The tracer 2,4-FBAS was environmental friendly with total weight of 22 kg. The tracer was put into the reinjection well on January 26, 2010. Then the sounding 5 wells were under monitoring and sampling. From 26th of January to 13th of July, there were a total of 603 samples collected and 336 have been analyzed. There was no tracer detected in any sample which means the volume of tracer in the production well was less than 1%. The test indicates that the well is quite capable in to accept reinjection. The flow rate reached 150 m³/h without pumping. It realized 1:1 of production well versus reinjection well. The second tracer test was performed from November of 2010 to March of 2011. This time the tracer was Fluorescein Sodium to avoid the interference of last test. The test improved the accuracy of detection and enlarged the detection scale. The results indicate there were three wells to the southwestern direction of reinjection well where minor amount of tracer was detected. The conclusion revealed the hydraulic connection and flow channel between wells. The maximum reinjection flow rate reached 180 m³/h. It revealed that the reinjection has little affection to influence on production. There's no direct hydraulic channel in between. Due to the anisotropy of karst geothermal reservoir, this test results only primarily reflect the temperature impact of the reinjection well to the surrounding production wells and will not reflect affect all the production wells in the field. Therefore, the long term reinjection test is necessary to perform and to enlarge the scale in order to obtain a sustainable development.

The geothermal development concession in Hebei province is not only in Xiong County but also other counties with rich geothermal resources. SGEG has started projects in Rongcheng, Gucheng, Xinji, Hengshui etc. All projects need reinjection work to secure the sustainable development both in limestone reservoir and sandstone reservoir. Due to the successful geothermal district heating implementation and reinjection work, Xiong County is approaching its objective to be a smoke-free city. And the Xiong County Model is learnt from all the country around. However, there are still lots of work to do to facility the development. The key issue for extend the scale of district heating is reinjection. In limestone reservoir, it is believed that the water level recovery will be realized by implementing reinjection in an area as large as possible of the geothermal field. There's no big technical difficulty. While for sandstone geothermal field, reinjection test is required to research the ability in different areas. The implementation plan is carried out along with the geothermal development.

3. REINJECTION TEST IN XIANYANG

SGEG's geothermal district heating project has started in Xianyang since 2006. The reinjection work has not carried out until 2012. The geothermal resource in this field is very rich in the sandstone reservoir. The normal geothermal well depth is 2000-4000 m. And the well head temperature is 60-110°C. Most of the wells are artesian with well head pressure between 1 and 2 bar. The geothermal development in this area has very long history which could be traced back to the Tang dynasty. The main utilization is district heating and bathing. The first reinjection well was drilled in 2008 by SGE. During 2012-2013, the first reinjection test was conducted on this well. Figure 6 shows the flow chart for of the reinjection system. There are two steps of filtration system with primary and fine levels to avoid physical block during reinjection. The deaerator is applied to avoid oxygen getting into the piping system. The test was performed during the heating season, and the results show that due to the multi-effect of air block, physical block and chemical block, natural reinjection was very limited. The main factor is physical block. The temperature of geothermal water is also highly effective factor for reinjection. The lower temperature proves the more amount of reinjection. It also took different pressuring test for reinjection, the higher pressure the more amount of reinjection amount.

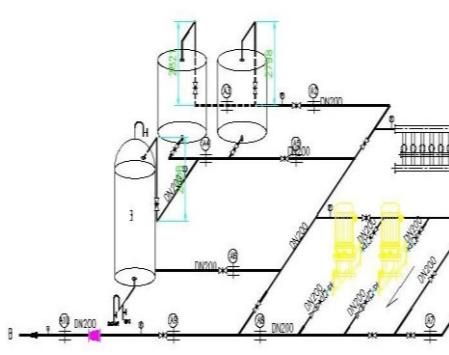


Figure 6: reinjection system on WH1 in Xianyang

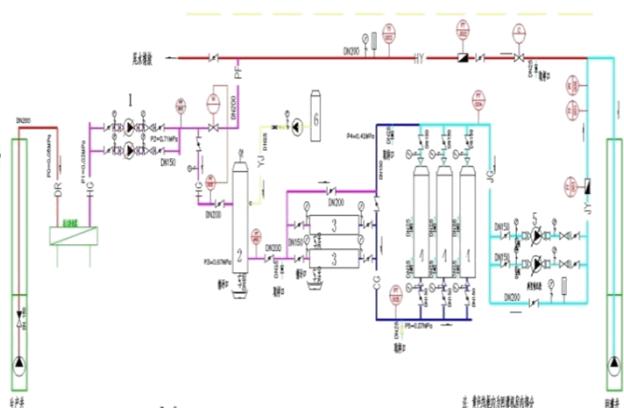


Figure 7: Schematic chart of reinjection system in WH2

In 2013, the second reinjection well was drilled. Based on the experience on last test and modification of the facilities, the second test was conducted during heating season 2013-2014. The result has given very positive conclusion that the highest reinjection amount has reached $148 \text{ m}^3/\text{h}$ without pumping. Figure 7 shows the schematic chart of the reinjection system. In this test, the filter fineness for primary filtration is $50 \mu\text{m}$ and for fine filtration is $3 \mu\text{m}$. The WH2 well depth is 2400 m. During the test, there are two period for testing. One is one production well versus one reinjection well, and the second period is two production wells versus one reinjection well. The locations are shown in Figure 8. On 9th of January 2014, tracer test was performed on WH2 well. There was no tracer detected in the surrounding wells which indicated that the movement of geothermal water is very slow. More research should be performed on this test afterwards. More detailed modification design should be carried out based on the results. Periodical pumping of the reinjection well is necessary to clean the well in order to increase the reinjection ability and protect the well. And the other factor for blocking is the fine sand in the geothermal water. It not only causes block in the well but also problems in the filtration system.



Figure 8: Well locations in Xianyang

4. REINJECTION TEST IN SHANDONG

The geothermal district heating project has started since 2011 in Laoling which belongs to Dezhou city of Shandong province where is rich in sandstone reservoir. ReInjection test has started since 2012. There was one reinjection well tested during 2012-2013 heating season. The depth of the well is 1530.61 m. It is a directional well. According to the pumping test, the flow rate is $127.86 \text{ m}^3/\text{h}$ with a water level dropdown of 38.9 m. The wellhead temperature is 53°C . The reinjection layer depth of the reinjection well is between 1199.69 m and 1420.30 m. The porosity of the aquifer is about 36.77- 40.95%, and the permeability is 11-30 md. After one heating season's test, the result showed that natural reinjection of this well could maintain $25 \text{ m}^3/\text{h}$. if the pump works, the amount will be increased by $60 \text{ m}^3/\text{h}$ average. The maximum flow rate during the test was $60-90 \text{ m}^3/\text{h}$ under the pressure of 0.4-0.45 MPa. Therefore, the most economical way is to combine natural and pressuring reinjection during the whole heating season along with the heating demand changes. According to the record of reinjection test, the steady reinjection flow under the related pressure test that the pressure is effective

For the heating season 2013-2014, the reinjection test has expanded from one well to two wells. The other well located in Central Century Compound. The well is also directional well with the depth of 1585m. The well head temperature is 52°C . And the flow rate is $120\text{m}^3/\text{h}$ while the water level drop down is 17m. The reinjection layer depth of the reinjection well is between 1192.4 m-1399.38 m. The porosity of the aquifer is about 30.81-39.37%, and the permeability is 10-30 md. The reinjection system is similar as the former one. Geothermal water is pumped out from the production well and then transmitted to the Heat Central to supply the

space heating for the compound. Then after heat exchanger, the discharged geothermal water firstly goes into the deaerator, then to the filtration system and pumps finally will be reinjected into the well. The process should be conducted under the strictly operation procedures. It is necessary to pump the well before reinjection if the well has been standing after drilling. Pumping until the water is clear enough without any sand is the first step before reinjection. The flow rate should be controlled step by step to be increased to the steady flow. The important parameters should be monitored and recorded carefully during the whole process such as water level, temperature, flow rate and pressure.

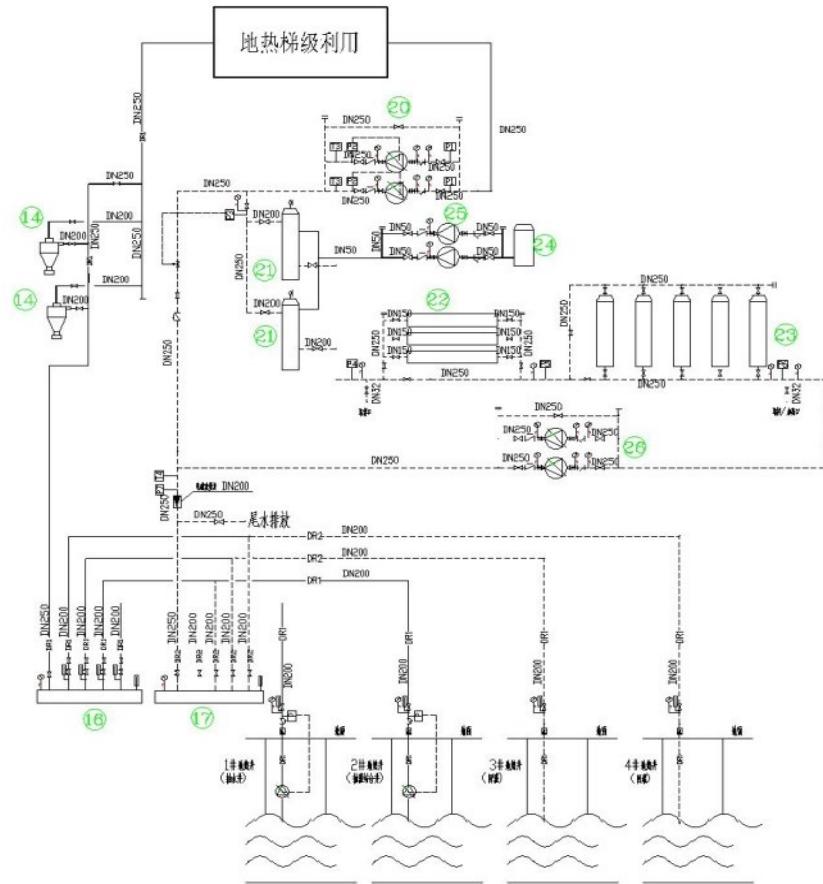


Figure 9: Reinjection system in Shandong

Table 1 below shows the results from two reinjection tests during two heating seasons. The flow rate has been decreased in the second year even with the same pumping pressure. There are many reasons for this difference. One possible reason is the physical block. The well after the last heating season's reinjection may block. Then the pumping work didn't last long enough to clear the well and the channel in the aquifer. After the test, a series of detection would be conducted to test the size of sediment particle. Geochemical work would also be performed to analyze the principle to reinjection block.

Table 1: Comparison of reinjection flow rate during two heating seasons

2013-2014 heating season	Well head pressure (MPa)	0.02	0.1	0.14	0.17	0.26	0.3
	Flow rate (m ³ /h)	50	68	49	45	54	53
2012-2013 heating season	Well head pressure (MPa)	0	0	0	0.1	0.2	0.35
	Flow rate (m ³ /h)	20	25	30	60	65	72
	Water level (m)	13	12	1	-	-	-

Geothermal development in Shandong province is also expanding from Laoling to other counties with rich geothermal resources. The majority of the areas are of sandstone type reservoirs. The comprehensive plan for reinjection in this area will be carried out based on all these tests. The long term monitoring will also be part of the future work.

5. CONCLUSIONS AND RECOMMENDATIONS

There are about 150 wells in total for SGEG in three geothermal development areas. The most important work is to manage the wells in scientifically manner both in production and reinjection function to obtain the sustainable development and maintain the reservoir in healthy and steady condition.

The success in reinjection for Xiong County is a very good model for sustainable development of geothermal resources. There are more detailed work to be performed in the design and operations. The reinjection in limestone reservoir is not as difficult as sandstone but essentially important in recharging the reservoir. Therefore, the scientific reinjection plan should be carried out for the future plan and expansion of the reinjection scale should be emphasized not only in the industry but also for the government.

Sandstone reinjection is regarded as the world wide difficulty. There are many tests performed in different geothermal fields in different countries. For our company, it is start-up period, there are lots of experiences and lessons to learn and accumulate. The reinjection work will be a long term plan to carry out to secure the resource development. Standard procedure for reinjection test should be carried out to guide the operation person to conduct the work properly. The monitoring data are essentially important to analyze the work performance.

6. REFERENCES

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