Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

A Study of the Technology for Geothermal Reservoir Reinjection Using Surface Water in the Dongli Lake of Tianjin

Liu Donglin[1], Yin Xiaoxiao[2], Shen jian[2] and Zhao Yanting[2]

[1]Center for Hydrogeology and Environmental Geology Survey, China Geological Survey.

[2]Tianjin Geothermal Exploration and Developing Designing Institute

529393809@qq.com

Keywords: Dongli Lake area; carbonate reservoir; ground water reinjection; water treatment system; tracer test; water-rock interactions experiments.

ABSTRACT

Dongli Lake geothermal area is a typical low-medium temperature sedimentary basin. By the end of 2018, there were 29 geothermal wells in this area, and static level falls nearly 5m annually due to the intensive development and utilization. Although reinjection percentage is about 90％ annually, the falling of the water level still relatively fast. The Dongli Lake area is abundant in ground water, through the treated lake water can be used for reinjection, three deep wells were drilled for ground water reinjection This paper briefly introduce the process of the water treatment system, and discusses the feasibility of the ground water injection based on tracer test result and water-rock interactions experiments.

1. INTRODUCTION

The Dongli Lake area is located in Tianjin Binhai New District and covers an area of 69 km2 (Figure 1). This area is abundant in low- medium temperature geothermal resources, which are stored in porous sedimentary reservoirs and bedrock (Duan et al., 2011). The highest temperature fluid is stored in Jxw reservoir. Jxw reservoir is hosted mainly by Mesoproterozoic dolomitic limestone, which belongs to semi-open and semi-closed bedrock subsystems, where geothermal karst fluids exist (Hu Y. et al., 2007). The geothermal water is mostly used for space heating during winter and small proportion of it is used for bathing and agriculture (Zong et al., 2016).

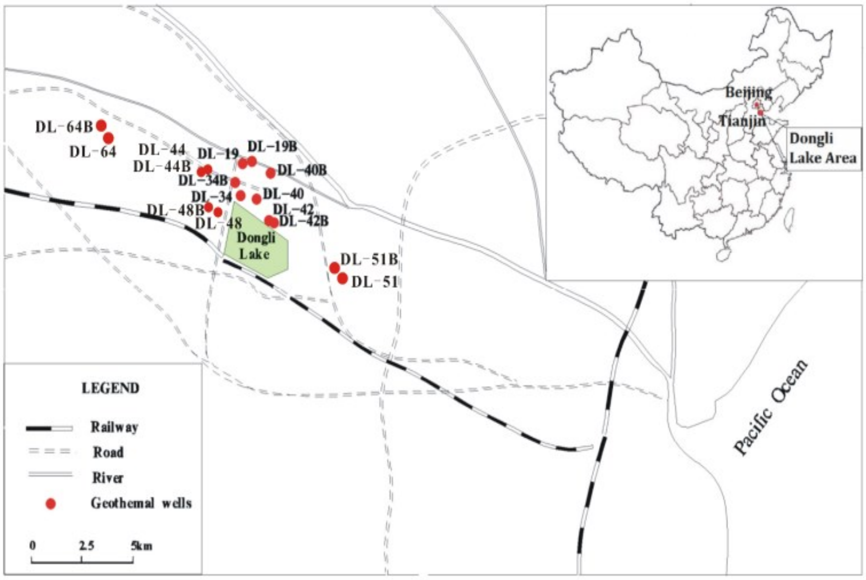

Figure 1: Map of the study area (from Wang, 2015)

By the end of 2016, there were 24 geothermal wells in this area, including 17 wells in the Jxw geothermal reservoir – 9 production and 8 injection wells, the average completed depth is about 2100m . In 2008 and 2009, the total annual production and injection were only 59.4×10^4 m^3 and 53.4×10^4 m^3, respectively (Zhao, 2010). In 2012, the total production rapidly increased and reached 140.7×10^4 m^3 (Zong et al., 2015). In 2013, the production increased to 157.4×10^4 m^3, with a slight decrease in the production in 2014, to 147.0×10^4 m^3. In 2015, the production increased to 162.3×10^4 m^3. In 2016, the production jump to 182.4×10^4 m^3.

Because of intensive development of geothermal resources water level gradually declined in DL-19 well from 2007 (Figure 2). The wells are used just in wintertime, i.e. from November 15th until March 15th, so water level fluctuates significantly between seasons. According to the dynamic monitoring data from 2007, the static water level in the Jxw reservoir was at about 100 m below the surface, while in 2016 it was at around 140 m depth. Hence, the annual decline is about 4 m/year (Zong et al., 2016).

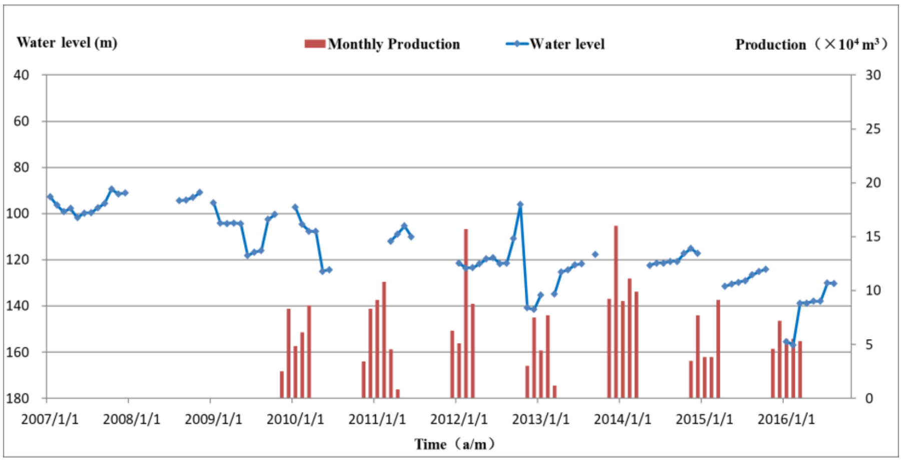

Figure 2: Water levels and monthly production of DL-19 from 2007 to 2016

There is a lake in the middle of this area with the storage capacity of 2000×104 m3. To maintain the pressure of the reservoir, one reinjection well DL-48B was drilled at the depth of 2200m, and a water treated system have been designed for the groundwater. This paper focus on the feasibility of the groundwater reinjection, based on the water-rock interaction experiment, ground water injection test and tracer test.

2. GROUND WATER TREATMENT SYSTEM PROCESS

The process flow of the ground water treatment system is shown in the Figure 3 below.

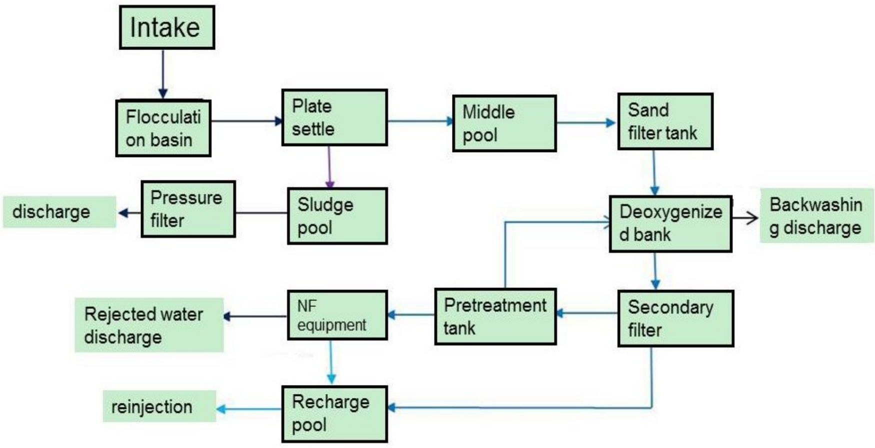

Figure 3: Schematic diagram of surface water reinjection's water treatment system

To be injected into thermal reservoir, the surface water (ie lake water) is enhanced by a pump, added fungicides in the pipeline during transportation to kill microorganisms, bacteria, etc; Then the water is sent to the coagulation tank to add coagulator. The mixture is stirred at a low speed to make the sediment, suspended solids, colloids and microorganisms forming large flocs and alum, which are separated from the water; Afterwards, water enters the inclined tube sedimentation tank to separate mud and water. The sludge is regularly discharged into the sludge tank, after thickening and filtering, the water is discharged and the sludge is transported to the landfill.

The effluent from the sedimentation tank enters the middle pool and is sent to the sand filter tank by the water supply pump to remove impurities such as suspended solids. After removing most of the dissolved oxygen in the water through the deoxygenized tank, it enters the precision filter to further remove suspended solids, colloids and other impurities in the water; The pretreated water partially overflows into the reinjection pool, partially enters the booster pump, and is pressurized to enter membrane system. After membrane filtration, water production into the reinjection pool, mixed with overflow pretreatment water, the water quality reaches the standard of reinjection water basically. According to the actual situation, if the pH and dissolved oxygen not meet the standard, the reinjection water can be treated by adding a small amount of acid (alkali) liquid and oxygen scavenger before refilling, then the treated reinjection water passes through the reinjection pump and is transported to the reinjection well into the thermal reservoir finally.

3. WATER-ROCK INTERACTION TEST

The water-rock interaction experiment of high temperature and high pressure reactor was determined by the temperature logging data of Wumishan geothermal reservoir. In the reaction temperature was 90℃, and pressure was 20MPa. This test included two groups, the reaction time was 10 days、30 days and 60 days (Table 1).

Table 1: Table of experimental schemes for different types of water samples and rocks

Water samples	Pressure	Temperature	Sampling time node（d）			Total days of reaction （d）
Formation water	20MPa	90℃	10	30	60	60
Treated surface water	20MPa	90℃	10	30	60	60

3.1 Preparation of cutting samples

The experimental rock sample was drilling cuttings (Figure 4). The rock character of geothermal reservoir was determined before test, and X-ray diffraction and scanning electron microscopy were used to analyze mineral composition of rock samples, specific surface area and pore size of rock samples were analyzed by specific and pore size analyzer.

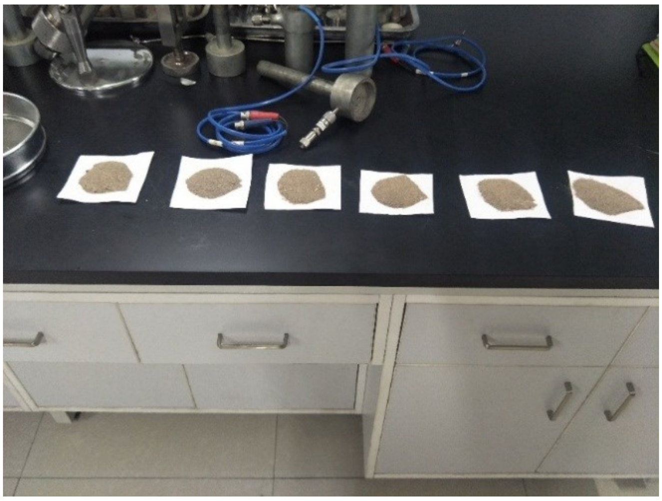

Figure 4: Cutting sample

3.2 Experimental equipment

In this test, ML-0.3 high temperature and high pressure reaction (Figure 5) was used. The standard capacity of the reactor was 300ml. The material was 316L stainless steel. The corrosion resistance of the reactor was strong. The maximum working temperature was 400℃ and the maximum pressure was 25MPa. The reactor is equipped with a magnetic stirring rod, which can adjust the stirring speed. At the same time, in order to maintain the required temperature of the experiment, the reactor is placed in the heating jacket, and the temperature is controlled by a thermal sensor.

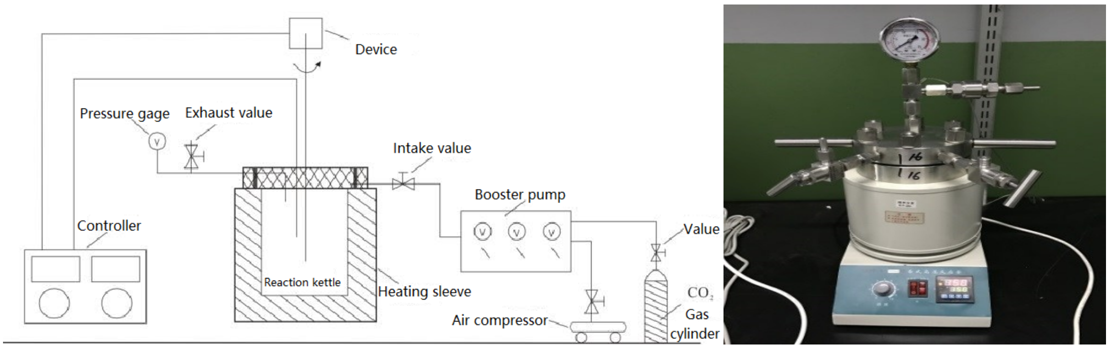

Figure 5: High temperature and high pressure reactor

3.3 Experimental procedures

(1) According to the water-rock ratio(15:1), 30g rock samples and 500ml water samples were weighed.

(2) The rock sample and solution were put into each reactor, sealed, and the reactor was placed in the heating jacket for heating. After reaching the set temperature, nitrogen was injected into the reactor through the air compressor and the booster system. After reaching the required pressure, the intake valve was closed and the reaction begins.

(3) According to the sampling time designed by the experiment, the corresponding experiments were stopped on the 10th, 30th and 60th days respectively, the heating system was closed, and the outlet valve was opened after cooling to room temperature for pressure relief.

(4) Open the sealing knob of the reactor, take the reacted rock sample out of the reactor and dried it at 40℃ for 48 hours immediately. Seal and store the reaction liquid after the reaction in plastic bottle for inspection.

3.4 Analysis of experimental results

(1) Six groups of specific surface area and aperture analysis were completed, and the results were shown in Table 2. The specific surface area of debris increased gradually after the reaction with treated Lake water, and stabled after the reaction with formation water. No obvious change was observed, indicating that no obvious corrosion or serious blockage occurred.

Table2: Specific Surface Area of Rock Samples and kong'jing Analysis

Types of rock samples	Reaction time	Specific surface area	Average hole diameter
Original cuttings	/	1.9776	11.8919
Cuttings reacted with treated lake water	10 天	1.5633	12.7391
	30 天	1.9920	11.8972
	60 天	2.0562	11.7079
Cuttings reacted with formation water	10 天	1.5044	12.9406
	30 天	1.4050	12.9580
	60 天	1.5433	12.5851

(2) The pH of treated lake water and formation water fluctuates between 7 and 8, and the TDS trend of treated lake water and formation water was consistent, which indicates that the ground water recharge and formation water recharge is basically no difference.

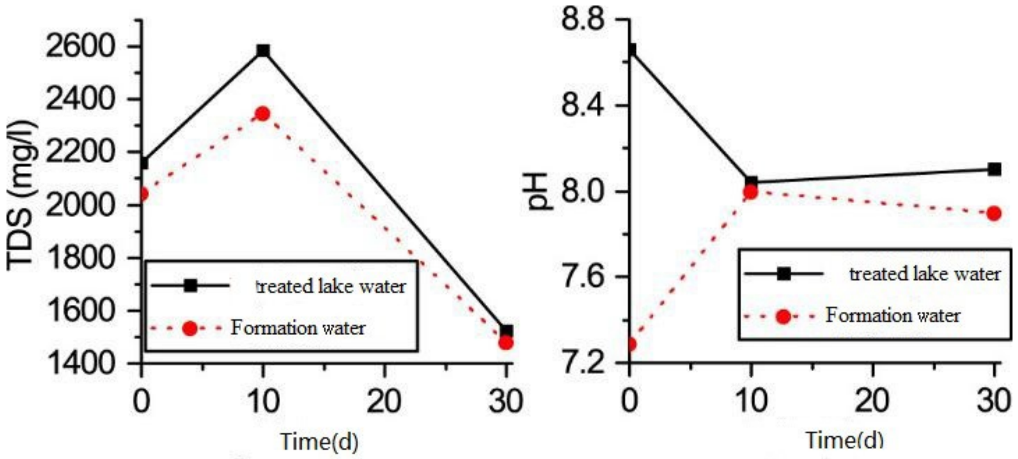

Figure 6: TDS and pH Changes in Two Water Samples

4. GROUND WATER INJECTION TEST

A ground water injection test had been carried out to verify the injection ability of DL-48B, before the reinjection test, the static water level of DL-48B well was measured to be 112.14m, and the corresponding liquid level temperature was 25℃. The following is a detailed description of the experiment:

(1) The first stage of the recharge experiment began at 13:00 on September 27, 2018, and ended at 10:00 on September 28. It lasted 21 hours, with an average temperature of 21.5℃, the steady recharge volume of 60m^3/h, the steady dynamic water level of 107.6 m and the stable time of 19h.

(2) The second stage of the recharge experiment started at 10:00 on September 28, 2018, and ended at 11:00 on September 30. It lasted 49 hours. The average temperature of the recharge fluid was 20.6℃, the steady recharge volume was 80m^3/h, the steady dynamic water level was 96.6m and the stable time was 30h.

(3) The third stage of the recharge experiment started at 11:00 on September 30, 2018, and ended at 9:00 on October 6. It lasted 142 hours. The average temperature of the recharge fluid was 19.8℃. The steady recharge volume was 100 m^3/h, the dynamic water level was 77.6m and the stable time was 100h.

(4) The fourth stage of the recharge experiment started at 14:00 on October 6, 2018, and ended at 11:30 on October 22. It lasted 237 hours. The average temperature of the recharge fluid was 19.2℃, the steady recharge volume was 120 m^3/h, the dynamic water level was 48.9 m and the stable time was 120 h.

(5) The fifth stage of the recharge experiment started at 11:30 on October 22, 2012 and ended at 20:00 on October 25, 2012. It lasted 81 hours. The average temperature of the recharge fluid was 14℃. The steady recharge volume was 140 m^3/h, the dynamic water level was 20 m and the stable time was 60h.

The basic data of this recharge experiment was shown in Table 3, and the diachronic curve was shown in Figure 7.

Table3: Basic data table for well test of surface water recharge DL-48B

Phase	Start-stop time	Steady recharge（m^3/h）	Temperature (℃)	Stable water level (m)	Stable duration (h)
1	9-27 13:00～9-28 10:00	60	21.5	107.6	19
2	9-28 10:00～9-30 11:00	80	20.6	96.6	30
3	9-30 11:00～10-6 9:00	100	19.8	77.6	100
4	10-6 14:00～10-22 11:30	120	19.2	48.9	120
5	10-22 11:30～10-25 20:00	140	14	20	60

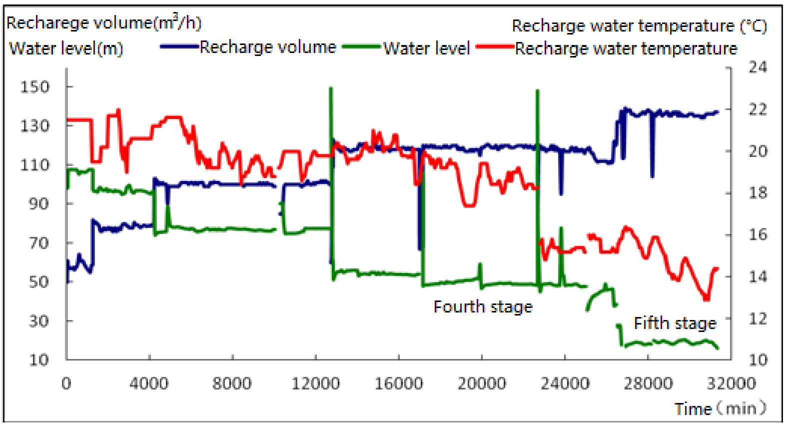

Figure7: Diagram of Surface Water Recharge Test in DL-48B Well in 2018

5. TRACER TEST

One ton Naphthalene Sulfate Sodium was injected into DL-48B well. This tracer test began on January 1, 2018 and ended on March 26, 2018. It lasted 84 days several production wells sampling and 1000 samples were obtained, only DL-48 well had recovery.

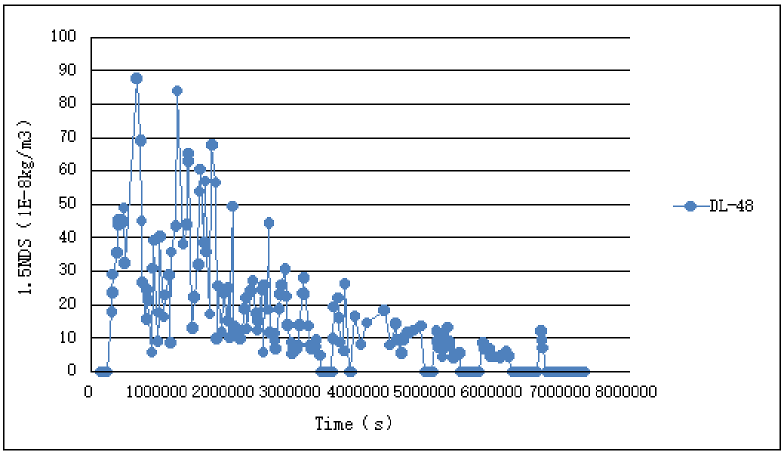

Figure 8: Recovery Concentration of Tracer in Well DL-48

Tracer recovery and analysis are interpreted by ICEBOX program as shown in Table 4.

Table 4: Interpretation Results of tracer testin nearest well DL-48

Results	DL-48
Date of first arrival	2018-1-4
First arrival time（d）	3
Recovery（kg）	0.0323
Rate of recovery（1E-5%）	323.0
Channel Length（m）	750
Seepage velocity（m/d）	53.48
Longitudinal dispersion（m）	358.8
Cross-sectional area（1E-5m^2）	156

According to the current production and injection patterns of DL-48 and DL-48B wells, the temperature variation of DL-48 wells in the next 100 years is predicted, as shown in Figure 2. The results show that the temperature of thermal storage in DL-48 well has only decreased by 0.001℃ after 84 years of operation, which can be neglected. It is obvious that there is no "cold-through" happens in DL-48 well.

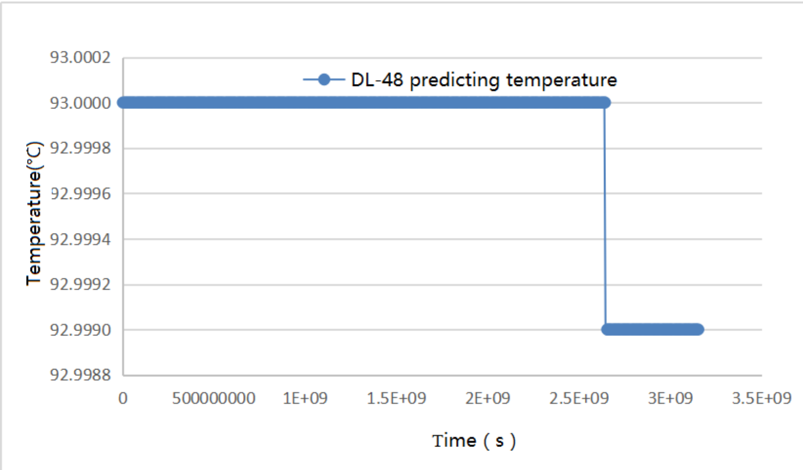

Figure 9: Prediction chart of 100-year thermal storage temperature in well DL-48

6. SUMMARY

(1) A ground water treatment system have been designed to treat the ground water meet the standard of reinjection water.

(2) According to the water-rock interaction experiment result the ground water injection has no obvious corrosion or serious blockage, and the pH and TDS of ground water injection is similar as the formation water injection.

(3) Based on the ground water injection test , the maximum injection flow rate is 140m^3/h.

(4) Tracer test result showing that the recovery rate is very low in DL-48, there will be no "cold-through" happens in DL-48 well.

ACKNOWLEDGEMENTS

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by National key R&D program of China (2018YFC0604305), China Geological Survey project (DD20190127 & DD20179621).

Sincerely thanks Zhao Sumin and Shen jian from Tianjin Geothermal institute for providing the data to finish this paper

REFERENCES

Duan Z., Pang Z., and Wang X.: Sustainability evaluation of limestone geothermal reservoirs with extended production histories in Beijing and Tianjin, China, Geothermics, 40, (2011), 125-135.

Wang Wanli : Modelling of tracer tests in a geothermal reservoir in Tianjin, China, Report 41 in: Geothermal training in Iceland 201, UNU-GTP, Iceland, (2016), 891-910.

Zhao Na : Geothermal simulation of lake water injection into the geothermal reservoir in Tianjin, China, Report 32 in: Geothermal training in Iceland 2010, UNU-GTP, Iceland, (2010), 711-730.

Hu Y., Lin L., Lin J., Cheng W., Zhao S., and Yu Y.: Report about the potential evaluation of the sustainable development of geothermal resources in Tianjin, Tianjin Geothermal Exploration and Development Designing Institute, report (in Chinese), (2007), 213 pp.

Tian G.: Sustainable development and utilization of geothermal resources in the Dongli Lake resort in Tianjin (in Chinese), China University of Geosciences, Beijing, MSc thesis, (2014), 106 pp.

Zong Z., Yan J., Wang B., Zhang S and Yin X.: The annual report of dynamicmonitoring of geothermal resources in Tianjin，Tianjin Geothermal Exploration and Development Designing Institute, report (in Chinese), (2016), 152 pp.