Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

The Comprehensive Test for Geothermal Tail-water Disposal

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Keywords: geothermal tail-water; disposal; test

ABSTRACT

Geothermal reservoirs and groundwater resources in layered porous media in large sedimentary basins have enormous exploitation potential because of their extensive distribution, great quantity, and feasible temperatures and drilling depths. The discharge of geothermal wastewater (i.e. tail-water) on the surface is a serious environmental issue because of its high salinity content, so the Bureau of Geology Exploration and Mineral Resources Exploitation in Shandong Province, China called for the study of the disposal technique of the geothermal tail-water. The disposal test process is as follows: take the waste of geothermal water to make physics-chemistry preparative disposal; filtration with manganese-sand set and/or double-medium equipment; filtration with ion exchange resins; nanofiltration membrane separation; and reverse osmosis separation. After separation, the cheap, clean water can be used as a material for chemical plants. However, in the case of deeply embedded geothermal groundwater resources, connate water(buried water), or bad recharge conditions, must be dried up for a long time exploitation, causing ground depression. Therefore, it is concluded that systems utilizing reinjection, i.e. closed-circuit cycle mode injection, in sandstone reservoirs are ideal for the realization of sustainable exploitation of the geothermal groundwater resources with favorable environmental conditions on the surface.

1. INTRODUCTION

The North China Basin is a large-scale oil and gas containing basin that the Mesozoic and Cenozoic fault-block basin are superimposed on. The Platform basin of Mesoproterozoic and Late Proterozoic has an area about 200,000 km^2 , and is shown in Figure 1.The basement of the basin was formed in the Archean and Proterozoic, and the covering structure was mainly influenced by the Yanshan movement. Since the period of Mesozoic, it has developed into a downfaulted basin successively. North of the basin is the Yanshan uplift, West is the Taihang uplift, Southeast is the Luzhong mountain uplift, Southwest is a warp, and northeast is Bohai Bay. From South to North, the distribution is as follows: the Jiyang depression, the Chengning uplift, the Huanghua depression, the Cangxian uplift, and the Jizhong depression in the basin. Since the Cenozoic, a thick buildup of sediment has occurred on the basin (up to 1000 meters in parts) abounding oil and gas resources as well as an abundance of geothermal water resources. There are mainly four types of thermal energy storage in the basin: pore-fissure thermal energy storage systems in Cenozoic clastic rock, fissure thermal energy storage systems in Mesozoic and upper Paleozoic clasolite (Cretaceous, Jura, Carboniferous, Permian), karst-fissure thermal energy storage systems in lower Paleozoic Cambrian-Ordovician carbonate rock, and massive fissure thermal energy storage systems in Neoarchaean metamorphic rocks. At present, Tianjin, Hebei, Shandong, and other provinces have carried out the exploration, development, and utilization of geothermal water successively, which has led to significant economic and social benefits.

In the middle and upper Proterozoic deposition, there are very thick diplomatic and siliceous carbonate rocks, with a thickness of up to 7000 m. The Lower Paleozoic Cambrian - Ordovician layer is 600-800 m, and there are thick sediments of limestone and diplomatic limestone. It developed karsts fissures, which indicate good geothermal potential. Generally, the edge of the basin is shallow and the potential for development and utilization is not great, but the local part is rich in water. Thermal energy storage systems with Mesozoic - Upper Paleozoic (Cretaceous, Jurassic, Carboniferous, Permian) clastic rock fissures are rich with water only in some fractures in highly developed zones, leading to a relatively low exploitation potential. The pore-fissure thermal energy storage system of Cenozoic clastic rock located in the shallow part of the basin is widely distributed and has large potential for exploitation and easy development and utilization.

The loosely deposited fluvial sandstone and mudstone thermal water reservoir of the Neogene period is very thick (about 1200-2000 m with a floor generally extending 700-1600 m) The Dongying formation (Ed) of the Paleogene period is usually 500-1300 m. It is composed of sandstone and mudstone and has a temperature of about 90°C, mineralization of more than 10 g / L in most cases, and a large amount of poor quality water The Guantao formation (Ng) of the lower Neogene is about 300-500 m and has coarse lithology mainly consisting of medium and fine sand with an individual layer of gravel and silt.

The Upper Minghuazhen formation (Nm) has a depth of 1000-1500 m. It has the attribute of a fine-coarse reverse cycle, meaning that the lower lithology is fine and the upper is coarse. Guantao (Ng) and upper Minghuazhen formation (Nm) of the Neogene are mainly thermal water aquifers. The thermal water temperature increases with the depth, with a maximum temperature is 60-85°C. Most of the water is fresh, as mineralization is generally less than 3g / L, and water chemistry type is HCO_3^-Na-oriented. However, the water quality in the lower segments of the two formations is poor and has a higher degree of mineralization, which is generally more than 500mg / L and can even reach up to 10g / L. In these segments, the water chemistry types are mainly Cl-Na-Mg and Cl-Na in most cases.

In such a vast area with such huge geothermal water resources, the economic and social benefits of its development and utilization are self-evident. However, there are two major problems. Firstly, discharging used and highly mineralized geothermal tail-water would be harmful to the ground environment. Secondly, the aimless development and utilization of geothermal water resources leads to the depletion of the resources (including flowrate and temperature), ground deformation, and other environmental and geological problems. The discharge of the geothermal tail-water of the Dongying formation near Dongying City in the Shandong Province is discussed in this article, along with the environmental problems it causes. An experimental investigation was carried out, and a proposal is presented discussing the problems that may arise, such as the depletion of resources and surface damage. Features of the Dongying formation are presented in Table 1.

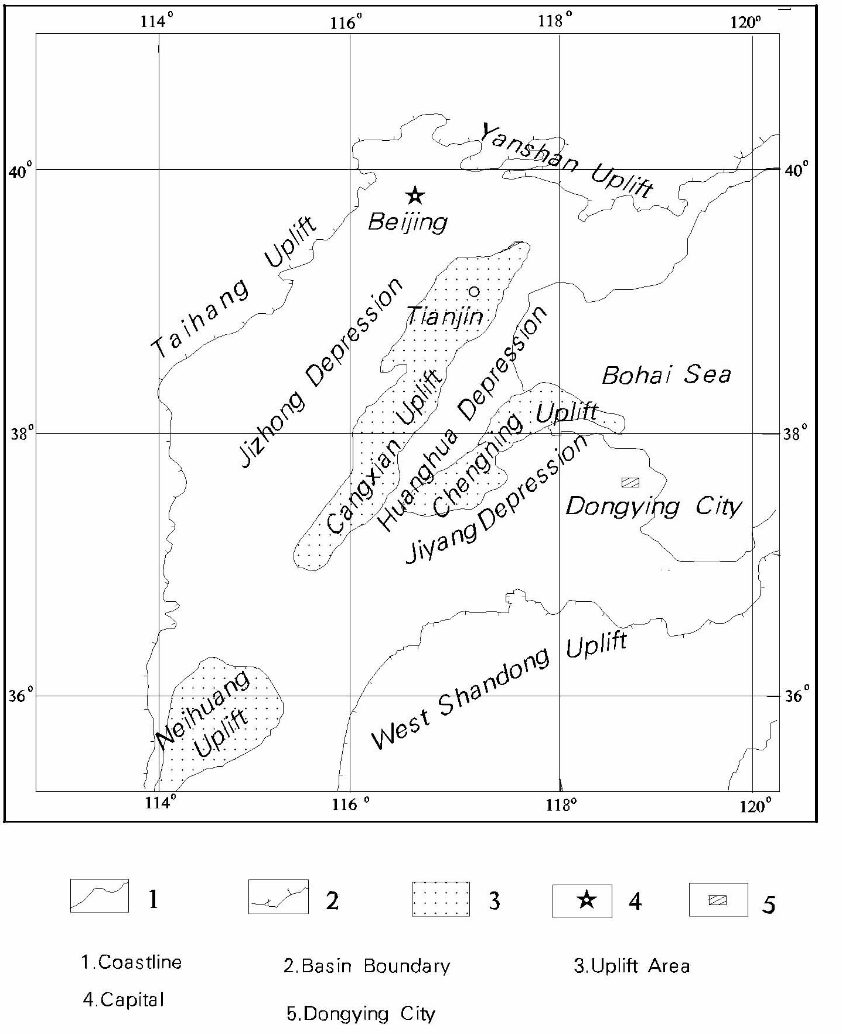

Figure 1: Geotectonic units of North China Basin and the location of Dongying City

Table 1: Quality features of geothermal water and tail-water in the Dongying formation of Dongying City

Indicators	Content	Indicators	Content
well depth (m)	1500、1800	temperature of well water (℃)	57~66
heat-exchanged temperature of water (℃)	36-45	cooled-temperature (℃)	30-45
saline salinity (g/L)	>23.33	Total hardness (mmol/L)	53.16
chloride ion (g/L)	13.65-14.00	Calcium ion (mg/L)	>1728.16
sodium ion (mg/L)	>6315.10	Magnesium ion (mg/L)	>239.04
potassium ion (mg/L)	18.05	pH	6

Note: The author selected a heating station of one living society that uses geothermal water for heating in Dongying City to carry out this study. There are two heat wells in the station, with depths of 1500m and 1800m, respectively. After hot water from the two wells circulates through heat exchangers, the geothermal tail-water is discharged directly. Data in this table are test results sampled in March 2008.

2. GEOTHERMAL TAIL-WATER PROCESSING EXPERIMENTAL RESEARCH

A geothermal tail-water processing experiment was completed in the field using experimental equipment that included a conventional water quality measurement instrument. The study spanned the 20 days between November 30, 2008 and December 19, 2008. The study consisted mostly of testing different conditions and processing equipment combinations. After optimizing the processor design, continuous tests lasting 1 hour, 4 hours, 10 hours, 16 hours, and 28 hours were run.

2.1 Experimental Geothermal Tail-water Quality

Experimental results concerning geothermal tail-water quality are shown in Table 3. It can be seen in the table that the salinity, hardness, etc. of the geothermal tail-water are all high. so direct discharge will cause harm to the environment. Therefore, it is significant to carry out experimental research and design a processing method for geothermal tail-water.

2.2 Treatment Processes of Tail-water

Through field investigation and study, it was decided that processing would mainly consist of the abundant pretreatment to the tail-water using a reverse osmosis processing craft to lower the salt content and hardness of the geothermal tail-water. A process flow diagram is given in Figure 2 and consists of:

Chemical pretreatment (water tank→preaeration tank→coagulation reaction tank→sedimentation tank) →regulating reservoir→manganese mineral filter→binary media filter→cartridge filter→anion exchange resin→cation exchange resin→primaty nanofiltration membrane→secondary nanofiltration membrane→reverse osmosis membrane→yielding water.

Table 2: Experimental mineralization of geothermal tail-water (mg/L)

items	Concentration	items	Concentration	items	Concentration
K^+	51.5	SO_4^{2-}	290.13	dissociated CO_2	6.07
Na^+	5625.00	HCO_3^-	88.34	soluble SiO_2	24.00
Ca^{2+}	2171.56	F^-	0.40	metasillicio acid	31.20
Mg^{2+}	557.91	Br-	40.55	total hardness	7720.34
NH_4^+	6.75	Sr	73.5	permanent hardness	7647.87
Fe^{3+}	0.16	Li	1.5	temporary hardness	72.47
Fe^{2+}	<0.04	Mn	3.50	total alkalinity	72.47
Cl^-	13636.91	Other metals	trace	mineralization	22496.12

Table 3: List of component content of experimental geothermal tail-water (mg/L)

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NH_4^+	6.75	Sr	73.5	permanent hardness	7647.87
Fe^{3+}	0.16	Li	1.5	temporary hardness	72.47
Fe^{2+}	<0.04	Mn	3.50	total alkalinity	72.47
Cl^-	13636.91	Other metals	Trace	TDS	22496.12

In the experiment, the equipment operated under three different pressures, enabling the water current to have three different rates of percolation (filter speed increased gradually). At first, each unit of equipment was tested in an isolated manner to inspect the tail-water processing effectiveness of each component of the processor. Subsequently, the processor was run continuously, and tail-water samples were taken.

2.3 Main Test Result

Geothermal water with high salinity also has high hardness mainly due to its high content of Na and Cl. The content of the two substances determine the content of total dissolved solids (TDS), so during the continuous trials, the TDS, hardness, and Na and Cl contents of the samples were determined. Their changes in concentration change reflect the overall removal of soluble ions.

2.3.1 The Dynamic Changes of the TDS

Table 4 and Figure 3 show the changes of water TDS during the consecutive operation of the individual processing units over different processing times.

It can be seen in this table that the final TDS after running one hour is 0.71g/L, which meets the constraint of a TDS of less than 1.5g/L. However, when the processing time was increased to 4 hours, the efficiency of the processing unit declines, and the treated volumes are less after passing through the filter, ion exchange column, and the NF and UF systems. Further, the removal in the reverse osmosis system falls dramatically with increased runtime, even though the TDS during that time remains substantially stable.

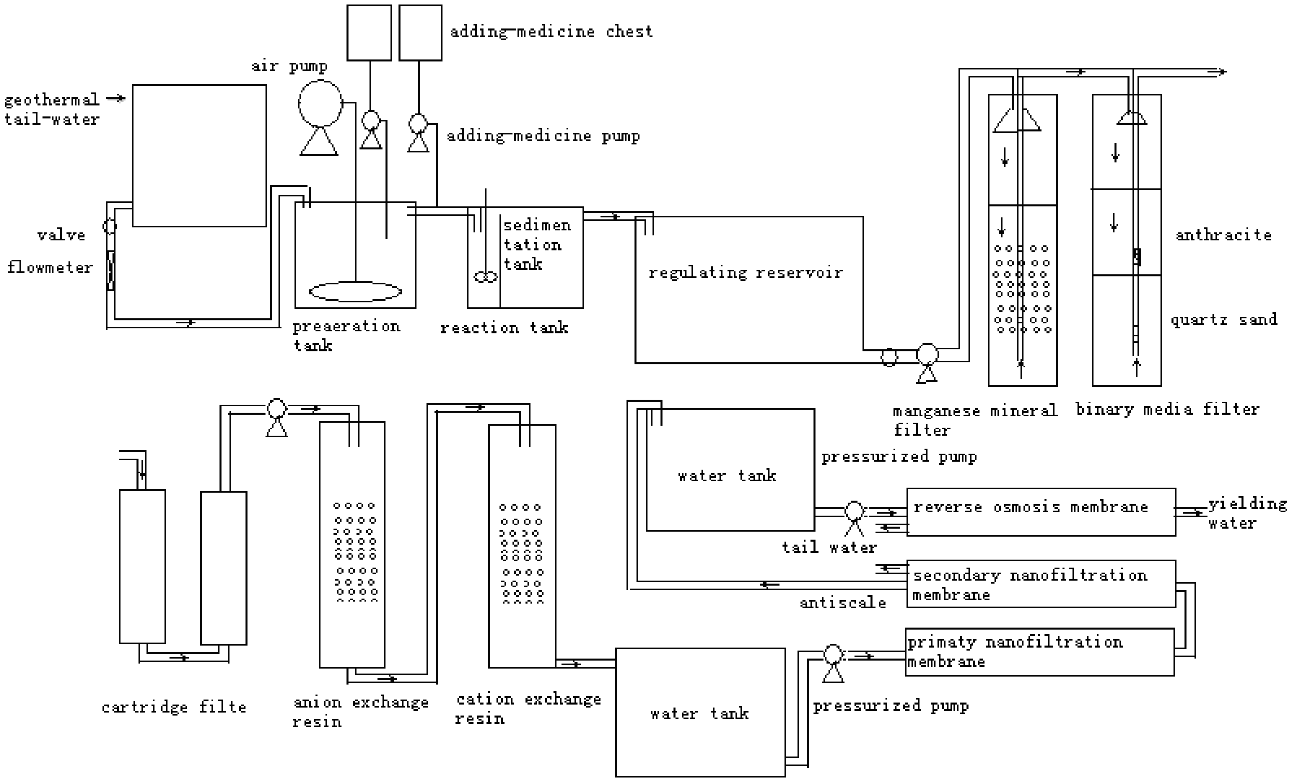

Figure 2: Test process flow diagram

Table 4: Dynamic changes of TDS during the operating cycle (g/L)

Running time	1h	4h	10h	16h	28h
Primary water	21.48	24.24	22.99	24.74	22.96
Filtered water comes from the precision instrument	17.2	24.59	23.43	24	24.48
Switched water comes from the cation exchange column	12.48	24.14	22.50	23.73	22.97
Water comes from the nanofiltration membrane	7.76	22.94	23.26	24.21	23.04
Water comes from the reverse osmosis filter	0.71	9.24	9.65	9.65	11.80
Total removal race	96.69%	61.88%	58.03%	60.99%	48.61%

2.3.2 Dynamic Changes of Hardness

The effects of processing and runtime on water hardness are displayed in Table 5 and Figure 4. It can be seen that the results of hardness removal were similar to the TDS results in the experiment. However, the reverse osmosis membrane had a higher removal rate at above 89%.

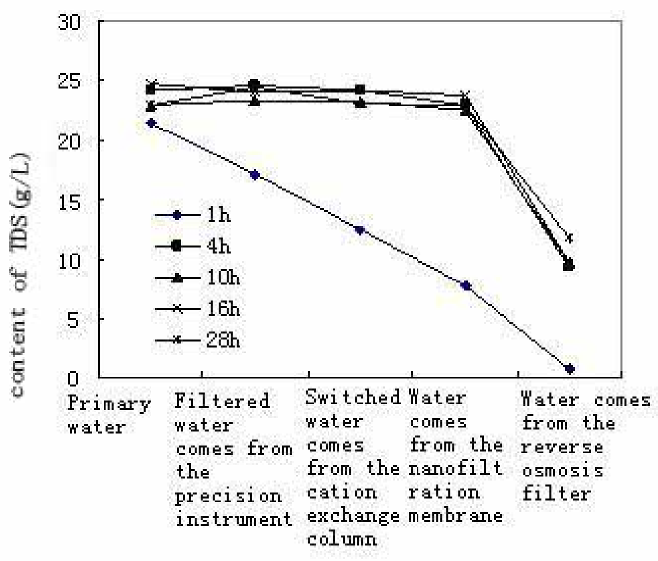

Figure 3: Dynamic changes of TDS during the operating cycle

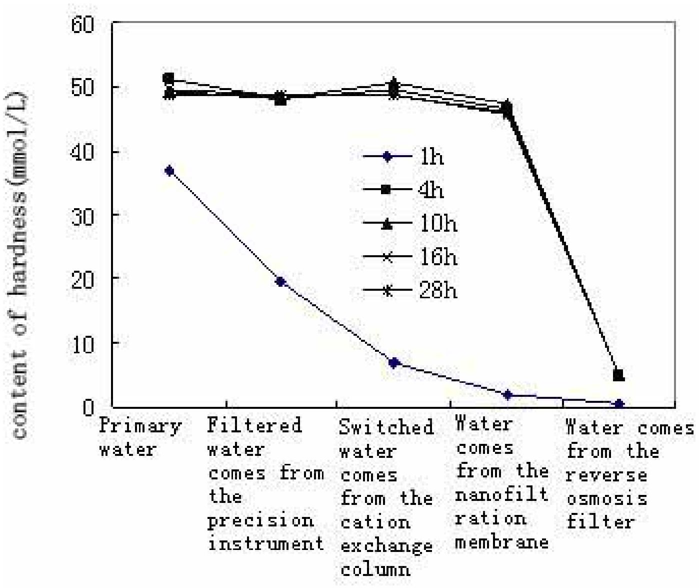

Figure 4: The change of hardness curve during continuous operation cycle

Table 5: Dynamic changes of water hardness during the operating cycle (mmol/L)

Running time	1h	4h	10h	16h	28h
Primary water	36.88	51.06	49.17	49.65	48.70
Filtered water comes from the precision instrument	19.62	48.23	48.23	48.70	48.70
Switched water comes from the cation exchange column	7.00	49.65	50.59	48.70	48.70
Water comes from the nanofiltration membrane	1.99	46.57	47.28	46.10	45.63
Water comes from the reverse osmosis filter	0.57	5.01	5.01	4.92	4.92
Total removal race	98.45%	90.19%	89.81%	90.09%	89.90%

2.3.3 Dynamic Changes of Sodium and Chloride

Tables 6 and 7 and Figures 5 and 6 show the changes in sodium and chloride contents in the water during continuous trial operation for different processing times and at different processing stages. Since sodium and chloride account for the majority of TDS, it is not surprising that these results mimic those of the TDS.

It can be seen in these figures and tables that desireable processing effects were realized after 1 hour of runtime, as the draining water quality can met the standards. But once the runtime surpassed 4 hours, the processing efficiency of the precise filters, positive bed, and sodium filtration processing unit started to decrease, and the tail-water quality gradually got worse. However, the processing efficiency of the reverse osmosis unit maintained a high efficiency.

2.4 The Improvement of Geothermal Water Treatment Process

After the above processing, the tail-water quality still didn't meet the local water discharge standards (TDS=1.5g/L). Therefore, the processor design was altered to include another reverse osmosis unit. After an experimental study, this addition was proved to be feasible. The results of the study following the addition of one reverse osmosis stage are displayed in Table 8 and demonstrate that the tail-water quality met the discharge standard.

The flow rate of our treatment was 5 L/min. According to the present water treatment situation, it is possible to improve the processing flow and overall efficiency of water treatment while reducing the processing cost.

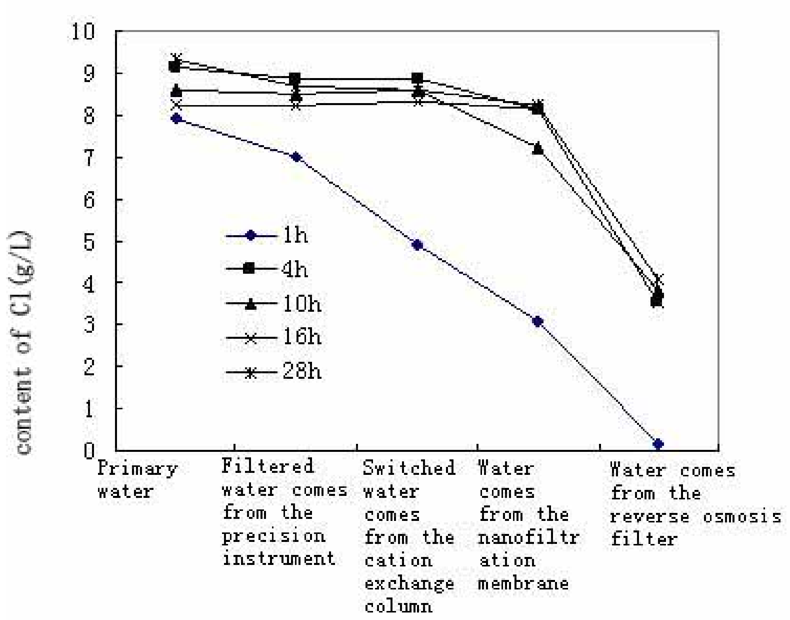

Figure 5: The change of chloride curve during continuous operation cycle

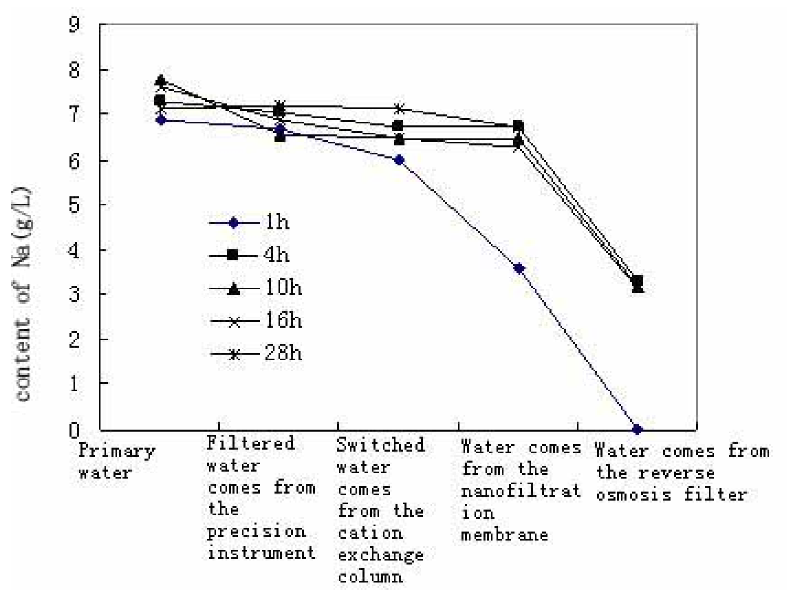

Figure 6: The change of sodium curve during continuous operation cycle2

Table 6: Dynamic changes of chloride during the operating cycle

Running time	1h	4h	10h	16h	28h
Primary water	7.89	9.13	8.60	8.24	9.31
Filtered water comes from the precision instrument	6.99	8.86	8.51	8.24	8.69
Switched water comes from the cation exchange column	4.9	8.86	8.60	8.33	8.60
Water comes from the nanofiltration membrane	3.1	8.15	7.23	8.15	8.24
Water comes from the reverse osmosis filter	0.18	3.55	3.81	3.55	4.08
Total removal race	97.72%	61.12%	55.70%	56.92%	56.18%

Table 7: Dynamic changes of sodium during the operating cycle

Running time	1h	4h	10h	16h	28h
Primary water	6.87	7.29	7.78	7.62	7.12
Filtered water comes from the precision instrument	6.66	7.04	6.56	6.87	7.20
Switched water comes from the cation exchange column	5.99	6.71	6.46	6.46	7.12
Water comes from the nanofiltration membrane	3.57	6.71	6.46	6.29	6.71
Water comes from the reverse osmosis filter	0	3.31	3.19	3.15	3.28
Total removal race	100%	54.60%	59.00%	58.66%	53.93%

Table 8: The dynamic changes of TDS during the continuous operation period after alteration of the processor (g/L)

Running time	1h	2h	4h	6h
Original water after the coagulation	18.48	19.24	18.87	19.02
Filtered water comes from the precision instrument	17.83	17.69	18.13	18.56
Water comes from the nanofiltration membrane	12.76	12.94	13.26	14.21
Secondary water comes from the reverse osmosis filter	0.75	1.24	1.45	1.55
Total removal race	95.94%	93.56%	92.32%	91.85%

3. DISCUSSION

3.1 The Feasibility of Geothermal Tail-water Disposal

During the operation of test equipment, the processing flow was 5L/min, and the average power was 2.3 kWh, equivalent to every square water of the electricity consumption for 7.93 kWh/m^3, in 0.55 Yuan every degree terms, the treatment cost 4.36 Yuan. Considering that the diseconomies of the smaller equipment, set the diseconomy coefficient to 0.85. At the same time, the use of a concentrated water pressure recovery system can reduce the energy consumption of the reverse osmosis by 40%, so when the scale extends, the cost of water will reach to 2.23 Yuan/ton. When accounting for the fees for the necessary pharmacy, the total cost of processing one ton of water can restricted to about 3.27 Yuan / m^3. The price of the local tap water is 2.8 Yuan / m^3. According to the 30% water recovery rate, compared to water with an admission rate of 30%, if the processed fresh water meets standards, it can be sold for a total cost of 2.5 Yuan / m^3, with a net decrease in cost of 0.3 Yuan/m^3. This is obviously feasible and very useful, especially for the regions that have great shortages of freshwater resources.

Because Dongying City is a saline soil area and its shallow groundwater has high salinity, terrestrial plants such as fresh water crops, vegetables, trees, and horticulture seedlings cannot survive. With the nourishment of fresh water irrigation, the survival of at least urban greening seedlings can be guaranteed. Thus, the production of fresh water has great significance, and this pattern of geothermal tail-water treatment is feasible.

3.2 Existing Problems

3.2.1 Processing Problems of Tail-water of Tail-water (Concentrated Seawater)

Tail-water of tail-water is the concentrated saltwater that is a byproduct of processing.

3.2.2 Exhaustion of Geothermal Water Resource

According to C^{14} dating analysis, the majority of geothermal water that is characterized by a distant recharge source and long cycle period has an age of more than 10,000 years. Therefore, geothermal water is not a massive renewable resource, because it would be exhausted by excessive mining.

Natural geothermal springs in the eastern Shandong province have been victim to unproductive exploitation. Natural geothermal springs have disappeared because of well exploitation, even at lower depths (most of the wells are deeper than 30 m). Water temperature decreased, water quality deteriorated, and finally, the geothermal water resource disappeared altogether.

3.2.3 Potential Harmful Problem of Land Subsidence

According to the above discussion, if the exploitation of the geothermal water resource in the sandstone aquifers of Dongying formation led to a great deal of drainage, land subsidence would occur due to the poor consolidation of sandstone in this area. Even at the more than 1000 m depths, this phenomenon may occur. Similar phenomena have occurred in Beijing and Tianjin, and a great deal of attention should be paid to these occurrences.

4. SUGGESTIONS ON THE TREATMENT METHODS OF GEOTHERMAL TAIL-WATER

Despite these problems, the geothermal water treatment test was successful. That is, by processing the geothermal tail-water, freshwater that met the discharge standards for reuse in such areas as urban greening was produced, However, the handling of the concentrated saltwater byproduct is still a problem, and the geothermal water can only be used for heating in the winter season. Further, the high temperatures of the tail-water discharged will cause a waste of geothermal resources and the thermal pollution of the ground. Combined with the knowledge that acquainted, put some treatment methods of the following to the geothermal tail-water for reference.

4.1 The Models of the Comprehensive Development and Utilization about Geothermal Water

4.1.1 Stepwise Use of Geothermal Energy

The most complete use of geothermal energy can be achieved through cascade development. To make full use of low-temperature geothermal water resources, the energy can first be used for home heating ,then used for greenhouse heating, and finally for the heating of aquaculture fisheries.

4.1.2 The Comprehensive Utilization of Geothermal Tail-water

There are two comprehensive utilization methods for geothermal tail-water.

Mode 1: Heat extraction, desalination, salt making

Because the salt content of treated geothermal tail-water can reach 50g/L and above, it has the potential for development. The general process of salt production from treated geothermal tail-water is shown in Figure 7. Study and development of concentrated water utilization methods and new chemical extraction techniques has been shown to achieve low-pollution, low waste, low power, high efficiency, high-salinity results. Some high salinity areas could consider this type of secondary processing.

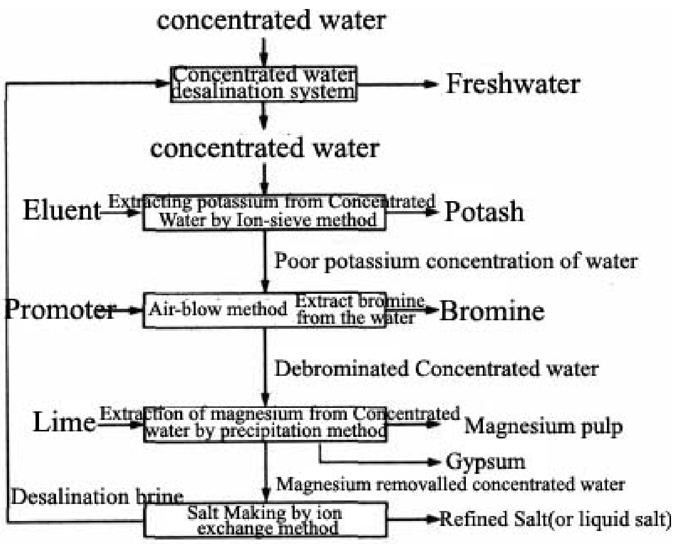

Figure 7: The comprehensive water utilization process based on the direct extraction from the concentrated brine

Mode 2: Heat extraction, desalination, recharge

Detail-water should be desalinated after heat extraction. Freshwater could be used for urban greening, and reclaimed water could be discharged or used for other purposes. Concentrated water could be recharged back into the reservoir, especially if the shallow groundwater has high salinity. Soil salinization is usually more serious, and therefore it could be suitable for concentrated water recharge. However, this does not solve the geothermal water resources exhaustion problem.

4.2 To Ensure the Sustainable Use of Geothermal Water Resources in the "Closed-Circuit Recirculation" Mode

Geothermal water resources are mainly located in deep groundwater aquifers, and recharge is limited or very small. In order to achieve sustainable use of resources and prevent water pollution of the environment, the "closed-circuit recirculation" model should be used. It is the end of treatment model of a closed circulatory system by the composition of by heat extraction, the use of the ground and tail-water recharge. In closed-circuit recirculation, two wells which tilt in different directions are generally drilled in the same reservoir: a production well and a reinjection well. The space between the two wells should be 800-1000m. This approach applies to the pore-type thermal energy storage and piston heat conduction type, for fracture-karst-type thermal energy storage, it is necessary to prevent Well-connected through the strong hydraulic fracture. The benefits of "the original soup" recharge are as follows: generally there is no chemical jam, the water reservoir will not be contaminated, it can effectively prevent the rapid decline of reservoir pressure, and it takes full advantage of the earth's crust to conduct heat so that the operation can continue.

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