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Hydrochemical Numerical Simulation of Fluid of Exploitation and Reinjection in Different Geothermal Reservoirs

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ABSTRACT:
Tianjin is one of the few cities in China which can do the geothermal reinjection. By the end of 2011, the volume of geothermal reinjection is 908.64x10^4 m^3. With the geothermal resources development strengthen, exploitation and reinjection systems of different layer in recent years also increase. Hydro chemical reaction of mixing different quality of geothermal fluid is so complicated that it is difficult to understand and forecast the trend of how the reinjection affect the fluid quality of injection well's reservoir without geochemical numerical simulation. In this paper, the time varying mix ratio was simulated for couples of well with different reservoir, using PHREEQC software. The simulation and its result provide a basis for rational development and protection of geothermal resources.

As an efficient way to exploit resources sustainably, geothermal fluid injection is becoming one of the important parts of recent geothermal management. The major composition of thermal fluid is from surrounding rocks (Zhang B.J., Shen Z.L., Qiao Z.B..2010), thus the segment difference of hydro chemical features can be used to investigate the properties of the fault age (Wu K.J., Ma C.M..2010). The research (sho Zhang Y.D., Gudni A.,Wei J.H.2006)was that the dynamic changing among hydro chemical field, temperature field and hydrodynamic force field in the geothermal reservoir is effectively relevant to each other. Because the water temperature of reinjection is lower than that of geothermal reservoir, and the concentration of the hydro chemical components may be different with the original fluid in geothermal reservoir layer, the reinjection, especially exploitation and reinjection between different reservoir, which may lead to the change of the hydro chemical field, as well as the hydrodynamic force field and thermal field. Since the chemical reaction among water of different qualities is complicated, it is very difficult to forecast the real situation by experimental means to simulate the mix of geothermal fluid of different water qualities, while the developed geochemical modeling method can solve this problem.

Chen(Chen Z.Y.,1998) used the geochemical program CHILLER to simulate the interaction between water and rock of multi component, which affect the features of reservoir during reinjection, and the result can help to understand the geochemical effect and provide suggestions to conduct the reinjection. Zheng(Zheng X.L., Guo J.Q. 1996) proposed a mixed model and got the mixing ratio of cold and hot water based on the observed data of oxygen isotope, chloridion concentration and the temperature of water sample. Bi (Bi E.P.. 1998) simulated the reinjection of low temperature geothermal field of Laugaland in Iceland and the results showed that there is no mineral sediment, i.e., quartz, except for the few calcite precipitation when reinjected with geothermal tail water, due to the chemical kinetics reasons. However, magnesium silicate sediment will be found in the mixing water when using underground water to reinject. Zhang (Zhang X.L., Liang X., Sun J..2007) found that the cold and hot water mixing ratio of Qicun geothermal field in Yizhou, Shanxi Province of China ranges from 1.0 to 3.2 by using PHREEQC. Those works are mainly focused on the calculation of the saturated coefficient of geothermal fluid in the same layer and the mixing ratio of cold and hot water, but the studies on time varying mixing ratio of different quality water is still insufficient for the limit of data.

In this paper, the mixing process of a pair of wells which exploiting and reinjecting between different reservoir named JN-05 and JN-05B in Tianjin will be simulated with different ratios using PHREEQC, and the simulated result will be compared with the historical water quality report. The temporal evolution of the mixing effect will be analyzed in order to predict the chemical reactions during reinjection. The result will provide a basis for the scientific exploitation and protection of geothermal resources from the prospective of hydro-geochemistry.

1. INTRODUCTION OF GEOTHERMAL WELLS

The pair wells of JN-05 and JN-05B are located at the north side of the agricultural science and technology park of southeast Tianjin. These two wells were constructed in 2002, and came into service after that. The wells are mainly used for the plant, cultivation and heating of the agricultural park. Geothermal resource diversified the agricultural production, and accelerates the local economy development.

JN-05 is a mesoproterozoic Wumishan reservoir geothermal well which is 3093.9 m deep. Lithology in geothermal reservoir is dolomite of Wumishan 3rd and 4th layer. The output water temperature is 88.1 ℃, and the exploitation rate is ranging from 80 m^3/h to 100 m^3/h. JN-05B is a geothermal well of Paleozoic Ordovician, 2024.4 m deep. Lithology in geothermal reservoir is limestone. The output water temperature is 62 ℃, and the exploitation rate is ranging from 60 m^3/h to 100 m3/h. As shown in Fig. 1, this pair of wells is located in the middle of Xiaohanzhuang Salient-Wanjiamatou geothermal field in the east part of Cangxian. Xiaohanzhuang Salient, distributed in the north-north-east (NEE) direction, is a broken massive denudation solitary which is lower in the south and higher in the north. Slope in the east and south part is steep, while in the north and west part is gently. The Cangdong Fracture, which is in the NNE direction, seriously affects the geothermal features of Xiaohanzhuang Salient. Moreover, Xiaoyingpan Fault and Xianshuigu Fault, which are in the direction of NE, also have some influence on the stratigraphic distribution and hydro thermal system of this area (Zhao S.M.et al,2010).

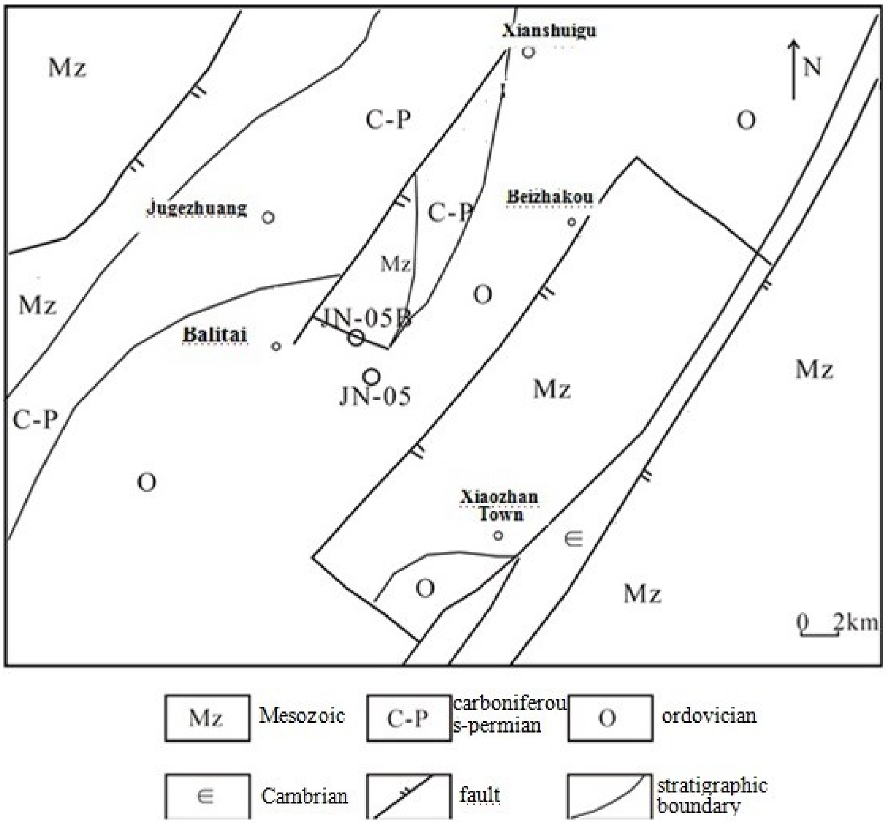

Figure 1 the location of geothermal wells: JN-05 and JN-05B

The exploitation and reinjection modes used in Tianjin area are usually as follows: one exploitation well and one reinjection well drilled in the same reservoir, two exploitation wells and a reinjection well, three exploitation wells and two reinjection wells and a exploitation well and a reinjection well drilled in different reservoirs, two exploitation wells and a reinjection well. Since the grout-ability in ordovician geothermal wells is very good, we use one exploitation well and one reinjection well operating mode in this pair of wells. JN-05 is used for exploitation and JN-05B is for reinjection, as shown in Fig. 2.

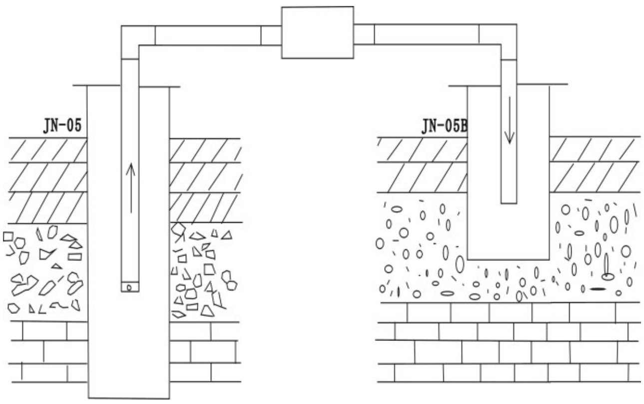

Figure 2 the schematic of the operating mode of JN-05 and JN-05B

2. INTRODUCTION OF PHREEQC

PHREEQC is a hydro-geochemical simulating software which was developed by United States Geological Survey (USGS). It is programmed using C language for the low temperature hydro-geochemical calculation. According to the input command from users, PHREEQC can chose equations for the chemical reactions and solve the equation set with modified Newton-raphson methods.

PHREEQC provides the users with four database. The input files are written by the users and the software will translate the commands for the model to simulate. The database can be also revised by using these input files for specific result. The standard output file is the result of the simulation of PHREEQC. The optional output file can be chosen by the users. In China, PHREEQC is commonly used for the analysis of chemical components.

3. MIXING SIMULATION USING PHREEQC

The component of fluid and the surrounding rocks in deep geothermal reservoir, where temperature and pressure are relatively high, is maintaining at a quasi-steady conditions without external influence. For example, the partial pressure of carbon dioxide in geothermal reservoir is usually $PCO_2=10^{-3}$ kpa. When exploiting water from geothermal reservoir, the pressure will decrease due to the mechanical oscillation of centrifugal pump. It will accelerate the evaporation of carbon dioxide, expressed as:

$$CaCO_3 + CO_2 - + H_2O Û \ Ca^{2+} + 2HCO_3^- \quad (1)$$

Eq. (1) indicates that carbonate is more likely to precipitate out as PCO2 decreases. When PCO2 increases, carbonate will transfer into soluble ion of Ca^{2+} and HCO_3^- . Therefore, the experimental results under indoor conditions cannot show the real situation under high temperature and high pressure conditions.

Table 1 lists the content data of major ions in the reinjection water (tail water in JN-05 after heat transfer) and the water in reinjection well of JN-05B. As shown, the quality of reinjection water and the exploitation well water are similar. Both of the two kinds of liquid are weak alkali water of $CL·HCO_3$-Na. Table 2 contains the major hydro-chemical contents of geothermal fluid in the well JN-05B from the year 2003 to 2010 after receiving reinjection from JN-05. Since the ion contents in the fluid of JN-05B is tending towards steady, it can be concluded that reinjection into different reservoir has little effect on the fluid of geothermal reservoir in the reinjection well.

The simulation in this paper is divided into 5 procedures: (1) Define the water quality in reinjection well based on the data of ion contents when JN-05B was built, with the consideration that the fluid will reach a balance point at LogPCO2=-3, where PCO2 is the partial pressure of carbon dioxide in geothermal reservoir. (2) Define the water quality in exploitation well base on the data of ion contents in reinjection water of JN-05 in the year of 2002. (3) Mixing the fluid in JN-05 and JN-05B according to the ratio of 0.1:1.0 to 1:1, and then calculating the change of major contents with different ratios. (4) The historical data of major components content in reinjection well, with the consideration of pressure balance: $LogPCO_2=-3$. (As shown in Table 3) (5) Using Q cluster analysis to compare the calculated results and the contents of major ions in reinjection well under balance conditions to obtain the time varying mixing ratios.

Table 1 Contents of major ions in JN-05 and JN-05B (Unit: mg/L)

Serial Number	Year	Temperature (℃)	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	SO_4^{2-}	Cl^-	TDS	Hydro-chemistry Type
JN-05	2002	32	7.50	498.6	44.1	27.3	7.1	503.4	259.7	432.5	1844.7	$Cl.HCO_3$-Na
JN-05B	2002	62	7.77	520.3	32.3	37.2	8	524.8	257	464.4	1905.8	$Cl.HCO_3$-Na

Table 2 Water quality in JN-05B after receiving reinjection

Serial Number	Year	Temperature (℃)	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	SO_4^{2-}	Cl^-	TDS
JN-05B	2003	35	8.23	523.6	32.3	39.6	7.5	525.2	262.6	462.8	1905.8
	2004	37	8.11	518.3	34.3	38.2	7.4	521.4	258.4	458.6	1883.7
	2005	39	8.04	516.8	38.6	37.8	7.4	520.8	259.8	459.4	1888.3
	2006	36	7.99	509.4	40.2	36.9	7.5	518.4	260.6	457.4	1892.6
	2007	38	8.21	501.6	42.1	30.8	7.4	513.3	257.4	453.5	1885.4
	2008	38	7.43	508.3	44	28.7	7.3	511.2	252	452.4	1878.4
	2009	39	8.17	501.3	44.8	27.1	7.1	508.5	256.2	444.8	1875.8
	2010	40	8.05	502.9	46.3	27.4	7.1	503.4	257	438.5	1869.6

Table 3 The content of major fluid components in JN-05B when balanced as LogPCO2=-3

Year	HCO_3^-	Ca^{2+}	Cl^-	K^+	Mg^{2+}	Na^+	SO_4^{2-}
2003	5.92E-03	6.02E-04	1.31E-02	8.19E-04	2.06E-04	2.23E-02	2.35E-03
2004	6.14E-03	5.98E-04	1.30E-02	8.69E-04	2.07E-04	2.21E-02	2.40E-03
2005	6.28E-03	6.01E-04	1.30E-02	8.78E-04	2.08E-04	2.21E-02	2.41E-03
2006	6.42E-03	5.96E-04	1.31E-02	9.26E-04	2.13E-04	2.22E-02	2.42E-03
2007	6.66E-03	5.12E-04	1.28E-02	9.53E-04	2.09E-04	2.15E-02	2.40E-03
2008	6.77E-03	4.86E-04	1.28E-02	9.78E-04	2.13E-04	2.18E-02	2.35E-03
2009	6.80E-03	4.60E-04	1.26E-02	1.07E-03	2.07E-04	2.15E-02	2.39E-03
2010	6.81E-03	4.71E-04	1.24E-02	1.07E-03	2.14E-04	2.16E-02	2.40E-03

4 RESULTS AND DISCUSSION

4.1 Q Cluster analysis

Table 4 shows the simulation result with different mixing ratio. It indicates that the contents of HCO_3^-、Ca^{2+} gradually increases with the mixing ratio when taking PCO_2 into account, while the contents of the other ions are stable, respectively. The correlation coefficient between simulation result and the measured data are shown in Table 5, using Q cluster analysis.

The cluster analysis result implies that the correlation coefficient is high during the first few years after the wells came into service. It is higher than 0.9000 in the four years from 2003 to 2006. The correlation coefficient between the measured data in 2003 and the simulation result with mixing ratio of 0.2:1 even reaches 0.9432, which indicates that the mixing ratio is strongly positive correlated to the time. As the time goes by, the correlation coefficient between the measured data (from 2007 to 2010) and the mixing ratio of 0.6:1 to 0.7:1 is stable between 0.9000 and 0.9200, while correlation coefficient is less than 0.9000 when compared with the mixing ratio of 0.8:1 to 1.0:1. This phenomenon agrees well with the real situation, for the movement of fluid in geothermal reservoir can affect the mixing chemical reactions in reinjection well, leading to a stable ion contents of mixing ratio less than 1.0:1.

Table 4 Simulation result of the content of major fluid component with different mixing ratios

Mixing Ratios	HCO_3^-	Ca^{2+}	Cl^-	K^+	Mg^{2+}	Na^+	SO_4^{2-}
0.1:1	5.89E-03	5.25E-04	1.30E-02	8.42E-04	2.00E-04	2.19E-02	2.35E-03
0.2:1	6.17E-03	5.35E-04	1.30E-02	8.65E-04	2.02E-04	2.19E-02	2.35E-03
0.3:1	6.38E-03	5.43E-04	1.29E-02	8.85E-04	2.05E-04	2.19E-02	2.36E-03
0.4:1	6.55E-03	5.49E-04	1.29E-02	9.01E-04	2.07E-04	2.19E-02	2.36E-03
0.5:1	6.70E-03	5.55E-04	1.28E-02	9.16E-04	2.08E-04	2.19E-02	2.36E-03
0.6:1	6.83E-03	5.59E-04	1.28E-02	9.28E-04	2.10E-04	2.19E-02	2.36E-03
0.7:1	6.95E-03	5.63E-04	1.28E-02	9.39E-04	2.11E-04	2.19E-02	2.37E-03
0.8:1	7.04E-03	5.67E-04	1.27E-02	9.49E-04	2.12E-04	2.19E-02	2.37E-03
0.9:1	7.13E-03	5.69E-04	1.27E-02	9.58E-04	2.13E-04	2.18E-02	2.37E-03
1.0:1	7.21E-03	5.72E-04	1.27E-02	9.66E-04	2.14E-04	2.18E-02	2.37E-03

Table 5 Correlation coefficient between measured data and calculated result with different mixing ratios

Mixing Ratios	2003	2004	2005	2006	2007	2008	2009	2010
0.1:1	0.9177	0.7965	0.7437	0.6865	0.5981	0.5789	04639	0.3911
0.2:1	0.9432	0.8833	0.8516	0.8497	0.6272	0.6710	0.4808	0.4513
0.3:1	0.8917	0.9066	0.8938	0.9057	0.7405	0.7878	0.5202	0.4889
0.4:1	0.8877	0.8916	0.9048	0.9151	0.7966	0.8536	0.6843	0.6965
0.5:1	0.8067	0.8690	0.9114	0.9106	0.8303	0.8869	0.7626	0.7728
0.6:1	0.7595	0.8419	0.8622	0.8972	0.8864	0.9053	0.8472	0.8800
0.7:1	0.7151	0.8184	0.8455	0.8839	0.9074	0.9011	0.9149	0.9078
0.8:1	0.6759	0.7938	0.8263	0.8678	0.8832	0.8669	0.8714	0.8943
0.9:1	0.6475	0.7728	0.8088	0.8530	0.8631	0.8354	0.8816	0.8545
1.0:1	0.6188	0.7549	0.7643	0.7701	0.7836	0.7914	0.7884	0.7946

4.2 Comparison of simulation result of ion component contents

It can be concluded from Fig. 3 that the contents of HCO_3^-、Ca^{2+}、Mg^{2+} are slightly increasing, while Cl^- is decreasing, when the balance of PCO_2 is assumed to exist. The simulation result with mixing ratios between 0.1:1 and 0.6:1 is in a good consistent with the measured water quality in JN-05B from 2003 to 206, while the simulation result with mixing ratio of 0.6:1 is closer to the measured data of 2007 to 2010, which agrees with the cluster analysis above. The contents of Na^+、SO_4^{2-} are stable, which is basically consistent with the simulation result.

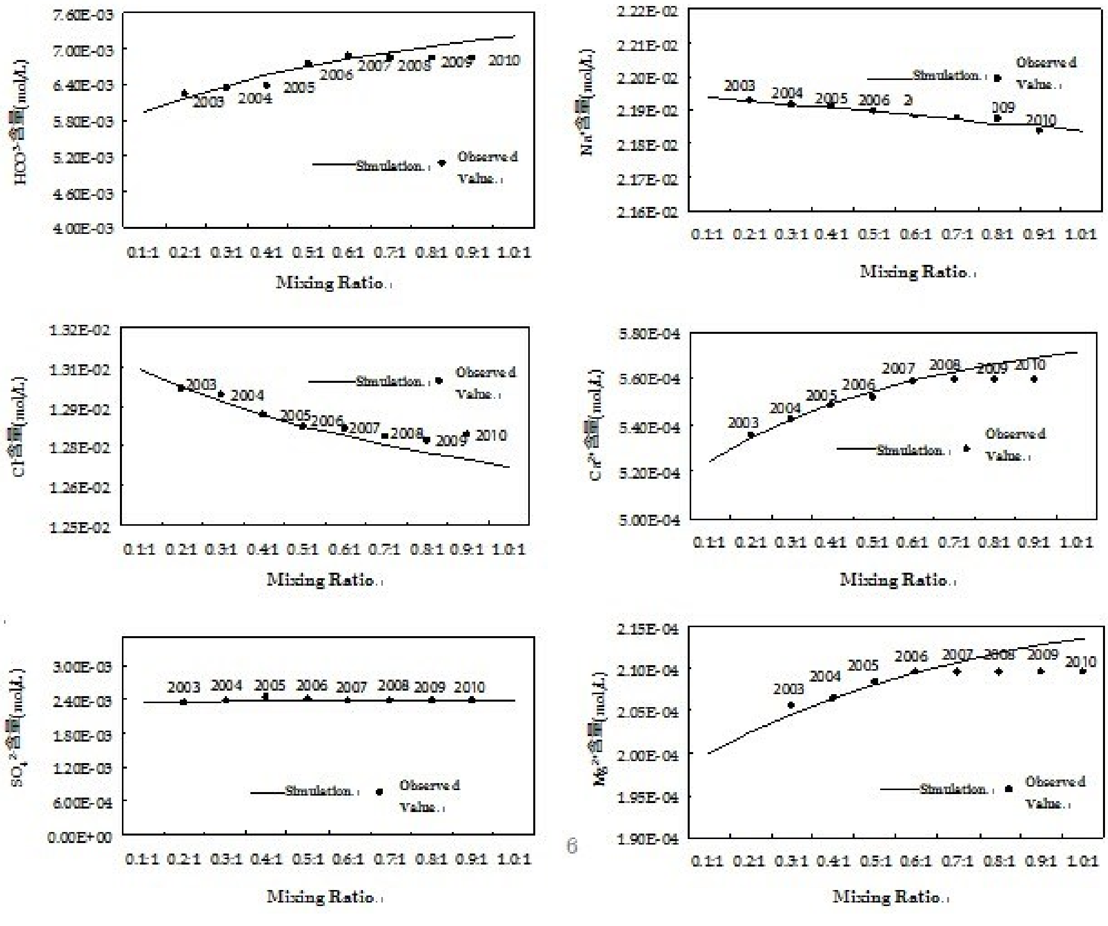

Figure 3 Fitting of the contents of major ion components in geothermal fluid

5. CONCLUSION

(1) The ion components in JN-05B are stable based on the measured water quality from 2003 to 2010. It indicates that the geothermal tail water reinjection in Wumishan exploited well has little influence on the fluid in geothermal reservoir.

(2) It is very important to measure the hydro-chemical data at the operating site. Some geothermal fluid parameters such as PCO_2 and redox potential are estimated by empirical values when using PHREEQC for simulation. The calculated result would be much more accurate if using the real parameters such as TDS、pH、PCO2 measured at the operating site.

(3) According to the simulation result, the mixing ratio of the reinjection water in JN-05 to the geothermal reservoir fluid in JN-05B is strongly positive correlated to time during the initial few years (2003 to 2007). As time increases, this ratio will come into a quasi-steady value between 0.6:1 and 0.7:1. It may be affected by the fluid movement in geothermal reservoir.

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