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Studies of the Reinjection Tests in Basement Geothermal Reservoir, Tianjin, China

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ABSTRACT

By the end of 2003, about 235 production wells(including 14 reinjection wells) have been drilled in Tianjin. The annual production rate was 24Mm^3 in 2003 and the reinjection rate was about 1.7Mm^3. The depth to the water level ranged from 22 to 70m and the draw-down rate was 6-9 m/year. The effect of reinjection in the WR45 doublet was analyzed. However, up to now, no temperature changes have been observed in surrounding geothermal production wells. The main side effect anticipated from reinjection is a cooling of the reservoir. Tracer tests are very important for understanding the mode of transport and flow-channel/fracture-space characteristics in doublet production/reinjection systems, and for estimation of the possible cooling that can result from injection.

1. INTRODUCTION

Tianjin is located in the northeast part of the Hua-Bei plane in NE-China, with the Yan Mountain to the north and Bohai Bay to the east. The total area of the region is about 11300 km^2. Most of the area is covered by Quaternary stratum. Base rock outcrops are limited to the mountain area of Ji county in the north[1].

In Tianjin, the main productive reservoirs are porous sandstone reservoirs (2 productive zones) and karst/fractured basement rock reservoirs (3 productive zones). The depth to the top of the karst/fractured base rock reservoir is over 950 m. Until now the maximum drilling depth is near 4000 m. The maximum discharge rate for a single well is more than 100 m^3/h, with wellhead temperatures ranging from 55 to –100°C. The water from this reservoir is mainly used for space heating, physical therapy, bathing, fish farming, etc. By the end of 2003, 235 geothermal production wells (including 14 reinjection wells) have been drilled in Tianjin. The annual production rate reached 24Mm^3 in 2003 and the reinjection was 1.7Mm^3. Currently the depth to the static water level varies between -35 and -90 m, with an annual draw-down rate of 6-9m[1].

In recent years, extensive research has been conducted in the areas of geothermal utilization technology, reinjection, reservoir engineering and digital system of geothermal monitoring/management. But some problems are still awaiting further investigation.

Since 1996, reinjection experiments have been conducted in the basement reservoir in Tianjin. Till now, there have been drilled 12 production/reinjection doublets, 10 of them located in Tianjin urban area. These doublet wells are essential for the protection and sustainable use of the geothermal resources in Tianjin. This paper describes the results of these reinjection experiments.

2. BASEMENT RESERVOIR REINJECTION

2.1 Geological Setting

The WR20 doublet was drilled in 1993, which is the first doublet drilled into the basement reservoir in Tianjin. The production well of this doublet was drilled into the Wumishan group of the Jixianian formation from the Proterozoic. Tthe reinjection well was finished in an Ordovician formation reservoir. Figure 1 shows a sketch of the design of the WR20 doublet (Wang Kun et al, 2001).

The WR45 doublet is the second production-reinjection doublet drilled into the basement reservoir. It was drilled in 1995. Figure 2 shows a sketch of the design of the WR45 doublet. Both of the production and reinjection wells were drilled into the Wumishan group of the Jixianian formation from the Proterozoic(Wang Kun et al, 2001).

2.2 Analysis of the WR45 Reinjection Tests

The main lithological units of the productive zone of the WR45 doublet are composed of dolomite and limestone. Karst-type fissures are well developed in the area of the doublet.

The first reinjection test was carried out with a high-pressure pump in Oct., 1996. Figure 3 shows some of the monitoring data collected during this test (Zeng Meixiang et al., 2002). After removing some abnormal data, caused by equipment problems, we found that the reinjection flow-rate was inversely proportional to the reinjection pressure during the test. When the pump pressure was 0.02 MPa, the reinjection rate was 100m^3/h. But the reinjection rate decreased to 86 m^3/h when the pump pressure was increased to 0.05 MPa. During the last stage, the pump pressure was 0.09Mpa and the reinjection rate settled at ~50m^3/h, more or less. This behavior can be explained by the following:

The WR45 doublet is located in the part of the Wumishan reservoir, where karst fissures are well developed. This is a double porosity porous-fractured medium. At the beginning of the reinjection test, flow along fissures dominates and the pump pressure had little effect on the reinjection rate. The reinjection water entered the aquifer quickly because of increased pressure gradient between reinjection and production well. As the reinjection continues, the effect of seepage into the porous medium started to increase. The velocity of the reinjection water in the reservoir became slower, and the flow-rate decreased. As a whole, the pump pressure increased and the injection rate decreased gradually as the reinjection test continued.

During the space-heating periods (Nov. – March) of 1999/2000 and 2000/2001, the WR45 doublet had been operated by gravity, without pumping. All the geothermal water extracted was reinjected into the reservoir directly after utilisation for heating. Because there are several geothermal wells around WR45 used for space heating simultaneously (Fig.4), the reservoir pressure decreased rapidly, and the water level in the reinjection well is now at about 30 m depth. However, up to now no temperature changes have been observed in the surrounding production well.

3. TRACER TEST IN THE BASEMENT RESERVIOR

To investigate the connections between the reinjection and production wells of the WR45 doublet, a tracer test was conducted in the winter of 1998-1999. We selected 10 kg of potassium iodide (KI) as the tracer. Meanwhile the chemical content of the water produced from the surrounding wells was monitored carefully. The resulting data are presented in Figure 5.

The monitoring data shows that the tracer concentration is almost constant in the production well, i.e. no noticeable recovery. On the other hand observation well GC45-2 shows some iodine recovery. This means that the hydro-geological connection between the production and reinjection well of doublet WR45 is indirect, but that there may be a direct (fast migration) channel between the reinjection well and other nearby geothermal production wells (such as production well GC45-1, which is about 2.5 km away from the reinjection well).

A mathematical model simulated the results from GC45-2 tries to understand the nature and structure of the fractures connecting GC45-2 and the reinjection well. Fig. 6 and Table 1 show the simulated recovery and model parameters, respectively. The simulation curve is composed of 4 pulses, corresponding to 4 flow channels/fractures. When the tracer was injected into the aquifer, it travelled rapidly along the most direct path, which had the smallest cross section. For this channel the tracer moved quickly to the production well and reached the maximum concentration in a very short time. If, on the other hand, the reinjected water diffuses into a large reservoir volume, only a small fraction of the tracer will be recovered and the time it takes it to reach peak value will be much longer. In the latter case, the thermal breakthrough time will not be a problem for the doublet system operation. Therefore, tracer tests are very important for understanding the mode of transport and flow-channel/fracture-space characteristics in doublet production/reinjection systems.

4. MATHEMATICAL MODELING OF DOUBLET SYSTEMS

The main side effect anticipated from reinjection is a cooling of the reservoir involved (Axelsson et al., 1995). Therefore, it is necessary to estimate the thermal breakthrough time for different injection-production well spacing, i.e. the time from initial injection until a significant cooling is observed in a producing well.

At present, the main reinjection mode in Tianjin is through doublet systems. Therefore, the TOUGH2 computer program was used to simulate the changes in the temperature field around a typical doublet system in the Wumishan aquifer for ten years into the future. Another doublet system WR82/83 is considered here with the distance of 4 m at wellhead and 980 m at the bottom. Taking the heat exchange between the reservoir and other strata at the top and bottom, a multi-aquifers model is set up to predict the temperature changes in the reservoir during reinjection. Figure 7 shows the simulation results. It appears that locating reinjection wells at a distance of about 100 m from production well should not cause a thermal break-through in less than 10 years.

It should be pointed out that reinjection is only carried out in wintertime in this case. The reinjected water will extract more thermal energy from the rock matrix when geothermal wells are shut down in summer, resulting in slower cooling rates. However, the result is highly uncertain because the flow channel dimensions are unknown. So, tracer tests are recommended in future research.

5. SUMMARY

The main conclusions and recommendations of this work may be summarized as follows:

- The main side effect anticipated from reinjection is the cooling of the reservoir involved. Also, the thermal breakthrough time depends on the geological structure of the reservoir. If the reinjection water diffuses into a large reservoir volume, the thermal breakthrough will not be a problem in doublet systems. But tracer tests are very important for understanding the mode of transport and flow-channel/fracture-space characteristics in doublet production/reinjection systems.

- The reinjected water will extract more thermal energy from the rock matrix when geothermal wells are shut down in summer, resulting in slower cooling rates. However, the result is highly uncertain because the flow channel dimensions are unknown. So a tracer test must be conducted to study the flow paths between injection and production wells, and the estimate of the possible cooling that results from the injection.

- Long-term monitoring of the Tianjin geothermal field must be further improved and equipped, so that any changes caused by reinjection will be observed as soon as possible.

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Table 1: Calculated parameters of the tracer test

	Cross section area Aφ	Dispersivity α_L	mass recovered (%)
Fissure 1	1.50 m^2	356 m	20
Fissure 2	15.7	142	39
Fissure 3	29.5	10.1	10
Fissure 4	54.7	162	22

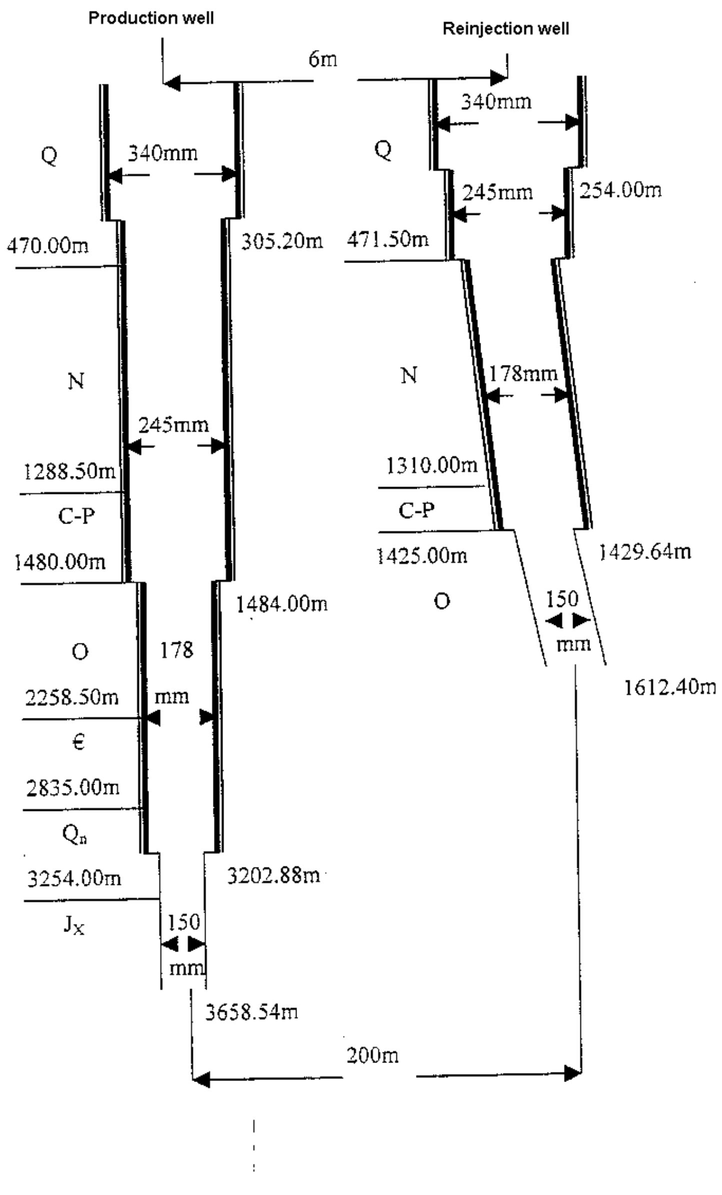

Figure 1:The design of the WR20 doublet system

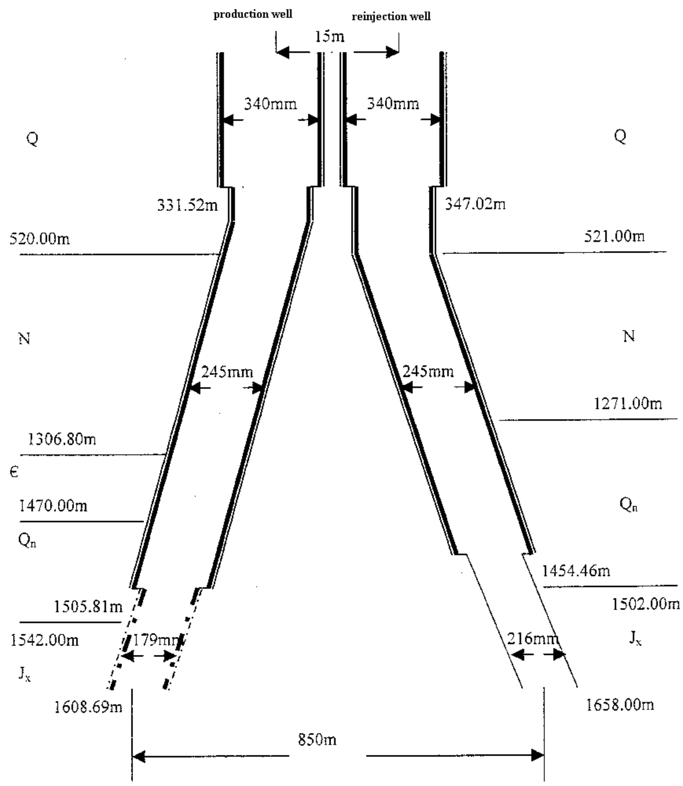

Figure2: The design of the WR45 doublet system

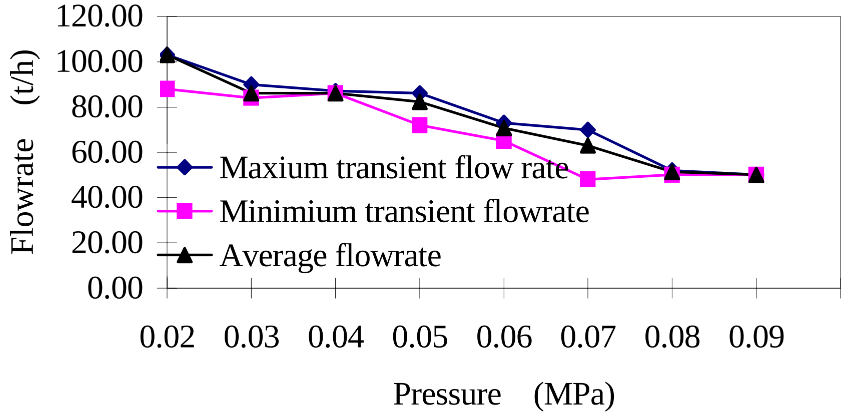

Figure 3. Relationship between the reinjection pressure and the flow rate for doublet WR45 in Oct. 1996.

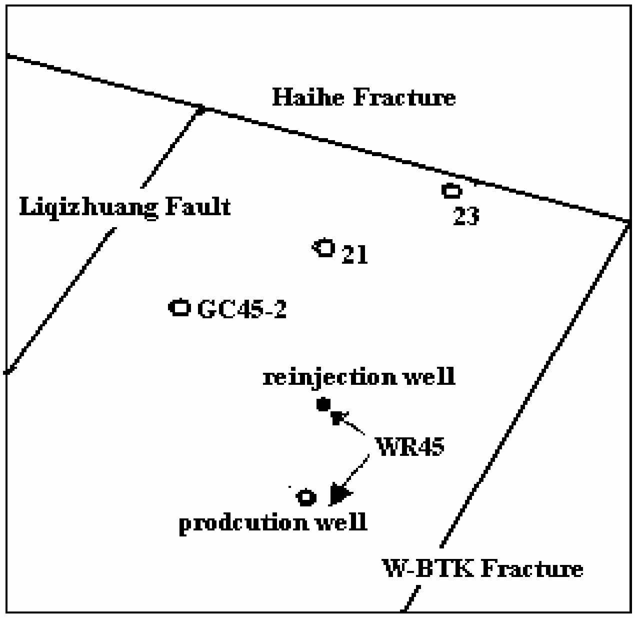

Figure 4: Location of the doublet WR45 system

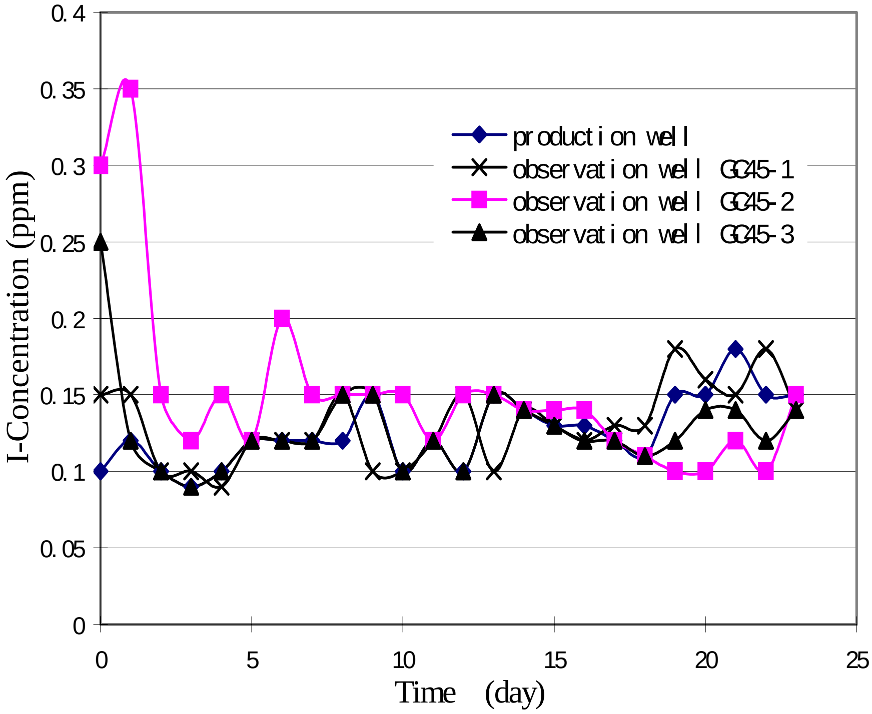

Figure 5:The recovery curves of the tracer concentration in the observation wells around WR45.

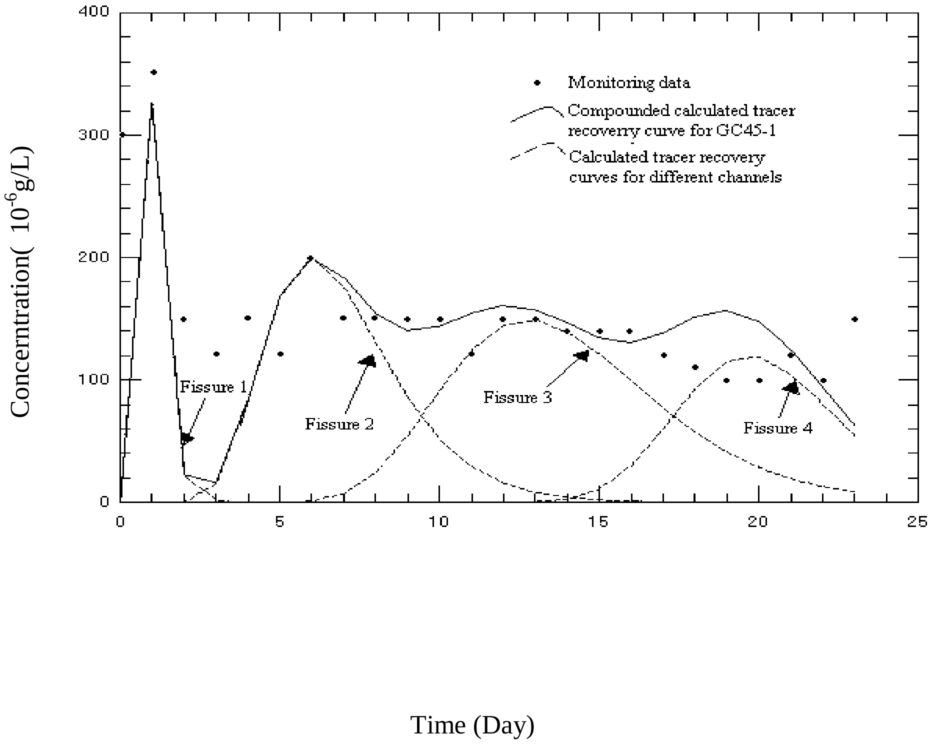

Figure 6: Calculated tracer recovery curves for observation well GC45-1 Each dashed line represents different channel connecting the reinjection and production wells.

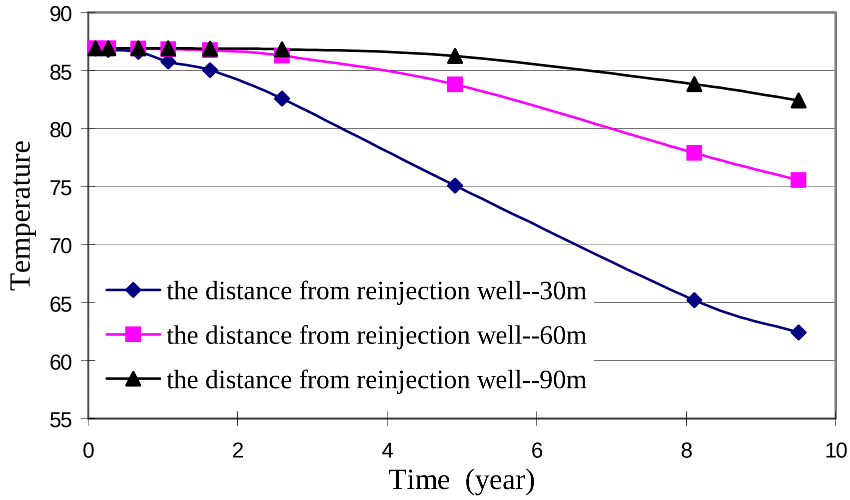

Figure 7: The duration curve of the temperature at different distances from reinjection well in the reservoir