Isotope Behavior During Circulation Test at the Hijiori EGS Site, Japan

Norio Yanagisawa

Institute for Geo-Resources and Environment, AIST, Tsukuba, Ibaraki, Japan

n-yanagisawa@aist.go.jp

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ABSTRACT

A long-term circulation test was conducted between November 2000 and August 2002 at the hot dry rock (HDR) test site in Hijiori, Japan. During this test, hydrogen and oxygen isotope composition of production wells (HDR-2 and HDR-3), injection well, river water and hot springs were analyzed.

The isotope ratio of the river water and hot springs plot along the meteoric water line. The isotope ratio of hydrogen and oxygen ratio of HDR-2 increased with circulation and reached value of -45‰ of δD and -4.6‰ of δ18O at end of May 2001, respectively. However δD and δ18O rapidly decreased to -54.4‰ and -8.6‰ respectively from May to June and came close to meteoric line. The isotope ratio of HDR-3 plot at higher δ18O than that of HDR-2 and the change of the isotope ratio of HDR-3 is similar as that of HDR-2.

The change of δ18O value of HDR-2 is corresponds with Cl concentration change during the circulation progress.

Introduction

Oxygen and hydrogen isotope data provide information about the origin and evolution of geothermal waters.

According to Hot Dry Rock (HDR) system or Enhanced Geothermal System (EGS), stable isotope data show the water source in reservoir or injected water. Recently, several EGS project are carried out in USA, Australia and Europe. In Japan, two HDR/EGS project carried out at Hijiori and Ogachi until 2002. After 2002 the research and development of EGS was suspended. However, after nuclear power plant accident at 2011, we need new EGS project and the review of previous project at Hijiori. At Hijiori HDR/EGS site, the long term circulation test was carried out from 2000 to 2002. The tracer response changed with circulation (Yanagisawa et al., 2002, 2003) and calcium carbonate and anhydrite scale precipitated in circulation system (Yanagisawa et al., 2008). This shows the geochemical condition change in Hijiori system.

This paper shows the results of stable isotope change of production and injection well at Hijiori test site and discuss the reservoir condition during circulation test.

Geology of Hijiori Test Site

Hijiori is located in the Yamagata Prefecture, in the northern part of Honshu Island, Japan (Fig. 1). The topography of the area is dominated by an approximately 1.5-2 km diameter volcanic caldera. The test site is at the southern rim of the Hijiori caldera where four boreholes (HDR-1, HDR-2a, HDR-3 and SKG-2) were drilled with true vertical depths ranging between 1800 and 2300 m. All these wells penetrated the basement rocks, which consist

Figure 1. Location of the Hijiori HDR test site in Japan and of the wells in the field (modified after Kuriyagawa and Tenma, 1999). Topographic contours are shown in m above sea level.
of Cretaceous granodiorite that has been intensively altered by hydrothermal processes. Based on the geological data gathered from the deep Hijiori wells, the granodiorite basement is unconformably overlain by the sedimentary rock at depth of 1500 m (Kitani et al., 1998; Tezuka and Niitsuma, 2001).

**Hijiori EGS Project**

The Hijiori project began in 1985 and ended in 2002. The development of the Hijiori HDR project was reviewed by Matsunaga et al. (2005). Several fluid injection/circulation tests have been carried out at the site. Water from the Nigamizu River was pumped into a holding pond (Fig. 2) and then injected into the fractured granodiorite. Eventually the heated water was extracted and re-injected. Two reservoirs were created. One of reservoir is the upper reservoir at about 1800 m depth. The other is the lower reservoir at about 2200 m depth. In 1991, a three-month circulation test was carried out to characterize fluid flow in the upper reservoir at Hijiori, at about 1800 m depth and with temperatures up to 250°C. After additional deepening drilling at HDR-2 and HDR-3, short-term (one-month) circulation tests and reservoir studies were carried out in 1995 and 1996 (Hyodo et al., 1996; Matsunaga et al., 1996; Miyairi and Sorimachi, 1996; Tenma et al., 1996).

From November 2000 to August 2002, a long-term circulation test (LTCT) was conducted. Pressure-Temperature-Spinner (PTS) logs, geochemical studies, Acoustic Emission (AE) and micro-earthquake monitoring and tracer tests were conducted (Oikawa et al., 2001; Kawasaki et al., 2002; Matsunaga et al., 2002; Tenma et al., 2002; Yanagisawa et al., 2002). The fluid circulation system is shown schematically in Fig. 2. A multi-stage centrifugal pump (ESP TJ9000) was used to inject fluid into the HDR reservoir at a constant rate; i.e. the total injection rate was 16.66 kg/s throughout the entire LTCT.

**Sampling and Analysis**

Table 1 shows the date of sampling for stable isotopes at the production (HDR-2 and HDR-3) and injection well (HDR-1). Sampling was initiated one week after starting circulation. After that, samples were collected near the date of tracer injection to compare the tracer and isotope responses. Two river water and five hot spring sample were collected near the test site (Figure 3). Fluids were sampled in 250ml plastic bottles. Analysis of hydrogen and oxygen isotopes were carried out using a Micromass OPTIMA isotope ratio mass spectrometer.

**Results**

Table 2 shows the results of the hydrogen and oxygen isotope analysis, which are plotted in figure 4. The isotope ratio of the river water plots on the meteoric line. This line is mean value for northeastern Japan. The isotope data for the five hot spring fluids plot near the meteoric line.
The isotopic compositions of fluid from HDR-2 changed as shown in figure 4. In early stages of the circulation the isotopic composition of HDR-2 lies near the meteoric line. With circulation, the isotope ratio of hydrogen and oxygen increased to -45‰ and -4.6‰ respectively by the end of May. The δD and δ18O decreased to -54.4‰ and -8.6‰ respectively between May and June, the values close to the meteoric line. δD increased from June to August and the data point came close to meteoric line and initial value.

The isotope ratios of HDR-3 are higher δ18O than that of HDR-2. The initial isotope ratio of hydrogen and oxygen are -52.3‰ and -5.5‰ respectively. With circulation, the δD and δ18O increased to -46.9‰ and -3.8‰ by the end of May and decreased to -48.6‰ and -4.3‰ by the end of June respectively.

The isotope ratio of injection fluid plots between that of production fluids and river water because the injection fluid is the mixture of production fluid and river water. The isotope ratio of injection depends on that of production well.

### Discussion

During the circulation test, several reservoir and geochemical change were observed at HDR-2 between May and June 2001. The wellhead temperature of HDR-2 rapidly decreased from 160 to 110 degree C, in the well temperature decreased, and tracer response from injection well became quicker (Yanagisawa et al., 2002). The concentration of SiO2 decreased, Ca and SO4 increased and calcium carbonate scaling occurred in the pipeline (Yanagisawa et al., 2008). Figure 5 shows Cl concentrations from 28 November 2000 to 21 September 2001. After several days of circulation, Cl concentration reached 3000mg/l at HDR-2 and HDR-3 and 1500 mg/l at the injection well. After May, Cl concentrations decreased and reached 250mg/l at HDR-2.

The value of hydrogen and oxygen isotope rations rapidly decreased at HDR-2 from May to June. In HDR-3, the δ18O value decreased with decreasing Cl concentrations. Figure 6 shows the relationship between δ18O value and Cl concentration of the sampled waters. The δ18O is about -10.5‰ and a low Cl concentration, values of HDR-3 are about -4‰ with about 5,000 mg/l, respectively.

These change of geochemical suggest to reservoir condition including fluid flow change. From the result of change of temperature and tracer response, the flow regime in the upper and lower reservoir was estimated as Figure 7 (Yanagisawa et al., 2002). Until May 2001, injection fluid reached to lower reservoir and mixed with high temperature fluid in lower reservoir. The mixed fluid reached the bottom of the production well and flow up. During flow up, the fluid mixed with lower reservoir fluid. The hot fluid

### Table 2. Hydrogen and oxygen stable isotope ratio at Hijiori test site.

<table>
<thead>
<tr>
<th>Sampling Point</th>
<th>Date</th>
<th>δD</th>
<th>δ18O</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDR-2</td>
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<td>-8.8</td>
</tr>
<tr>
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<td>-6.4</td>
</tr>
<tr>
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<td>-45.0</td>
<td>-4.6</td>
</tr>
<tr>
<td>HDR-2</td>
<td>6/29/2001</td>
<td>-54.4</td>
<td>-8.6</td>
</tr>
<tr>
<td>HDR-2</td>
<td>8/17/2001</td>
<td>-50.0</td>
<td>-8.8</td>
</tr>
<tr>
<td>HDR-2</td>
<td>12/1/2000</td>
<td>-52.3</td>
<td>-5.5</td>
</tr>
<tr>
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</tr>
<tr>
<td>HDR-3</td>
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<td>-4.3</td>
</tr>
<tr>
<td>HDR-3</td>
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<tr>
<td>Injection</td>
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<td>-8.7</td>
</tr>
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<td>-8.8</td>
</tr>
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<td>-10.1</td>
</tr>
<tr>
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<td>-10.2</td>
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<td>-9.6</td>
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<td>Hot spring #5</td>
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<td>-53.2</td>
<td>-10.2</td>
</tr>
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</table>

### Figure 4. δD-δ18O diagram of the production wells, HDR-2 (closed circle), HDR-3 (closed square), injection well (closed triangle), river water (open square) and hot springs (open circle). The solid line is the local meteoric water line. The number shows the sampling month from November 2000 to August 2001.

### Figure 5. Cl concentration during circulation from 28 November 2000 to 21 September 2001.
in reservoir has high Cl concentration and high δ¹⁸O value, the production fluid has higher Cl and higher δ¹⁸O value. However with circulation progress, the injection fluid dissolve anhydrite in fracture of lower reservoir, the flow path from injection well to HDR-2 became wider and the reservoir temperature decreased. Then, at June of 2001, the pressure in the wellbore of HDR-2 increased and fluid started to flow into the upper reservoir at HDR-2. Because of this fluid inflow into the shallower reservoir, the reservoir pressure increased, as was clearly detected by monitoring well SKG-2 (Tenma et al., 2002). After this flow change, the high temperature, Cl concentration, δ¹⁸O value fluid did not flow to HDR-2, the wellhead and in-well temperature of HDR-2 decrease and Cl concentration and δ¹⁸O value decreased and close to meteoric line including river fluid.

**Conclusion**

A long-term circulation test was carried out from 25 November 2000 to 31 August 2002 at the Hijiori test site. The hydrogen and oxygen stable isotope ratio was measured in sampled from the production and injection wells, hot springs and river waters. The results are follows;

1. The isotope ratio of the river water and hot springs plot along the meteoric water line with mean value for northeastern Japan.

2. The isotope ratio of hydrogen and oxygen ratio of HDR-2 increased with circulation and reached value of -45‰ of δD and -4.6‰ of δ¹⁸O at end of May 2001 and decreased to -54.4‰ and -8.6‰ at end of June, respectively. The isotope ratio of HDR-3 plot at higher δ¹⁸O than that of HDR-2.

3. The change of δ¹⁸O value is corresponds with Cl concentration change during circulation.

**References**


