

## **TRACER MONITORING BY A FIBER-OPTIC FLUOROMETER DURING A LONG-TERM CIRCULATION TEST AT THE HIJIORI HDR SITE**

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### **ABSTRACT**

A long-term circulation test has been started on 25 November 2000 at the Hijiori hot dry rock (HDR) test site. At the beginning stage of the test, two tracer experiments were conducted by NIRE to evaluate flow regime in a deep reservoir at a depth of 2,200 m and Japan Petroleum Exploration Co to validate the effectiveness of two-phase tracers. During the experiments, production fluids were continuously monitored by a fiber-optic fluoremeter to obtain real time data of fluorescein tracer concentration. We succeeded to obtain a good response curve at the second attempt after a minor modification of a flow cell. Result of two tracer experiments suggests that the volume of flow path between an injection well HDR-1 and a production well HDR-2 rapidly increased during the beginning stage of the circulation test.

### **INTRODUCTION**

A tracer test is an important tool in determining flow regimes in a geothermal reservoir. In HDR systems, tracer experiments have been used to estimate reservoir volumes and also its changes with circulation conditions (Robinson et al., 1987; Matsunaga et al., 1996). Since spatial distribution of flow in an HDR reservoir influences the efficiency of heat extraction, tracer response in production fluid is important information on estimating the volume of the reservoir and then the lifetime of the HDR reservoir.

At the Hijiori HDR reservoir, several connections are detected between an injection well HDR-1 and two production wells, HDR-2 and HDR-3 by Pressure-Temperature-Spinner (PTS) surveys (Miyairi and Sorimachi, 1996). Fracture volume in each connection is quite small compared with wellbore volume of HDR-2 and HDR-3 and tracer injected usually comes out within few days after the injection. Hence frequent sampling is required to obtain a good

response curve of tracer. We installed an automatic fluid sampler by which we can collect fluid samples at every 15 minutes at a site. However the breakthrough time of tracer tend to be changed by operational conditions such as injection flow rate and pressures at the production wells. Hence we still need to collect many fluid samples without real-time information of tracer return. To eliminate troublesome work of sampling at the site, we apply the fiber-optic fluoremeter to continuously detect fluorescein tracer during a long term-circulation test for two years.

### **LONG-TERM CIRCULATION TEST**

After the success of a three-month circulation test of 1991 in a shallow reservoir, New Energy and Industrial Technology Development Organization has progressed their R&D project to develop a deeper and hotter region (2,200 m depth and temperatures up to 270 °C). A deep reservoir was successfully created by a hydraulic fracturing from HDR-1 and deepening the two production wells HDR-2 and HDR-3 during three years after the three-month circulation test. In 1995 and 1996, short-term circulation tests were carried out in the deep reservoir. PTS surveys, well tests with multi-flow rates, and tracer experiments during the tests revealed the very complex flow regime and the severe interaction of the shallow and deep reservoirs (Hyodo et al., 1996; Matsunaga and Tao, 1998; Miyairi and Sorimachi, 1996; Tenma et al., 1996, 1999).

For the long-term circulation test of two years, an injection pump, surface facility, and a new micro-seismic monitoring system were prepared between 1997 and 1999. The circulation test has been started on 25 November.

Schematic figure of a fluid circulation system at the Hijiori HDR site is shown in Figure 1. A multistage centrifugal pump of ESP TJ9000 is newly installed and used to injection. According to keep surface pressure below 10 MPa, injection was started at relatively low flow rate injection. Constant injection

at a scheduled flow rate of 16kg/s was attained on 4 December. Recovery rate of injection fluid from HDR-2a and HDR-3 was around 60 % and production temperature of both wells reached to around 170°C at that time.

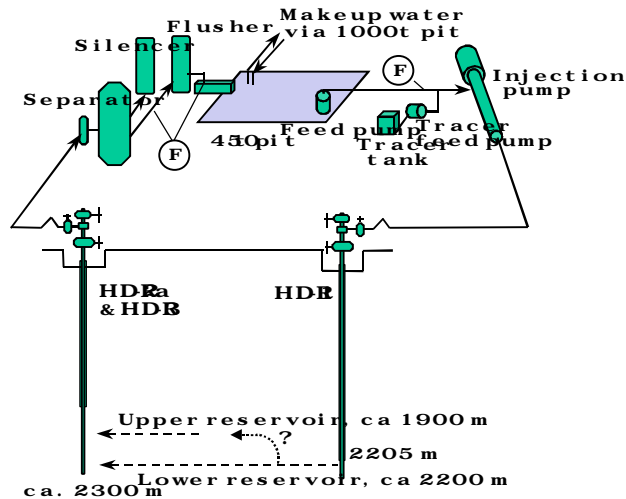


Figure 1. Schematic diagram of a circulation system at the Hijiori test site. Marks of (F) indicate sampling points of injection and production fluids.

## TRACER EXPERIMENT

As mentioned above, the tracer experiments were conducted two times in last December at the beginning stage of the circulation test. First tracer experiment was initiated on 6 December, just after the production from HDR-2a and HDR-3 became stable. The experiment was carried out to confirm an initial flow condition in the reservoir. In the experiment, potassium iodine, potassium bromide, and fluorescein were used. Around 14 kg each of potassium salts and 230 g of sodium fluorescein (Uranine) were dissolved in circulation fluid at a 1 m<sup>3</sup> tank. Tracer solution was fed into a main suction line to the injection pump by a feed pump as shown in Figure 1. About 0.7 m<sup>3</sup> of tracer fluid was injected over a period of about 8 minutes. In the second experiment, 172 g of Fluorescein with 4 kg each of R-134a and R-23 gas tracers was injected by JAPEx Co. on 18 December over a period of 10 minutes.

Produced fluid from HDR-2a and HDR-3 was collected using an auto sampler at sampling lines branched from hot fluid lines after steam separators. Fluid sample was collected in a 250 ml bottle at every time scheduled. Fluids were filtered through a 0.45 μm membrane and then kept in plastic bottles. Electrical conductivity and pH were determined on site. HCO<sub>3</sub> was analyzed in the chemistry laboratory

at NIRE by titration with H<sub>2</sub>SO<sub>4</sub>. Tracer and major dissolved species will also be analyzed by ion chromatography (Cl, SO<sub>4</sub>, Br, I, Na, K, Ca), ICP-ES (Si, Na, K, Ca, Mg, I), and fluorospectrometry (Fluorescein).

At the site, a flow-through cell with a fiber optic sensor was installed in the outlet line of the HDR-2a sampler and fluorescent was continuously monitored by a Gotschy Optotechnik LLF-M portable fluorometer (Benischke and Leitner, 1992). Simultaneous multiple channel analyses with a detection limit of 0.1 parts per billion of Fluorescein could be achieved using the LLF-M fluorometer with plastic optical fibers. Schematic diagram of the monitoring system is shown in Figure 2.

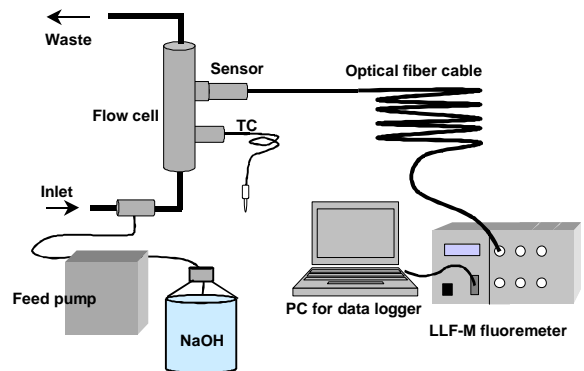


Figure 2. Measurement system of fluid fluorescent. At the second experiment, sodium hydroxide fluid was injected for adjusting pH.

At the first experiment, we used a modified sensor head made of silica for high temperature measurement. However high attenuating effect at a connector between the silica sensor head and a plastic cable restricted a high resolution of measurement. We failed to obtain fluorescent signal at the first experiment. Hence, at the second experiment, we changed a sampling place of HDR-2a fluid and also cooled fluid for using a plastic fiber sensor and cable. Using a feed pump, fluid was introduced into the flow-through cell by a constant flow rate of 1 l/minute. 0.1 mol/l of sodium hydroxide fluid was also continuously fed by a flow rate of 3 ml/minute to fluid for adjusting pH and stabilizing fluorescent intensity. Fluorescent intensity was obtained every minute by the LLF-M spectrometer. Seventeen samples were collected in 250 ml bottles at an outlet of the flow cell. Fluorescein concentrations of the fluid samples were analyzed at NIRE to calibrate the measurement of the LLF-M fluorometer. As shown in Figure 3, the intensity and concentration of fluorescein clearly showed a linear correlation.

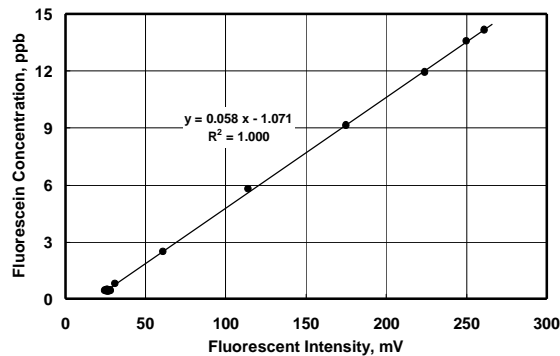


Figure 3. Calibration curve for obtaining fluorescein concentration at the second tracer experiment.

## RESULTS OF EXPERIMENT

Figure 4 shows the return curve of fluorescein in HDR-2a for the second tracer experiment.

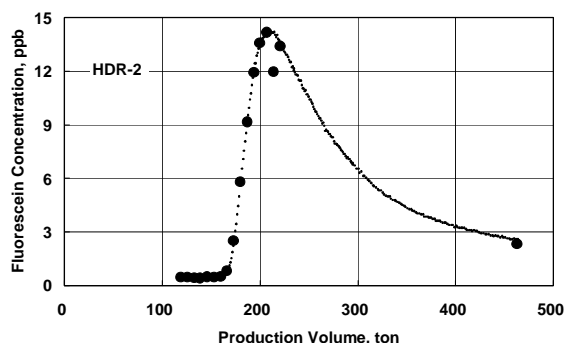


Figure 4. Return curve of fluorescein tracer at HDR-2a. Solid circles are analytical results of the fluid samples. Each dot indicates the concentration calculated from the measurement of the LLF fluorometer.

From Figure 4, if we assume that density of fluid was one  $\text{ton/m}^3$ , breakthrough and modal volumes are obtained as  $168 \text{ m}^3$  and  $208 \text{ m}^3$ , respectively. Since wellbore volume of HDR-2a is roughly  $79 \text{ m}^3$ , an apparent volume of the main flow path from HDR-1 to HDR-2a can be estimated as  $130 \text{ m}^3$ . However there is an inlet flow from the shallow reservoir, we need to have other data, such as PTS logs, to obtain the true volume of the main flow.

Figure 5 shows a comparison of three response curves for the first and second tracer experiments in the long-term circulation test and the fourth tracer experiment at the one-month circulation test in 1996 (Matsunaga and Tao, 1998). By comparison of two response curves for the first experiment in 2000 and the fourth experiment in 1996, the modal volume is almost same in both curves but the width at a half

height of the response curve becomes large in the former curve. Hence we may conclude that much change did not occur in the main flow path but closure might occur in the outer part in the fracture between HDR-1 and HDR-2a.

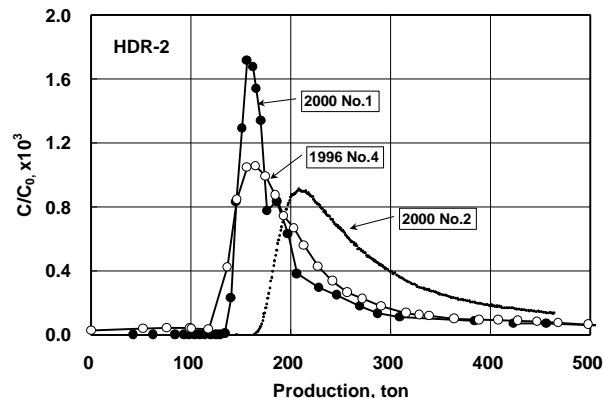


Figure 5. Comparison of three response curves of tracer experiments in 1996 and 2000 circulation tests.

Difference of two response curves of the first and second tracer experiments in 2000 indicates that temporal variations in the flow distribution occur in the region between HDR-1 and HDR-2a.

Figure 5 also shows the effectiveness of the continuous tracer measurement on site. Although a duplicated peak is recognized after the main peak in the response curve of the first tracer experiment in 2000, there is still the uncertainty of sampling and analysis as there are a few data points. If we applied the LLF-M measurement, as shown in the response curve in the second tracer experiment, we could easily recognize and distinguish peaks.

## SUMMARY

A long-term circulation test has been initiated on 25 November 2000 at the Hijiori HDR test site. At the beginning stage of the test, two tracer experiments were conducted by NIRE and JAPEx Co. In the second experiment, the fiber-optic fluorometer was successfully applied to monitor fluorescein in HDR-2a production fluid. Result of two tracer experiments indicates that the volume of flow path between HDR-1 and HDR-2 rapidly increased during the beginning stage of the circulation test. The quantitative analysis of the tracer experiments is restricted by the complexity of the flow regime in the multi-well and multi-fracture system. PTS logs could be useful data to analyze the flow regime. *In-situ* measurement of fluorescent in boreholes will also be a promising method for determining the flow regime in the HDR reservoir system.

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