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RESERVOIR MONITORING BY TRACER TESTING DURING A LONG TERM CIRCULATION TEST AT THE HIJIORI HDR SITE

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ABSTRACT

A long-term circulation test has been conducted since 27 November 2000 at a hot dry rock (HDR) test site in Hijiori, Japan. During the test we carried out tracer test every two or three months for monitoring flow regime in the reservoir. Tracer reagents among potassium salts, sodium fluorescein, and naphthalene sulfonates were dissolved in 1 m^3 of water and pumped in a deep reservoir at a depth of 2,200 m. Fluids from two production wells HDR-2a and HDR-3 were sampled and analyzed to obtain tracer response curves. A fiber-optic fluoremeter was also applied to obtain real time data of fluorescein concentration. Comparison of each tracer response curve suggests that the flow regime in the reservoir was severely affected by anhydrite precipitation in the production wells and also temperature draw down in the reservoir.

INTRODUCTION

A long-term circulation test (LTCT) has been conducted since 27 November 2000 at a hot dry rock (HDR) test site in Hijiori, Japan. Purpose of LTCT is evaluation of heat extraction from a multi-well and multi-fracture reservoir at there. During the test New Energy and Industrial Technology Development Organization (NEOD) have carried out pressure-temperature-flow (PTS) logging, geochemical monitoring of circulation fluid, and microseismic monitoring to characterize the reservoir. Beside these logging and monitoring, since tracer response in production fluid is important information on estimating the volume of the reservoir and then the lifetime of the HDR reservoir, we have conducted tracer tests for determining flow and its changes in the reservoir.

LONG-TERM CIRCULATION TEST

Outline of the Hijiori test site and recent progress of the LTCT are already described by Oikawa et al. (2001) and Kawasaki et al. (2002), hence we brief a circulation system and then explain flow data because these data are very important to evaluate tracer tests.

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 used to inject fluid at a flow rate of 16kg/s. In the first stage of the LTCT from 27 November 2001 to 15 November 2002, fluid was injected to a lower reservoir through a well HDR-1. Flow rate since the start of the first stage is shown in Figure 2. After set up an injection line to SKG-2, the second stage of the LTCT was started on 23 December 2001. Fluid has been injected into an upper reservoir through SKG-2 and the lower reservoir through HDR-1 in the stage. Injection flow rate to both SKG-2 and HDR-1 are kept constant at around 8.3 kg/s. HDR-2a and HDR-3 have been used for production wells in all stages. Temperatures of productions and injection in the first stage are shown in Figure 3. It should be noted that temperature at HDR-2a decreased rapidly from 150 ºC on 11 June to 110 ºC on 13 July.

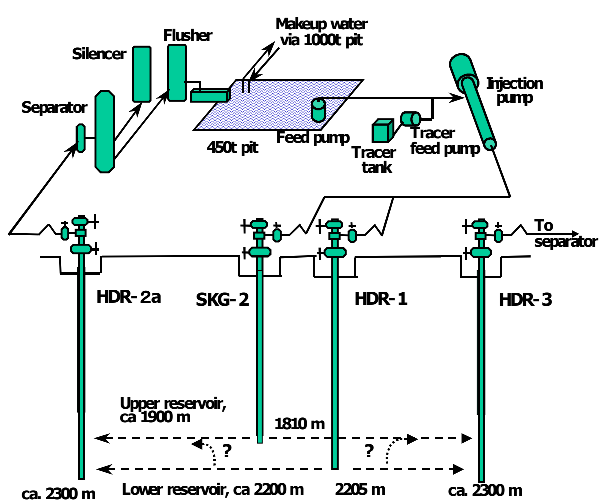


Figure 1. Schematic diagram of a circulation system at the Hijiori test site

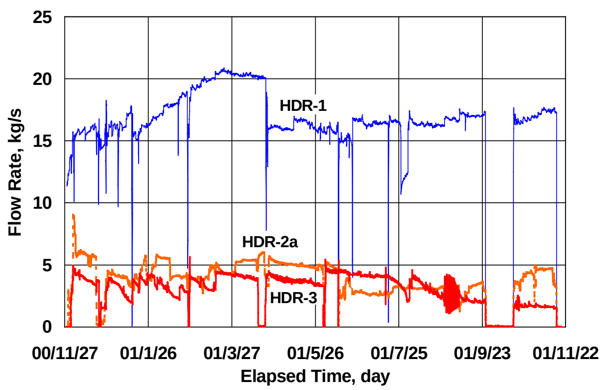


Figure 2. Flow rates of injection (HDR-1) and productions (HDR-2a and HDR-3) since the start of the first stage in the LTCT.

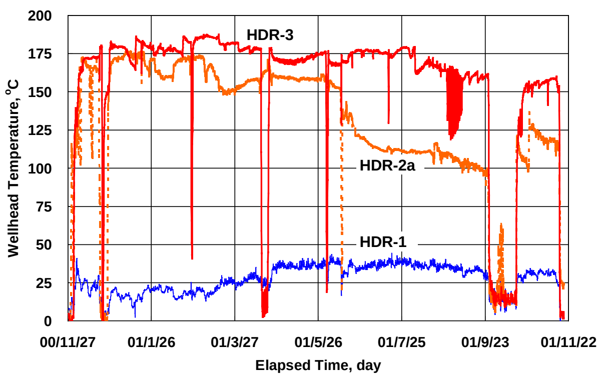


Figure 3. Fluid temperatures of injection (HDR-1) and productions (HDR-2a and HDR-3) since the start of the first stage in the LTCT.

TRACER TEST

Tracer tests have been conducted 7 times until the early January 2002 as listed in Table 1. In six tracer tests of the first stage, two or three kinds of tracer among potassium salts (KI and KBr), Na fluorescein (Uranine), and two naphthalene sulfonates (Rose et al., 1999) are selected and used. Around 15 kg of potassium salts and 200 g of Uranine and a naphthalene sulfonate were dissolved in circulation fluid at a 1 m^3 of tank. Tracer solution was fed into a main suction line to the injection pump by a feed pump with as shown in Figure 1. Flow rate of the feed pump is about 100 l/min. At the seventh tracer test, which was carried out in the second stage, we should inject tracer individually to a high-pressure line from the injection pump to SKG-2 or HDR-1 for assessing flow paths in the upper and lower reservoirs. Hence we used a small high-pressure pump to inject tracer fluid with a flow rate around 15 l/min. from a 200 l tank into the injection line to SKG-2 or HDR-1.

Produced fluids from HDR-2a and HDR-3 were collected using an automatic sampler at sampling lines from weir. Fluid sample was collected in a 250 ml bottle at every time scheduled. At the site, we measured pH and electrical conductivity of fluid. Fluorescent of production fluid was continuously monitored by a portable fluoremeter with a fiber optic sensor at a flow-through cell in the sampling line (Matsunaga, et al., 2001). Tracer and major dissolved species are analyzed at laboratory by ion chromatography, ICP-ES, and fluorospectrometry.

Table 1. Tracer tests at the Hijiori site during the LTCT

No.	Time	Tracer(s)		Injection Well
1	2000 12/6-9	KI KBr Uranine	14.5 kg 14.3 kg 230 g	HDR-1
2	2001 3/7-10	KBr NS Uranine	20.0 kg 207 g 230 g	HDR-1
		KI NS Uranine	20.0 kg 220 g 189 g	HDR-1
3	2001 5/23-5/26	KBr ANS Uranine	20.0 kg 210 g 252.3 g	HDR-1
4	2001 6/28-30	ANS Uranine	182 g 188 g	HDR-1
5	2000 8/15-18	KI ANS Uranine	20.0 kg 193 g 294 g	HDR-1
6	2001 11/2-8	KBr Uranine	20.0kg 206.8 g	HDR-1
		NS Uranine	74.2 g 133.0g	HDR-1
7	2002 1/9-14	KBr Uranine	20.0 kg 153.2 g	SKG-2
		KI ANS Uranine	15.7 kg 196.1 g 158.7 g	HDR-1
		KI Uranine NS	1.78 kg 315.1 g 204.7 g	SKG-2 HDR-1

*1: NS=1naphtarendisulfonateacid
*2: ANS=7amino1,3naphtarendisulfonateacid

RESULTS OF TRACER TESTS

Figure 4 shows the return curves of Uranine fluorescence in HDR-2a and HDR-3 for the fourth tracer test. As you easily seen in Figure 4,

From Figure 4, if we assume that density of fluid was one ton/m^3, breakthrough and modal volumes are obtained as 168 m^3 and 208 m^3, respectively. Since wellbore volume of HDR-2a is roughly 79 m^3, an apparent volume of the main flow path from HDR-1 to HDR-2a can be estimated as 130 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.

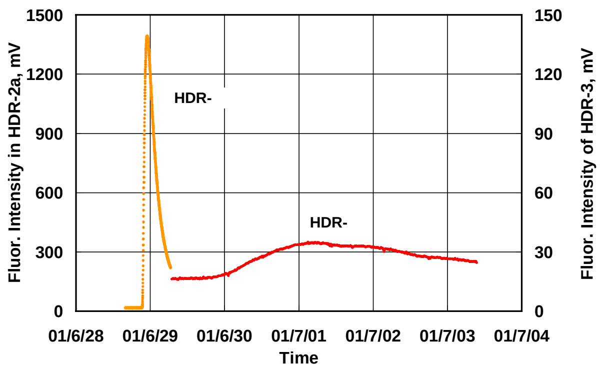
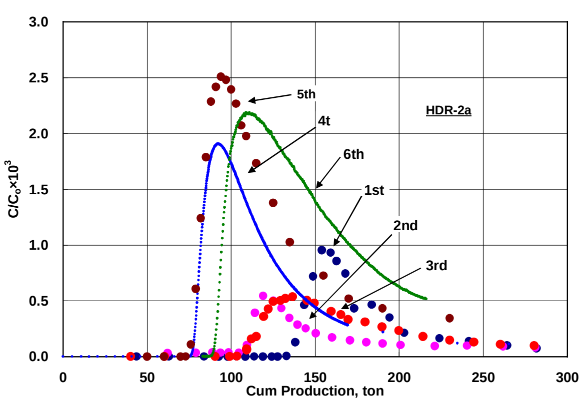


Figure 5 shows a comparison of three response curves for the first and second tracer experiments in the long-term circulation test and the fourth tracer experiment at the one-month circulation test in 1996 (Matsunaga and Tao, 1998). By comparison of two response curves for the first experiment in 2000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

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 fluoremeter 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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