Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

HDR Reservoir Evaluation by Tracer Test with Circulation Condition

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Keywords: HDR, EGS, Tracer Test, Fluorescein, Reservoir Evaluation, Geochemistry, Optical fiber

ABSTRACT

In the Hijiori HDR test field and the Habanero EGS field, tracer tests were carried out with circulation test progress using an optical fiber system and laboratory analysis. At the Habanero site, the breakthough volume was found to be 4000 m^3, and the peak volume was found to be 9000 m^3 at a 560 m distance from the injection well to the production well.

These values were compared to those of the Hijiori site. If a similar fracture pattern can be assumed, the volume is proportional to the cubic of the distance. The Habanero fracture pattern seems to be similar as early stage of Hijiori test site due to the fact that the tracer peak volume of Habanero is 300 times larger than HDR-2 and 90 times larger than HDR-3.

With respect to progressing circulation in Hijiori, the volume tended to be smaller at shorter flow paths, but from HDR-1 to HDR-3, the volume became larger.

1. INTRODUCTION

A tracer test is a useful method for determining flow regimes in a geothermal reservoir. In Hot Dry Rock (HDR) and Enhanced Geothermal System (EGS) test fields, tracer tests have been conducted to estimate reservoir volumes and their changes with circulation conditions (Robinson at al., 1987; Matsunaga et al., 1996). Since the spatial expansion of HDR/EGS reservoirs influences the efficiency of heat extraction, tracer response in production fluid gives important information for estimating the volume and lifetime of the HDR/EGS reservoir.

At a hot dry rock (HDR) test site in Hijiori, Yamagata, Japan, a long-term circulation test (LTCT) was conducted from 27 November 2000 to 31 August 2002 (Kawasaki et al., 2002, Oikawa et al., 2001). While the LTCT was being carried out, tracer tests were conducted to determine the flow regime in the reservoir and its changes in circulation. Results of these tests have been reported (Matsunaga et al., 2001, 2002; Yanagisawa et al., 2003). An additional work was needed to obtain a precise estimate of reservoir volume by subtracting wellbore volumes and accounting for mixing effects between two reservoirs at the dual injection stage. Calibrated tracer response curves were used to evaluate the flow regime during the dual injection stage of the LTCT (Matsunaga et al., 2005).

After the Hijiori project, tracer tests were carried out at the Habanero EGS field in Cooper Basin, South Australia, and the first tracer curve was successfully obtained during the closed-loop circulation test lasting from December 2008 to February 2009 (Yanagisawa et al., 2009).

A comparison of the tracer volumes of the Hijiori and Habanero test sites is offered here, and the effect of well distance on tracer volume is discussed.

2. TRACER TEST

2.1 Optical Fiber System

Na fluorescein (Uranine) was used for tracer tests in both the Hijiori and Habanero HDR/EGS test fields. This fluorescent tracer was continuously monitored in the production fluid using a portable fluoremeter with a fiber optic sensor (Benischke and Leitner, 1992) at a flow-through cell in the sampling line (Matsunaga, et al., 2001), as shown in Figure 1. To calibrate fluorescien concentration, fluid was sampled for analysis at a laboratory using fluorospectrometry.

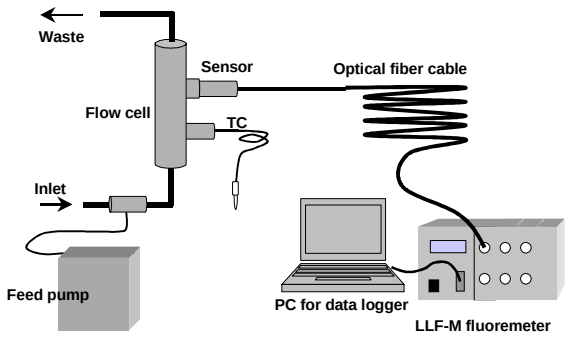

Figure 1: The optical fiber measurement system.

2.2 Tracer Test at Hijiori Site

During the LTCT, twelve tracer tests were conducted. Usually, about 15 kg of potassium salts and 200 g of Uranine and a naphthalene sulfonate were dissolved in the circulation fluid in a 1 m^3 tank. Then, the tracer solution was fed into a main suction line to the injection pump. The Schematic diagram of the circulation system is shown in Figure 2.

And after the seventh tracer test, 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.

2.3 Tracer Test at Habanero Site

At the Habanero site, a tracer test was designed with two tracers: 1, 3, 5-naphthalene trisulfonate (1,3,5-NTS) and sodium fluorescein. The 1,3,5-NTS dose was 100 kg in 800

l of water, and the sodiuim fluorescein dose was 50 kg, resulting in a total tracer mix volume of 900 l. The tracer mix was injected into Habanero #1, and the circulation pump was restarted at 16:00 on 17 December 2008 with a fluid injection rate of 14 kg/s.

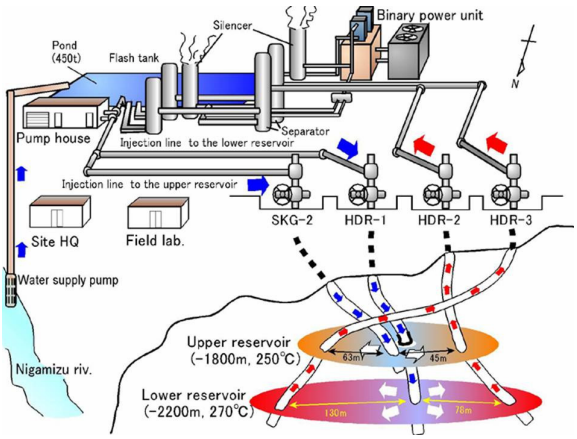

Figure 2: Schematic diagram of circulation system at Hijiori HDR site.

The tracers were detected at a sampling panel after the cooling tower by optical fiber system shown in Figure 3, and the fluorescein and 1, 3, 5-NTS concentrations in collected samples were analyzed in laboratory (Yanagisawa et al., 2009).



Figure 3: Sampling panel and optical fiber system at the Habanero site.

3. RESULTS

3.1 Habanero Tracer Result and Optical Fiber System

At the Habanero site, fluorescence counts were made at 5 minute intervals between 18 December and 25 February 2009, as shown in Figure 4. In this Figure, the fluorescence record shows a tracer breakthrough at 4 days and a peak concentration at about 9 days. However, the counts had a much lower value than that of the Hijiori tracer test, as shown in Figure 5, and many spikes exist in Figure 4.

The reason for the lower counts is the low pH of the Habanero test site. During circulation, pH was about 5.5 and the light intensity of the fluorescein become very weak compared to that at higher pH values. In the case of Hijiori, high counts were observed due to the high pH value of 8.0 at the same fluorescein concentration of 500 ppb.

Further, mineral scale formed on the optical fiber at Habanero, causing the fluorescence counts to be relatively low and spiky. The presence of barite drilling mud and other particles in the fluid may have also contributed to the scatter.

Then, NaOH was added to fluid samples to detect real fluorescien concentrations with a laboratory analyzer, and the peak concentration in the Habanero test was about 500 ppb.

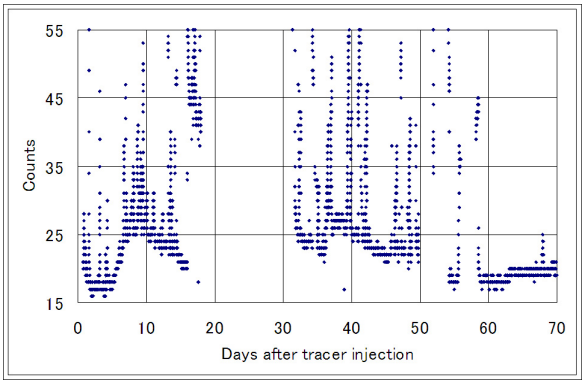

Figure 4: The tracer response curve by optical fiber system at Habanero site (pH-5.5).

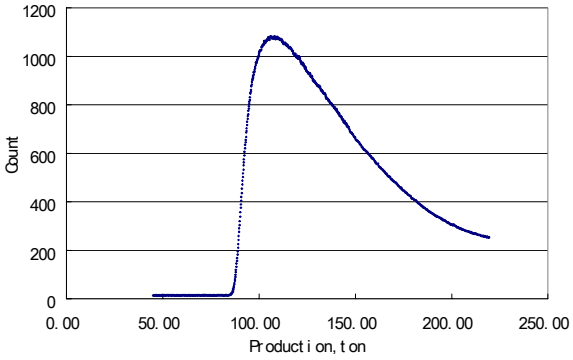

Figure 5: The tracer response curve byoptical fiber system at Hijiori site (pH-8.0).

As can be seen in Figure 4, flow was stopped on several occasions during the tracer test, especially from day 18 to day 32 after injection (from 4 to 18 January) and from day 49 to day 55 (from 4 to 10 February), due to intermittent pump failures and cleaning scaling.

An adjusted time curve (i.e. with hiatus periods removed) was calculated by assuming a flow rate of 14 kg/s and dividing the total produced mass by the mass flow rate at each point in flow-time, as shown in Figure 6.

Figure 6 and Table 1 show that the total flow volume before tracer breakthrough was about 4000 m^3, and that before the peak was about 9000 m^3.

Table 1: The breakthrough and peak volume by tracer response at Habanero site

From Habanero- 1			Flow (kg/ s)	Breakthrough Volume (ton)	Peak Volume (ton)
Hab.3	560m	1/ 2 month	14	4000	9000

3.2 Breakthrough and Peak Volume Between Habanero Site and Hijiori Site

These volumes at the Habanero site were compared to those at the Hijiori site using a tracer test performed about half a

month from starting circulation. The tracer response at the Hijiori first test is shown in Figure 7, and breakthrough and peak volumes are shown in Table 2.

Table 2: The breakthrough and peak volume by tracer response at lower reservoir of Hijiori site

Lower reservoir From HDR-1			Flow (kg/s)	Breakthrough Volume (ton)	Peak Volume (ton)
HDR-2a	70m	1/2 month	6	20	32
		6 month	4.7	2	12
HDR-3	130m	1/2 month	4.1	25	100
		6 month	4	120	270

The peak volume of Habanero (9000m^3) is about 300 times larger than that of HDR-2a from HDR-1 and 90 times larger than that of HDR-3 from HDR-1. Further, the well distance at the Habanero (560 m) is 8 times larger than that of HDR-2 and 4.3 times larger than that of HDR-3.

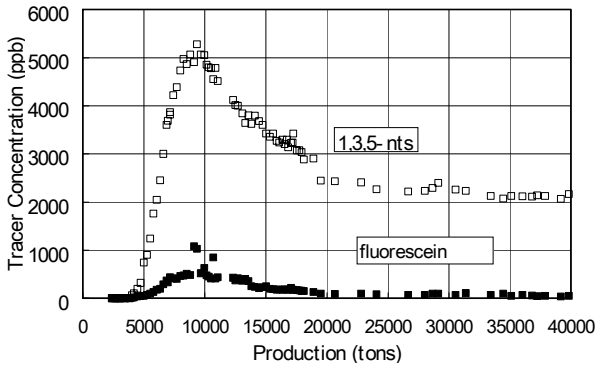

Figure 6: 1, 3, 5-nts and fluorescein concentrations versus total fluid production measured in samples taken from the sampling panel.

If the reservoir volume is considered to be proportional to cubic of distance under a similar fracture pattern in the reservoir, the Habanero reservoir seems to be similar to the Hijiori lower reservoir in the early stages. This seems to be the case here, as the peak volume of Habanero is about the cubic of 6.7 times larger than HDR-2 and about the cubic of 4.5 times larger than HDR-3.

However, the tracer volume changed with circulation at the Hijiori HDR field. Figures 7 and 8 show the tracer curve change from half a month to 6 months after injection started in HDR-2 and HDR-3, respectively. The breakthrough and peak volumes are shown in Table 2.

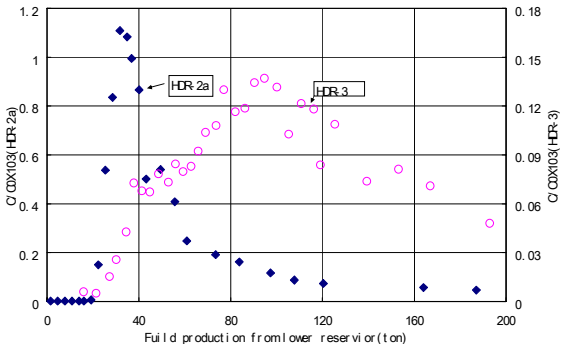

Figure 7: Tracer response at the first tracer test of HIjiori LTCT.

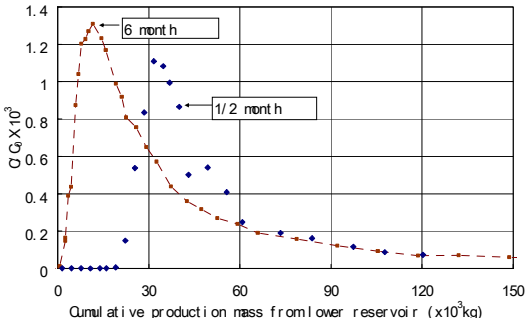

Figure 8: Tracer response change at HDR-2 well in Hijiori site.

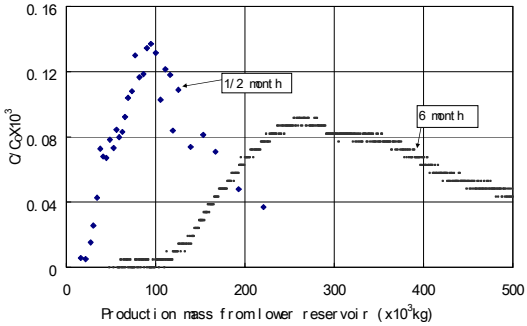

Figure 9: Tracer response change at HDR-3 well in Hijiori site.

In HDR-2, the volumes decreased by thermal breakthrough in the reservoir due to the higher conductivity of the reservoir by anhydrite dissolve to cool injected water.

In contrast, the volume increased in HDR-3. Due to higher temperatures, anhydrite re-precipitated in the reservoir, and flow paths become longer to escape precipitation.

The reservoir volume change (decreasing or increasing) seems to depend on the well distance, reservoir conductivity, and fluid temperature. The breakthrough and peak volumes of the upper reservoir of Hijiori are shown in Table 3. Due to the short distance, the volume decreased in the first 4 months. However, the volume of HDR-2a rapidly decreased due to shorter distance.

In the case of Habanero site, the well distance is 560 m, and the injection fluid temperature is higher than that at Hijiori. The volume may have increased, but this should be checked in future.

4. SUMMARY

At the Habanero site, it was found that the breakthough volume was 4000 m^3 and the peak volume was 9000m^3 at a 560 m distance from injection well to production well.

These values were compared to those at the Hijiori site. If the volume is roughly proportional to the cubic of distance in two reservoirs, they may have similar fracture patterns. Thus, the Habanero fracture pattern seems to be similar to the early stages of the Hijiori test site, because the tracer peak volume of Habanero is 300 (about cubic of 6.7) times larger than HDR-2 and 90 (about cubic of 4.5) times larger than HDR-3, while the well distance of 560 m at Habanero is about 8 times larger than that of HDR-2 and 4.3 times larger than that of HDR-3.

Table 3: The breakthrough and peak volume by tracer response at upper reservoir of Hijiori site

Upper reservoir From SKG-2			Flow (kg/s)	Breakthrough Volume (ton)	Peak Volume (ton)
HDR-2a	45m	1/2 month	5.2	35	90
		4 month	6	5	13
HDR-3	63m	1/2 month	2.6	65	100
		4 month	2.6	40	52

ACKNOWLEDGEMNTS

The authors express their appreciation of the NEDO and their contractors of the Hijiori project for helping to conduct tracer tests.

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