Habanero Tracer Tests in the Cooper Basin, Australia: Key Results for EGS Development

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The first tracer test of an Enhanced Geothermal System (EGS) in Australia was conducted in December 2008 and January 2009. The test involved circulating fluid (~14 kg s^{-1}) between an injection well, Habanero #1, and a production well, Habanero #3, for about 66.5 days through a closed-loop system in order to characterize the connection between the wells (560 m separation) and to estimate the tracer-swept volume of the reservoir. Two tracers were used: uranine and 1,3,5-naphthalene trisulfonate.
The tracer 'breakthrough' occurred after 4 days and the peak concentration occurred at 9 days. The tracer-swept pore volume was calculated to be 18,500 m^3 which is comparable in size to the reservoir of an EGS project located in Soultz-sous-Forêts, France.

Keywords: Cooper Basin, Australia, EGS, HDR, granite, tracer, fluorescien, uranine, naphthalene trisulfonate, circulation

Introduction

Geodynamics Ltd began developing its EGS project in the Cooper Basin, South Australia, in 2002. Since then Geodynamics has drilled 4 deep wells (Habanero #1, #2 and #3 and Jolokia #1), commenced drilling a fifth (Savina #1), and has constructed the Habanero closed-loop system. The project site is located in the remote north-east of South Australia as shown in Figure 1.

In March 2008, an open loop test was carried-out achieving a 20 kg s^{-1} production rate at Habanero #3. On 9 December 2008 a six week circulation test commenced. The test involved the circulation of 12 to 15 kg s^{-1} of geothermal fluid from Habanero #1, through the reservoir (at a depth of ~4,200 m) to Habanero #3 located 560 m away. A week later a tracer test was initiated with the aim of estimating the reservoir tracer-swept pore volume. Tracer testing is considered useful for estimating EGS and Hot Dry Rock (HDR) reservoir volumes (e.g., Robinson at al., 1987; Matsunaga et al., 1996). Reservoir volume is important because it influences the efficiency of heat extraction and the thermal and economic potential of EGS and HDR projects. This paper presents the results of the first tracer test at the Habanero well field in the Cooper Basin,

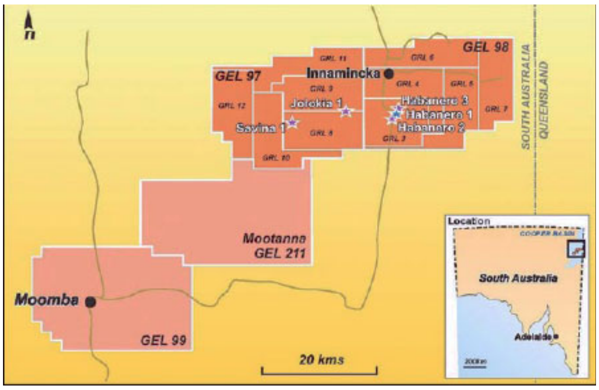

Figure 1: Location of the Geodynamics Limited Cooper Basin geothermal exploration sites

Method of tracer test

The tracer test was designed with two tracers: 1,3,5-naphthalene trisulfonate (1,3,5-NTS) and sodium fluorescein ('uranine dye'). 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. There were no fluid losses and the background concentrations of 1,3,5-NTS and sodium fluorescein were negligible. The tracer mix was injected into Habanero #1 and the circulation pump was restarted at 16:00 on 17 December 2008. The tracer injection and system is shown in Figure 2.

Figure 2: The tracer injection system at the Habanero site

Figure 3: The fibre-optical fluorometer (left hand side) and fluid sampling panel (right hand side) used in the test carried out at the Habanero site.

Tracer concentrations in the Habanero closed-loop were monitored for about 66.5 days. A fibre-optic fluorometer and fluid sampling panel are shown in figure 3. The fibre-optic fluorometer was used to used to obtain real-time fluorescence 'counts' which is useful for optimizing the bottled-sample sampling-rate and for comparing with laboratory measurements (Matsunaga et al.,2001, Matsunaga et al.,2002, Yanagisawa et al.,2002, Yanagisawa et al.,2003). Fluid samples were taken from sampling panel located downstream of the cooling tower. The bottled samples were sent to AIST, Japan, and to the University of Utah, USA, for chemical analysis.

Results

Results of the Continuous Field Sampling

Fluorescence counts were made at 5 minute intervals between 18 December and 25 February 2009 (see Figure 4). Mineral scale formed on the optical fibre (the fluid pH was about 5.5) 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.

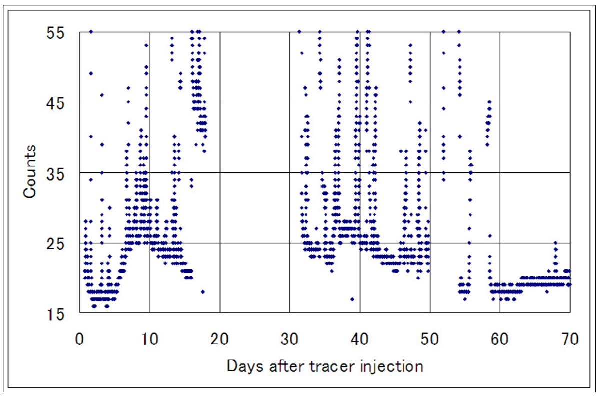

Figure 4: Habanero tracer test, fluorescein counts by optical fibre analyzer

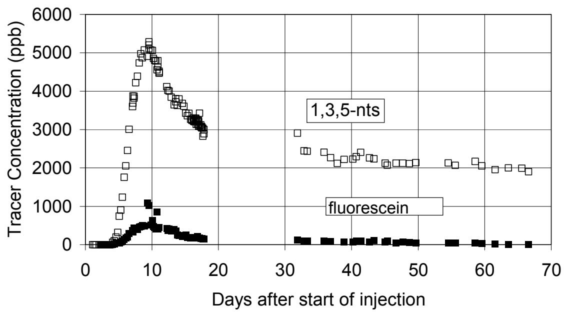

Figure 5: 1,3,5-NTS and fluorescein concentrations versus days after start of injection measured in samples taken from the sampling panel

The fluorescence record shows a tracer breakthrough at 4 days and a peak concentration at about ~9 days.

Results of the Laboratory Analysis

Fluorescein and 1,3,5-NTS concentrations of the samples collected over the 66.5 day sample period are shown in Figure 5. Due to unscheduled pump stoppages and the need to remove scale from the optical fibre, the circulation was stopped temporarily on several occasions during the tracer test. Hiatus periods included 4 to 18 January and 4 to 10 February. The data shown in Figure 5 are based on actual sampling time regardless of whether the fluid was circulating or not.

After 4 days of circulation the tracers were detected and concentrations reached a peak at about 9 days, consistent with the real-time monitoring results. An adjusted time curve (i.e. with hiatus periods removed) was calculated by assuming a flow rate of 14 kg s^{-1} and by dividing the total produced mass by the mass flow rate at each point in flow-time (see Figure 6).

Figure 6 shows the total flow volume at tracer breakthrough was about 4000 m^3 and was about 9000 m^3 at the peak concentration.

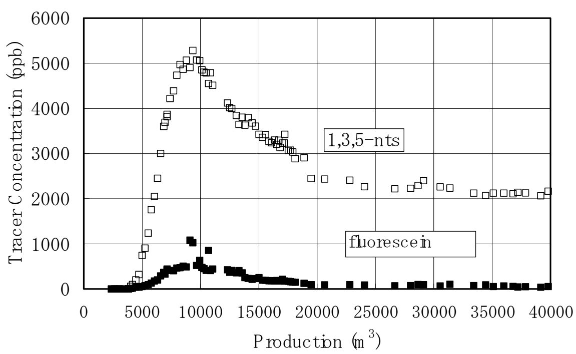

Figure 6: 1,3,5-NTS and fluorescein concentrations versus total fluid production measured in samples taken from the sampling panel

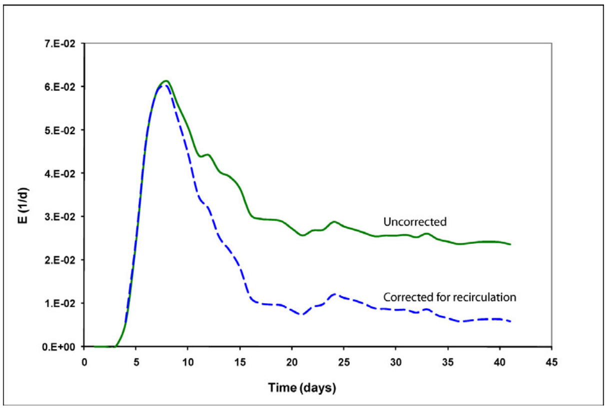

Figure 7: Plots of the residence time distribution function E(t) (upper curve) and the deconvoluted E(t) (lower curve) versus time

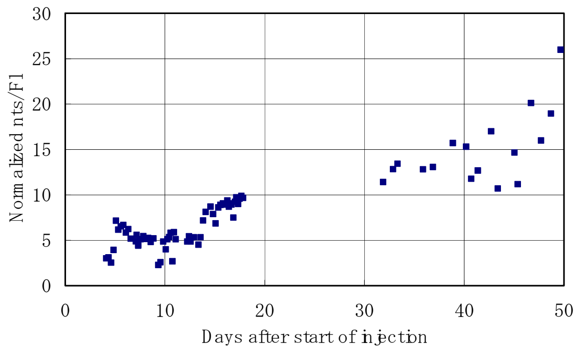

Figure 8: Normalized tracer concentration ratio 1,3,5-nts (nts) and fluorescein (fl) versus time.

To compare this with the Hijiori HDR volumes: at the first tracer test of Hijiori site, the tracer peak volume between HDR-1 and HDR-3 occured about half month after starting the long circulation test, and was about 100 m^3. This is 90 times smaller than the tracer peak volume at Habanero. However, the separation distance of the Habanero wells (560 m) is four times greater than for the Hijiori HDR-3 site (130m).

Estimation of Reservoir Tracer-Swept Pore Volume

The tracer-swept pore volume at the Habanero site was calculated using a program developed at Idaho National Laboratory (INL) that provides a standardized method of interpreting tracer return curves (Shook and Forsmann, 2005).

The program first calculates a residence time distribution function E(t):

$$E(t) = \frac{C(t) \cdot \rho \cdot Q}{M_t} \qquad \text{Equation 1}$$

where C(t) is tracer concentration, ρ is fluid density, Q is mass flow rate, and M_t is the mass of tracer injected. The program then conducts a "de-convolution" calculation, which subtracts the effects of tracer recirculation to create a new E(t) function.

This calculates what the tracer return curve would look like if the tracer had been removed from the circulation fluid at the production well after making only one pass through the reservoir. The program then extrapolates the return curve to infinite time assuming exponential decay. It then calculates the fraction of tracer-returned, a mean reservoir-residence time and the reservoir pore volume.

As described above, a constant flow rate of 14 kg s^{-1} was assumed for the duration (41 days) in which 50.4 tonnes of brine was circulated. Shown in Figure 7 (upper curve) is a plot of the residence time distribution function E(t). The lower curve is the de-convoluted E(t) curve.

Based on the assumptions described above, the mean residence time was 23.7 days and the fraction of tracer returned was 0.78. The calculated tracer-swept pore volume was 18,500 m^3. For comparison, a calculation using the same software and the tracer and flow data associated with the 1997 GPK1-to-GPK2 doublet test at Soultz-sous-Forêts, France, yielded a pore volume of 16,000 m^3 (Rose et al, 2006). The distance between production and injection well of the Habanero site is around 560 m and similar to the Soultz site.

Estimation of Reservoir Temperature

Fluorescein will decompose at temperatures greater than 200°C, whereas 1,3,5-NTS is thermally stable. From the ratio of 1,3,5-NTS concentration to fluorescein concentration, the reservoir temperature may be estimated with prior knowledge of the temperature-to-half-life relationship for fluorescein.

The concentration ratio of 1,3,5-NTS and fluorescien normalized by injected tracer amount is shown in Figure 8. At about 13 days, the concentration ratio rapidly changed from 2.2 to 7 and after 13 days, the ratio gradually increased from 7 to 10. This means that the half-life of the fluorescein was ~3 days and the reservoir temperature was approximately >250°C.

The scatter in the chart may have been due, in part, to the cooling effects of re-injection (refer Figure 7).

Summary

The first EGS tracer test in Australia was carried out at the Habanero well field in the Cooper Basin, South Australia, in 2008-2009. The main results of tracer test are as follows:

1) Tracer breakthrough occurred 4 days after tracer injection and tracer peak occurred about 9 days after tracer injection;

2) Based on an average flow rate of 14 kg s^{-1} the total flow volume at tracer breakthrough was ~4,000 m^3 and the total flow volume at tracer peak-concentration was ~9,000 m^3;

3) The tracer-swept pore volume of the Habanero reservoir is about 18,500 m^3 and is comparable in size to the Soultz-sous-Forêts EGS reservoir; and

4) Based on the thermal properties of fluorescien and 1,3,5-NTS, the reservoir temperature is estimated to be >250°C.

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