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GEOCHEMISTRY CHANGE DURING CIRCULATION TEST OF EGS SYSTEM

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ABSTRACT

During closed-loop circulation test at Habanero EGS site, South Australia, Na, K and Cl concentration were gradually increasing and highwer than those of the previous open flow production test.
In this system, increasing of Na, K may be due to dissolution of feldspars of granite rock at reservoir depth.
Similar trend is shown in production well at Hijiori EGS site, Japan. In Hijiori system, at first 3 month of 2000-2002 long term circulation test, Na,K,Cl were increased and about half concentration of Habanero site. And Ca and SO_4 are slightly higher.
This difference is due to the circulation system. At Hijiori, open loop system and injection fluid was supplied from near river water. Then, anhydrite ($CaSO_4$) was dissolved.
On the other hand, at Habanero, closed loop system and no fluid was supplied during circulation. In addition the chemical composition of the granite in which the fluid is circulating is also different, with low-calcium granite at Habanero and high calcium tonalite/granodiorite at Hijiori.

INTRODUCTION

Fluid chemistry of Enhanced Geothermal Systems (EGS) shows the result of water-rock interaction in stimulated reservoir. The change of fluid chemistry is related to the reservoir conditions and in particular the temperature change during circulation. To estimate the lifetime of an EGS system, the monitoring of fluid chemistry is important.
In Australia, development at several EGS fields is progressing with support to companies from the Australian Government. The first of these projects is the Habanero field, Cooper-Basin, South Australia by Geodynamics Limited.
Geodynamics Limited. started development of the Habanero site in Cooper Basin, South Australia in 2002 and drilled three deep wells (Habanero #1,#2,#3). This 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 and about 20kg/s were produced from Habanero #3, and production fluids and gas were sampled at wellhead and separator and analyzed (Geodynamics, 2008).
In July 2008, during preparation for circulation test, open loop production was carried out and production fluid was again analyzed (Ngothai et al., 2009).

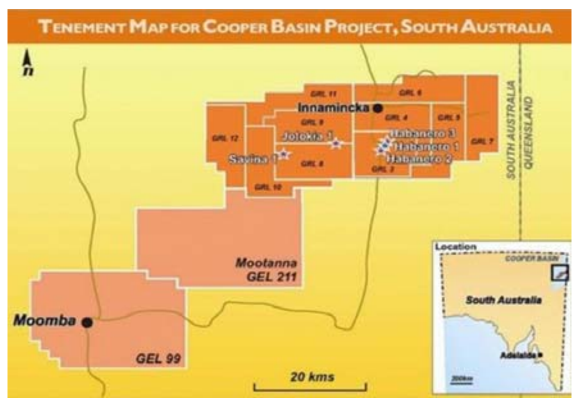

Figure 1: Location of the Geodynamics Limited Cooper Basin geothermal exploration sites.

Geodynamics then constructed a high pressure closed loop system between Habanero #1 and #3 for binary power plant, and a 6 weeks circulation test was carried out starting on 9 December 2008. About 14 kg/s, fluid was injected into Habanero #1. The fluid flowed through the reservoir at about 4,200 meter depth and was produced in Habanero #3 560m from Habanero #1.
During the circulation, a tracer test was carried out. Two kinds of tracer, 1,3,5-naphthalene trisulfonate (1,3,5-NTS) and sodium fluorescein (‘uranine dye’), were injected from Habanero #1 at 17 December 2008. The tracer appeared at the production well in 4 days and reached peak 9 days after injection. From the tracer curve, tracer swept volume and tracer return ratio were estimated (Yanagisawa et al., 2009).

For tracer analysis, we collected several water samples at the Habanero site and we analyzed the chemical composition of these samples.
This paper presents the results of the fluid chemistry at the tracer sampling line during closed loop circulation test and compares these results with the production fluid of the open loop test. It also compares the results with other EGS fields.

METHODS OF FLUID SAMPLING

During the circulation, the fluid samples were taken from a sampling panel located downstream of the cooling tower (see Figure 2). This sampling panel is located after the cooling tower near the injection well Habanero #1. When fluid flowed through the cooling tower, the fluid was cooled to about 90°C. The fluid was further cooled at sampling panel to about 45°C.
For tracer test, the fluid was sampled in 50 ml bottles about 4 times per day in early stage of circulation. Problems with the injection pump resulted in the ceasing of circulation from 4 to 18 January 2009. After the circulation restarted, the fluid was sampled one per day. The bottled samples were sent to AIST Japan for chemical analysis.
After tracer analysis less than 40 ml of sample was available for chemical analysis. For these samples, the Na, K, Ca, Cl and SO_4 concentration were analyzed by ion chromatography.

Figure 2: The fluid sampling panel used in the test carried out at the Habanero site.

RESULTS AND DISCUSSIONS

Results by fluid chemical analysis at Habanero circulation test

Figure 3 shows the results of fluid chemistry from 20 December 2008 to 22 February 2009, during the circulation test. The first sample shows Na 5000 mg/l, Ca 20 mg/l etc. The Na, Ca, K and Cl concentrations of the last sample were higher than those of the first sample. But these fluid concentrations were almost constant, for example, Na concentration was ranged from 4900 to 5400 mg/l during circulation. Then, during circulation, average Na concentration was 5107 mg/l, K was 694 mg/l, Cl was 8885 mg/l, Ca was 23.9 mg/l and SO_4 was 38.8 mg/l.

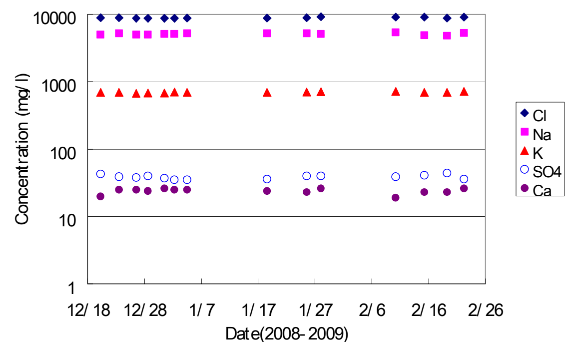

Figure 3: The fluid sampling panel used in the test carried out at the Habanero site.

Water rock interaction at reservoir during circulation

Before the closed loop circulation test, open loop flow tests were carried out between March and July 2008. Fluid chemistry was analyzed by Geodynamics (2008) in March and by Nogthai et al. (2009) in July.
Table 1 shows the results of the average concentration of separator fluid in March, the average of wellhead fluid in March, the average of wellhead fluid in July and the average of the closed loop circulation test.

Table 1: The average concentrations (mg/l) of open flow test at March and July and this closed loop circulation test.

	Cl	Na	K	Ca	SO_4
Open flow test March 2008	7485	3810	561.7	23.1	33.5
Open flow test July 2008	8235	3810	643.5	25.5	36.0
Average of circulation	8886	5107	694.3	23.9	38.8

In this table, the average concentration of Na, K and Cl of the closed circulation test are higher than those of the previous production tests. Especially Na concentration of the circulation test is 30 % higher than previous tests. K and Cl concentration seems to increase gradually.
The increasing of Na, K and Cl is corresponding to those increasing during circulation as shown in Table.1. Increasing of Na, K may be due to

dissolution of feldspars (albite ((NaCa)AlSi3O8), and microcline (KAlSi3O8) etc.) of granite rock at reservoir depth. The dissolution of feldspars were detected in a laboratory size circulation system under 250ºC and 50 bar by Kuncoro (2010) as shown in Figure 4.
And Table 2 shows the ratio of Na/K at field flow tests and laboratory test. These values are ranged from 6 to 8 and Na tends to higher at circulation test. This shows the corresponding field data and laboratory data.

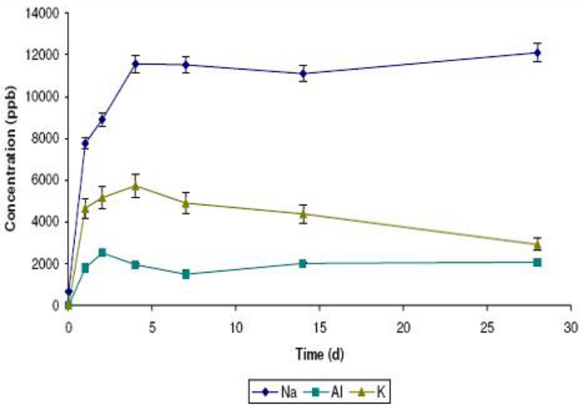

Figure 4: Concentration change during lab circulation test (after Kuncoro et al., 2010).

Table 2: The ration of Na/K at field flow test and Laboratory test.

	Na(mg/l)	K(mg/l)	Na/K
Open flow test March 2008	3810	561.7	6.78
Open flow test July 2008	3810	643.5	5.92
Average of circulation	5107	694.3	7.35
Lab test	12.0	2.0	6

Estimation of reservoir temperature

Table 3 shows the results of estimated reservoir temperature by alkali geothermometer, Tnkc: Na/K/Ca geothermometer Fournier and Truesdell (1973), Tnk (Trues): Na/K geothermometer of Truesdell (1976) and Tnk (Fourn): Na/K geothermometer of Fournier (1983) during open flow test and circulation test. Tnkc is between 270 and 280ºC, Tnk(Trues) is between 220 and 250 ºC and Tnk (Fourn) is form 244 to 266 ºC .
During production including circulation test, Tnkc shows around 275ºC and corresponding to estimated reservoir temperature by Geodynamics. And This value corresponds with the temperature estimated by fluorescein decomposition during the tracer test.

Table 3: The Geothermometer of openflow and circulation test at habanero site.

	Tnkc	Tnk (Trues)	Tnk (Fourn)
Open flow test March 2008	274.7	243.7	260.4
Open flow test July 2008	280.9	251.8	266.4
Average of circulation	272.2	223.1	244.8

Comparison with other HDR/EGS field

At Hijiori HDR/EGS test, the geochemistry is almost constant during first 3 month as shown in Figure 5. This is similar as the Habanero circulation test

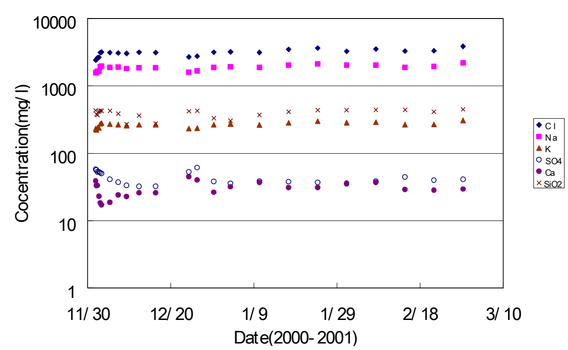

Figure 5: Fluid chemistry of HDR-3 of Hijiori HDR field at early stage of circulation test.

Table 4 shows the fluid chemistry of GPK-S2 well of Soultz (Baticci et al, 2010), HDR-3 well of Hijiori site in December 2000 (NEDO, 2001) 15 days after injection and this circulation test. The Na, K and Cl concentration at Soultz is ten times higher than those of Habanero site. And Ca of Soultz is about 250 times higher than the Habanero site. Due to high Ca concentration

Table 4: The fluid concentration (mg/l) of GPK-S2 well of Soultz, HDR-3 well of Hijiori and Habanero circulation test.

	Cl	Na	K	Ca	SO_4
Habanero#3 Circulation	8886	5107	694.3	23.9	38.8
Hijiori HDR-3	4160	2580	361	32.5	50.4
Soultz GKP-2S	57800	26800	2880	6650	17.1

At Hijiori site, Na, K and Cl concentrations are half of Habanero site. And Ca and SO_4 are slightly higher. This chemical difference may be due to the

circulation system. At Hijiori, open loop system and injection fluid was supplied from near river water. Then, anhydrite ($CaSO_4$) was dissolved. On the other hand, at Habanero, closed loop system and no fluid was supplied during circulation.
In addition the chemical composition of the granite in which the fluid is circulating is also different, with low-calcium granite at Habanero and high calcium tonalite/granodiorite at Hijiori. Table 5 shows the mineral composition of Reservoir granitic rock. At Hijiori, the ration of anhydrite is 4.9% and this is cause to high SO_4 in fluid and Ca source of Calcite scale in HDR-2a.

Table 5: Mineral composition of Reservoir granitic rock

	Habanero Granite	Hijiori Tonalite
Quartz	39.3	35.3
Plasioclase	29.7	38.2
K-feldsper	18.1	2.1
Muscovite/Biotite	8.5	0.4
Carbonate	1.1	1.3
Chrolite/Clay M	0	6.5
Sericite	0	9.5
Pyroxene	2.2	0
Epidote	0	1.8
Calcopyrite	1.1	0
Anhydrite	0	4.9
Total	100	100

And at Hijiori site, after half year, temperature at wellhead rapidly decreased and tracer return became earlier at HDR-2a only 70 meter from injection well. Then calcium concentration rapidly increased from 30 to 200 ppm as Figure 6 due to dissolve anhydrite of reservoir under low temperature condition especially near injection well. And calcite scale problem occurred at pipeline of HDR-2a.

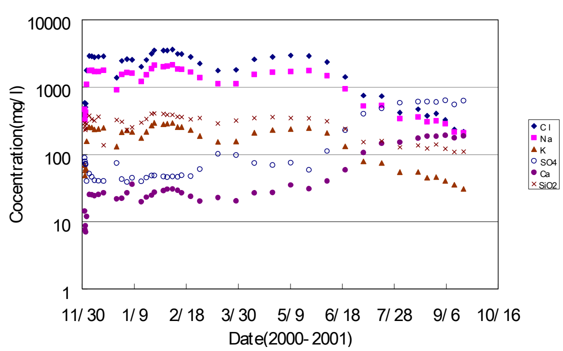

Figure 6 Fluid chemistry of HDR-2 of Hijiori HDR field during circulation test.

The fluid chemistry shows the possibility of scaling, and calcium concentration is related calcite and anhydrite scaling. And silica, sulfate etc. are important to predict the scaling in pipeline and production well.

And during circulation, Na and Cl concentration wer change at Hijiori and Habanero site. But the trend of relation of Na and Cl has difference between Hijiori and Habanero site. Figure 7 show the relation of Na and Cl. At Hijiori, Na and Cl changed with similar ratio. But at Habanero, The ratio Na and Cl was changed and it is higher Na ratio at high Na and Cl concentration.

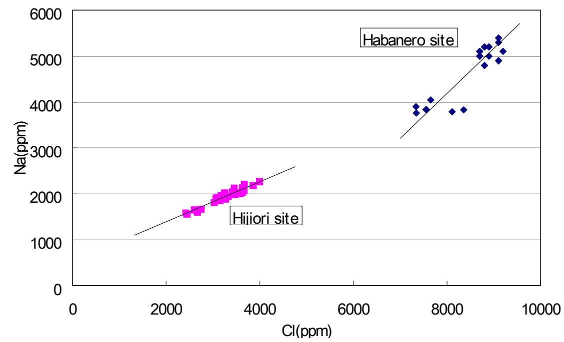

Figure 7 Na and Cl concentration during circulation at Hijiori and Habanero site

Geochemical monitoring of neighbor hot spa from Hijiori HDR site

In Japan, there are about 28,000 hot spa and many hot spa exist near geothermal power plants.
At several regions, hot spa owners against to construct geothermal power plants and this is one of reason of preventing to development of geothermal in Japan. And owners of geothermal power plants have to monitor of flow and geochemical condition of nearby hot spa.

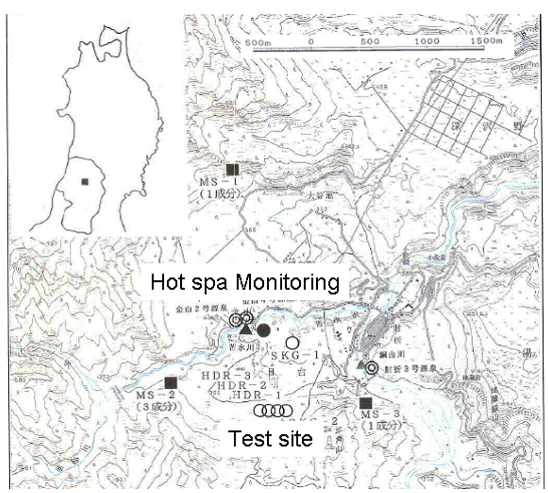

Figure 7 Hot spa monitoring site near Hijiori HDR/EGS site

Figure 7 shows the hot spa monitoring site and Hijiori HDR test site. Between hot spa and Hijiori test is about 1 km distance.
Then, the several chemical concentration were measured at hot spa by NEDO. And Figure 8 show the geochemical data at hot spa from April of 2000 to April of 2003. At Hijiori, the circulation test was carried out from November of 2000 to August of 2002 and this data including befor and after circulation test.
In spite of rapidly chemical change of HDR-2a and HDR-3, the geochemistry of hot spa was almost constant. Then, at Hijiori site, the spa was independent from HDR/EGS circulation system.

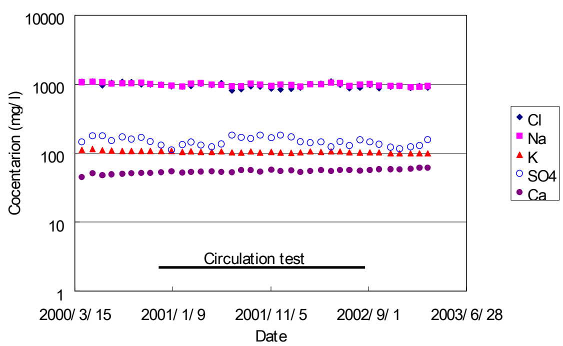

Figure 7 Fluid chemistry of Hot spa monitoring site near Hijiori HDR/EGS site

CONCLUSIONS

Production fluid chemistry during a 6 weeks closed loop circulation of Habanero site was analyzed and compared with previous open production tests. The results are as follows,
1) During the circulation, fluid chemistry is almost constant. The average Na concentration was 5,107 mg/l, K was 694 mg/l, Cl was 8,885 mg/l.
2) Na, K and Cl concentration during circulation were higher than those of the previous production test possibly due to the dissolution of feldspars in the granite at reservoir depth (4,200m, 250ºC).
3) The geothermometer of Na/K/Ca geothermometer Fournier and Truesdell during circulation is about 270ºC.
4) The Ca and SO4 concentration of Hijiori is higher than Habanero site. This is due to the anhydrite of reservoir granite and cause to calcium carbonate scale of Hijiori system.

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