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ESTIMATION OF MINERAL TRANSPORTATION IN HDR CIRCULATION TEST

Norio Yanagisawa, Isao Matsunaga and Hajime Sugita

National Institute of Advanced Industrial Science and Technology
16-1 Onogawa
Tsukuba, Ibaraki, 305-8569, JAPAN
e-mail: n-yanagisawa@aist.go.jp

ABSTRACT

In Hijiori HDR test site, a long-term circulation was conducted from November 2000 to August 2002. During circulation test, we carried out tracer test and collected scale samples at pipeline and deep production well. The power generation test was carried out last 3 month after 1 month preparation for power plant and pipeline and separator were cleaned up before test.

During power generation test, breakthrough and peak volume were gradually decreased and anhydrite scale was picked up from 2000 meter depth of well by PTS survey tool. After power generation test, we measured the thickness of calcite scale on pipeline of HDR-2. About 40 to 60 mm thickness means about 2.7 ton calcite precipitations. And we estimated the calcite volume from fluid chemistry using Ca, HCO3 and SO4 composition. As Ca is 40/96 of SO4 before calcite precipitation, about 12 ton calcite precipitations on pipeline and shallow part of production well.

This calcite precipitation mass was a part of decreasing reservoir mass of tracer test. And tracer mass change included anhydrite disslove and precipitaed mass in reservoir and deep production well.

INTRODUCTION

The Hijiori Hot Dry Rock (HDR) test field, located in Yamagata Prefecture as shown in Figure 1, was created through a series of hydraulic stimulation experiments. A deep and a shallow reservoir were created and four wells (SKG-2, HDR-1, HDR-2a and HDR-3) have been drilled. Well SGK-2 is completed in the shallow reservoir only, well HDR-1 is completed in the deep reservoir only, while the remaining two wells (HDR-2a and HDR-3) are open to both reservoirs as shown in Figure 2(Oikawa et al.,2001, Kawasaki et al.,2002).

From November 2000 to August 2002, a long term circulation test (LTCT) was conducted in the field. The purpose of the LTCT is the demonstration and evaluation of heat extraction from a multi-fracture reservoir with multiple wells. As this was the first LTCT of an HDR system in the world, several kinds of tests were carried out. And after the LTCT, much scale precipitation on pipelines and in production well was recognized and the scale influenced production and reservoir survey (Yanagisawa et al.,2004).

From June 2002 to August 2002, the last 3 month of LTCT, binary power generation test was carried out. Before power generation test, the scale of pipeline was removed. Then we can measure the scale precipitation rate during power generation.

This paper presents the results of precipitation rate of the scale in the pipeline and compare with the chemical composition, measured reservoir volume change by tracer test and discusses the water-rock interaction in the Hijiori HDR system.

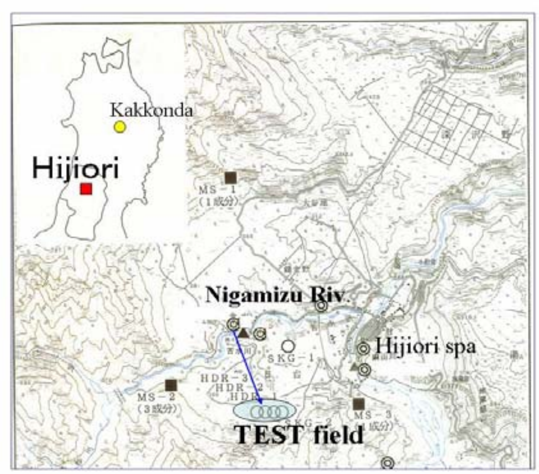

Figure. 1. The location of Hijiori HDR test field in Japan

CIRCULATION TEST IN HIJIORI HDR

The fluid circulation system at the Hijiori HDR site is shown schematically in Figure 1. A multi-stage centrifugal pump (ESP TJ9000) was used to inject the fluid at a constant flow rate of 16.66 kg/s. From 29 April to 31 May 2002, injection was stopped to prepare for the power generation test.

From 1 June to 31 August 2002, power generation test was carried out and the water injection ratio of

HDR-1 to SKG-2 was kept at 3:1. The changes in production temperatures with time during the power generation test are shown in Figure 3.

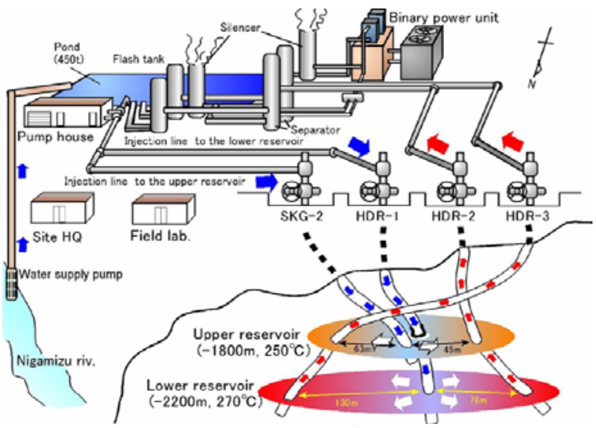

Figure. 2. Schematic diagram of a circulation system at the Hijiori test site

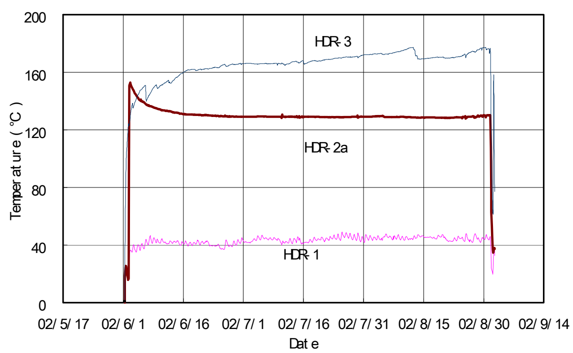

Figure. 3. Wellhead temperature of production well (HDR-2a and HDR-3) and injection well(HDR-1) during power generation test from 1 June to 31 August,2002

SCALE AND FLUID ANALYSIS

Scale sampling points are shown in Figure 4. Scale was collected downhole during the flow test in the production well by the PTS survey tools, and at various points in the surface equipment in September 2002, after the end of the flow test. Scale samples were also collected from the sampling pool at the downstream end of the hot water flow lines several times during the LTCT(Yanagisawa et al.,2004).

The bulk sample was powdered for X-ray diffraction and chemical analysis such as ICP-ES method, ion chromatography and high-frequency burning infrared absorption method.

Fluid was corrected at sampling pool after scale precipitation at hot water line. Ca and SO4 concentrations were measured by ion chromatography and HCO3 concentration was measured using the titration with H2SO4.

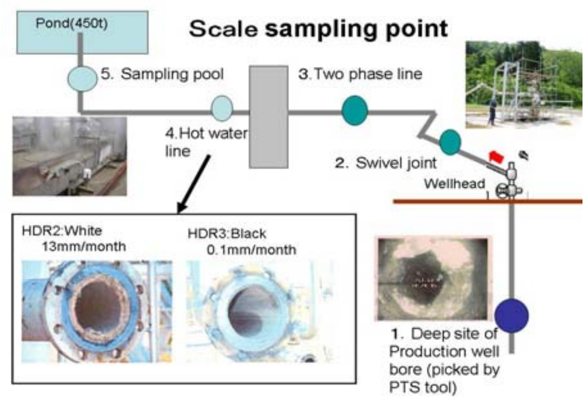

Figure. 4. Scale sampling point in production well and pipeline of HDR-2a and HDR-3.

RESULTS

Measurement of scale mass of pipeline

Figure 4 shows several photos of the pipeline in September 2002, after the end of the LTCT. The scale samples from well HDR-2 are white and thick, while those from well HDR-3 are black and thin. The scale precipitation rate of HDR-2 is about 13mm/month.

Then, we consider about only HDR-2 scale because much amount of scale and easily analysis. Figure 5 shows the several photos of the samples on the pipeline of well HDR-2 in September 2002, after the end of the LTCT. The photos arranged from left to right are at the swivel joint, the two phase line and the hot water line. Table 1 shows the results of chemical analysis and thickness of scale after 3 month flow. The main composition is calcium and carbonate.

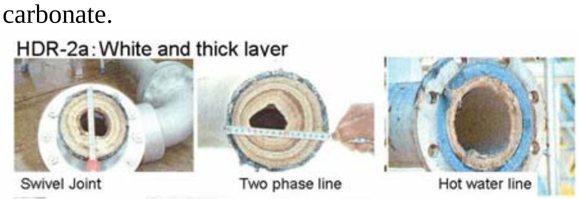

Figure. 5. The photo of cross section of pipeline at swivel joint, two phase line and hot water line in HDR-2

	Chemical ratio (%)			
	CaO	SO_4	CO_2	Thickness
Wellbore	40.6	53.8	4.0	
Swivel Joint	54.94	1.25	42.30	45mm
Two phase line	55.25	1.38	42.50	40-60mm
Hot water line	52.99	2.75	40.30	20mm
Sampling pool	51.2	3.7	38.6	

Table. 1. Chemical composition and thickness of scale sample at several points in HDR-2 on September 2002 after power generation test

From the thickness of scale and the diameter and length of pipeline, we calculated the mass of scale.
The inner diameter of pipeline is 6 inches (15.2cm) and the length of two phase line from wellhead to separator is 51.5 m. As the average thickness of scale is about 50 mm, the scale volume of two phase line is 0.825 m3.
On the other hand, the length of hot water line from separator to sampling pool is 17.5 m and the same inner diameter as two phase line. As the average thickness of scale is about 20 mm, the scale volume of two phase line is 0.145 m3.
Then, the total volume of scale is 0.97 m2. As the density of calcite and aragonite scale is about 2.7, the total mass of scale is about 2.6 ton.

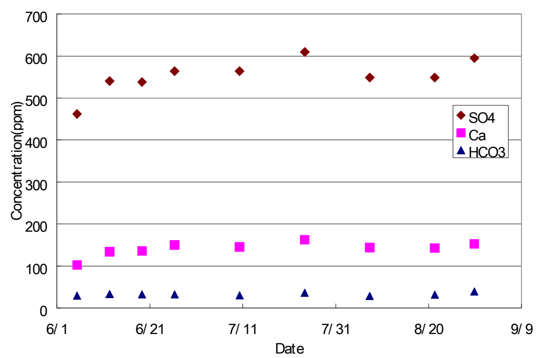

Figure.6. Chemical change of SO4, Ca and HCO3 concentration of HDR-2 during power generation test

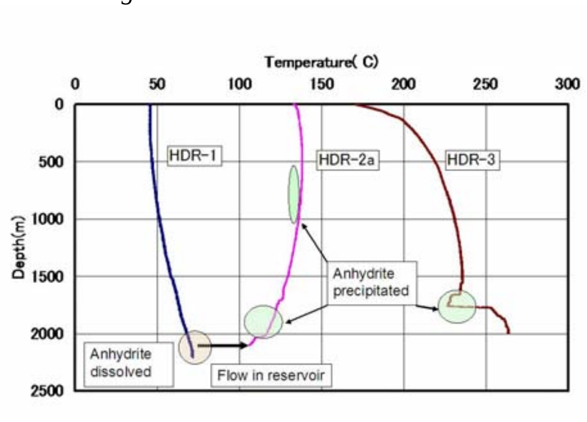

Figure. 7 Temperature depth profiles of wells at July. 2002 with scaling process

Estimation of scale mass from fluid chemical change

Figure 6 shows the fluid chemical composition of SO4, Ca and HCO3 at the sampling pool of HDR-2a. During 3 month, SO4, Ca and HCO3 were almost constant because the temperature is almost constant shown in Figure 2. And Ca is lower than 40/96 of SO4 because the fluid was sampled after precipitation of calcite. Before precipitation of calcite, Ca concentration is estimated as 40/96 of SO4. And the difference between measured Ca at sampling pool and estimated Ca as 40/96 of SO4 is the Ca concentration as precipitation for calcite and aragonite in pipeline and the shallow part of production well.

Figure 7 shows the depth temperature profile of production and injection well at July 2002 during power generation test. At 2300 m depth of feed point of injection well, injection fluid dissolve anhydrite vein and the Ca and SO4 concentration become higher. As fluid flow in reservoir and production well, fluid temperature become higher and Ca and SO4 react and precipitate as anhydrite.
As temperature of HDR-2a gradually increase from feed point at 2100m to 500m, anhydrite precipitate below 500m depth. After fluid passed at 500 m depth, the temperature of fluid gradually decrease and SO4 concentration become constant.
Then, at 500m depth Ca concentration is estimated highest and 40/96 of SO4.
Figure 8 shows the estimated Ca and HCO3 concentration at 500m depth of well before calcite precipitation. After precipitation of calcite, 90 ppm Ca concentration decreased and 136ppm HCO3 decreased as shown in figure 9.

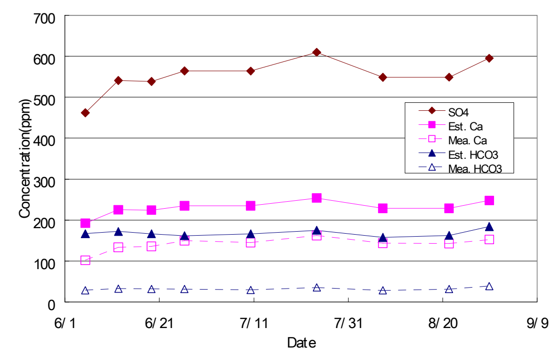

Figure. 8 Estimated Ca and HCO3 concentration of HDR-2 before calcite precipitation during power generation test.

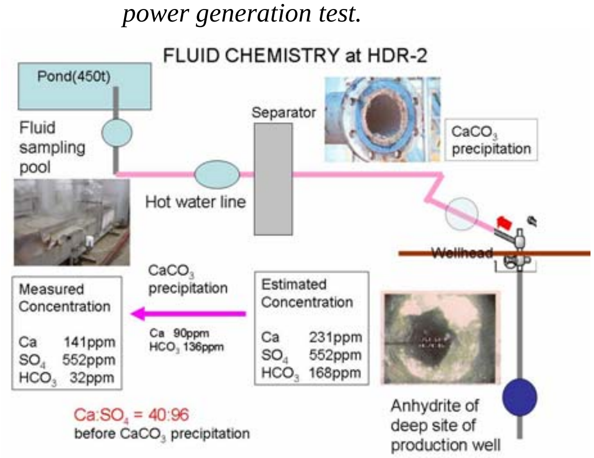

Figure. 9 Scale sampling and fluid composition change in HDR-2a.

On the other hand, total mass flow of HDR-2 during 3 month was 53,600 ton measured by flow meter.
From Ca concentration change and total flow mass, about 12 tons calcite precipitated from 500m depth to sampling pool.

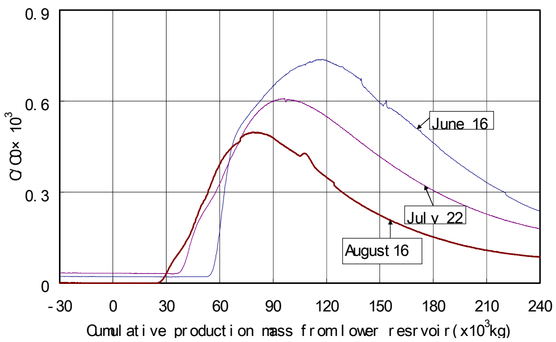

Figure. 10 Change of tracer response curve during the power generation test: From HDR-1 to HDR-2a.

DISCUSSION

The estimated value of calcite precipitation from fluid chemistry is about 12 tons and the five times as the measured calcite mass on ground. This means that about 9.4 tons calcite scale precipitated from 0 to 500 meter depth of production well.
The average thickness of calcite scale in production well is about 9 mm. And Ca concentration for 12 ton calcite means that 15.6 ton anhydrite. Then anhydrite precipitate at production well and reservoir, more than 15.6 ton anhydrite dissolved near injection well and transported.
And Figure 10 shows the change of tracer response curve during the power generation test from HDR-1 to HDR-2a(Yanagisawa et al.,2003). This figure shows the breakthrough and mode volume gradually decreased with circulation due to anhydrite dissolution in reservoir. The reservoir volume change is more than 15.6ton and a part of dissolved anhydrite will precipitated at high temperature region at deep well.

CONCLUSION

After the 3 month power generation, we measured the thickness of calcite scale on pipeline of HDR-2. About 40 to 60 mm thickness means about 2.7 ton calcite precipitations. And we estimated the calcite volume from fluid chemistry using Ca, HCO3 and SO4 composition. As Ca is 40/96 of SO4 before calcite precipitation, about 12 ton calcite precipitations on pipeline and shallow part of production well.
Calcite scale precipitated in shallow well about 4 time as on pipeline and more than 15.6 tons anhydrite dissolved at injection point and was transported to production well and pipeline and precipitated as calcite.

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