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Interference of production between two wells during a one month circulation test at the Hijiori Hot Dry Rock test site

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ABSTRACT

In 1995, a one-month circulation test (Exp.9501) was carried out with HDR-1 as an injection well and HDR-2 and HDR-3 as production wells at the Hijiori HDR site in Yamagata prefecture, Japan. There are two reservoirs in a high temperature granite at the site. Exp.9501 was the first circulation test to evaluate characteristics of the deeper reservoir at about 2200 m deep and was a preliminary test for the subsequent two-years circulation test.

The interference between the two reservoirs was observed because of water level changes in production wells. This observation was simulated by using a wellbore heat transfer (WBHT) code and concluded that this could occur when downhole pressure changed by heating up of the wellbore. Geochemistry of the produced fluid support this conclusion.

INTRODUCTION

Since 1984, field tests have been conducted to develop a heat extracting system to evolve the heat from hot dry rock at Hijiori caldera in Yamagata Prefecture. The well, SKG-2 (depth 1802 m) was drilled to explore a geothermal reservoir. The bottom hole temperature of SKG-2 was 254 °C, but the system was dry. Subsequent New Energy and Industrial Technology Development Organization, NEDO, started an HDR development project to demonstrate extracting the heat from hot rock. A reservoir was created by hydraulic stimulation at about 1800 m deep in 1986. The amount of injected water was 1080m^3. HDR-1(depth 2206 m), HDR-2(depth 1910 m) and HDR-3(depth 1907 m) were drilled to construct a circulation system in 1987, 1989 and 1990. Three circulation tests were performed to estimate the shallower reservoir characteristics using these wells until 1991. During a 90 days circulation test using four wells in 1991, the amount of hot water and steam produced from three production wells was about 80 % of the total injected water(Yamaguchi et al., 1992).

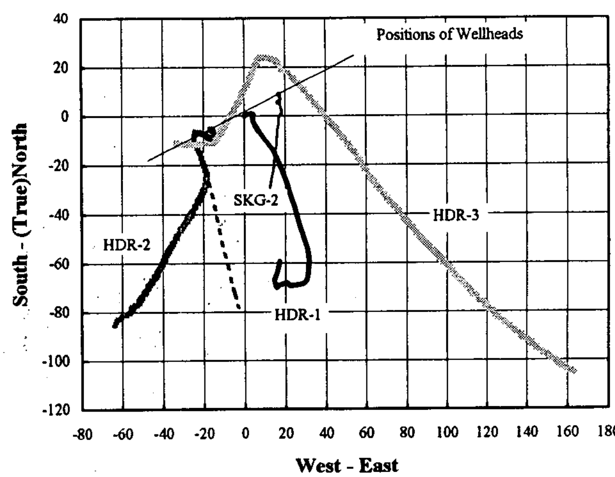

Fig. 1. Trajectories of injection and production wells at Hijiori hot dry rock test site.

As a result of the success, it was proposed to carry out a larger scale and higher temperature development of the deeper reservoir. In 1992, hydraulic stimulation with about 2000 m^3 water was conducted at a depth between 2151 and 2205 m in HDR-1 to create a deeper reservoir. In 1993 and 1994, HDR-3 and HDR-2 were deepened to a depth of 2303 m and 2302 m to intersect the deeper reservoir, and a 3-wells system was established. Trajectories of these wells are shown in Fig. 1. The distance from HDR-1 to HDR-3 was about 125 m at the depth of reservoir and from HDR-1 to HDR-2 was about 100 m.

In 1995, a preliminary circulation test (Exp.9501) was conducted with an injection well HDR-1, and two production wells HDR-2 and HDR-3 for one month(Sato et al., 1995). The purpose of Exp.9501 was to evaluate the deeper reservoir characteristic for the long term circulation test and to improve the connectivity of the deeper reservoir between the injection well and production wells. The injection flow rate is shown in Fig. 2. At the beginning of the test, water was injected under high pressure to improve the connectivity at the maximum flow rate of about 60 kg/s. After initial high flow rate injection, the productivity of the deeper reservoir was evaluated using around 16.7 kg/s or 33.4 kg/s during Exp.9501.

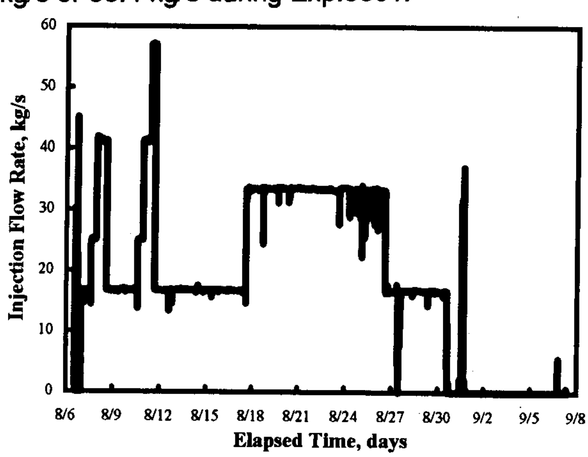

Fig. 2. Injection flow rate from HDR-1 during Exp.9501.

In this paper, we discuss the interference between the shallower reservoir and production wells on the basis of observed water level changes in wells at the beginning of Exp.9501.

WATER LEVEL CHANGES IN PRODUCTION WELLS AT THE BEGINNING OF EXP.9501

During the initial period of Exp.9501, water level in production wells were monitored until water level reached both wellheads. Water level of HDR-2 and HDR-3 was -43 m and -45 m when the injection was started in HDR-1. As shown in Fig. 3, water level rose in the both production wells during the pumping, and water level went down once the pumping was stopped. Also, water level of HDR-2 rose faster than that of HDR-3. Water level of HDR-2 reached the wellhead at about 1 a.m. on August 7 and HDR-2 started producing. Water level of HDR-3 was gradually rising during production of HDR-2, but began to go down at about 8 a.m. on August 7.

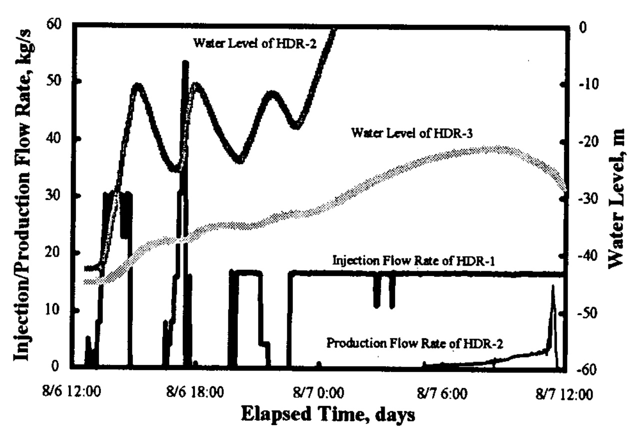

Fig. 3. Water level and production flow rate from HDR-2 and HDR-3 at the beginning of Exp.9501.

As noted in Fig. 4, the shallower reservoir is located at a depth of 1800 m with an injection well SKG-2 and the deeper reservoir at a depth of 2200 m with an injection well HDR-1. Both reservoirs are connected with HDR-2 and HDR-3. Therefore, we think that water injected in HDR-1 flowed into the shallower reservoir through the deeper reservoir, or produced from the shallower reservoir.

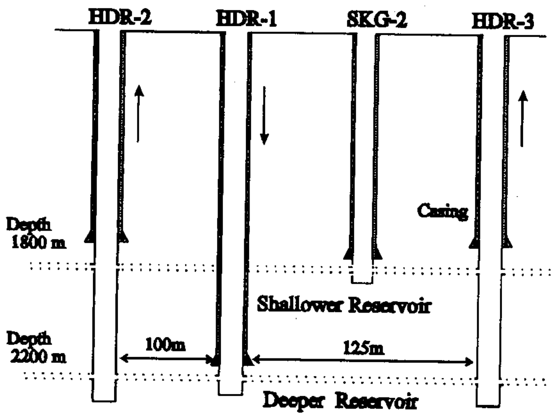

Fig. 4. The concept of Hijiori HDR test site.

DOWNHOLE PRESSURE AT THE SHALLOWER RESERVOIR LEVEL AND FLUID FLOW IN PRODUCTION WELLS

We examined the interference between the shallower and the deeper reservoirs by downhole pressure changes in HDR-2 and HDR-3. For the input data, the downhole temperature obtained by the temperature log before Exp.9501 and the flow rate of the rise of water level was converted, we calculated pressure of production wells on the intersection of the shallower reservoir at about 1800 m deep using by WBHT code(Cremer et al., 1979). Downhole pressure in HDR-2 and HDR-3 calculated by WBHT and water level of HDR-3 are shown in Fig. 5. As shown in Fig. 5, production pressure of HDR-2 and HDR-3 increased gradually when pumping was started. Once hot water was produced from the wellhead of HDR-2, the density of fluid in the well became lower since the borehole was heated up, then downhole pressure at a depth 1800 m began to decrease. This phenomenon occurred from 4 a.m. on August 7, while pressure of HDR-3 at the shallower reservoir kept increasing. In HDR-2, production of hot water continued and pressure at the intersection kept dropping, and at last pressure of HDR-2 became lower than that of HDR-3 as shown by point A in Fig. 5. As shown in Fig. 5, water level of HDR-3 started to go down from the point A. We interpret that hot water in HDR-3 began to flow toward HDR-2 through the shallower reservoir. By continuation of the production flow, pressure of HDR-2 decreased more and more. At the point B, when pressure in HDR-2 became lower than initial pressure of the shallower reservoir as shown in Fig. 5, it is likely that fluid within the shallower reservoir began to flow toward HDR-2.

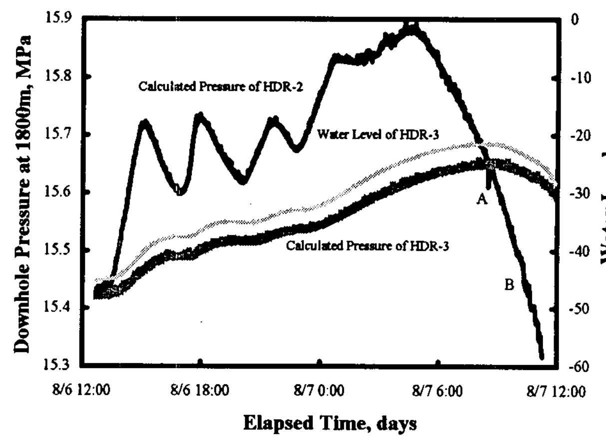

Fig. 5. Calculated pressure of HDR-2 and HDR-3 by WBHT and water level of HDR-3.

GEOCHEMISTRY OF FLUID ON HDR-2

During Exp.9501, fluid sampling was periodically carried out at the wellhead of HDR-2 and HDR-3. As stated before, three circulation tests were performed to evaluate the shallower reservoir. Hence concentrations of dissolved species in fluid within the shallower reservoir were diluted. For example, the concentration of Cl which is a inert species changed from 600 ppm to 180 ppm during the three-months circulation test in 1991(Matsunaga et al., 1994). Therefore, we thought that fluid flowed from the shallower reservoir changed the concentration of the dissolved species in produced fluid on HDR-2.

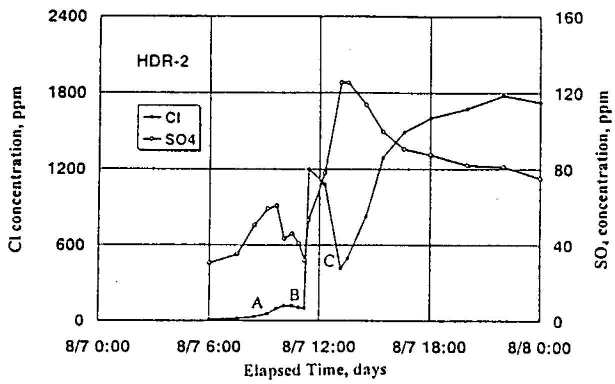

Fig. 6. Cl and SO_4 concentration of production fluid on HDR-2 at the beginning of Exp.9501.

The change in concentration of Cl and SO_4 in produced fluid from HDR-2 at the beginning of Exp.9501 is shown in Fig. 6. Since the concentration of Cl was very low from start of production to the point B as shown in Fig. 6, it suggests that fluid within casing was produced during this period. After the point B, the Cl concentration suddenly increased up to 1200 ppm and then decreased to 430 ppm. Since the fluid volume produced from HDR-2 between 9 a.m. (point A in Fig. 5) and 2:17 p.m. (point C in fig. 6) was almost equal to the wellbore volume between the wellhead and the intersection of the shallower reservoir, it suggests that fluid in the shallower reservoir began to flow into HDR-2 and mixed with the deeper reservoir fluid. After the point C, the increase of the Cl concentration suggest the mixing ratio of the fluid that flowed through the deeper reservoir increased, or that flowed beyond the intersection of the shallower reservoir including the higher concentration.

CONCLUSION

In the recent three-well system at the Hijiori test site, HDR-2 and HDR-3 intersected the shallower and the deeper reservoirs. Therefore, we were worried that the circulation fluid leaks into the shallower reservoir before Exp.9501. However, the result of Exp.9501 indicates that no leakage occurred once the production wells heated up and the downhole pressure became lower than the original reservoir pressure. This result is very promising in order to develop the multi-fracture production system in hot dry rock masses.

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