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A STUDY OF THE PRESSURE-FLOW RESPONSE OF THE HIJIORI RESERVOIR AT THE HIJIORI HDR TEST SITE

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ABSTRACT

Since 1986, R&D project of Hot Dry Rock (HDR) geothermal energy has been carried out at Hijiori in Yamagata prefecture, Japan. At present, the Hijiori HDR system has two reservoirs (a shallow reservoir and a deep reservoir) and four wells (SKG-2, HDR-1, HDR-2a and HDR-3) as is shown in Figure 1. The Hijiori multi-reservoir system consists of two injection wells in the artificial reservoirs (SKG-2 into the shallow reservoir, HDR-1 into the deep reservoir) and two production wells, HDR-2a and HDR-3, which also intersect the shallow reservoir.

Considering a cost performance, multi-reservoir system is important technique for the development of HDR. In order to clarify the behavior of the multi-reservoir system as a first step, we had investigated a pressure-flow relation between SKG-2 and HDR-3 of the shallow reservoir. In this paper, we added the new data between SKG-2 and HDR-3 of the shallow reservoir. Furthermore, we examined the pressure-flow relation between SKG-2 and HDR-2 of the shallow reservoir, and compared with the relation of the deep reservoir.

1. INTRODUCTION

The Hijiori HDR test site is located on the southern edge of the 2km-in-diameter Hijiori caldera, which was formed about 10,000 years ago. Topographic effects extend underground, and the prevalence of fracture groups has a strike in the east-west direction and a dip to the northern side with high angle.

The history of the R&D project of Hijiori HDR geothermal energy is divided into two phases. The first phase was during 1985 to 1991, when the shallow reservoir had been created and various technological developments were carried out. In Exp.9102 in 1991, the recovery rate of hot water and steam was about 78 % and extracted heat energy was about 8.5 MW thermal (Yamaguchi et al., 1992, Kruger and Yamaguchi, 1993).

Based on the results obtained from shallow reservoir, aiming at the construction of a larger scale and higher temperature reservoir, the deep reservoir was created by hydraulic fracturing at depth of about 2200m in 1992. Two wells were deepened to a depth of about 2300 m to penetrate the deep reservoir; Present Hijiori multi-reservoir HDR system was established in 1994. In 1995 and 1996, two short-term circulation tests (Exp.9502 and Exp.9602) were conducted to evaluate the deep reservoir characteristics for the long-term circulation test. And, preparation for a long-term circulation test was started from 1997 (Nagai and Tenma, 1997).

2. PRESSURE-FLOW RELATION OF THE SHALLOW RESERVOIR

To estimate the characteristic of the multi-reservoir system, Tenma et al. (1999) examined the differential pressure and discussed the pressure-flow relation between SKG-2 and HDR-3 of the shallow reservoir.

The PTS (Pressure – Temperature – Spinner) data of the deep reservoir was obtained in the flow enhancement test (Exp.9602). As the new data about the flow rate and pressure of HDR-3 were obtained by the PTS loggings, we attempted to analyze the new data.

Pressure and flow rate of the shallow reservoir had been acquired by PTS logging in the 1991 90-day circulation test (Exp.9102). At first, we analyze the pressure-flow relation between SKG-2 and HDR-2 of the shallow reservoir. Summary of these tests and the data of the shallow reservoir are as follows.

2.1 Flow enhancement test in 1996 (Exp.9602)

In 1996, Exp.9602 was carried out using HDR-1 as an injection well and HDR-3 as a production well. The purpose of the experiment was to improve a connectivity of fractures between HDR-1 and HDR-3, because the connectivity between these wells was poor compared to that of between HDR-1 and HDR-2a (Tenma et al., 1997). The injection flow rate was kept constant at 16.7 kg/s during the Exp.9602. As shown in Figure 2, the pressure of the shallow reservoir was monitored through SKG-2 during the experiment.

A PTS logging was carried out four times within two production wells HDR-2 and HDR-3 during the experiment. The results of PTS logging are also shown in Figure 2**.** In this figure, black/white bars on a horizontal axis show the production flow rates from deep/shallow reservoirs, respectively. In the PTS loggings of September 1st and 5th, it was unable to measure the flow rate from shallow reservoir because of the sensitivity of the PTS tool.

The flow rate and pressure between SKG-2 and HDR-3 of the shallow reservoir was estimated using following procedure. The measured downhole pressure profile, that is shown in Figure 3, is used to estimate ΔP_p . On the other hand, downhole pressure monitored in SKG-2 is used to estimate ΔP_i. Here, the differential pressure is defined as the difference between ΔP_i and ΔP_p. Regarding to the production well HDR-3, produced fluid rate from shallow

reservoir can be estimated by subtracting that of deep reservoir from the measured flow rate at the wellhead.

2.2 90-day circulation test in 1991(Exp.9102)

Exp.9102 was a three-month circulation test using SKG-2 as an injection well, and HDR-1, HDR-2 and HDR-3 as production wells as was shown in Figure 4. The purpose of Exp.9102 was to estimate the characteristic of the shallow reservoir at 1800m deep.

PTS logging was carried out once a week in the three production wells during the experiment. Therefore, these PTS data can be used to estimate the pressure and flow rate of the shallow reservoir. In the middle of the experiment, the shallow reservoir seemed to change its characteristic by some unknown reason (Tenma et al. 1994). Thus, the PTS data of the latter period in the experiment was used to estimate ΔP_p.

In order to estimate ΔP_i, WBHT code (Cremer et al., 1979) was used to calculate the downhole pressure profile of SKG-2. The result is shown in Figure 5. In this way, the pressure-flow relation between SKG-2 and HDR-2 of the shallow reservoir was estimated.

In Figure 6, solid triangles show the relation between flow rate and differential pressure obtained by the procedures mentioned above. That is, these triangles show the relation between SKG-2 and HDR-2. In Figure 6, another data points are obtained from the analysis between SKG-2 and HDR-3, not HDR-2. It is seen from this figure that there is not so much difference between two paths. This means, for the shallow reservoir, there exists no impedance anisotropy as long as judging from this figure.

3. PRESSURE-FLOW RELATION OF THE DEEP RESERVOIR

Miyairi et al. (1996) discussed the relationship of the pressure-flow relation of the deep reservoir. Based on this result, we re-estimated the pressure-flow relation using the differential pressure.

In 1995, a preliminary circulation experiment (Exp.9502) was conducted with an injection well HDR-1, and two production wells HDR-2 and HDR-3 (Sato et al., 1995). The main purpose of the experiment was to evaluate the deep reservoir's characteristic for the long-term circulation experiment and to improve the connectivity of the deep reservoir between injection and production wells. The flow rate histories of injection and production wells are shown in Figure 7.

At the beginning of the experiment, 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 deep reservoir was estimated under the flow rates of about 16.7 kg/s or 33.4 kg/s during the test.

As is shown in Figure. 7, PTS logging was carried out to evaluate the characteristic of the deep reservoir. The flow rate and pressure were measured within the production well. The downhole pressure of HDR-1 was also calculated by WBHT code.

4. COMPARISON OF SHALLOW AND DEEP RESERVOIR

The pressure-flow relations of both the shallow and the deep reservoirs are shown together in Figure 8. The results obtained from this figure are as follows.

1) In the shallow reservoir, the flow impedance between SKG-2 and HDR-2 is almost same as that of between SKG-2 and HDR-3.
2) In the deep reservoir, the flow impedance between HDR-1 and HDR-2a is lower than the impedance between HDR-1 and HDR-3.
3) The flow impedance of the shallow reservoir is lower than that of the deep reservoir.

5. CONCLUSION

Using the result of Exp.9102, Exp.9502 and Exp.9602, the pressure-flow relations of both the shallow and the deep reservoirs are discussed in this paper. In the future, we plan to make a detail model of the multi-reservoir based on these results.

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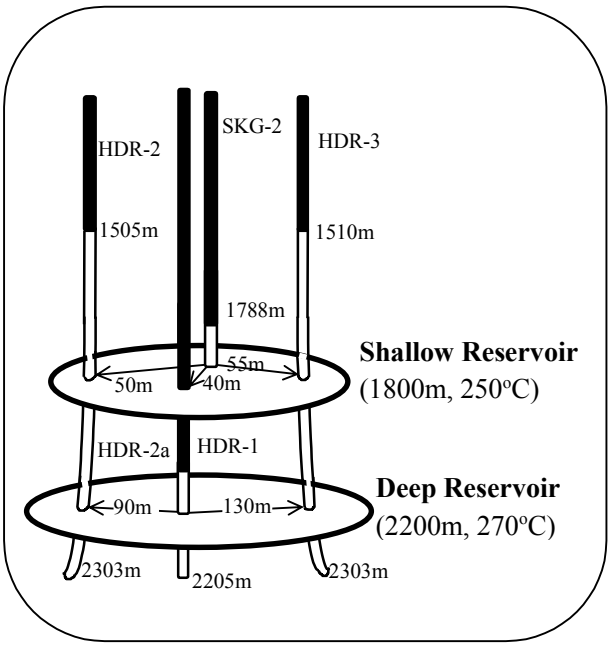

Figure 1 Concept of the recently Hijiori HDR System
Black zone shows casing. In 1994, HDR-2 was plugged back down to a depth of about 1600m and deepened to. To avoid confusion, the deepened HDR-2 is referred to as HDR-2a.

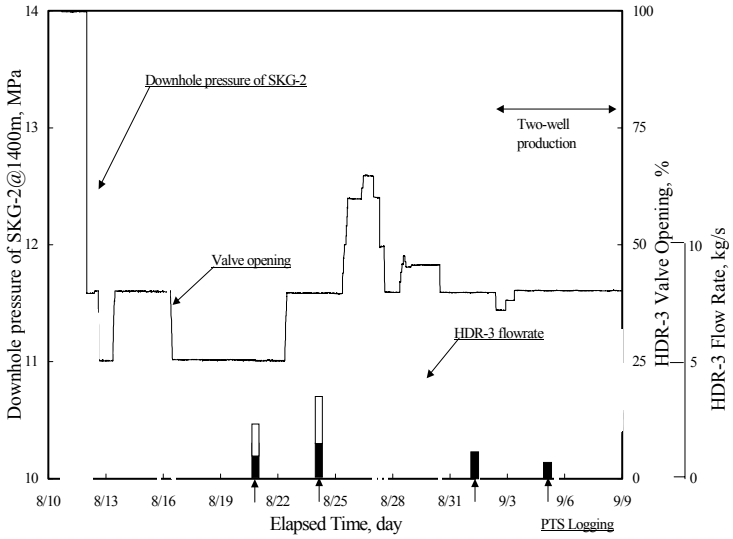

Figure 2 History of downhole pressure, valve opening and flow rate (HDR-3).
Arrows on horizontal axis show the date of PTS Logging.

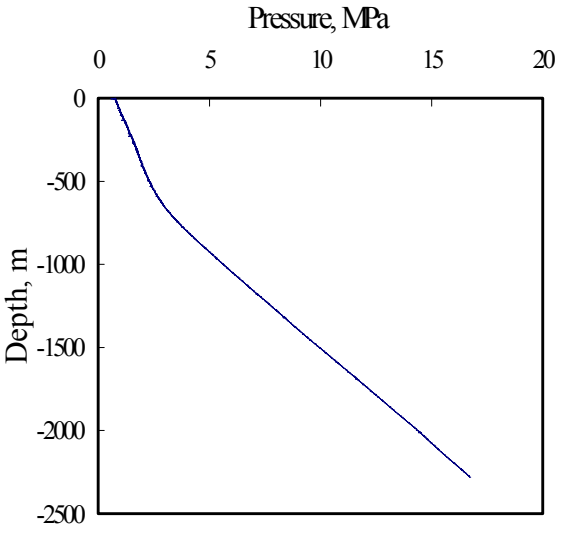

Figure 3 The pressure profile of HDR-3 at September 1

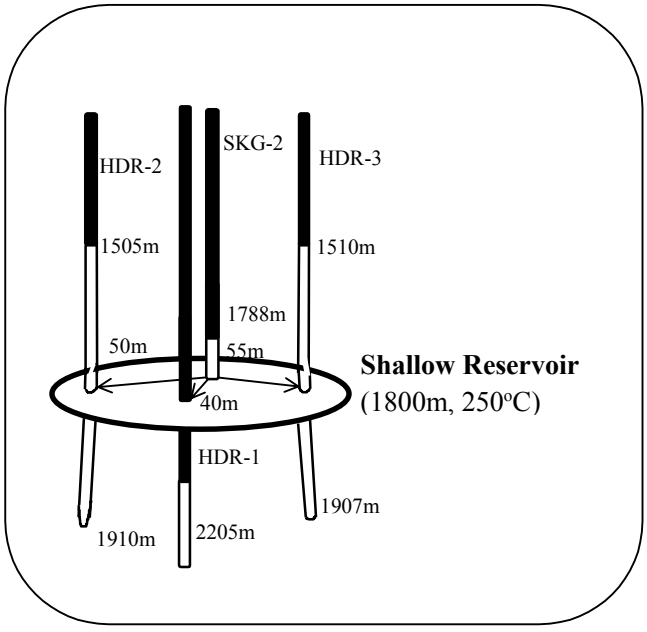

Figure 4 Concept of the Hijiori HDR System in 1991
black zone shows casing.

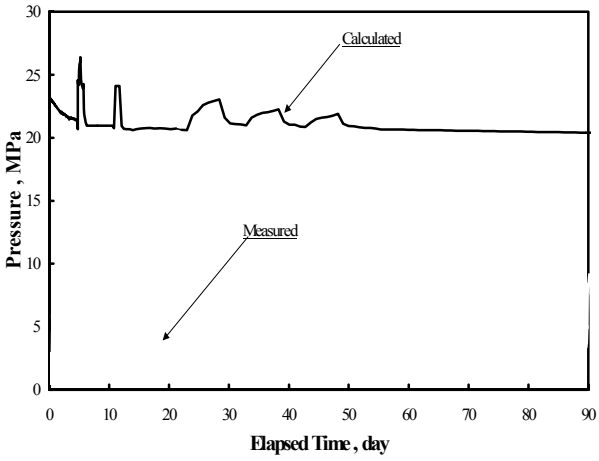

Figure 5 Measured downhole pressure of SKG-2 with estimated pressure by WBHT code

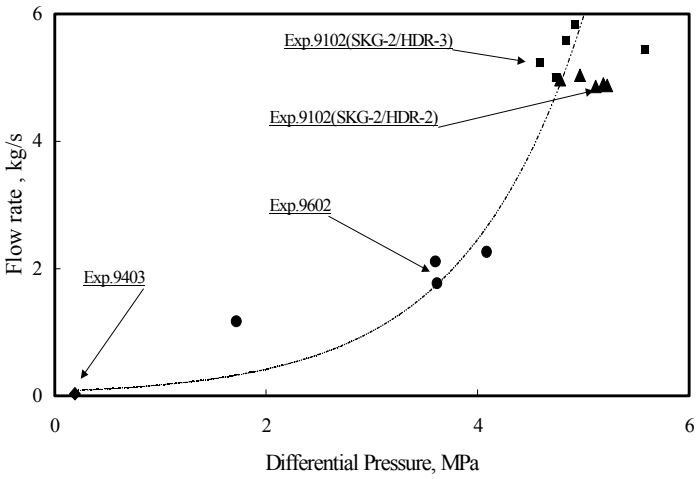

Figure 6 Relation of the flow rate to differential pressure of the shallow reservoir

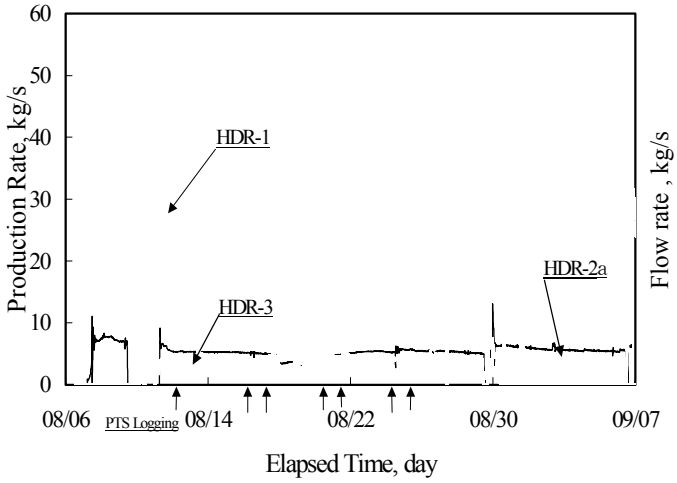

Figure 7 History of Injection/Production flow rate
Arrows on horizontal axis show the date of PTS logging.

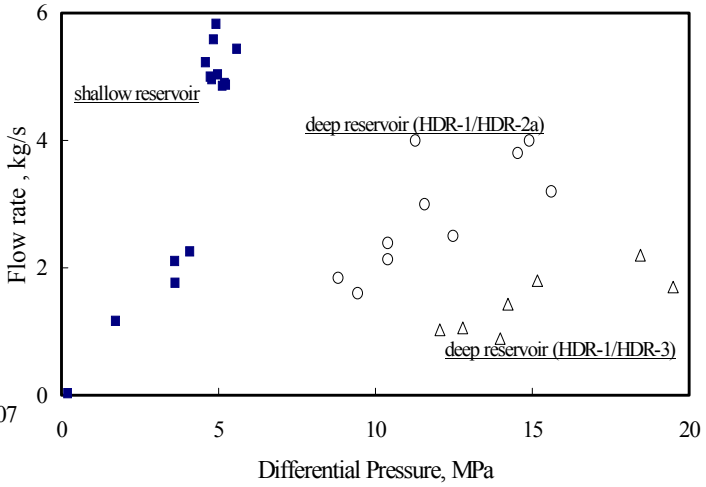

Figure 8 Relation between the shallow and the deep reservoirs