Estimation of Productivity from the Shallow Reservoir Using Pressure Monitoring Data in SKG-2 at the Hijiori HDR Test Site

Norio Tenma[1], Tsutomu Yamaguchi[1], Kazuhiko Tezuka[2] and Yasuki Oikawa[3]

[1]National Institute of Advanced Industrial Science and Technology(AIST), Tsukuba, Ibaraki, 305-8569, Japan, tenma-n@aist.go.jp
[2]Japan Petroleum Exploration CO., Ltd (JAPEX), Chiba, 261-0025, Japan
[3]New Energy and Industrial Technology Development Organization (NEDO), Tokyo, 170-6028, Japan

Keywords

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ABSTRACT

From November 27, 2000, a two-year circulation test (Long-term circulation test; LTCT) was started with HDR-1 as an injection well, and HDR-2a and HDR-3 as production wells at the Hijiori HDR site in Yamagata prefecture, Japan. There are two reservoirs (a shallow reservoir and a deep reservoir) in high temperature granite at the site. The shallow reservoir was located at the depth of about 1,800 m with the injection well SKG-2 and the deep reservoir at the depth of about 2,200 m with the injection well HDR-1. Both reservoirs were connected with HDR-2a and HDR-3 as production wells (Figure 1).

In the second half of the LTCT, we plan to use HDR-1 and SKG-2 as injection wells; HDR-2a and HDR-3 will continue to used as production wells. To assist in predicting this later stage of the LTCT, it is important to grasp the relationship of the productivity of both reservoirs.

Aiming to evaluate the characteristics of the multi-reservoir system, we estimate the pressure-flow relationship in the Hijiori HDR reservoir (Tenma *et. al.*, 2000), and examine productivity using this relationship. The results indicate that ratios of productivity from the shallow reservoir of both wells are different, with well of HDR-3 producing more from the shallow reservoir than well HDR-2a., implying that HDR-2a has a better hydraulic connection to the deep reservoir.

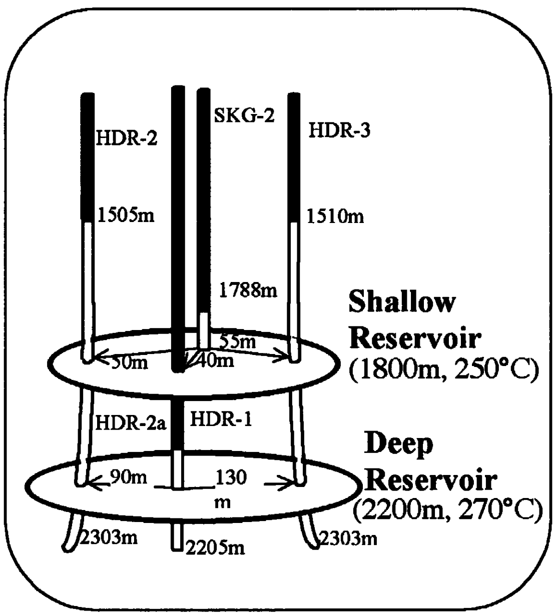

Figure 1. Concept of the recently Hijiori HDR System (Black zone shows casing). (Note: In 1994, HDR-2 was plugged back down to a depth of about 1600m and deepened. To avoid confusion, the deepened HDR-2 is referred to as HDR-2a.)

Introduction

The Hijiori HDR test site is located on the southern edge of the 2 km diameter Hijiori caldera, which was formed about 10,000 years ago. Topographic effects extend underground, and the predominant fracture orientation is E-W, with a high angle of dip to the N.

The history of the Hijiori HDR geothermal energy R&D project is divided into two phases. The first phase was during 1985 to 1991, when the shallow reservoir was created and various technological developments were carried out. The second phase started in 1992, when the deep reservoir was created by hydraulic fracturing at a depth of about 2200 m. Two wells were deepened to about 2300 m to penetrate the deep reservoir, and the 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 LTCT. The LTCT was final stage of the second phase; this test began on November 27, 2000.

Long-Term Circulation Test (LTCT)

The long-term circulation test (LTCT) was conducted with injection well HDR-1, and production from wells HDR-2 and

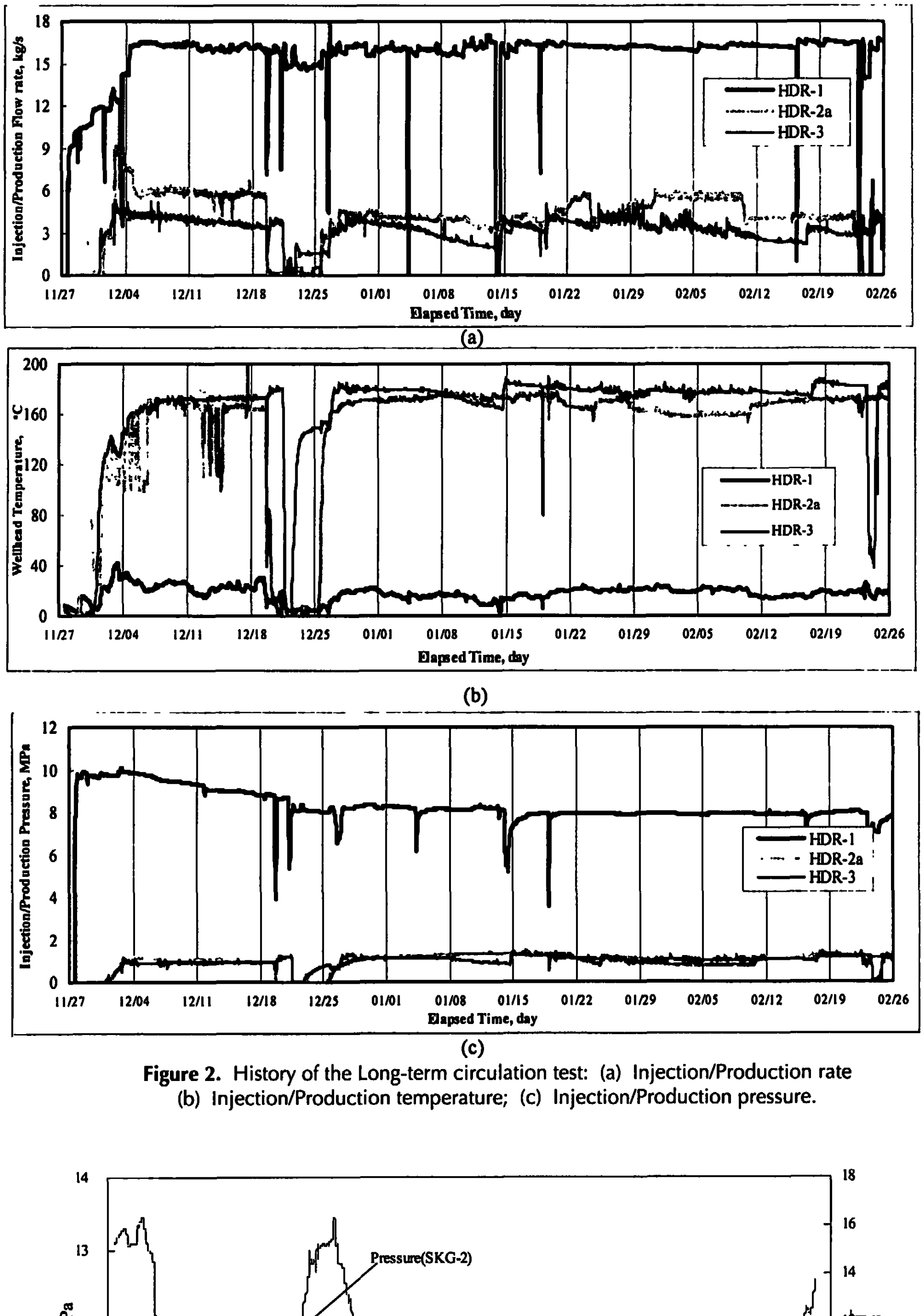

Figure 2. History of the Long-term circulation test: (a) Injection/Production rate (b) Injection/Production temperature; (c) Injection/Production pressure.

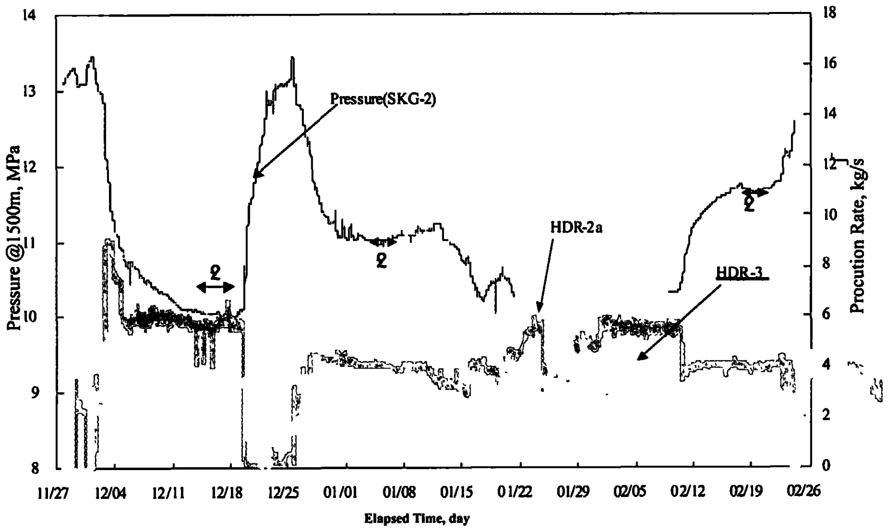

Figure 3. History of pressure data in shallow reservoir and production rate.

HDR-3 (Oikawa *et. al.*, 2001). The purpose of test was estimation of the long-term production characteristics of the Hijiori HDR reservoir and to provide data to calibrate the numerical model of the system.

To evaluate the deep reservoir's characteristic for the long-term circulation, the injection flow rate was almost 16.7 kg/s as shown in Figure 2(a). The amount of steam and hot water from HDR-2a was larger than that from HDR-3. The total fluid recovery rate was about 50%. As shown in Figure 2(a), the initial rate of water injection was relatively low. The reason for this was the necessity of keeping injection pressure lower than 10MPa to ensure the safe operation of the surface facility (Figure 2c). as injection pressure gradually decreased from 10 to 8 MPa, the injection rate was increased to a maximum of 16.7 kg/s(Figure 2 (c)). Production pressure was maintained at approximately 1MPa throughout the test. Wellhead temperature at the two production wells were about 180°C as noted in Figure 2(b). NEDO is planning to continue this test until September 2001, at which time another test will be started with injection into HDR-1 and SKG-2 and production from HDR-2a and HDR-3.

Pressure Monitoring Data in Shallow Reservoir

The Hijiori HDR system has two reservoirs (the shallow reservoir and the deep reservoir) and four wells (SKG-2, HDR-1, HDR2a and HDR3). We observed the phenomenon that fluid within the shallow reservoir flows toward production wells according to the pressure distribution in the reservoir (Tenma *et. al.*, 1995). Thus, to better understand the characteristics of the multi-reservoir system, the pressure of the shallow reservoir was monitored in well SKG-2 during the LTCT. At the beginning of this test, we measured the water level of well SKG-2. But trouble of the measurement tool was happened, we changed the pressure monitoring at the depth of 1,500m. Pressure monitoring data from the shallow reservoir and production flow rate data from both wells were plotted versus time in Figure 3.

As noted in Figure 3, pressure in the shallow reservoir declined rapidly in response to production from wells HDR-2a and HDR-3. Pressure recovery after shut-in of the produc-

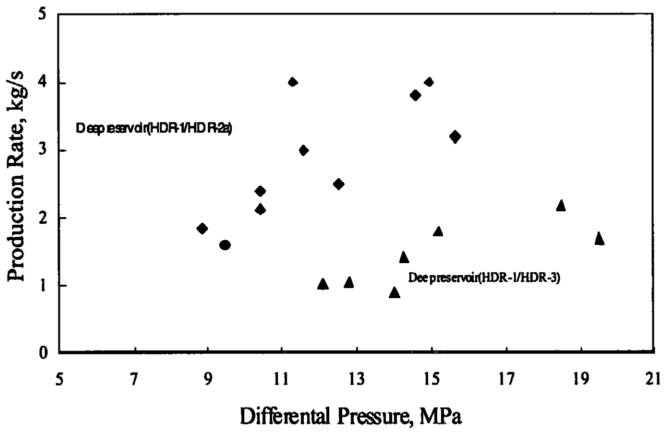

Figure 4. Relationship of flow rate and differential pressure in the deep reservoir.

tion wells was also rapid. Since SKG-2 is completed within the shallow reservoir, these pressure data clearly show how the shallow reservoir responds to production.

Productivity From the Shallow Reservoir

To estimate the characteristic of the multi-reservoir system, we examined the differential pressure and discuss the pressure-flow relationship at the Hijiori HDR reservoir. Using this relationship, we attempted to study productivity from the shallow reservoir during the LTCT. The relationship of the differential pressure and production flow rate in the deep reservoir are shown in Figure 4. Also, we define that the differential pressure is the amount of ΔP_i and ΔP_p as noted in Figure 5(a). Here $\Delta P_i = P_i - P_0$; $\Delta P_p = P_0 - P_p$; P_i is the downhole pressure of the injection well; P_p is the downhole pressure of the production well; P_0 is the initial downhole pressure of the well.

We have determined productivity from the shallow reservoir using following procedure as noted in Figure 5(b).

1) We calculate the downhole pressure of HDR-1(Pi) using the wellbore heat transfer (WBHT) code(Smith *et. al.*, 1982).
2) We assume that pressure of the shallow reservoir and the downhole pressure of production wells are equal during periods when the pressure in the shallow reservoir is stable, as observed in well SKG-2. These downhole pressure of the production wells are noted in Figure 3 using a triangular symbol, and we get P_p .
3) Using the initial downhole pressure data for the injection and the production wells from the PTS logging, we calculate the ΔP_i and ΔP_p
4) We add the ΔP_i and ΔP_p to get the differential pressure using the concept illustrated in Figure 5(a).
5) We get the production flow rate from the deep reservoir using the relationship of the differential pressure and flow rate as shown in Figure 4 using a triangular symbol for well HDR-3 and a diamond-shaped symbol for well HDR-2a.
6) We then subtract the calculated flow rate from the deep reservoir from the total flow rate measured at the wellhead to calculate productivity from the shallow reservoir, as shown in Figure 6.

As noted in Figure 6, productivity from the shallow reservoir in the LTCT is a tendency of productivity in prior circulation test (Exp.9502 & Exp.9602). Thus, we think that characteristics of multi-reservoir system do not change. Also, productivity from the shallow reservoir in HDR-3 is larger than that in HDR-2a in the same total flow rate measured the wellhead. As the connection to the deep reservoir differs in the two production wells, well HDR-2a produces more from the deep reservoir than

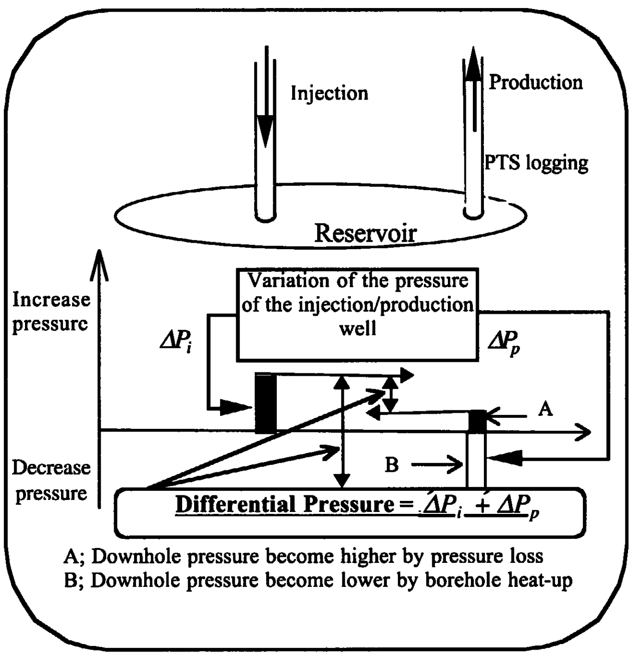

Figure 5(a). Idea of the Differential pressure.

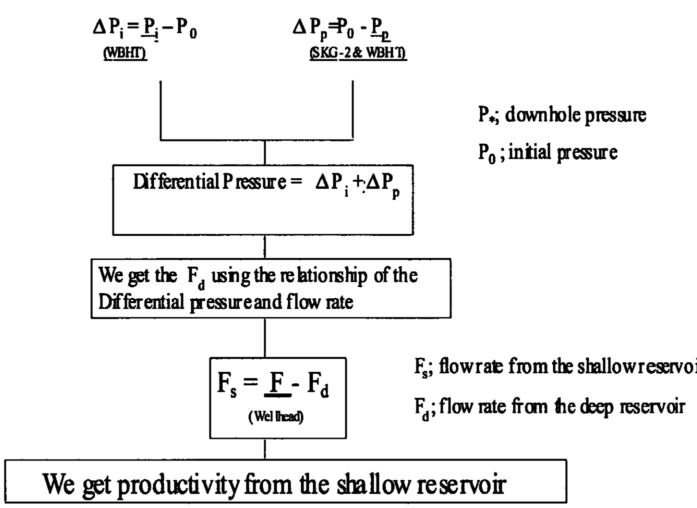

Figure 5(b). Step to get productivity from the shallow reservoir.

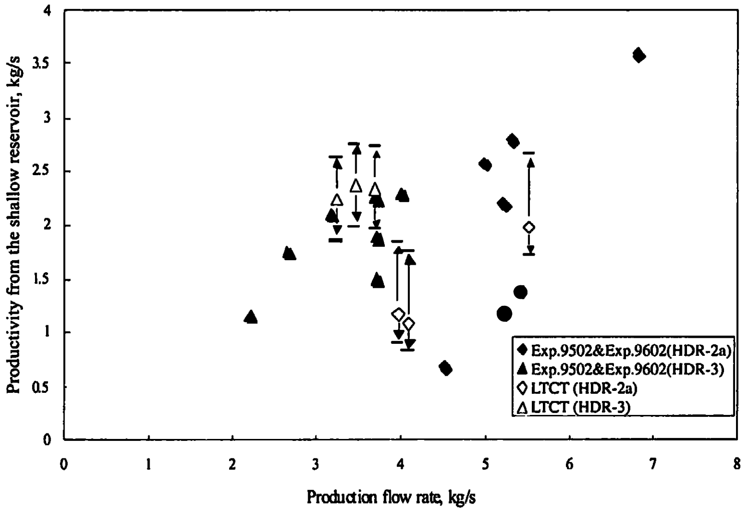

Figure 6. Relationship of productivity (shallow/shallow & deep) and production rate (Arrows show the error area in this analysis.).

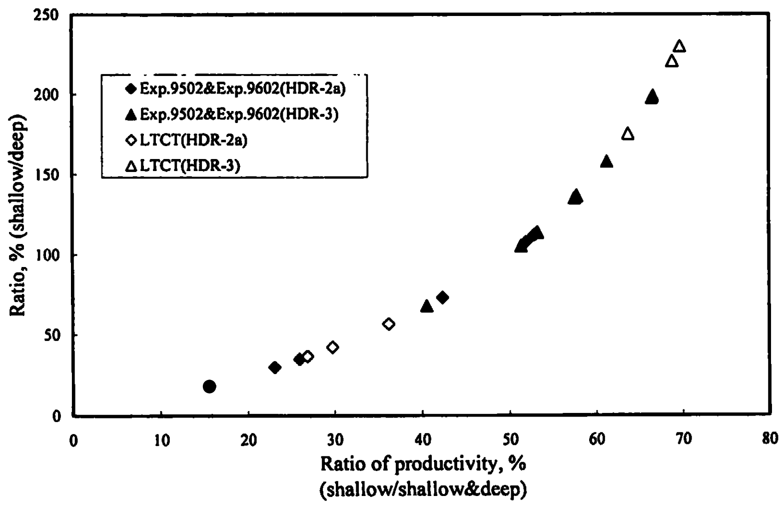

Figure 7. Relationship of the ratio of productivity and ratio.

HDR-3. Therefore, productivity from the shallow reservoir is different.

Also, relationship of the ratio of productivity from the shallow reservoir and the ratio is plotted in Figure 7. Therefore, if all production was derived from the deep reservoir, the ratio is 0; alternatively, if all production was derived from the shallow reservoir, the ratio would be infinity. As noted in Figure 7, data of HDR-2a and HDR-3 are same lines. But, line of HDR-2a is located in left, influence of productivity from the shallow reservoir is small. If production flow rate increase, line of HDR-2a shift the right, and we observe that the production flow rate and productivity both increase in well HDR-2a, while productivity remains constant in well HDR-3, because of line of HDR-3 is located in right.

Conclusion

We continue to measure the injection/production flow rate, temperature, pressure and pressure of the shallow reservoir of the LTCT at the Hijiori HDR test site. Using these data and the relationship of the differential pressure and flow rate, we estimate productivity from the shallow reservoir. Our analysis shows that productivity from the shallow reservoir of the two production wells are different, with the productivity for HDR-3 being larger than that of HDR-2a. We suggest that the difference of connectivity in both production wells cause a difference of productivity. We think the injection ratio of SKG-2 and HDR-1 in the second half of the LTCT using this result. We think that injected water to SKG-2 is same value of production from the shallow reservoir to obtain the high heat extraction from the Hijiori reservoir.

These observations about the proportion of production from the deep and the shallow reservoirs will also be used to help calibrate the numerical model of the multi-reservoir at Hijiori. This modeling effort, which is planned for 2002, will represent the first attempt to accurately quantify the behavior of the Hijiori reservoir under long-term exploitation.

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