HEAT EXTRACTION EXPERIMENT AT HIJIORI TEST SITE

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ABSTRACT

NEDO (New Energy and Industrial Technology Development Organization) conducted a research on development of hot dry rock (HDR) that is a future geothermal resource of energy. As a verification of heat extraction capacity of artificial geothermal reservoir of HDR, a heat extraction experiment for long term was planned three years ago. Preparation, surface instruments, reservoir modeling, prediction of heat extraction behavior, a design of experiment and so on, took three years and the actual experiment of heat extraction was ready to be started. It was started from the late of November and it will last for two years. Though we met unexpected high injection impedance at the beginning and stop of production for 6-days caused by well logging, heat extraction test still continues now. Injection rate is 60t/h and injection pressure is about 8MPa Hot water and steam are produced from wells successfully and production temperature is around 180 deg. C at wellhead. Recovery is about 50% and thermal output is up to 9MW.

INTRODUCTION

HDR is a principal geothermal resource in the future. HDR system utilizes only heat of hot rock and doesn’t need rich geothermal fluid of natural geothermal system (reservoir and fluid supply). In other words, HDR development is to create artificial geothermal system. The artificial reservoir is created by hydrofrac and fluid supply is replaced with an injection well and surface water (e.g. river water). Ordinary geothermal resource that is easy to develop will be exhausted and will be difficult to develop in the end. HDR has huge amount of resource that is equal to the amount of ordinary geothermal resource.

NEDO is conducting a research on development of this future resource of energy. As a verification of heat extraction ability of HDR reservoir, a heat extraction experiment for long term, over a year, at Hijiori test site was planned to study a life of HDR reservoir that is required for stepping up to a next stage of development. The test was called “Long-term circulation test”. Preparation took three years and actual experiment of heat extraction has been ready to be started. It was started from the late of November and it will last for two years. Preparation and results of the start of experiment is reported in this paper.

HIJIORI TEST SITE

Hijiori test site is located at inner southern edge of Hijiori caldera. NEDO started field experiments for HDR development at the site in 1985. This was the first domestic field study of HDR that would produce the actual geothermal steam from the artificial reservoir. Hijiori project consists of two stages of development. On the first stage, small size heat extraction system, named “upper reservoir”, was planned and demonstrated at Hijiori site. It took seven years to reach a final 90-days circulation test that was conducted to study short-term heat extraction behavior of the upper reservoir (Yamaguchi, et al., 1992).

Second stage was started at same field, Hijiori, in 1992 following up to the first stage. Heat extraction system of higher temperature and larger reservoir size
was designed. Distance between injection point and production point was planned over a hundred meter. All wells used in the first stage were reused in the second stage. HDR-1, 2 and 3 were extended to deeper area. The upper reservoir is located around 1,800m depth and a new reservoir, called “lower reservoir”, is created around 2,200m depth in 1992. A role of HDR-1 was changed from a production well to an injection well. HDR-2 and HDR-3 were used as the production wells as before. SKG-2 still remained as an observation well of the upper reservoir and was reserved as an injection well to the upper reservoir in the future study. As shown in an underground part of fig.1, heat extraction system of the second stage that has two injection wells connected to each reservoir independently and two production wells connected to both reservoir was constructed at the site until 1995. In 1995 and 1996, one-month circulation test was conducted to estimate heat extraction ability of lower reservoir for a design of a long-term circulation test in the future. According to results of the circulation tests, a heat extraction test for over a year at least will be needed for evaluation of a life of artificial reservoir of Hijiori. Preparation of the long-term circulation test started in 1997.

**PREPARATION**

Preparation needed three and a half years for the long-term circulation test. A main reason why it took such a long time was the money problem. The long-term circulation test required much money to continue the circulation. The proceeding speed of the Hijiori HDR project was slowing down until an enough budget could be used. However, this made enough time to discuss a design of experiment and to reevaluate the model of Hijiori reservoir.

**Surface instruments**

A surface part of fig. 1 illustrates the simplified surface structures of Hijiori test site. A half of surface structures are reused. Production lines of HDR-2 and HDR-3 are almost same as the last circulation test conducted in 1996. A smart and new electric injection pump of turbine flow was prepared for long-term circulation test instead of engine plunger pumps of powerful. Electric facilities had to be constructed newly to the site for the heavy load of the electric pump. Power line was extended to the site and usability of electricity in the site was improved much. Injection line was newly prepared for a new injection pump and a strict pump house was build for a heavy snowing. Two movable houses were also prepared for observation and temporal geochemical experiments. Water supply line from a river to the site was modified for dry and cold winter. Because

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*Fig. 1 Surface facilities and heat extraction system of HDR in Hijiori site.*
Hijiori is very famous for heavy snowing, a snow melting system is constructed in the site and a maintenance team of snowy road to the site is employed for winter.

**Design of experiment**

A main object of this long-term circulation test is to know a life of artificial reservoir as accurate as possible because the life has to be over 20 years in a practical development stage in the future. A model of Hijiori reservoir was improved year by year in the preparation, reevaluating the data. For example, fracture analysis (Tezuka and Niitsuma, 2000), stress estimation (Sasaki and Kaieda, 2000) were conducted. The model included both upper and lower reservoir and 3-D location of main flow path of each reservoir was reflected to the model (Karasawa et al., 2000). The injection flow rate was set to 60t/h for a comparison to the past data. Thermal behavior of heat extraction test for two years was simulated varying injection flow ratio of the upper and lower reservoirs to know if thermal draw down will be enough to analyze a life of Hijiori reservoir. According to the analysis, one-year circulation of lower reservoir and one-year circulation of both upper and lower reservoir is suitable to estimate the life of Hijiori reservoir (Karasawa et al., 2000).

**RESULTS**

**Outlook of start up of circulation test**

Just before the circulation test, an injection test was conducted for 2-days, from 11/25 to 11/26. The long-term circulation test was started, following the injection test, in the afternoon of 11/27. It took over five days for heat up of both production wells. At the beginning, injection flow rate was lower than planned it because of high impedance of injection well that were unexpected. An ability of injection pump was not enough for such high impedance. Injection impedance was decrease slightly day by day. It took a week for reaching the planned injection rate. On 12/5, chemical tracer was injected to the reservoir and samplings of produced hot water from both production wells were conducted for a week. Secondary valves, which control production rate, of production wells were adjusted around 40% of opening to pressurize wells and to prevent intermittent production. Production status became stable once around the middle of December. On 12/19, HDR-2 was surveyed with PTS (Pressure, Temperature and Spinner) logging tool to observe production points. This logging made HDR-2 production stop and HDR-3 production was also stopped with in the logging of HDR-3 conducted two days later. It also took over five days for heat up of dual wells again. From 12/22, both wells reproduce hot water and steam again and the circulation test continues now.

**Injection test**

The injection test was content with step-rate test and shut-in pressure observation. During the injection test, pressure of three wells, HDR-2, HDR-3 and SKG-2 were observed. Pressure of SKG-2 well was especially important in the test because SKG-2 well is only connected to upper reservoir. HDR-2 and HDR-3 are connected to both upper and lower reservoir. Therefore, pressure behavior of upper reservoir could be observed directly with this SKG-2 monitoring. Injection rate to HDR-1 was kept constant as possible.

**PTS logging and stop of production**

PTS logging was conducted to know both temperature and flow rate of each production point and each injection point. Measured data will be used in the model simulation study mainly and the model will also be used in a prediction of heat extraction behavior over 10 years. PTS logging is very important in this circulation test because direct status of production point and injection point is measured with only this tool.

After the heat-up, both production wells produced hot water and steam satisfactory until the first PTS survey of HDR-2. Temporary recovery rate was up to 60% just before the PTS logging. Production of HDR-2 stopped while a first down survey of PTS tool. Water level of HDR-2 appeared immediately at depth of 200m from the surface. It took 6 days to reproduce hot water again from HDR-2. Down survey of HDR-3 was conducted after two days from the HDR-2 survey. Production of HDR-3 also stopped while second down survey, but first down survey was completed fortunately. It takes one day to reproduce hot water from HDR-3 again. Only the production data of HDR-3 was obtained in the logging. Measures to this stop of production have to be planed before a next PTS survey that is scheduled to be conducted at the beginning of February.

**Recent circulation status**

After reproduce of both wells, the circulation test continues now. Current status (on 1/10/2001) of the test is shown in table 1. Recent recovery is kept lower than it just before the stop of production because the pressure of upper reservoir is intended to be kept higher. This is a part of measures to the stop of production by the PTS logging. Excluding the PTS problem, two case of trouble could be expected in the long-term circulation test. One is faster cooling of HDR reservoir and another is line squeezing by silica scale because the test is conducted truly long time as named.

According to the latest plan, this circulation test will be continued to next October. In next October,
circulation test will be stopped for maintenance and an injection line to the upper reservoir using SKG-2 will be added to the surface instruments. After the maintenance, secondary year of long-term circulation test will begin and it will be continued to the fall of 2002. In the second year, active control of the upper reservoir is planned now. PTS logging and geochemical survey will be conducted every other month.

### Table 1. Circulation status on 1/8/2001

<table>
<thead>
<tr>
<th>HDR-1</th>
<th>HDR-2</th>
<th>HDR-3</th>
<th>HDR-2+HDR-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection pressure (MPa)</td>
<td>8.1</td>
<td>1.29</td>
<td>1.07</td>
</tr>
<tr>
<td>Injection flowrate (t/h)</td>
<td>57</td>
<td>10.2</td>
<td>7.2 17.4</td>
</tr>
<tr>
<td>Production pressure (MPa)</td>
<td>1.29</td>
<td>4.4</td>
<td>2.3 6.7</td>
</tr>
<tr>
<td>Production temperature (deg.C)</td>
<td>1.29</td>
<td>14.6</td>
<td>9.5 24.1</td>
</tr>
<tr>
<td>Production flowrate of hot water (t/h)</td>
<td>9969</td>
<td>14244</td>
<td></td>
</tr>
<tr>
<td>Production volume of steam (t)</td>
<td>8394</td>
<td>11014</td>
<td></td>
</tr>
<tr>
<td>Production volume (t)</td>
<td>18363</td>
<td>25258</td>
<td></td>
</tr>
<tr>
<td>Recovery (%)</td>
<td>26%</td>
<td>21%</td>
<td>42%</td>
</tr>
</tbody>
</table>

### DISCUSSION

In the summer of 1995 and 1996, circulation tests using lower reservoir for about one month were conducted. Injection tests were also conducted at the start and the end of both circulation tests. After the Christmas, long-term circulation test reached over 30-days successfully and could be comparable. First circulation test using lower reservoir was conducted in 1995 to study a character of lower reservoir. Thermal output and recovery were measured under two kinds of injection flow rate, 60t/h and 120t/h. It was pointed out that connectivity between HDR-1 and HDR-3 was not good. Second circulation test was designed to improve this connectivity problem. Several flow patterns were tried in the circulation test in 1996. The improvement of the connectivity was not clear unfortunately. However, improvement of the connectivity is thought not to be necessary to conduct the long-term circulation test because of a fairly stability of the HDR-3 production in both circulation tests.

### Comparison to the past injection tests

According to the injection test in last November, injection pressure is high, over 10MPa, as the first injection test conducted in 1995. Injection impedance to HDR-1 was decreasing to the time of circulation in the past. Therefore, the injection impedance of the first injection test in 1995 is highest and the injection impedance of last injection test is lowest. After the circulation test of 1996, injection pressure was 7.5 MPa. A blank between the 1996 circulation test and this circulation test is over 3-years. This blank is the main reason of high injection impedance.

### Comparison to the past circulation tests

In the present circulation test, total recovery is up to 50%. This is much higher than the past circulation tests. In 1995, total recovery was 40% and 31% in 1996. Pressure of upper reservoir is much lower than the past tests. The lowest pressure of the present test was 9.5MPa at 1500m depth of SKG-2 and the temporary recovery was up to 60% then. The lowest one in 1995 test was 11.6MPa at the same depth of SKG-2 and the lowest one in 1996 was 10.9MPa. This very low pressure of upper reservoir may relate to such a high recovery. Maximum thermal output of the present test is over 9MWt. This is the highest one in this project.

### CONCLUSIONS

NEDO started the long-term circulation test from the end of last November. A main object of this long-term circulation test is to know a life of artificial reservoir of HDR. Troubles were occurred but that were not serious fortunately. Interesting points in the start of the test are below.

1. Unexpected high impedance of injection at the beginning
2. Higher recovery
3. Very low pressure of the upper reservoir
   This test continues for tow years. In the second year, active control of the upper reservoir is planned.

### ACKNOWLEDGEMENTS

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### REFERENCES


