PROCEEDINGS

"Geothermal Energy and the Utility Market - The Opportunities and Challenges for Expanding Geothermal Energy in a Competitive Supply Market"

March 24 - 26, 1992
San Francisco, CA

Sponsored by:

U.S. Department of Energy
Assistant Secretary, Conservation and Renewable Energy
Geothermal Division
Washington, DC 20585
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
RECENT DEVELOPMENTS IN JAPAN'S HDR PROGRAM

Tsutomu Yamaguchi
Geothermal Energy Technology Department
New Energy and Industrial Technology Development Organization

Introduction

Japan is one of the most active volcanic countries in the world, and it is understood to have very abundant geothermal energy. In Japan, where only a limited amount of other natural energy resources are domestically available, geothermal energy is one of the nation's purely indigenous energy sources. Its development therefore, has, been anxiously urged. Geothermal energy is classified generally in several types: vapor dominated type resources, which are mainly used to generate electric power, and low grade hydrothermal fluid and hot dry rock type resources, most of which are not used at present in Japan.

NEDO, the New Energy and Industrial Technology Development Organization, promotes the technological development of geothermal energy utilization in order to increase the use of this type of energy, particularly in such technical fields as the development of a power plant that uses hydrothermal fluids. This type of plant will enable the effective use for power generation of not only steam, but also geothermal fluid, so as to permit the use of hot water that flows out in great quantities together with useful geothermal steam.

The vast volume of geothermal water with medium to high temperature left intact underground will also be possible to utilize. Research themes promoted by NEDO, the Geothermal Energy Technology Department and the budget for FY 1991 (from April 1991 to March 1992) are listed below.

1) Development of 10MW Class Binary Cycle Power Plant ($2.0M)
2) Development of Down-hole Pump ($3.0M)
3) Development of Technology for increasing Geothermal Energy Recovery ($5.9M)
4) Development of Measurement While Drilling System ($0.4M)
5) Development of Hot Dry Rock Power Generation Technology ($7.1M)

The total amount of 18.4 Million dollars is allocated for FY 1991 ($1 = 130 yen). Figure 1 shows the budgets from FY 1990 to 1992 (requested). The total amount of budgets listed above is grouped into 'Technology R & D' in Figure 1. Figure 1 also shows the budgets for 'Survey & Promotion' items conducted by NEDO.

This paper reviews the history of HDR development in Japan and summarizes the recent development of NEDO's HDR project.

Since FY 1985, NEDO has been conducting research to develop basic technologies for hot dry rock geothermal power generation at Hijiori, Okura Village in Yamagata Prefecture. The main purpose of this research is developing a heat extracting circulation system in hot dry rock of depth and temperature similar to those expected for a commercial scale operation. Within this scope, NEDO developed fundamental technologies for creating an artificial geothermal reservoir, establishing hydraulic communication between wells, logging boreholes, observing acoustic emission (AE) events for fracture mapping, evaluating flow through the reservoir, and estimating geothermal heat recovery.

In the hot dry rock geothermal project, especially in Japan, it is important to understand how pre-existing fractures affect hydrofracture development. At present, there are a number of methods that can be employed to understand the fractures, but it is necessary to evaluate which are most appropriate and accurate. Since FY 1989, we have been performing small-scale fracture characterization experiments on-site in Iitate Village, Fukushima Prefecture, where the granite basement rock outcrops.
The locations of the Hijiori and I-itate test sites are shown in Figure 2. Figure 3 shows the schematic history of the Hijiori project, together with other HDR work in Japan.

Brief History of HDR Project and Study Program

Since FY 1978, the Hot Dry Rock geothermal power project performed field tests to develop technology at the northwestern foot of Yakedake Mountain in Gifu Prefecture. This work is a part of the Sunshine Project of the Agency of Industrial Science and Technology, Ministry of International Trade and Industry. From 1981 to 1986, NEDO participated in the Hot Dry Rock geothermal energy development program at the Fenton Hill test site in the USA (a joint study program of Japan, USA, and Germany under the agreement of IEA).

Based on the results of the Yakedake and the IEA studies, NEDO has been establishing the basic technologies for developing Hot Dry Rock geothermal energy under the conditions of high temperature, high pressure and geological structures of Japan. For this purpose, NEDO has been carrying out field test work at Hijiori since FY 1985, with the support of the Sunshine Project. The Hijiori project site is located at the southern edge of Hijiori Caldera which has two kilometers of diameter formed about ten thousand years ago (as shown in Figure 4).

From 1985 to 1986, a seven-inch casing was installed in the existing SKG-2 well (1,802m deep, bottom hole temperature of 253°C), which had been drilled to exploit a conventional hydrothermal reservoir. A hydraulic fracture was created from a 14m uncased zone at the bottom hole.

In FY 1987, the HDR-1 (1,805m deep) was drilled into the hydrofracture to create an artificial reservoir. NEDO successfully circulated water between the two wells through the fracture. The distance between the two wells is about 35m in the neighborhood of the bottom of the holes.

In FY 1988, NEDO conducted a heat-extracting circulation test for two weeks. In this test, hot water and steam at a maximum temperature of 180°C were recovered. However, the test data could not be used to identify the reservoir's characteristics because the hot water and steam from the production well blew out intermittently. After the circulation test, well HDR-1 was deepened to 2,205m, and a PBR casing liner was installed leaving the bottom 50m of the hole open.

In FY 1989, well HDR-2 was drilled to confirm the location of the fracture created by hydraulic fracturing, and to begin steady production. HDR-2 intersected very closely to expected position, thus confirming the results of fracture mapping by AE. After completion of the HDR-2 drilling (1,909m deep), a circulation test was carried out during a period of 29 days. Heat energy of 4.5MW was produced from hot water and steam at a temperature of 160°C to 170°C. A recovery rate of fluid during the circulation test remained at 32%. The flow was nearly continuous over the duration of the test.
In FY 1990, well HDR-3 (1,907m deep) was newly drilled to enhance the recovery rate. At this point in time, a multi-wellbore circulation system, which consists of 1 injection well (SKG-2) and 3 production wells (HDR-1, HDR-2, HDR-3) was completed. A small amount of water was injected into well SKG-2 to examine the pressure response of well HDR-3. It seemed that there were good connections between wells SKG-2 and HDR-3. The history of development is summarized in Figure 5.

In FY 1990, well HDR-3 (1,907m deep) was newly drilled to enhance the recovery rate. At this point in time, a multi-wellbore circulation system, which consists of 1 injection well (SKG-2) and 3 production wells (HDR-1, HDR-2, HDR-3) was completed. A small amount of water was injected into well SKG-2 to examine the pressure response of well HDR-3. It seemed that there were good connections between wells SKG-2 and HDR-3. The history of development is summarized in Figure 5.

1986 Conducted hydraulic fracturing (1000m³)
SKG-2

1987 Drilled HDR-1

1988 Conducted 2 weeks-circulation
HDR-1

1989 Drilled HDR-2
Conducted 1 month-circulation
HDR-1

1990 Drilled HDR-3

1991 Conducted 3 months-circulation
HDR-1

Fig.5 Summary of Hijiori development

Progress in FY 1991

In FY 1991, a 3-month circulation test was conducted, using SKG-2 as an injection well and HDR-1, HDR-2, and HDR-3 as production wells. The schematic view of the wells is shown in Figure 6. This circulation test was begun on August 6 and conducted until November 3. The total amount of water injected during this circulation test was 134,500 tons. The injection flow rate had been basically kept constant at 1 ton/min over the circulation test. The injection water recovery rates and the thermal output are summarized in Table 1. Table 1 also shows the result of the circulation test conducted in FY 1989 for comparison. In FY 1989, the production well HDR-3 had not been drilled yet. As shown from Table 1, the recovery rate during the 90-day circulation test was almost 77%, which is almost two times higher than those of the 2-production well system conducted in FY 1989. The thermal output, which was defined as the enthalpy extracted from the hydraulic fractures, was almost 8MW.

Figure 7 shows the wellhead temperature changes of each well during the circulation test. Although the wellhead temperature of HDR-2 and HDR-3 are decreasing slightly, HDR-1 was increasing over the circulation test. The temperature of the injection water into SKG-2 had been kept almost constant at 50°C.

Table 1. Summary of two circulation tests

<table>
<thead>
<tr>
<th>Test in 1989</th>
<th>Test in 1991</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping duration</td>
<td>29 days</td>
</tr>
<tr>
<td>Wells</td>
<td>SKG-2</td>
</tr>
<tr>
<td>HDR-1, HDR-2</td>
<td>HDR-1, HDR-2</td>
</tr>
<tr>
<td>Injection flow rate</td>
<td>1 m³/min</td>
</tr>
<tr>
<td>pressure</td>
<td>5 MPa</td>
</tr>
<tr>
<td>Recovery</td>
<td>32%</td>
</tr>
<tr>
<td>Production temp.</td>
<td>160-175 °C</td>
</tr>
<tr>
<td>Thermal output</td>
<td>4.5 MW</td>
</tr>
</tbody>
</table>
Figure 8 shows the production rates of 3 wells. Fifty days after the beginning of the circulation test, the production rates of HDR-2 and HDR-3 were almost the same, and twice as much as HDR-1 production rate.

The pressure temperature and flowrate (PTS) loggings were conducted frequently during the circulation test. Figure 9 shows the temperature profiles within the three production wells. The dotted lines in this figure show the initial temperature profiles, and the solid lines show the temperatures of the final stage in the circulation test. This figure shows the temperature profiles between 1,500m and 1,900m. In this interval of depth, HDR-2 and HDR-3 have uncased zones. The profile of HDR-1 was somewhat vague because of a PBR casing liner inserted in FY 1988. As seen in Figure 9, all production wells had multiple production zones indicated by arrows. The bold arrows show the main production zone in each well. The distances between the bottom hole of SKG-2 (injection point) and the main production zones of HDR-1, HDR-2, and HDR-3 were 61m, 47m and 71m, respectively. Figure 10 shows the history of the fluid temperatures estimated at the outlet of each fracture zone in HDR-3. Figure 11 shows the feed ratio (contribution) of each production zone within HDR-2 and HDR-3.
Future Plan

In FY 1991, the 90 day circulation test was conducted using the fractures around 1,800m depth. In FY 1992, we will create a hydrofracture from a 50m uncased zone (2110m to 2200m) at the bottom of hole HDR-1.

Acknowledgement

This document describes the work of many individuals involved in NEDO Hijiori Hot Dry Rock Program. The specific contributions of Isao Matsunaga (National Institute for Resources and Environment) and Makoto Miyairi (JAPEX) are gratefully acknowledged.

The HDR project in Hijiori is supported by the Sunshine Project, AIST, MITI. We thank the Sunshine Project Promotion Headquarters.

Acoustic Emission (AE) had been monitored during the circulation test by a surface net which consists of 10 stations, and by a double-sonde downhole system in SKG-1 which consisted of tri-axial component AE sonde and a single component hydro-phone sonde. Because the recovery rate was so high compared to the circulation test conducted in FY 1989, AE activities had not been observed during the circulation test. On the last day of the circulation test, all the wellheads of the production wells were completely closed and the injection rate into SKG-2 was increased to 3 tons/min to promote the AE activity. In this stage, about 50 AE activities had been observed and located.