LONG-TERM CIRCULATION TEST AT HIJIORI SITE, JAPAN

Y. OIKAWA[1], K. KAWASAKI[1], T. TOSHA[1], N. TENMA[2] & Y. SATOU[3]

[1]New Energy and Industrial Technology Development Organization, Tokyo, JAPAN
[2]National Institute of Advanced Industrial Science and Technology, Tsukuba, JAPAN
[3]Geothermal Energy Research & Development Co., Ltd., Tokyo, JAPAN

SUMMARY – The New Energy and Industrial Technology Development Organization (NEDO) is conducting research on development of hot dry rock (HDR), a future geothermal resource. A small heat extraction system for HDR was constructed in a geothermal area, Hijiori. To verify the heat extraction capacity of these artificial HDR geothermal reservoirs, a long-term heat extraction experiment was planned and is now being conducted. The test commenced last November and was successfully continued over 240 days to the end of July. Maximum thermal output was 9.3 MWt in the early part of the circulation test when recovery was over 60%. These figures had decreased to 5MW and 42%, respectively, by the end of July. Thermal output and surveyed temperature profile data provided clear thermal draw down of the production zones in HDR-2a. The model of the Hijiori system can be reevaluated with this data and will be used in the verification.

1. INTRODUCTION

The role of HDR in the development of geothermal energy will become increasingly important in the future. The HDR system utilizes only the heat from hot rock and does not require the rich geothermal fluid in a natural geothermal system (reservoir and fluid supply). The artificial reservoir is created by hydrofrac and the fluid supply is replaced with an injection well and surface water (e.g. river water). Therefore, HDR is applicable to many places where comprehensive geothermal development cannot be undertaken. HDR is a vast resource equal to ordinary geothermal resources. The water injection techniques of HDR are also applicable to comprehensive geothermal development to enhance the fluid supply in the natural geothermal system.

NEDO is working on the development of this energy resource. A small heat extraction system of HDR was constructed in an actual geothermal area to develop a construction method for the HDR system. The site was named "Hijiori test site" after the name of a hot spring town near the site. To verify the heat extraction ability of HDR reservoirs, a long-term heat extraction experiment at Hijiori test site was planned to assess the life of the HDR reservoir prior to advancing to the next stage of development. The test, now called the "Long-term Circulation Test," was begun last November and is scheduled to last for one-and-a-half years. Results of the first eight months of the experiment are reported in this paper.

2. HIJIORI TEST SITE

The Hijiori test site is located at the 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 actual geothermal steam from an artificial reservoir. The present Hijiori project consists of two stages of development. In the first stage, a small heat extraction system, now called the "upper reservoir", was planned, created and tested. It took seven years to reach a final 90-day circulation test that was conducted to study the short-term heat extraction behavior of the upper reservoir (Yamaguchi, et al., 1992). At this stage, a newly conceived concept of heat extraction system—one injection well and multiple production wells—was presented and demonstrated. This concept was applied to more permeable areas where there is evidence of improved recovery.

The second stage was started at the same field, Hijiori, in **1992** as a follow up to the first stage. A larger heat extraction system (higher temperature and larger reservoir size) was designed. The distance between the injection point and the production points was designed to be greater than one hundred meters. Fig. 1 shows a conceptual diagram of the present Hijiori HDR system. All wells used in the first stage were reused in the second stage. HDR-1, 2 and 3 were extended to deeper areas. A new reservoir, called "lower reservoir," was created around **2,200m** in depth in **1992.** The role of HDR-1 was changed from a production well to an injection well. HDR-2 and **HDR-3** are used as the production wells as before. **SKG-2** remained as an observation well of the upper reservoir and is reserved as an injection well to the upper reservoir for future studies. As shown in Fig. 1, the heat extraction system of the second stage that has two injection wells connected to each reservoir independently and two production wells connected to both reservoirs were constructed at the site prior to **1995.** In **1995,** a one-month preliminary circulation test was conducted to estimate the heat extraction ability of the lower reservoir in order to design a future long-term circulation test. Thermal output and recovery were measured under two injection flow rates, **16.7kg/s (60t/h)** and **33.3kg/s (120t/h).** It was pointed out that connectivity between **HDR-1** and HDR-3 was inadequate. The second circulation test was designed to improve this connectivity problem. Several flow patterns were **tried** in a one-month circulation test in **1996.** Unfortunately, improvement in connectivity was not clarified. However, such an improvement is not thought to be necessary to conduct the long-term circulation test because of fairly stable HDR-3 production during both circulation tests. According to the results of these circulation tests, a heat extraction test of a minimum of a year would be necessary to evaluate the life of the artificial reservoir of the Hijiori HDR system. Preparation for the long-term circulation test **started** in **1997,** requiring three years for completion. In late last November, the long-term circulation test was begun. Fig. 1 also illustrates the fundamental surface structures of the present Hijiori test site.

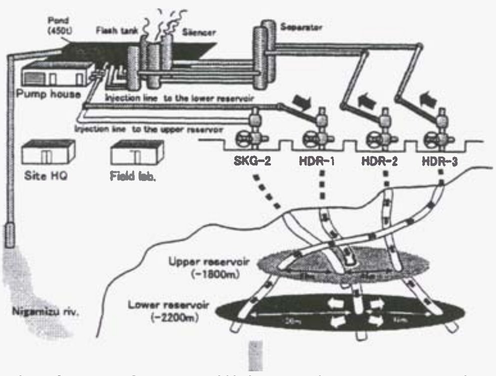

Fig. 1. Surface Facilities and Heat Extraction System of HDR in Hijiori Site

3. EXPERIMENTS

3.1 Objectives and Design

The most important objective of this long-term circulation test is to evaluate the life of an artificial reservoir, which must exceed **15** years in the future practical development stage. The model of the Hijiori HDR system evaluated with data from the long-term circulation *test* will provide an optimized heat extraction design and the optimized life of this small HDR system. Moreover, during the long-term circulation.test, problems may arise which must be solved prior to the practical development stage.

Though the complex structure of the Hijiori HDR system that has dual reservoirs presented difficulties in creating a model, this model was improved during the preparation stage by reevaluating data. For example, fracture analysis (Tezuka and Niitsuma, **2000),** stress estimation **(Sasaki** and Kaieda, 2000), and reservoir simulation (Tenma et al., 2000) were conducted. The model includes both the upper and lower reservoirs and reflects the 3-D location of the main flow path of each reservoir and natural fracture distribution system as anisotropic permeability (Karasawa et al., **2000).** The Hijiori **HDR** system has two injection wells with one connected only to the upper reservoir and the other connected only to the lower reservoir. Therefore, we can inject water into each reservoir independently. The injection flow rate was set at 16.7kg/s for comparisons with past data from one-month circulation tests conducted in each **1995 and 1996. The** thermal behavior of the heat extraction test over two years was simulated by varying the injection flow ratio of the upper and lower reservoirs to ascertain if the thermal draw down would be sufficient to analyze the life of the Hijiori reservoir. According to the analysis, an initial one-year circulation test of the lower reservoir will provide adequate thermal draw down of the lower reservoir and a subsequent half-year circulation test of both the upper and lower reservoirs will provide the important characteristics of a dual circulation system needed in the future stage of HDR development (Karasawa et al., **2000).**

The long-term circulation *test* started on November **27, 2000** and will continue for one-and-a-half years, including maintenance periods. The first long halt for maintenance is scheduled for October **2001** during which an injection line to the upper reservoir using **SKG-2** will be added to the surface equipment. The subsequent half-year of the long-term circulation test **will** then begin, continuing to mid-2002. Active control (water injection) of the upper reservoir will be conducted for the second year.

3.2 Equipment and Facilities

A new electric turbine injection pump was prepared for the long-term circulation test in place of the previous engine plunger pumps. A permanent pump house was built as a countermeasure against heavy snow. Injection equipment for geochemical tracers was connected to the injection line. The water supply line from the river to the test site was modified for the dry and cold winter weather. Geochemical sample ports were added to the injection line to investigate the contents of the injection water. Production lines commonly used in geothermal fields in Japan were employed. Steam from the production lines blows directly into the air. Hot water from the production lines pours into the make-up pond and is reused as injection water after being mixed with river water. Geochemical sample ports were also added to these production lines. Two prefabricated buildings were prepared for observation and temporal geochemical experiments. A snow-melting system was constructed at the site and a road maintenance team is employed during the winter to maintain the access route to the site because Hijiori is infamous for heavy snows.

The measurement system of injection/production data was newly constructed and includes a warning system to a remote watch house about 1 km from the site. A PTS (Pressure, Temperature and Spinner) logging tool that measures pressure, temperature and flow rate in a wellbore was prepared for direct measurement of injection zones and production zones in the well. An AE measurement system was reconstructed for permanent measurement and is also used for seismic monitoring. This system has four permanent observation wells; in addition, eight temporary observation wells are currently being installed to the system.

4. RESULTS

4.1 Overview

This circulation test successfully continued for over 240 days as at the end of July. In the test, injection status, production status and AE events were measured continuously. PTS logging was conducted approximately every six weeks. Geochemical sampling was conducted every week and a geochemical tracer test was conducted approximately every two months. In this test, three very important findings have been revealed. The first is a scale problem in the production wellbore, just like that in a conventional geothermal well. The second was an occurrence of a large AE event. The last was the very good thermal draw down observed in HDR-2a. The current status (on Aug. 9, 2001) of the test is shown in Table 1.

Table 1. Present Injection/Production Status (August 9,2001)

	HDR-1	HDR-2	HDR-3	HDR-2 +HDR-3
Temporary *status*				
Injection pressure (MPa)	6.4			
Injection flowrate (kg/s)	15.5			
Injection temperature (deg.C)	36			
Production pressure (MPa)		0.08	0.72	
Production temperature (deg.C)		112	169	
Production flowrate of bot water (kg/s)		2.7	2.6	5.3
Production flowrate of steam (kg/s)		0.47	0.97	1.44
Production flowrate (kg/s)		3.17	3.57	6.74
Recovery (%)		20%	23%	43%
General status				
Injection volume (t)	371,064			
Production volume of bot water (t)		65.683	58,021	123,704
Production volume of steam (t)		24,906	19,250	44,156
Production volume (t)		90,589	77,271	167,860
Recovery (%)		24%	21%	45%

4.2 Injection Status

Extremely high injection pressure prevented us from injecting water at the planned rate at the start of the long-term circulation test. Five days were required to increase the injection rate up to the planned rate of 16.7kg/s. The injection pressure decreased from over 10MPa to about 8MPa in one-and-a-half months. Though the mid-winter injection temperature was very low, about 4 deg. C, it has now increased to over 20 deg. C.

4.3 Production Status

Fig. 2 shows production data from the circulation test. Recovery can be controlled with secondary valves installed in the production line near the wellhead. The actual range of the recovery control is from 40% to 60% under stable production conditions. Recent recovery is maintained as high as possible and remains around 42%. Though wellhead temperature cannot be used as a simple indicator of fluid temperature owing to its dependence on wellhead pressure, the temperature of HDR-2a is about 110 deg. C and that of HDR-3 is about 170 deg. C, as shown in Table 1. Thermal output (production enthalpy - injection enthalpy) has remained about 5 MWt under stable production conditions.

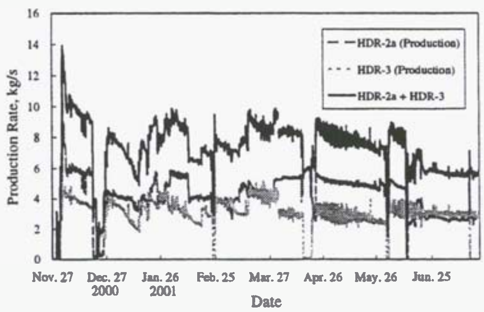

Fig. 2. Production History of the Long-term Circulation Test

4.4 PTS Logging, AE Measurement, Geochemical Survey and Environmental Monitoring

PTS logging is conducted to measure directly the pressure, temperature and flow rate of the production/injection zones of the well. The measured data will be used mainly in the model simulation study and the model will be used in the prediction of heat extraction behavior over 10 years. PTS logging is indispensable to this circulation test because the direct status of production zones and injection zones can be measured only with this tool. Each production well is connected to both upper and lower reservoirs and thermal draw down is expected to be observed only in the lower reservoir during the first year. PTS logging was conducted five times. The first two loggings were successfully conducted in both production wells, but in the third logging, the PTS tool was not lowered below about 2,030m depth in HDR-2a. On the fourth and fifth loggings, the PTS tool did not go below a depth of about 1,990m in HDR-2a and did not go below about 2,000m of HDR-3. Anhydrite scale deposits in the boreholes caused this unexpected phenomenon. Hence, the thermal draw down of the production zones in the lower reservoir was not revealed directly. Only comparable data to 1,990m depth in HDR-2a and to 2,000m in HDR-3 were measured. Thermal draw down of the lower production zones of HDR-2a was assumed to be at a depth of 1,990m. It was over 140 deg. C in the latest (fifth) PTS logging. Thermal draw down of the lower production zones of HDR-3 was over 15 deg. C. in the last successful (third) PTS logging.

AE measurement is conducted to observe fluid movement in and around the artificial reservoir induced by injection water. This is an indirect method of reservoir monitoring. Over 250 AE events have been observed since January and obvious reservoir extension has not been observed at this point.

Geochemical surveys are conducted to ascertain the volume and flow path characteristics of the artificial reservoir. Two types of geochemical measurement are conducted in the circulation test. One is a so-called tracer test conducted by IGE (Institute for Geo-resources and Environment, known previously as NIRE) and the other is analysis of natural content ions conducted by NEDO.

Environmental monitoring is conducted to determine the environmental effects resulting from the circulation test. Two kinds of monitoring are conducted. One is seismic monitoring and the other is a geochemical survey of the natural spa water and river water. A large AE event occurred in the early morning of March 29 and some local residents heard a sonic vibration caused by this large event.

5. DISCUSSION

5.1. Injection Pressure

After the preliminary circulation test in 1996, the injection pressure was decreased to 7.5 MPa under a flow rate of 16.7kg/s. Therefore, the injection pressure was suggested to be about 8 MPa for the long-term circulation test and would decrease as time passed. According to the injection test of last November just prior to the long-term circulation test, the injection pressure was high, over 10 MPa under, a flow rate of 16.7kg/s., similar to that of the very first injection test conducted in 1995 before the first preliminary circulation test. The interim between the 1996 circulation test and this circulation test is longer than 4 years and is the main reason of the high injection pressure. About one month was required for the injection pressure to decrease to about 8 MPa under a flow rate of 16.7kg/s. This indicates the hydraulic character of the artificial reservoir could recover.

5.2 Production Behavior

Production status was unstable in this long-term circulation test. The steam and hot water production of each well fluctuated easily caused by very small movements of the production valves or by injection stoppage caused by trouble or maintenance. The hot water supply from the upper reservoir had a very important role in the production till June. The production ratio from the upper reservoir was estimated to be about 50% in the preliminary circulation test in 1995 and the upper reservoir was used passively (as in the circulation test in 1995) in the first half of the long-term circulation test. Therefore, the pressure balance between the production well and the upper reservoir controls production from the upper reservoir. In other words, the status of the production well controls production ability by only itself. This passive production from the reservoir is not controlled directly by surface operation. Therefore, a direct comparison between this circulation test and the past circulation test is not straightforward.

In the circulation test in 1995, the highest stable recovery was 55%, while recovery over the last five days was 50%. Total recovery was 39% because of a 33.3-kg/s-injection operation (recovery; 30%) conducted for ten days. The total production ratio of HDR-2a/HDR-3 was 1.9 and the maximum thermal output was 9.3 MWt. The circulation test in 1996 aimed to improve the productivity of HDR-3. The highest stable recovery during the improvement check test was 52% and total recovery was 31% because of shut-in of HDR-2a for 23 days. Temporary recovery in the present circulation test was over 60% in the early period and decreased to about 42% at the end of July. Present total recovery will be about 44% at the end of September. This total recovery characteristic is similar to the preliminary circulation test in *1995.* The stable thermal output of the present test was up to *9.3* MWt in the early period and decreased to 5MWt. Thermal draw down of HDR-2a caused this fall in thermal output. Wellhead temperature decreased from 160 deg. C to 110 deg. C at the end of July. In other words, thermal draw down of HDR-2a is enough to estimate the life of an artificial reservoir. The model of the Hijiori system can be reevaluated with this data from HDR-2a.

6. CONCLUSIONS

NEDO started the long-term circulation test late last November. The main objective of this long-term circulation test is to ascertain the life of an artificial HDR reservoir. Troubles occurred but, fortunately they were not serious and the circulation test still continues. The interesting points are noted are below.

1. Unexpected high injection pressure over 10 MPa at the beginning at the beginning of the test was observed,. and injection pressure has not declined as expected. This indicates that the hydraulic character of the artificial reservoir is recoverable during circulation stoppage.

2. Unstable production status caused by variable production from the upper reservoir suggests the difficulty of passive use of the reservoir.

3. Max. thermal output was *9.3* MWt in the early term of this circulation test when recovery was over 60%. These values decreased to *5MW* and 42% at the end of July.

4. Thermal draw down of over 140 deg. C from the production zones of the lower reservoir in HDR-2a was clearly observed.

This test will continue for one-and-a-half years. In the final half-year, active control of the upper reservoir is planned (dual injection and production).

7. ACKNOWLEDGMENTS

The NEDO HDR R&D project was funded and promoted by the New Sunshine Program, Agency of Industrial Science and Technology, Japan.

8. REFERENCES

Karasawa, H., Egawa, Y., Tenma, N. and Kadowaki, M. (2000). Results of experiments and future plan of the Hijiori HDR project. *Proceedings* of Asia *Geothermal Symposium 2000,* 12-17.

Sasaki, S. and Kaieda, H. (2000). Determination of stress state at the Hijiori HDR site from focal mechanisms. *Proceedings of the World Geothermal Congress2000*, 3859.

Tenma, N., Yamaguchi, T., Tezuka, K. and Karasawa, H. (2000). A Study of the pressure-flow response of the Hijiori reservoir at the Hijiori HDR test site. *Proceedings* of *the World Geothermal Congress2000*, 3917.

Tezuka, K. and Niitsuma, H. (2000). Stress estimated using microseismic clusters and its relationship to the fracture system of the Hijiori hot dry rock reservoir. *Engineering Geology,* 56, 47-62.

Yamaguchi, T. et al. (1992). 90-day circulation test at Hijiori test site. *Geothermal Resources Council Transactions,* 16, 417-422.