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HEAT EXTRACTION EXPERIMENT AT HIJIORI TEST SITE (FIRST YEAR)

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ABSTRACT

NEDO (New Energy and Industrial Technology Development Organization) researches development of hot dry rock (HDR). In order to verify the heat extraction capacity of dual artificial reservoirs of HDR, a long-term heat extraction experiment was started on November 27, 2000. In the first year of the test, only a single reservoir was used for circulation. The test was successfully continued for over 330 days as at November 15, 2001. Max. thermal output was 9.3 MWt when recovery was over 60%. These figures had decreased to 3.6 MWt and 39%, respectively, by December 10 2001. Thermal output and surveyed temperature profile data provided clear thermal draw down of the production zones in HDR-2a. In the second year, dual reservoir circulation and a power generation test is scheduled. The model of the Hijiori system can be reevaluated with these data and will be used in the verification.

INTRODUCTION

HDR will play an important role in the development of geothermal energy in the future. The HDR system requires an artificially driven geothermal reservoir. The artificial reservoir of HDR is created by hydrofrac and surface water (e.g. lake water) is pumped through an injection well. This technique can develop very hot geothermal resources with less geothermal fluid and is also applicable to enhance/sustain ordinary geothermal usage.

NEDO has been conducting research on HDR development techniques since FY1985. The research will continue through next fiscal year (FY2002) when HDR development plans will be reexamined.

A heat extraction experiment called “Long-term Circulation Test” is being conducted at Hijiori test site to study the life of the HDR reservoir. This experiment is the final one before the said reexamination. This test was started on November 27, 2000 and will last until August 2002. The first year results of this test are reported in this paper.

HIJIORI TEST SITE AND UNDERGROUND HDR SYSTEM

The Hijiori test site is located in a small caldera with a diameter of about 2km. The target basement rock is a granodiorite that lies below 1,500m in depth. Hijiori spa town is located 1km from the test site. Field experiments of HDR development by NEDO were started at the site in 1985. Two stages of development were conducted in this project. In the first stage, a small heat extraction system, called “upper reservoir” now, was planned and created because the hydraulic characteristics of the artificial reservoir, especially connectivity between the injection well and the production well, in a domestic basement rock had not been thoroughly investigated at that time. The distance between the injection zone and the production zone was planned to be within several tens of meters for the above reason. One exploratory well, SKG-2, which was drilled by a private company, was borrowed and modified for full-hole pressurizing (hydrofrac and injection). Three production wells, called HDR-1, HDR-2a and HDR-3, were drilled sequentially to the upper reservoir located about 1,800m in depth to produce boiling water and steam. Distances between the injection zone in SKG-2 and HDR-1, -2a and -3 at 1,800m in depth were 38m, 33m, and 63m, respectively. In this stage, a new concept of HDR system, that of one injection well and multiple production wells, was presented and was demonstrated at the Hijiori site to show the effectiveness of this concept. Basically, this model was thought to improve the low recovery rate of each production well of the Hijiori system. A final 90-day circulation test was conducted to study short-term heat extraction behavior in 1991 at the end of the first stage (Yamaguchi, et al., 1992).

The second stage was started at the same field in 1992 after completion of the first stage. A larger heat extraction system was designed to survey methods of scale enhancement of HDR. One method is a lateral extension of the HDR reservoir. The distance between the injection zone and the production zone was planned to be greater than one hundred meters, about double the diameter of the upper reservoir. Another method is a vertical extension of the HDR system. A deeper and higher temperature area was targeted for a new reservoir. All wells used in the first stage were reused in the second stage. HDR-1 had already been modified to be used as a hydrofrac/injection well in the second stage to 1991. Hydrofrac was conducted to create the new reservoir on HDR-1 in 1992 as planned. PBR (Polished Borehole Receptacle) and 5” DP were used for isolation of a pressurized zone in the well. Over 2,100t of water were injected into the bottom of HDR-1, 2,200m in depth, and the highest injection rate reached 70 kg/s(4.2 t/min). HDR-3 was simply extended to a deeper area in 1993. The bottom of HDR-3 was 2,300m in depth then. HDR-2a was side-tracked and was re-drilled from 1,613m to 2,300m to maintain distance from the injection well.

The role of HDR-1 was changed from that of a production well in the first stage to that of an injection well in this stage. HDR-2a and HDR-3 are used as the production wells as before. SKG-2 remained as an injection well to the upper reservoir and can be used as an observation well of the upper reservoir. As shown in the underground part of 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 was constructed at the site prior to 1995. In 1995 and 1996, one-month circulation tests were conducted to estimate the heat extraction ability of the lower reservoir in order to design a future long-term circulation test. According to the results of the circulation tests, a heat extraction test of a minimum of one year will be needed to evaluate the life of the artificial reservoir of Hijiori. Preparation for the long-term circulation test had started in 1997 and finished in November 2000.

EXPERIMENT

Objectives

The main objective of this long-term circulation test is to estimate the life of an artificial reservoir of HDR as accurately as possible because the life must exceed 20 years in the future development stage. The injection flow rate was set to 60t/h for a comparison with past data. The thermal behavior of the artificial

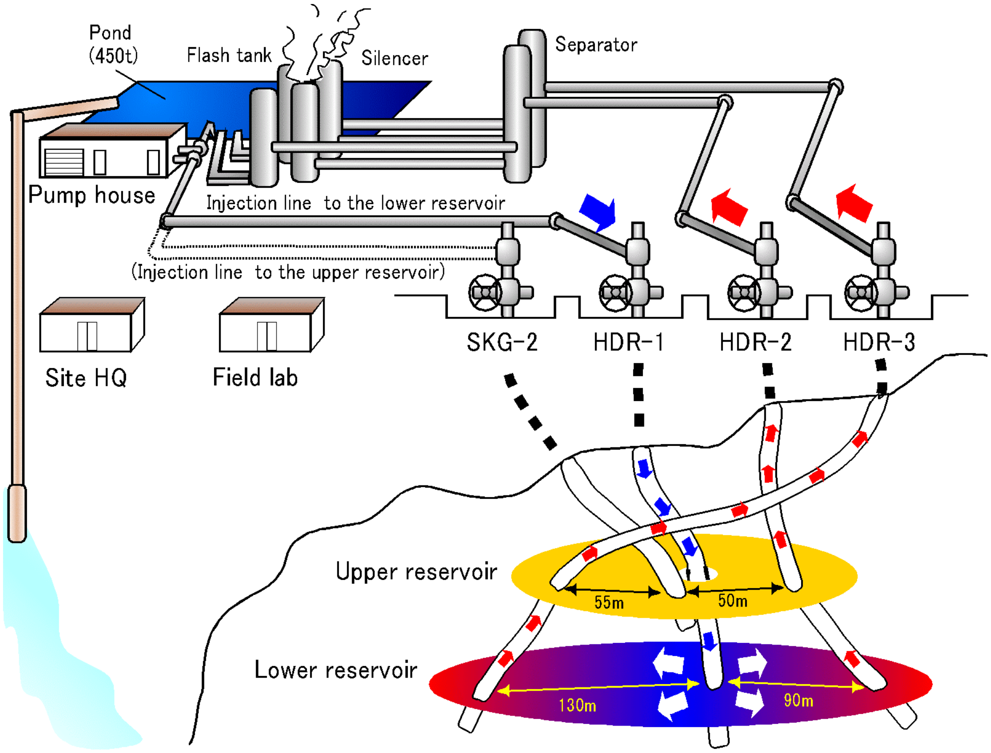

Fig. 1 Surface facilities and heat extraction system of HDR in Hijiori site (dual circulation test).

reservoir in the heat extraction test over two years was analyzed using a simulator to determine whether a thermal draw down is sufficient for such estimation or not. According to the analysis, a one-year circulation of the lower reservoir results in a thermal draw down of over 50 deg. C on HDR-2a and a thermal draw down of over 10 deg. C on HDR-3. These figures are suitable to estimate the life of the Hijiori reservoir (Karasawa et al., 2000).

Another objective is to further improve the model of Hijiori reservoir. The model includes both the upper and lower reservoirs and reflects the 3-D location of the main flow path of each reservoir (Karasawa et al., 2000). The model was significantly improved annually due to the progress of the Hijiori project by reevaluating the data. For example, fracture analysis (Tezuka and Niitsuma, 2000) and stress estimation (Sasaki and Kaieda, 2000) were conducted.

Moreover, significant problems and troubles in the circulation test will be considered in future tasks to assist HDR development in the next stage.

Surface instruments

The surface part of Fig. 1 illustrates the simplified surface structures on the Hijiori test site. The production lines of HDR-2a and HDR-3 are almost the same as those of the last circulation test conducted in 1996. These lines are ordinal ones that have a cyclone separator, a steam line with a silencer and hot water line with a flash tank. A new electric turbine pump was prepared as a main injection pump for the long-term circulation test in place of the previous engine plunger pumps. Power lines were extended to the site significantly improving the usability of electricity on the site. A durable pump house and a snow melting system were built at the site because Hijiori is infamous for heavy snows. Two prefabricated buildings were also prepared for observation and temporal geochemical experiments. The water supply line from Nigamizu River to the site was modified for the dry and cold winter weather.

Monitoring system on circulation status

A monitoring system on injection/production status was constructed to measure circulation parameters and to semi-automatically handle any emergency situation. Many sensors are attached to the injection/production lines. Pressure sensors directly measure the pressure data. Temperature data are measured indirectly. A thermistor is attached into a short protection pipe inserted in the injection/production lines. The flow rate is measured with two kinds of flow meters; one a differential pressure type, the other a vortex type.

PTS tools and AE monitoring system

PTS tools were very useful to measure the in-situ state of the production/injection zones. These tools were made for surveys of wells at the Hijiori site and were used many times in the Hijiori project. These tools are old and have analog armored cables with a thermal limit up to 300 deg. C.

The AE monitoring system consists of continuous and temporal measurement stations. The former involves three stations around 50m in depth on the rim of the caldera and one deep station around 500m in depth in well SKG-1 near the center of the caldera. The latter is called a "surface net" and has eight measurement stations. The stations are located about 100-150m in depth. The surface net is only available from June to November because of heavy snow.

Experimental plan

The basic plan of the long-term circulation test consists of two different circulation patterns. The first one is called "deep circulation" and the second one is called "dual circulation". In deep circulation, only the deep reservoir was used as an active reservoir. In this circulation, HDR-1 was the only injection well and another injection well, SKG-2, was used as an observation well of pressure in the upper reservoir. In dual circulation, both the upper and the lower reservoir will be used as active reservoirs and both HDR-1 and SKG-2 will be used as injection wells.

The latest experimental schedule is shown in Fig. 2. Deep circulation was continued from late November 2000 to the middle of November 2001. Additionally, scale reaming of HDR-2a was conducted in October 2001. Dual circulation began on December 24 2001 and includes a 3-month power generation test in mid-2002.

The injection/production data of surface instruments are measured continuously during circulation. PTS

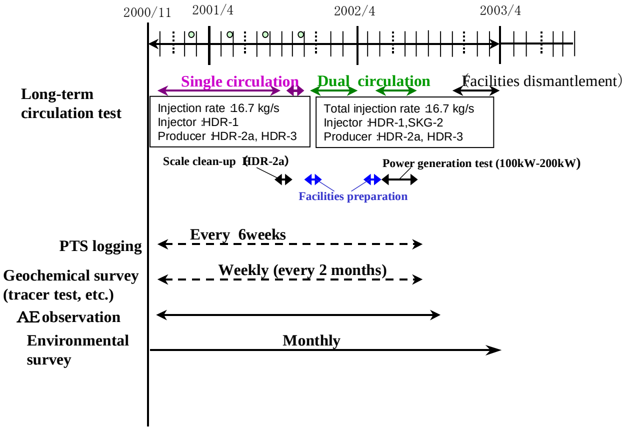

Fig. 2 Schedule of the long-term circulation test conducted at Hijiori site.

(Pressure, Temperature, Spinner) logging surveys of injection/production zones in the wellbore are carried out every 6 weeks. Geochemical surveys are conducted weekly ,in principle, but the frequency is increased during a start-up term or a restart-up term. AE (Acoustic Emission) events are observed not only during circulation but throughout the long-term circulation test. Environmental monitoring, surveys of surface waters and seismic monitoring are also conducted continuously in the long-term circulation test.

RESULTS

Overview

This circulation test was successfully continued for almost one year except for stoppage (for 19 days) for undergoing periodic inspection of the equipment and facilities and reaming the scale ceiling inside the casing of HDR-2a.

The injection status, production status and AE events were measured continuously. PTS logging was conducted approximately every six weeks. Geochemical sampling was conducted weekly and a geochemical tracer test was conducted approximately every two months.

Three very important findings have been revealed. The first is the scale problem in the production wellbore, similar to that in a conventional geothermal well. The second was the occurrence of a large AE event. The last was the very good thermal draw down observed in HDR-2a. The latest status (on November 10, 2001) of the test is shown in Table 1.

Table 1. Present Injection/Production Status (November 10, 2001)

	HDR-1	HDR-2a	HDR-3	HDR-2a +HDR-3
Temporary status				
Injection pressure (MPa)	6.07			
Injection flowrate (kg/s)	16.2			
Injection temperature (deg.C)	33.1			
Production pressure (MPa)		0.38	0.7	
Production temperature (deg.C)		120.5	161.5	
Production flowrate of hot water (kg/s)		4.27	1.28	5.55
Production flowrate of steam (kg/s)		0.49	0.29	0.78
Production flowrate (kg/s)		4.76	1.57	6.33
Recovery (%)		29%	10%	39%
General status				
Injection volume (t)	478,389			
Production volume of hot water (t)		86,130	69,655	155,785
Production volume of steam (t)		27,946	22,485	50,431
Production volume (t)		114,076	92,140	206,216
Recovery (%)		24%	19%	43%

Injection status

The injection status was almost stable throughout the test period. 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. The injection pressure decreased over time. The injection temperature fluctuated between 20 - 40 deg. C.

Production status

Fig. 3 shows production data from the circulation test. The production was unstable during the circulation test. Especially, the period of instability continued for about one week in late August 2001 with cyclically intermittent production of HDR-3.

Recovery was 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. The recovery is maintained as high as possible and was around 39% on December 10, 2001. 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 115 deg. C and that of HDR-3 is about 160 deg. C, as shown in Table 1. Thermal output (production enthalpy - injection enthalpy) has remained about 3.6 MWt under stable production conditions.

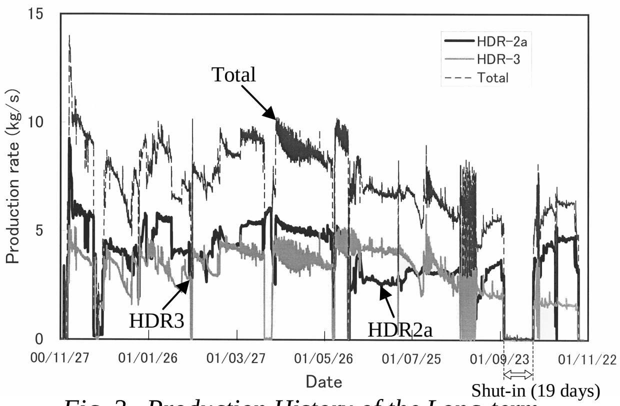

Fig. 3. Production History of the Long-term Circulation Test

Scale reaming

Anhydrite scale deposited in the boreholes prevented lowering the PTS tool below a depth of about 2000m in both HDR-2a and HDR-3. The scale of HDR-2a was successfully removed by coiled tubing method to measure the many main feed zones of the deeper reservoir in HDR-2a. The reaming of HDR-3 was not undertaken from the financial standpoint. After the reaming of HDR-2a, the injection pressure was lower at the constant rate of 16.7 kg/s and recovery of the HDR-2a was higher. Meanwhile, the recovery from HDR-3 was rather lower.

PTS logging, AE measurement, geochemical survey and environmental monitoring

PTS logging is conducted to directly measure the pressure, temperature and flow rate of 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 only be measured with this tool. Each production well is connected to both upper and lower reservoirs and thermal draw down is expected only in the lower reservoir during the first year. PTS logging was conducted six 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 owing to scale buildup. On the fourth and fifth loggings, the PTS tool did not proceed below a depth of about 1,990m in HDR-2a and did not go below a depth of about 2,000m in HDR-3. In the sixth logging, the tool went below a depth of 2,275m, close to the well bottom in HDR-2a, by reaming the scale.

Hence, the thermal draw down of the production zones in the lower reservoir was not revealed directly. Only comparable data to the 1,990m depth in HDR-2a and 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 around 140 deg. C in the latest (sixth) 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. About 270 AE events have been observed since January, 2001 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 of AIST) and the other is analysis of natural content ions conducted by NEDO.

Environmental monitoring is conducted to determine the presence of environmental effects resulting from the circulation test. Two kinds of monitoring are conducted. One is seismic monitoring while 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, 2001 and some local residents heard a sonic vibration caused by this large event.

DISCUSSION

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 to decrease as time passed. According to the injection test of November, 2001 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 characteristics of the artificial reservoir could recover.

Production behavior

Production status was unstable in this long-term circulation test. The steam and hot water production of each well fluctuated easily by very small movements of the production valves and injection stoppage caused by trouble or maintenance. The hot water supply from the upper reservoir had a very important role in the production until June, 2001. 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. Said another way, the status of the production well controls production ability by only itself and 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. Total production ratio of HDR-2a/HDR-3 was 1.9 and max. thermal output was 9.3 MWt. The circulation test in 1996 aimed to improve 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 term and decreased to about 39% at the end of the test on November 10, 2001. The total recovery was about 43% for the year. This total recovery characteristic is similar to that of the preliminary circulation test in 1995. The stable thermal output of the present test was up to 9.3 MWt in the early term and decreased to 3.6 MWt. 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, 2001. 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.

PROCESS OF SCALE BUILDUP

Anhydrite scale was deposited in the boreholes of the production wells. That phenomenon was unexpected because it was not indicated in the preliminary circulation test of one month in 1995. In the long-term test, scale remarkably appeared 4-5 months after start of circulation.

More anhydrite is dissolved in the water at lower temperatures and recrystallizes at higher temperatures. It is assumed that anhydrite leaves the rock and is dissolved in the water while the cold water from HDR-1 is flowed to HDR-2a or HDR-3. The circulation water was increasingly concentrated for 4-5 months and it became saturated with anhydrite. Finally, anhydrite recrystallized at a higher temperature while proceeding up the casing and deposited as scale inside the casing. That phenomenon will be interpreted in more detail with quantitative evaluation of the geochemical and PTS data.

CONCLUSIONS

NEDO started the long-term circulation test in late November, 2000. The main objective of this long-term circulation test is to ascertain the life of an artificial HDR reservoir. Troubles occurred but, fortunately, were not serious and the first half of the circulation test was completed. Interesting points with regard to the circulation test to the present time are below.

1. Unexpected high injection pressure over 10 MPa at the beginning was observed; injection pressure has not declined as expected. This indicates that the hydraulic characteristics of the artificial reservoir are recoverable during circulation stoppage.

2. Unstable production status caused by variable production from the upper reservoir suggests difficulty of passive use of this 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 3.6 MWt and 39% around one year from the start of circulation.

4. The anhydride scale of HDR-2a was successfully clear by the coiled tubing method.

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

On December 24, 2001, dual injection and production was started through operating of four wells and will be continued till August 2002, following which we will reveal the relation between the upper and lower reservoirs.

ACKNOWLEDGMENT

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