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Review of the HDR Development at Hijiori Site, Japan

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ABSTRACT

Hijiori HDR (Hot Dry Rock) project was one of the famous HDR development programs. NEDO (New Energy and Industrial Technology Development Organization) carried on this domestic HDR project from 1985 to 2002. Much new knowledge were found in Hijiori project and contributed to the progress of the international HDR development. Although Hijiori project successfully reached to the final long-term circulation test, conducted from 2000 to 2002, development of HDR in Japan stops for the time being not because of technical reasons but political ones. A review program was started just after the final experiment at Hijiori site to summarize and to discuss the potential of Hijiori project for the future.

A review committee was organized and discussions were started. At the start of our discussions, recognition of the current HDR concept was the main theme. On the next step, which has a technical theme, five subgroups, overall system design, field characterization, reservoir creation, circulation/heat extraction and monitoring, were set up and discussions were continued both in the subgroups and in the whole committee. A brief history of the Hijiori project, an outline of the review and several interesting topics discussed in the review will be presented in this paper.

1. INTRODUCTION

Geothermal energy should be encouraged in this "Environmental Century" because of its low emission feature. HDR will play an important role in the future development of geothermal energy because it can enlarge usable geothermal resources.

A concept of HDR power generation was proposed by researchers of Los Alamos National Laboratory in early 70's. Oil crisis's in later 70's makes us aware of the potential of geothermal resources and boosted up the research and development of HDR in the world. In 1975, basic research on HDR was also started in Japan.

Hijiori HDR project was one of the famous HDR development programs in the world. NEDO started this domestic HDR project at Hijiori site in 1985 applying knowledge and experience from Fenton-Hill HDR project. NEDO carried on Hijiori project from 1985 to 2002. Many new knowledge and new aspects were found in Hijiori project and contributed to the progress of the international HDR development, these include concepts, techniques, field characteristics, reservoir evaluation and so on. While Hijiori project successfully reached to the final long-term circulation experiment, conducted from 2000 to 2002 as planned, the next step of the development failed to be launched. Large-scale development of HDR in Japan stops for the time being not because of technical reasons but political ones.

A review program was started from autumn of 2002 just after the final experiment at Hijiori site to summarize and to discuss the potential of Hijiori project for the future. Though a review report in Japanese has almost been finished, a whole review report is too long to be presented here. Therefore, a brief history of the Hijiori project, an outline of the review and several interesting topics discussed in the review will be introduced in this paper.

2. A BRIEF HISTORY OF HIJIORI PROJECT

The Hijiori test site is located in a caldera with a diameter of about 2km. The target basement rock was a granodiorite that lies below 1,500m in depth. Hijiori spa town is located 1 km east from the test site, therefore the site name.

Field experiments of HDR development by NEDO were started at the Hijiori site in 1985. Two stages of development were conducted in the project. In the first stage, a small heat extraction system, called "upper reservoir", 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, was modified for full-hole pressurizing (hydrofrac and injection). Three production wells, called HDR-1, HDR-2 and HDR-3, were drilled sequentially to the upper reservoir located about 1,800 m in depth. Distances between the injection zone in SKG-2 and HDR-1, 2 and 3 at 1,800 m in depth were 38 m, 33 m, and 63 m, respectively. At this stage, a new concept of HDR system, that of one injection well and multiple production wells, was presented and was demonstrated 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 reservoir 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 a new reservoir on HDR-1 in 1992. PBR (Polished Borehole Receptacle) and 5" DP were used for isolation of a pressurized zone in the well. Over 2,100 t of water were injected into the bottom of HDR-1, 2,200 m 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 2,300 m in depth then. HDR-2 was sidetracked and was re-drilled from 1,613m to 2,300m to maintain distance from the injection well. The re-drilled HDR-2 was named "HDR-2a" to distinguish it from the old trajectory.

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 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 Figure 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. A long-term circulation test started in late November 2000 just after 3-years preparation. The main objective of this long-term circulation test was to ascertain the life of an artificial HDR reservoir. The test was successfully carried out and artificial geothermal steam was produced continuously.

A circulation test using deeper reservoir in the first half of the long-term circulation test and a circulation test using dual reservoirs in the latter half reached to 550 days of circulation in total. A binary power unit was brought to the site and practiced for the last three months. An ability of the Hijiori HDR system was cleared and scale was deposited unexpectedly in the production wellbore, but it will be managed in the future. (Yanagisawa, et al. (2002), Yanagisawa, et al. (2003), Tenma, et al. (2003), Tenma, et al. (2004))

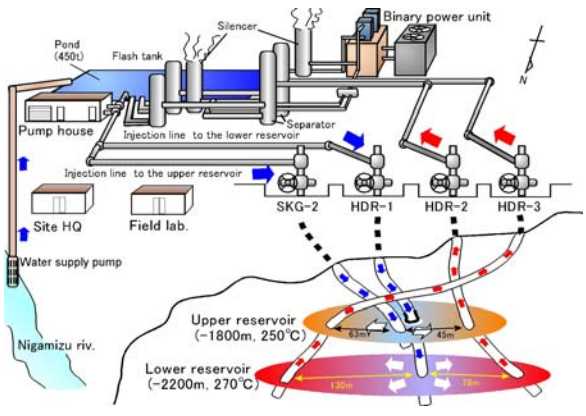

Figure 1: Conceptual diagram of Hijiori HDR system (2002/6-8).

3. REVIEW CONCEPTS

3.1 Review Committee

A review committee of twenty-one persons was organized in Oct. 2002. A chairperson is Prof. Niitsuma from Tohoku University. Committee members are from private companies, universities and research institutes. Persons not deeply involved with the Hijiori project joined the committee as key members to add points of view from outside of the HDR world. Discussions were carried on to the end of Mar. 2004. A mailing-list for the discussions was set up and everyday discussions were conducted with e-mails. Face-to-face meetings were also held nine times for direct discussions.

3.2 Scope and Policy

In the early days, HDR development targeted deep, hot and low-permeable basement rocks. As the development progressed, HDR techniques appeared to be applicable to various underground conditions and various rocks, therefore a target of HDR development also extended. Our review was mainly focused on topics related to Hijiori experiences to clear and to simplify a wealth of the Hijiori project, instead of on various topics related to the extended HDR concept.

At a start of our discussions, recognition of the current HDR concept was the main theme. Results of both the Hijiori project and the international HDR developments were discussed to update the HDR concept, which includes resources, applications and social significance. At this step, structure and policy of this review were also discussed. Past attainment and future tasks of HDR techniques was directed to bring into relief in order to show a guideline for future HDR engineers and researchers. On next step, five subgroups having a technical theme were set up and discussions were continued both in the subgroups and in the whole committee.

3.2 Structure

Principally, five subjects/discussion-groups were set up to discuss technical features deeply. Figure 2 shows a conceptual diagram of the five subjects, overall system design, field characterization, reservoir creation, circulation/heat extraction and monitoring, referring to the Special Issue Hot Dry rock / Hot Wet Rock Academic Review (1999). Overall system design included an updated HDR concept.

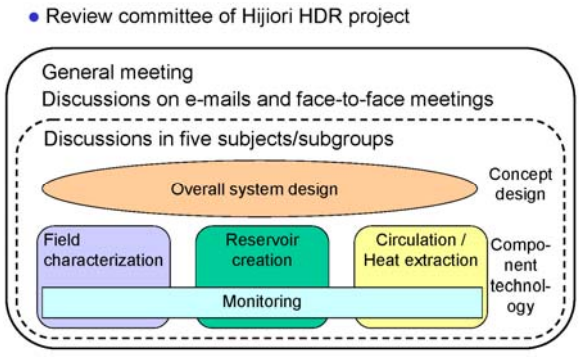

Figure 2: Conceptual review structure of Hijiori HDR project.

4. INTERESTING TOPICS

4.1 Overall System Design

The Overall system design subgroup treats an integration technique of the component technologies, concrete usages and practical plans for future development including updated HDR concepts.

4.1.1 Present HDR concept

Simplified HDR concept is shown in Figure 3. Heat extraction with water circulation between the surface and a target rock mass (layer) is the same as the originally proposed idea at the very first time. However, a present target rock property of HDR has been extended in terms of thermal condition, depth, lithology and permeability. In thermal condition, low temperature rock could be targeted. Low temperature leads to a more shallow development depth. Target rock lithology was extended to non-granitic rocks and more permeable rock could be developed with down-hole pumps. The present HDR concept includes "hot water in deep (porous) layer", "Hot Wet Rock" and "EGS".

This abstracted concept can spread the target and the usage of HDR. However, various underground and surface equipment conditions have to be dealt properly. Future extension of the HDR usage will require a proper system design in each case. Therefore, overall system design is a key component of the HDR future.

4.1.2 Contribution of Hijiori project

The Hijiori project was one of the successors of the Fenton Hill project. An initial system design was mainly based on the experiences of the Fenton Hill. However, in the development of Hijiori, HDR reservoir had to be created within a Japanese complex basement. Low recovery was the principal problem in the early stage of Hijiori. The flow path of the Hijiori reservoir depends on a natural fracture/fault structure and half of the injected water run past it and was unrecoverable. The recovery problem was solved with an improved system design. Finally, dual production wells were set on both sides of the injection well and recovery was increased up to 80% at that time. This experience shows us the importance of proper technical application to a field character. From another viewpoint, a proper overall system design can let the HDR concept be applicable to various underground conditions. The Hijiori project shows the importance of overall system design.

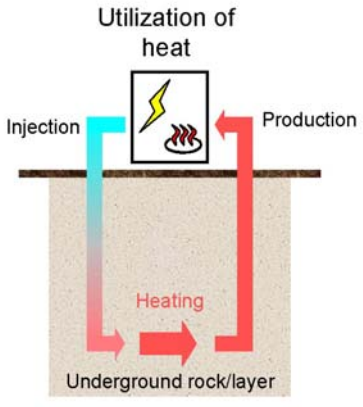

Figure 3: Simplified HDR concept

4.1.3 Future task

Technical aspects, environmental aspects and commercial aspects are included in the overall system design considering a practical use. This overall system design was never completely conducted to a real field development of HDR. Demonstration of this overall system design will be required in the future HDR development.

4.2 Field Characterization

Field characterization includes field selection. In Hijiori project, the field selection step was not strictly carried out. Several property of target rock, temperature over 250 ^{o}C, granitic lithology and lack of geothermal fluid, were known before the start-up. As a field character of Hijiori had been cleared, the old HDR concept had to be modified.

4.2.1 Contribution of Hijiori project

Field character of Hijiori is different from Fenton Hill. Hijiori HDR reservoir depends on a natural fracture/fault structure of target rock and field stress is not high. Hijiori showed a potential of HDR applicability to a complex basement rock. Through the project, importance of field characters appeared, such as temperature, lithology, fracture property and stress state. Fracture property and stress state are particularly important in HDR development.

Field characterization process of HDR must be continued while the development with updated information and provides improved understandings to the project headquarter. In Hijiori project, integration of various underground information was demonstrated to make an improved model of HDR reservoir (Tezuka and Niitsuma (2000), Tezuka and Watanabe (2000)) and a successful multi-level circulation system was created within a Japanese complex basement finally.

4.2.2 Future task

Field characterization is very important in the overall system design. HDR circulation system will be adapted to a field character. Future research has to be toward to know required properties as soon as possible.

4.3 Reservoir Creation

Reservoir creation is a key of HDR system construction. It treats flow path construction or flow path moderation underground. A HDR reservoir must be constructed both in proper size and in proper hydraulic conductivity.

4.3.1 Contribution of Hijiori project

HDR reservoir is classified into three principal types, closed, opened and intermediate (Ito and Hayashi (2003)). A closed type shows a high injection pressure and a high recovery. Fenton Hill reservoir is classified into this type. An opened type shows a low injection pressure and a low recovery without production support equipment, such as down-hole pump. Soultz reservoir is classified into this type. Hijiori and Rosemanowes reservoir is classified into intermediate type. Intermediate type HDR reservoir needs to be created carefully in a hydrofrac/stimulation design. A higher injection pressure easily causes a reservoir to have overcapacity in volume and leads to low recovery. A lower injection pressure leads to a very small size of recoverable reservoir. Hijiori experiences gave lessons of difficulty in handling intermediate type HDR reservoir and indicated possibility of applying HDR techniques to every basement rock.

In Hijiori, dual one-injection-two-production reservoirs were created in different depth for the first time in the world. A one-injection-two-production well design was very effective in improving recovery. It will be a standard unit for a HDR reservoir of low hydraulic conductivity. Various techniques were conducted to measure reservoir properties successfully. For example, AE/micro seismic measurement revealed a reservoir structure (Sasaki (1998)), PTS (Pressure, Temperature, Flow) logging revealed major flow paths and their hydraulic properties and BHTV revealed fracture distribution of a target rock.

4.3.2 Future task

The Hijiori reservoir is relative small, the longest well distance between an injection point and a production point was about 130m, because it was not designed to be used as a heat exchanger of a pilot power station. In the future, size of a reservoir has to be controlled properly to be equivalent to an output of power station. A proper balance of size and recovery is a future task in development of such an intermediate type HDR reservoir.

4.4 Circulation and Heat Extraction

Circulation and Heat extraction section focuses on various matters of actual heat extraction from underground. Modeling, simulation and prediction are also done here.

4.4.1 Contribution of Hijiori project

At the end of the Hijiori project, a long-term circulation test was conducted. Reservoir temperature was over 250 ^{o}C and a circulation period was reached in 550 days in total. That was the first trial of heat extraction from such a high temperature rock for such a long term. Additionally, binary power generator was tested to investigate problems in a future use. Scaling problem and importance of temperature management was clarified in the test.

A data integration method for reservoir modeling was developed as Hijiori project progresses. Almost all data, for example, geological structure, core data and logging data, could be integrated in the model (Tezuka and Watanabe (2000)). Tracer tests were conducted to monitor flow paths' state and tracer response curve showed change of the nature of flow paths in the circulation test (Yanagisawa, et al. (2002), Yanagisawa, et al. (2003)). AE/micro seismic measurement was useful to know the reservoir extension behavior during the circulation test. Environmental monitoring has been conducted from the start of the project until the end of over 17 years. No considerable influence on the surface ground water system was observed.

4.4.2 Future task

The Hijiori project was focused on not failing to make an underground HDR reservoir. Proper surface facility was not investigated well before the final long-term circulation test. Scaling also occurs in HDR circulation system and large temperature drawdown can make it a serious problem. Various approaches have to be considered to solve it. For example, addition of the scale inhibiter, an improved flow path control that does not use cooled flow paths, and a full-closed circulation method with small temperature drawdown in a surface heat exchanger are worth considering.

4.5 Monitoring

Monitoring treats observation and measurement techniques of HDR. Each component technology can be applied to other industrial fields as an underground conditions measurement package. AE/micro seismic measurement, well logging, geochemical measurement, injection/production monitoring and surface inclination measurement were conducted in Hijiori site. Each method can be applied to other HDR development as a measurement package excluding surface inclination measurement. Surface inclination measurement needs more HDR experiences in an actual heat extraction. An AE/micro seismic measurement package of Japan was found to work well in Australian HDR development lately.

5. THE FUTURE HDR DEVELOPMENT

Enormous heat energy is stored underground. Extension of the HDR target to a lower temperature region will bring a broad usage of HDR with low-emission of CO_2. Wide HDR contributions in a future society from a high temperature area to low temperature area are ideal. A flexible overall system design and creation of a usable reservoir in sedimentary rock will ease the difficulties of HDR target extension and help build the concept of "HDR anywhere".

HDR techniques are also applicable to the ordinary geothermal development supplying water to the hydrothermal system. Decline of the output could be mitigated if the decline is caused by water loss from the geothermal reservoir. Sustainability can also be controlled very well. In Japan, medium-size (10-50MW) geothermal development has slumped. Research and development of HDR should be carried on to address this difficult situation. Though HDR development has stopped in Japan, international cooperation of HDR development can be focused upon and should be continued.

6. CONCLUSIONS

Japanese HDR project had paused and the review team examined the results of Hijiori. Five technical subjects, overall system design, field characterization, reservoir creation, circulation/heat extraction and monitoring, were set for a detailed discussion and the updated HDR concept, Hijiori contributions and the future tasks were discussed.

The updated HDR concept can spread the target and the usage of HDR. Future extension of the HDR usage will require a proper system design in each case. Overall system design will be a key component of the HDR future. HDR will have a key role to sustain the future energy needs of society.

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