Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

OUTRLINE OF THE OGACHI HDR PROJECT AND CHARACTER OF THE RESERVOIRS

Koichi KITANO*, Yoshinao HORI* and Hideshi KAIEDA*,

*Central Research Institute of Electric Power Industry (CRIEPI), 1646 Abiko, Abiko City, Chiba, Japan

Keywords: Hot Dry Rock, Circulation Test, Geothermal Reservoir, Geological Structure, Ogachi

ABSTRACT

Since 1989, in furthering the development of HDR technology, CRIEPI has conducted numerous experiments at their Ogachi test site in southern Akita Prefecture , Japan. At a depth of 1000m at this site, the reservoir rock is granodiorite at a temperature of 230°C. From 1989 to 1992, an injection well (OGC-1) was drilled to a depth of 1000m and then two vertical separated artificial reservoirs were created by hydraulic fracturing. Then, in 1993, a production well (OGC-2) was drilled through the two HDR reservoirs to a depth of 1100m. From 1993 to 1995, three water circulation tests were conducted between the injection and production wells. In the 1995 circulation test, hot water and vapor at a temperature of 165°C was produced from the HDR reservoirs at a recovery rate of 25%.
During the past three years, individual flow testing of the upper and lower HDR reservoirs was conducted which showed that the production capacity of the upper reservoir was less than 1/20 that of the lower reservoir. Supporting reservoir diagnostic testing and analyses, to determine the fracture structures and flow paths within and around the two separate reservoirs, was also performed during this time. These included the observation and analysis of pressure-induced acoustic emissions (AE), the determination of the orientations and magnitudes of the in-situ stresses, and 3D numerical simulations of the reservoir flow. The results from this most recent series of flow tests and supporting AE analyses suggest that both the upper and lower reservoirs were formed by the pressure-opening of natural joints within the rock mass, and that the upper reservoir has a length of about 800 m and an orientation roughly 90° from the orientation of the 1000-m-long lower reservoir.

1. INTRODUCTION

Advances in geothermal energy are giving new dimensions to the development of clean, natural energy resources. HDR power generation is a new method of using geothermal energy and enables us to utilize these abundant resources with very little developmental risk. Projects to make this technology practical are now under way in the U.S., Europe, Australia and Japan.
Since 1989, CRIEPI (Central Research Institute of Electric Power Industry) has been developing methods to create multiple reservoirs which store water and allow the efficient extraction of geothermal energy for power generation. Experiments have been conducted at the Ogachi HDR site, Akita Prefecture, Japan, through research of phases-to(Fig.1). CRIEPI has succeeded in circulating water through underground HDR reservoirs to provide a steady supply of hot water and steam .
Making HDR power generation a practical technology requires a detailed understanding of how the artificially induced underground fractures extend and how water flows through them. The objectives of the Ogachi experiments in Phase-since 1996 are to develop the methods as follows:

(1)Exploration methods for deep underground geological structures; for example the location of faults from which the injected water flows from the reservoirs
(2)Evaluation methods, not only for reservoir size and direction of growth, but also for the fracturing mechanism in the reservoirs
(3)Evaluation methods for the nature, distribution and structure of the cracks or fractures developed in the reservoirs and for their ability as water flow paths
(4)Hydraulic evaluation methods for permeability, modal volume and water flow paths of the reservoirs
(5)Computer simulation methods for estimating the production capacity of the reservoirs such as the water recovery rate, the fluid production temperature, and the visualization of the main flow paths in the reservoir

Details of these results will be described in accompanying papers submitted to this congress by CRIEPI's members as follows: K.Suzuki et al.(2000) are concerning (1),H.Kaieda et al.(2000) are (2), H.Ito and K.Kitano (2000) are (3),K.Shin (2000) is (2), K.Kiho (2000) is (4) and H.Suenaga et al.(2000) are (5). In this paper, we describe an outline of the Ogachi project as an introduction to those papers and some characteristics of the Ogachi reservoirs created by hydraulic fracturing.

2. OUTLINE OF RESULTS OF PROSPECTING AND EXPERIMENTS

CRIEPI has been conducting Hot Dry Rock (HDR) Geothermal Energy Development experiments at Ogachi in Akita Prefecture, northeast Japan (See Fig.2)since the beginning in 1989, following the Akinomiya Project (phase-,1986-1988) as a preparation stage for the Ogachi Project (See Fig.2).

2.1 Creation of Multiple Reservoirs

In 1990, the second year of phase-(1989-1992. See Fig.2,3), an injection well (OGC-1) was drilled to a depth of 1,000m where the rock temperature was measured at 228 °C. Then, the well was cased except for a 10m openhole section at the bottom. In 1991, over 10,000 m^3 of water was injected into the openhole section at the bottom of the well, creating a fractured area about 200 m thick and about 500m wide, propagating 1,000m in the NNE direction, as estimated from the envelope of the AE hypocenter locations. After the lower reservoir was created, the casing pipe were milled from 711 m to 719 m to produce an openhole section called a window. Then, the openhole section at the bottom was filled with sand. In 1992, an upper fracture was created at the window depth by injecting nearly 5,500 m^3 of water. The upper fracture, also about 200m thick, was estimated to have extended over a 400 x 800m area in a ESE direction, as estimated from the shape of AE hypocenter distribution (Kaieda H., et al., 1993).

2.2 Heat Extraction from Hot Dry Rock

In January,1993, a production well (OGC-2) was drilled to a depth of 1,100m. In 1995 OGC-1 was re-drilled from 1,000m to 1,027m to extend the water injection (openhole) region. After a re-drilling, OGC-1 was stimulated by injecting a total volume of 3,400 m^3 of water at a flow rate of 105 m^3/hour and at a well head pressure of 18 MPa. OGC-2 was also stimulated by injecting a total volume of 4,300 m^3 of water at a flow rate of 135 m^3/hour and at a well-head pressure of 18 MPa (See Table-1).

We conducted a one-month circulation test between these wells to confirm the above mentioned re-drilling and stimulation effects. During the circulation test, the injection pressure decreased to 7 MPa, about a half of that in 1994, and the water recovery from the production well increased to 25%, about twice as much as that in 1994. The produced water temperature of 160 to 165°C (a maximum of 169°C) was measured .

Therefore, we concluded that the extension of the bottom-hole water injection interval and the pressure stimulation of these wells was more effective in reducing the water injection pressure and improving water recovery. Fig.4 shows the result of the circulation test in 1995 (Kitano K., et al. 1996).

2.3 Evaluation of Water Flow in the Reservoirs

In spite of many important results, new problems and tasks for our prospect developed, like understanding the different directions of the two reservoirs and the low water recovery rate in comparison to other HDR sites. In 1996, we reexamined our previous plan for the Ogachi experiment, and presented a new plan involving individual flow tests of the two reservoirs.

In 1997, after injecting about 13,000 m^3 of water, we flow tested the upper reservoir by plugging off the lower reservoir in OGC-1. Water was injected into OGC-1 at a well head pressure of about 18MPa with a flow rate of about 15 m^3/hour. Though injection was continued for 7days, the water level in OGC-2 was stable at a depth of 40-50 m below the surface80-90 m above natural level at the end of the upper reservoir injection test.

Because of the mechanical packer failure in OGC-1, we could not conduct a separate circulation test of the lower reservoir. Then a water circulation test through both the upper and lower reservoirs was conducted. Water was injected into OGC-1 at a flow rate of 30 m^3/hour and at a well-head pressure of about 13 MPa for 9 days On the second day of the test, water was produced from the well-head of OGC-2. The produced water flow rate was stable at 70-80 liters per minute at a well-head pressure of 0.3 MPa (Kitano K., et al.,1998).

Comparing the results of the circulation test in 1997 with the results in 1995the injection pressure doubled at the same injection rate of 30m^3/hour, and the recovery rate decreased to 15% of the injected rate from 25% in 1995.

2.4 Geophysical Prospecting

For the purpose of developing methods of investigating the underground structure for siting HDR and geothermal power systems, we have applied and improved the CSAMT method, the TDEM method and the gravity method since 1986.

In phase-, for the purpose of clarifying the existence and the distribution of faults around the Ogachi experimental field, we conducted the CSAMT method in 1996, gravity prospecting in 1997, and the seismic reflection method in 1998. From these results, two faults trending NW-SE were estimated to be located at 500m and 900m to the west of the Ogachi experimental field.

2.5 Computer Simulation

We have also developed a computer simulation code (GEOTH3D) to indicate the production flow volume and to help predict the behavior of underground water flow visually. The key feature of GEOTH3D is that the locations and magnitudes of the AE, which are measured when the rock is split by high-pressure water, are used to define the distribution of the water permeability that expresses the ease of passage of water through the rock. This approach allows us to accurately predict the behavior of the underground flow.

We have examined the accuracy of GEOTH3D by comparing it with field data that had been acquired for a 30-day water circulation test in 1995. It was found that the results derived from the computational model were well-correlated to those measured in the field tests (Eguchi Y., et al., 1998).

3. CHARACTERRISTICS OF THE RESERVOIRS

3.1 Geological Structure around the Reservoirs

The Ogachi site is situated in the mountainous region at an elevation of about 600 m. The geology of the Ogachi site consists of Cretaceous granodiorite covered with Tertiary lapilli tuff to a depth of 300m from the ground surface (Fig.2). A number of pre-existing or natural joints are developed in the granodiorite (the basement rock of the site and also the reservoir rock for hydraulic fracturing), with an average spacing of about 8 cm as observed from geological investigations and with a comparably low natural permeability.

Both the results of the CSAMT and the gravity prospecting data showed a remarkable subsidence of the surface of the basement rock at a distance of several hundreds of meters west from the Ogachi experimental field. The results of the seismic reflection data in 1998 showed two remarkable discontinuities in the signal image of the reflection waves, which were estimated to come from the boundary plane between the upper lapilli tuff and the lower granodiorite. They are 500m and 900m to the west of the Ogachi experimental field and are suggested to be faults. A 3D basement rock distribution map was obtained by adding the seismic reflection data to the CSAMT data and these faults were expressed as steep inclinations of the basement rock in this map. They were estimated to have the same NW-SE trends and to effect an escape of a small volume of the injected water out of the reservoirs .

3.2 Reservoir Sizes and Propagated Directions of the Fracturing

The sizes of the upper and the lower reservoirs estimated from AE focus distribution showed about 800m and 1000m at the longest span respectively. It was thought that both reservoirs were sufficiently wide to extract heat from the hot dry rock, although the propagated direction of these were different, that is the upper one showed to the east and the lower one extended to the NNE.

From the results of the joint survey from core observations and the BHTV survey at OGC-1 and OGC-2, the directions of the natural joints were different for each reservoir region; that is, the lower one has a dominant direction of N-S to NE-SW and the upper one has no dominant direction. According to the results of the fault plane solution of AE ,which were determined by using original AE location and P-wave first motion distribution on the focal hemisphere, almost all AE events were caused by shear slippage and these shear planes were estimated to have a dominant direction of N-S at the lower reservoir and at the upper reservoir to have some directions of E-W, N-S and NE-SW.

On the other hand, the principal stress direction from a core disking method, the most reliable method among several kinds of stress orientation methods performed at the Ogachi site, showed NE-SW horizontally. It was thought that the growth directions of both the upper and the lower reservoirs were able to be explained under this stress direction with no contradiction.

3.3 Rock Permeability

It was thought that rock permeability in and around the reservoirs was important for evaluating the characteristics of the reservoir. Flow tests for measurement of permeability under controlled pressure at each well and between OGC-1 and OGC-2 were conducted before and after fracturing. Summarizing these results, the permeability of the rock before fracturing was x 10^{-6} to 10^{-7}cm/sec. and after fracturing it was x 10^{-4} to 10^{-5} cm/sec. It was thought that the former showed initial rock permeability around the reservoirs, and the latter showed well-developed fractured rock permeability in the reservoirs. It should be taken into account that these values showed an average of a section or a part of the rock with a 10 to 100 m interval and also had some error .

3.4 Hydraulic Characteristics of the Reservoirs between OGC-1 and OGC-2

The feed points in OGC-2 were recognized at some points in each interval of 730m to 750m depth and 960m to 1070m depth by PTS logging in 1994, the former interval situated in the upper reservoir and the latter in the lower one.

It was estimated that the production was distributed 15% to the upper reservoir and 85% to the lower reservoir. From the results of a tracer test in the 1994 circulation test, the response curve of the tracer density showed a bi-modal curve. The modal volumes of the upper and the lower reservoirs were estimated to be about 10m^3 and about 250m^3 respectively.

The results of a tracer test during the 1995 circulation test showed one modal response curve and a modal volume of 135 m^3 . This means that the hydraulic characteristics of the reservoirs were changed by the stimulation at OGC-2 and the addition of openhole at the bottom of OGC-1 after the 1994 circulation test and the enhanced connection between the wells. The result of the circulation test by the water injection only from the upper reservoir in 1997 showed that the production water didn't reach the well-head of OGC-2, unless a total water volume of 3000 m^3 was injected for 10 days. This suggested that not only did the upper reservoir have a weak connection between OGC-1 and OGC-2, but also some volume of the production water flowed down into the lower reservoir in OGC-2.

The ratio of the openhole intervals (the injection intervals) of the upper reservoir to the lower reservoir in the OGC-1 was about 4 to 5 in 1994 and was about 1 to 4 in 1995 respectively. Taking these injection intervals into consideration, it was estimated after the 1994 circulation test that a production volume from the upper reservoir of OGC-2 was less than 1/20 of the lower one . This was also supported by the results of the upper reservoir circulation test mentioned above and results of the GEOTH3D simulation.

4. SUMMARY AND CONCLUSIONS

(1) In phaseof the Ogachi HDR Project, an injection well (OGC-1) was first drilled to a depth of 1000 m and then two vertically separated HDR reservoirs were created by hydraulic fracturing. Then, as part of phase beginning in 1993, a production well (OGC-2) was drilled through the two fractured reservoirs to a depth of 1100m. Between 1993 and 1998, four circulation tests we performed between the injection and production wells. The 30-day circulation test in 1995 resulted in the production of water and vapor at a temperature of 165°C , with a fluid recovery rate reaching 25% of the injection rate.

(2) Each of the HDR reservoirs, based on the distribution of AE locations recorded during the several fracturing operations, contains enough fractured volume for significant heat extraction. However, the directions of fracture propagation of these two vertically separated reservoirs were different from each other, the directions probably being strongly influenced by the presence of different oriented sets of dominant natural joints in each of the reservoir regions.

(3) In order to establish more reliable evaluation methods for HDR reservoirs, it is necessary to examine some of the underlying assumptions being made in applying these evaluation methods. For example, what is the true correspondence between the AE hypocenter distribution and actual reservoir shape and the related volume available for heat extraction? As another example, is there a clear correspondence between the magnitude of the AE and induced fracture permeability ?

In FY 1999, a new bore hole will be drilled through one of the areas concentrated AE recorded at Ogachi to obtain data on the relationship between AE, the opening of natural joints, and reservoir permeability. This rock mass interrogation, from 1999 to 2001, will involve well logging, flow testing and other measurement techniques.

It is planned that in the future, this new borehole will function as a second production well for the Ogachi HDR site. Ultimately, the goal of these ongoing studies, tests and experiments by CRIEPI is to demonstrate the viability of geothermal heat extraction through multiple HDR reservoirs with multiple production wells.

REFERENCES

1)Kaieda H., Jones R.H., Sasaki S. and Ushijima K., (2000), ‘Ogachi HDR reservoir evaluation by AE geophysical methods’, Submitted to this congress.

2)Kiho. K., (2000), ‘Study on surface area estimation of the Ogachi HDR reservoir by geochemical method’, Submitted to this congress.

3)Shin K., (2000), ‘Stress state at Ogachi site’, Submitted to this congress.

4)Ito H. and Kitano K., (2000), ‘Fracture investigation of the granitic basement in the HDR Ogachi project’ Submitted to this congress.

5)Suzuki K., Kusunoki K. and Kaieda H., (2000), ‘Geological structure around the Ogachi Hot Dry Rock test site using seismic reflection and CSAMT surveys’, Submitted to this congress.

6)Suenaga H., Eguchi Y., Yamamoto T. and Kitano K., (2000), ‘A fully three-dimensional thermo-hydraulic computation of the Ogachi HDR reservoir’, Submitted to this congress.

7)Kitano K., Hori, H. and Kaieda H., (1996), ‘Outline of the Ogachi Project in 1995’, Preprint of 3rd International HDR Forum,pp.60-61

8)Kaieda H., Sasaki S., Suzuki K., Ushijima K. and Kitano K., (1998), ‘Ogachi Reservoir Evaluation by the AE and Electric Measurements’, Proceedings,4th Int. HDR Forum, Strasbourg, France.

9)Kitano K., Hori Y., Suzuki K. and Fujimitsu Y., (1998), ‘Results of Underground Structure Exploration and Individual Flow Test of Multiple Reservoirs at Ogachi HDR Site in 1997’. Proceedings of 4th international HDR forum, Strasbourg, France.

10)Eguchi Y., Yamamoto T., Kitano K., Nishihara T. and Ohnishi H., (1998), ‘Three-dimensional computation of velocity and pressure fields in the Ogachi HDR reservoir’, 4th Int. HDR Forum, Strasbourg, France.

FY	Experiment	Injection			Production			Reservoir	
		Flow rate (l/min)	Wellhead Pressure (MPa)	Total Water Volume ($\times 10^3$)	Flow Rate (l/min)	Temper-ature (Max:°C)	Recovery (%)	Area of AE Distribution ($\times 10^3$)	Modal Volume of Tracer Test (m^3)
91	Lower Fracturing	640	18-18.5	10	-			500	
		710	18-18.5						
92	Upper Fracturing	500	22-22.5	5	-			300	
		700	23.5						
93	22 days Circulation	750	17	21	12	109	2	-	
		1200	19		30				
94	Production Well Fracturing	750	13	3	-			80	
	5 months Circulation	500	13	140	50	160	10	-	10-15(Upper)
		750	16		65				230-250(Lower)
95	Injection Well Fracturing	1500	16	4	-			20	
	Production Well Fracturing	2200	18	4	-			80	
	1 month Circulation	500	7	24	125	170	25	-	135
		750	9		150				
97	Upper Reser.Circulation	150	19	3	-			-	
	Injection from Production Well	750	10	10	-			-	
		500	7.5						
	Upper Reser.Circulation	220	19	3	-			-	
	10 days Circulation	500	13	6	75	116	15	-	138

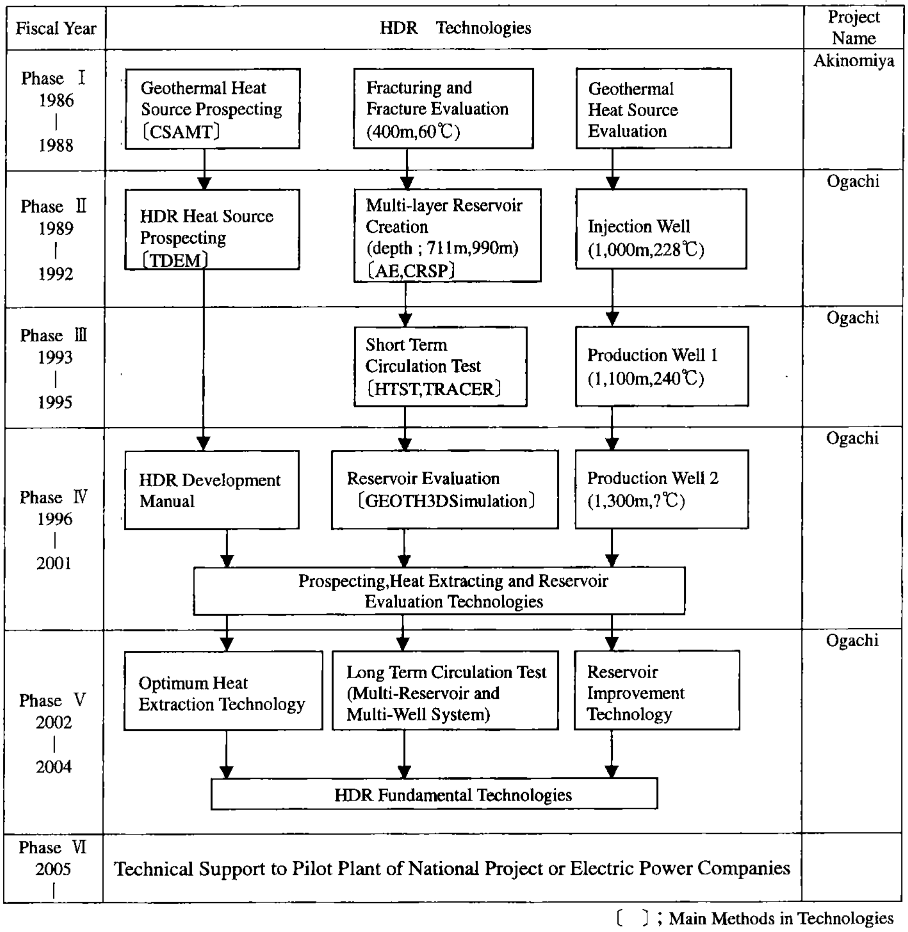

Fig.1 Ogachi Project for HDR Develoment

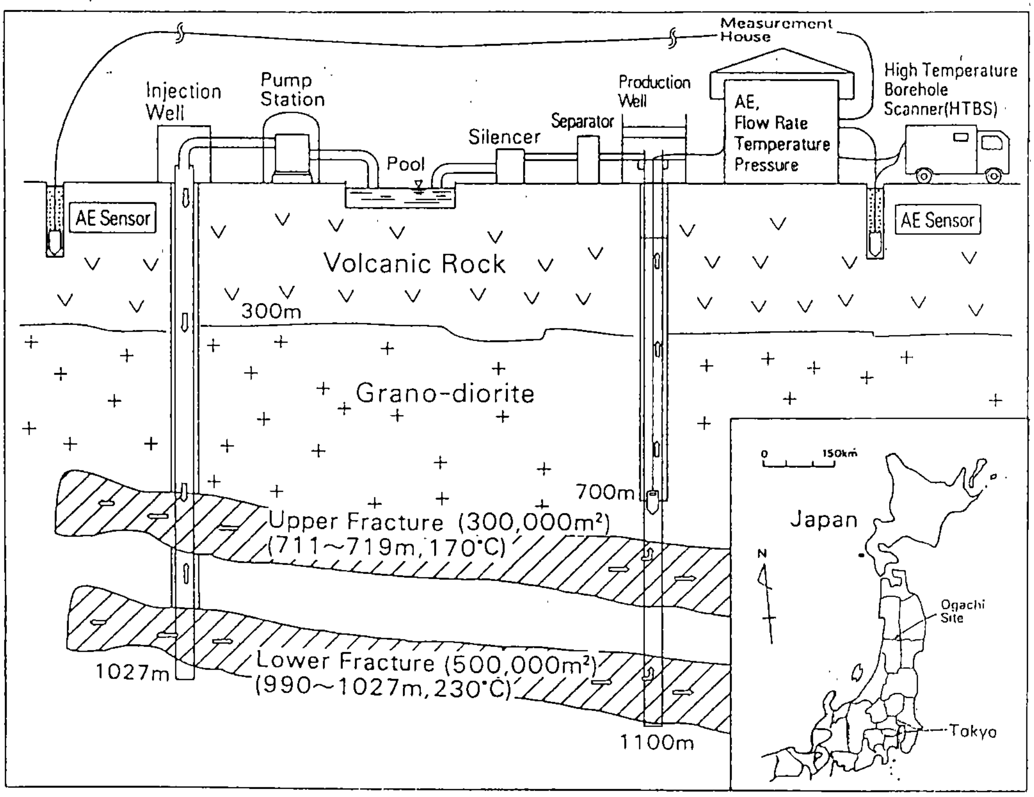

Fig.2 Illustration of Ogachi HDR Experiment

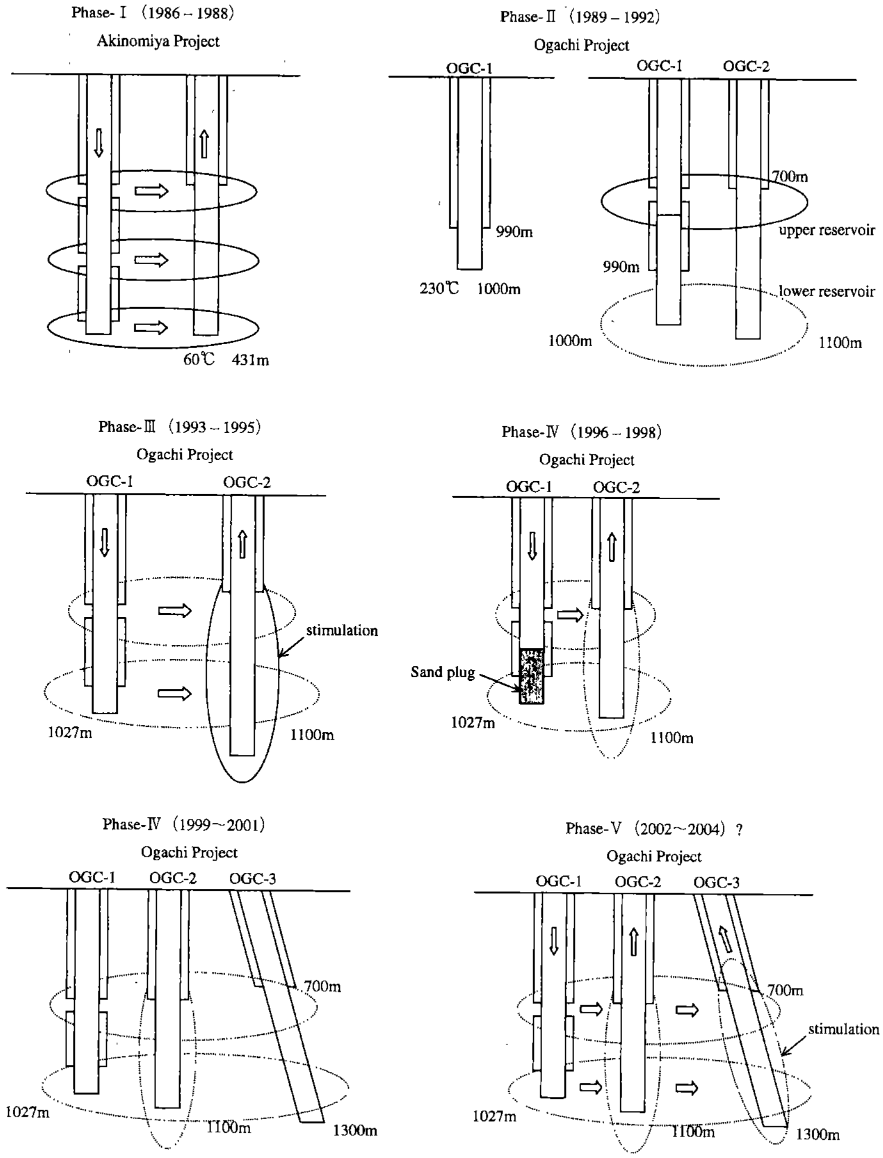

Fig.3 Process of Ogachi HDR Experiment

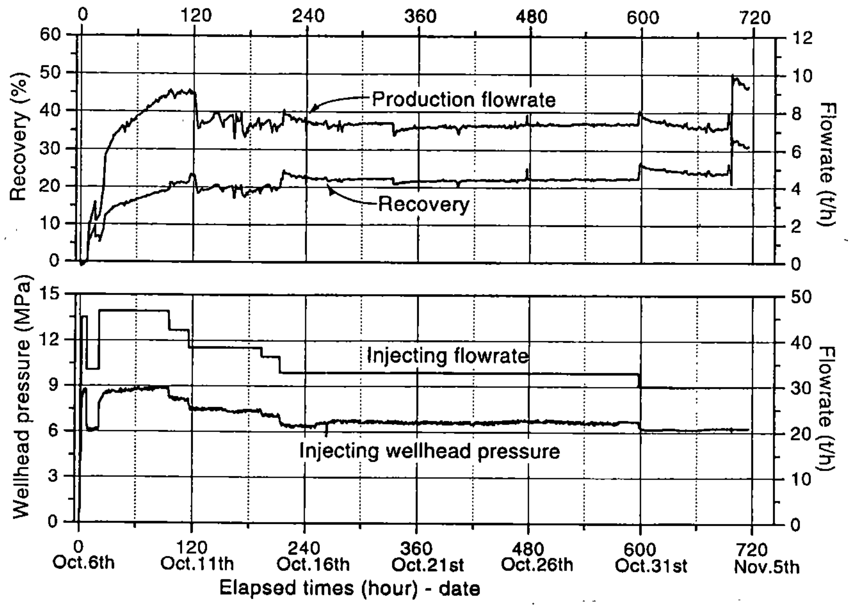

Fig.4 Time History Water Circulation Test in 1995.