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ANALYSIS OF HEAT EXTRACTION FROM THE HIJIORI AND OGACHI HDR GEOTHERMAL RESOURCES IN JAPAN

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ABSTRACT

Heat extraction from HDR geothermal resources in Japan has been carried out in several circulation tests under experimental development programs supported by the Japanese government and the electric utilities of Japan. Two major HDR resources under current investigation are the Hijiori HDR reservoir (by NEDO) and the Ogachi HDR reservoir (by CRIEPI) both in the northern Honshu region of Japan. Several circulation tests of one to several months have been conducted in each resource to obtain reservoir flow characteristics necessary for planning long-term production tests in later phases of the two programs. For optimum thermal analysis of the resources, expectations of energy extraction behavior is needed to evaluate the resources for commercial energy mining operations. Several aspects of the two resources, such as geologic structure and total resource size and heat content as defined by the temperature distribution in relation to the reservoir stimulation geometry needs further analysis. To assist in evaluating the thermal extraction aspects of the tests, comparison of modeling forecasts with measured test data were carried out. Heat extraction calculations with the Stanford Geothermal Program heat-sweep model, based on radial sector flow estimation, were made for the several circulation tests during the 1990s. The resulting calculations of thermal energy extraction from the test segments were accumulated to evaluate long-term expectations for each resource. Analysis of the combined data for the two somewhat differently stimulated HDR resources should be of value in evaluation of the northern Honshu region of Japan a s a long-term useful source of HDR geothermal-energy-derived electric power.

1. INTRODUCTION

Development of HDR geothermal technology for electric power generation in Japan is currently focused on two experimental sites, the Hijiori field supported by the New Energy and Industrial Technology Development Organization (NEDO) and the Ogachi field supported by the Central Research Institute of the Electric Power Industry (CRIEPI) for more than a decade. Status reports on these two sites are distributed routinely. Since 1991, several short-term circulation tests have been carried out at the two fields to evaluate the response to the respective reservoir stimulation programs and to measure the pressure-flowrate reservoir characteristics. Summaries of the status of these tests were reported by Tenma and Iwakiri (1998) for Hijiori and Kitano, Kiho, and Hori (1999) for Ogachi. An important aspect of these experimental HDR projects is an early estimation of the commercial feasibility of the HDR resources, which are generally determined from long-term production tests. The key parameters for these estimates are: (1) the extractable flow-acc essible heat content above the system abandonment temperature; (2) the optimum heat extraction rate for recovery of operating c osts; and (3) the resource lifetime for amortization of the total i nvestment.

In preparation for planned long-term production tests, preliminary evaluations were made of the heat extraction aspects of the short-term circulation tests to date. Three tests were made at Hijiori: (1) 90 days in 1991; (2) 25 days in 1995; and (3) 31 days in 1996. Four tests were carried out at Ogachi: (1) 20 days in 1993; (2) 151 days in 1994; (3) 30 days in 1995; and (4) 10 days in 1997. Much of the focus on these tests were to determine the hydraulic connections and flow conditions in the reservoir. The most recent analysis of the heat extracted form these short-term circulation tests were reported by Kruger and Tenma (2000) for Hijiori and Kruger, Yamamoto, and Eguchi (1998) for Ogachi.

An important aspect of this series of short-term circulation tests for long-term assessment of the reservoir is the cumulative heat extracted during each of the flow-test segments. The total heat extracted from each test needs to be included in the total energy extraction over the lifetime of the resource. For this purpose, estimates of the cumulative heat extracted from the several tests have been made using the simple, one-dimensional Stanford Geothermal Program heat-sweep model (Hunsbedt, Lam, and Kruger, 1983) revised to calculate heat extraction from the reservoir based on radial sector flow estimated by the fraction of observed production flow relative to measured injection flow. The thermal output was estimated by the model's two heat-sweep methods of calculated temperature cooldown at the production well and calculated thermal-front velocity at abandonment temperature from temperature cross-sections across each zonal sector. The two methods provide estimates of heat extraction from each reservoir zonal sector during the circulation periods and an estimate of the reservoir lifetime to the selected abandonment temperature.

2. HEAT EXTRACTED FROM THE TESTS

A summary of the heat extracted from the three short-term circulation tests at Hijiori and the four tests at Ogachi is listed in Table 1. The mean flowrates were calculated as weighted averages of the raw data in equal time intervals. The mean heat extraction rate was obtained by weighted averaging of the interval production flowrate and the mean enthalpy over each time interval. These were summed to obtain the heat extracted from the zonal sector over the circulation period. The range of lifetime results from the two temperature decline methods.

The parameters listed in Table 1 cover the key aspects of estimating the thermal properties of the reservoir as can be deduced from short-term circulation tests. The major uncertainty is the thermal reserves available for heat extraction above a technology determined abandonment temperature. The thermal reserves are, in turn, a function of the long-term circulation regime which determines the range of production flowrate. The production flowrate determines the ratio of mean fluid residence time to the mean rock thermal constant. The latter parameter (Kruger, 1983) is a function of the mean fracture spacing for fluid flow, which determines the rate of heat transfer to the rock-block surfaces.

The reservoir volume can be estimated by several methods. The most common is an evaluation of the most likely flow geometry around the wellbore system. Other methods derive from (1) a basis for limiting the volumetric envelop of microseismic events to that most likely to bound the circulating fluid contact volume within the accessible fracture network, (2) measurement of modal fluid (tracer) volume and mean porosity of the reservoir, (3) a basis for limiting the pressure inflation response (Brown, 1991) to the fluid contact volume, and (4) evaluation of the prior heat extraction history. An example of the range of such estimates is given in Robinson and Kruger (1992) compiled for the Fenton Hill HDR reservoir.

The available heat content, HC, (PJ) of a stimulated HDR reservoir is given by:

$$HC = (\rho V_r)\, C_p\, (T_r - T_a) \qquad (1)$$

where ρ = rock density (kg/m^3)
V_r = reservoir volume (m^3)
C_p = rock specific heat (J/kg-C)
T_r = mean initial reservoir temperature (C)
T_a = application abandonment temperature (C)

Although none of the tests in Table 1 were long-term production tests (with flow durations from 10 to 151 days), the data are still useful for qualitative estimates of potential heat extraction rates (deliverability) and extrapolated lifetime to abandonment temperature (longevity). The production data for each of the seven circulation tests in the table were integrated in time and the mean injection and production flowrates were calculated. From temperature logs, the downhole mean heat extraction rate was calculated. These data were used to estimate the total energy extracted, HE, (TJ) by:

$$HE = \int_{t_0}^{t_a} Q(t)\, \Delta h(T_i, T_f, t)\, dt \qquad (2)$$

where Q = production flowrate (kg/s)
h = fluid enthalpy (kJ/kg)
T_i = injection fluid temperature (C)
T_f = bottom-hole produced fluid temperature (C)

Δh is the increase in enthalpy of the circulating fluid above that of the injected fluid. The estimates of lifetime in Table 1 were calculated from the SGP 1-D heat sweep model.

Details of the individual circulation tests are available in the following reports for Hijiori: 90-day 1991 test (Kruger and Yamaguchi, 1993); 25-day 1995 test (Kruger, Sato, and Shinohara, 1996), and 31-day 1996 test (Kruger and Tenma, 2000) and for Ogachi: 22-day 1993 test (Kaieda, et al, 1995), 151-day 1994 test (Kruger and Yamamoto, 1995), and the 30-day 1995 and 10-day 1997 tests (Kruger, Yamamoto, and Eguchi, 1998).

In the multi-well, multi-horizon reservoirs created in the Hijiori and the Ogachi fields in Japan, where both the injection and production wells have multiple entry intervals, estimation of the production flow geometry is difficult, especially in the very short flow times in which injection flow rate is varied and fluid recovery is small. In the analysis of the 90-day flow test at Hijiori in 1991, the first attempt was made to model the recovery fraction of the injected fluid for thermal analysis with zonal sector flow geometry in which fluid flow is confined to a zonal sector angle over the mean width of the reservoir proportional to the fluid recovery rate. The zonal sector flow angle is given by

$$\alpha = 2\pi\, Q(p)/Q(i) \qquad (3)$$

where Q(p) = mean production flowrate, (kg/s)
Q(i) = mean injection flowrate, (kg/s).

Analysis of heat-sweep flow though the zonal sector was made in two forms: (1) with variation of mean fracture spacing to observe the effect of heat transfer rate from rock blocks to the circulating fluid; and (2) as a temperature cross-section at constant mean fracture spacing to observe the passage of the frontal zone through the sector. The results of these analysis provides the estimates of longevity as the time when the production well bottom-hole temperature decline curve falls below the abandonment temperature and as the time when the thermal frontal zone at the abandonment temperature reaches the production well.

3. THE SGP 1-D HEAT SWEEP MODEL

The SGP 1-D Heat Sweep Model was initiated by Hunsbedt (Hunsbedt, Kruger, and London, 1978) in a physical model of a uniform fractured-rock hydrothermal reservoir to measure heat extraction with limited geologic and thermodynamic data. The model was improved to estimate heat extraction from reservoirs of rock blocks of irregular shapes and size distributions (Kuo, Kruger, and Brigham, 1977) in terms of heat transfer from a sphere of equivalent thermal radius, for which the heat transfer equations can be solved analytically (Carslaw and Jaeger, 1973). Experimental verification of the model was shown by Hunsbedt (Hunsbedt, et al, 1979). The model was compared to the MULKOM geothermal reservoir simulator (Pruess, 1983) and the results were given by Lam, et al, 1988. The model was further improved to provide for radial and doublet flow (Lam, 1990), non-uniform initial temperature distribution (Lam and Kruger, 1989), and zonal sector flow (Kruger and Yamaguchi, 1993).

The thermal physics of the model is summarized in Kruger (1983). The basic parameter of heat extraction rate can be indexed by the number of heat transfer units, N, which is the ratio of two time parameters governed by the hydraulic and thermal properties of the reservoir. The hydraulic index is the mean residence time of the circulating fluid, a measure of how long the surrounding fluid is in contact with the rock blocks. The thermal index is the mean-size rock-block time constant, a measure of the rate with which heat from inside the rock blocks can be conducted to the block surfaces for heat transfer. Thus, for low values of N (large production flowrate), cooldown of the flow path is rapid with a corresponding decrease in the fraction of available heat content produced. For high values of N (small production flowrate), a large fraction of the available heat content is recovered, but at a smaller thermal power extraction rate. For a given HDR reservoir, an optimum flowrate exists to maximize thermal power extraction and maximum recovery of the thermal energy reserves.

4. APPLICATION OF THE MODEL

The SGP 1-D Heat Sweep Model has been used for several studies of hydrothermal and HDR geothermal resources for estimating fluid sweep and percolation recharge with cooldown history matching in operating fields and for scenario analysis in new fields. For HDR geothermal systems, the model can be used to analyze the heat extracted from existing circulation tests and to predict the range of heat extraction potential from newly stimulated reservoirs prior to short-term well testing and long-term production testing. Prior application studies for the Hijiori and Ogachi HDR resources were referenced in Section 2 and the heat extraction results are summarized in Table 1. New results for two prior tests are included in Table 1: (1) a revision of the Ogachi 1993 22-day circulation test; and (2) analysis of the Hijiori 1996 31-day circulation test (Kruger and Tenma, 2000). Plans for long-term circulation tests are being completed for the Hijiori system as it currently exists and for the Ogachi reservoir following completion of a second production well on the other side of the injection well. Predictions of estimated heat extraction for these long-term production tests are calculated for comparison with the test data when the tests are underway.

4.1 The 1993 Ogachi 22-day Circulation Test

The initial thermal analysis of the first short-term circulation test following completion of the two-layer stimulated reservoir in the Ogachi resource was summarized in Kruger, Yamamoto, and Eguchi, 1998 based on the evaluation of the hydraulic communication data reported by Yamamoto, Fujimitsu, and Motojima (1995). The revised estimate of heat extraction was made with the actual test data provided by CRIEPI and using an estimate of the reservoir volume based on zonal sector flow geometry. The mean injection and production flowrates were calculated in 12-hour increments over the 22-day circulation period for use in the heat sweep model. The ratio of mean production flowrate (0.28 kg/s) to mean injection flowrate (16.7 kg/s) was about 1.67%, resulting in a zonal sector angle of only 6 degrees. The simulated cooldown curve for this narrow sector flow angle using the same mean rock-block fracture spacing obtained from the later tests, is shown in Figure 1. The curve shows, for this very small recovery fraction, constant production fluid temperature for more than 4 years and an estimated lifetime to abandonment temperature of about 6.5 years. The amount of heat extracted was calculated for the same 12-hour increments over the production period. For mean enthalpy increase of 950 kJ/kg at mean heat extraction rate of 0.26 MJ/s, the total heat extracted was 0.51 TJ.

4.2 The 1996 Hijiori 30-day Circulation Test

The latest short-term circulation test in the Hijiori system was run in the summer of 1996 as a series of eight test segments within the flow enhancement program described in NEDO (1996). A summary of the test segments is given in Table 2. The salient features of the circulation test from the standpoint of heat extraction, neglecting the step-rate tests before and after circulation, are: (1) the constant injection flowrate under several changes in injection pressure and (2) the change in flow regime for the one production well (HDR-3) flow period and the two production well (HDR-3 and HDR-2a) flow period. Since both of these changes in condition affect the internal flow patterns (and the effective zonal sector volumes), a detailed study of the effective reservoir sizes (and corresponding heat content and lifetime to abandonment temperature) for the test segments has been prepared separately by Kruger and Tenma (2000). A summary of the overall heat extraction results based on the test data is given in Table 3. In the 8 days of flow to well HDR-2a, the thermal production was 25% of the total heat extracted compared to 75% for well HDR-3 over the full 30-day period, reflecting the greater flow recovery fraction of well HDR-2a compared to that of well HDR-3.

4.3 The Planned Long-Term Production Tests

Prediction of energy recovery over long production periods based on reservoir characteristics obtained from short-term well tests depends primarily on the selection of the appropriate flow geometry over the thermal reservoir volume. For the prior short-term circulation tests, the reservoir volume was selected on a test by test basis to match the known test conditions. Since there has not been a long-term test in either of the two resources, selection of the reservoir volume from the prior history given in Table 1 is very uncertain. In the manner of estimating a range of probable reservoir volumes used for the Fenton Hill long-term flow test (Robinson and Kruger, 1992), reservoir volumes were estimated by the NIRE and CRIEPI staffs by the same set of technologies. The results for Hijiori and Ogachi are summarized in Table 4.

For the Hijiori planned LTPT, sufficiently precise data are not available for fixing the reservoir volume for the expected one-to-two year circulation period. The uncertainty is compounded by the observation in the 1996 circulation test that when HDR-2a was shut-in, flow entries were measured at both the upper and lower fracture zones of HDR-3, but on flowing to both wells, the production from HDR-3 was only from the lower zone. With the other key flow geometry factors well established, such as sector radius, mean initial temperature, and planned injection flowrate, it appears that the most useful criterion for evaluation of the test results as they are accumulated would be a set of Type Curves of estimated cooldown as a function of mean reservoir thickness over a range of possible production flowrate which determines the zonal sector angle, and thus the zonal sector volume. The general flow geometry for the Hijiori LTPT, adapted from Tenma and Iwakiri (1998) is shown in Figure 2. The corresponding system cross-section for the Ogachi reservoir with the completed new well is shown in Figure 3. For both resources, cooldown simulations were run for a range of production recovery from 10% to 50% for each well in 10% increments which corresponds to a range of zonal sector angles from 36 to 180 degrees, for a range of mean reservoir thickness from 50 m to 200m. The resulting cooldown curves for the Hijiori LTPT are shown in Figures 4 and 5.

For the Ogachi planned LTPT, the range of estimated reservoir volume is also shown in Table 4, but some of the values do not include data for the new well completed after the 1996 short-term circulation test run with only the old well. Thus, for evaluation of the Ogachi LTPT, it also appeared most useful to prepare a set of type curves for the old and new wells similar to those prepared for Hijiori. The flow criteria for zonal sector dimensions with the planned injection flowrate were selected for the LTPT from the system cross-section in Figure 3. The resulti ng cooldown type curves are shown in Figures 6 and 7.

5. DISCUSSION

Summaries of the evaluation criteria for the cooldown type curv es for the two LTPTs are listed in Table 5 (for Hijiori) and Tabl e 6 (for Ogachi). For Sector-1 (HDR-2a) at Hijiori and Sector-1 (old well) at Ogachi, cooldown to bottom-hole production flu id temperature of 220ºC should be observable within one year of circulation if the effective mean reservoir thickness is of the order of 50m or less. For thickness greater than 100m, definitiv e cooldown may not be observed at either resource for a produc tion period less than two-years. In any case, from a reservoir ev aluation point-of-view, increasing production time with no mea surable decline in fluid temperature continually sets the minim um reservoir thickness, and thus, the minimum resource size for the given production flowrate. The availability of these cooldo wn type curves, which can be adjusted to other production con ditions, especially if the production flowrate continues to increa se with time under constant injection flowrate, should assist in t he long-range evaluation of the Hijiori and Ogachi HDR geothe rmal resources in Japan and provide the basis for comparison of the two long-term thermal energy extraction behavior.

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REFERENCES

Brown, D.W. (1991). Recent progress in HDR reservoir engineering, Geoth. Progr. Review IX, USDOE, pp. 153-157.

Carslaw, H.S. and Jaeger, J.C. (1973). *Conduction of Heat in Solids*, 2nd Edition, Oxford University Press, Glasgow.

Hunsbedt, A., Iregui, R., Kruger, P. and London, A.L. (1979). Energy recovery from fracture-stimulated geothermal reservoirs, ASME-AIChE Heat Transfer Conference, Paper 79-HT-92.

Hunsbedt, A., Kruger, P. and London, A.L. (1978). Energy extraction from a laboratory model fractured geothermal reserv oir, *J. Petro. Tech.*, Vol. 30 (5), pp. 712-718.

Hunsbedt, A., Lam, S. and Kruger, P. (1983). User's manual f or the 1-D Linear Heat Sweep Model, Stanford Geothermal Program Technical Report SGP-TR-75.

Kaieda, 1995 [??]

Kitano, K., Kiho, K., and Hori, Y. (1999). Overview of the Ogachi Project. *Proceedings*, Ogachi International Workshop, Abiko, Japan, 16 March 1999.

Kruger, P. (1983). Experimental studies on heat extraction fro m fractured geothermal reservoirs. In: *Hydraulic Fracturing an d Geothermal Energy*, S. Nemat-Nasser, H. Abe, and S. Hirakawa, (Eds), Martinus Nijhoff Pub., The Hague, pp.373-39 7.

Kruger, P. (1993). The concept of geothermal energy mining, Proceedings, *Hot Dry Rock Geothermal Energy for U.S. Electric Utilities*, Electric Power Research Institute, Palo Alto, CA.

Kruger, P. and Tenma, N. (2000). Heat extraction analysis of the 1996 Hijiori 31-day circulation test. *Proceedings*, 25th Stanford Geothermal Workshop on Geothermal Reservoir Engineering, Palo Alto, CA, January 2000, in prep.

Kruger, P., Sato, Y. and Shinohara, N. (1996). Energy extraction analysis of the 1995 Hijiori 25-day circulation test, *Geoth.Res. Counc.Trans.*, Vol. 20, pp. 457-463.

Kruger, P. and Yamaguchi, T. (1993). Thermal drawdown analysis of the 90-day circulation test, *18th Stanford Workshop on Geothermal Reservoir Engineering*, SGP-TR-145, pp. 111-118.

Kruger, P. and Yamamoto, T. (1995). Heat extraction from the Ogachi 151-day HDR circulation test, *Geoth.Res. Counc.Trans.*, Vol. 19, pp. 269-273.

Kruger, P., Yamamoto, T. and Eguchi, Y. (1998). Heat extraction from Ogachi HDR Geothermal Resource, 23rd Stanford Workshop on Geothermal Reservoir Engineering, SG P-TR-158, pp. 330-335.

Kuo, M.C.T., Kruger, P. and Brigham, W.E. (1977). Shape-f actor correlations for transient heat conduction from irregular-s haped rock fragments to surrounding fluid, *AIChE-ASME Heat Transfer Conference*, Paper 77-HT-54.

Lam, S.T. (1990). The effect of heat-sweep induced thermal stress on reservoir rock thermal conductivity, Ph.D. Dissertatio n, Stanford University, Stanford, CA.

Lam, S.T., Hunsbedt, A., Kruger, P. and Pruess, K. (1988). Analysis of the Stanford Geothermal Reservoir Model experiment using the LBL Reservoir Simulator, *Geothermics*, Vol.17, pp.595-605

Lam S.T. and Kruger, P. (1989). Doublet heat sweep model with bounded initial temperature distribution, 14th Stanford Workshop on Geothermal Reservoir Engineering, SGP-TR-122, pp. 249-256.

NEDO (1996). FY1996 Summary of Hot Dry Rock Geother mal Power Project, Geothermal Energy Technology Departmen t, NEDO, Tokyo, 54 pp.

Pruess, K. (1983). Development of the General Purpose Simulator MULKOM, Annual Report 1982, LBL-15500.

Robinson, B.A. and Kruger, P. (1992). Pre-test estimates of temperature decline for the LANL Fenton Hill long-term flow test, *Geoth.Res.Counc.Trans.*, Vol. 16, pp. 473-479.

Tenma, N. and Iwakiri, S. (1998). Program of the preparatory period for a long-term circulation test on the Hijiori HDR proje ct. *Proceedings*, 4th International HDR Forum, Strasbourg, France, 28-30 September 1998.

Yamamoto, T., Fujimitsu, Y., and Motojima I. (1995). Hydraulic communication tests at the Ogachi HDR site, Japan. *World Geothermal Congress Trans.* pp. 2701-2705.

Table 1. Summary of Heat Extraction History

Parameter (units)	Hijiori (T_a=150C) 1991	1995	1996	Ogachi (T_a=140C) 1993	1994	1995	1996
Res.Vol. ($10^6 m^3$)	0.66	6.3	--	0.14	0.75	1.77	0.91
Ht.Cont. (PJ)	0.18	2.2	--	0.03	0.18	0.34	0.18
Flow time (days)	90	25	30	22	151	30	10
Mean Q(i) (kg/s)	16.7	24.7	16.7	16.7	10.8	9.7	7.8
Mean Q(p) (kg/s)	12.8	4.8	5.2	0.28	1.01	2.01	0.84
Mean HER (MJ/s)	27.5	7.9	7.8	0.3	9.6	1.9	0.9
Ht.Ext'd. (TJ)	0.12	16.6	11.8	0.5	--	4.8	0.8
Est'd Life (yrs)	>0.7	>5.0	--	6.5	7.5	13.5	16

Table 2. Segments of the Hijiori 1996 Circulation Test

Date	Operation	Q(l/s)	P(MPa)
10 Aug	1st step-rate injection	4.2-30.0	1.8-10
10-16	flow to HDR-3 only	16.6	8.7
16-22	back-pressure stimulation	16.6	8.2
22-25	comparative P production	16.6	8.0
25-30	comparative P production	16.6	7.6
30-02 Sep	comparative P production	16.6	7.5
02-08	flow to HDR-3 and HDR-2a	16.6	7.4
09	2nd step-rate injection	4.2-30.0	2.1-7.4

Table 3. Heat Extraction from the Hijiori 1996 Test

Parameter	HDR-2a	HDR-3	Combined
Circulation time (hr)	189	741	--
Mean injection rate (kg/s)	16.6	16.6	--
Mean production rate (kg/s)	5.36	3.39	8.75
Mean heat extraction rate (MJ/s)	4.49	3.32	7.81
Heat extracted (TJ)	2.98	8.84	11.8

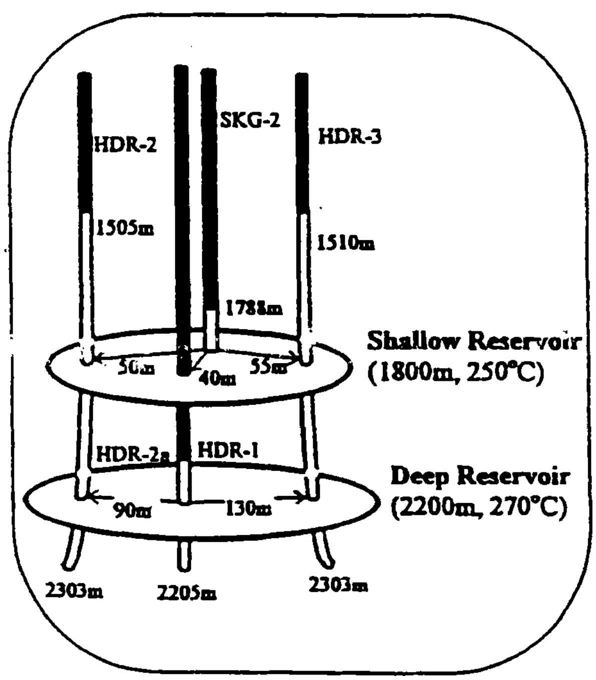

Fig. 2. Schematic view of the Hijiori HDR system. (from Tenma and Iwakiri, 1998).

Table 4. Estimates of Reservoir Volume

Method	Condition	Estimated Volume ($10^6 m^3$) Hijiori upper	Hijiori lower	Ogachi upper	Ogachi lower
Swept geom.	low est.	6.3		0.75	
flow volume	high est.	20		8	
Microseismic	Magn >1.5			0.012	0.65-1.
			1		
events	1σ envelop			3.7	10.0
Tracer	modal vol/				
testing	porosity			0.2	3-5
Pressure	bulk mod,K				
testing	K∗ΔV/ΔP			2	
Prior heat	for whole				
extraction	reservoir	0.7 - 6.3		0.14 - 1.8	

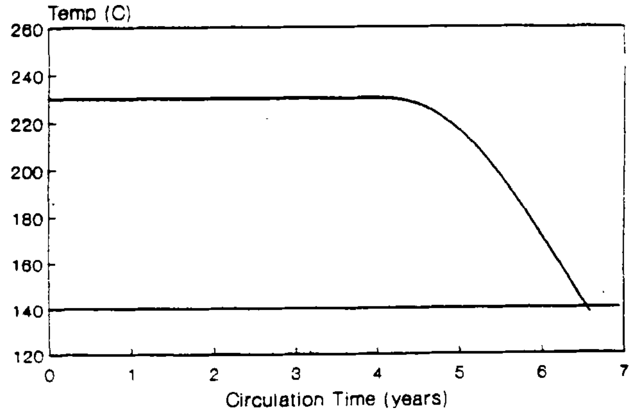

Fig. 1. Simulated cooldown curve for the Ogachi 1993 test.

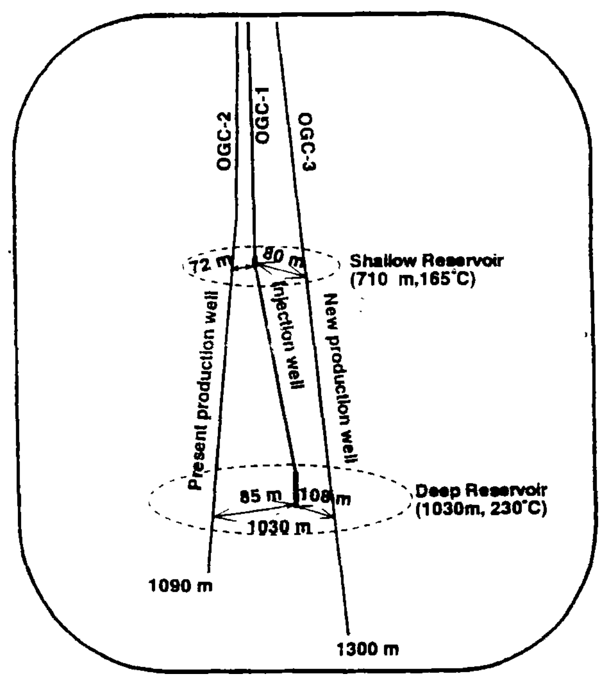

Fig. 3. Schematic view of the Ogachi HDR system with the new production well.

Table 5. Cooldown predictions for the Hijiori LTPT.

Time (months)	Sector-HDR-2a				Sector-HDR-3			
	Z-bar (m)				Z-bar (m)			
to T(f) (°C)	50	100	150	200	50	100	150	200
220	10	23	39	55	24	58	90	128
200	12	27	43	59	28	63	98	134
T(a)	16	36	54	72	37	76	114	152
T(f) at 2 yrs (°C)	120	218	256	259	225	260	260	260

Table 6. Cooldown predictions for the Ogachi LTPT.

Time (months)	Sector-1 (old well)				Sector-2 (new well)			
	Z-bar (m)				Z-bar (m)			
to T(f) (°C)	50	100	150	200	50	100	150	200
220	12	31	52	72	24	59	95	130
200	16	36	59	81	28	66	103	140
T(a)	23	47	72	97	39	79	120	160
T(f) at 2 yrs (°C)	130	228	230	230	220	230	230	230

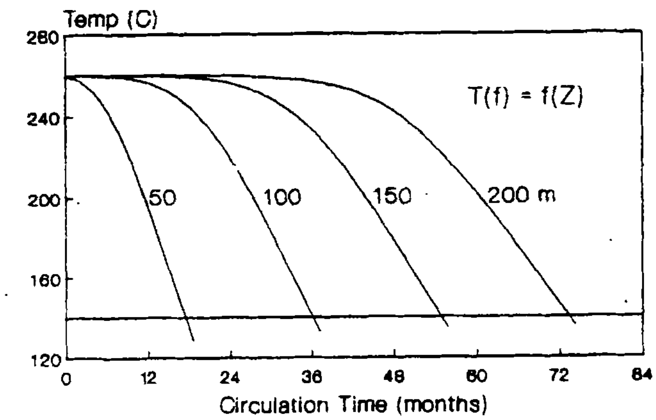

Fig. 4. Cooldown type curves for the HDR-2a sector of the planned Hijiori LTPT as function of mean reservoir thickness.

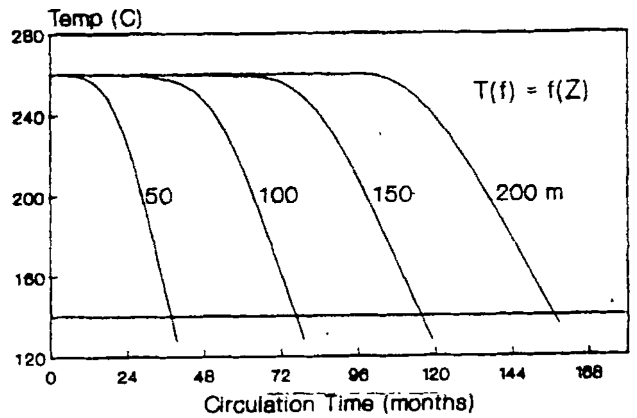

Fig. 5. Cooldown type curves for the HDR-3 sector of the planned Hijiori LTPT as function of mean reservoir thickness.

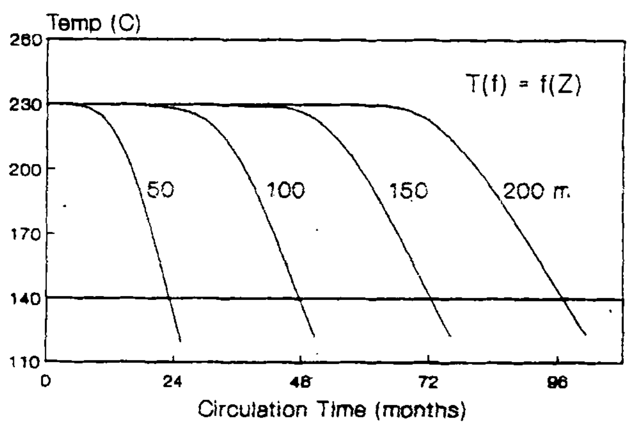

Fig. 6. Cooldown type curves for the existing-well sector of the planned Ogchi LTPT as function of mean reservoir thickness.

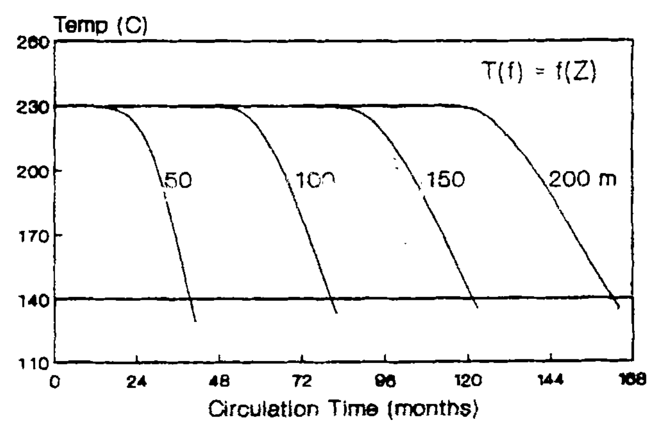

Fig. 7. Cooldown type curves for the new-well sector of the planned Ogachi LTPT as function of mean reservoir thickness.