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WELL STIMULATION USING COLD-WATER INJECTION EXPERIMENTS IN THE SUMIKAWA GEOTHERMAL FIELD, AKITA PREFECTURE, JAPAN

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ABSTRACT

Cold-water injection experiments with cold river water at a high injection flowrate were applied to a well stimulation to improve the productivity and injectivity of geothermal wells at Sumikawa. Injection and warming up were repeatedly conducted for each well. This paper briefly describes the results of cold-water injection experiments for three production wells (SA-1, SA-2, and SA-4). The injectivity of each well was improved, and the productivity of SA-1 and SA-4 was increased increasingly after cold-water injection experiments.

INTRODUCTION

Mitsubishi Metal Corporation (MMC) has been conducting exploration to generate 50 MWe from the Sumikawa geothermal field, Akita prefecture, Japan. The discharge test program undertaken during 1989 involved seven production wells and five reinjection wells. Prior to the 1989 discharge test program, cold-water injection experiments were applied to a well stimulation to improve productivity and injectivity. Hydraulic fracture treatments with gelled fluid and proppant were applied to a geothermal well stimulation (e.g. Morris and Bunyak, 1981). The cold-water injection experiments at Sumikawa were carried out discontinuously with cold river water at a high injection flowrate and low wellhead pressure. Cold-water injection experiments were conducted on five production wells (S-4, SA-1, SA-2, SA-4, SB-1) and two reinjection wells (SB-2, SB-3). The total cost was approximately ¥34,000,000 (around ¥5,000,000 per well).

This paper briefly describes the efficiency and limitations of cold-water injection experiments based on the results of SA-1, SA-2, and SA-4. These wells individually indicated different levels of performance during cold-water injection experiments.

BACKGROUND

The Sumikawa geothermal field is located on the northern slope of Mt. Akita-Yake-Yama. Subsurface temperatures appear to be highest to the south, implying that thermal anomalies are associated with the east-west volcanic chain located south of the field. Underground pressures are approximately uniform throughout the area. In the shallower parts of the field, the vertical pressure distribution is characterized by a substantially sub-hydrostatic gradient, implying a two-phase region. This region with a low gradient begins as deep as +400mASL and extends up to the base of Quaternary lacustrine sediments. The depth of

the bottom of the two-phase region probably increases southward toward Mt. Akita-Yake-Yama. Fluid flows are principally through an extensive network of fractures. During drilling, regions of lost circulation are frequently encountered within the high temperature zone.

Figures 1 and 2 show the localities of wells and the conceptual model of Sumikawa geothermal field.

SA-1 was directionally drilled to a depth of 2002m. The bottom of the 9-5/8-inch casing was set at 1099m, and a 7-inch slotted/blank liner was installed below this depth. Lost circulation zones below a depth of 1099m were recorded at 1797m and 1879m, and were blind-drilled below a depth of 1890m. The various log surveys (resistivity, sonic, temperature, and geology) showed the anomaly at 1830-1850m, 1870-1890m, and 1910-1930m, implying permeable zones.

SA-2 was directionally drilled to a depth of 2005m. The bottom of the 9-5/8-inch casing was set at 1099m, and a 7-inch slotted/blank liner was installed below this depth. All lost circulation ($> 0.035 \text{ m}^3/\text{s}$) was encountered at 1964m during drilling with river water, and blind drilling was employed below 1964m owing to a blowout at that level. The various surveys showed that permeable zones are located at 1500m and 1964m.

SA-4 was directionally drilled to a depth of 2009m. The bottom of the 9-5/8-inch casing was set at 1203m, and a 7-inch slotted/blank liner was installed below this depth. Lost circulation zone below a depth of 1203m was not recorded. However warm-up profiles shortly after injection implied that most of the water loss occurred at 1350m.

DESCRIPTION OF TEST

Each well (SA-1, SA-2, SA-4) was injected discontinuously from April 15 to May 18, 1989. Injection and warming up were conducted repeatedly for each well. Injection tests to obtain I.I (Injectivity Index) and permeability-thickness product were carried out before and after the cold-water injection experiments. Discharge of SA-1, SA-2, and SA-4 in order started in June. Table 1 shows the schedule of cold-water injection experiments for SA-1, SA-2, and SA-4.

Cold-water injection experiments were conducted with cold river water utilizing two forced pumps (max. flowrate = $0.07 \text{ m}^3/\text{s}$, pumping press. = 2.5 bars) and two reciprocating pumps (max. flowrate = $0.04 \text{ m}^3/\text{s}$, pumping press. = 70 bars).

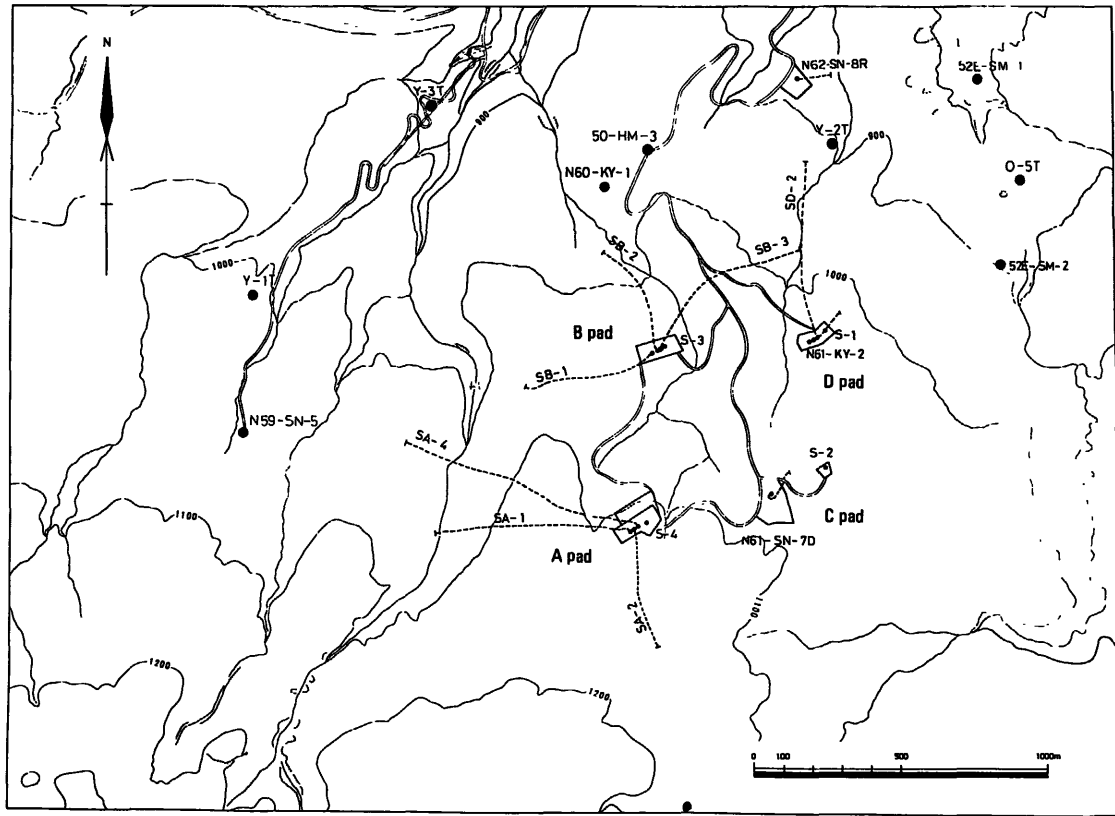


Figure 1. The Sumikawa wellfields.

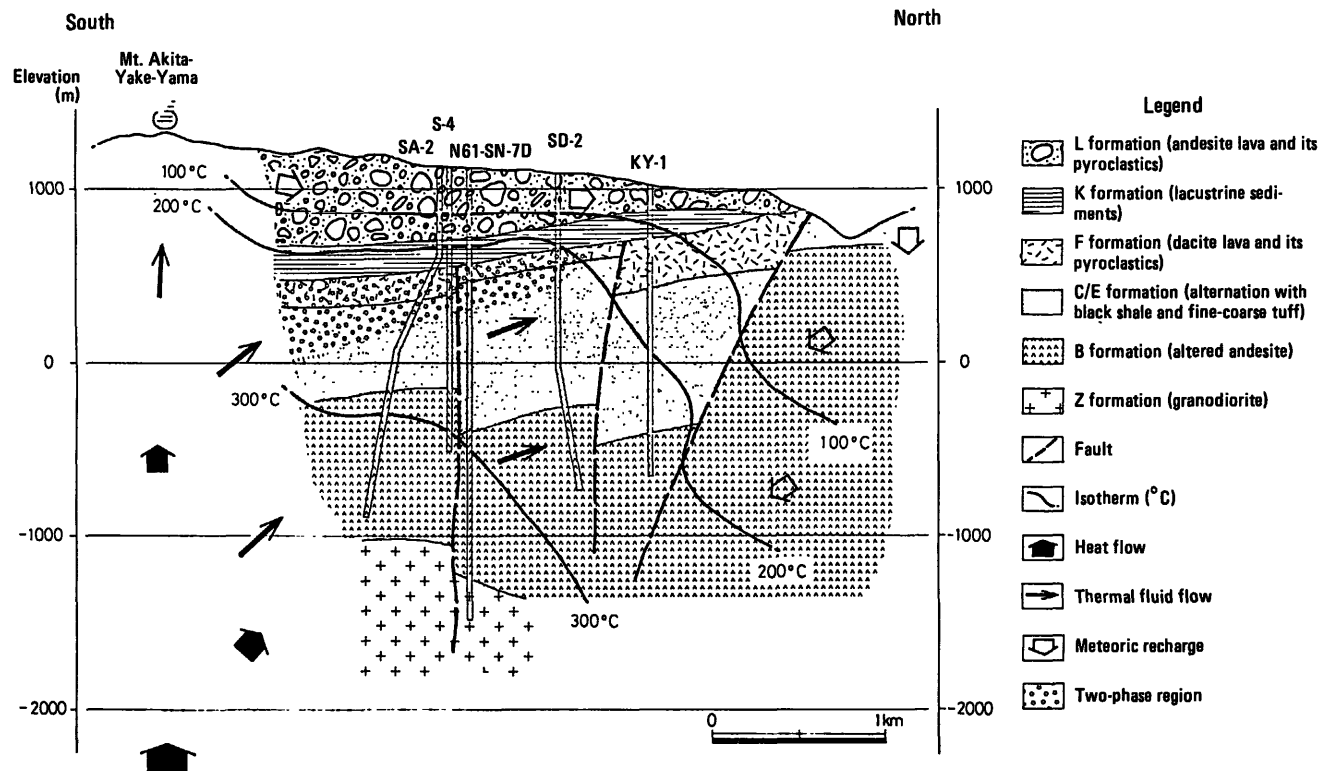


Figure 2. Conceptual model of Sumikawa geothermal field.

Table 1. Schedule of cold-water injection experiments.

Well No.	April 1989				May 1989			
	15	20	25	30	1	5	10	15 18
SA-1	* ▲	○○○ ▲▲▲		▲	○ ○○○		○	○*
SA-2	* ▲	○○○ ▲▲	▲		○		○○○○	* ▲
SA-4	* ▲		○○○ ▲▲▲		○○○○○○○○○○			* ▲

* Injection test

○ Injection at high flowrate (0.06 to 0.11 m³/s)▲ Injection at low flowrate (0.003 m³/s)

In the case of low well-head pressure during injection, only two forced pumps were used. The river water was injected from the wellhead without using a tubing pipe. We observed the wellhead pressure and injection flowrate during injection. The high flowrate and low wellhead pressure indicate high injectivity.

In the early part of each injection segment, the injection performance illustrated in Fig. 3 was commonly observed.

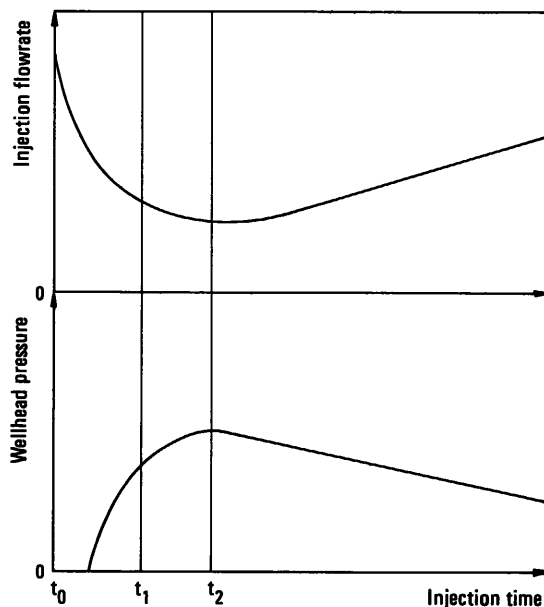


Figure 3. Simplified injection performance.

We interpreted the injection performance illustrated in Fig. 3 as follows.

- 1) $t_0 - t_1$: Term of displacement of hot water and cold water in wellbore

Change of injection flowrate and wellhead pressure depend mainly on pump operation. Hot water in wellbore enters the reservoir.

- 2) $t_1 - t_2$: Term of cold water into reservoir (I)

Depending on the change of physical properties (temperature, density, viscosity et al.) of injected water in a reservoir, the injection flowrate decreases and the wellhead pressure increases. Injected water slightly affects reservoir.

- 3) After t_2 : Term of cold water into reservoir (II)

The physical properties of injected water have been almost constant, and changes in permeability appeared. The changes in permeability may be due to fracturing, thermal cracking, thermal contraction, and solid dissolution (Grant et al., 1982).

Data after t_2 is significant for interpreting the well stimulation.

ANALYSES OF DATA

In order to evaluate the injectivity changes, we assumed I.Ia(t) (apparent injectivity index).

$$I.Ia(t) = Q(t)/(P(t) - P_0)$$

where

$P(t)$	= $P_{WH}(t) + \rho(t)gh$	
$I.Ia(t)$	= apparent injectivity index	(m ³ /s-Pa)
$Q(t)$	= injection flowrate	(m ³ /s)
$P(t)$	= downhole pressure	(Pa)
P_0	= undisturbed downhole pressure	(Pa)
$P_{WH}(t)$	= wellhead pressure	(Pa)
$\rho(t)$	= average density of water in wellbore	(kg/m ³)
g	= gravity acceleration	(m/s ²)
h	= height between wellhead and major feed zone	(m)

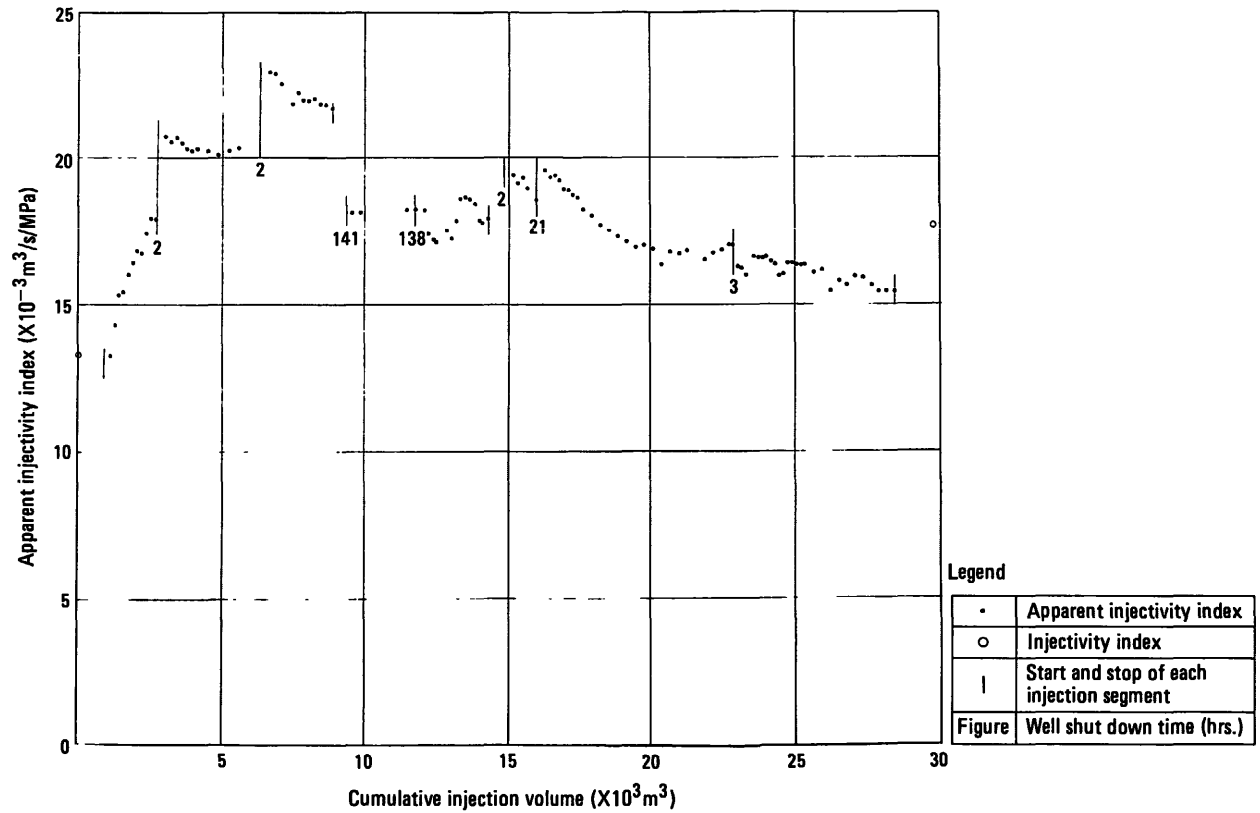
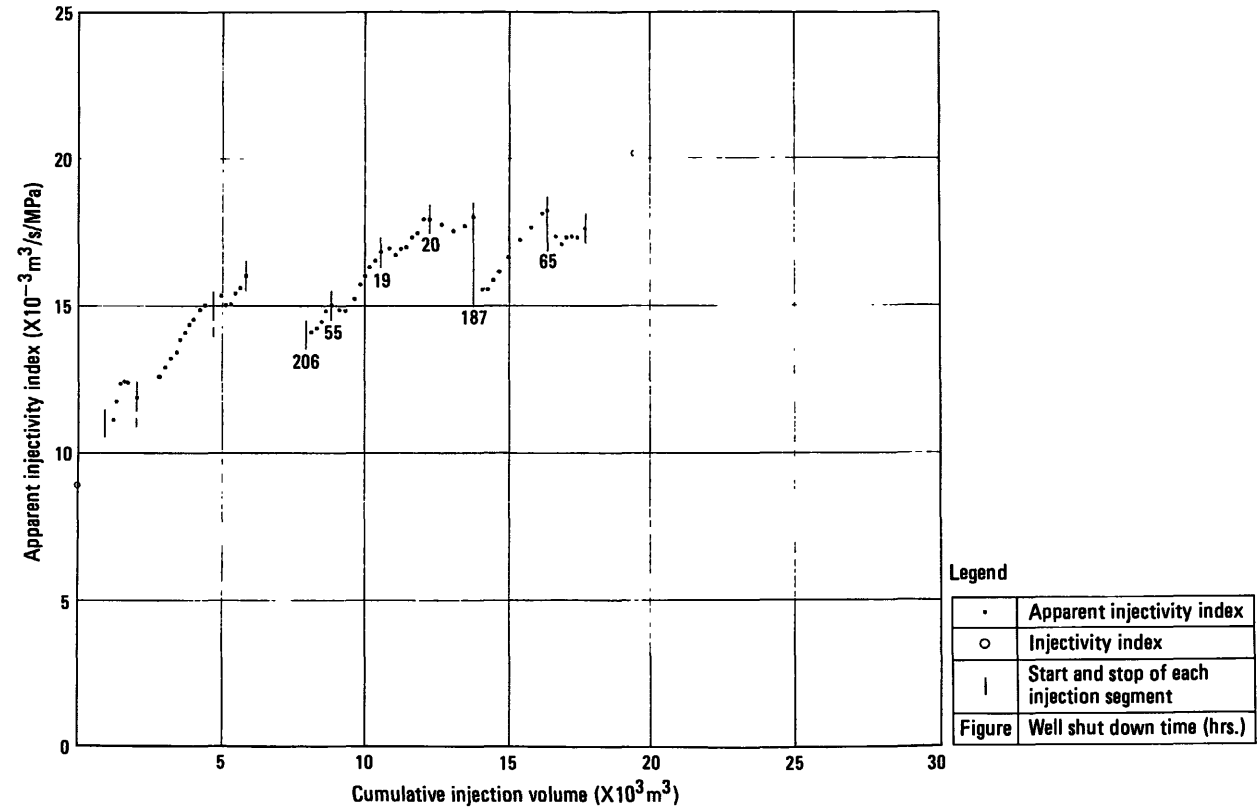
Table 2 shows assumed values to calculate I.Ia(t) for each well.

Table 2. Presumed values to estimate I.Ia(t).

Well No.	Initial pressure (MPa)	Feedpoint depth (m)	
		Drilling depth	Vertical depth
SA-1	10.81	1879	1727
SA-2	9.49	1500	1449
SA-4	8.33	1360	1260

We calculated I.Ia(t) using data after displacing hot water and cold water in a wellbore (after t_1 in Fig. 3). Then we assumed that the average temperature of water in wellbore was 30°C, average density is 1000 kg/m³.

The resulting values obtained for I.Ia(t) are plotted as data points in Figs. 4a-4c, as a function of the cumulative volume of water injected into the well.



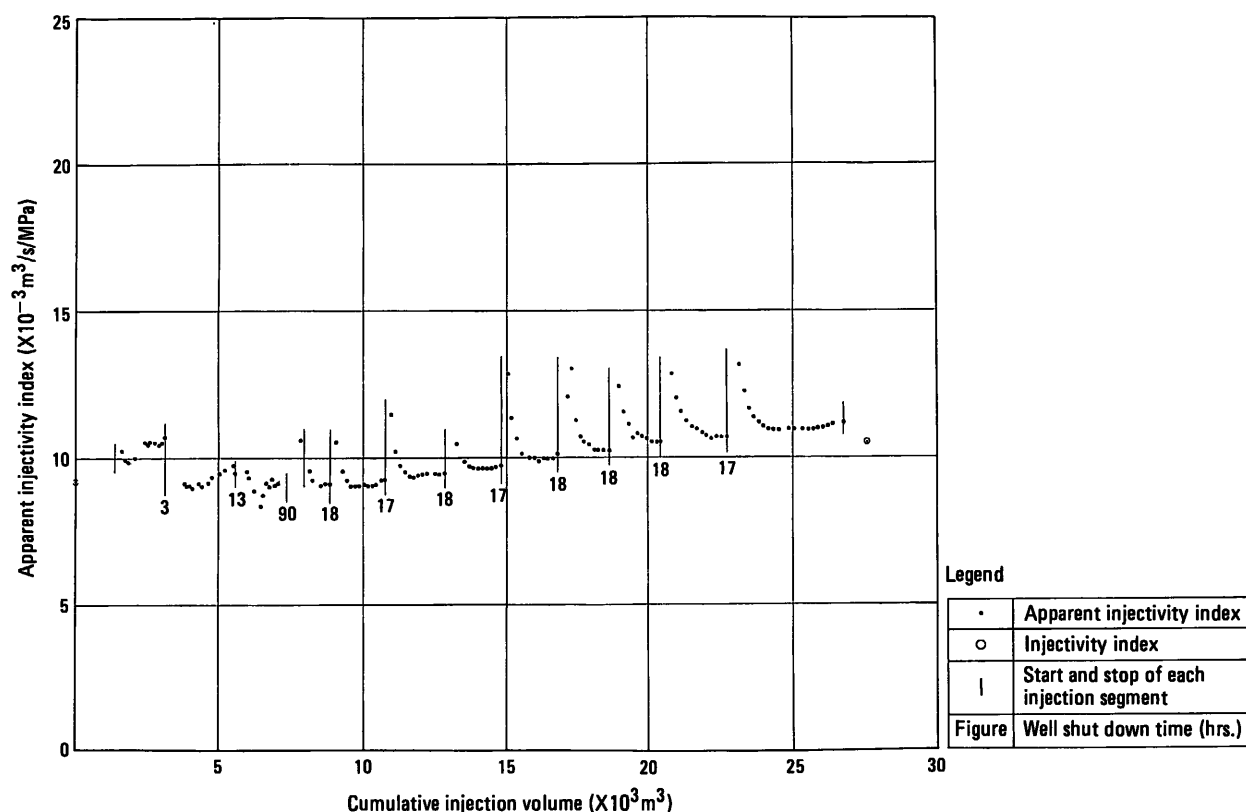


Figure 4c. Apparent injectivity index as a function of cumulative injection for SA-4.

I.Ia(t) of SA-1 increases during injection and decreases while the well is shut down, and I.Ia(t) shows a tendency to increase with cumulated water. Magnitude of I.Ia(t) increase is large.

I.Ia(t) of SA-2 rapidly increases in the early part of the cold-water injection experiments. But I.Ia(t) tends to decrease in the latter part.

I.Ia(t) of SA-4 gradually increases in steps with repeated injection, and the magnitude of the I.Ia(t) increase is small. I.Ia(t) decreases rapidly in the early part of each injection segment.

DISCUSSION OF RESULTS

Possible explanations of the I.Ia(t) change were considered as follows.

Possible reasons for I.Ia(t) increase are (1) cleaning of fracture, (2) development of microcracks due to thermal contractions, and (3) increases in apertures of fractures due to thermal contraction and/or the injection pressure (Bodversson et al., 1984).

Reasons for I.Ia(t) decrease are considered (1) effect of cold water with low viscosity, (2) plugging fracture and solid deposit induced by injection with cold river water, and (3) existence of low permeable zone at a long distance from the well.

Table 3 shows I.I (Injectivity Index) as estimated by injection tests, I.Ia(t), and the production flowrate before and after cold-water injection experiments.

I.Ia(t) corresponds with I.I, and the injectivity of each well was improved. With regard to productivity, the production flow-

Table 3. Comparison of I.I, I.Ia(t), and production flowrate before and after cold-water injection experiments.

Well No.	Before experiment					After experiment							
	I.I	I.Ia(t)	Production data *1			I.I	I.Ia(t)	Production data *2			Production data *3		
	($10^{-3} \text{ m}^3/\text{s}/\text{MPa}$)		*4 (kg/s)	*5 (kJ/kg)	*6 (bars)	($10^{-3} \text{ m}^3/\text{s}/\text{MPa}$)		*4 (kg/s)	*5 (kJ/kg)	*6 (bars)	*4 (kg/s)	*5 (kJ/kg)	*6 (bars)
SA-1	8.9	11.1	9.3	2330	4.9	20.2	18.2	13.7	2420	4.9	17.2	2510	4.8
SA-2	13.3	13.3	7.6	2840	5.0	17.7	15.5	7.3	2800	4.9	3.6	2760	5.5
SA-4	9.2	8.4	6.7	2830	3.5	10.5	11.2	6.9	2800	5.1	7.9	2760	5.0

*1: measured in November 1988

*4: production flowrate

*2: measured in August 1989

*5: flowing enthalpy

*3: measured in November 1989

*6: wellhead pressure

rate of SA-1 and SA-4 increased more or less after cold-water injection experiments, and shows a tendency to increase.

SA-1: $I_{1a}(t)$ increased during injection and decreased while the well was shut down. The major reason was that the $I_{1a}(t)$ change was considered to be due to the effects of thermal contraction. After a long shut-down time, however, $I_{1a}(t)$ did not return to the initial value prior to the cold-water injection experiments. This may indicate the development of fractures with relatively large apertures. The temperature profile shortly after a cold-water injection experiment showed that the most of the water injected is lost at 1950m, and the rest of the water injected lost at 1880m and 1980m. The spinner log during production implies permeable zones at around 1950m and below 1970m. The artificially created fractures are assumed to intersect the natural fractures in the vicinity of SA-1.

SA-2: The precise reason for $I_{1a}(t)$ change is not known at present. The $I_{1a}(t)$ increase in the early part is inferred to relate to the removal of skin damage. Unfortunately, we could not run below 1100m due to casing damage after completion, and it was impossible to survey the condition of the wellbore during production. A possible explanation for the productivity decrease after cold-water injection experiments is considered to be the change of well condition (e.g. well collapse).

SA-4: According to SA-4, both the effect of thermal contraction and viscosity of injected cold water are assumed to compensate for each other. This may indicate the development of microcracks and the low formation permeability in the vicinity. Temperature profile shortly after cold-water injection experiments showed that the major permeable zones are 1350m and 1570m, and the minor permeable zones are 1930m and 1980m. The spinner log during production showed a major permeable zone at 1350m and a minor permeable zone at 1580m.

CONCLUSION

Cold-water injection experiments with cold river water at high rates were conducted discontinuously for three wells (SA-1, SA-2, and SA-4) for a well stimulation at Sumikawa geothermal field, Japan.

1) Among the three production wells, a large improvement of productivity was obtained on SA-1, and the production flow-rate of SA-1 did not decline without proppants. The artificially created fractures are assumed to intersect the natural fractures in the vicinity of SA-1.

2) The productivity of SA-4 was slightly improved. The small improvement of productivity of SA-4 is considered to be the cause of the low permeability formation in the vicinity. According to SA-4, hydraulic fracture treatments may be promise for a future well stimulations.

3) Considering the cost, the cold-water injection experiments are effective in some cases.

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