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FIELD EXPERIMENTS OF INJECTION IN THE OTAKE GEOTHERMAL FIELD, JAPAN

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ABSTRACT

The Otake geothermal waters have been injected into two injection wells up to for 656 days. The injection and other two observation wells range in depth from 365 to 450 m. During the injection test, the falloff test and the maximum injectivity test were repeated to examine the decrease of injectivity. Using fluorescent dye, the tracer test was also conducted to determine the connectivity between two of the four wells. The permeability-thickness product(kh) of Injection Well R-2 has reduced from 91 darcy-m to 5 darcy-m after injecting 5.49×10^5 m^3 water. In the case of R-1, its injectivity was almost lost after injecting a total of 4.59×10^5 m^3 water. The value of kh 224 darcy-m decreased to 0.79 darcy-m, and the water level rose up over the well head.

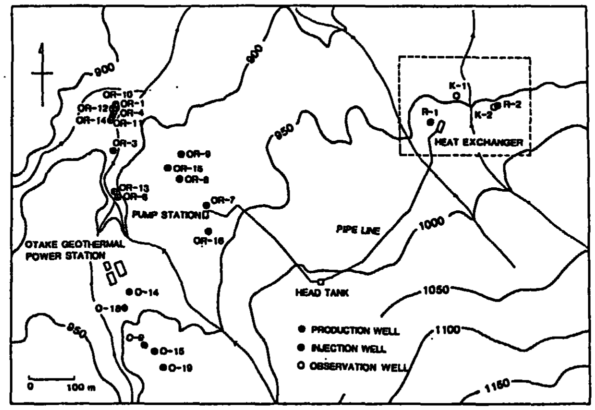

Fig.1 Location map of wells and the test site.

INTRODUCTION

Injecting geothermal water supersaturated with amorphous silica causes the decrease in injectivity of wells(Inoue and Shimada, 1985, Hauksson and Gudmundsson, 1986). The injectivity decrease may be resulted from the permeability reduction due to silica deposited in cracks around an injection well. For example, at Otake and Hatchobaru, Japan, where the full scale injection is being adopted, the injectivity of wells decreases about 30 % a year(Kinoshita, 1980).

Kyushu Electric Power Company operating the Otake and the Hatchobaru geothermal power plants has conducted a research project on silica deposition under the promotion by the New Energy Development Organization. The studies were started in April 1981 and ended in March 1987. The project consists of three parts; 1)Chemical experiments on the behavior of silica in geothermal water(Nishiyama et al., 1985), 2)Laboratory experiments on the silica deposition in porous cylinder(Itoi et al., 1984; Nishiyama et al., 1985), 3)Field injection test in the Otake geothermal field.

Of these studies, we present the results of field tests, in which the waters piped from Otake has been injected into two injection wells up to for 656 days. The falloff test and the maximum injectivity test were conducted to investigate the injectivity decrease. The tracer test was also carried out.

FACILITIES FOR INJECTION TEST

The injection test was conducted at a place, about 800 m north-east of the Otake power station to avoid the effect of the injection in the developed field(Fig.1). Two injection wells were drilled to the depths 365 m(R-1) and 387 m(R-2), together with two observation wells of depths 410 m(K-1) and 450 m(K-2). The four wells are all cased except the intervals where a slotted liner is inserted. Circulation losses were found at depths of 325-405 m in an acidic alteration zone. Reservoir temperatures measured by a thermistor thermometer range from 120 to 162 °C; lower than fluid inclusion temperatures of the Otake reservoir(200-220 °C). Observation wells were used to detect tracers injected into the injection wells.

Geothermal waters from Poduction Wells O-15 and O-9, flashed under the atmospheric pressure, were first piped to a heat exchanger. Then, the waters flow to the pump station near Injection Well OR-7. There are two water pumps with one extra pump to send the waters to the test site at a total flow rate of 70 m^3/h, 120 m^3/h at maximum. A pipe line which is 150 mm diameter and 860 m long was built to send the waters from the pump station to the test site. A cooling apparatus was installed at the test site with a capacity of cooling down water from 80 to 50 °C at a rate of 30 m^3/h.

INJECTION TEST

Injecting geothermal waters into R-1 was started on October 8,1983 and terminated on January 31,1986. The waters of 50, 60, and 80 °C were injected at a constant flow rate,30 m^3/h. The injection was stopped several times during the test due to the removal of silica scales formed in the cooling apparatus and to the maintenance work of the testing facilities. The actual injecting period is, therefore, 638 days in total. The total amount of injected water is 4.59×10^5 m^3.

At Well R-2, the injection was started on July 4, 1984 and stopped on September 7, 1986 at three different temperatures 50, 60, and 80 °C. For the first 54 days, the waters were injected at a rate of 90 m^3/h, which resulted in a rapid decrease in injectivity. Therefore, the injection flow rate was reduced to 30 m^3/h. The actual injecting time was 656 days and the amount of injected water was 5.49×10^5 m^3, both in total. The injecting conditions are summarized in Table 1.

The falloff test and the maximum injectivity test were repeated to follow the injectivity decrease during the injection test. Downhole pressures for the two tests were measured with a Kuster pressure gage. Ramey's type curves are used to analyze the data of falloff test. The maximum injectivity is defined by the injectable amount of waters into a well without pressurizing at the wellhead. During the maximum injectivity test, the waters of 80°C were injected at several flow rates ranging from 5 to 70 m^3/h. The pressure in a well stabilizes after two hours injection at each flow rate. On a log-log paper, a linear relationship between pressure and flow rate is extrapolated to obtain the amount of injectable water, under the pressure equivalent to the water level reaching to the well head.

Table.1 Injecting conditions for Wells R-1 and R-2.

WELL	INJECTING TIME (days)	FLOW RATE (m^3/h)	TEMPERATURE (°C)
R-1	$0 \le t \le 227$	30	50
	$227 < t \le 503$	30	60
	$503 < t \le 638$	30	80
R-2	$0 \le t \le 53$	90	80
	$53 < t \le 282$	30	80
	$282 < t \le 468$	30	60
	$468 < t \le 656$	30	50

Table.2 The average silica concentrations and the saturaion ratios of the injected waters sampled in R-1 and R-2.

WELL	TEMPERATURE (°C)	SILICA CONCENTRATION (mg/l)	SATURATION RATIO
R-1	50	587	3.2
	60	564	2.0
	80	564	2.0
R-2	80	565	2.0
	60	541	2.6
	50	552	3.0

The tracer test was conducted sixteen times during the injection test to examine the connectivity between wells using fluorescent dye as a tracer. Fluorescent dye of 10 kg was mixed into the injected waters. The waters at designed depths in an observation or an injection well was sampled every four hours by a downhole water sampler.

SILICA CONCENTRATION OF WATER

Geothermal waters of Production Wells O-9 and O-15 contain about 570 and 620 mg/l of silica at 96 °C; their mixture at the exit of the heat exchanger about 600 mg/l at 95 °C. The water temperature lowered to 85 °C and the silica concentration decreased by about 30 mg/l during the transportation to the test site.

Table 2 gives the average silica concentrations in the waters, which were collected during the injection , and the saturation ratios of silica. The waters were sampled at depths of 340 m in R-1 and 370 m in R-2, respectively.

The deposition rate of silica become large as the value of saturation ratio increases. Lower injecting temperatures, therefore, cause the rapid decrease in injectivity.

RESULTS AND DISCUSSION

1.INJECTION WELL R-1

Figure 2 shows the decrease in permeability-thickness product(kh) of R-1 with time in a dimensionless form, kh/k_0h. Temperatures of the injection waters are also indicated in the figure. The dimensionless wellbore storage and the skin factor were estimated to be 10^3 and 20. These values almost unchanged during the injection test. The initial value of kh was 224 darcy-m measured on the 12th day of the injection started. A rapid decrease in kh/k_0h was observed for the first 154 days; kh/k_0h on the 154th day was 0.353. Values of $kh/k h$ almost unchanged until the 372th day. A jump of kh/k_0h from 0.389(351th day) to 0.147 of 392th day was observed. The value of kh/k_0h, then, reduced gradually. When the injection terminated on January 31,1986, after 638 days, the value of kh/k h was very low, 0.0035(0.79 darcy-m).

In Fig.3, the change in depth of water level with time of R-1 is shown. The measured pressure at a depth of 375 m during the maximum injectivity test (injecting water of 80 °C at 30 m^3/h) is converted to the height of the water column. The

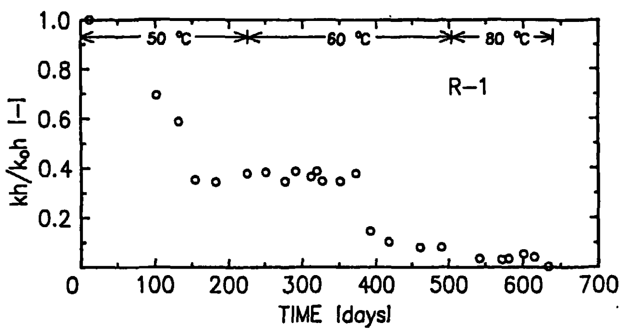

Fig.2 Decrease in permeability-thickness product with time for R-1.

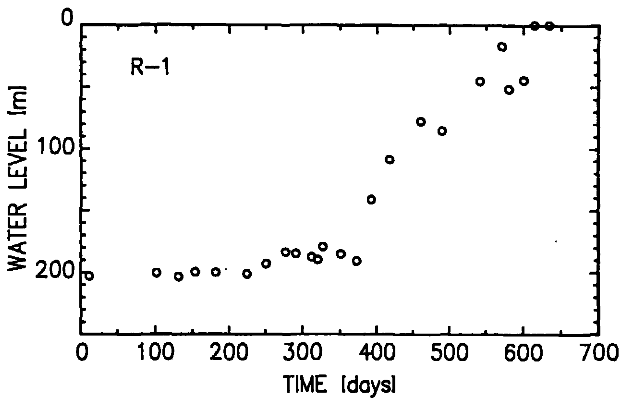

Fig.3 Change in water level with time for R-1.

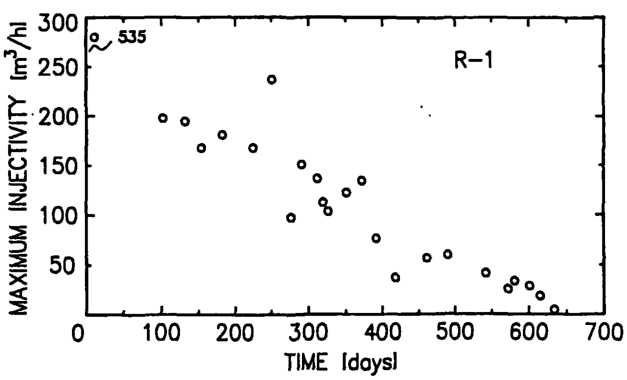

Fig.4 Decrease in maximum injectivity with time for R-1.

rising rate of water level until the 379 th day was rather small. A rapid rise occurred on the 392 th day corresponding to the sudden decrease in kh/k h in Fig.3. The water level continued still rising. The water level reached up to the well on the 615th day at a rate of 19 m^3/h and on the 634th day at a rate of 5 m^3/h. A similar behavior of the water level was reported at the injection well in the Svartsengi field, Iceland (Hauksson and Gudmundsson, 1986).

Figure 4 shows the decrease of maximum injectivity with time. The initial value is estimated to be 535 m /h on the 12th day of the injection. It decreased rapidly to 198 m^3/h on the 102th day. The maximum injectivity ,then, declined almost linearly with time. When the injection test was stopped on the 638th day, the maximum injectivity was less than one percent of the initial value, 5 m^3/h.

2.INJECTION WELL R-2

In Fig.5, the decrease of permeability-thickness product in dimensionless form(kh/k_oh) with time is shown. Values of the dimensionless wellbore storage and the skin factor were the same as those of R-1. These values almost unchanged during the injection test. The initial value of kh was 91 darcy-m measured on the 19th day of the

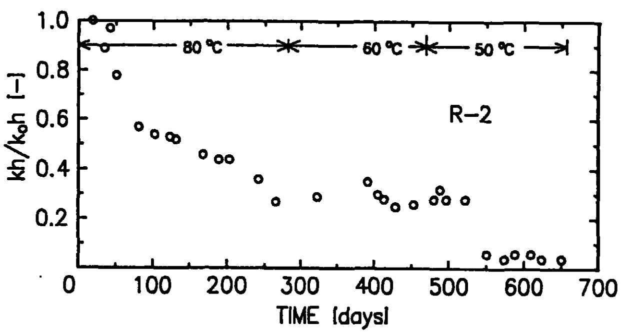

Fig.5 Decrease in permeability-thickness product with time for R-2.

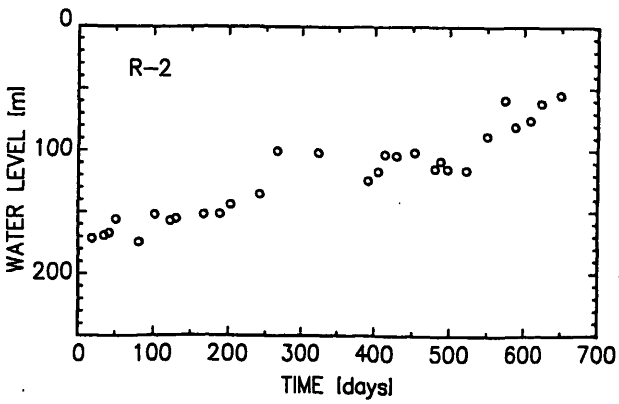

Fig.6 Change in water level with time for R-2.

injection. A rapid decline of kh/k_0h was also observed in R-2 at early stages of the injection. When the value of kh/k_0h decreased to 0.57 on the 81th day, the decrease rate of kh/k_0h, then, became smaller to decline linearly until the 266th day. After that, kh/k_0h was almost constant for 256 days. It dropped suddenly from 0.28 on the 522th day to 0.05 on the 550th day. When the injection test was terminated after 656 days, kh/k_0h was as low as 0.04(5 darcy-m).

The rise of water level in R-2 with time is shown in Fig.6. The water level was first located at a depth of 171.5 m and rose by 15.5 m on the 51th day during injecting water of 80 °C at a rate 90 m^3/h. When the amount of injecting water was reduced to 30 m^3/h on the 53th day, the depth of the water level dropped: 174.2 m on the 81th day. The water level, then, gradually rose up to 55.3 m in depth when the injection was terminated. This rising behavior of water level is quite different from that of R-1.

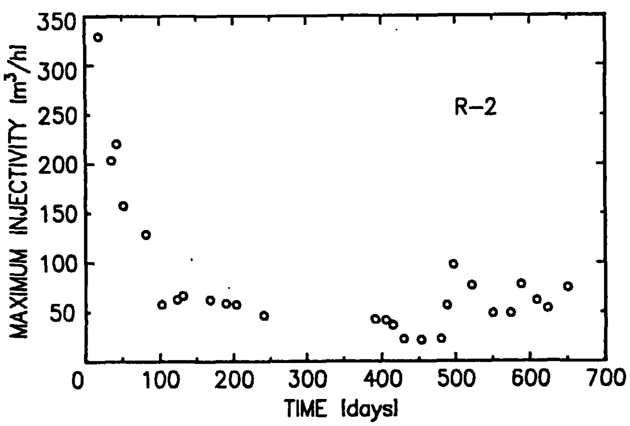

Fig.7 Decrease in maximum injectivity with time for R-2.

The decrease in maximum injectivity with time in R-2 is shown in Fig.7. A rapid decrease in maximum injectivity also occurred in R-2 at early stages of the injection. The initial value of 329 m3/h on the 19th day reduced to 58 m^3/h in 83 days. The maximum injectivity, then, gradually decreased down to 23 m^3/h on the 480th day, less than 10 % of the initial value. It jumped up to 57 m^3/h on the 488th day and varied in a range of 49 m3/h to 98 m3/h for a period between 488th day and the end of the injection. These values in the maximum injectivity do not correspond to the decrease of kh/k_0h nor the rise of water level in the same period. This may be attributed to an error caused by the method of obtaining the value of the maximum injectivity.

Although the total amount of injected water into R-2 is larger by 0.9×10^5 m^3 than that into R-1, the R-2 injectivity was less damaged. This is probably because that the injecting period of 80°C water into R-2(whose silica saturation ratio is lower than those of 60 °C and 50 °C) is longer in comparison with R-1.

3. TRACER TEST

Tracers were injected into Wells R-1, R-2, and K-1 at different periods. The well connectivity between two wells is high in three of five sets; R-1 and K-1, K-1 and R-2, and R-2 and K-2. No communication was observed between Wells R-1 and R-2 nor R-1 and K-2. Part of the results are summarized in Table 3. The maximum tracer speed is calculated dividing the well distance by the time required for the first detection of the tracer. It is on the order of 3 m/h, one order high compared with 0.3 m/h in the Otake field (Hayashi et al., 1978). The average tracer speed is the well distance divided by the time when the maximum concentration is recorded.

The injected waters was 8.3 in pH value. However, the waters which were collected during the tracer test into R-2 at a depth of 370 m ranged in pH from 3.8 to 6.9 in December, 1984. This may be due to that the injected waters flowed through zones of acidic alteration. Three months later, the pH of the waters shifted to higher in a range from 4.2 to 7.2.

Table.3 Results of the tracer test.

INJECTION WELL	OBSERVATION WELL	DISTANCE (m)	FIRST DETECTION t (h)	FIRST DETECTION vm (m/h)	PEAK CONCNTRATION t (h)	PEAK CONCNTRATION va (m/h)
K-1	R-2	101	36	2.8	102	0.99
R-1	K-1	74	-	-	29	2.6
R-2	K-2	5	1.6	3.1	3	1.7

*) Detection time(t), maximum tracer speed(v_m) and average tracer speed(v_a)

CONCLUSION

Field injection experiments using four wells have been conducted in the Otake field, Japan. The results are as follows:

1. The injectivity of Well R-1 markedly decreased during injecting the total of 4.59×10^5 m^3 waters for 638 days. This is probably due to that 80 % of the total injected waters are at relatively lower temperatures of 50 and 60 °C, which have higher saturation ratio of silica. The initial water level during injecting water of 30 m3/h was located at a depth of 203 m, and rose up to the well head by the end of the test.
2. The injectivity of Well R-2 is less damaged in comparison with that of R-1, regardless of its larger amount of the total injected water, 5.49×10^5 m^3/h. The reason for this may be that about a half of the injected waters is at a higher temperature of 80°C.
3. At early stages, permeability-thickness product(kh) decreased rapidly both at Wells R-1 and R-2 when the injection temperatures range from 50 to 80 °C.
4. Using fluorescent dye as a tracer, high inter well connectivity between two of the four wells was ascertained in three of five sets. The maximum tracer speed determined is on the order of 3 m/h.

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