COOLING EFFECT AND FLUID FLOW BEHAVIOR DUE TO REINJECTED HOT WATER IN THE HATCHOBARU GEOTHERMAL FIELD, JAPAN

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key words: cooling effect, Hatchobaru, injection, pressure, simulation, tracer test

ABSTRACT

In the Hatchobaru geothermal field, the power output had declined due to a cooling effect from 110 MWe to 90 MWe within the first two years after commencement of commercial operation of the second power unit (No.2 Unit). In order to clarify this cooling mechanism, tracer tests and numerical simulations were conducted. The simulation results show that 21% of reinjected hot water returned to the production area, and the temperature of production area dropped subsequently by 11°C within the first two years. Furthermore, results of case studies suggest that a distance of more than 500 m between production area and reinjection area are necessary to mitigate the cooling effect. Therefore, the locations of most reinjection wells were changed so that they were at least 500 m away from the production area. As a result, the declining trend of power output was actually reduced.

1.INTRODUCTION

In the Hatchobaru geothermal field in central Kyushu, Japan, Kyushu Electric Power Co., Inc. started the commercial operation of the first unit (No.1 Unit; 55 MWe) in 1977 and the second unit (No.2 Unit; 55 MWe) in 1990. A double-flash system has been adopted in both units, and waste hot water of 90 °C has been reinjected in the northern region of the power station after withdrawal of secondary steam.

The geothermal system in the field is of a typical water-dominated type. The main productive reservoir extends at a depth of 800 - 1500 m along the Komatsuike subfault. The primary hot water of the production reservoir is believed to ascend from a deep level in the southeastern part of the field.

Chloride ion concentration of reservoir water before the development was 1400 - 1600 ppm and showed a simple increasing trend from northwest to southeast (Shimada et al.,1985). The silica temperature of main reservoir was around 275 - 280 °C (Hirowatari,1991). The chloride ion concentration and silica temperature however, began to change immediately after reinjection of waste hot water started in 1977. The chloride ion concentration in the reservoir fluid adjacent to the reinjection area increased to a level of nearly 2800 ppm, and the silica temperature dropped to below 240°C by 1988. For a short period after the start of operation of the No.2 Unit, the reservoir water showed a significant increase in chloride ion concentration and a drop of silica temperature.

Fig.1-1 shows the development history of the Hatchobaru geothermal field. When the reinjection rate increased from 278 kg/s to 389 kg/s due to the commencement of operation of the No.2 Unit, the power decline rate per year of the No.1 Unit increased significantly from *6%* to 14%.

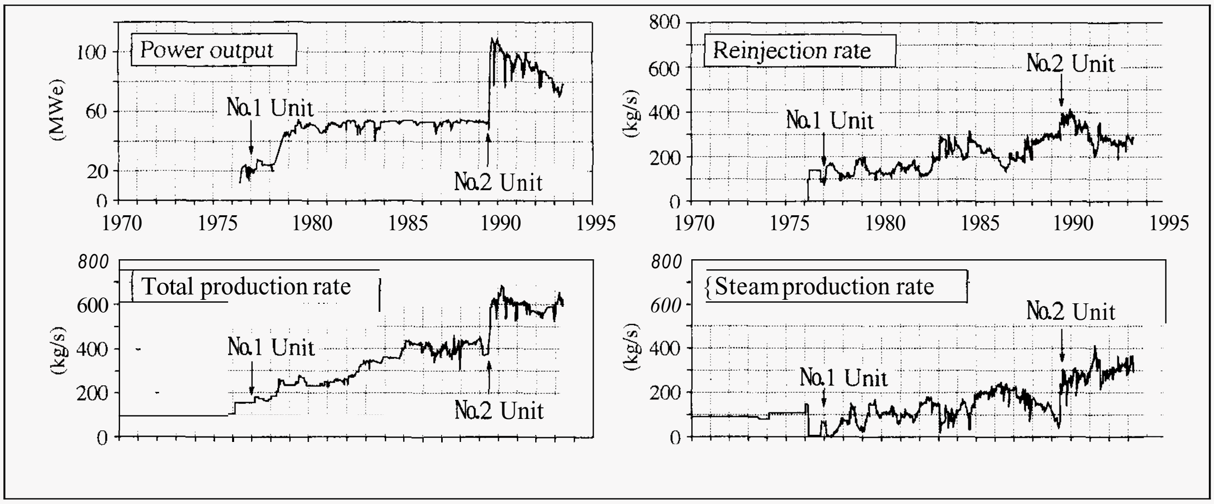
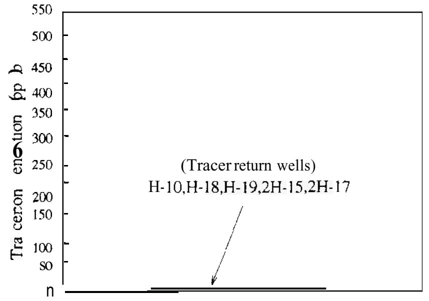


Figure 1 - 1 Development history of the Hatchobaru geothermal field, Japan



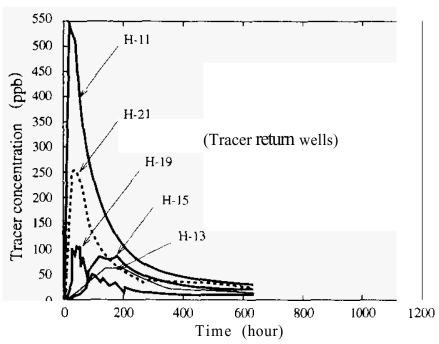


Figure 2 - 2 Result of tracer test for 2HR-2

Fig.2-1 and Fig.2-2 show the results of the tracer tests for HR-31 and 2HR-2, respectively. **These** results showed different tracer return patterns. The tracer injected in HR-31 was detected after 177 - 252 hours in 5 production wells, H-10, H-18, H-19, 2H-15 and 2H-17. The detected maximum concentration of tracer was only 5 - 8 ppb. On the other hand, the tracer injected in 2HR-2 was detected after 29 - 125 hours in 5 production wells, H-11, H-13, H-15, H-19 and H-21. The detected maximum concentration of tracer reached 56 - 546 ppb.

Fig.2-3 shows the tracer return patterns. Reinjected water returns along the predominant faulting direction of NW-SE such as the Komatsuike fault and the Komatsuike subfault. It is considered that the hydrostructural boundary obtained by pressure interference tests also controls the fluid behavior, hecause it coincides with the tracer return path for 2HR-2. On the basis of the length of the paths and return times, tracer return velocities of HR-31 and 2HR-2 were estimated to he 4.3 - 7.1 m/h and 4.6 - 14.3 m/h, respectively. **These** results show that there are some paths of very rapid communication between reinjection area and production area.

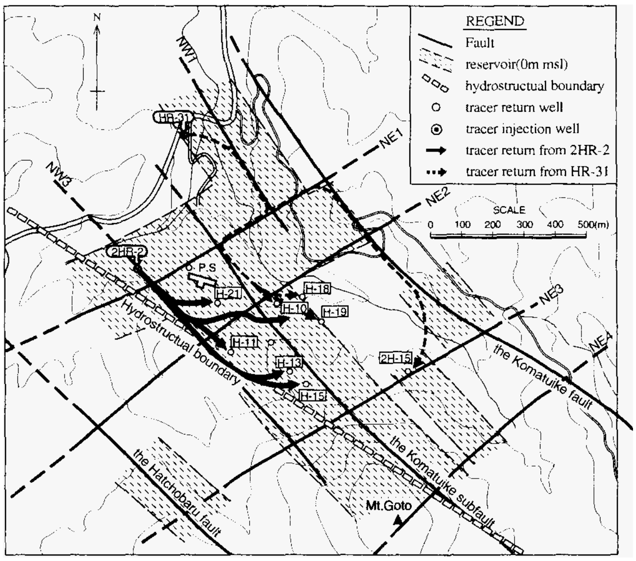


Figure 2 - 3 Tracer return patterns for 2HR-2 and HR-31 *tests*

2.2 Data analysis

The cumulative return rate of reinjected water and temperature drop of production area were analyzed by using dispersion equations. Table 2-1 shows the results.

Table 2 - 1 Results of tracer test analysis

tracer injection well / tracer return well	HR-31		2HR-2	
	return rate (%)	temperature droo (℃)	return rate (%)	temperature drop (℃)
H-10	0 5	4	0 2	0
H-11	-	-	24 2	36
H-13	0 2	1	2 5	6
H-15	0 2	1	6 0	13
H-18	1 7	8	1.0	1
H-19	0 5	3	4 0	6
H-20	0 2	1	N D	0
H-21	N D	0	9 8	16
2H-15	0 6	3	0 6	1
2H-17	1 5	8	0 8	1
2H-18	-	-	1 9	2

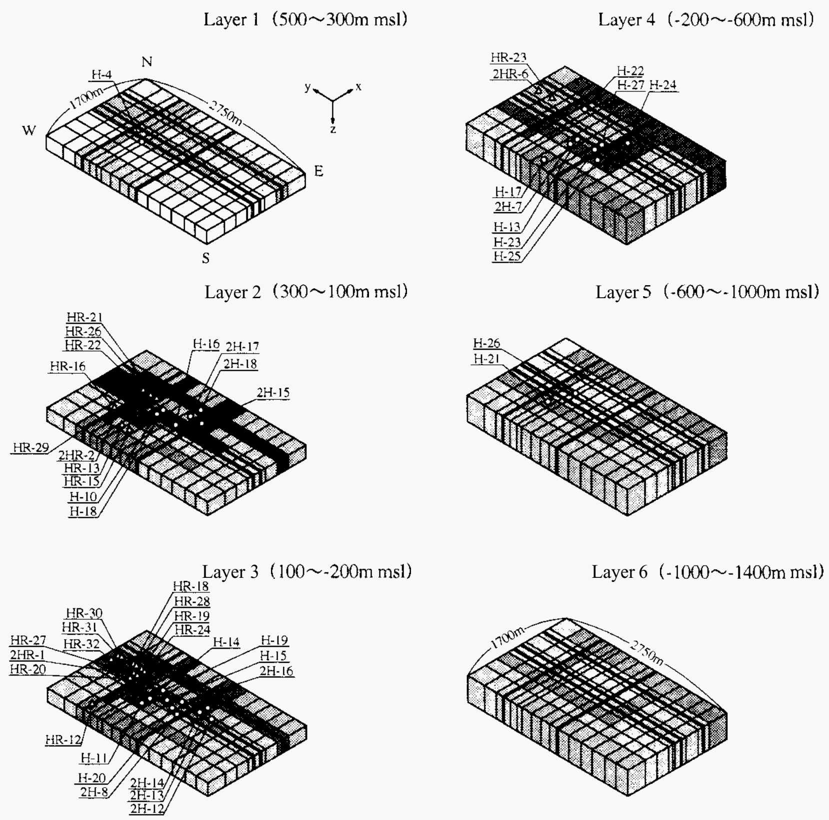
N.D.···Not detected
- ···Well was shut in.

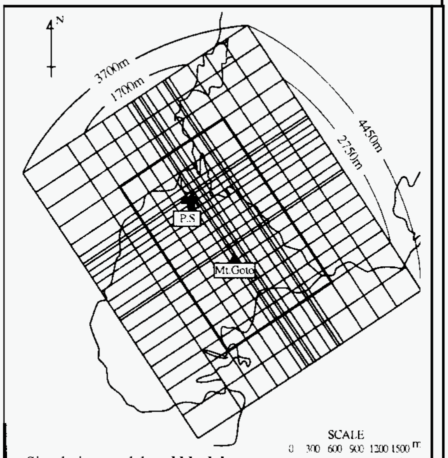
Based on the analysis, the following conclusions were drawn regarding the cooling effect:

1) Cumulative returns for HR-31 and 2HR-2 were calculated to be 5.4% and 51.0%, respectively.

2) The maximum temperature drops of production area caused by the reinjection for HR-31 and 2HR-2 were estimated to be 8 °C and 36 °C, respectively.

3) Taking the effects of the other reinjection wells around HR-31 and 2HR-2 into consideration, the maximum temperature drop caused by these reinjections were estimated to be 12°C and 50°C, respectively.





Simulation model and block layout

Density (kg/m³)	Porosity (-)	Specific heat (J/kg℃)	Thermal conductivity (W/m℃)
2500	0.1	850	2.0

o Production well Δ Reinjection well

Classification	Permeability (md)		
	X	Y	Z
●	2000	52700	71
●	20	527	71
●	15	150	21
●	5	54	7
○	14	28	4
○	0.1	7	1
○	1.5	1.5	0.2
○	1	1	1.4

Figure 3 - 1 Numerical model of the Hatchobaru geothermal field

3. NUMERICAL SIMULATION

For the purpose of studying the behavior of the reinjected water and the cooling effect within the reservoir, a numerical simulation was conducted.

3.1 Reservoir Model

For this study, a three-dimensional, integrated finite-difference numerical model of the field was refined based on the results of tracer tests. Fig.3-1 shows the numerical model which covers a total area of 16.5 km^2, extending 4.5 km in the NW-SE direction and 3.7 km in the NE-SW direction. In the vertical dimension, the model extends from 500 m above msl (mean sea level) to 1400 m below msl. The model consists of 2484 gridblocks in 6 layers.

Considering that there were some paths of very rapid communication within the reservoir, with very rapid fluid movement (up to 14.3 m/h), highly permeable paths were modeled along the estimated fluid paths such as the Komatsuike fault, the Komatsuike subfault and faults in the NE-SW direction. From the pressure interference tests, the average transimissivity within the reservoir along the Komatsuike subfault is estimated to be 82 - 96 darcy m and the reservoir is thought to have an impermeable boundary along the fault (Tsuru and Tokita,1994).

The permeability distribution was finally defined by history matching of the measured and calculated temperatures and pressures. The calibrated numerical model suggests that the horizontal permeability is higher than the vertical permeability.

3.2 Simulated Cooling Effect

Fig.3-2 shows some examples of history matching for wells H-4, H-11, H-14, and H-18. All of these wells were influenced by the inflow of reiniected water. Although the production from H-4 and H-11 has already stopped, H-14 and H-18 are still being used. Simulated temperature history shows that the temperature of the production area has dropped by 30 - 60 °C in the 17 years since the commencement of reinjection in 1977. The temperature of the reservoir adjacent to the reinjection area shows a tendency to decrease rapidly. The temperature drop of H-4 was probably caused by the inflow of reinjected water of HR-5 located 300 m northwest of H-4.

When the reinjection of HR-5 was started, the hot water discharged from H-4 was acidified by the formation of sulfuric acid. The acid was considered to he formed by oxidation of H_2S by air present as a contaminant in reinjected water (Shimada et al.,1985). Lowering the reinjection rate of HR-5 allowed the pH of the discharged water of H-4 to recover.

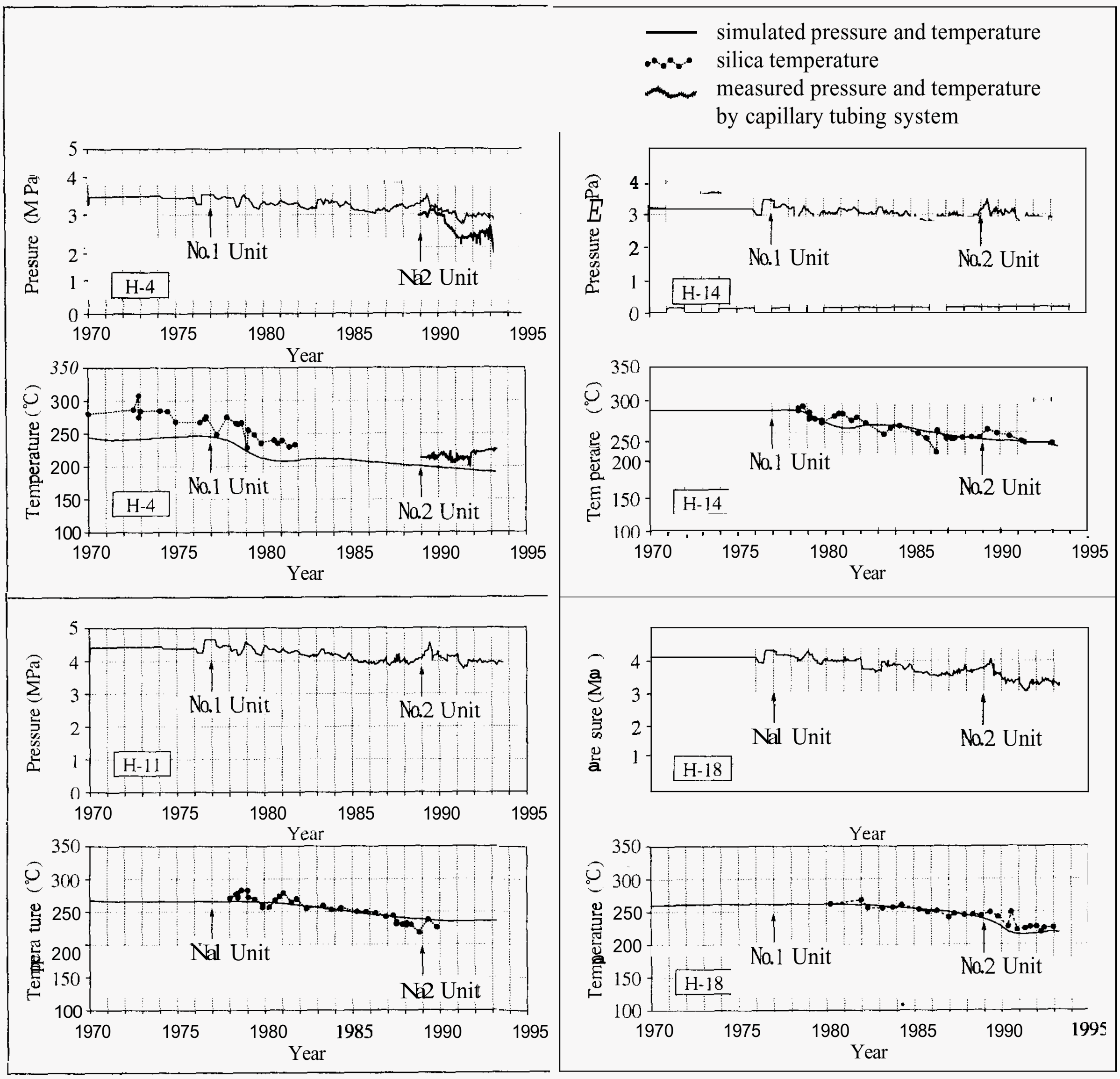


Figure 3 - 2 History matching for wells H-4, H-11, H-14 and H-18

The temperature of H-18 dropped rapidly by 20 °C within the first 1.5 years after the commencement of operation of the No.2 Unit. It was caused by the increase in inflow rate of reinjected water, as the total reinjection rate increased from 278 kg/s to 389 kg/s.

Fig.3-3 shows changes of average pressure and temperature in the reservoir along the Komatsuike subfault. Fig.3-4 and Fig.3-5 show the changes of the areal and sectional temperature distribution.

Based on the simulation results, the following conclusions were drawn regarding the cooling mechanism:

1) The cooling area was spread along the Komatsuike fault and the Komatsuike subfault, reflecting the distribution of high permeability.

2) Although the average temperature of fluid stored in the production area along the Komatsuike subfault was 270 °C before the development, it dropped by 18 °C within 12 years after the commencement of operation of the No.1 Unit. Furthermore, it dropped by 11 °C from 252 °C to 241 °C after the commencement of operation of the No.2 Unit.

These temperature changes are explained by the inflow of reinjected water in response to continued pressure drawdown.

3) The reservoir pressure along the Komatsuike subfault decreased by 0.7 MPa within 12 years after the commencement of operation of the No.1 Unit. In addition, it decreased further by 0.3 MPa within 3 years due to the increase of withdrawal of production fluids from 400 kg/s to 611 kg/s after the commencement of operation of the No.2 Unit. These pressure drawdowns in the production area accelerated the return of reinjected water.

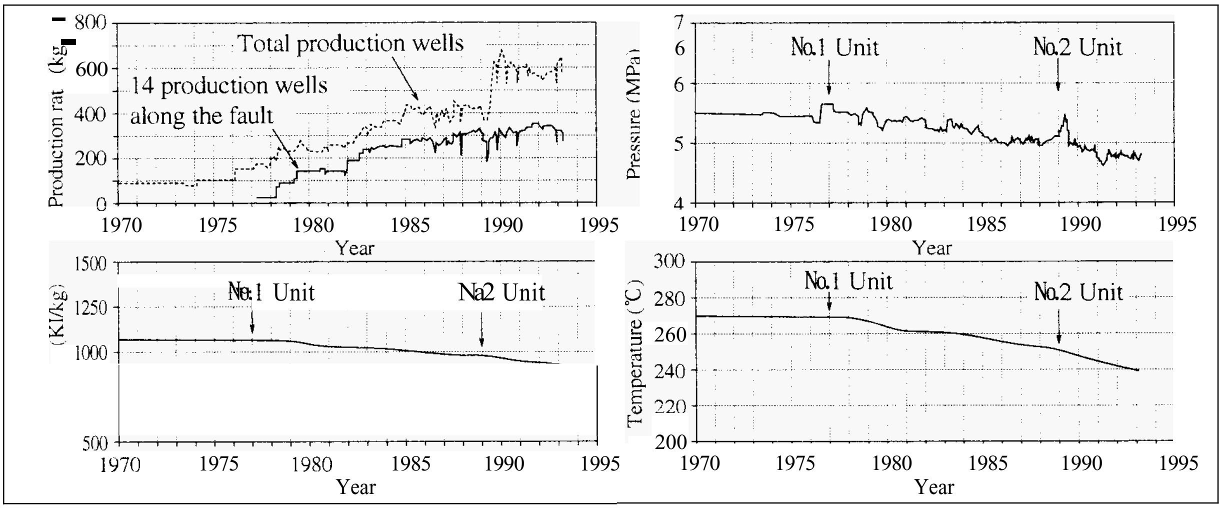


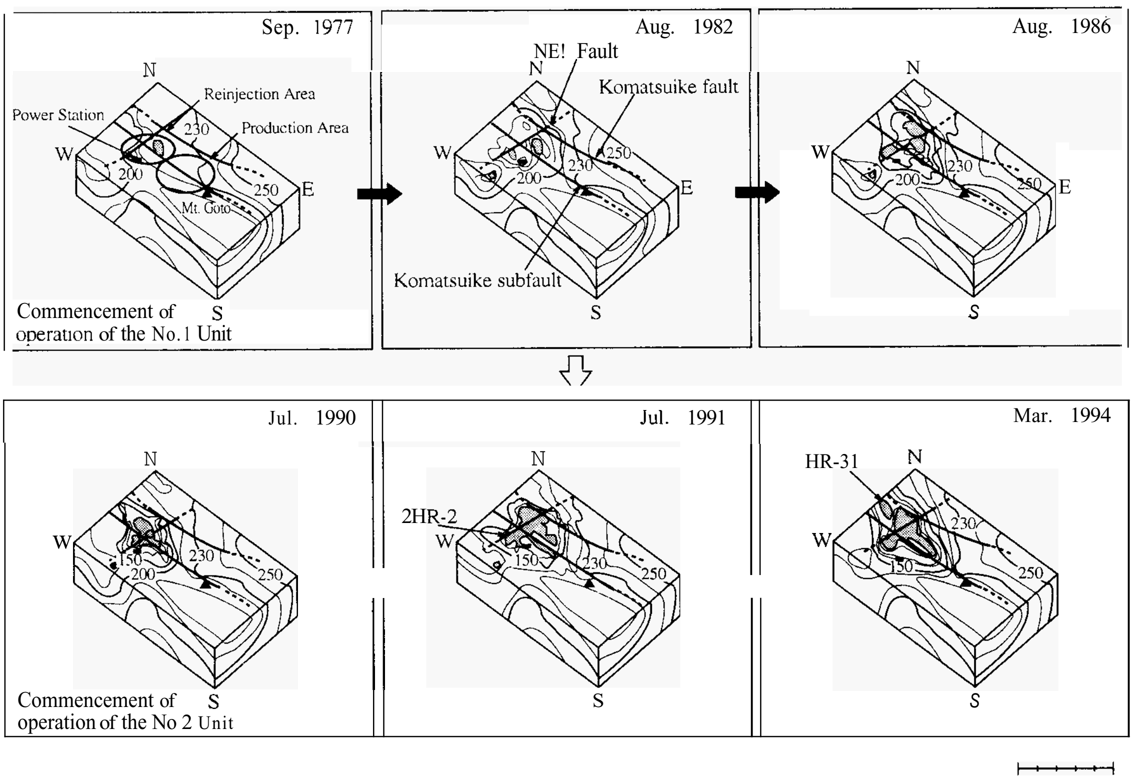
Figure 3 - 3 Changes of average reservoir pressure and temperature along the Komatsuike subfault

4) When the reinjection for 2HR-2 was started in 1991, the reservoir temperature dropped rapidly.

In this period, the amount of water returned to the production area was estimated to be roughly 75 kg/s, which corresponds to 21 % of the total of reinjection rate of 350 kg/s.

5) From the results of case studies, it was found that a distance of more than 500,m should he kept between the production area and reinjection area to counteract the cooling effect.

Therefore, the locations of most reinjection wells were changed to at least 500 m away from the production area in 1992. **As** a result, the declining trend of power output was actually reduced. In addition, the stoppage of reinjection around 2HR-2 brought about a quick recovery in the productivities of H-11 and H-21 which had declined rapidly after the start of reinjection around 2HR-2.



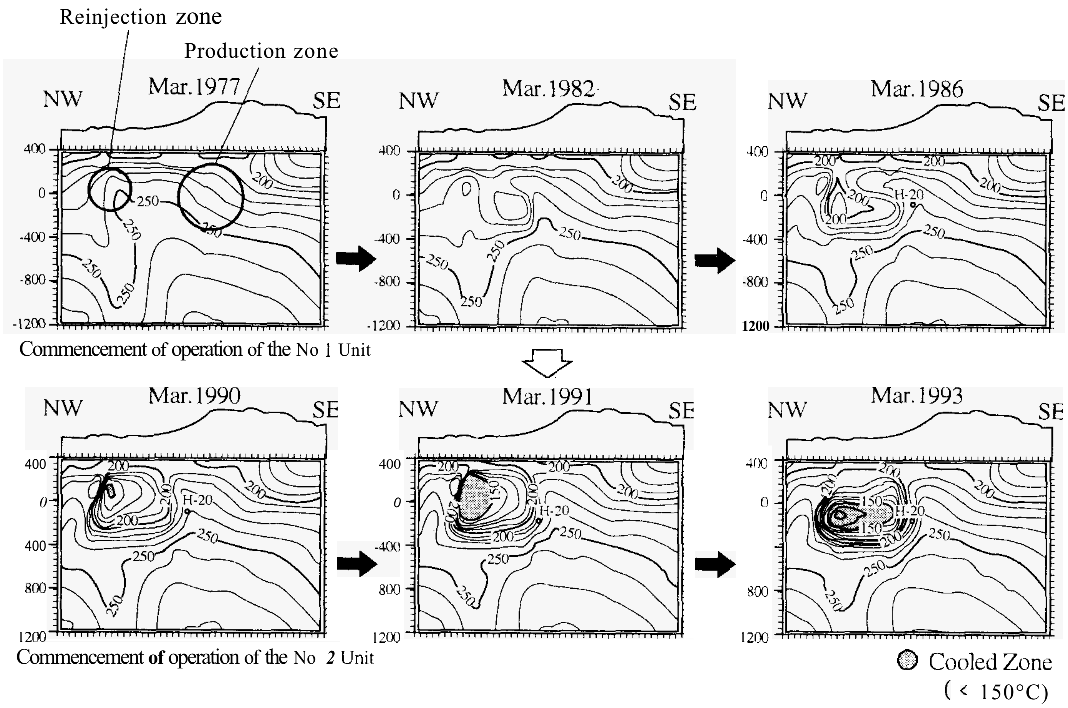


Figure 3 - 5 Simulated changes of sectional temperature distnbution dong the Komatsuike subfault

4. CONCLUSIONS

1) Based on results of the tracer tests, it was concluded that there are some paths of very rapid communication among some wells, such as the Komatsuike fault, the Komatsuike subfault and the faults aligned in the NE-SW direction. The analyzed tracer tests data shows that 51.0 % of reinjected water in 2HR-2 returned to the production area located 250 m east of 2HR-2, and subsequently the temperatures of discharged fluid for 5 production wells dropped by 6 - 36 °C. Tracer return velocities were estimated to be 4.0 - 14.3 m/h.

2) Taking the results of the tracer tests into consideration, the three dimensional numerical simulation model of the field was refined and used for clarification of the cooling mechanism. Simulation results show that both an increase of reinjection rate and a pressure drawdown in the production area accelerated the return of reinjected water after the commencement of operation of the No.2 Unit. Specifically, the average temperature of the main production area along the Komatsuike subfault dropped by 18 °C from 270 °C to 252 °C within 12 years after the commencement of operation of the No.1 Unit. It dropped by a further 11 °C from 252 °C to 241 °C due to the increase of reinjection rate from 278 kg/s to 389 kg/s after the commencement of operation of the No.2 Unit. The decline of power output from 110 MWe to 90 MWe within the first two years was caused by reinjected water inflow which was a result of the production-induced pressure drawdown of around 0.3 MPa.

3) The strength of the cooling effect is related to the locations of the reinjection wells. According to the simulation results, the temperature of the production area dropped rapidly after the start of reinjection around 2HR-2. In this period, the return of reinjected water was estimated to be roughly 75 kg/s, which corresponds to 21 % of the total reinjection rate of 350 kg/s. The simulation results suggest that a distance of more than 500 m between production and reinjection areas is required for mitigating the cooling effect. As a result of the relocation of most reinjection wells, the declining trend of power output was actually reduced.

5. REFERENCES

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