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THE MIXING OF THE COOLING WASTE WATER REINJECTED WITH THE PRODUCTION FLUID AT THE UENOTAI GEOTHERMAL POWER STATION

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ABSTRACT

At the Uenotai geothermal power station, the cooling waste water had been reinjected into underground through the reinjection Well F-1. Reinjection into Well F-1 started in February, 1993. After one and a half years (June,1995), the production well T-44, which was originally producing only steam from the feed zone located 250 meters away from the reinjection zone of Well F-1, started producing steam-water mixtures as the fluid enthalpy decreased, and the injection capacity of Well F-1 coincidentally increased about four times. These phenomena suggest subsurface interference between the two wells. On the basis of monitoring of stable isotopic ratios, fluid chemistry, and production history of Well T-44, a quantitative interpretation was made.

1. INTRODUCTION

The Uenotai geothermal power plant, located in the southern part of Akita prefecture, Japan (Naka and Okada, 1992), has been in commercial operation since March 1994, initially with 27.5 MW which was increased to 28.8 MW in February 1997. Akita Geothermal Energy Co. Ltd. (AGECO) has been supplying steam from production wells to the power plant operated by Tohoku Electric Power Company Inc. Figure 1 shows the location of the power plant and the wells. The hot water separated from the steam at each production pad B and pad C has been reinjected into the injection wells drilled from D- and E-pad, respectively. The steam condensate (waste water) from the power plant has been reinjected into wells at F-pad.

2. INTERFERENCE BETWEEN WELLS F-1 AND T-44

Figure 2 shows the production history of Well T-44 which is deviated toward the SE from C-pad and the reinjection history of Well F-1 vertically drilled from the F-pad. The horizontal distance between the T-44 production zone and F-1 is about 250 meters. The injectivity capacity of F-1 was originally very small : 18 tons/hour even using a high-pressure injection pump. It has substantially improved since mid-1995, and eventually the well was capable of injecting at least 85 tons/hour of water without pumping. It is considered that the well was stimulated by continuously injecting cold waste water (30℃) into the high-temperature formation. Well T-44 had been producing saturated steam with a very minor amount of hot water since the start-up of the power plant, while the fluid enthalpy started decreasing in May 1995, producing less steam with a significant amount of hot water, indicating a very severe interference between Wells F-1 and F-44. To avoid further mixing of waste water into Well T-44, reinjection operation into F-1 was ceased in May 1996 by switching it into the well F-2 which was drilled toward the SW from the same pad. Total waste water reinjected into Well F-1 was approximately 660,000 tons. Since Well F-1 was shut, the steam production from Well T-44 has been regained, as seen in Figure 2 and no distinct evidence of the interference between Wells F-2 and T-44 has been observed.

3.HYDROGEN AND OXYGEN ISOTOPE STUDY

3.1 Uenotai area

Figure 3 is a plot showing deuterium (δ D) and oxygen-18 (δ^{18}O) contents in surface water, hot spring water and thermal water from the Uenotai production wells based on the data in Table 1. It also shows the local meteoric water line, $\delta D=8\times\delta^{18}O+22$, intersecting isotopic values for the local surface waters, most of which are plotted in a relatively small range: δ D=-60 to -65 ‰ and δ^{18}O=-10.3～-11.0 ‰ as already discussed by Matsubaya and Uchida (1990). It was indicated that the Uenotai samples are of meteoric origin (Matsubaya et al., 1988) and have a distinctively lower δ D value than that of meteoric water. The reason for the discrepancy of the hydrogen isotopic ratios has not been well understood yet.

3.2 Change of isotopic ratios in Well T-44 water

Table 2 and Figure 4 show the change of the isotopic ratios of the thermal water produced from Well T-44 and the waste water reinjected into Well F-1. The data represents in terms of total flow the composition which was calculated from isotopic ratios in liquid and condensate samples, using the steam fraction. The isotope values of reinjection water into Well F-1 has been shifting toward a higher level, from δD=-38 to -40 ‰ and $\delta^{18}O$=-4.7-4.8 ‰ in 1994 to δD=-29 ‰ and $\delta^{18}O$=-2.3 ‰ in July 1996. These values were averaged and plotted in Figure 4 (point B).
The T-44 fluids were plotted approximately at δD=-70 ‰ and $\delta^{18}O$=-10 ‰ before the power plant was put in operation. However the samples had been shifted to higher isotope levels with time along a straight line since the mixing of the F-1 waste water with T-44 reservoir fluid occurred until it reached a value of δD=-52 ‰ and $\delta^{18}O$=-6.5 ‰ in April 1996. The values then returned back to lower levels along the same line (mixing line), but not to the original composition (A). The samples remained almost constant, as indicated by location C (δD=-65 ‰ and $\delta^{18}O$=-9 ‰) since November 1997.
One possible explanation is that contamination effects by the waste water had almost disappeared by November 1997, but the isotopic ratios of the T-44 fluid itself had been shifting with time from A to C because of mixing of the fluid of a different reservoir with the original fluid.

3.3 Estimation of mixing ratio

On the basis of the assumption that the mixing of F-1 reinjection water with the T-44 thermal fluid occurred during the period from February 1995 to November 1997, the mixing ratio was estimated using a linear relation shown in Figure 4. The isotope shift of the T-44 reservoir fluid as assumed above was also taken into account. Figure 5 is a diagram showing the relation between the F-1 reinjection rate and the estimated mixing ratio. The ratio reached up to 50 % in April 1996 and has declined since the injection was stopped. As shown in Figure 6, the enthalpy of T-44 production fluid remained stable at about 2,800 kJ/kg until May 1995, and as the mixing ratio increased, it drastically declined to as low as 1,800 kJ/kg. When reinjection of waste water into F-1 was stopped, the enthalpy started increasing and returned to the original level.
It is worthwhile to continue monitoring the isotopic ratios of produced and injected fluids to have a more quantitative insight into fluid migration in the Uenotai reservoir.

4.CONCLUSIONS

The interference between the reinjection Well F-1 and the production Well T-44 started since May 1995.

With the mixing of F-1 waste water with the T-44 reservoir fluid, the isotope values of the T-44 fluid has shifted toward a higher level, from approximately at δD=-70 ‰ and $\delta^{18}O$=-10 ‰ before the power plant was into operation, to δD=-52 ‰ and $\delta^{18}O$=-6.5 ‰ in April 1996 along the mixing line. The values then returned back to lower levels along the same line after injection was stopped.

On the basis of the assumption that the mixing of F-1 reinjection water with the T-44 thermal fluid occurred during the period from February 1995 to November 1997, the ratio reached up to 50 % in April 1996 and then declined since the injection was stopped.

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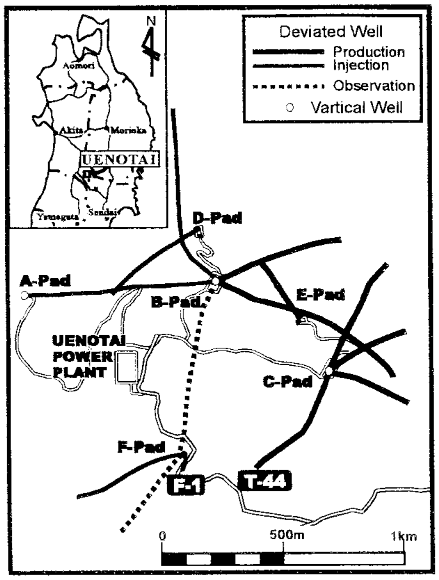

Figure 1.Location map of well pads and trajectories of wells in the Uenotai area

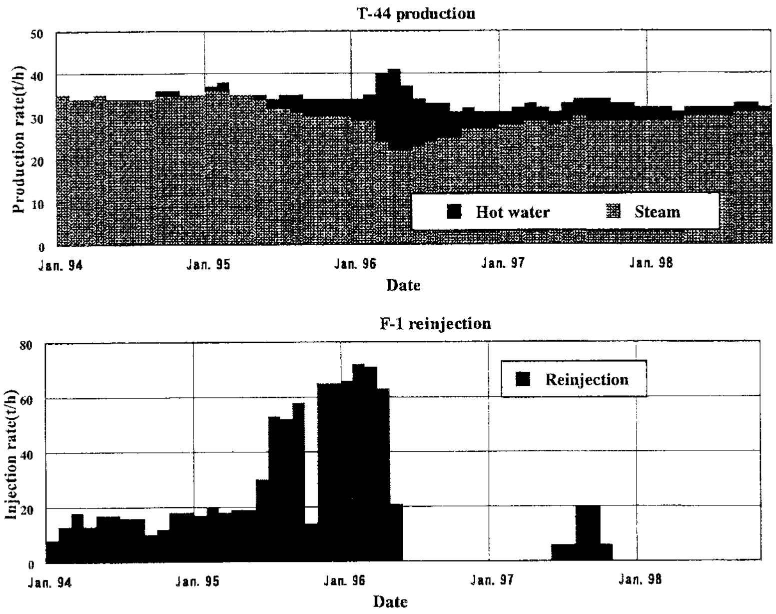

Figure 2.Production and reinjection history of Wells T-44 and F-1

Table 1.Hydrogen and oxygen isotopic ratios of surface water and hot spring water around the Uenotai area

No.	Localities	δD, ‰	δ^{18}O, ‰
Surface water			
1	Yakunai River	-61.0	-10.3
2	Takakura Sawa	-62.9	-10.6
3	Yujiri Sawa	-64.8	-10.9
4	Wasabi Sawa	-63.2	-10.7
5	Ground Water	-61.0	-10.5
6	Doroyu Sawa	-61.9	-10.8
7	Oyasu Sawa	-60.0	-10.3
8	Tochiyu	-60.2	-10.0
9	Minase River	-57.1	-9.8
10	Ohyu Sawa	-56.7	-9.6
Hot spring			
11	Takanoyu	-62.8	-9.7
12	Kawarage	-56.4	-7.2
13	Doroyu	-58.6	-8.4
Uenotai			
14	T-42	-72.6	-10.2
15	T-46	-70.5	-11.0
16	T-53	-71.6	-10.6

Table 2.Hydrogen and oxygen isotopic ratios of Wells T-44 and F-1

No.	Well	Date	δD, ‰	δ^{18}O, ‰
1	T-44	Dec.1993	-72.8	-10.3
2	〃	May.1994	-72.4	-10.4
3	〃	Feb.1995	-71.0	-9.9
4	〃	Aug.1995	-64.5	-8.7
5	〃	Nov.1995	-64.4	-8.5
6	〃	Apr.1996	-52.4	-6.6
7	〃	May.1996	-53.3	-7.0
8	〃	Jun.1996	-55.1	-7.1
9	〃	Aug.1996	-57.6	-7.6
10	〃	Nov.1996	-61.7	-8.2
11	〃	Feb.1997	-63.0	-8.3
12	〃	May.1997	-63.8	-8.5
13	〃	Jun.1997	-63.0	-8.5
14	〃	Aug.1997	-65.4	-8.5
15	〃	Nov.1997	-64.6	-8.7
16	〃	Jan.1998	-65.6	-8.7
17	〃	Feb.1998	-65.6	-8.7
18	〃	Mar.1998	-64.3	-8.8
19	〃	May.1998	-64.7	-8.4
20	〃	Aug.1998	-66.7	-8.8
21	〃	Nov.1998	-64.8	-8.8
22	F-1	Jul.1994	-40.5	-4.7
23	〃	Aug.1994	-38.1	-4.8
24	〃	Jul.1995	-28.6	-2.3
25	〃	Dec.1995	-30.0	-3.3

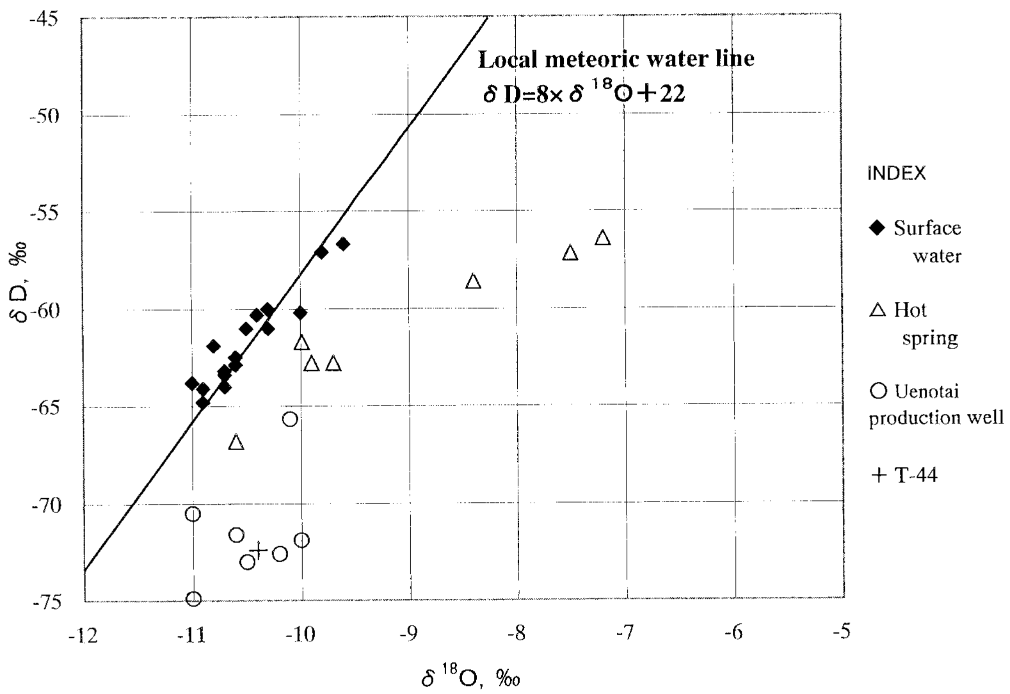

Figure 3. δ D vs. δ ^{18}O of surface water , hot springs and Uenotai production wells

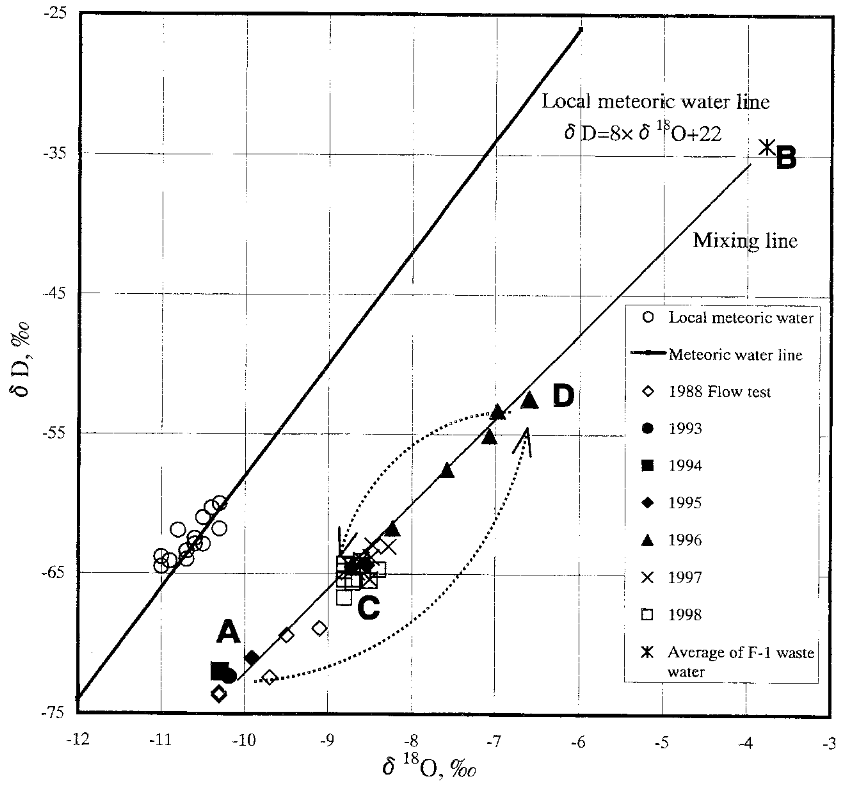

Figure 4. δ D vs. δ ^{18}O of T-44 fluid samples

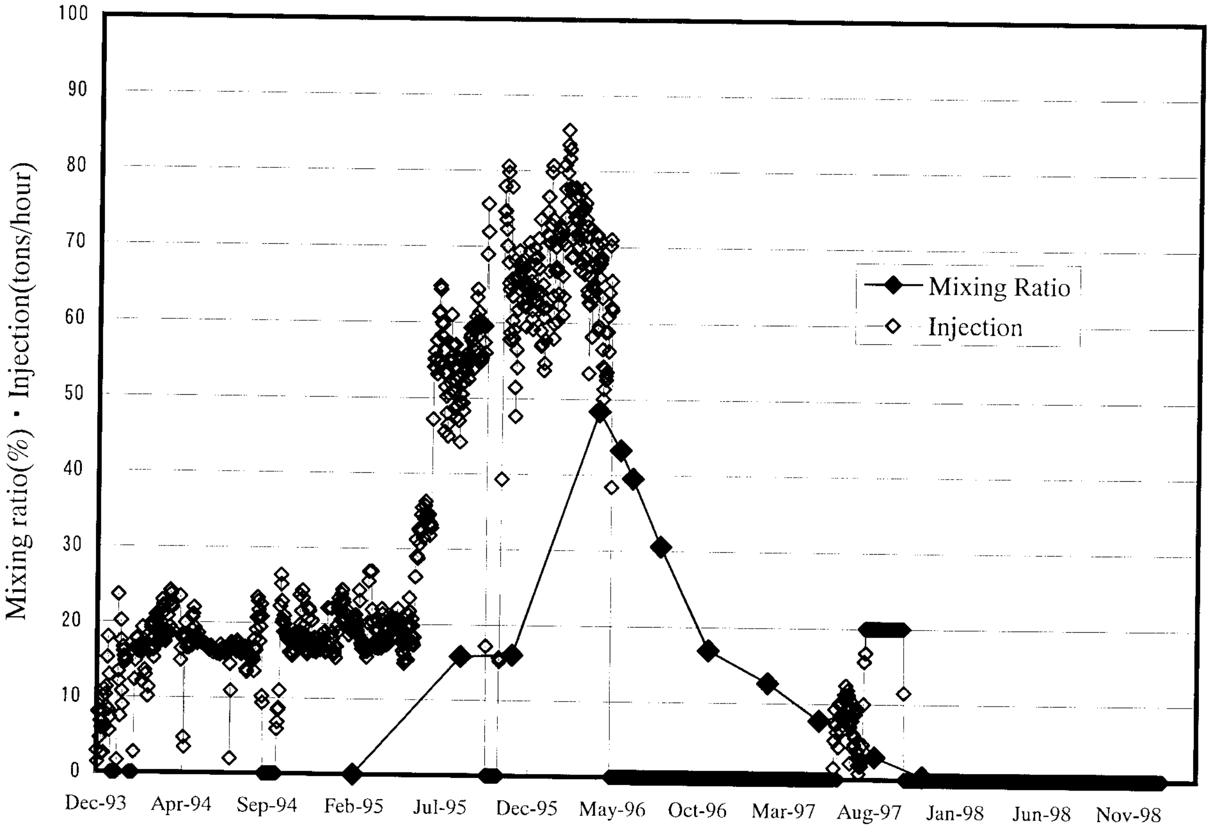

Figure 5.F-1 reinjection rate and the estimated mixing ratio

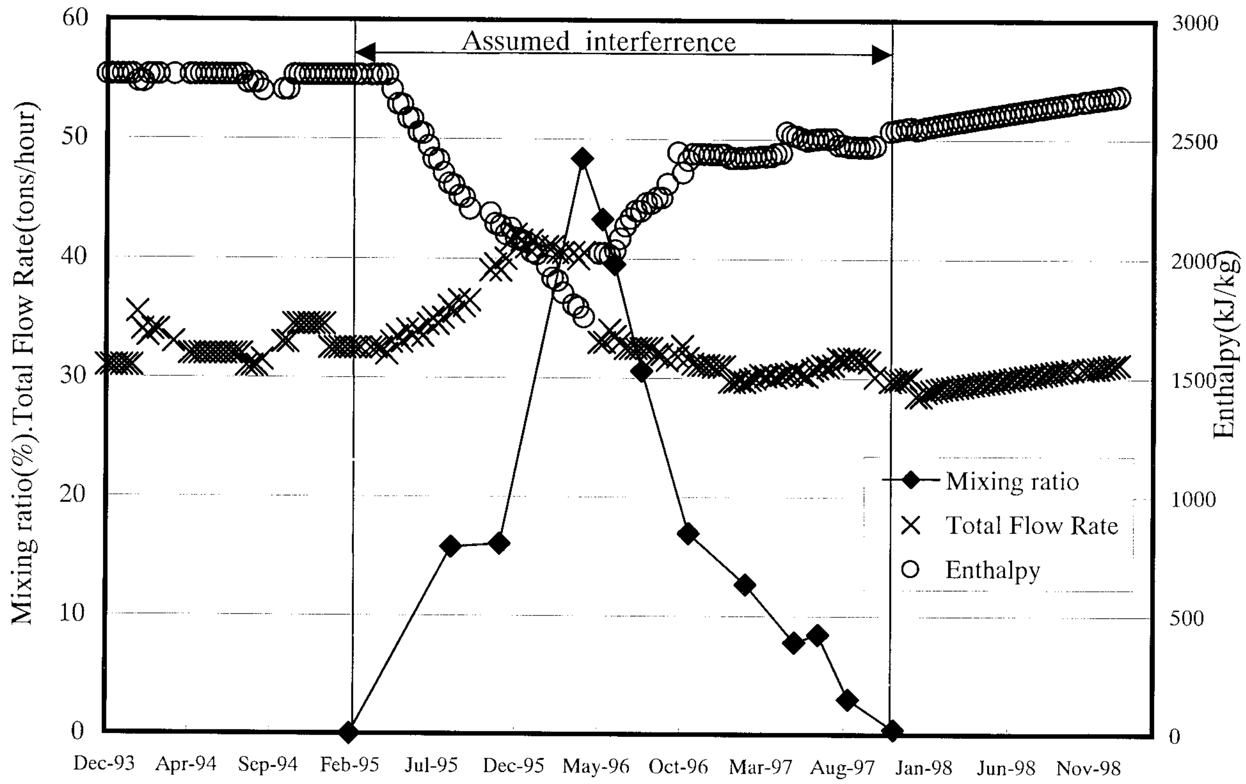

Figure 6.Flow rate of Well T-44 and its enthalpy, estimated mixing ratio