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THE DECREASE OF CAPACITY IN RE-INJECTION WELLS IN THE TAKIGAMI FIELD, JAPAN

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ABSTRACT

The Takigami Geothermal power plant (Unit: 25MW, Location : Fig.1) has been running since Nov.1st, 1996. The annual capacity factor in Takigami has been over 96% in the past two years. The capacity of production wells is almost stable, and the decrease of production rate is negligible. This result almost coincides with the expectation before operating. But in the re-injection wells (total injection rate 1,100 t/h), the decrease of the capacity is remarkable, and the rate of decrease in injection capacity has exceeded our expectations. Specifically, the rate of decrease in injection capacity was about 25%/year (270 t/h/year) in the first year after start-up, and 18% (195 t/h/year) in the second year. Recently, the rate of decrease has slightly improved, but the decrease is still continuing. At first, we expected injection rates to decline about 5%/year, because the closed system of re-injection (at a re-injection temperature of about 130 degrees C) was adopted in Takigami, so the unsaturated silica content would be relatively low, and silica scale problems would not occur as a result. In addition, the permeability in the re-injection area was very high, so the pressure interference among re-injection wells was almost negligible. According to the results of several investigations, it is inferred that the decrease of the capacity of the re-injection wells has been caused by silica scale clinging to and blocking the fissures of the reservoir, and not by pressure interference among re-injection wells. It is necessary to search for methods of inhibiting silica scaling to achieve stable operation at Takigami.

1. INTRODUCTION

We inferred that silica scale would not deposit in the fissures of the reservoir and would not cause a decrease of re-injection capacity, because we had adopted a closed re-injection system to keep the silica concentration below or only slightly over the saturated silica concentration at the re-injection temperature. For this reason, we estimated the rate of decrease in re-injection well capacity would be 15% to 20% in the first year, and about 5%/year thereafter. The reservoir pressure was estimated to rise due to pressure interference among re-injection wells in the first year, and it was postulated that this increase of reservoir pressure might cause a decrease of injection capacity. The estimation of decreasing capacity due to one-dimensional superposition analysis of pressure interference is indicated in Fig.2. In addition to pressure interference, there is one more factor that could cause decreasing injection capacity. It is the increase in pressure drop due to increasing roughness of casing. After the first year, scale deposition would gradually affect the capacity of wells. The decline rate of 15% to 20% in the first year was estimated in consideration of pressure interference and pressure loss in the pipes. The decline rate of 5%/year in second year after start-up was estimated based on the over-saturated concentration of silica at Takigami and the decline rate (Tahara, 1988, Fig.3). But, the actual decline rate of re-injection well capacity was about 25%/year in the first year after start-up of the power plant, and 18%/year in the next one-half year. In this half a year, it seems that the decline rate has moderated, but the declining trend is still continuing at 10%/year (Fig.4). The actual decline rate has been bigger than what was estimated.

2. INFERENCE OF THE CAUSES OF CAPACITY DECREASE

We analyzed the reservoir pressure increase caused by pressure interference among wells and the transmissivity changes caused by the silica scale damage to infer the causes of the capacity decrease in re-injection wells.

2.1 Inference of the capacity decrease caused by pressure interference

In order to estimate pressure change caused by interference among wells, a 3-dimensional numerical model has been made for the Takigami re-injection area, 1.65km × 1.60km. The total number of the blocks is 3,078, dividing the N-S direction into 19 grids, the E-W direction into 18 grids, and the depth into 9 grids. After matching the initial condition of the reservoir, we made a suitable numerical model of reservoir by trial and error, and continued to calculate the pressure of the blocks until the pressure change calculated in model coincided with the real pressure change. The simulator used in this study is Tough2. The range of permeability inferred by the numerical model is from 1 to 5,000 md. By using this numerical model to evaluate the decrease of capacity in the re-injection wells, we concluded that the reservoir pressure increase by pressure interference was slight, and that the capacity of wells would not decrease in future (Fig.5). This result is the almost the same as that of expectations before start-up.

2.2 Analysis of silica scale deposition in fissures

It is assumed that silica deposition in fissures causes the decrease of capacity in re-injection wells. We tried numerical estimation of silica scale deposition, in addition to observing the condition of the inside wall of the well head pipe line.

<u>Evaluation of silica scale deposition by using a numerical method</u>
The evaluation of silica deposition has been done by using the formula which calculates Cs, which is the silica concentration contributing to silica deposition, and which is an input parameter for running the silica scale deposition simulator developed by Kyushu University. The formula for calculating Cs is based on an idea that the deposition speed of silica scale is proportional to the over-saturation of silica in water. This formula to calculate Cs is an experimental one that has been deduced from the results of a trial experiment conducted by NEDO. Cs is a function of the concentration of silica in the water, the temperature of the water, and the pH. Fig.6 is a plot of Cs calculated under the condition of Takigami re-injection water. As a result, the possibility that silica scale deposits in fissures in Takigami is as follows:

- The water just after separation from a flow of steam and water (at a temperature is 135 degrees C) seems not to generate silica scale (Cs = 0 mg/l).
- In case the temperature of water decreases below 120 degrees C by the time the water reaches the well head or the layer of the reservoir, silica scale will form (Cs = 0 - 0.38 mg/l).
- In case a flow of water is separated into steam and water (at a temperature less than 100 degrees C), silica scale will form (Cs = 0 - 0.49 mg/l).

Considering the three factors, that re-injection temperature at the well head is about 130 degrees C, that the temperature of the re-injection reservoir is about 170 degrees C, and that silica concentration used for the estimate is higher than the real condition (not considering steam loss), this study indicates that silica scale will not easily be created in water under these conditions.

<u>Observation of the inner wall of the re-injection well head</u>
We observed the condition of the inner wall in a re-injection well (well name

TT-19) by removing a valve installed at the re-injection pipe line.
Flowing conditions and observation results were as follows:

a. Flowing conditions

- re-injection term: nine months
- re-injection temperature: 130 degrees C (7 months)
  125 degrees C (2 months)
- re-injection rate: 48 t/h (initial)
  27 t/h (at time of observation)
- well head pressure: 5 bar
- concentration of silica in water: about 500 ppm (Table.1)

b. Observed results

Silica scale with a thickness of about 1 mm deposited on the inner wall of the pipe at the upstream end of the valve. In the valve, the silica scale deposited in a wave-like pattern. The thickness of the scale was about 4 mm on the top of the waves and about 1 mm on the bottom. At the downstream end of the valve, the direction of scale creation was not as clear as at the upstream end of the valve. Considering this result, it seems the flow regime was turbulent. The thickness of scale was about 1 mm. The scale was not created in a wave-like pattern. The composition of the scale was amorphous silica according to an assay. From these observations, it has been found that silica scale deposits on the inner wall of pipe line at a rate of several mm/year at Takigami. Similarly, we can easily anticipate that silica scale will deposit in fissures of the reservoir and will deteriorate the transmissivity of the layer.

2.3 Inference of the cause of the capacity decrease in re-injection wells

It has been proved that silica scale depositing in fissures of reservoir may be the main cause of the capacity decrease in re-injection wells, because the reservoir pressure would not rise so high according to the pressure interference evaluation, and silica scale actually deposits on the wall of the pipe line. As the transmissivity in the re-injection area is so high (several 100 darcy-m), the re-injection capacity seems to be high enough to inject hot water at a rate of over 1,100 t/h.

3. INFERENCE OF THE RADIUS OF THE SILICA SCALE DEPOSITION AREA IN FISSURES

3.1 Simulation

We tried to estimate the radius of silica scale deposited in fissures of the reservoir in the case of hot water being re-injected in Takigami continuously. The simulator is the one that was developed by Kyushu University in 1987 as mentioned before. The conditions of the simulation model are as follows:

The depth of re-injection well is 1,500m. The silica concentration contributing to deposition as silica scale (Cs) is assumed to be 0.38 mg/l for the simulation. This concentration is the value adjusted to the condition in which the re-injection temperature is 100 degrees C. Though the re-injection temperature of 100 degrees C is lower than the actual re-injection temperature (130 degrees C), the decline rate of injection capacity calculated by adopting the concentration of 0.38 mg/l coincides with the actual decline rate. The flow rate of re-injected hot water is 100 t/h, and the period of calculation is 2 years.

Under these conditions, the radius influenced by the silica scale deposit was calculated. It was inferred from the simulation that the radius of the silica scale deposition around the re-injection well was about 20 m (Fig.7). It is suggested that the amount of scale is small outside a 20-m radius from the re-injection well, so that the permeability beyond a 20-m radius probably remains at its initial value.

3.2 An example of recovering capacity in a declining well

As it has been found that silica scale deposition only occurs over a relatively small area (namely only near the re-injection well), a re-drilling or a sidetrack drilling would seem to be one effective method of recovering injection capacity. Actually, a sidetrack drilling has been tried on one re-injection well in which injectivity had already declined. The example is re-injection well TR-3, described as follows:

a. The condition before sidetrack drilling

The re-injection capacity of TR-3 was initially 80 t/h, and was 30 t/h before sidetrack drilling. The capacity of TR-3 had decreased about 50 t/h after the well had been in use as a re-injection well for two and a half years. Similarly, re-injection well TR-2 had decreased in injection capacity from 230 t/h to 120 t/h in the same period. The combined capacity of TR-3 and TR-2 was 150 t/h before sidetrack drilling.

b. Sidetrack drilling

Well TR-3 was re-drilled to a point near the well TR-2 (which had high initial potential) to recover injection capacity. Based on the estimated area of silica deposition, the sidetrack well (named TR-3S) was drilled to a point about 20 m away from the fracture of TR-2.

c. Effect of the sidetrack drilling

The sidetrack of TR-3 started losing circulation at a point about 50 m away from the fracture of the well TR-2, and it was completed at that point. According to an injection test, the re-injection capacity of TR-3S is about 150 t/h, though the capacity of TR-2 was reduced to about 100 t/h because of pressure interference between TR-2 and TR-3S. The combined capacity of TR-2 and TR-3S is about 250 t/h, so injection capacity has been increased about 100 t/h by the sidetrack drilling of TR-3 (Fig.8). Considering this result, it is indicated that the estimation of the area of silica scale deposition is approximately correct.

4. FUTURE WORK

At Takigami, the main cause of the capacity decrease in re-injection wells is the influence of silica deposition in fissures of the reservoir. Therefore, the establishment of methods to prevent silica deposition should be a near-term focus. The present areas of investigation at Takigami are the following:

a. pH adjustment

Generally, it is known that pH adjustment is effective for the prevention of silica deposition. The pH of hot water at Takigami is about 9 at atmospheric temperature. To look for the proper pH that is effective for scale prevention, it was planned in 1999 to measure the speed of polymerization of silica over a range of pH values. A pH adjustment test will be run using a slim well in 2000.

b. Injection of silica inhibitor

It is planned to test the effectiveness of an inhibitor in place of pH adjustment. The test for the choice of inhibitor will be done at the same time as the pH adjustment test.

c. Establishment of a better configuration of re-injection wells

Takigami is roughly divided into areas of high and and low silica concentration. The reservoir temperature is about 250 degrees C at the western part of Takigami and about 210 degrees C at the eastern part. The difference of reservoir temperature is reflected in the difference of dissolved silica concentration. The average concentration of silica at the western part of the Takigami reservoir is about 640 ppm and the concentration at the eastern part is about 430 ppm (Table.1). The concentration of total silica in the eastern part is about 200 ppm lower than that of the western part. Under the present re-injection system, hot water separated at each production site is gathered into one vessel, where it mixes with water from other wells before flowing to the re-injection wells. If waters with high and low silica concentrations are flowed in two separate pipelines, it may be possible to maintain the capacity of re-injection wells where water with a low silica concentration is re-injected. Actually, there is one re-injection well at Takagami which has maintained its initial capacity (200 t/h) for three years. This well has been used to re-inject water that has been separated at atmospheric pressure and that has a low silica concentration. Therefore, one of the methods of preventing silica scaling is to re-inject without mixing waters of high and low silica concentration, though measures should also be taken to apply other methods (for example, pH adjustment for water with high silica concentration). It will be necessary to investigate restructuring the re-injection well configuration after studying the reason that one of the re-injection wells has been able to maintain its initial capacity. This study will be done in 2000.

CONCLUSIONS

- Considering the silica concentration, re-injected water at Takigami was not expected to deposit silica in fissures and on the surface of pipe lines.
- But, according to observation, silica scales actually do deposit at a rate of several millimeters per year on the surface of pipe lines, and perhaps also in fissures.
- The main cause of the decrease of re-injection capacity at Takigami is silica scaling that has blocked flow channels.
- In the case of Takigami, it is estimated that the radius of silica scale deposition around re-injection wells is about 20 m. Therefore, the permeability possibly remains at its initial level at distances greater than 20 m from re-injection wells.
- Sidetrack drilling aimed at the fractures close to existing wells is one of the effective methods to recover the capacity of re-injection wells damaged by scale deposition.

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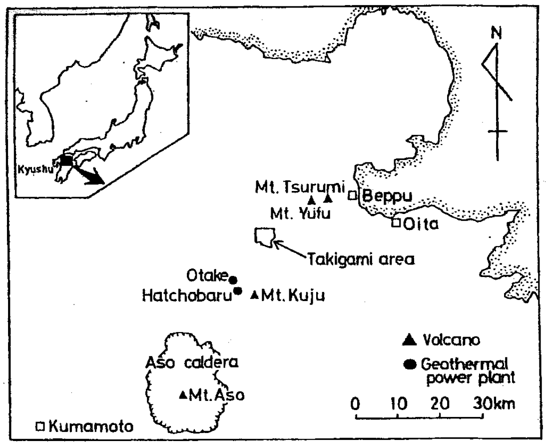

Figure 1. Map of Takigami Field

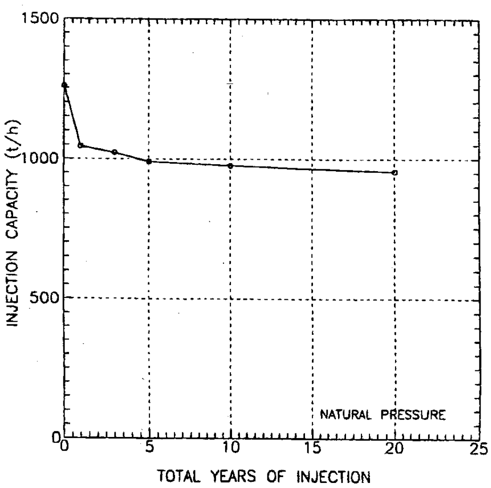

Figure 2. Estimation of capacity change calculated by one-dimensional analysis

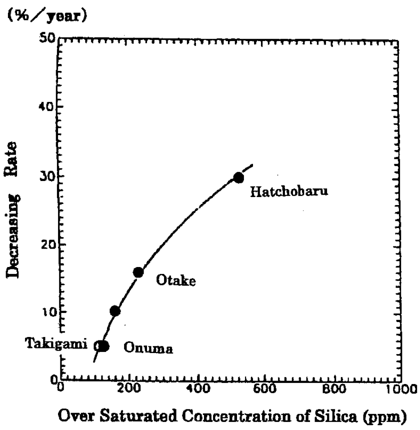

Figure 3. Plot of over-saturated concentration of silica vs. decrease rate of capacity. Tahara (1988)

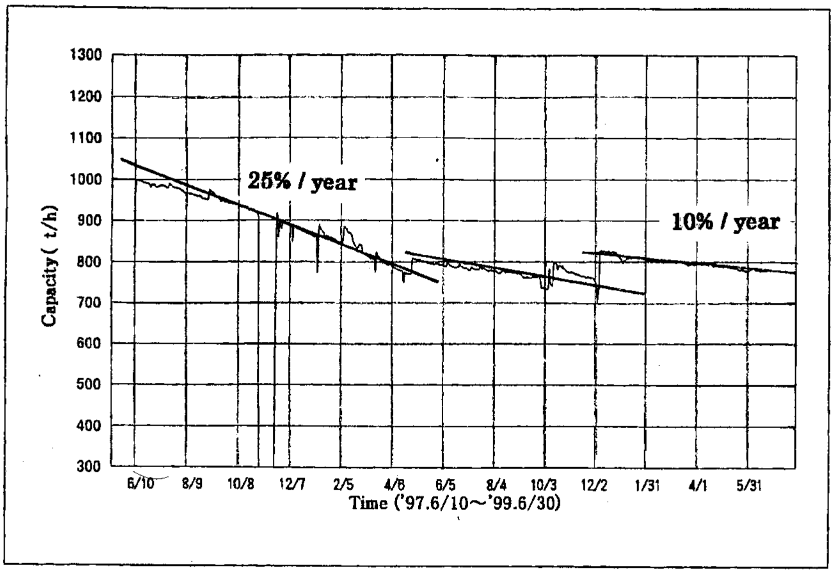

Figure 4. Capacity change of Takigami re-injection wells

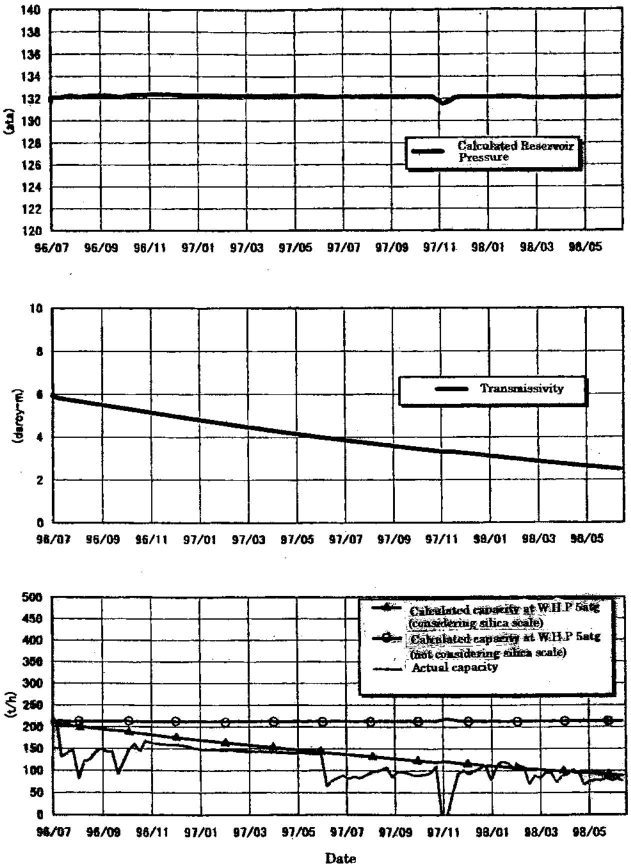

Figure 5. Simulation results of re-injection well TT-23
The pressure of reservoir is not increased
by interference. Scale depositing must be
considered to match the actual decrease of capacity.

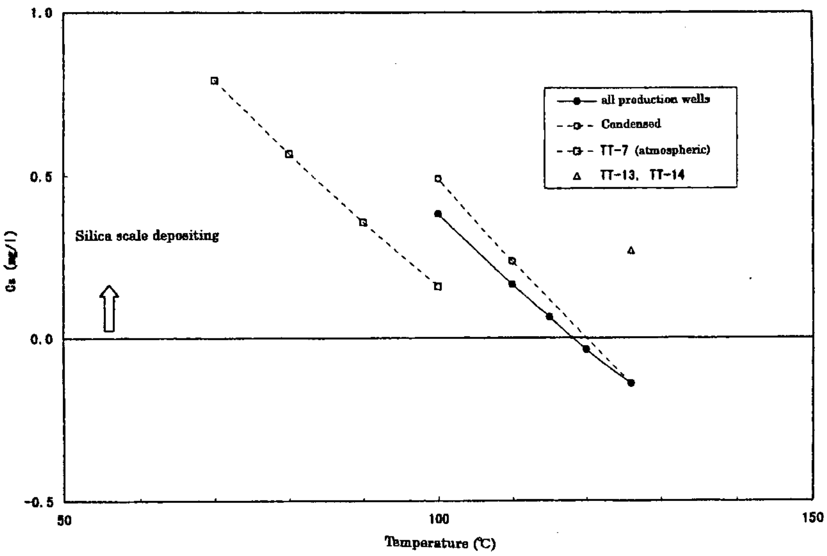

Figure 6. Depositing trend of silica scaling
in case of some re-injection conditions

Table1. Representative chemical data of production wells in Takigami

Sample (well name)	Sampling Temp.*(℃)	pH (20℃)	Li	Na	K	Ca	Cl	SO_4	HCO_3	CO_3	B	SiO_2
						ppm						
TT-2	124	9.0	1.6	466	47.1	18.8	547	238		53	5.6	365
TT-7	110	9.1	2.1	475	63.3	20.6	640	154	11	53	7.0	441
TT-8	100	9.2	1.7	488	57.4	12.3	585	251	13	47	5.2	473
TT-13	121	8.9	2.8	514	93.3	14.2	758	108	36	36	9.1	675
TT-14	123	9.1	2.6	502	89.0	8.4	785	95	-	53	9.8	593

Chemical concentration of each sample are analyzed by ICP spectrometer.
*: The liquid phase from geothermal wells was separated at the sampling temperature and collected after cooloing. No steam was lost from liquid phase after separation.

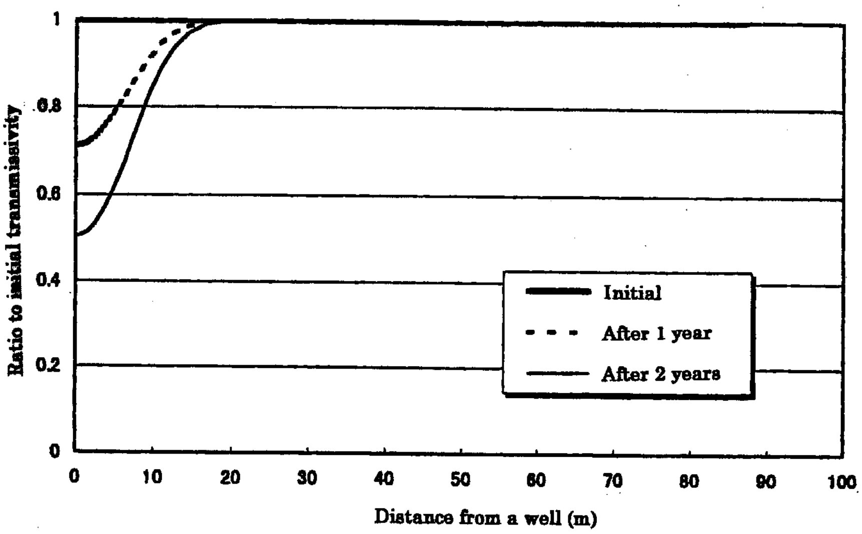

Figure 7. Estimation of area where silica scale deposits around a re-injection well

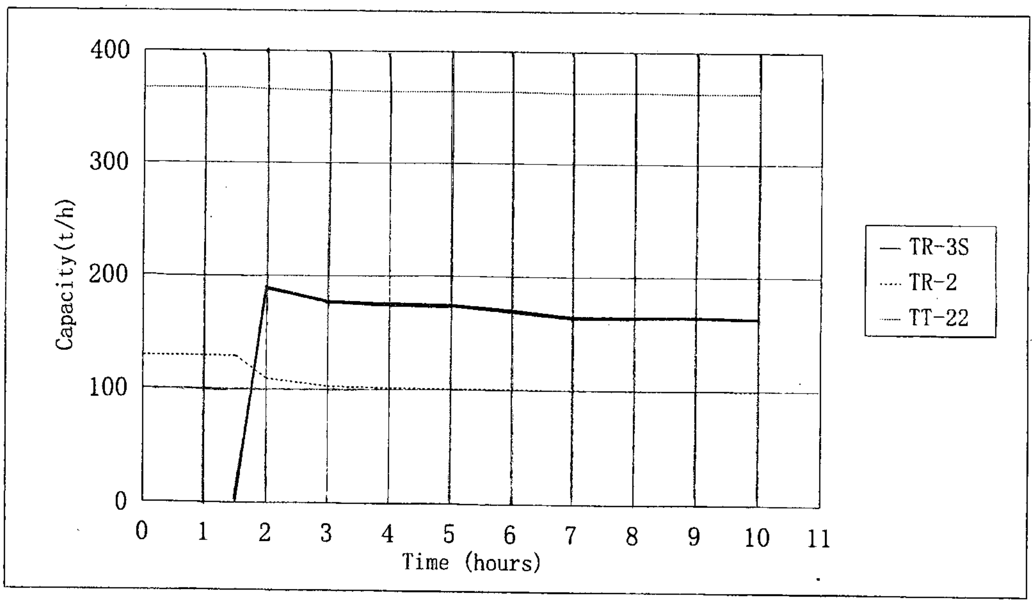

Figure 8. Capacity change of TR-2 and TR-3S which was re-drilled and aimed at TR-2