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PRODUCTION HISTORY OF THE OHNUMA GEOTHERMAL FIELD, NORTHEAST JAPAN

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ABSTRACT

The Ohnuma geothermal field is located in the northern part of the Hachimantai volcanic region, Northeast Japan. The Ohnuma geothermal power station has been operated by Mitsubishi Materials Corporation (MMC) since 1974. Since then, only two make-up production wells were drilled in 1976 and 1983, while several reinjection wells were drilled between 1980 and 1992. The rated plant generating capacity has been increased progressively from 6 MWe in 1974 to 9.5 MWe in 1986. Temporal changes in production flow rate, production enthalpy and chloride concentrations are observed in response to changes in the operating conditions of the production and reinjection wells. Decline in production enthalpies and increase in chloride concentrations were observed but with less effect on both parameters when injection is done further away from the production sector.. Quartz temperature, however, remains comparatively stable. It is estimated that production fluids being returned from reinjection wells has not been fully re-equilibrated with respect to quartz. Recently, stable production flow rates and declining enthalpies were observed. This results in the decline of the steam flowrates and the reduction in the generating capacity of the plant to 7.4 MWe. Over 25 years, the observed low decline in the steam flow has been controlled because of proper reservoir management. Drilling of make-up wells were limited since meeting the rated plant capacity is not being forced. The temperature of the Ohnuma geothermal reservoir is moderate and the reservoir fluids are of low salinity. These reservoir characteristics cause to prolong the longevity of the Ohnuma production wells.

1. INTRODUCTION

The Ohnuma geothermal field is located in the northern part of the Hachimantai volcanic region, Northeast Japan. In this region, active volcanoes, hot springs and fumaroles abound. Three other geothermal power stations are installed at Sumikawa, Matsukawa and Kakkonda. The Sumikawa geothermal power station, which is operated by Tohoku Electric Power Company Inc. and Mitsubishi Materials Corporation (MMC) since 1995, is situated about 2 km to the west (Ariki *et al*., in press). There are also numerous geothermal manifestations in the region around Mt. Hachimantai and Mt. Yakeyama.

In 1965, MMC started an exploration program in the northern part of the Hachimantai volcanic region, to delineate potential geothermal prospects. This exploration program resulted in the selection of the Ohnuma and Sumikawa fields as prospective targets for further exploration and development. The Ohnuma geothermal power station was completed in 1973, and has been operated commercially by MMC since 1974 with four production wells (O-3Ra, O-3Rb, O-5R, and O-6R) and three reinjection wells (O-1R, O-2R and O-7R). After the commencement of the commercial operation, two make-up production wells (O-8R and O-10R) were drilled in 1976 and 1983 while two make-up reinjection wells (O-8T and O-9T) were drilled in 1980 and 1984 by MMC. All of these production and reinjection wells lie within an area approximately 1 km in diameter. The rated generating plant capacity has been increased progressively from 6 MWe in 1974 to 9.5 MWe in 1986. In order to utilize hot water from the Ohnuma production wells, eight reinjection wells (K-series wells; from K-1 to K-8) are drilled in Kazuno-city; about 1km north of the Ohnuma production wells. The well localities are shown in Fig.1.

The development history, the geothermal system, geochemical monitoring, and numerical studies of the Ohnuma geothermal reservoir were discussed by Yora *et al*. (1973, 1977), Kubota (1988), Kubota *et al*. (1989), Shigeno *et al*. (1992), and Kubota and Matsubaya (1998). This paper presents the reservoir behavior estimated from monitoring data, and reservoir management on the Ohnuma geothermal reservoir.

2. RESERVOIR DESCRIPTION

In Hachimantai volcanic region, north-south structure characterized by a dual series of graben and uplift zones was formed. The east-west volcanic chain connects Mt. Hachimantai and Mt. Yakeyama, which are active volcanoes intersecting with north-south structure at the southern part of the Ohnuma geothermal field (Yora *et al*., 1977).

The conceptual model is shown in Fig. 2. The stratigraphy of the Ohnuma field consists of Quaternary volcanic rocks, lacustrine sediments, and Tertiary formations. The Tertiary formations consist of the siliceous shale in its deepest layer, andesitic to dacitic volcanic and its pyroclastic rocks, and marine sediments of Miocene to Pliocene age. The Ohuma geothermal reservoir is a liquid-dominated type with a two-phase zone overlying the liquid phase beneath Quaternary rocks. Subsurface temperatures appear to be highest to the southeast, implying that the thermal anomaly is closely associated with the east-west volcanic chain located to the south in the area. It is believed that deep heat sources in the area itself underlie the volcanic chain. The temperatures at the feed zones of production wells are estimated at range of 220 and 240 deg. C, and underground pressures are approximately uniform throughout the area at depth. Correlation of reservoir pressure P (MPa) against elevation Z (mASL) is given by the following (Kubota, 1988):

$$P = (785.7 - Z) \times 769.8 \times 10^{-5}$$

The surface elevation of the Ohnuma geothermal field is approximately +950 mASL. The feed zones are situated at range from -400 mASL to -800 mASL, and the reinjection zones of O-series wells and K-series wells are at range from +400 mASL to -200 mASL and at from +200 mASL to -600 mASL respectively.

The Ohnuma reservoir fluids are of low salinity and mainly of the Na-Cl type. The noncondesible gas content is very small, typically <0.1 volume % of the produced steam typical of geothermal reservoir with moderate temperatures from 220-240 deg. C.

3. PRODUCTION HISTORY AND RESERVOIR RESPONSE TO EXPLOITATION

At the Ohnuma geothermal power station, the flow rates of individual wells are measured using orifice plate for steam, and weir box for hot water. Brine from the production wells are sampled monthly and noncondensible gases are sampled once per three months. However, downhole surveys were conducted only several times over 25 years after the commencement of the power station.

Yearly total production flow rate and yearly flow-rate-weighted average production enthalpy from the Ohnuma production wells are shown in Fig.3. Reinjection flow rates of individual wells are also shown in Fig.4 (no data in 1973). The Ohnuma geothermal power station had started producing electricity since 1973 with four production wells (O-3Ra, O-5R, and O-6R) and three reinjection wells (O-1R, O-2R and O-7R). After the commencement of the commercial operation in 1974, two make-up production wells (O-8R and O-10R) started flowing in 1976 and 1983. Well O-9T and K-series wells started reinjection in 1984 and 1987 respectively. Since then O-9T and K-series wells have been major reinjection wells. The production history of the Ohnuma geothermal power station is classified into four stages based on operational conditions of the production and reinjection wells.

1) From 1973 to 1976 (Trial operation period): Total production flow rate showed increasing trend. Production enthalpy declined abruptly in the first year and subsequently showed increasing trend.
2) From 1976 to 1983 (start of O-8R operation): Total production flow rate increased from 1976 to 1977 and subsequently showed a declining trend. Production enthalpy was relatively stable. Well O-8R stopped producing in 1983. This is attributed to cooling of temperatures, and coincides with the decline in production enthalpy.
3) From 1983 to 1987 (start of O-10R operation): Production flow rate increased from 1983 to 1985 and subsequently showed stabilization. Production enthalpy increased from 1983 to 1985 and subsequently showed decreasing trend. Well O-10R showed excess enthalpy in the first few years.
4) After 1987 (start of reinjection into K-series wells): Production flow rate increased from 1987 to 1989 and subsequently stabilized. Production enthalpy showed decreasing trend except in the period 1992 to 1994.

From Fig. 3, two significant changes in production history were observed in 1977 and 1984 . It is during these periods when production started in wells O-8R and O-10R. Before 1977, total production flow rate showed increasing trend, while production enthalpy abruptly declined in first year and subsequently showed stable condition. Between 1977 and 1982, production flow rate showed declining trend, while production enthalpy is relatively stable. After 1984 up to 1989, production flow rate increased and subsequently has been stable, while production enthalpy showed decreasing trend.

Yearly flow-rate-weighted average chloride, which is calculated at reservoir condition, is shown in Fig. 5. Chloride concentration trend also showed significant changes in 1977 and in 1984. Before 1977, chloride concentration showed increasing trend. Between 1977 and 1980, chloride concentration was nearly stable. This subsequently decreased in 1984. After 1984, chloride concentration showed increasing trend. Between 1992 and 1994, while reinjection flow rate into well O-9T had been relatively low, chloride concentration showed decreasing trend. It appears that high reinjection flow rate into well O-9T caused high chloride concentration in producing fluid due to mixing of producing fluids and reinjection fluid which indicate short residence time in the reservoir before returning to the production sector.

The results of tracer tests are shown in Table 1. In the Ohnuma geothermal field, the tracer tests were conducted six times. Wells O-7T, O-7R, O-1R and O-2R were major reinjection wells before 1984. The tracer test using well O-8R was conducted to investigate the interference between the production wells. The tracer test using well K-8 in 1993 was carried out to investigate the hydrological communication between the Ohunma production wells and K-series wells, and the result showed longer residence time and better recovery ratio than the tracer tests using the O-series reinjection wells. Better heat extraction is observed in the K-series wells.

These behaviors mentioned previously varied in response to changes in operational conditions of the production and reinjection wells.

Fig. 6 shows temporal changes in production flow rate, production enthalpy, quartz temperature (Fournier, 1981) and chloride concentration of well O-3Rb. Well O-3Rb is situated relatively near the O-series and K-series reinjection wells. Production flow rate from O-3Rb ranges between 26 kg/sec to 30 kg/sec. After 1984 (except in 1992-1995), production enthalpy showed declining trend. Chloride concentration, after 1984 (except in 1992-1993), showed increasing trend. As discussed previously, production flow rate, production enthalpy and chloride concentration varies in response to changes in operational conditions of reinjection wells. Quartz temperature, however, had been comparatively stable. However, recent quartz temperatures were found higher than the measured temperature, and is evaluated to be due to “silica breakthrough” (Malate and O’sullivan, 1991). “Silica breakthrough” were observed in wells O-3Rb, O-5R and O-6R. The other production wells (O-3Ra and O-10R) were not evaluated for “silica breakthrough” as no recent downhole temperature measurements were available.

Numerical studies using lumped parameter model on the Ohnuma geothermal field were discussed by Kubota *et al*. (1989), Shigeno *et al*. (1992), and Kubota and Matsubaya (1998). The results of Kubota and Matsubaya (1998) are as follows:

- mass of fluid in the reservoir is approximately 4.8×10^9 kg under the exploited condition in 1990.
- recycling fraction of the reinjected hot water to the reservoir is 75 %.
- Temperature of water reinjected to the reservoir rises more than 100 deg. C during residence in the reservoir.

The authors are conducting the numerical simulation using three-dimensional grids model to apply to reservoir management.

4. RESERVOIR MANAGEMENT

The Ohnuma geothermal power station has a small capacity with low turbine inlet pressure. The rated generating electricity output has gradually increased from 6 MWe in 1974 to 9.5 MWe in 1986. Fig. 7 shows the generating electricity and turbine inlet-pressure. The Ohnuma geothermal power station has been producing electrical power ranging from 6.2 MWe to 9.4 MWe, and turbine inlet pressure has been a range of 0.14 MPa absolute to 0.19 MPa absolute. Utilization factor over 25 years operation ranges between 75% to 95%. The present generating electricity and turbine inlet pressure are 7.4 MWe and 0.16 MPa absolute respectively.

According to original development plan, the distance among feed zones of production wells was planned at range of 200 m to 250 m (Wakita and Miyazaki, 1992). After the results of the 1973 extensive production test using several wells, wells O-8R and O-10R had been spaced far apart to reduce well interference. Similarly, the distances between the production and reinjection wells have also been increased as far apart as possible.

Low declining trend of the steam flow rate and only a a few make-up production wells drilled in the area has been made possible because of proper reservoir management giving more impetus on the sustenance of the field rather than meeting the required plant capacity. The Ohnuma production wells are drilled within moderate temperature (220 - 240 deg. C) discharging low salinity fluids. These reservoir fluid characteristics resulted in none well damages for the Ohnuma production wells (e.g. casing break, scaling). With the moderate reservoir temperatures, the turbine inlet pressure was designed at .16 Mpaa. It is thus expected that these factors would favor the longevity of the production field.

As shown in Table 1, reinjection into K-series wells is expected to be suitable for heat extraction by "cold sweep" because the injection zones of K-series wells are situated farther from production zones and relatively deeper than those of O-series reinjection wells.

In order to increase the generating electricity, MMC scheduled to drill make-up production well (O-11R) to the southeastern east of the existing production zone in 1999.

5. CONCLUDING REMARKS

This paper reviews the reservoir behavior and reservoir management over 25 years operation of the Ohnuma geothermal power station. Temporal changes in production flow rate, production enthalpy and chloride concentration are recognized to in response to changes in operational conditions of the production and reinjection wells. Low declining trend in the steam flow rate and few make-up wells drilled were realized because of proper reservoir management allowing the power plant to generate lesser than plant capacity to avoid reservoir degradation.

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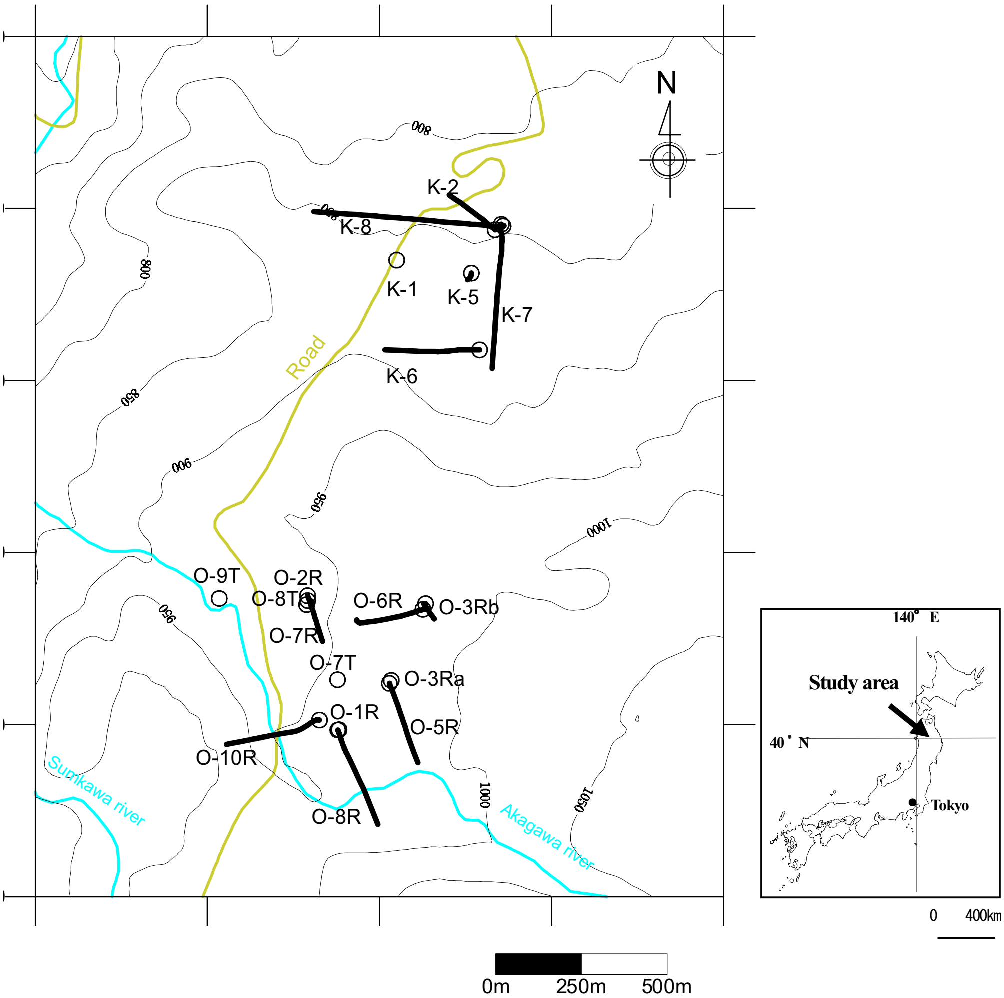

Figure 1. Well Localities of the Ohnuma geothermal Field.

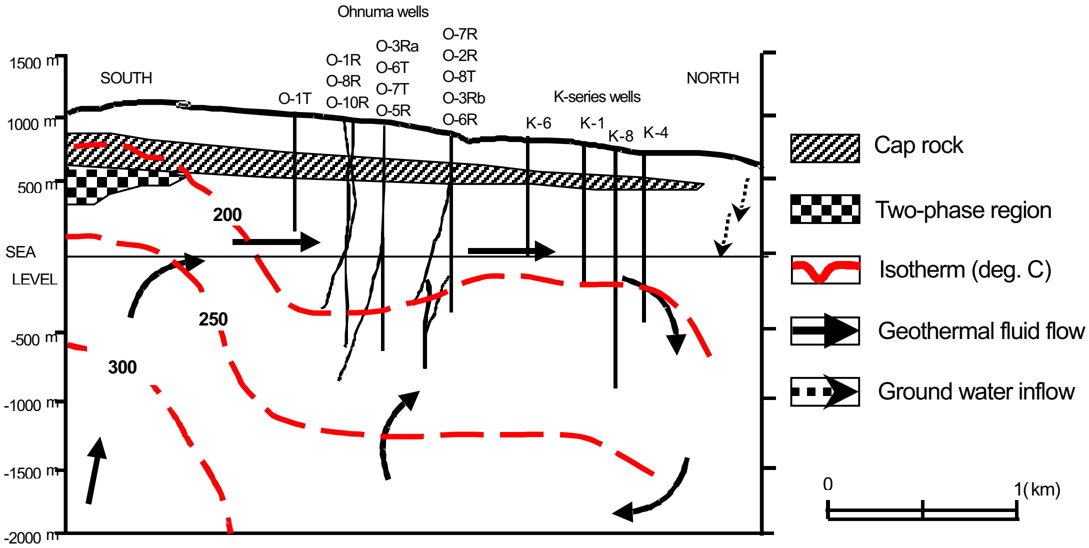

Figure 2. Conceptual Model of the Ohnuma geothermal Reservoir
(adapted from Kubota, 1988).

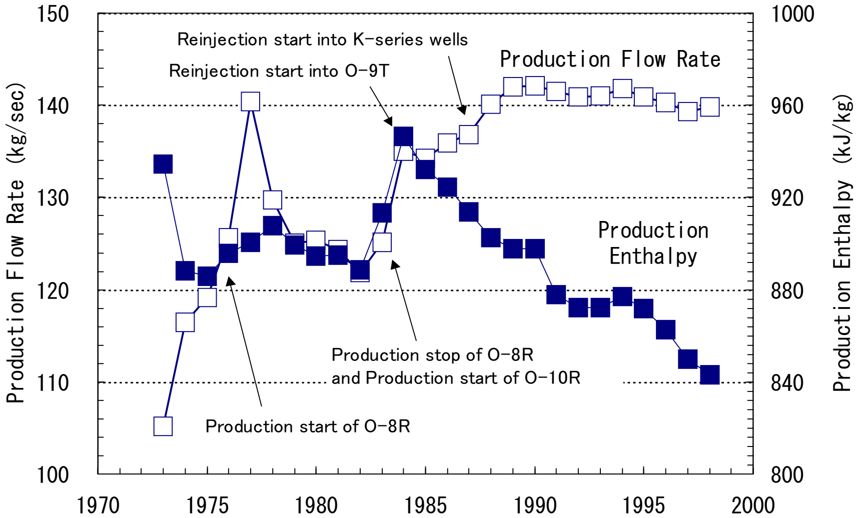

Figure 3. Yearly average production flow rate and yearly flow-rate-weighted average production enthalpy.

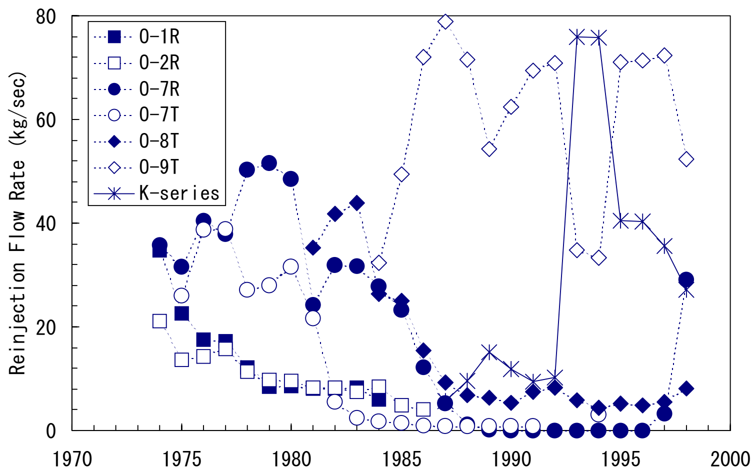

Figure 4. Yearly average reinjection flow of individual wells

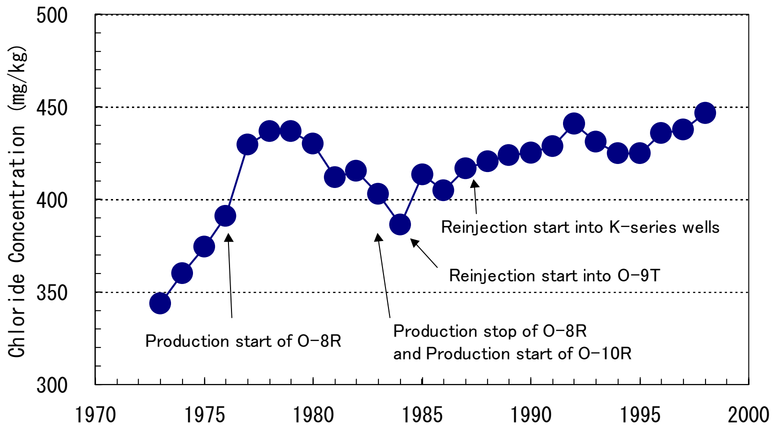

Figure 5. Yearly flow-rate-weighted average chloride concentration.

Table 1. Results of the tracer tests (adapted from Ito *et al*., 1977).

Injection well	Date	arrival time	O-3Ra	O-3Rb	O-5R	O-6R	O-8R	O-10R
O-7T	1975/03/10	First arrival time	27hrs	10days	10days	N.R.	N.D.	N.D.
		Peak arrival time	77hrs.	unclear	21days	N.R.	N.D.	N.D.
O-7R	1975/07/01	First arrival time	4days	4days	7days	68hrs.	N.D.	N.D.
		Peak arrival time	19days	10days	55days	12days	N.D.	N.D.
O-1R	1976/06/30	First arrival time	48hrs.	13days	43hrs.	N.R.	N.D.	N.D.
		Peak arrival time	36days	36days	169hrs.	N.R.	N.D.	N.D.
O-2R	1976/11/02	First arrival time	73hrs.	93hrs.	N.R.	42hrs.	N.D.	N.D.
		Peak arrival time	8days	9days	N.R.	114days	N.D.	N.D.
O-8R	1983/09/16	First arrival time	N.R.	N.R.	N.R.	N.R.		10hrs.
		Peak arrival time	N.R.	N.R.	N.R.	N.R.		9days
K-8	1993/10/29	First arrival time	39days	27days	136days	28days	N.D.	N.R.
		Peak arrival time	88days	64days	168days	64days	N.D.	N.R.

Injection well	Date	Recovery condition	O-3Ra	O-3Rb	O-5R	O-6R	O-8R	O-10R
O-7T	1975/03/10	Recovery ratio (%)	10.6	0.0	tr.	0.0	N.D.	N.D.
		Mixing ratio (%)	8.0	0.0	tr.	0.0	N.D.	N.D.
O-7R	1975/07/01	Recovery ratio (%)	7.8	5.0	13.9	7.5	N.D.	N.D.
		Mixing ratio (%)	8.7	8.5	24.9	8.7	N.D.	N.D.
O-1R	1976/06/30	Recovery ratio (%)	1.8	5.8	7.1	0.0	N.D.	N.D.
		Mixing ratio (%)	1.0	4.4	6.3	0.0	N.D.	N.D.
O-2R	1976/11/02	Recovery ratio (%)	14.7	3.4	0.0	17.4	N.D.	N.D.
		Mixing ratio (%)	5.9	1.8	0.0	7.6	N.D.	N.D.
O-8R	1983/09/16	Recovery ratio (%)	0.0	0.0	0.0	0.0		17.1
		Mixing ratio (%)	0.0	0.0	0.0	0.0		17.0
K-8	1993/10/29	Recovery ratio (%)	12.2	24.5	1.1	20.9	N.D.	N.R.
		Mixing ratio (%)	12.1	19.0	1.2	17.2	N.D.	N.R.

Remarks: N.D. No Data
N.R. No Return

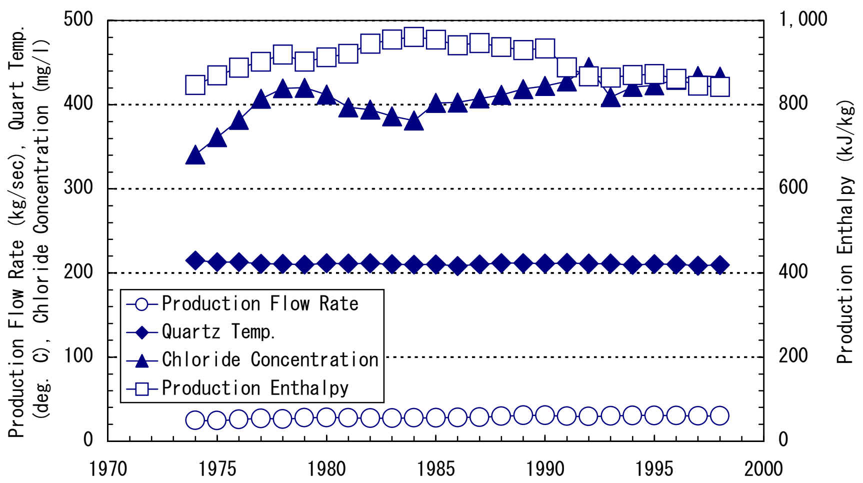

Figure 6. Yearly average production flow rate, quartz temperature, chloride concentration and production enthalpy of Well O-3Rb.

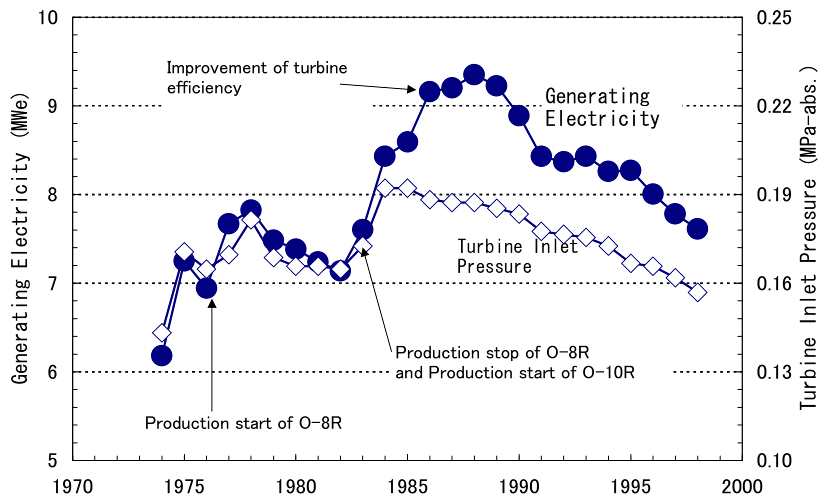

Figure 7. Yearly average generating electricity and turbine inlet pressure.