Eighteen Year History of Reservoir Development in the Ogiri Geothermal Field, Japan

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ABSTRACT
The Ogiri geothermal power plant started its operation in March 1996 with installed capacity of 30MW. Since the beginning of operation, the plant has successfully maintained high utilization factor of over 90% in average. Timely change of well operations and developing a new area within Ogiri contributed to the long term high level productivity of the plant.

1. Introduction
The Ogiri geothermal field is located in the northern part of Kagoshima prefecture, southern Kyushu, Japan (see Fig.1). The elevation of the field ranges between 700m and 900m.

The Ogiri geothermal power plant has been operating for 18 years, since 1996, and has achieved a significantly high utilization factor being ranked as a top among geothermal power plants in Japan (see Fig.2). The Ogiri reservoir is a water-dominated system with a steam cap in shallow zone in reservoir (Goko, 2000). This paper summarizes the development history, layout of facilities, geothermal structure of the field, then expansion of development in an adjacent area for production after the year 2005.

2. Outline of the Ogiri Geothermal Field
2.1 Development History
The Ogiri geothermal field is located within the Kirishima geothermal area where surface surveys including geology, geophysics and geochemistry were conducted by private companies in 1973 followed by surveys for geothermal development by the government started in 1975 (Kodama, 2000). On the basis of the interpretations of the surveys, a three dimensional reservoir model was developed for evaluating the output potential. Simulated
results concluded that Ogiri has a potential for producing 350 t/h of steam for 30 years. On the other hand, discharge tests in four production wells and two reinjection wells were conducted for four months from January to April in 1977. This test confirmed 125 t/h of steam production which was equivalent to 14 MW power generation. At the same time, interferences among wells and decline of production were also evaluated, and steam production of 380 t/h for 20 years was estimated. Upon these evaluation results, a construction of 30 MW power plant were determined.

After other several surveys had been conducted continuously, the Estimation Committee of the Geothermal Project in the Ogiri District of Kyushu Electric Power Co., Inc. identified the reservoir as a resource with a feasible potential of 30MW in 1987 (Kodama, 2000). Nittetsu Kagoshima Geothermal Co., Ltd. was founded for promoting geothermal development in the Kirishima district in 1990 and drilled production and reinjection wells. After completion of environmental assessment, construction of steam supply facilities and a power plant, the plant started its operation on 1st March, 1996.

2.2 Layout of Surface Facilities

The Ogiri power plant is a joint project between Kyushu Electric Power Co., Inc. and Nittetsu Kagoshima Geothermal Co., Ltd., which are responsible for the power generation and the steam production, respectively.

The Ogiri power plant is located in the center of the property about 500m wide and 1,500m long on the slope of a gentle hill. Production wells were drilled at three well pads in the eastern part of the area where elevation is relatively high within Ogiri, while reinjection wells drilled at three well pads in the western part with lower elevations. The difference in elevation between the highest production pad and the lowest reinjection pad is about 130m, hot water separated at each production well pad flows naturally to the reinjection wells according to the gravity. The layout of facilities related to the steam supply is shown in Fig.3. The numbers of production and reinjection wells are seventeen(17) and ten(10), respectively, as of March 2014 while they were ten(10) and seven(7) when the operation of the plant was started.

2.3 Geothermal Structure

A geothermal system in the Kirishima area is controlled by fault and fracture systems oriented along two main directions, NW-SE and ENE-WSW (Goko, 2000). The Ginyu fault is one of the ENE-WSW striking faults in Ogiri and plays as the main reservoir for steam production. A group of the Ogiri deep fault is located parallel to the Ginyu fault, to the south, and divided into three faults: the Ogiri deep fault No.1, 2, and 3. The Ogiri deep fault No.2 plays as the main reservoir for reinjection. The NW1 fault is of NW-SE striking and crosses both the Ginyu fault and the Ogiri deep faults (see Fig.4).

The Ogiri geothermal field is located on the western slope of Kirishima volcano. Thus, the subsurface temperature in Ogiri features a high temperature zone in the eastern part of the field and gradually decreases toward the west.

3. Operation History of the Ogiri Power Plant

3.1 Reinjection Wells for Maintaining Reservoir Pressure

Steam production rate significantly decreased compared to the initially predicted value after one year since the start of operation (Horikoshi et al., 2005). This decrease is probably caused by pressure drop of reservoir.

There are three types of reinjection wells in the field. They are classified on
the basis of the effects on production wells as, 1) injected water that flows through the Ginyu fault and quickly returns to production wells within a week, 2) a part of injected water that returns to production wells through the Ginyu fault, 3) injected water will not flow to production well or takes about a month to reach production wells.

In order to maintain the reservoir pressure, reinjection wells whose injected water flowing quickly back to production wells had been utilized since April 1997.

### 3.2 Change of Reinjection Operation for Maintaining Reservoir Temperature

Reservoir temperatures clearly started decreasing after one year operation of the reinjection wells above. Numerical simulation of reservoir performance indicated that the reservoir temperature decrease could be moderated or avoided by adopting reinjection scheme at wells whose injected water travels slowly to production wells or does not reach to the production wells. Then, from a stable reservoir management view, reinjection of waste water had been switched to the wells that do not provide any serious effect on temperature of production zone. This new reinjection operation was started in April 1999. Then, temperature of production zone remained temporarily while the reservoir pressure continued decreasing. However, both reservoir pressure and temperature progressively decreased. Geochemical studies indicated that the temperature drop might have been caused by inflow of shallow low temperature water induced by reservoir pressure drop (Horikoshi et al., 2005).

### 3.3 Production With Steam Dominated Wells

There are two types of production wells in Ogiri: steam dominated well and water dominated well. Steam dominated wells produce either dry saturated steam or steam-water mixture of high steam-water ratio such as one to one-three while the water dominated wells produce steam-water mixture with steam-water ratio to be one to five or six.

In order to moderate reservoir pressure decline, steam dominated wells had been mainly operated for steam production since March 2001 (Horikoshi et al., 2005). Thus, mass withdrawal from the reservoir would be reduced for a required amount of steam for power generation. Reservoir pressure and temperature, however, continued decreasing but with a relatively low rate.

### 3.4 Expansion of the Development Field

The Ginyu fault plays as a main reservoir and its performance convinced us that the production capacity was not enough to maintain steam production for 30MW. Therefore, exploration for development in the adjacent area was started in 2004. In order to find a new target for production wells that can be drilled in the present well pads, an electromagnetic survey was conducted in the south-eastern part of Ogiri. This part in Ogiri is located closer to the center of Kirishima volcano and is estimated to be in the high temperature zone (Goko, 2000). In addition, other surveys that were already conducted supported an existence of fault structures (Horikoshi et al., 2005).

### 3.5 Electromagnetic Survey

Electromagnetic survey was conducted within an area of 1.1 km EW x 1.2 km NS: audio-magnetotelluric sounding (AMT) survey for 66 locations and magnetotelluric sounding (MT) survey for 6 locations (Horikoshi et al., 2005). In Ogiri, low resistivity zone extends along the Ginyu fault of high permeability. Thus, a similar resistivity structure may support a presence of fault structure of high permeability, probably a prosperous reservoir.

Figure 5 shows topography map together with 50 ohm-m depth distribution in the shallow zone and 10 ohm-m depth distribution in the deep zone. In the northwestern part, we can see a remarkably low resistivity structure corresponding to the Ginyu fault. In addition, we can also find a slightly anticline of resistivity in the southern edge of this survey area. Interpretation of the seismic reflection survey also extracted fault structures around this edge area. Thus, this area can be a promising target for new production wells. Strike of this fault was estimated to be ENE-WSW, being parallel to the Ginyu fault. Other fault structures were also estimated, this fault group was named as the Ogiri deep faults with the name of No.1, 2, 3, with an order of increasing number from the Ginyu fault.

![Topography and resistivity distribution maps.](image)

**Figure 5.** Topography and resistivity distribution maps.

### 3.6 Production Wells Drilled in the Adjacent Area

There are four production wells, Well A, B, C, and D, drilled in the adjacent promising area. They are described in detail as follows;
1) Well A

Production well A was drilled in 2005 for the first time in the Ogiri deep faults. The well was drilled for about 2,300m drilling length, 1,800m vertical depth with 1,200m horizontal deviation. The well has 47 degrees of maximum inclination. The well succeeded in discharging but wellhead pressure was not high enough to be connected to the main steam line. Thus, the well was implemented with sidetrack drilling by aiming the Ogiri deep fault No.2, which was confirmed by the logging after completion of the well. Well A started discharging in November 2005, but with oscillation in production rate. After workover in the well, Well A has started stable production of steam as a steam dominated well. However, two steam dominated production wells and one water dominated well located close to Well A stopped producing. This may be because that an interface between steam-water two-phase zone and water liquid single phase zone in reservoir moved to shallow depth. Enhanced vaporization of liquid water extracts latent heat from liquid water single phase zone then temperature dropped water may flow downward to the feed zone of the water dominated production well leading to the failure of discharging.

Even with an additional production well A, it was confirmed that stable production of steam at about 280t/h for 30MW is difficult. Therefore, steam production has been controlled to the amount being equivalent to the output of 25.5MW in September 2006. This was the first operation of the Ginyu fault with less steam production compared with the full production of steam. This production characteristic is the same as in Well B. Therefore, it was concluded that the Ogiri deep faults No.1 and No.2 do not have direct and hydrologic connection, but closely related through the NW1 fault.

2) Well B

Well B was drilled by aiming the Ogiri deep fault No.3 located the most southward from the production well pad. The well penetrated the Ogiri deep faults No.2 and No.3 and its drilling depth reached about 3,100m. The well was completed as open hole below 1700m down to the well bottom.

Well B was successful and connected to the steam line in November 2007. A production logging for pressure-temperature-spinner (PTF) showed the presence of a downward flow in the well from the feedzone corresponding to the Ogiri deep fault No.2 to that of No.3. This result confirmed that the reservoir pressure of No.2 is higher than that of No.3. The Ogiri deep fault No.2 is used as the main fault for reinjecting water of 80% to 90% of the total amount of the separated water. This may be the reason of high reservoir pressure in the Ogiri deep fault No.2. As a result, Well B can produce fluids only from the Ogiri deep fault No.2. Furthermore, decrease rate of steam production in Well B is higher than the other wells, probably caused by the cooling due to reinjecting water return.

3) Well C

Well C was started drilling in April 2010 by aiming the Ogiri deep fault No.1 whose presence was confirmed in Well B. The well was drilled to the depth of 1,850m and succeeded discharging with less amount compared to the predicted one. However, the drilling was stopped at this depth, because there was a possibility that further drilling might have penetrated the Ogiri deep fault No.2. Pressure interference was detected in Well B during the production test of Well C.

Well C has started production in December 2010, but discharge rate gradually decreased probably because of decreases in reservoir pressure and temperature. This production characteristic is the same as in Well B. Therefore, it was concluded that the Ogiri deep faults No.1 and No.2 do not have direct and hydrologic connection, but closely related through the NW1 fault.

4) Well D

Well D was started drilling in July 2012 for the purpose of covering shortage of steam caused by continuous attenuation of Well B and Well C. Well D was drilled by aiming the Ogiri deep fault No.3, which was expected to have no interference with Ogiri deep faults No.1 and No.2. Well D was drilled to the depth of about 2,400m, and intersected the Ogiri deep fault No.3 at the depth of 2,200-2,360m.

However, at production test in Well D, confirmed that the well had produced fluids from feedzones of the Ogiri deep fault No.2 as well as No.3. We can say that Well D is the first well succeeded in producing fluid from the Ogiri deep fault No.3. The well intersected both the Ogiri deep faults No.2 and No.3 as same as the Well B. We considered that Well D produces from the Ogiri deep fault No.2 and No.3 for the following reason. Well D produces from only two of five fractures classified as the Ogiri deep fault No.2 while Well B produces from whole of Ogiri deep fault No.2. In addition, permeability of the Ogiri...
deep fault No.3 of Well D is considered higher than that of Well B as other possibilities.

4. Conclusions

The Ogiri geothermal power plant has been operated for 18 years since 1996 with high utilization factor of over 90%. This performance has been achieved by adopting several methods for steam production and reinjection operations. They are summarized as follows,

1. Reservoir pressure in the Ginyu fault has been maintained by operating reinjection wells with less effect on temperature decrease in the production zone.

2. Steam production from the main reservoir of the Ginyu fault has been limited to the amount equivalent to about 24MW power generation.

3. Additional geothermal steam for covering the installed capacity of the plant has been produced from an adjacent area where no interference occurs with the main reservoir of the Ginyu fault.

References


