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Replacement of the Onikobe Geothermal Power Station, Japan

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ABSTRACT

This paper describes the replacement of the Onikobe geothermal power station located in Miyagi prefecture in Japan. The Onikobe geothermal power station, 15 MW single flash plant, began operation in 1975 as the 4th geothermal power plant in Japan. The power station was shut down in 2017 after 42 years of operation due to aging of the facilities and power output decline due to abandonment of production wells those were damaged by steam explosion incident in 2010.

The power station area is restricted to a relatively small area due to steep surface topography and a national park regulation. Moreover, different kinds of fluid, i.e., neutral and strong acidic brine, co-exist within a small space in the Onikobe reservoir. During 42 years exploitation of the former plant, we have experienced many operational difficulties which arise from the reservoir characteristics involving a rapid production decline in early stage of exploitation, silica scaling from neutral brine in surface facility and reinjection wells, corrosion problem of flow lines and well casing due to acidic brine, smectite scaling within a wellbore due to mixing of different kinds of fluid from different feed zones and cold water migration to production wells from reinjection wells. The new plant was designed based on the experiences of the 42 years operation. New production wells were completed using production casing of anti-corrosion material, and neutral and acidic brine are treated separately by different flow lines from production wells to injection wells to avoid severe scaling problem that could be occurred by mixing each other.

The replacement work took place from 2019 to 2023, including drilling of 5 new production wells and 5 new reinjection wells. The temperature profiles of new production wells showed temperature decline in deeper part, which revealed a cold sweep process in the fractured reservoir by reinjected water during long term production and reinjection. Although the well production enthalpy was lower than expected, required steam flow rate was successfully obtained. The new Onikobe power station, 14.9 MW single flash system, began operation in April 2023 as scheduled.

1. INTRODUCTION

The Onikobe geothermal power station is located in Miyagi prefecture in northern part of Japan (Figure 1). The single flash power plant began operation in 1975 as the 4th geothermal power plant in Japan. Output of the plant was 9 MW at first and was increased to 12.5 MW in 1979 and finally increased to 15 MW in 2010. The power plant had continued stable operation without major problems for many years despite encountering many operational difficulties (Akasaka et al., 2001). However the steam explosion incident occurred at the well field in 2010 (Akasaka et al., 2011) which led to abandonment of 3 production wells, and a power output of the plant was decreased drastically.

Because of the power output decline and deterioration of the facilities, replacement of the plant was planned. The power station was shut down in 2017 after 42 years of operation. All the facilities were demolished including abandonment of all the existing wells. The replacement works including the drilling of 5 new production wells and 5 new reinjection wells were initiated in 2019 and the new Onikobe power station, 14.9 MW single flash system, began commercial operation in April 2023 as scheduled.

This paper reviews briefly the various operational difficulties encountered in the 42 years of operation of the former Onikobe power station and describes the replacement works of the power station which were designed based on the experiences gained from the long term operation.

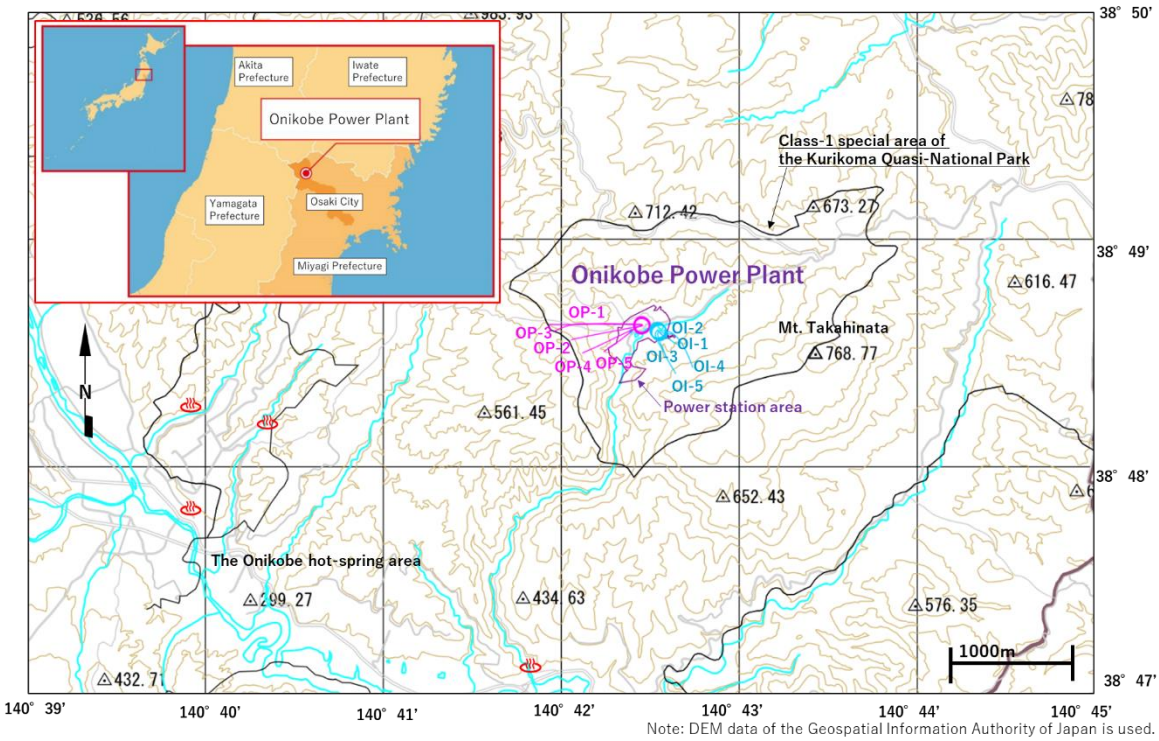

Figure 1: Location of the Onikobe geothermal power station and the planar trajectory of production and injection wells. Purple solid line shows the power plant area boundary. Black solid line shows the Kurikoma Quasi-National Park boundaries.

2. THE ONIKOBE GEOTHERMAL RESERVOIR SYSTEM

Figure 1 shows a location of the Onikobe area and the well location of the new power plant. The Onikobe geothermal field is located within the Onikobe caldera, which measures approximately 9 km (north-south) by 7 km (east-west). The Takahinata-yama dacite dome is located southeast of the power plant, which is the youngest volcanic rock (0.24-0.35 Ma) inside the caldera and considered to be heat source in the Onikobe field. There is the Onikobe hot-spring area inside the caldera to the west of the power station, which is consisted of several hot springs. The power station area is restricted to relatively small space surrounded by steep topography that results in narrowing the area of production and reinjection well targets. The power station is also located within the Class-1 special area of the Kurikoma Quasi-National Park in which new geothermal development is strictly prohibited, however replacement of already-built plant is allowed. Therefore, the replacement of the power station was also affected by the national park regulation.

Figure 2 shows a conceptual model of the Onikobe geothermal system. The geology around the power station consists, in descending order, of the Katayama lacustrine deposit, the Ofukazawa andesite member of the Akazawa Formation, the Sannozawa Formation of Pleistocene, the Kanisawa Formation, a local member of the "Green Tuff of Miocene", and Pre-Tertiary granodiorite as the basement of the region.

A water- dominate geothermal reservoir is formed mainly in the Kanisawa Formation, especially in vertical fractures caused by a local horst structure (relating to the NW-SE dome structure) with a temperature of around 250 °C. This is a main production zone of the Onikobe geothermal power station. A two-phase zone in the reservoir, shallower than 300 m in depth, is located in the Ofukazawa Andesite Member, and production wells of early exploitation stage produced steam from the shallow two-phase reservoir, because high acidic brine was encountered at deep part just beneath the power station area by exploratory wells; GO-10 and 11.

Two types of fluids are encountered in the Onikobe deep geothermal reservoir, one is neutral (pH = 6.7-7.8) and the other is acidic (pH = 3). Klein et al. (1990) and Ajima et al. (1998) discuss the geological/thermal structure and the fluid chemistry of this area. The acidic fluid is characterized by higher concentrations of acid-sensitive constituents (Mg, Fe, Pb, Zn) and Cl compared with the neutral one. There is a strong correlation of low pH with high concentrations of acid-sensitive constituents and Cl (Truesdell and Nakanishi, 2005). On the basis of a spatial relationship between the acidic fluid zone and acidic alteration (pyrophyllite) zone, it is suggested that acidic fluid might be upwelling along the fault that forms the horst structure. Production wells of the new Onikobe power station produces both types of fluids, same as the former plant.

Formation temperatures reach 250 °C at elevation -500 m ASL, and reach 288°C at -750 m ASL in the central area (which was measured in well GO-11). Based on acidic fluid distribution inferred so far , we estimate that high acidic geothermal brine is upwelling from deeper zone at the power plant area and flow laterally to the west under the cap rock with evolving water-rock interaction.

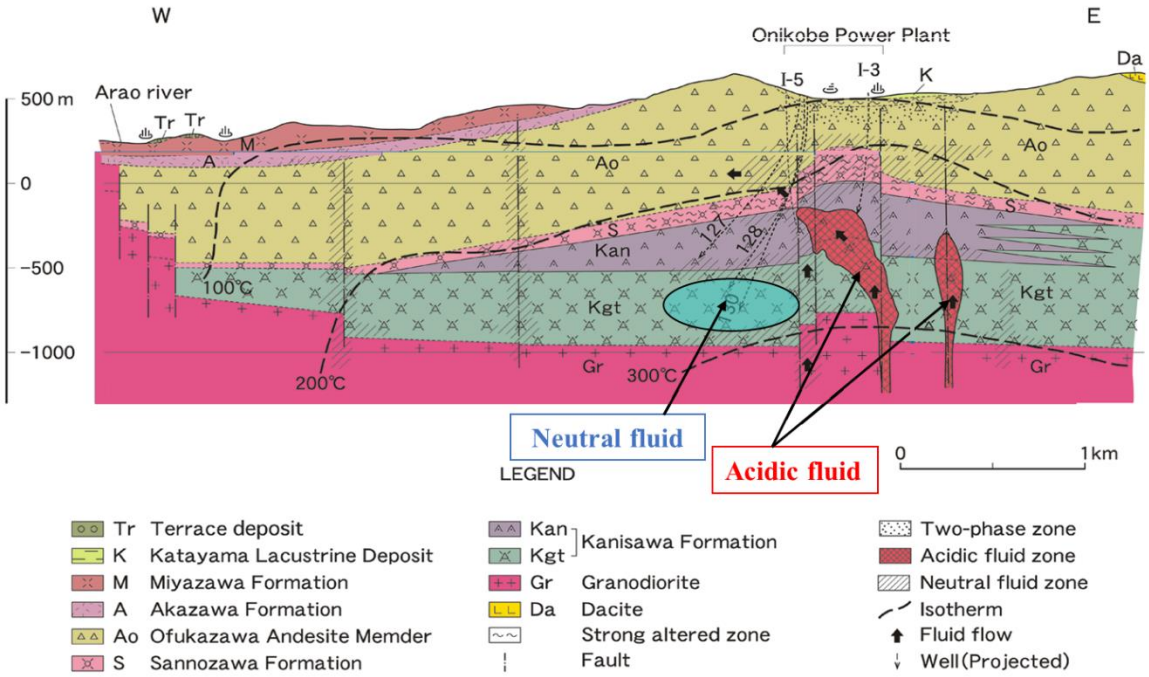

Figure 2: East-west cross-section of geological and temperature structure of the Onikobe geothermal system.

3. PRODUCTION HISTORY OF THE FORMER POWER PLANT

Figure 3 shows the production history of the former Onikobe power station. During the 42 years exploitation, we have experienced many operational difficulties which arose from the reservoir characteristics. A rapid production decline occurred in early stage of exploitation due to over-production (; guessed) by the shallow vertical production wells (200-300 m depth) and/or adverse effect of reinjection within the small power plant area. After drilling of declined make-up wells to obtain steam from neutral brine zone at outside of the plant area to the west, silica scaling problems became prominent in surface facility and reinjection wells. In the meanwhile, some of the make-up production wells were encountered high acidic brine and corrosion/erosion problem of flow lines and well casing also became prominent during operation. Smectite scaling within a wellbore due to mixing of different kinds of fluid from different feed zones were occurred in two production wells; well 128 and well 132 (Ajima et al., 1998). Based on the experiences of corrosion problem of casing pipe due to acidic brine and scaling issues caused by mixing of different kinds of fluid in a wellbore, subsequent make-up wells were drilled and completed by targeting solely neutral or acidic brine zone from the start, and for the production well targeting acidic brine zone, a casing pipe of anti-corrosion material was set in upper part of production casing (Akasaka et al., 2001). These countermeasures for various operational difficulties enabled us to keep sustained operation of the plant until 2010 when the steam explosion incident occurred at the well field near production well 128 (Akasaka et al., 2011). Well 128 was damaged by the steam explosion incident and followed by blowout from the well. Finally, 3 wells; well-128, 136 and 138, involved within the crater formed by the steam explosion incident were plugged and abandoned (Takizawa et al., 2013, and Akasaka et al., 2015), and a power output of the plant decreased drastically.

Figure 4 shows locations of production and reinjection wells of the former power plant and their flow rates as of July 2007. At that time, the Onikobe power station produced almost the same amount of acidic fluid as neutral fluid for operation (the production ratio was acidic fluid 50 % and neutral fluid 50 % to satisfy the total flow rate). Reinjection was taken place mainly at two separate areas, *i.e.* the eastern and the southern injection zones. A geochemical study of changes in chemical components of produced fluids from each production wells and tracer testings performed periodically revealed the connectivity between production and reinjection wells (Ajima et al., 2010), and it was appeared that production wells were more affected on the whole by reinjection from the southern injection area than from the eastern injection area in terms of mixing ratio of reinjected water to the total production flow rate of a well, and this led to production enthalpy decline. Predominant fractured zone trending NW-SE delineated by CSAMT survey seems to act as a permeable flow path between the southern reinjection and production wells. Considering the behavior of reinjected water in the former plant, only eastern injection area was chosen for reinjection in the replacement.

For silica scaling issue, field and laboratory experiments of mixing neutral and acidic brine at the surface were performed with the aim of pH control to prevent silica scaling from neutral brine. The results of the experiments appeared that a severe scaling problem with precipitation from both fluids could be occurred depending on a mixing ratio that affects pH value of the mixture. Based on the results, we finally decided to deal with different kinds of fluid separately and not to mix each other, because fraction of different kinds of fluid to total production flow rate of the plant could not be controlled, and the fraction would be changed during long term operation according to make-up well drillings.

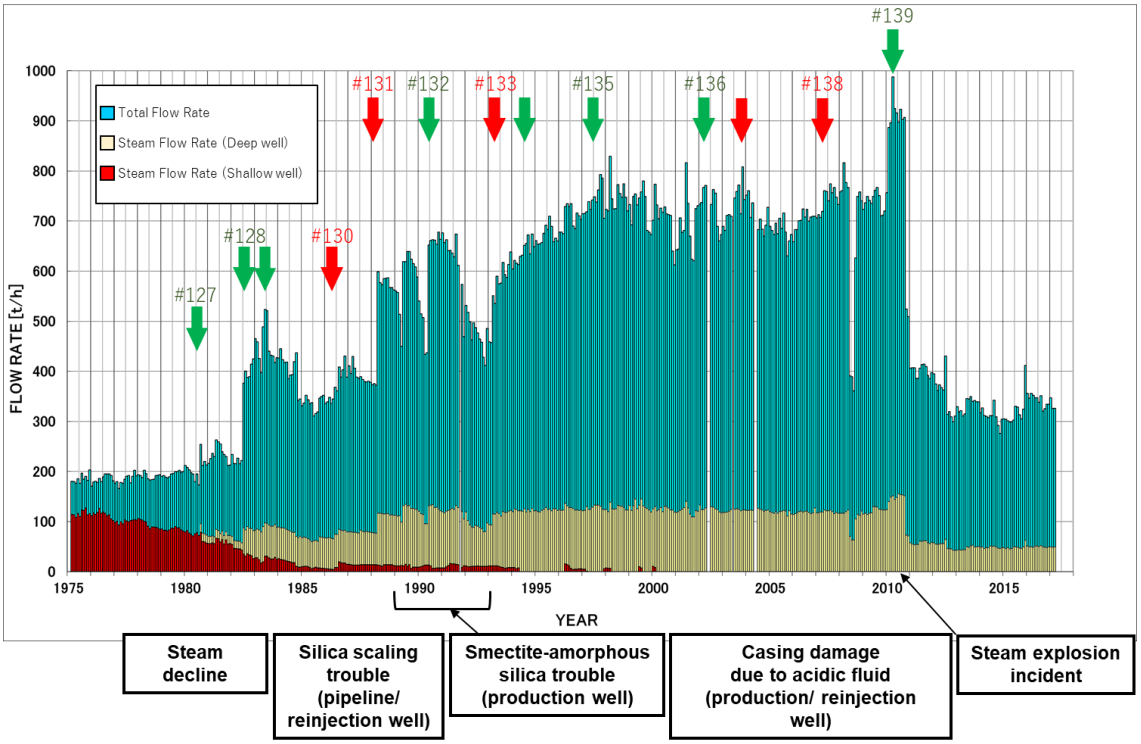

Figure 3: Production history of the former Onikobe power station. Make-up wells are shown in green and red arrows; green: neutral, red: acidic. pH value of well 128 fluid changed acidic after 1991.

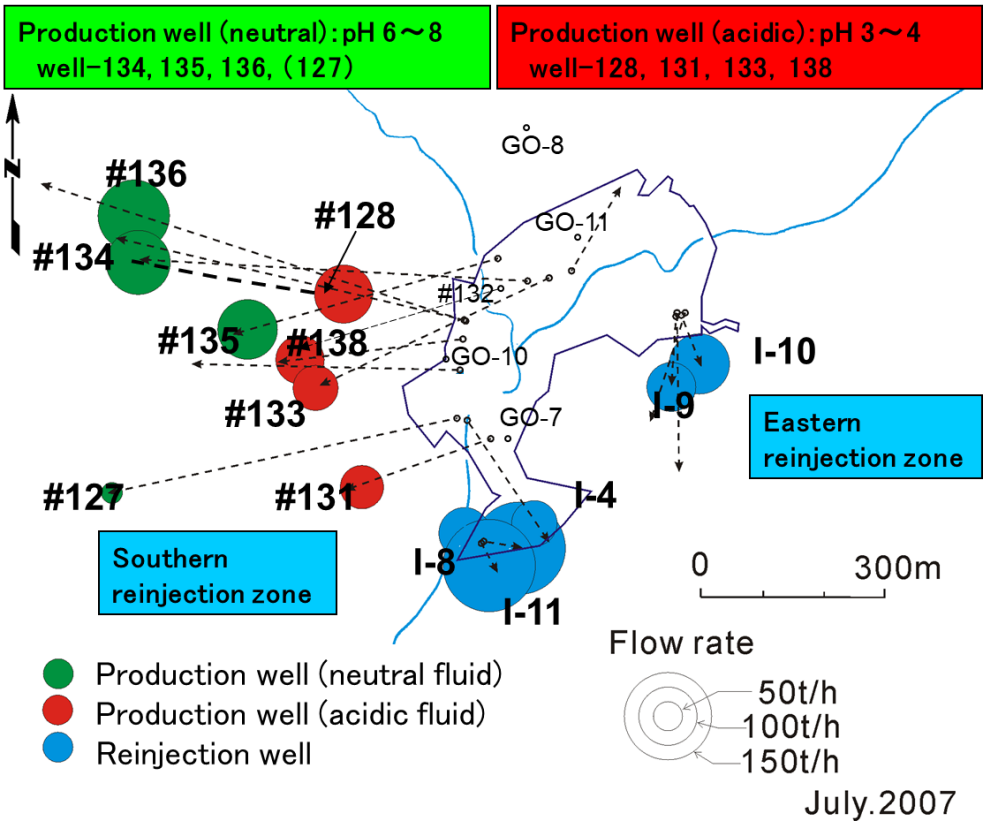

Figure 4: Well locations of the former power plant and their production/reinjection flow rates as of July 2007. Location of well-132 and GO wells are also shown; those were abandoned at the time.

4. THE REPLACEMENT WORK

Because of the power output decline after the steam explosion incident and deterioration of all the facilities, a replacement of the plant was planned. Figure 5 shows a comparison of layouts of the former and the new plant. Due to regulations of the national park, the replacement work took place by a manner of "scrap and build type"; the former plant was demolished to make space for the new plant, and without making any modifications to the ground form. The existing wells of the former plant were all abandoned. The new power station building was built exactly in the same place as the former plant, and the height and area of the main station building was designed not to exceed the former power plant. Wellhead locations of production and reinjection wells were assembled in the designated area as likely two well pads, unlike the former plant in which wellhead locations were spread out in the area. In addition, because of the steam explosion incident occurred in 2010, all the permanent facilities were placed away from high underground temperature area, and as a result, the power plant was replaced as a compact power plant as shown in Figure 5. To investigate shallow subsurface temperature distribution in the power station area, 50 m depth temperature survey was conducted by drilling many shallow wells, and maximum temperature of 154 °C was measured at depth of 50 m.

The replacement work took place from 2019 to 2023. The replacement work was mainly consisted of well drillings, construction, installing of facilities such as the power generating units. The power plant area is restricted to a relatively small area, therefore the facilities were needed to be squeezed into a small area. Also, the Onikobe area is a deep-snow area, and the snow covers over 1 m deep in winter season, so that the replacement work could not be carried out in the winter season. Despite the tight schedule and small workspace for construction, the replacement work was completed as planned, and the new Onikobe power station, 14.9 MW single flash system, began operation in April 2023.

One of the characteristics of the new Onikobe geothermal power station is that the neutral and acidic brine are treated separately by different flow lines from production wells to injection wells to avoid severe scaling problem that could be occurred by mixing each other. The new plant has prepared 4 individual steam handling system (flow lines and separators) so that it can deal with different kinds of brine flexibly depending on their composition ratio; regardless of the fluid character of additional make-up wells in the future.

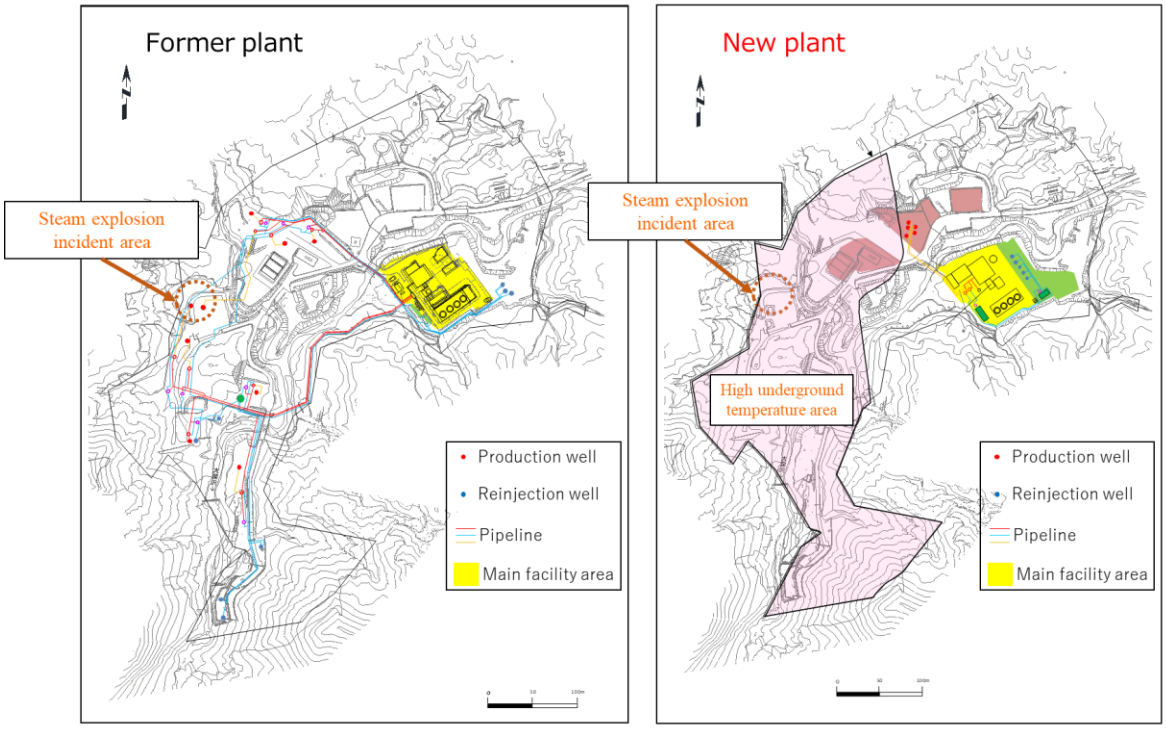

Figure 5: Comparison of the layout of the former and new plant.

4.1 DRILLING OF THE PRODUCTION AND REINJECTION WELLS

The drillings of the wells were carried out from 2019 to 2021. 5 production wells (OP-1 - OP-5) and 5 reinjection wells (OI-1 - OI-5) were newly drilled as shown in Figure 6. The new production wells were drilled directionally to the west side of the area, designed as the length of 1,250 m ~ 1,600 m. Production area is placed almost in the same area as the former plant. The production wells were completed by using ϕ 9-5/8" production casing of anti-corrosion material and ϕ 8-1/2" open hole. Even for the wells aiming to neutral fluid, production casing of anti-corrosion material was set because it needs to drill through the intermediate acidic zone to reach the neutral fluid, and to deal with the case of change in pH of produced fluid occurred during long term operation which was previously experienced. The new reinjection wells were drilled to the east side of the area, designed as the length of 620 m ~ 1,250 m, somewhat shallower than production zone.

All the wells were drilled as planned to the aimed targets and successfully encountered permeable fractures. Most of the wells captured the target at the expected depth, although some wells captured the target shallower or deeper than expected, and there was the case of sidetracking.

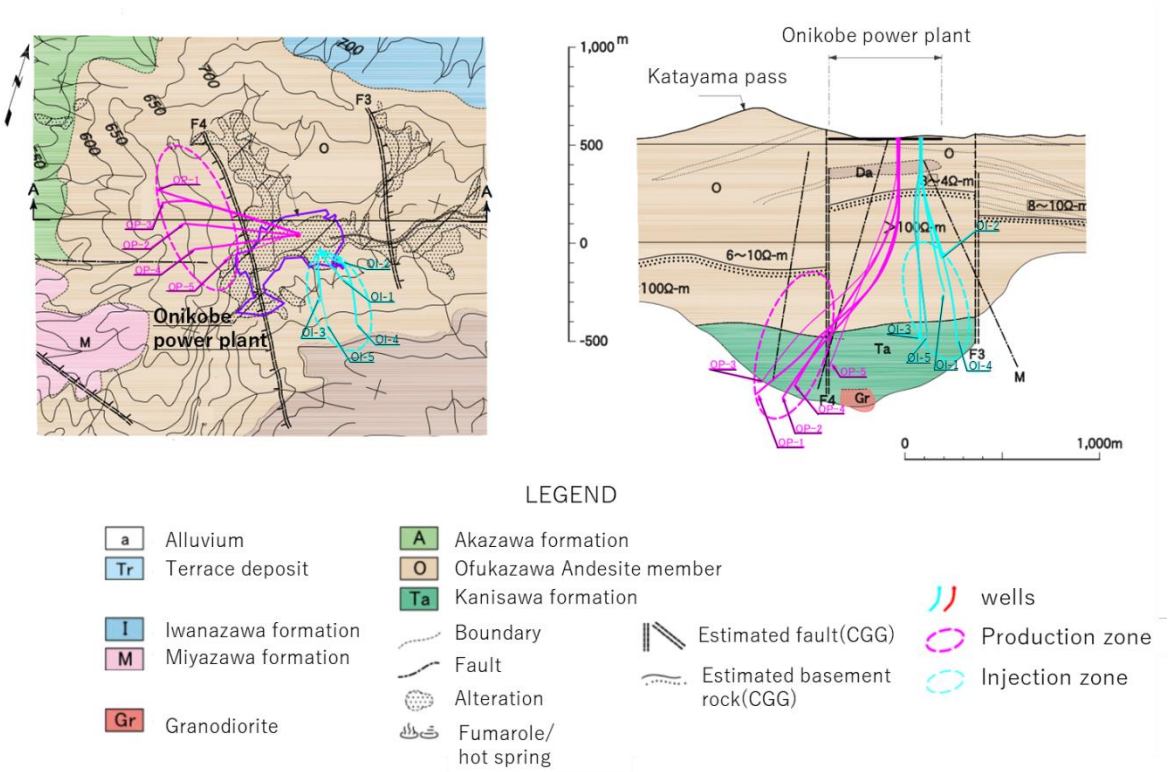

Figure 6: Horizontal and sectional view of the Onikobe field with trajectories of new wells.

4.2 WELL TESTS

Various well loggings (heat recovery survey etc.) and injection test were carried out after completion of new wells. Injection capacities of injection wells were obtained by the injection test. For production wells, short term production tests were carried out to confirm flow capacity, fluid character, feed zone conditions and so on. Production tests on OP-1and 2 (drilled earlier) were carried out in 2020 at almost 1 year after well completion (Figure 7), and production tests on OP-3,4 and 5 (drilled later) were carried out in 2022. The production tests included a static PT (pressure & temperature) logging just before production initiation, flow rate measurements at various well head pressure, geochemical fluid sampling, PTS (pressure, temperature and spinner) loggings at flowing condition and build-up test after shut-in.

Figure 7: Production test on OP-1 during construction of the new power station.

4.2.1 Reservoir Pressure Profile

Figure 8 shows downhole feedpoint pressures in the wells as function of feedpoint elevation. The data of newly drilled production and injection wells (OP and OI wells) are plotted as well as of exploratory wells (GO wells) drilled before exploitation (before 1970) and of wells drilled for the former plant including make-up wells drilled during operation. The straight line in the figure shows least-square fit of the new well data, and it seems to represent the pressure profile of the Onikobe reservoir at present. Data of the former plant wells are somewhat scattered along the strait line, and data of deviated make-up wells (after well-127) seems to be plotted just below the line, suggesting that feedpoint pressure of these make-up wells would indicate decreased reservoir pressure due to operation at the time. Data of exploratory well (GO wells) are also plotted near the line. These exploratory well data may not be accurate enough because the data were estimated by using available water level data and some temperature measurements data in a well, those obtained more than 50 years ago. Considering the uncertainty of the data, we estimate that the reservoir pressure has almost recovered to its natural state level after 3.5 - 5 years since the former plant shut down. In the replacement work, the accurate feedpoint pressure data (: pressure pivot during heat recovery of a well) of the new production wells were obtained, and we could get a clear understanding of the natural state pressure profile of the Onikobe reservoir at present.

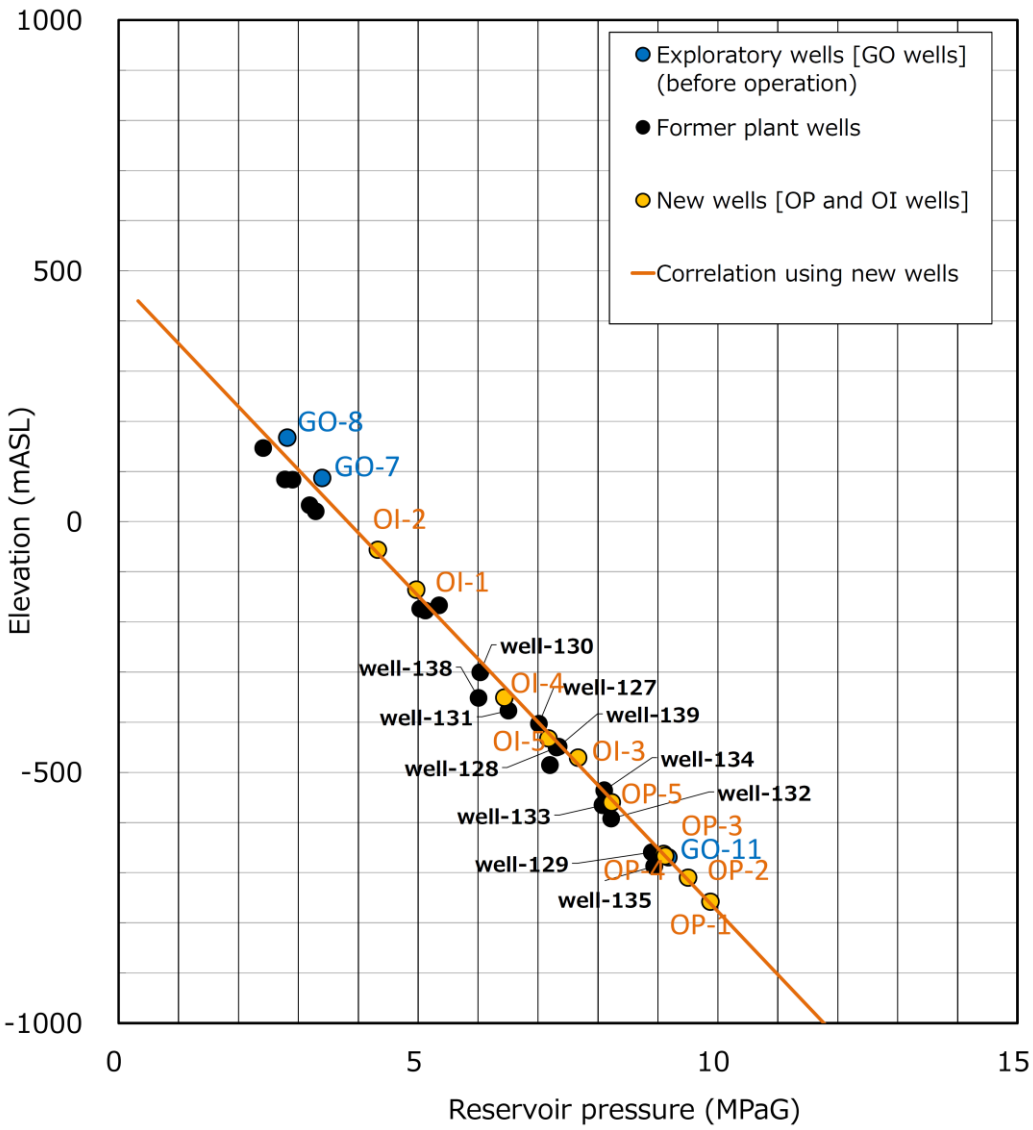

Figure 8: Measured downhole feed-point pressure in the wells as function of its elevation. The straight line shows the estimated reservoir pressure profile of the Onikobe reservoir.

4.2.2 Temperature Profiles in the New Production Wells

Figure 9 shows the temperature profiles in the newly drilled production wells as well as the estimated temperature profile of the Onikobe reservoir before exploitation. These temperature profiles were obtained after 55 days - 1 year of temperature recovery since well completions and are estimated to represent formation temperature at present, that is after 3.5 - 5 years since the former plant shut down. The estimated temperature profile of the Onikobe reservoir before exploitation in the figure was inferred based on measured temperature in well GO-11. These temperature profiles of the new wells show temperature decline in deeper part. Well OP-5 was drilled to the fracture zone of GO-10, which was the exploratory well and was not used for production. It is estimated that a cold reinjected water of the former plant might have cooled down not only fracture zone but also adjoining matrix zone of the fractured reservoir. The temperature profile reveals the result of cold sweep process in the fractured reservoir by reinjected water in the long-term operation of the former plant. Based on the pattern of temperature decline in deeper part in these wells, we could also estimate that cold reinjected water may flow laterally to production zone near the bottom of the reservoir which seems to be located just beneath bottom holes. The bottom of the permeable reservoir would be a granitic basement rock, and the depth is inferred to be around -900 m ASL.

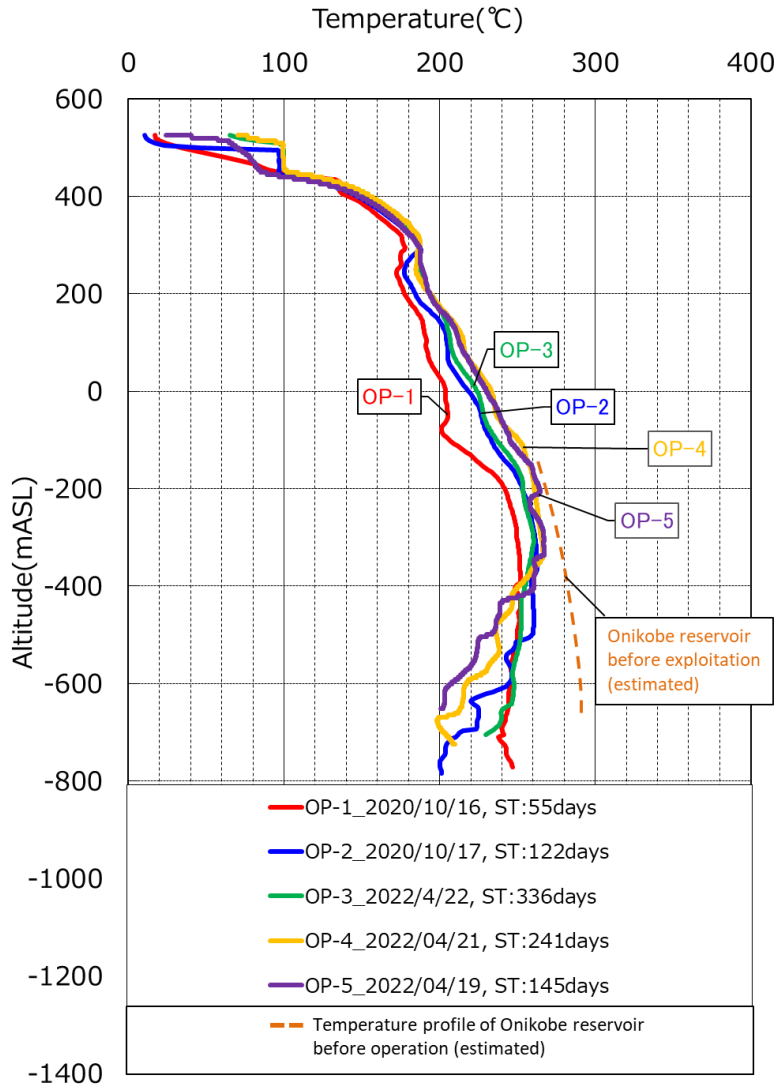

Figure 9: Static temperature profile in the new Onikobe wells and the estimated temperature profile before exploitation.

4.2.3 Production Capacity of the New Production Wells

The production capacity of each production well was estimated based on the measured flow rate data in short term production test and by calculation to fit the data using the wellbore two-phase flow simulator. We used the wellbore simulator WENG developed by NEDO (Tsutsui et al., 1991). Figure 10 shows the representative example of calculation in well OP-1. Flowing feedpoint temperature of 241 °C was measured by PTS survey at feedpoint depth of 1,497 m in well OP-1. Well head condition for a specific flow rate can be calculated by the wellbore simulator using available downhole data like feedpoint enthalpy, static feedpoint pressure and productivity index (PI) etc. Figure 10 shows the comparison of measured temperature and pressure profiles in flowing condition with calculated results of the simulation using the available feedpoint data. Once calculated pressure and temperature profiles attained good match with measured data, a flow rate at any specific wellhead condition can be estimated. Figure 11 shows the comparison of measured well characteristic (flowrate vs. well head pressure plot) with calculated wellhead conditions equivalent to various feedpoint conditions and PI data of 2.6 kg/s/bar that was estimated from well test data. Based on the calculated well characteristic, production capacity of well OP-1 equivalent to a designed operating pressure of separator was estimated about 40 t/h of steam. Well OP-1 was encountered relatively high permeable fracture, therefore was completed as a good producer.

Same kinds of calculation of well characteristics were performed for each production test of the newly drilled wells. Those well model parameters and PI for each production well are useful for evaluation of changes in well characteristic in the future and/or a future numerical reservoir simulation study where the well model will be incorporated into a reservoir simulation model. Although the well production enthalpy was lower than expected as shown in Figure 9, required steam flow rate was successfully obtained by the new production wells.

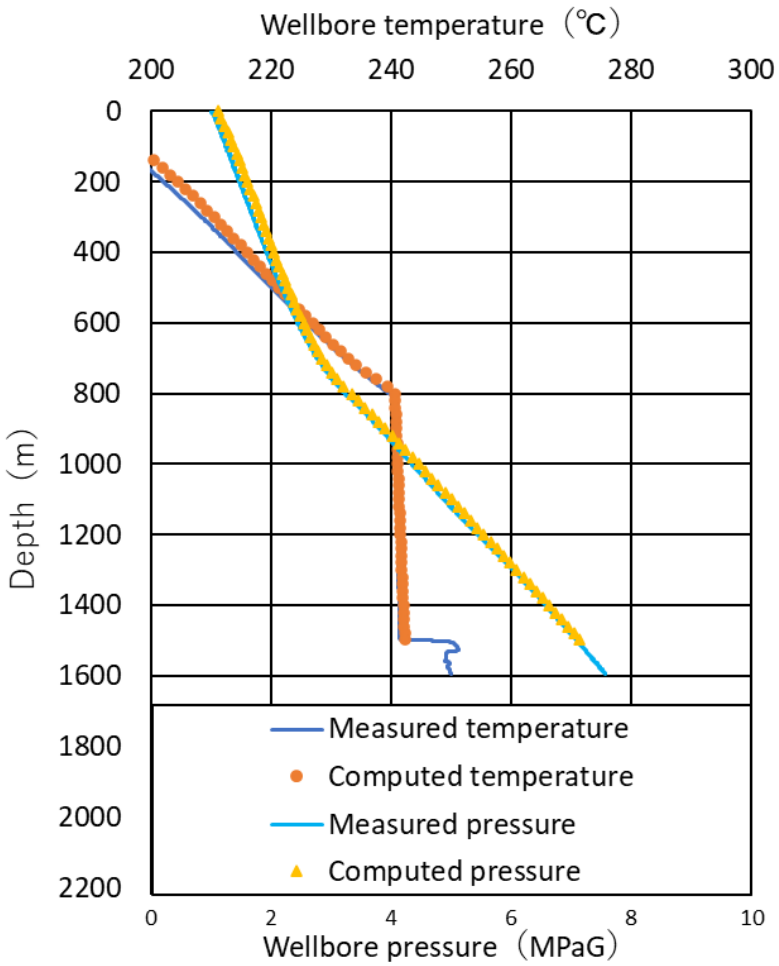

Figure 10: Comparison of measured temperature / pressure profiles in well OP-1 with computed results of two phase flow wellbore simulation.

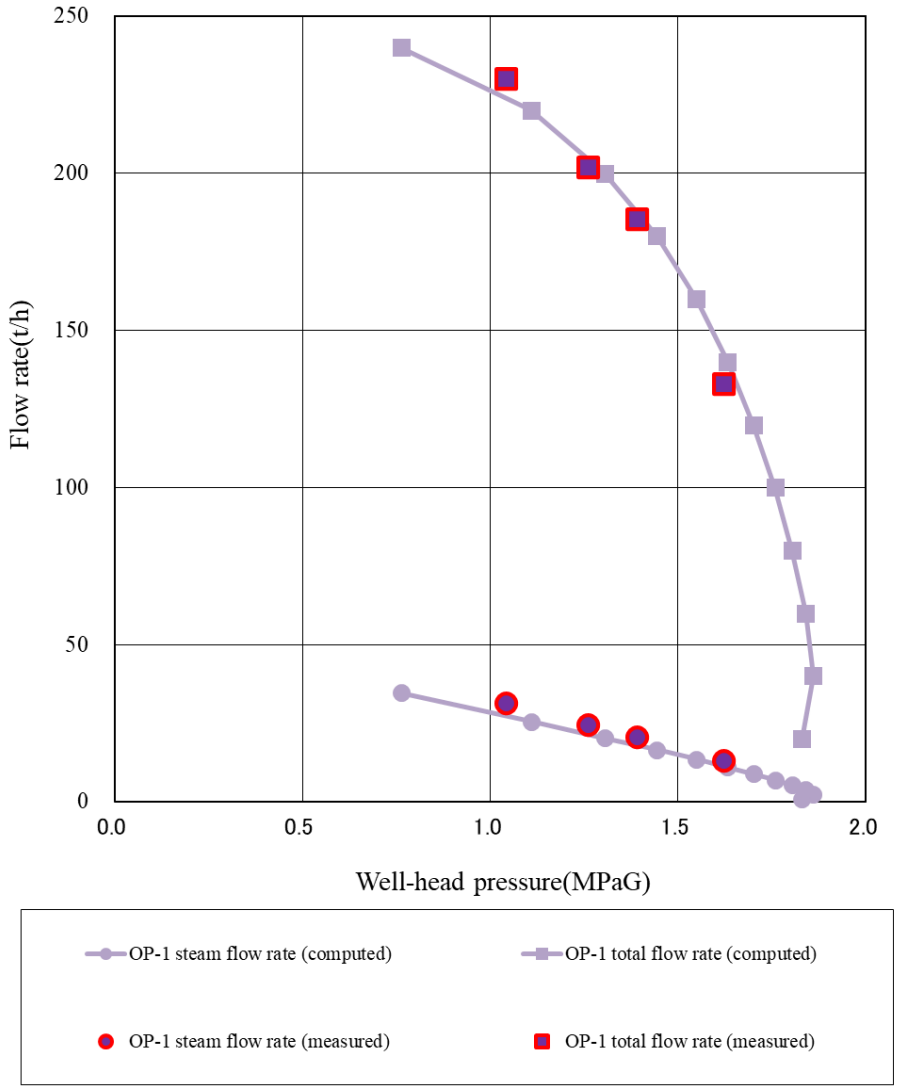

Figure 11: Flow rate vs. wellhead pressure of well OP-1.

5. CONCLUDING REMARKS

The former Onikobe geothermal power station, 15 MW single flash plant, was shut down after 42 years of operation, due to aging of the facilities and power output decline affected by the steam explosion incident. The replacement of the plant was planned under national park regulation, and new power station was designed based on various experiences obtained during the 42 years of operation. The replacement work took place including new production and injection well drillings. By the well drillings, insight of reservoir pressure profile of natural state was newly obtained. A cold sweep process in the fractured reservoir by long term reinjection operation was also revealed. Although the well production enthalpy was lower than expected, required steam flow rate was successfully obtained by the new production wells. After 4 years of construction works, the new Onikobe power station, 14.9 MW single flash system, began operation in April 2023 as scheduled.

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