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GEOTHERMAL FIELD DEVELOPMENTS IN JAPAN

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ABSTRACT

The present situation of the geothermal field developments in Japan is such that eight geothermal power stations are being operated, while there are still many geothermal areas to be explored. Up to this day, the target of geothermal exploration has mainly been the areas by surface geological survey and the existing geothermal reservoirs are located not deeper than 1,500m depth. Recent geothermal energy development shows a trend from the study on vapor dominated or liquid dominated hydrothermal resources in shallow zones to that on hydrothermal resources in deeper zones. Exploration wells of 3,000m depth class have been drilled in Japan.

INTRODUCTION

There are altogether eight geothermal power plants in operation in Japan. They are, in order of commencement of operation, the Matsukawa Power Plant of the Japan Metals and Chemicals Co., Ltd. (Matsuo-mura, Iwate Prefecture), the Otake Power Plant of the Kyushu Electric Power Co., Ltd. (Kokonoe-machi, Oita Prefecture), the Onuma Power Plant of the Mitsubishi Metal Corporation (Hachimantai, Akita Prefecture), the Onikobe Power Plant of the Electric Power Development Co., Ltd. (Naruko-machi, Miyagi Prefecture), the Hatchobaru Power Plant of the Kyushu Electric Power Co., Ltd. (Kokonoe-machi, Oita Prefecture), the Kakkonda Power Plant (Shizukuishi-machi, Iwate Prefecture) of the Japan Metals and Chemicals Co., Ltd., and the Tohoku Electric Power Co., Ltd., the Suginoi Power Plant (Beppu-shi, Oita Prefecture) that was constructed as a non-utility power plant by the Suginoi Hotel Co., Ltd., and the Mori Power Plant (Mori-machi, Hokkaido) that was put in operation on November 26, 1982 by the Donan Geothermal Energy Co., Ltd., and the Hokkaido Electric Power Co., Ltd. These geothermal fields, except Matsukawa of the vapor dominated type, are mostly the water dominated type. Then, under expansion are the Hatchobaru and Kakkonda Power plants, where development works are presently in progress. The eight geothermal power plants mentioned above have generated a combined power of 1,203 x 10^6 kWh/yr, and the mean working rate and load factor of all these power plants combined lie on a high level of 95.4% and 87.3%, respectively, reflecting the very high reliability levels of these geothermal power plants.

The work of surveying and developing geothermal energy resources in Japan is being advanced under consignment by the New Energy Development Organization (NEDO), the central organ in the country for geothermal energy development, with aid extended by the Ministry of International Trade and Industry (MITI). Although there are still many geothermal areas to be explored, it will take a long time to realize their steam production. These exploration and development of geothermal resources are mostly based on the organized basic investigation, which has started from the fiscal year 1973 by the Geological Survey of Japan. According to the reports by the G.S. group, the distribution of thermal areas in Japan is geologically divided into five categories as follows: (1) Neogene Tertiary green tuff areas, (2) Neogene Tertiary sedimentary basins, (3) Neogene Tertiary plutonic rock areas, (4) Pliocene-Quaternary sedimentary basins, and (5) Quaternary volcanic areas. Among these, the Pliocene-Quaternary sedimentary basins are areas of normal terrestrial heat flow. The Tertiary plutonic rock areas have locally abnormal heat flow, but heat flow from the Tertiary sedimentary basins and green tuff areas is generally higher than that of normal heat flow areas. There are one hundred and eleven sites of steam fumaroles, boiling springs and hot springs with water temperature higher than 90°C in the abovementioned areas and most of these are distributed in the Quaternary volcanic areas.

To promote geothermal development, the G.S. of Japan picked up thirty high potentiality geothermal areas characterized by remarkable geothermal anomaly. Most of these areas have often been designated as national parks or quasi-national parks, and the geothermal development within these areas needs beforehand permission of the Environment Agency. The Japan Geothermal Energy Development Center has investigated geothermal potentiality and feasibility of its development through surface survey and well drilling (about 1,000m depth) under instructions from the Power Generation Section and Geothermal Resources Development Investigation Committee, which belong to MITI.

Before 1977, the target of geothermal exploration has mainly been the areas by surface geological survey and the existing geothermal reservoirs are located not deeper than 1,500m depth. In 1977, the G.S. of Japan selected the fifteen promising geothermal areas based on the items of (1) indication of large scale geothermal reservoir, (2) detection of 3,000m - 4,000m depth reservoir, (3) relationship on volcano distribution and (4) geothermal activities in Neogene Tertiary sedimentary basins and Quaternary volcanic areas. The exploration wells of 3,000m depth class were drilled from 1978 by MITI to make clear of the deep geothermal reservoirs in Hohi area where Otake and Hachobaru power stations are located.

MATSUKAWA

The Matsukawa power plant is located about 50 km north west of Morioka City, about one and half hours drive. It occupies the southern corner of the Towada Hachimantai National Park and is in a basin of the upper stream of the Matsukawa river with an altitude of 900m above sea level. Mt. Iwate, an active volcano, can be seen in a north west direction from here. Matsukawa has been known as a sulphuric hotspring area from old times.

In January 1964, drilling of the first production well at Matsukawa turned out to be very successful. The amount of steam from a well which was 945m deep reached more than 60 t/h which represents a possible output of 5,000 kw. The first in Japan and the world's fourth geothermal power plant of 22 MW capacity was constructed here in October 1966.

Geologically, this area is covered by Quaternary volcanic rocks, with existence of a caldera around Mt. Marumori and a steep cliff consisting of altered rocks along the Matsukawa river presents wild topographical features made by the violent volcanic activity of early times. In spite of the fact that there were but a few geothermal manifestations without a boiling point like substance at the surface, simple steam and hot water emitted from the wells when drilled by the Field Office to a depth of about 300m. The first geothermal energy investigation was started in 1956. The Geological Survey of Japan, belonging to the Agency of Industrial Science and Technology, joined the investigation. Thus, a cooperative study between the Geological Survey and JMC (Japan Metals and Chemicals Co.,Ltd.) was commenced in 1958. From then forward for ten years much effort for development was exerted until the project finally reached its goal with the completion of the geothermal power plant.

Based on the data obtained from the drillings, the geological succession in this area can be described as follows: from upper to lower; Quaternary Matsukawa andesite; the Tertiary Pliocene Tamagawa welded tuff formation; Miocene Yamatsuda; Koshidomaezawa; and the Sakamotozawa and Kunimitoge formations, respectively. Seven production wells are divided into three types by their steam characteristics. The first type is the well characterized by the emission of wet steam for some periods before becoming a superheated steam; for a period of five months in the case of the No.2 well and for one year in the case of the No.1 well. The second type is the well which has a continuous emission of wet steam up to the present. The No.3 well corresponds to this category. The last type is the well which has had a continuous emission of superheated steam so far, but producing dry steam when the emission first started. Well No.5, 6 and 7 which are located at the upper stream of Akagawa river are of this type. It goes without saying that this last type is most useful for generating power.

Geophysical prospecting carried out at two levels; one is at the surface, the other is in the bore holes. The VES (vertical electric sounding) method has been applied for gathering information about geologic structure and rock alteration. In order to survey the geologic structure and fractured zones concerned with producing geothermal steam, a large scale seismic survey has been conducted in this area. From the method of seismic reflection with four fold, much information about the underground structure in the base rocks covered by the Quaternary volcanic complex has been obtained. It goes without saying that core samples obtained by drilling give important information about the geologic structure and the occurrence of geothermal fluid. Besides core survey, it is possible to get data on subsurface structure from the survey by the geophysical logging of a hole. To facilitate this type of survey, temperature and electric loggings have been made in all exploration and production wells in this area.

Eight production wells 945 - 1,500m deep have been drilled so far in the Matsukawa area, among which seven wells (except the No.4 well) supply steam for the power station. A typical arrangement of insertion of casing pipes in this area has been as follows: from upper to lower, 30m of surface C.P. of 18", 250m of conductor C.P. of 13 3/8" and 500m of production C.P. of 9 5/8" which are surrounded by cementing material. From 500m deep to the bottom of hole, slotted 7" pipe is inserted into the remaining 8 5/8" of the hole after drilling is completed.

The slits in the slotted pipes are arranged in a zig zag formation with 14 lines per 220 mm in length. Each line has an area of 80mm x 5.5mm and total lines occupy 5 - 7% of he surface area of a slotted pipe.

Except where steam begins to flow out naturally, a blow out of steam is caused artificially by using a sand pump or a bailer. In Matsukawa, the No.7 exploration well was drilled by a method of directional drilling. Directional drilling was undertaken by using a turbo-drill of 6 5/8" diameter at a depth of 292m, with a horizontal distance from the well head to the bottom of the hole being 175.85m at a depth of 600m. By using this directional method, it is possible to reduce the area of the drilling site and thereby the total length of the steam gathering pipe lines.

ONUMA

The Onuma geothermal field began steam production in 1973. As for geology of this field, Quaternary volcanic rocks (70 to 150m thick) and Tertiary formation (more than 2,000m thick) have been confirmed in the course of geologic survey. The Quaternary andesitic rocks cover most of the area. The Tertiary formation consists mainly of dacite and andesite and their pyroclastics and sediments of Miocene to Pliocene age. Many volcanoes are known to be distributed on the uplifted block formed by a series of faults and folds. Prevailing geologic structure in the area is N-S and NW-SE trending tectonic lines which are characterized by the faults, block movement and graben structure. Geothermal manifestations such as geysers, fumaroles, mud pots and hot spring are found along the subsided structure of the graben trending in N-S which is confirmed by the regional gravity survey. A number of zones of surface alteration due to geothermal activities have been recognized covering a total area of more than 5 km^2. The elongation of the surface alteration in E-W and N-S directions reflects the subsurface geologic structure. The E-W trending alteration zone represents the tectonic line of Tamagawa to Goshogake and the N-S trend of alteration zone appears to be along the graben structure.

Gravity survey and electrical one were carried out in this area. Using La Coste G type gravimeter, gravity survey was conducted in order to determine significant subsurface geologic structure prevailing in the area. In Ohnuma, Bouguer anomaly values varying from -65 to -38mgal were found. Therefore, this area lies in a typical negative Bouguer anomaly area. A large and elongated low gravity zone having graben structure has been confirmed which trends N-S from Shibari to Goshogake. Ohnuma geothermal plant is considered to be located at the center of this graben structure. Schlumberger array employing direct current resistivity method was used throughout the survey covering a total length of 72 line km. Low resistivity zone with values less than 10Ωm in AB/2 = 800m extends continuously from north to south. A specific low resistivity zone was distinguished to appear from Sumikawa passing through Ohnuma, then to Komonomori in the graben structure.

Based on the chemical composition of hot spring waters from the area, they are classified into three groups; SO_4 type is the most abundant among three groups. Weak alkaline to neutral NaCl type occurs only at Shibari and Zenikawa on the northern part of the area. Tamagawa hot spring is famous as HCl type with low pH value. Analysis of the discharged water from the production wells of the Ohnuma power plant shows 2,500 to 3,000 ppm solids content, mainly of sodium chloride and silica.

Five production wells have been drilled by rotary drilling machine with final diameter of 8 5/8 inches and slotted pipes of 7 inches in diameter in the deeper parts. At about 1,300 to 1,700m depth thick piles of dacite, andesite and their pyroclastics are closely interbedded with each other and strongly fractured forming hot water reservoir. Being closely spaced between production wells, mutual interference on their production output is noted. However, the annual decrement of the steam production is very small. As geothermal steam is accompanied with hot water, the steam separator at the wellhead effectively separates steam from hot water. The separated steam is transmitted to the power station through the main steam pipe. Condensed steam is recycled as cooling water. A part of hot water is being utilized to fresh water by means of heat exchanger and the remainning is re-injected into the ground through re-injection wells.

OTAKE

The Otake area, covering Kokonoe Town, Kusu District, Oita Prefecture, is located at 6km northwest of Mt. Kuji in the central part of the Northern Kyushu. As for topography, it lies between Mt. Kuroiwa at its south-east, Mt. Waita at its north-west and Mt.Misokobushi at its west. They are dormant volcanoes, and constitute a valley of Kusu River, running from south to north. And its elevation is in the range from 900m to 1,100m above sea level. Natural steam fumarole zone is distributed in the direction of south-north, and also fumarloes and hot springs are located in this neighborhood. Main ones of them are arranged from the south in the order of Komatsu-, Otake- and Kawara-Fumaroles and Sujiyu- and Hizenyu-Hot Springs.

The Otake area was selected for the geothermal development as follows; (1) It is in natural steam fumarole zone among mountain ranges of Kuju, and in the vicinity of this area such surface manifestations of geothermal activity as Fumaroles and hot springs are brisk. (2) Near Kawara-Fumarole, a well was drilled in 1927 and steam obatined at the depth of 84m. It has been spouting steam-water mixture for 30 years approximately, though the steam production from the well was decreased gradually and stopped lately. (3) It gives comparatively less influence to the hot springs or private houses in the neighborhood, though situated rather inconveniently. Besides, the residents are generally cooperative.

Results from the preliminary survey revealed that comparatively new hornblende andesite and volcanic complex of Mt. Kuroiwa covers the Mt. Waita and Mt. Ichimoku. At Komatsu-Fumarole there exists clay-soil originated by considerable hydrothermal alteration, and underground water is stored to be comparatively scarce. At both Otake- and Kawara-Fumaroles there are more pyroclastic rocks than clayey ones.

The activity of steam fumaroles at Komatsu-

Fumarole was powerful over wide areas. Otake-

Fumarole was more or less weaker than the former. Kawara-Fumarole was the weakest of all three, and also its range in activity was narrow. The scale and activity of three Fumaroles grew smaller toward the north. As to the traffic convenience, Kawara-Fumarole is best, since it is close to the road, while Otake-Fumarole is located at about 200m east to the road, from which a mountain path leads to it. Komatsu-Fumarole is located in the distance of 800m south from the terminal, and is most inconvenient of all, though it is reached by a mountain path.

Based on the results of preliminary surveys, steam wells were drilled in Otake area to obtain super-heated natural steam. Sites of wells were selected near Otake-Fumarole, which is convenient for transportation of drilling equipment and preparatory works, and also in the neighborhood of Kawara-Fumarole and between two Fumaroles. During the term between February 1953 and December 1956, 4 steam wells were drilled at the depth of 300m to 900m. The whole well produced powerful discharges of steam-water mixture instead of super-heated steam. At that time, it was considered from the surrounding geological conditions that the steam reservoir existed in the tertiary sediment, of which the depth were estimated in the range of 500m to 600m. Nevertheless, the drilling operation for Otake well No.3 drilled to the depth of 900m did not proved the existence of the tertiary sediment. Of course, it was found after the well-completion that the discharge from the well was also the mixture of steam and hot water. In such a manner, it was impossible to get the superheated steam from the well for primary object in the geothermal power generation.

In December 1961, steam of 16 t/h was obtained by separating the steam-water mixture from geothermal well mentioned above. Accordingly, geothermal exploration and researches were enterprised for the object to generate electric power using separated steam. In order to develop the geothermal power generation, it is essentially need to collect the information in detail on the range of geothermal areas, conditions of subsurface structure to be stored the mixture of steam and hot water as well as the production capacity, well performance and the life of wells.

At first, it was decided to apply some geophysical exploration (magnetic, gravity, resistivity and temperature) to the wide area including Otake and Hatchobaru areas, and secondly to investigate further subsurface condition by boring. In conclusion, such geophysical explorations revealed the possible existence of geothermal hot water, channels suppling heat and connecting to thermal source, and the promising geothermal area of ellipse with major axis of 3 km extending from south to north and minor axis of 1.5 km extending from east to west including Otake and Hatchobaru areas, which is indicated by low resistivity zone. To confirm the results of geophysical exploration, to clarify geological structure and to investigate the existence of geothermal steam and hot water, two test borings of 1,000 meter class were carried out in the southern area of Otake geothermal field.

A possibility of geothermal field development was obtained by the test results of Otake Well No.5 in Dec. 1961. Accordingly, a plan was made on the drilling of 5 productive wells, Nos.6 through 10, during the term from December 1963 to March 1966. Otake power station has a capacity of 12.5 MW, and has been operating since 1967. At that time, Otake Wells No.6 through No.10 produced the steam, but Otake Well No.6 ceased production in the end of 1967, Well No.7 in 1975, Well No.8 in 1977, Well No.10 in 1980 due to a loss in enthalpy, respectively. Since that time, steam production had declined. In 1979 and

1981, production was raised by the directional drilling of new production wells No.14, No.15 and No.16. At present, the output of Otake power plant keeps about 8 MW with four production wells (these three wells and Well No.9) and four reinjection wells (Nos. 10 through 13).

HATCHOBARU

Hatchobaru No.1 Unit (55 MW) was completed in 1977 as the world's first double-flash type geothermal power plant and has been operating satisfactorily. Kyushu Electric Power Co. has been conducting the development of geothermal steam and the construction and operation of power plants under an integrated system from geothermal exploration to power plants, and completed Otake No.1 Unit (12.5 MW) in 1967 and Hatchobaru No.1 Unit (55 MW) in 1977. When Hatchobaru started operation, the output was 23 MW due to insufficient steam production and reinjection capacity caused by a delay in drilling. However, the output increased steadily with successful drilling, reaching the rated output of 55MW in 1980. It has since then been operating satisfactorily at an average annual capacity factor of about 90%, though the amount of steam sometimes runs low.

When the geology of Kyushu is examined macroscopically, there are two major rifts running from east to west and from north to south, effusing a large number of volcanoes. A section of the east-west rift, i.e., Oita-Kumamoto line, is occupied by the Kuju volcanic group which is the heat source of the Hatchobaru geothermal field. The depth of the geothermal reservoir at Hatchobaru was previously 800 -1,500m (lower Hohi stratum or Usa stratum). However, as a result of drilling of a 2,000m class production well (H-17) in 1980 and a 3,000m exploratory well (HT-5-1) in 1982 as part of the survey for the development of No.2 Unit, the geotectonic condition has been ascertained to a considerable extent. As regards the order of strata from the surface, Kuju volcanic rocks (Quaternary), Hohi volcanic rocks (Quaternary), Usa strata (Tertiary) and the basement rocks (Mesozoic era) are found. The basement rocks appear at a depth of about 2,000m with granite intruding into metamorphic rocks (crystalline schists) and forming alternating strata. The hydrothermal altered minerals (epidote and calcite) found in small cracks in the basement rocks suggest the possible existence of a deep reservoir zone.

A total of 18 production wells have been drilled so far in the Hatchobaru area, 12 of which with successful blowing. The number of currently blowing wells is 10, generating 55 MW. The geothermal reservoir zone in the Hatchobaru area is assumed to be fractures which developed along a fault. Therefore, the probability of successful blowing is high if the production well is drilled through fault planes. Two faults, Komatsu-ike sub-fault and Hatchobaru fault, have been confirmed in the Hatchobaru area. In particular, the former is a major discharge fault and successful blowing resulted in most of those wells drilled through this fault at 1,000 - 2,000m. The characteristics of production wells vary from well to well. However, the ratio of steam to hot water in the blowing fluid is about 1:2 (mouth pressure of about 8 kg/cm^2g) with the non-condensable gas content averaging 0.5% (weight %). Since the output of production wells has been decreasing at a rate of about 10% per year, it is necessary to drill an additional well every year.

A total of 17 reinjection wells have been drilled so far in the Hatchobaru area, 14 of which are in current use. In addition, three of unsuccessful steam production wells have been used as reinjection wells. There is no complete failure for reinjection wells. Even in the case of a completely dry hole, it is possible to develop lost circulation of water artificially by patiently repeating appropriate pressurization and boiling out. There are two major problems involved in reinjection wells: a rapid fall in reinjection capacity and the interference of reinjection with the steam production zone. As for the reinjection capacity, since it decreases by about 20% every year, it is necessary to provide from two to three additional wells annually. This seems to be primarily due to the silica content in the hot water. The interference with the steam production zone poses an extremely serious problem in the Hatchobaru area. Since this area offers few locations suitable for reinjection, e.g., recharge fault, many reinjection wells were drilled near the steam production stratum at the early stage of development. As a result, gradual cooling of production wells occurred and, in particular, two production wells situated relatively near reinjection wells stopped blowing (H-4 and H-6). In order to prevent the cooling of production wells due to reinjection, it is desirable to completely stop reinjection in the neighboring area. However, this is not possible under the present conditions. Accordingly, of the total hot water of 750 t/h, about 250 t/h is diverted to the Otake area for reinjection to ease the effect.

SUGINOI

Suginoi geothermal power plant of the Suginoi Hotel, having the capacity of 3 MW, the smallest in Japan, started operation in Aug. 1981. The attention of Japanese people interested in geothermal field development is directed to this plant operation because of its unique features characterized by the multipurpose utilization including electricity generation, heating and cooling energy, recreation and therapy in baths and spas and so on. Seven wells were drilled from 180m to 400m depth. At present, these wells produce steam of 50 t/h and hot water of 25 t/h from bottom hole where temperature is 90°C - 230°C.

ONIKOBE

The Onikobe power plant is located in Onikobe Katayama district, Naruko-machi, Miyagi Prefecture and is operated by the Electric Power Development Company, Ltd. Licensed plant capacity is 12.5 MW, total steam production in twelve wells is about 50 t/h and hot water reinjection rate in two wells is about 150 t/h. Most of production well concentrate to the shallow zone (depth 200 - 400 meters) with lower steam productivity. One directional well drilled in 1980 produced steam of 17 t/h and PH 5 hot water of 50 t/h from a 1,000m zone.

MORI

The Mori power plant in Nigorikawa geothermal field located in Southern Hokkaido is a 50 MW station operated by Donan Geothermal Energy Co. Ltd., and the Hokkaido Electric Power Co. Ltd. It has been producing since Nov. in 1982. In this field, it is necessary to pay much attention to the high CO_2 gas content in the steam, and high HCO_3 ion content in the hot water. The plugging of scale deposit in pipe intercepts the output of Mori power plant.

KAKKONDA

The Kakkonda power station in the Takinoue geothermal field located in Iwate prefecture, northeastern part of Honshu, Japan is a 50 MW station operated by JMC and Tohoku Electric Power Company. It has been producing since May in 1978.

Based on the results of the detailed surveys made during the period from 1967 to 1972, drilling of six exploration wells of 700 - 1,000m deep was commenced in September, 1972 and completed in February, 1974. By the data obtained from drilling and geological and geophysical loggings made in the wells, possibility of geothermal development in this area was furthermore supported. Thus, based on the results of the synthetic analyses of the surface and subsurface exploration, drilling of the production and reinjection wells started in August, 1974, for the purpose of geothermal development in this area. During the period from August 1974 to August 1977, 11 production wells of 1,000 - 1,600m deep and 15 reinjection wells of 500 -700m deep were drilled. On the other hand, construction of wellhead equipment and steam gathering pipelines was commenced in May, 1975 and completed in November, 1977. At that moment, all the construction works of steam supply system came to an end.

Installations related to steam supply system include geothermal wells, separators, steam gathering pipelines, steam header and silencer. Among these, geothermal wells are divided into two types, one for production and another for reinjection. Because Takinoue is located in the National Park, where land use for construction of roads, drilling sites, steam gathering pipelines and power plant is normally prohibited by environmental concerns, a grouping method was adopted in Takinoue for the drilling of the geothermal wells, which meant that two or three wells were grouped in small base areas. Due to the reasons mentioned above, five drilling base areas, named A, B, C, D and E, were prepared in Takinoue. Accordingly, most wells in a base area were drilled by directional drilling with such an arrangement as multi-legs of an octopus. Moreover, to drill production wells, air drilling method was adopted in this area. In this method, air is used as circulating fluid for mud water and it has such merits that drilling rate is increased, long life of drilling bits can be kept, permeable cracks are protected from plugging by cuttings and fractures with geothermal fluid can be checked. Nine among 11 production wells were drilled by air drilling, showing that this method can be used in such a hot water area as Takinoue.

Compared to Matsukawa which is one of the vapour-dominated areas, Takinoue is a typical hot water area as mentioned already. Therefore, much hot water gushes out from the production wells with steam. The separator is used for separating steam from hot water at the ground surface. Separated hot water is sent to the reinjection wells, while steam is transported by pipelines and is gathered in a steam header. In Takinoue, the steam header is set up in B base area which is located near the power plant. The dry steam is sent to the steam header and the separated hot water is disposed into the reinjection wells in B and A base areas.

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