Fuji Electric's Recent Activities and Latest Technologies for Geothermal Power Generation

Shigeto Yamada † Shizuka Makimoto † Hiroaki Shibata †

ABSTRACT

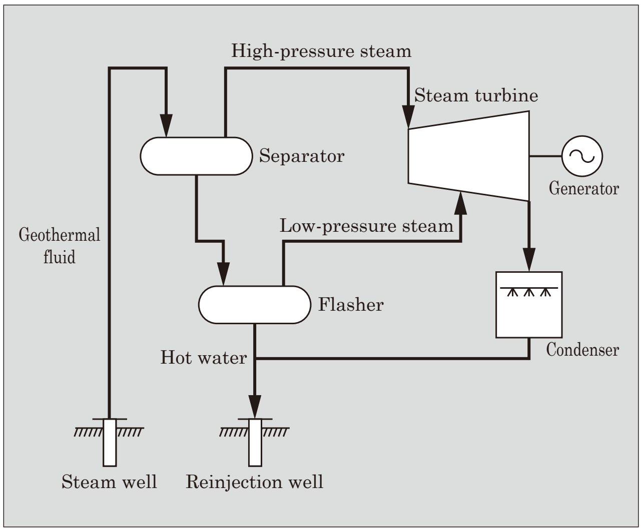
Fuji Electric has been involved in geothermal power generation since the 1980s, and is now recognized as a leading company for supplying geothermal power plants. This paper introduces two recently completed geothermal power plants, Wayang Windu in Indonesia and Kawerau in New Zealand. The world's first practical application of a steam purity monitoring system equipped with a fault diagnosis function and an operation support function helps to improve the utilization rate of the plant. A binary power generating system, developed so that low-temperature geothermal resources can be utilized, has successfully completed a 200 kW pilot unit operation, and is slated to be introduced to the market during 2010.

1. Introduction

Geothermal energy is a renewable energy source known for having extremely low levels of CO_2 emissions. According to calculations by the Central Research Institute of Electric Power Industry, the amount of CO_2 emissions per 1 kWh is 975 g for coal-fired power generation and 519 g for LNG combined power generation, but only 15 g for geothermal power generation[1].

Fuji Electric delivered Japan's first geothermal power facility to Hakone Kowaki-en in 1960. Then, in 1980, Fuji Electric delivered a 35 MW geothermal power facility for the Ahuachapán, El Salvadore Geothermal Power Station, and entered the geothermal power generation market in earnest. In the 1980s, Fuji Electric delivered 30 geothermal power units, totaling approximately 800 MW, to the United States and the Philippines, and came to be recognized as a leading manufacturer of geothermal power facilities. In the 1990s, Fuji Electric delivered 15 geothermal power units having a total combined capacity of approximately 700 MW. Although there appears to have been slightly fewer units delivered in the 1990s than in the 1980s, these delivery figures include three 77.5 MW units for the Philippines and one 110 MW unit for Indonesia both of which include the scope of entire geothermal power stations, and this was the time when Fuji Electric transitioned from a manufacturer of geothermal power equipment to a plant manufacturer in charge of the complete construction of a power station. Upon entering the 21st century, Fuji Electric has continued to build upon its successful track record of geothermal projects, and in early 2010, aiming for completion of a 139 MW geothermal power station, the world's largest capacity single-turbine geothermal power station, Fuji Electric initiated the onsite pilot operation.

Fig.1 Steam flow in geothermal power generation system (double-flash cycle)



The abovementioned projects are based entirely on the flash cycle geothermal power generation. Flash cycle geothermal power generation uses geothermal steam directly to a steam turbine separated at separator from mixture of geothermal steam and hot water. Figure 1 shows a flow diagram of this process. Fuji Electric's share is approximately 40% in the world for the flash-cycle geothermal power facilities delivered over the past 10 years.

This paper discusses Fuji Electric's recent geothermal projects, and introduces a geothermal binary power generation system, newly developed in addition to the flash-cycle method, and the world's first geothermal steam purity monitoring system which has been used in practical applications.

† Energy Solution Group, Fuji Electric Systems Co., Ltd.

2. Recent Geothermal Power Projects

Table 1 lists Fuji Electric's recent geothermal power projects. During the 3-year period from 2007 to 2009, Fuji Electric delivered and completed seven 398 MW geothermal power generating facilities. For 2010 and beyond, four 248 MW units are slated for shipment and completion. Among 11 projects listed in Table 1, the seven projects marked with an asterisk next to the plant name are EPC (engineering, procurement and construction) contracts in which Fuji Electric is working in collaboration with local contractors.

The Wayang Windu, Kawerau and Nga Awa Purua projects include steam separation systems composed of a separator for separating geothermal fluids from hot water and a scrubbing system for removing, as much as possible, impurities from geothermal steam.

2.1 Wayang Windu Geothermal Power Station[2]

The Wayang Windu Geothermal Power Station is located in Java, Indonesia. In 1997, Fuji Electric received an order for a geothermal power station consisting of two 110 MW units. However, plans for Unit 2 were frozen due to the Asian economic crisis, and therefore the comprehensive civil engineering and construction works completed in 1999 including the Unit 1 power generating facility and only the foundation works for Unit 2. Then in 2007, construction of Unit 2 was resumed, its capacity increased to 117 MW, and was completed in 2009. Figure 2 shows a bird's-eye view of the geothermal steam production well and the geothermal power station.

As mentioned above, at the time when Unit 1 was completed in 1999, the foundation work for Unit 2 was also completed with the same specifications as Unit 1, and equipment for Unit 2 had to be the same size as that for Unit 1. Because of this restriction, the condenser cooling system was redesigned so that the turbine exhaust pressure would be lower than that of Unit 1. As a result, although the turbines and generators of Units 1 and 2 are of the identical design, the output has been increased, from the 110 MW output of Unit 1 to 117 MW for Unit 2.

Table 1 Recent geothermal power generation projects

Country	Plant name	Capacity (MW)	Completion
Philippines	Northern Negros *	49.7	June 2007
Indonesia	Lahendong 2 *	20	June 2007
Iceland	Svartsengi 6	33	February 2008
Indonesia	Kamojang	63	February 2008
New Zealand	Kawerau *	95.7	August 2008
Indonesia	Wayang Windu *	20	February 2009
Indonesia	Lahendong 3 *	117	March 2009
Nicaragua	San Jacinto 3	38.5	February 2010
Iceland	Reykjanes 3	50	March 2010
New Zealand	Nga Awa Purua *	139	April 2010
Indonesia	Lahendong 4 *	20	September 2011 (expected)

* : EPC contract

Fig.2 Bird's-eye view of Wayang Windu Geothermal Station

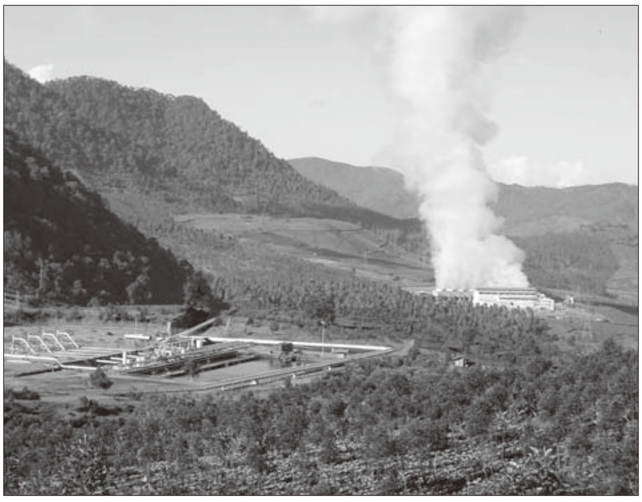


Fig.3 Bird's-eye view of Kawerau Geothermal Power Station

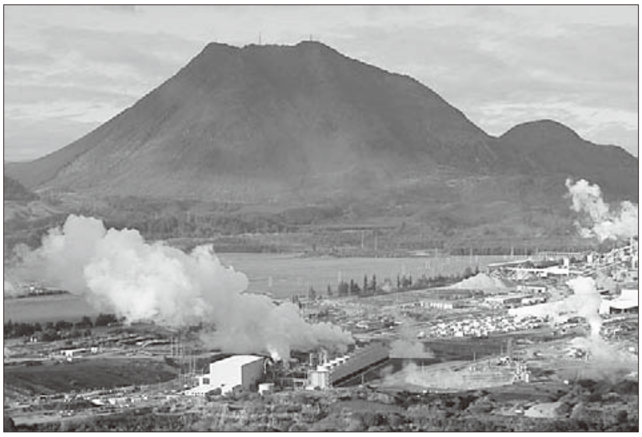


Fig.4 External view of steam separation system

2.2 Kawerau Geothermal Power Station[3]

The Kawerau Geothermal Power Station is located in the northeast region of the North Island of New Zealand. The plot of land on which the power station is built is the site of a former runway and therefore has a flat rectangular shape of 150 m (W)×350 m (L). A double-flash type steam separation system is located on the same area besides the power generating facility, which receives a two-phase flow, i.e., a mixture of geothermal steam and hot water, and supplies steam to the turbine. Figure 3 shows a bird's-eye view of the Kawerau Geothermal Power Station.

The steam separation system incorporates a design for supplying steam that is as clean as possible to the turbine. The steam separation system employs highly efficient separators, and also a scrubbing system for removing scale components such as silica that are likely to dissolve in small amounts of mist contained in the generated steam. With the scrubbing system, water is sprayed inside the steam piping, small amounts of mist are captured and discharged at drains located along the steam piping, and the scrubber ultimately removes mist and other moisture from the system. Figure 4 shows the external appearance of the steam separation system.

The Kawerau Geothermal Power Station employs a large geothermal turbine having the world's largest class last-stage blade of 798 mm, and realizes a rated output of 95.7 MW and maximum output of 113 MW. The power station was completed and handed over to the customer in August 2008, which is a short period of only 22 months from the signing of the contract in November 2006.

3. Geothermal Binary Power Generation System

As a result of rapidly rising fuel prices, measures enacted to prevent global warming, restrictions on CO_2 emissions and the like, there is increasing interest in promoting the utilization of renewable energy sources. Among renewable energy sources, geothermal power generation systems are basically not affected by weather and time of day, and are capable of stable power generation. In the flash-cycle geothermal power generation projects that Fuji Electric has been involved to date, high temperature and high pressure geothermal steam is necessary, and ensuring the geothermal resources capable of power generation had been one of the issues.

Figure 5 shows the conceptual applicability of geothermal power generating systems based on the geothermal fluid temperature and the desired output capacity. The conventional flash-cycle method is used in power generating systems where the geothermal fluid is at a high temperature and the output capacity is large, while binary power generation is used in power generating systems where the geothermal fluid temperature is low and the output capacity is small.

Geothermal binary power generation systems use geothermal fluid as a heat source to vaporize a working fluid having a lower boiling point than water, and the vaporized working fluid drives a turbine to generate power. Since a low-boiling-point working fluid is used, sufficient pressure can be obtained for power generation even when a relatively low temperature geothermal fluid is used as the heat source. Figure 6 shows a schematic diagram of a geothermal binary power generation system.

In order to expand its product series of geothermal power generation systems, Fuji Electric plans to commercialize a geothermal binary power generation system, and carried out demonstration tests in cooperation with the Kirishima Kokusai Hotel in Kirishima City of Kagoshima Prefecture from August 2006 through October 2009. The results of the demonstrated operation showed that, the rated power of 190 kW and maximum power of 220 kW were achieved under continuous operation conditions as planned. Table 2

Fig.5 Scope of geothermal power generation system applications

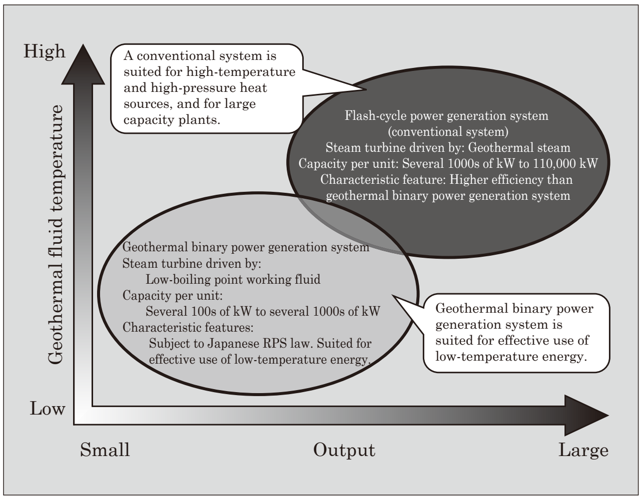


Fig.6 Conception diagram of geothermal binary power generation system

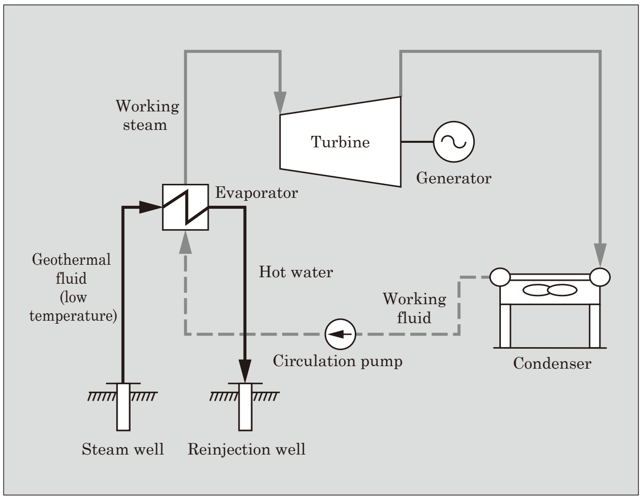


Table 2 Main specifications of geothermal binary power generation system demonstration plant

Heat source	135 °C geothermal (hot spring) steam
Output (capacity)	Rated: 190 kW (Max.: 220 kW)
Working fluid	Isopentane (C_5H_{12}, boiling point 28 °C)
Cooling method	Air-cooled

Fig.7 Geothermal binary power generation system demonstration plant

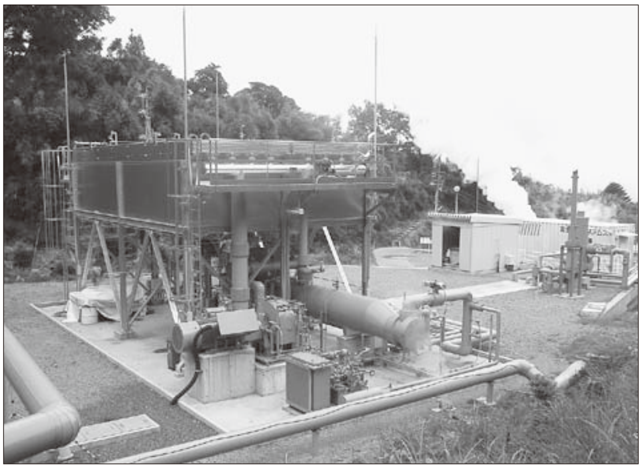
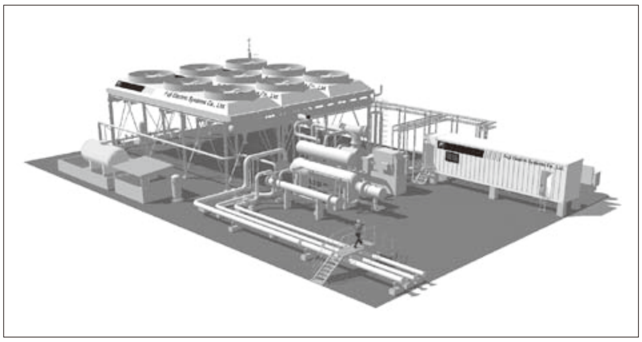


Table 3 Main specifications of commercial geothermal binary power generation system

Heat source	135 °C geothermal steam and geothermal hot water
Output (capacity)	2,000 kW
Working fluid	Normal pentane (C_5H_{12}, boiling point 36 °C)
Cooling method	Air-cooled

Fig.8 External view of 2,000 kW geothermal binary power generation system



lists the specifications of the demonstration plant and Fig. 7 shows the external view of the equipment.

Based on the results of a survey of market, development for commercialization was carried out with a standard 2,000 kW as the first step. Table 3 lists the main specifications and Fig. 8 shows the external appearance.

A pentane system, which is in a liquid phase at room temperature and normal pressure, was selected as the working fluid considering easier handling during charging to and extracting from the equipment. Isopentane was used as the working fluid for the demonstration plant, however normal pentane is selected as the working fluid of the 2,000 kW commercial unit considering handling difficulties of isopentane during extremely hot period. Because it is often difficult to secure enough cooling water in geothermal sites such as the mountainous areas, the air-cooling system is used.

The first unit of this commercial geothermal binary power generation system is slated to be launched in 2010. The series with larger output is also planned for overseas markets.

4. Steam Purity Monitoring System

Geothermal steam contains various dissolved components, such as chloride ions, silica, that originate in the hot water and are a major cause of turbine corrosion and scale deposition. Measurement of the dissolved components in geothermal steam is typically performed once every several months. Under such circumstances, the deposition of scale on the turbine is normally be in progress and often affects the turbine performance even before such scaling will be found during a overhaul period. Moreover, recently, carryover of chemicals for the production wells treatment or pH adjustment of the hot water is also considered as the cause the steam properties to deteriorate. Therefore, a system has been developed to monitor impurities and gases in geothermal steam periodically so that plant operators can know expected conditions of the turbine and possible problems in advance.

4.1 Overview of steam purity monitoring system

As shown in Fig. 9, this device is configured from a steam purity monitor and a diagnosis system, and the functions of each area described below.

(1) Steam purity monitor

The steam purity monitor enables control items pertaining to the required steam properties be measured in real-time. Figure 10 shows a schematic diagram of the steam purity monitor. The following six items can be analyzed automatically.

(a) pH
(b) Silica concentration
(c) Chloride ion concentration (calculated value)
(d) Specific conductivity
(e) Cation conductivity
(f) NCG concentration

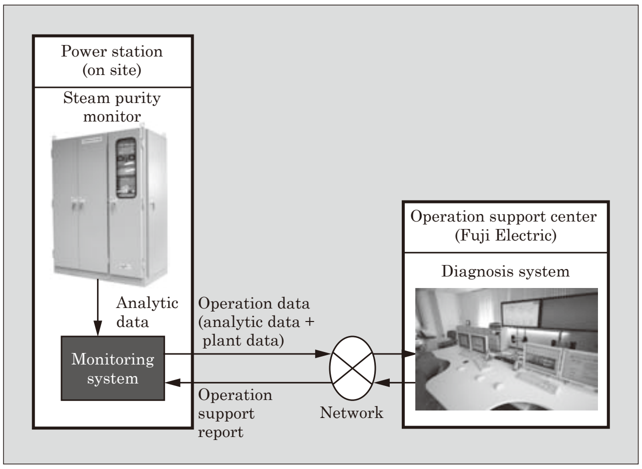
(2) Diagnostic function

The diagnostic function uses statistical techniques to diagnose geothermal steam properties, and in addition to diagnosing abnormal conditions, also performs presymptomatic diagnoses of the possibility of scale deposition. Data obtained from automated measurements is used to evaluate the properties of steam at that time.

(3) Operation support function

The operation support function provides the requi-

Fig.9 Block diagram of geothermal steam purity automatic analyzing device



site guidance for improving the steam properties and for improving operation to prevent scale deposition and corrosion inside the turbine. Based upon online measurements of the amount of gas, the operation support function also provides guidelines for the appropriate series to be operated in a gas extraction system.

4.2 Effect of steam purity automatic analyzing device

The introduction of a steam purity automatic analyzing device and the constant monitoring of scale and corrosion components are expected to produce the following effects.

(1) Improvement of plant utilization rate

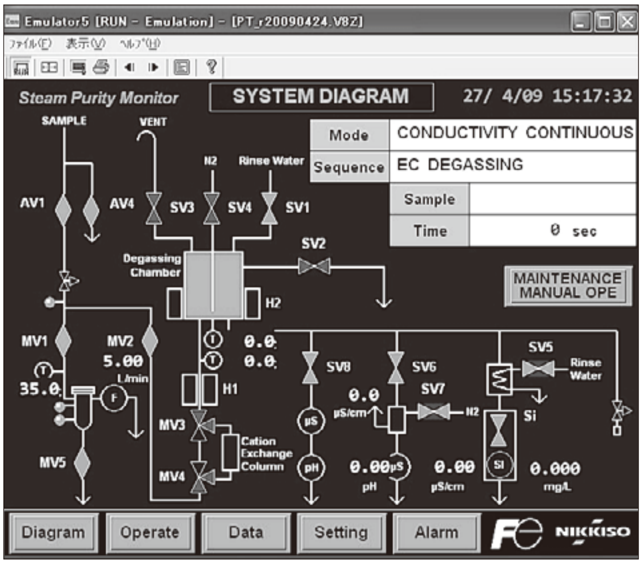
Plant operation support reports are provided so that the condition of steam generating equipment can be ascertained. Additionally, the implementation of measures to prevent scaling and the estimation of the extent of turbine scale deposition enable longer time intervals between turbine overhauls.

(2) Economic operation of gas extraction system

According to the change in quantity of gas, Fuji Electric provides the appropriate turbine series to be operated, enabling the amount of steam consumption and the amount of power consumption to be reduced.

This system, after undergoing demonstration testing for six months in a geothermal power station in Japan, has been delivered with the commercial Unit 1 to the Nga Awa Purua geothermal power station in New Zealand, and trial operation began as of January 2010. In addition, this system is also scheduled to be delivered to a geothermal power station in Iceland in 2010.

Fig.10 Schematic diagram of steam purity monitor



5. Postscript

Fuji Electric has delivered sixty units of geothermal power generation facilities with a total capacity of 2,324 MW, and has also gained market recognition as a contractor of geothermal power plants. In addition to this track record of success, Fuji Electric has also added a geothermal binary power generation system capable of using low-temperature geothermal resources to its product lineup, and is confident of being able to satisfy a wide range of customer needs.

From a global perspective, research of EGS (Enhanced Geothermal System) that generates geothermal steam artificially is proceeding in such countries as the United States, Australia and Germany in addition to power generation from the conventional geothermal resources. Fuji Electric is also monitoring industry trends in order to contribute to the utilization of power from this new geothermal resource.

Fuji Electric remains committed to expanding the utilization of power generated from geothermal resources, and will continue contributing to efforts to reduce CO_2 emissions, which are a cause of global warming.

References

(1) CRIEPI News No.338. Central Research Institute of Electric Power Industry.

(2) Design and Construction of Wayang Windu Unit 2 Geothermal Power Station, Yamaguchi N., GRC Transactions. Geothermal Resource Council. vol.33. p.773-777.

(3) Technical Features of Kawerau Geothermal Power Station, New Zealand, Muto T., GRC Transactions. Geothermal Resource Council. vol.33. p.721-725.

e-Front runners

＊ All brand names and product names in this journal might be trademarks or registered trademarks of their respective companies.