Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Fuji Geothermal ORC Power Generation System

Hiroshi Oyama[1], Shigeto Yamada[2]Saki Kondo[3]

1923 / FUJI ELECTRIC CO., LTD., 1-1 Tanabeshinden, Kawasaki-ku, Kawasaki-city 210-9530, Japan

[1] oyama-hiroshi@fujielectric.com

[2] yamada-shigeto@fujielectric.com

[3] kondo-saki@fujielectric.com

Keywords: Geothermal binary, ORC, power plant, Japan

ABSTRACT

Geothermal energy is recognized as one of the important renewable energy also in Japan, however the current generating capacity is only about 0.2% of total electricity generation. After the Great East Japan Earthquake followed by the Fukushima nuclear power plant accident, Japan's government accelerated various deregulations and incentives to promote usage of the renewable energy. However there still are some difficulties to expand the geothermal energy development in Japan. Large capacity geothermal resource developments are still ongoing, and recent developments are mainly small capacity such as 100kW class "Onsen (hot-spa)" power generation or 2,000-5,000 kW medium size power plants.

1. INTRODUCTION

It is said that Japan has the world third largest potential of geothermal resources. METI, Ministry of Economy, Trade and Industry, has been studying what issues need to be solved to promote more geothermal energy development and the result of the study was reported in 2009. Based on the report, METI started to promote incentives and deregulations. Such promotions were accelerated after the Great East Japan Earthquake in 2011 followed by the Fukushima nuclear power plant accident, and various incentives and deregulations were issued including a feed-in tariff (FIT). The tariff under the Japan's FIT for a newly constructed geothermal energy is 26 yen/kWh for 15,000kW and larger capacity and 40 yen/kWh for less than 15,000kW. However the installed capacity of the geothermal power plants is just 530MW as of early 2017 and its generation is only about 0.2% of total electricity generation. Most of large capacity geothermal developments are still under exploration or construction stage, on the other hand, small and medium capacity geothermal power plants have been constructed already, utilizing the existing hot-spa hot water or newly drilled production wells. Especially, 37 units of small capacity ORC power generating system were installed from 2011 to 2017, ranging from 20kW to 440kW. Table 1 is the list of geothermal power plants constructed after the Great East Japan Earthquake until March 2017.

Location	Type	Capacity kW	Completion	Location	Type	Capacity kW	Completion
Oita	ORC	1x72	2013.01	Oita	ORC	1x125	2015.07
Oita	ORC	2x72	2014.01	Oita	ORC	3x20	2015.08
Oita	ORC	2x72	2014.01	Nagasaki	ORC	3x72	2015.09
Nagano	ORC	1x20	2014.04	Oita	ORC	1x20	2015.12
Hyogo	ORC	2x20	2014.04	Oita	ORC	1x125	2016.01
Oita	ORC	1x72	2014.07	Tochigi	ORC	1x20	2016.03
Kumamoto	ORC	3x20	2014.07	Oita	ORC	1x65	2016.04
Oita	ORC	4x125	2014.11	Oita	ORC	1x125	2016.07
Tottori	ORC	1x20	2015.01	Oita	ORC	1x125	2016.07
Oita	--	1x11	2015.02	Oita	ORC	1x72	2016.09
Kagoshima	ORC	1x1,580	2015.02	Hokkaido	ORC	1x125	2016.11
Oita	ORC	1x5,000	2015.06	Fukushima	ORC	1x440	2016.11
Oita	ORC	2x125	2015.06	Hokkaido	ORC	1x72	2017.03
Kumamoto	Flash	1x2,000	2015.06	Oita	ORC	1x5,050	2017.03

Table 1: Geothermal power plants constructed in Japan in 2011 – 2017.

2. FUJI ORC POWER GENERATION SYSTEM

Fuji constructed the 220kW ORC power plant as a pilot unit and operated it from 2006 to 2009 to verify its design, operability and performance. Fuji has supplied 82 units of flash system geothermal power plant and total generation capacity 3,200MW for 35 years. Fuji designs and provides the geothermal ORC system based on the technology of the flash system and experiences of the above pilot plant.

Fuji has two models of ORC turbine named Frame6 and Frame10. Fuji provides any system of over 5,000kW by combining these two models. Fuji optimizes turbine blade design and provides high efficient turbines although the turbine frame is two models. Table 2 shows typical specification.

Turbine Model		Frame6	Frame10	2xFrame10
Rating	MW	~ 6	~ 10	~ 15
Heat source		Steam / Brine		Brine
Cycle		Single pressure		Dual pressure
Working fluid		Normal pentane / R245fa		

Table2: Typical specification.

3. FEATURES OF TAKIGAMI BINARY POWER PLANT

Takigami Binary Power Plant is located at Kokonoe-machi, Oita in Kyushu area, and is operated by Idemitsu Oita Geothermal Co., Ltd.(Idemitsu). Idemitsu has been supplying geothermal steam to Takigami Power Station operated by Kyushu Electric Power Co., Inc. since 1996, and their steam supply business is very successful. There is more than 1,000 t/h separated brine at about 130 oC being reinjected. The idea is to utilize this separated brine to generate additional electricity, without adding a new production wells. The power plant location was selected at a spare space in the existing production well pad area, therefore, additional land development was not required. Idemitsu and Fuji signed an EPC Contract in April 2015, construction completed by the end of February 2017, and the commercial operation commenced on March 1, 2017. This is the first installation of a commercial geothermal ORC power plant by Fuji. The rated generator output is 4,500kW under the average annual ambient wet bulb temperature, and the maximum generator output is 5,050kW at the average winter time ambient wet bulb temperature. The registered output of 5,050kW is the largest of any geothermal ORC unit in Japan.

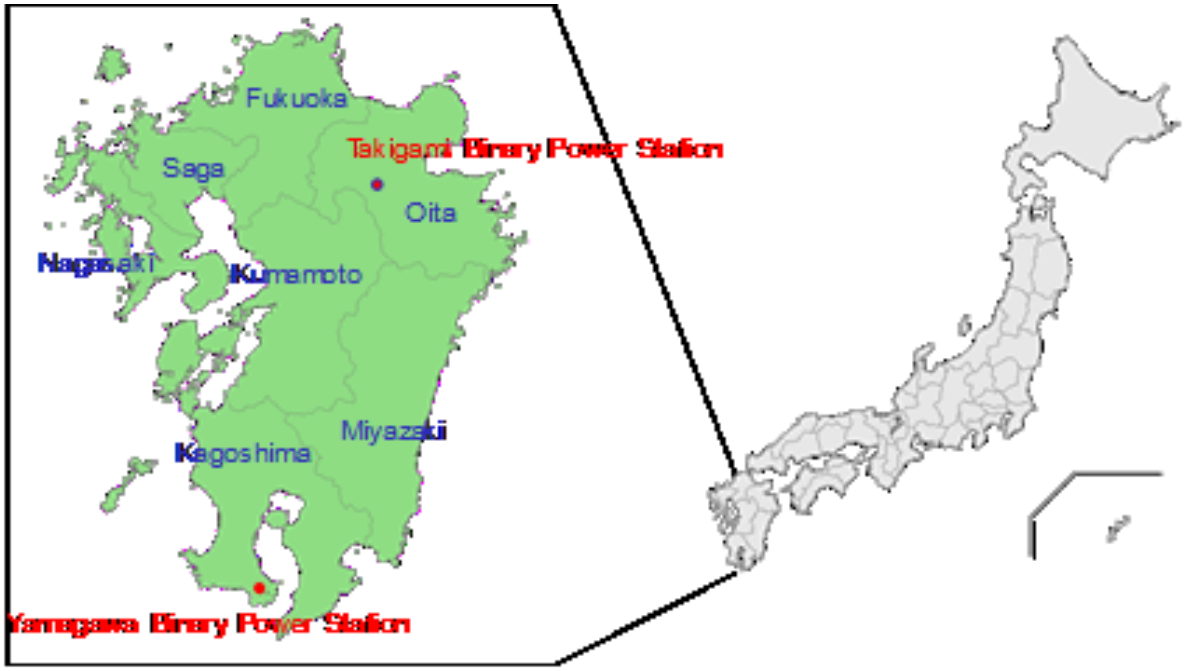

Figure 1: Location of Takigami Binary Power Plant and Yamagawa Binary Power Station.

3.1 Overview of Power Plant

Figure 2 shows an overview of the Takigami Binary Power Plant. Figure 3 shows a system flow. The brine branched from the reinjection line is pressurized by two brine supply pumps and goes to one super-heater, two evaporators, one preheater and back to the reinjection line. Due to the restriction of available area, a water-cooled condenser is used, and the cooling tower is constructed for the cooling water supply to two water-cooled condensers. Makeup water to the cooling water circuit is supplied by surplus water from the cooling tower at the existing Takigami Power Plant. R245fa is used as the working fluid to minimize the plot area of the plant, eliminating the additional area that would have been required for the fire-fighting system and fire-fighting area if hydrocarbon had been used as the working fluid.

Figure 2: Overview of the Takigami Binary Power Plant.

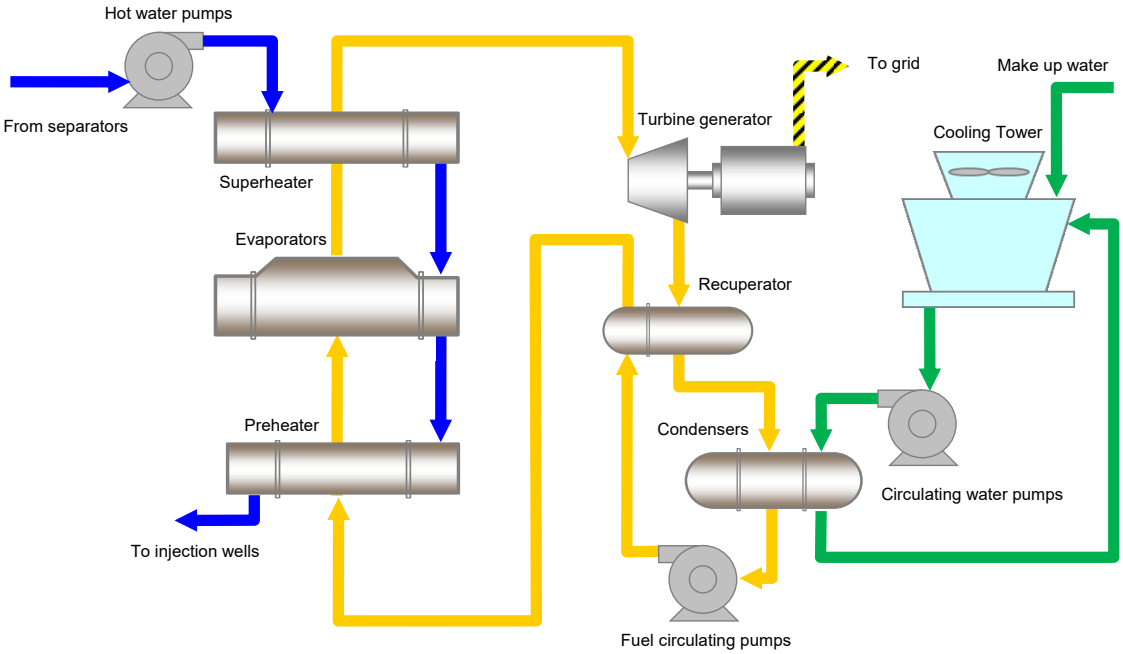

Figure 3: System flow of the Takigami Binary Power Plant.

3.2. Features of each equipment

3.2.1. Turbine

The turbine was designed and manufactured by Fuji. The turbine uses reaction blades and basically a similar design to Fuji's geothermal steam turbines. The basic difference is the shaft seal type; Fuji's ORC turbine uses double mechanical seals, while the geothermal steam turbines use a steam seal. The turbine rotation speed is 1,800 rpm which is half of Fuji's standard geothermal steam turbines. Table 2 shows the specifications of the ORC turbine.

Rated inlet vapor pressure	kPaG	1,440
Rated inlet vapor temperature	°C	120
Rated generator output	kW	4,500
Maximum generator output	kW	5,050
Rotating speed	Min^{-1}	1,800

Table 3: Specifications of Takigami ORC turbine

3.2.2 Heat exchangers

The heating system consists of one preheater, two evaporators and one super-heater. The material of tubes for all of these heat exchangers is duplex stainless steel, based on the long-term operational experience of the reinjection system by Idemitsu. Figure 4 shows the heating-circuit heat exchangers.

Figure 4: Preheater, evaporators and super-heater.

The cooling system consists of one recuperator and two water-cooled condensers. The condenser tubes are of 316 stainless steel. The condensed working fluid is extracted by the working fluid pumps and pumped to the preheater. Figure 5 shows the cooling-circuit heat exchangers.

Figure 5: Water cooled condensers and recuperator.

3.3. Site construction works and commissioning works

Construction of the civil works commenced in April 2016, and construction of the electro-mechanical works commenced in September 2016. All components of the equipment are installed outdoors except for the electrical and control system. The Kyushu area is located the south-west part of Japan; however, the ambient temperature goes down below 0 oC in winter, and snow sometimes fell at the site. The site-testing works commenced in December, 2016, therefore the site-testing and commissioning works were sometimes conducted under down to -10 oC ambient temperatures or during snow storms. Even under such severe ambient conditions, the site-testing and commissioning works proceeded on schedule, and the performance test was completed in the middle of February 2017, followed by one week of continuous operation confirmation.

4. FEATURES OF YAMAGAWA BINARY POWER STATION

The Yamagawa Binary Power Station is located at the Yamagawa Power Station which is the geothermal power plant operated by Kyushu Electric Power Co., Inc. in Ibusuki-City, Kagoshima of Kyushu area, and is operated by Kyuden Mirai Energy Company, Inc. (Kyuden Mirai). The brine from the separator had been directly returned to the reinjection wells at the Yamagawa power station. The brine is more than 600 t/h at about 180 oC. This power station effectively utilizes the heat of this brine (approx. 600t/h) and make generation, without adding a new production wells. Kyuden Mirai and Fuji signed an EPC Contract in June 2016, the construction works completed and the commercial operation commenced on February, 2018. The rated and maximum generator output is 4,990kW.

4.1. Overview of Power Plant

Figure 6 shows an overview of the Yamagawa Binary Power Station. Figure 7 shows a system flow. The brine branched from the reinjection line is changed to two phase fluid by the separator inlet valve and goes to the separator. The two phase fluid is separated brine and steam. After that the brine goes to the preheater and the steam goes to the evaporator. Normal pentane (n-pentane) is used as the working fluid. Because n-pentane is flammable fluid, fire-fighting system was supplied and fire-fighting area was laid out around the binary system. n-pentane is pressurized by the pentane pumps and goes to the recuperator, the preheater and the evaporator. The n-petane is heated by the preheater and vaporized by the evaporator. The vaporized n-pentane rotates the turbine. The type of condenser is air cooled condenser because no available cooling water.

Figure 6: Overview of the Yamagawa Binary Power Station.

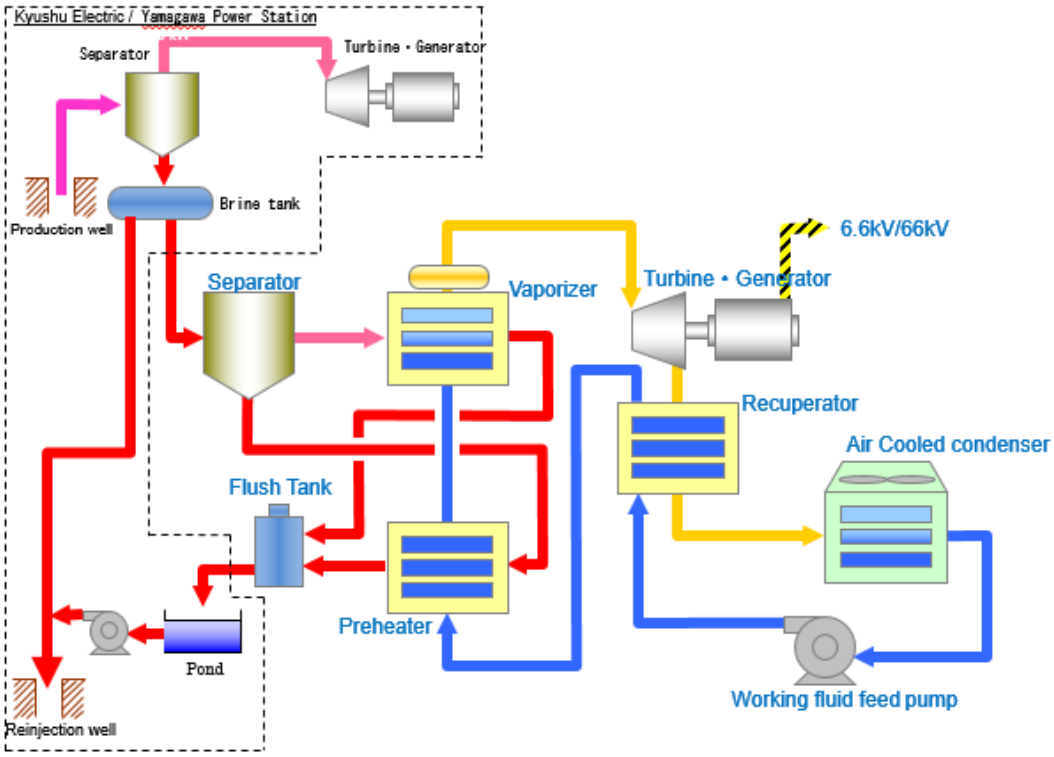

Figure 7: System flow of the Yamagawa Binary Power Station.

4.2. Features of each equipment

4.2.1 Turbine

The turbine was designed and manufactured by Fuji as well as Takigami Table 3 shows the specifications of the ORC turbine and Figure 8 shows the ORC turbine and the generator.

Table 3 Specifications of Yamagawa ORC turbine

Rated inlet vapor pressure	kPaG	820
Rated inlet vapor temperature	ºC	122.1
Rated generator output	kW	4,990
Maximum generator output	kW	4,990
Rotating speed	min^{-1}	1,800

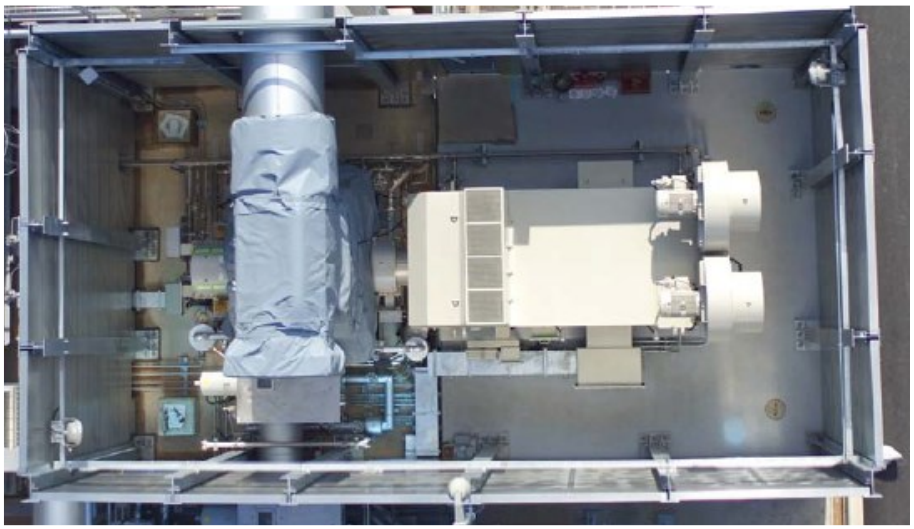

Figure 8: ORC turbine and Generator

4.2.2 Heat exchangers

The heating system consists of one preheater and one evaporator. The material of tubes for all of these heat exchangers is super duplex stainless steel, considering composition in brine which has high chloride ion. The cooling system consists of one recuperator and air cooled condenser. The fan blades and motors are low noise type considering surrounding environment. The condensed n-pentane is extracted by the pentane pumps and pumped to the preheater. Figure 9 shows the heat exchangers.

Figure 9: Heat exchangers.

4.3. Site construction works and commissioning works

Construction of the electro-mechanical works commenced in May 2017. All components of the equipment are installed outdoors except for the electrical and control system. The Kagoshima area is located in typhoon street. The typhoons came four times to the power station area during construction period. Measures to prevent scattering and upset were carried out each time. The site-testing works and commissioning commenced in December, 2017. The all commissioning works and the performance test were completed in February, 2018 and the commercial operation commenced.

5. CONCLUSIONS

Fuji completed two plants with different type of ORC system Takigami and Yamagawa, for working fluid and cooling system. Fuji will reflect the findings obtained from these plants in the future plant design and will provide total solution for geothermal power generation industry both flash and ORC system.

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