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Developments of Geothermal-Biomass Hybrid GPP and IoT-AI System for GPP

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ABSTRACT

I introduce two projects executed by CRIEPI since 2013 with government subsidy, (1) Hybrid GPP project and (2) Geothermal IoT-AI project.

(1) Hybrid GPP project (FY2013-2017): We have developed highly efficient geothermal power plants to be hybridized with the other energy source, which is biomass, solar thermal energy, or exhaust heat from fuel cells, and so on. It is expected that the thermal efficiencies of these systems are improved by superheating the main steam through the use of the other energy sources. We have investigated the system feasibility of these hybrid power plants in the light of the engineering, economic performance, environmental laws and regulations. And now we have narrowed down the proposed site to install a new hybrid GPP for the first time in Japan.

(2) Geothermal IoT-AI project (FY2018-): To make maintenance easy and lower maintenance cost, we have developed a surveillance IoT camera that can scan the numerical data from attached display on the power generator and a plant performance evaluation system using AI technology for small-scale binary power plant (less than 2,000kWe).

These two projects are supported by NEDO program, P13009 (FY2013 - FY2020). NEDO is a semi-governmental organization in Japan to promote the development and introduction of new energy technologies.

1. INTRODUCTION

Although Japan has about 100 active volcanoes and the world's third largest reserves of geothermal resources after United States and Indonesia, its geothermal generation capacity was ranked only eighth and has not improved in the last decade.

The main obstacle was environmental protection laws in national parks in Japan. Even though Japan has one of the largest reserves of geothermal resources in the world, more than 80% of them lie within national parks. Therefore, the development of GPPs and the drilling of wells, as well, have been strictly restricted. Rules set in the 1970s suspended the construction of new GPPs inside national parks except for at six sites in operation or under construction at the time. Without reforming the regulations that restrict the development of GPPs within national parks, the geothermal potential that Japan possesses has limited use and cannot be effectively used to produce electricity.

The second obstacle is, until recently, a lack of governmental support for geothermal development. Geothermal energy was recognized as a "new energy" until 1997. However, since then geothermal energy has been excluded from the definition of new energies, subsidies were reduced every year. On the other hand, Japan enacted a RPS (Renewable Portfolio Standard) law in 2003. This law requires electric companies to produce a certain amount of electricity by renewable energy to increase their use and expand the market for renewable energy. However, geothermal energy (flash steam power plants) was also excluded from the RPS law. Since then, geothermal energy has lost support from the government.

In July 2011, the FIT (Feed-in tariff) was adopted by the Japanese parliament. The MoE (Ministry of the Environment) in Japan has gradually relaxed regulations in national parks by 2015. Due to these government policies, in the past several years new GPPs and binary power plants have already been built in Japan. Thus, now it is expected that the usage of geothermal energy will spread more rapidly in future years. Based on the government estimates, the generation capacity of GPPs can be tripled by 2030.

In Japan, some projects related to geothermal technology are currently in progress. At MoE, some demonstration projects have been conducted to promote social acceptance and to maintain a balance between the development of a GPP and the protection of national parks. Also, at national institutes under the jurisdiction of METI (Ministry of Economy, Trade and Industry), practical studies have been conducted with the aim of reducing the cost and development risk of GPPs.

Within this context, we have developed Hybrid GPP and Geothermal IoT-AI system with government subsidy. Hybrid GPP is a highly efficient hybrid GPP combined with other thermal energy sources such as biomass, solar heat and exhaust heat from fuel cells. It is expected that the thermal efficiency of GPPs can be improved by super-heating the main flow of steam through the use of other energy sources. And IoT-AI system is a plant performance evaluation system for small-scale geothermal binary power plant. This system leverages AI technologies for scanning the numerical data from attached display on the power generator and can analyze the plant performance based on the plant operation data.

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2. HYBRID GPP PROJECT

In this project, our aim is to develop a hybrid GPP by effectively combining geothermal energy and other types of thermal energy.

2.1 System Concept

Figure 1 shows the system configuration of a highly efficient hybrid GPP, and the T-s (Temperature-Entropy) diagram of the system. In a typical GPP, the turbine inlet steam is saturated. If there is even only a small heat drop in the turbine, the resulting thermal efficiency of a GPP will be much lower than that of a thermal power plant. Therefore, we have investigated the idea of improving both the power output and the thermal efficiency of a GPP by super-heating the turbine inlet steam. By analyzing the performance of the highly efficient hybrid GPP, we've discovered that the power output increased by 30% and the thermal efficiency was more than 20% higher in prescribed production well steam conditions: 2,721.8kJ/kg at 0.5MPa, and cooling water conditions in winter (Nakao, 2016 and Nakao, 2017).

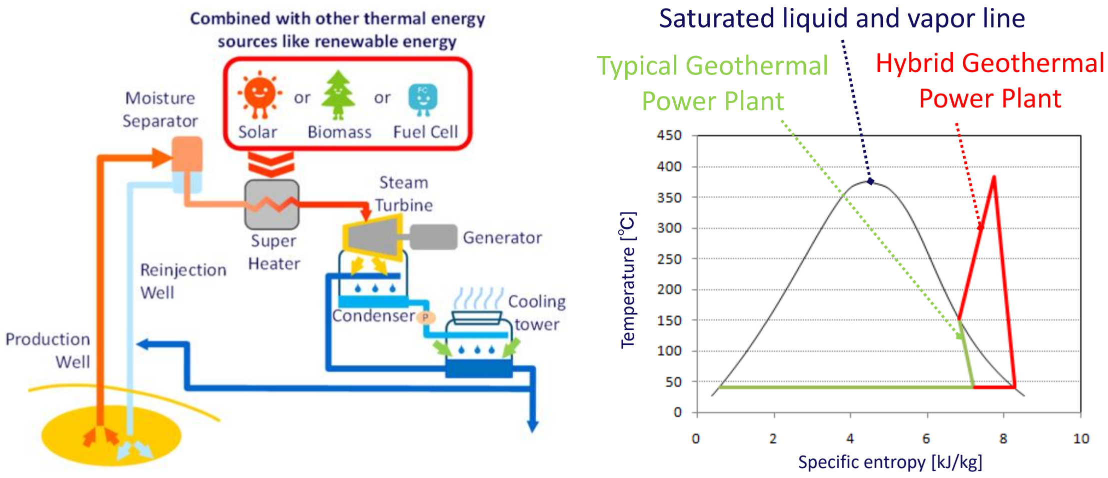

Figure 1: System configuration (Left) and T-s diagram (Right) of a highly efficient hybrid GPP

2.2 Other Thermal Energy Sources Combined with GPP

We have developed a highly efficient hybrid GPP combined with other thermal energy sources, which are biomass, solar heat, or exhaust heat from fuel cells, and so on. It is expected that the thermal efficiencies of a GPP are improved by super-heating the main steam through the use of other thermal energy sources. We have looked into the system feasibility of highly efficient hybrid GPPs from the point of view of engineering, economic performance, environmental laws and regulations.

As for solar heat, it would be impractical to install solar heat collectors in national parks in Japan, and it is not feasible to gather sufficient solar heat in these environmentally sensitive regions to super-heat the geothermal steam up to approximately 400℃. Fuel cells also have great feasibility in performance and operability, but is quite expensive. As a result, we found that a highly efficient hybrid GPP combined with biomass has greater feasibility than other thermal energy sources in Japan. Thus, we have proceeded with investigating a geothermal-biomass highly efficient hybrid GPP, such as the following:

Table 1: Reliability verification of other thermal energy sources combined with a GPP in Japan

<table>
<tr><th></th><th>Biomass</th><th>Solar heat</th><th>Fuel cell</th><th>Micro Gas Turbine</th></tr>
<tr><td>Regulation in national parks</td><td>Needs to meet emissions regulations</td><td>Needs large site area for solar heat collectors</td><td>Needs to store combustible fuel</td><td>Needs to store combustible fuel and meet emissions regulations</td></tr>
<tr><td>Performance</td><td rowspan="2">✓
Higher than that of biomass power plant</td><td rowspan="2">✗
Shortage of direct solar radiation in Japan</td><td>✓
Very high efficiency</td><td>Lower than that of Combined Cycle Gas Turbine</td></tr>
<tr><td rowspan="2">Cost</td><td>✗
Initial cost is still high</td><td>✗</td></tr>
<tr><td colspan="4">Be able to share power generation facilities such as steam turbine, condenser, cooling tower and ejector</td></tr>
</table>

Others	FIT schemes apply	Combination with GPP has less output fluctuation than PV alone	Wide load range Zero-emission Quick response to load variation	High CO_2 emissions
Comprehensive evaluation	✓	✗	Depends on initial cost	✗

2.3 Plant Performance of Geothermal-Biomass Highly Efficient Hybrid GPP

The heat-and-mass-balance diagram of a geothermal-biomass highly efficient hybrid GPP was calculated. Table 2 shows major analysis conditions for a GPP, and Figure 2 shows the configuration of a biomass heating facility, which is additionally arranged on a GPP. In this project, the generation capacity of the geothermal-biomass hybrid GPP was determined to be approximately 4MWe to evaluate plant performance.

The main conditions of the saturated geothermal steam were 2,721.8kJ/kg at 0.5MPa, and the flow rate was chosen for a gross power output of 3MWe from the GPP without biomass. The flow rates of the turbine leakage, gland-seal steam, and cooling water in the oil cooler and other system components were estimated from the specifications of existing units in Japan. As for a biomass heating facility, we determined the capacity of each element apparatus by calculating the heat-and-mass-balance of it, and we have made a preliminary estimation of the auxiliary input.

Table 2: Major analysis conditions for a GPP

Variable	Value
Main geothermal steam conditions	
-Flow rate	24.6t/h
-Pressure	0.5MPa
-Specific enthalpy	2,721.8kJ/kg
-NCG	1wt%
Turbine adiabatic efficiency	82%
Vacuum condition	685mmHg
-Cooling water temperature	28°C
-Wet-bulb air temperature	20°C
Pump efficiency	80%
Flow ratio of steam ejector	0.6

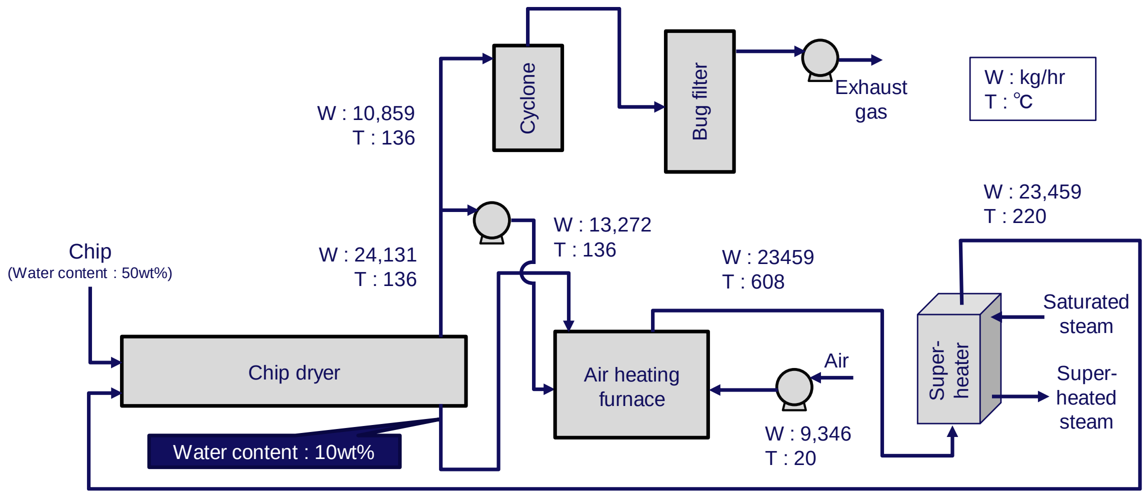

Figure 2: Configuration of a biomass heating facility

Figure 3 shows an advantage of a geothermal-biomass highly efficient hybrid GPP. In our analysis, the gross power output increased by 928 kWe owing to an increase in the temperature of the turbine inlet flow and the gross thermal efficiency is approximately two points higher than that of a GPP without biomass. Then, the net power output increased by 863kWe, and the net thermal efficiency (biomass) of the system was calculated to be 22.2% (HHV: Higher Heating Value of a biomass). It is much higher than that of a biomass-fired power plant.

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Here, the net thermal efficiency (biomass) was defined as follows:

Net thermal efficiency (Biomass) [%] =

(Increased net power output [kWe] – Biomass auxiliary input [kWe]) / HHV of biomass fuel [kWth]

Compared to a biomass-fired power plant, the geothermal-biomass highly efficient hybrid GPP would lead to effective utilization of biomass chips. The net power output of the system has increased by about 10% due to combining a GPP with a biomass-fired power plant. In the case of operating a typical GPP and standard biomass-fired power plant respectively, the net power output was 3,399 kWe altogether. Whereas, in the case of a geothermal-biomass highly efficient hybrid GPP, the net power output was 3,716 kWe, because the auxiliary input for biomass heating facility would be reduced by half in comparison to that of a standard biomass-fired power plant. Moreover, the geothermal-biomass highly efficient hybrid GPP has an advantage in efficiency and economics as the system share a large-scale turbine and generator.

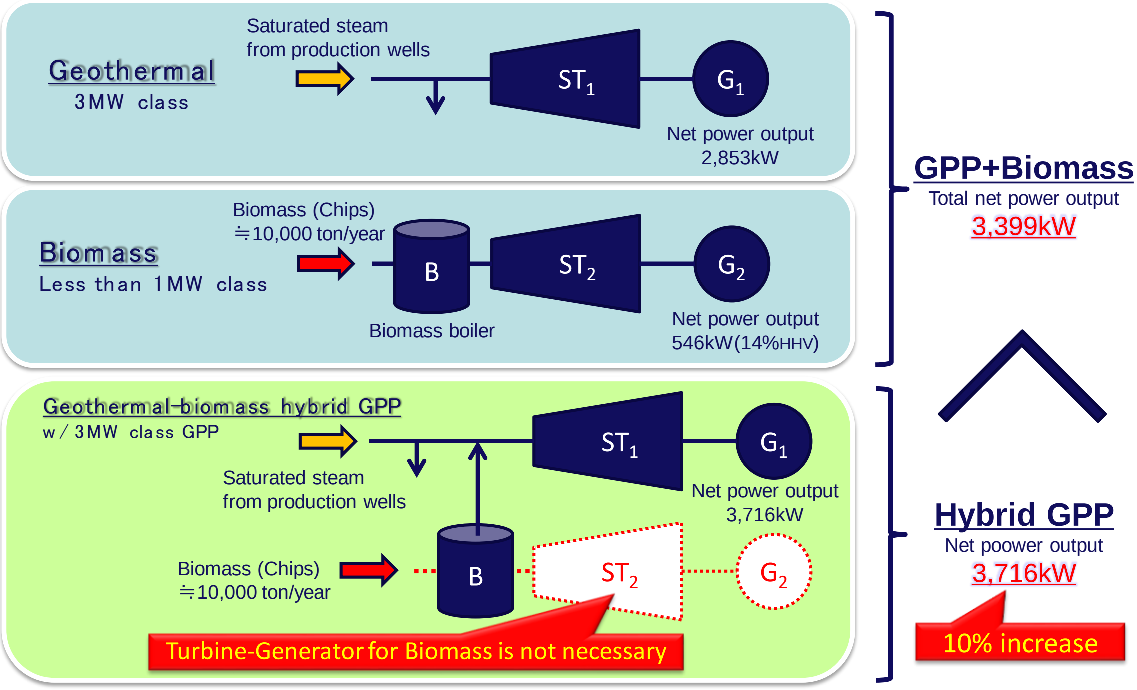

Figure 3: Advantage of a geothermal-biomass hybrid GPP

We have also calculated the net thermal efficiency (biomass) of hybrid system with the amount of biomass from sustainable management, that is the capacity of the system, as the parameter, then we found that there is competitive advantage in a range of the capacity of hybrid system. Figure 4 shows the relationship between the capacity and the net thermal efficiency of biomass-fired power plant. Plots and dashed line in the figure refer to the efficiency of existing biomass-fired power plants in Japan and square regions refer to the efficiency of hybrid system.

In the case of over 5MWe (approximately over 50,000 ton/year), the efficiency would be well over 20%HHV. Thus, using procured biomass as fuel in biomass-fired power plant is more profitable than using them in hybrid system. And then, if we can procure a large amount of biomass and use them as multi-fuel for 1,000 MWe class coal-fired power plant, that is a type of hybrid system "Coal-Bio Hybrid Power Plant", the efficiency would be well over 40%HHV (□ in Figure 4).

However, biomass is not necessarily procured anywhere in Japan. Therefore, if we cannot procure the sufficient amount of biomass, we have to use them in biomass-fired power plant in the net thermal efficiency lower than 20%HHV. In this case, geothermal-biomass hybrid GPP has an advantage in regard to efficiency, because it is utilize biomass in the system of over 20%HHV (■ in Figure 4).

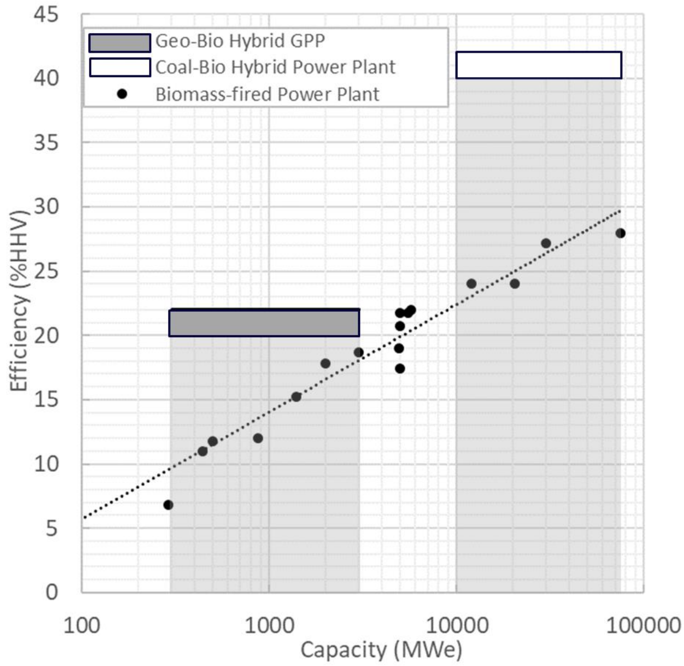

Figure 4: Relationship between the capacity of biomass-fired power plant and the net thermal efficiency

2.4 Geothermal Fluid Heating Experiments

In order to assess the feasibility of a highly efficient hybrid GPP, saturated geothermal steam super-heating experiment was performed in the geothermal field in Japan in 2016 and 2017. In 2017, we have conducted a demonstration test using a super-heater pipe that is the same size as that of commercial-sized facility, in order to confirm the durability of the super-heater and obtain more information to design a biomass heating facility.

Figure 5 shows system flow diagram of geothermal fluid heating apparatus. In this experiment, two-phase geothermal fluid was provided to the moisture separator from an actual production well directly and saturated steam separated from the two-phase geothermal fluid. The saturated geothermal steam separated at the moisture separator flowed into the bottom of super-heater pipe (Length 3,000mm × Inner diameter 20mm). The inlet steam condition was 110℃ at atmospheric pressure, and the flowrate of the steam was 36kg/h, and a small amount of silica was contained in saturated geothermal steam at an outlet of the moisture separator (average of 4mg/L) during our experiments. Then, the outlet steam temperature was 400℃ for this experiment. Thus, the top of the super-heater pipe had been exposed for 5 days to the super-heated steam that was at least over 390℃. Then, the super-heated steam was condensed at a cooler, in order to measure its flowrate and analyze its properties. After the super-heating experiments, we have observed a quantity of silica scale adhesion on the inside wall of the heat exchanger.

Figure 6 shows the observation results of a transverse cross section of the heat exchanger (super-heater) for saturated geothermal steam by electron microscopic photography. After the super-heating experiments, we observed the inside wall of the super-heater pipe, and found that no silica scale formation observed on the inner surface of section (b). Although the Silica adhesion was observed on the surface of section (a), the amount of the silica scale formation was less than that on the surface of thermostatic pipe.

This result suggests that saturated geothermal steam can be super-heated without worrying about scale adhesion; that is, the geothermal-biomass highly efficient hybrid GPP has high feasibility.

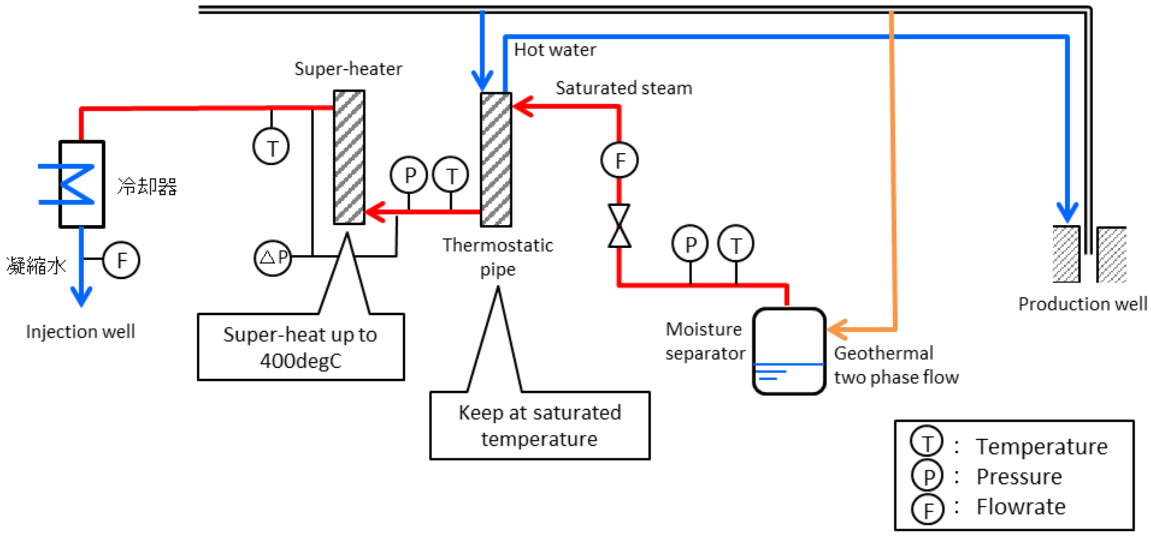

Figure 5: System flow diagram of geothermal fluid heating apparatus

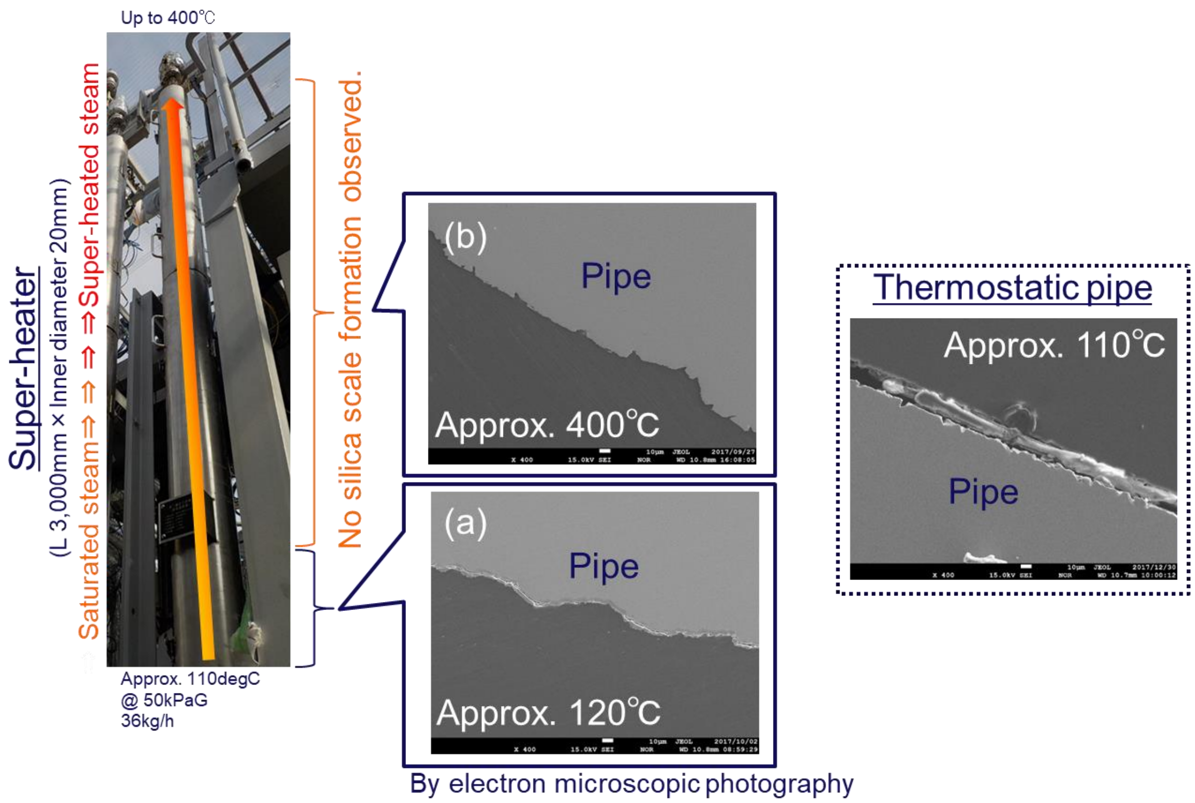

Figure 6: Observation results of a transverse cross section of the heat exchanger (super-heater) for saturated geothermal steam by electron microscopic photography (5 days later)

3. GEOTHERMAL IOT-AI PROJECT

On the basis of the obtained operation data, the geothermal binary power plant owner or maintenance business operator have analyzed the performance of major equipment, such as the heat exchanger, turbine, pump and cooling tower. However, their performance is affected by production well condition and seasonal temperature changes; thus it was very difficult to investigate their actual performance. In addition, even if the most inefficient equipment has been identified by operation data analysis, it was not possible to predict how the plant efficiency is improved by replacing it.

In our institute, we have developed general purpose software: EnergyWin^{TM} (Koda, 1999; Takahashi, 2007; Nakao, 2011) to analyze the thermal efficiencies of various power generation systems, such as the BTG (boiler, turbine, and generator) system, GTCC (gas turbine combined cycle) system, IGCC system, fuel cell and GPP, and we have applied it to more than 8 existing GPP units in Japan. Because we have created this entire program using the new algorithm (Patent number:3857840 (patented in Japan)), this software has the ability to solve the non linear simultaneous equations of a power generation system very rapidly and the flexibility to set various calculation conditions. This software can not only identify the performance-deteriorated or performance-reduced equipment in a power generation system but also provide quantitative estimations for each equipment against electric power output or thermal efficiency.

Recently we have added a new function to our software to utilize the standard property library: REFPROP (NIST Reference Fluid Thermodynamic and Transport Properties Database). Therefore, using the software, we have started to develop a new plant performance analysis system based on actual operation data for geothermal binary power plant "Yurihama GPP (Kyowa Chiken Consultant Co., Ltd)" in Japan (Figure 7).

Figure 7: Geothermal binary power plant "Yurihama GPP"

Figure 8 shows the configuration of geothermal IoT-AI system for "Yurihama GPP". This system has a surveillance IoT camera that can scan the numerical data from attached display on the power generator and transfer operation data to the isolated computer. Then, using EnergyWin^{TM}, the heat and mass balance of the entire system for every instant is analyzed continuously, and the owner or maintenance operator can analyze the plant performance and evaluate the effectiveness of the plant maintenance strategy to make maintenance easy and lower maintenance cost. The plant performance analysis system includes a "trend analysis system" and a "factor analysis system". Using the results calculated by EnergyWin, the plant performance tendency can be grasped or the effect of the performance degradation of certain equipment on a plant can be simulated.

<u>Trend and Factor analysis system</u>

The trend analysis system can draw easily the trend charts of all analysis results and correlation graphs shown below and provide quantitative estimations for each equipment against the electric power output or thermal efficiency of the plant.

- Turbine inlet pressure vs. main steam flow rate
- Turbine pressure ratio vs. turbine adiabatic efficiency
- Cooling water temperature vs. turbine outlet pressure
- wet-bulb air temperature vs. cooling tower (CT) capability

  vs. cold water temperature of CT

Then, factor analysis system can determine the effects of the performance changes of various equipment on the entire plant. In this system, we have prepared the program that can calculate the heat and mass balance of the entire plant from each equipment performance. Thereby, the user can only choose the analysis results of the trend analysis system obtained in two periods and analyze the difference in plant performance between periods. That is, the system can estimate the effectiveness of an operation and/or a strategy, and can also evaluate the effect of a seasonal factor.

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As one example, the owner or maintenance operator usually check a graph of the relationship between the wet-bulb air temperature and the cold water temperature of the cooling tower to evaluate the CT performance. If the performance of the cooling tower deteriorates over time, the cold water temperature at the same wet-bulb air temperature increases. However, it is difficult to observe in this graph whether there has been a significant secular change on CT. On the other hand, this system can analyze the CT capability based on the actual operation data. Therefore, using this system, we can assess whether it is necessary to repair CT at the next inspection. Cooling tower capability η_{ct} is defined as follows:

$$\eta_{ct} = \frac{(L/G)_a}{(L/G)_P} \qquad (1)$$

where

$(L/G)_p$ = design water-to-air ratio of cooling tower

$(L/G)_a$ = water-to-air ratio in which actual data is converted into design condition

Now we are in the middle of producing the IoT device for the plant, and we will install it at the end of September. In this paper and presentation, I will report the latest status of this project.

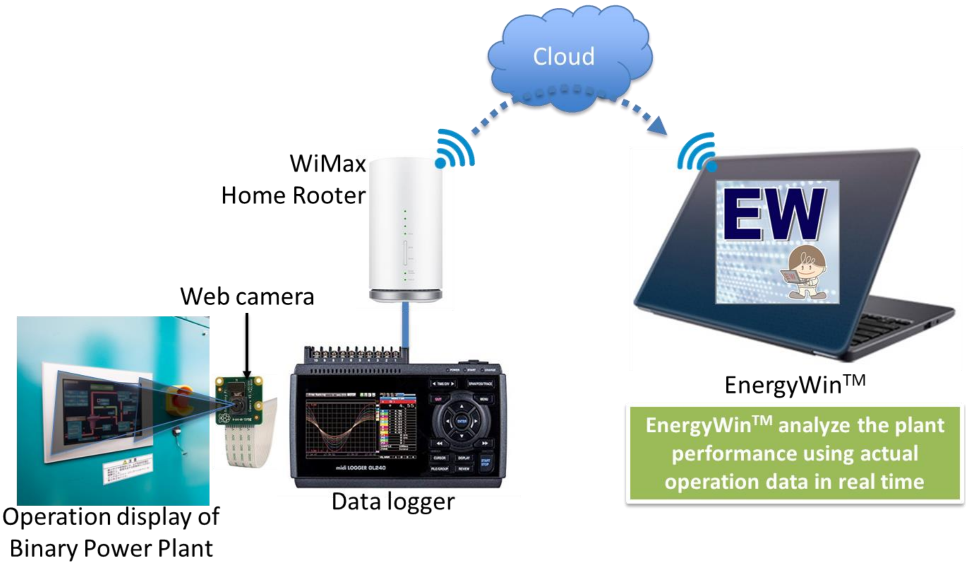

Figure 8: Configuration of geothermal IoT-AI system for "Yurihama GPP"

4. CONCLUSION

We have developed a geothermal-biomass highly efficient hybrid GPP combined with biomass heating facility. It is expected that the thermal efficiency or the power output of a GPP can be improved using this combination. Therefore, we have looked into the feasibility of these hybrid GPP systems in terms of their engineering, economic performance, environmental laws and regulations. In 2017, saturated geothermal steam super-heating experiments were performed. As a result, we confirmed that the hybrid GPP can be realized. However, in order to confirm the durability of the super-heater or evaporator and obtain more information to design a biomass heating facility, demonstration tests directed in practical use are needed.

And we have started to develop a new plant performance analysis system based on actual operation data for geothermal binary power plant "Yurihama GPP". This system has a surveillance IoT camera that can scan the numerical data from attached display on the power generator and transfer operation data to the isolated server. Then, EnergyWin™ analyze the plant performance and evaluate the effectiveness of the plant maintenance strategy to make maintenance easy and lower maintenance cost. Now we are in the middle of producing the IoT device for the plant, and we will install it at the end of September. In this paper and presentation, I will report the latest status of this project.

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