Recent Activities Regarding Performance Improvement of the Geothermal Power Plant

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ABSTRACT

The efficient utilization of geothermal resources requires continual enhancement of the performance and reliability of the power generating facilities, including not only the steam turbines, but the condenser performance as well. In this paper, we introduce development of condensation simulation method inside the condenser as an improvement of the performance of the power generation facility, and the actual equipment design and verification efforts using it.

1. Introduction

Mitsubishi Hitachi Power Systems, Ltd. (MHPS) is a company that Mitsubishi Heavy Industries, Ltd. and Hitachi, Ltd. integrated February 1st, 2014 with the thermal power generation system business of both companies. Our geothermal power generation business inherited the business of Mitsubishi Heavy Industries Ltd. mainly. After delivering test steam turbines for geothermal power generation in Japan in 1951, we have installed a total of 107 units in 13 countries including Japan while developing and applying various technologies to improve performance, economical efficiency, and reliability. We have supplied 3,249 MW of geothermal power generation facilities as output.

We have developed various corrosion control technologies to cope with geothermal steam quality differences based on the region, and have been trying to improve the performance including the specifications of the entire plant, based on experiences and techniques relating to geothermal power generation equipment accumulated in the history.

In this paper, as an effort to improve the performance of power generation equipment, we introduce the latest high efficiency and high reliability technology based on the results of the Los Azufres geothermal power plant which achieved the one-year operation rate guarantee in February 2016 in Mexico and the Matsuo-Hachimantai geothermal power plant which started commercial operation in January 2019. Both of plants introduced direct contact condenser connected to an axial exhaust turbine.

2. Recent Activities Regarding Performance Improvement of the Geothermal Power Plant

2.1 Direct Contact Condenser for Axial Flow Turbine

The type of geothermal power generation equipment from the viewpoint of turbine exhaust direction can be roughly classified into four types as shown in Figure 1. In general, downward exhaust (Downward) and upward exhaust (Upward) are adopted in many cases, but in the case of downward exhaust, it is necessary to increase the turbine installation level (or dig down the condenser to the underground). And in the case of upward exhaust, since the turbine exhaust direction is changed twice, the pressure loss becomes larger than other type of exhaust direction. On the other hand, in the case of axial flow exhaust (Axial), the installation level of the turbine and the condenser can be set to the same level, and because there is no change in the exhaust direction, the pressure loss is small, so that it has advantages regarding high efficiency and low cost. The difference between "with surface condenser" and "with direct contact condenser" in the figure is the difference whether the condenser is a surface condenser or a direct contact condenser.

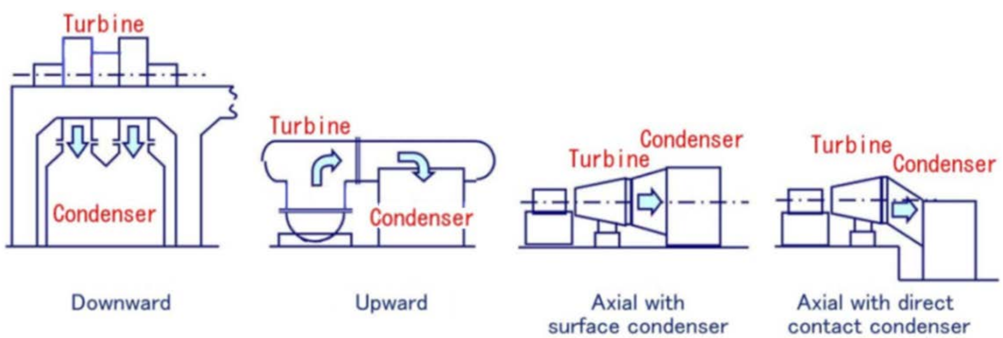

Figure 1: Line up for Turbine Exhaust Direction

Although geothermal power generation facility applies direct contact condenser in many cases, it will be needed investigation on exhaust flow direction. In the case of a direct contact condenser, the cooling water sprayed into the condenser falls downwards. In the case of downward exhaust and upward exhaust, since the turbine exhaust duct is connected to the upper side of the condenser, the steam flow inside the condenser flows from vertically upward to downward, so that the direction of downward flow of the cooling water . However, in the case of the axial flow exhaust system, since the turbine exhaust duct is connected to the side of the condenser, it flows into the condenser horizontally. Since the cooling water sprayed into the condenser falls due to gravity but it is blown sideway the turbine exhaust, it flows in a complicated locus. Therefore, in designing a direct contact condenser connected to an axial flow exhaust turbine, it is necessary to appropriately arrange the cooling water spray in consideration of the direction of both of the steam flow and the cooling water flow in the condenser.

2.2 Fluid-condensation iteration analysis of direct contact condenser

Based on the above background, we jointly developed a Fluid-condensation iteration analysis technology (Nagayama et al., 2018) using CFD (Computational Fluid Dynamics) in collaboration with Research & Innovation Center, Mitsubishi Heavy Industries, Ltd. and it is useful for designing the spray arrangement of the direct contact condenser connected to an axial exhaust turbine. As an analysis tool, ANSYS Fluent Ver. 13.0 is used, and a Discrete Phase Model (DPM) is applied to droplet track calculation. However DPM can consider the drag acting on the droplet, handling of vapor condensation phenomenon on the surface of the droplet is not considered as standard. So we have developed the steam condensation phenomena as UDF (User Defined Function) and newly incorporated in the model. Specifically, the amount of condensation on the surface of the droplet is calculated based on the condensation heat transfer coefficient separately obtained by the heat transfer test in this model, and the vapor component corresponding to the obtained condensation amount is removed from the gas phase and released. It is a model that reproduces the condensation phenomenon on the droplet surface by distributing the latent heat of condensation to the liquid phase. The analysis tool incorporating this condensation model makes it possible to analyze the coupled interaction of three phenomena: the flow of gas phase (steam and non-condensable gas), the flow of liquid droplets, and vapor condensation on the surface of droplets.

The next step was application of the analysis method to a model of an actual condenser. Figure 2 shows the condenser model used for the analysis and the result of analysis. The turbine exhaust flows from the left side of the drawing and is discharged from the non-condensable gas discharge port connected to the lower right. On the other hand, the cooling water is sprayed as droplets from the spray model installed in the condenser, and the steam is condensed by the cooling water. Each parameter (injection angle, injection initial velocity, droplet diameter, etc.) necessary for the spray model is obtained by a spray injection test which is separately performed. The condenser model in this figure is actually constituted as a three-dimensional model with a depth also in the direction into and out of the page. The contour diagrams shown in the figure are gas phase side calculation results on the vapor concentration distribution. The inlet (turbine exhaust) on the left side of the graphic has a uniform vapor concentration, but the vapor concentration is low (meaning that non-condensable gas concentration is high) from the center of the condenser to the lower right of the graphic, it can be found that condensation occurs in the turbine exhaust advancing direction.

On the other hand, although not shown here, droplet track tends to be blown to the right due to the influence of the turbine exhaust flow from the left side of the graphic as a whole. Some tracks will collide with the spray pipe and the wall halfway, but in this analysis the droplets that collided with the wall surface are removed from the analytical model as they do not contribute to condensation afterwards. It is considered strict evaluation condition in consideration of the contribution to the condensation at the time of flow down the wall after colliding with the wall surface and the contribution to condensation due to re-scattering. The cooling water droplets sprayed from the spray model simultaneously solve the spray droplets track from all the nozzles installed in the spray pipe. Therefore, although it can be said that the flight time is relatively long and contributes sufficiently to condensation based on the position of spray installation, for example, the droplets sprayed from the spray installed in the vicinity of the wall collide with the wall before the temperature rises sufficiently. In some cases it does not really contribute to condensation. In an actual design, it is decided to determine the appropriate arrangement of the cooling water spray nozzle by comprehensively considering the liquid droplet flight time, the droplet terminal temperature and the gas phase side condensation amount obtained from these calculation results.

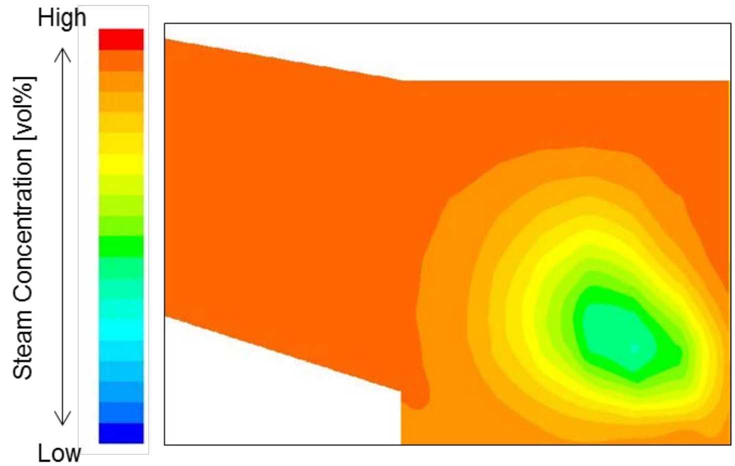

Figure 2: Steam Concentration Distribution

2.3 Application to Actual Power Plant

MHPS has delivered two geothermal power plants than combine an axial exhaust turbine and a direct contact condenser. These cases are introduced below.

2.3.1 Los Azufres III Phase I Project

Table 1: Particulars of Los Azufres III Phase I Steam Turbine

Operation Date	February, 2015
Customer	Comision Federal de Electricidad (CFE)
Type	SC1F : Single Casing Single (Axial) Flow
Rated output	50,000 kW at Net output
Rated speed	3,600 rpm
Main steam pressure	approx.8.0 bara
Main steam temperature	approx.170.4 deg C

This geothermal power plant locates in Los Azufres, Michoacan State which is at 250 km west of Mexico City. This project was ordered by Comision Federal de Electricidad (CFE, as the Geothermal Power Plant for Los Azufres III Phase I. MHPS provided design, manufacturing, purchasing, installation, civil work and commissioning of the main facilities such as a steam turbine and the auxiliary machines. Mitsubishi Electric Corporation supplied generators.

Since this power generation plant was the first facility as a combination of axial flow exhaust turbine and direct contact condenser for MHPS, careful performance verification was carried out with cooperation of Research & Innovation Center, Mitsubishi Heavy Industries, LTD. at commissioning. As a result of above, we found that the measured value in the actual equipment exceeds the predicted value by the CFD simulation regarding the steam condensation rate (= condensed steam flow rate / turbine exhaust steam flow rate) which is an index of the condensing performance of the condenser. In this predictive evaluation, it is considered that the prediction value was low because it was severely evaluated by some assumptions taking into consideration that it is the first type of machine, so by accumulating actual equipment evaluation results in subsequent projects in the future, it is necessary to review these assumptions to raise prediction accuracy. In addition, between February 2015 and February 2016, the CFE plant achieved 99.6% availability.

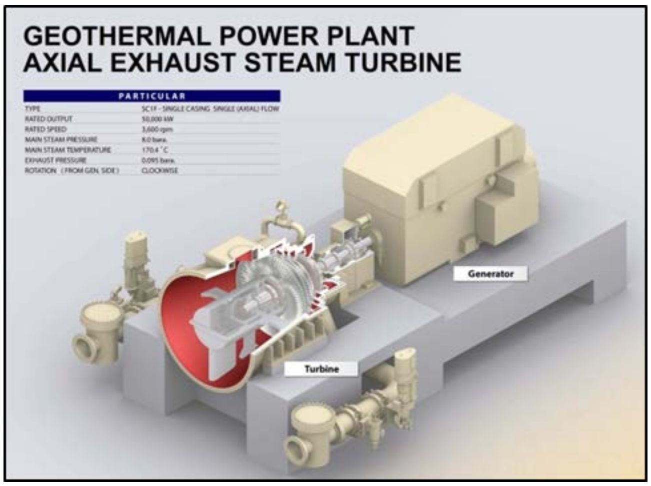

Figure 3: Cut View of Los Azufres III Phase I Steam Turbine

2.3.2 Matsuo-Hachimantai Project

Table 2: Particulars of Matsuo-Hachimantai Steam Turbine

Operation Date	2019
Customer	Iwate Geothermal Power Co., Ltd.
Type	SC1F : Single Casing Single (Axial) Flow
Rated output	7,499 kW at Generator output
Main steam pressure	approx.4.5 bar-abs
Main steam temperature	approx.148 deg C
Rated speed	approx. 6,000 rpm

This geothermal power plant locates in Hachimantai City, Iwate prefecture, Japan, and as a trend of the reappraise of the effectiveness of renewable energy in Japan, this power plant has been put into operation after a long period of 22 years since the last construction of a geothermal power plant with a capacity of more than 7 MW. MHPS is in charge of delivering main equipment such as steam turbine and condenser and JFE Engineering Co., Ltd. is in charge of construction of power plant.

Figure 4 shows the shipping condition of the turbine delivered to the site. As shown in the figure, a modular turbine was applied in order to simplify on‐site construction and transportation work. This turbine is the first axial flow exhaust turbine for flash type geothermal power generation facility in Japan, and the direct contact condenser applied to the turbine was also designed including optimization of spray nozzle arrangement. As a result, satisfactory performance was satisfied in the performance test and delivery was completed, and commercial operation has begun in January 2019.

Figure 4: Steam Turbine for Matsuo-Hachimantai Geothermal Power Plant

3. Conclusion

In this paper, we introduced development of condensation simulation method inside the condenser as an improvement of the performance of the power generation facility, and the actual equipment design and verification efforts using it.

The single-casing axial flow exhaust turbine, which our Group has been developing in recent years, can be connected to a condenser without changing the flow direction of the turbine exhaust as shown in Figure 2, and the pressure loss of exhaust can be reduced compared to the conventional upward exhaust and downward exhaust turbine.

In addition, since the turbine and the condenser are installed at the same height, it is possible to proceed with both the installation work in parallel and the construction period can be shortened. In addition, it can be listed up as one of the characteristics of the axial turbine that height of the turbine house can be lowered largely and as a result construction fee can be reduced. （Morita et al., 2016）

As a power generation facilities maker, by proposing optimal design conditions and systems for each power plant, and developing technologies to improve the reliability and economy of each equipment, in response to the needs of various markets, we would like to contribute to the further spread of geothermal power generation.

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