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# RECENTLY DEVELOPED GEOTHERMAL POWER PLANTS IN JAPAN

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## INTRODUCTION

Geothermal energy is a valuable, purely domestic, recyclable natural energy for energy resource-scare Japan, comparable to hydroelectric energy and is environment-friendly energy because it generates electric power without burning fossil fuels and emitting $CO_2$.

From the view-points of effective use of domestic natural resources and diversification of energy sources, we have developed geothermal resources as a part of electric power source development in all stages of the construction of the geothermal power plants and developed Otake Power Station in 1967 (11,000 kW initially and 12,500 kW in 1979) which was the first utility geothermal power station in Japan.

Following the development of Otake Power Station, we developed Hatchobaru Power Station Unit 1 in 1977, which was the first domestic full-fledged geothermal power station (23,000 kW initially and 55,000 kW in 1980) and Hatchobaru Power Station Unit 2 (55,000 kW) in 1990. Both power stations are located in Kyushu, Japan.

Till now we have developed 68 geothermal power stations all over the world, including power plants now under design and/or construction.

Now we are designing and manufacturing two utility geothermal power plants in Japan. The two geothermal power plants are Sumikawa Power Station (50,000 kW) and Yamagawa Power Station (30,000 kW). We are developing Sumikawa Power Station with Tohoku Electric Power Co. and Yamagawa Power Station with Kyushu Electric Power Co. We introduce below the two power stations and present technical features.

## SUMIKAWA AND YAMAGAWA

Sumikawa Power Station generates 50,000 kW and is of top-exhaust two-flow condensing geothermal turbine. (SC2F-23", or single-casing 2-flow with the last rotating blade of 23 inches) The turbine is classified into MODULAR-50. The number of 50 means the standard output of 50 MW.

While Yamagawa Power Station generates 30,000 kW and is of top-exhaust single-flow condensing geothermal turbine. (SC1F-25", or single-casing 1-flow with the last rotating blade of 25 inches) The turbine is classified into MODULAR-25.

Figure 1 and 2 shows system diagrams of the two plants.

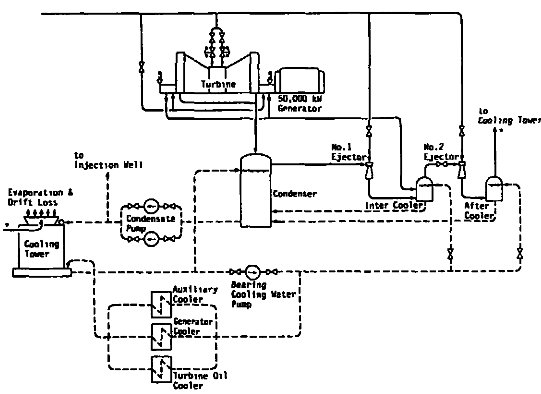


Figure 1 System Diagram of Sumikawa Power Station

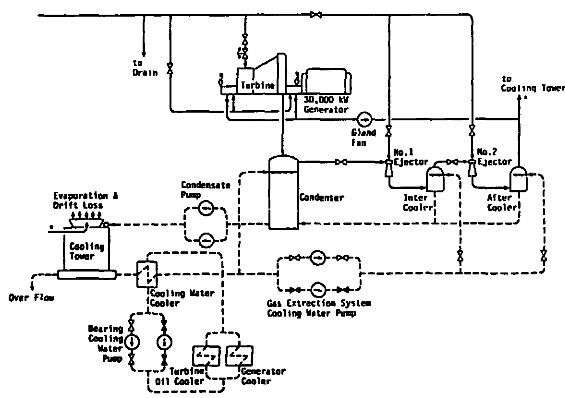


Figure 2 System Diagram of Yamagawa Power Station

Table 1 shows main schedules of the construction and commissioning of the two plants.

Sumikawa Power Station is located in Akita Prefecture, Tohoku, Japan. And Yamagawa Power Station is located in Kagoshima Prefecture, Kyushu, Japan. Refer to Figure 3.

Table 1 Schedule of the Construction of Sumikawa and Yamagawa

| Item | Sumikawa | Yamagawa |
|---|---|---|
| Beginning of Construction | Apr. 1993 | Sept. 1993 |
| Commissioning | March 1995 | March 1995 |

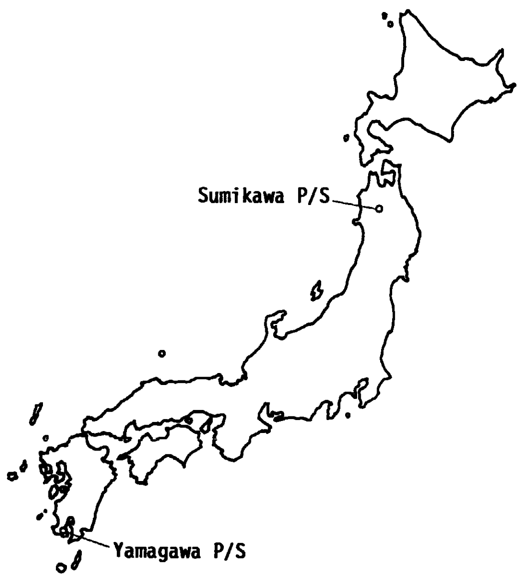


Figure 3 Locations of Sumikawa Power Station and Yamagawa Power Station

1. Basic Design

Generally speaking, as unit output becomes smaller, construction cost per unit output (kW) goes higher. In these two plants, the rise of the construction cost per unit output is suppressed as far as possible by using a compact design as mentioned below.

Upward top-exhaust type module turbine is used, thereby obviating the need for high floor turbine base, which would be necessary for bottom-exhaust type turbines. The condenser is arranged outdoor to make the turbine house compact. It is important to make the turbine house compact, since it is cost-saving and the two geothermal power plants are located neighboring National Parks. In designing the plants and steam facilities, consideration was given to the shape and color of housing. Production wells, injection wells and steam and hot water transmission pipes are all installed in compact manner within the compound of the power stations. Along the edge of the power plants, trees are planted by selecting appropriate kinds and growing method taking into account the environmental conditions. Thus, it is considered that harmony with the natural landscape is maintained.

2. Heat Cycle

In designing turbine inlet steam pressure, an optimum point is obtained on the basis of the characteristics of steam wells.

Hot water at Yamagawa Power Station contains much silica, making it necessary to raise the brine separator operating pressure to some extent. As the result, steam conditions are decided as 10.8 bara and 183.2 °C.

While steam conditions of Sumikawa Power Station is decided as 4.9 bara and 151.1 °C.

To prevent scale deposition in injection wells, single flash cycle system is adopted in both the plants because hot water temperature can be held high and hot water ratio is low. This system also is simple and advantageous in construction costs of steam transmission equipment than double flash cycle system.

Brine separators are provided around steam production wells and hot water is returned into injection wells. Steam separated in the brine separators is collected in a steam reservoir in separating bases and led into the power plants through one steam transmission pipe.

3. Control of the Plants

Generally speaking, geothermal plants are operated continuously at full load. This is same case with Sumikawa Power Station and Yamagawa Power Station. The plants will be monitored at all times from remote places from the plants, except at start-up of the plants.

Start-up operation of the plants will be performed from the control room of each power station. The shut-down of the plants can also be done in remote place. Aimed at safe and easy plant operations during start-up and shut-down, plant control and monitoring systems are designed as far as possible to permit central monitoring operations for the whole plant, and operations from shut-down condition to full load operation and from normal operation to shut-down are automated.

Especially the control of the steam turbines is conducted by digital electro/hydraulic governor. For operations of equipment, CRT operations will be adopted.

## 5. Turbine Details

The main specifications of Sumikawa Power Station and Yamagawa Power Station are shown in Table 2. And cross sectional views are shown in Figure 4 and 5.

Table 2 Specifications of Sumikawa Turbine and Yamagawa Turbine

| Item | Sumikawa | Yamagawa |
|---|---|---|
| Turbine Type | SC2F-23" | SC1F-25" |
| Output at Generator Terminal | 50,000 kW | 30,000 kW |
| Rotation | 3,000 rpm, Clockwise viewed from turbine to generator. | 3,600 rpm, Clockwise viewed from turbine to generator. |
| Main Steam Press. | 4.9 bara | 10.8 bara |
| Main Steam Temp. | 151.1 °C | 183.2 °C |
| Turbine Exhaust Press. | 0.11 bara | 0.13 bara |
| Blading | o 5 Stages x 2 23" LP End<br>o Blades of 1st and 2nd stages are of Integral Shroud Blade (ISB).<br>o 1st nozzles are no scaling nozzle cooled by water.<br>o Nozzles of 2nd ∿ 5th stages are of bow type. | o 6 Stages x 1 25" ISB LP End<br>o Blades of all stages are of ISB. |

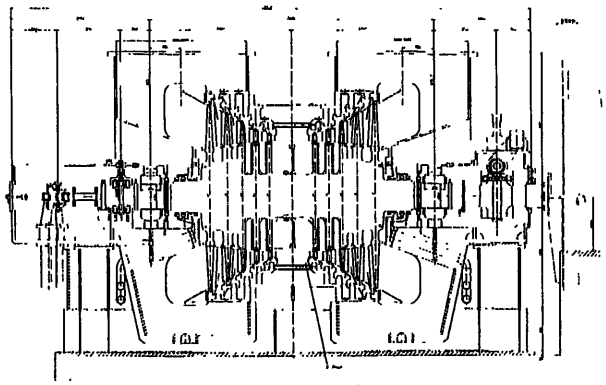

Figure 4 Cross Section of Sumikawa Turbine

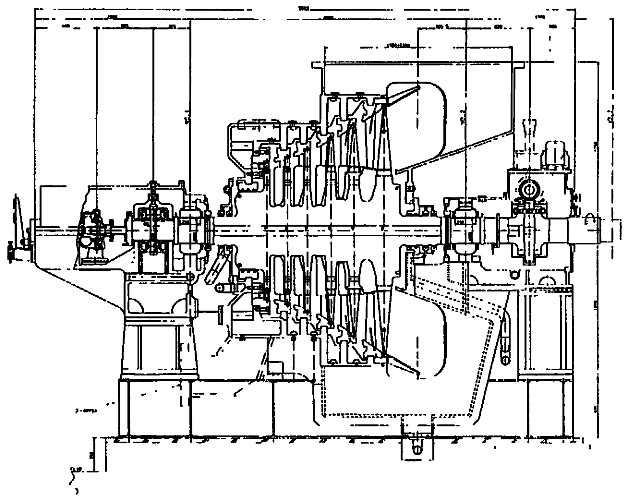

Figure 5 Cross Section of Yamagawa Turbine

### (i) Blading

As for Sumikawa Power Station, the height of the last blade is 23-inch. Rotating blade of 1st and 2nd stages are of Integral Shroud Blade (ISB).

There are two special features about Sumikawa's blading;

- No Scaling Nozzle Cooled by Water

1st stage nozzle are cooled by water running in the nozzle to prevent nozzle scaling.

- Bow Nozzle

2nd - 5th stages nozzles are of bow type to increase efficiency by decreasing secondary flow loss.

These two special features are explained later.

As for Yamagawa Power Station, the height of the last blade is 25-inch. All rotating blades are of ISB.

(ii) Main Stop Valve and Governing Valve

To avoid sticking of the valve stem due to steam scales, the swing check type and the butterfly type are used for the main stop valve and the steam governing valve, respectively. And teflon seal of non-leak type is adopted between valve stem and bush. For further improvement in reliability, grease lubrication is adopted between valve stem and bush.

## 6. Generator Details

Air-cooled type generators are adopted which is standard for this class. Refer to Table 3.

Table 3 Specifications of Sumikawa Generator and Yamagawa Generator

| Item | Sumikawa | Yamagawa |
|---|---|---|
| Generator Type | Synchronous Generator | Synchronous Generator |
| Output | 55,600 kVA | 34,000 kVA |
| Excitation | Brushless | Brushless |
| Cooling | Air Cooled | Air Cooled |

Internal pressure impression equipment for raising the pressure in the generator above the external pressure is provided to prevent $H_2S$ gas from entering the generator, and all copper materials inside the generator are varnished or covered with insulation tape so that they will not be exposed at overhaul inspections. As the excitation device, a brushless exciter is adopted which is advantageous in maintenance and space saving.

## 7. Plant Details

(i) Condensate Pump

Considering good operating results in Hatchobaru Power Station, a vertical can pit type pump is adopted which is compact in installation area and easy in coping with noise problem.

(ii) Condenser

To make the turbine house compact, the condenser is arranged outdoor, and the spray jet type condenser is adopted in the two plants. The spray jet condenser requires less cooling water than a surface condenser, and is unsusceptible to the effects of noncondensible gas.

As for the material, stainless clad steel plates is used for the shell considering corrosive gas and condensed water peculiar to geothermal steam and water.

(iii) Air Ejector

To make the turbine house compact, the air ejector are arranged outdoor. High-reliability, single-train, two-stage ejector type without driving unit is adopted in the two plants.

(iv) Bearing Cooling Water Cooler

As for Yamagawa Power Station, reflecting the operating results in Hatchobaru Power Station, independent systems with fresh water circulation including a heat exchanger are adopted for bearing cooling water for generator cooler and turbine oil cooler, and a bearing cooling water cooler is provided in the cooling tower intake reservoir.

As for Sumikawa Power Station, bearing cooling water from the cooling tower is supplied to auxiliary cooler, generator cooler, and turbine oil cooler, as well as to inter cooler and after cooler.

(v) Pipe and Valve

The turbine house space is minimized by efficiently arranging turbine exhaust pipe, main steam pipe and circulating water pipe.

(vi) Turbine House

The turbine house space is greatly saved by reducing the number of component equipment items by simplification and rationalization as mentioned above. The height of the turbine house is reduced by installing the turbine and generator on the ground level.

(vii) Cooling Tower

An economical, two(2)-cell cooling tower is adopted in Yamagawa Power Station, and four(4)-cell cooling tower in Sumikawa Power Station, which have functions of exhausting and diffusing extracted gas as well as cooling circulating water. The cooling tower is arranged taking into account the condition of gas diffusion based on the meteorological data on direction and velocity of wind.

## NEW TECHNOLOGIES APPLIED

### (i) No Scaling Nozzle Cooled by Water

Generally, there are many impurities in geothermal steam, such as $SiO_2$, iron, chloride, etc. These impurities will cause serious troubles to the turbine.

Typical troubles of geothermal turbine are valve sticking, erosion, corrosion, load down with scaling, and stress corrosion cracking.

All these troubles are caused by the above impurities. So, it is not too much to say that the amount of impurities in geothermal steam entering the turbine will determine the reliability and life of geothermal power station.

Scaling is the most severe at the first stage nozzle because saturated steam entering the turbine moistens at the first stage nozzle and condenses on the surface of the nozzle. However, the temperature of the nozzle is high, so the condensed water evaporates again, leaving the scale such as $SiO_2$ on the surface of the blade. (Figure 6)

No scaling nozzle is the nozzle cooled by water which runs in the nozzle, lowering the temperate of the nozzle and limiting the evaporating of water on the nozzle surface. (Figure 7)

Sumikawa Power Station is the first plant we implement the water cooled nozzle.

### (ii) Bow Nozzle

The bow nozzles are applied to 2nd to 5th stage nozzles of Sumikawa Power Station.

The bow nozzle configuration of "Full-3D Design Rateau Blade" presses the steam flow against end walls of the tip and base section by blade force.

As the result, the development of vortex and boundary layer can be reduced, and hence, the secondary flow loss is reduced. Refer to Figure 8, 9, 10 and 11.

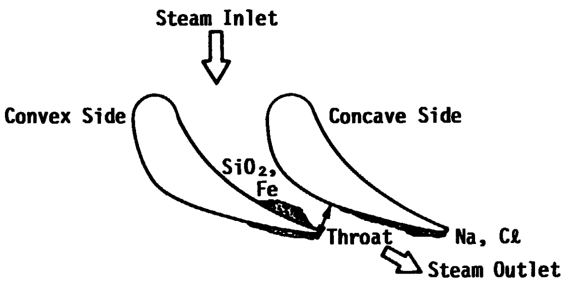


Figure 6 Scaling Phenomenon of First Stage Nozzle

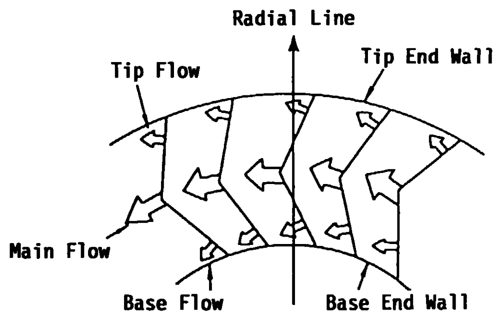


Figure 8 Turbine Internal Flow

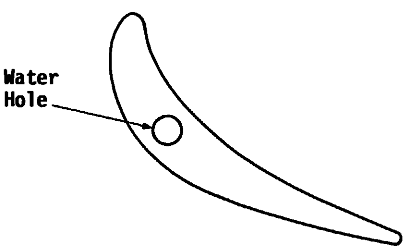


Figure 7 Water Cooled Nozzle

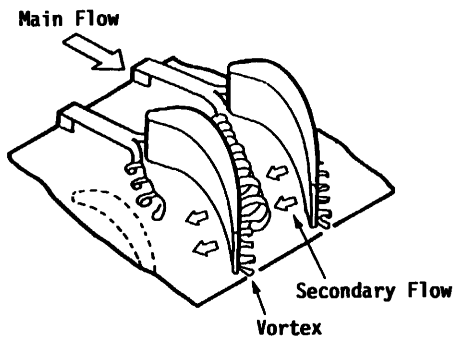


Figure 9 Secondary Flow and Vortex

Figure 10 Bow Nozzle (Model Turbine Blades)

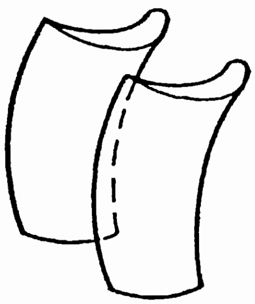

Figure 11 Sketch of the Bow Nozzle

## CONCLUDING REMARKS

We have introduced in this paper the two power stations, which are now under design and construction.

From the view-points of effective use of domestic and worldwide natural resources and diversification of energy sources, we would like to develop further geothermal resources as a part of electric power source development.

## ACKNOWLEDGEMENTS

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