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GEOTHERMAL POWER PLANTS IN JAPAN ADOPTING RECENT TECHNOLOGIES

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Abstract

Japan is located in a volcanic zone where there are widespread and valuable geothermal energy resources with huge amount of potential. However, geothermal power generation is not developed as desired due to high cost.

The new technologies are applied to the four plants which we constructed recently in order to realize an improvement in economy and reliability. Those plants have been successfully operated and achieved high dependability.

1. Introduction

Geothermal power generation is a desirable energy source from the view point of energy security in Japan which relies on imports for more than 80% of its energy because geothermal resources are purely indigenous and are considered a superior source for power generation with less impact on the environments in that CO_2 emission is very low. The Japanese government has a policy of developing geothermal power generation in order to realize these advantages.

However, geothermal power generation is not developed as desired at the present time because its power generating costs are relatively higher than those of thermal or nuclear power generation for the reasons given below:

- -Prospective geothermal power generating resources are mostly located inside of national parks and development of the resources is regulated.
- -Development period is longer than 10 years.
- -Drilling costs are relatively high.
- -Risks inherent to development of underground resources are high.

Under the recent circumstances of low and stable costs of fossil fuels, it is considered an urgent task to improve the economical benefit and reliability in order to spread and extend geothermal power generation. MHI has conducted research and development of new technologies and applied them to plants to improve the economy and reliability with consideration to operating results of geothermal power plants and special characteristics of geothermal steam.

This paper discusses the technologies which we applied to the four turbine units which we supplied to Sumikawa Geothermal Power Station (owned and operated by Tohoku Electric Power Corporation), and, Yamagawa, Ogiri and Takigami Power Stations (owned and operated by Kyushu Electric Power Corporation) in order to realize an improvement in economy and reliability of geothermal power generation. This paper also describes the operating results from the initial commercial operation up to the present time.

Fig-1 Locations of recent geothermal power plants
Table-1 Design specification of recent geothermal power plants

2. Sumikawa geothermal power station

2-1. Outline of power station

Sumikawa geothermal power station, located in Akita prefecture, Tohoku district, is the first plant to which MODULAR-50 was applied. MODULAR-50 is a standard turbine unit with double-flow and top-exhaust construction. The capacity range of MODULAR-50 is from 40MW to 70MW depending on steam conditions. MODULAR-50 is installed on a ground-level concrete foundation, eliminating the need for a turbine base of 5-7 meters in height to reduce the cost of civil work.

Turbine steam exhaust is condensed in a direct-contact type jet condenser installed outdoors. The gas extraction system is a two-stage ejector type.

Fig-2 Sumikawa geothermal power plant
Fig-3 MODULAR-50

2-2 New technologies

(1) *Water-cooled nozzle*

Water-cooled nozzles were adopted for the first stage. All nozzles are provided with holes in profile for clean and cool water to pass through to reduce nozzle metal temperature and thereby prevent re-evaporation and concentration of drain fluid, which causes scaling on first-stage nozzles.

Fig-4 Water cooled nozzle

(2) *Full 3-dimensionally designed "Bow" nozzle*

Bow nozzle design is adopted for high pressure stages. The bow nozzles were developed by three-dimensional fluid dynamics analysis. Nozzle profile is bowed along the radial line to press steam flow against the end walls at tip and base of the nozzle. As a result, boundary layer thickness and the development of vortexes at each end wall decreases, and the secondary flow loss is reduced and performance is improved.

Fig-5 Bow nozzle

(3) *Wet- and dry-type cooling tower*

In Sumikawa field, the minimum ambient temperature is expected to be –20 degC, so it was anticipated that with an ordinary wet-type cooling tower, the moisture contained in the exhaust air may freeze and stick to the nearby trees and break branches. To avoid this problem, a dry- and wet-type cooling tower was adopted. A dry- and wet-type cooling tower consists of a wet type cooling section in which heat exchange is achieved by direct contact between water and air, and dry cooling section in which heat exchange between water and air is achieved via tubes. In winter, both dry and wet sections are operated to reduce moisture contained in the exhaust air and prevent sticking of ice on nearby trees. In summer, it is desirable that only the wet section is operated in order to achieve higher performance.

Fig-6 Dry- and wet-type cooling tower

(4) Remote control

The power station is remotely controlled from Kazuno city 31 km away to minimize the number of operators in the power station and to reduce operating costs.

3. Yamagawa, Ogiri and Takigami power station

3-1 Description of power stations

Yamagawa and Ogiri power station are located in Kagoshima Prefecture in Kyushu island and generate 30MW each. Takigami power station is located in Oita prefecture, Kyushu island and generates 25MW. MODULAR-25 for which low erection cost and civil cost in service in the U.S, was adopted for these three units to maximize the economic benefit in Japan. The capacity range of MODULAR-25 is from 20MW to 35MW. Turbine exhaust is condensed in a direct-type jet condenser installed outdoors. The gas extraction system is of the two-stage ejector type in Yamagawa. Since main steam pressure of Ogiri and Takigami is not high enough to drive a 2nd stage ejector, a hybrid type consisting of an ejector for the 1st stage and a vacuum pump for the 2nd stage is adopted. These 3 plants have a closed-cycle bearing cooling water system for the bearing oil cooler and generator air cooler, that is independent from the auxiliary cooling water system used for gas extraction system by means of shell and tube-type heat exchanger.

Fig-7 Yamagawa geothermal power plant
Fig-8 Ogiri geothermal power plant
Fig-9 Takigami geothermal power plant
Fig-10 MODULAR-25 turbine generator

3-2 New technologies

(1) Titanium blades

The location of Yamagawa is very close to the sea, and chloride concentration in hot water is approximately 20,000ppm. In order to maintain reliability against corrosion or stress corrosion cracking, titanium(Ti-6Al-4V) is selected for the 1st stage moving blade where the steam condition is cyclic between wet and dry, and where corrosion is most severe.

(2) Bow nozzle

In Yamagawa power station, bow nozzles are used in 1st, 2nd and 3rd stage nozzles as in Sumikawa power station.

(3) Integral shroud blade(ISB)

In ISB construction, the tenon rivet and shroud band can be eliminated and accumulation of harmful impurities around the tenon rivet and stress corrosion cracking due to the impurity can be effectively prevented. In addition, the ISBs have contacts with neighboring blades and remarkably reduce the vibration stress by about 20% or less compared to conventional blades.

ISB was applied to all 4 above-mentioned turbine units in order to realize higher reliability.

Fig-11 Integral shroud blade

(4) Remote control and supervising system

Yamagawa and Ogiri power stations are remotely controlled from Sendai power station, which is 80km away from Yamagawa and 60km away from Ogiri. Takigami power station is also remotely controlled from Otake geothermal power station, which is 14km away from Takigami power station.

Yamagawa, Ogiri and Takigami geothermal power plants are remotely operated and supervised by a few operators only during the day on week days. During weeknights and on holidays, they are remotely controlled and supervised, and no operator is working in each power station.

Supervision of operating condition, plant control such as load change and data logging can be done at both individual control room and the remote control station. Plant start-up is performed at each geothermal power plant control room because remote start-up is legally prohibited. Special attention was paid to plant interlock logic to maintain a high level of safety.

4. Operation experiences

A geothermal power station serves as a base load power station to maximize the economic benefit. This is because a geothermal power station uses natural energy which cannot be stored. In order to carry out economical power generation, it is necessary to operate a power station at a high availability performing proper operation and maintenance.

Fig.12 shows the availability of the 4 plants since initial commercial operation. All 4 plants have shown high availability (over 90%), even including outages due to periodic inspections, indicating a high reliability of both steam generating equipment and power generating equipment and verifying that proper operation and maintenance have been conducted.

Fig-12 Availability of 4 recent plants

(2) **Operation and maintenance technology**

In order to achieve high reliability and economy, improvements not only in design and manufacturing stages should be made but also in operation and maintenance. Operation and maintenance technologies used in the 4 plants is described below, together with the operating conditions.

5-1. Scaling and maintenance technique

(1) Countermeasures to scaling in Yamagawa

In Yamagawa, scaling has been experienced in the turbine first-stage nozzles since the initial commercial operations, and resulting to difficulty in maintaining the rated output because of a reduction in nozzle throat area. Severity of scaling on nozzles is indicated by the nozzle blocking ratio, A, as defined by the equation (1). In Yamgawa power station, this blocking ratio increased in a short period of time as shown in Fig.13. If scaling advances further, rubbing between stationary parts and moving parts occurs and may damage the turbine. So in Yamagawa, scaling was removed by water washing to the turbine.

(Definition of nozzle blocking ratio)

$$A = \left(1 - P_2 / P_1\right) \times 100 \qquad (1)$$

P_1: $Steam\ chest\ pressure\ actually\ measured\ (kg / cm^2 a)$

$P_2 = (P_0 / G_O) \times G_1$

P_0: $Steam\ chest\ pressure\ in\ clean\ condition\ (kg / cm^2 a)$

G_0: $Steam\ flow\ in\ clean\ condition\ (kg / h)$

G_1: $Steam\ flow\ actually\ measured\ (kg / h)$

Fig-13 Nozzle blocking ratio in Yamagawa
Fig-14 Scaling on first stage nozzle in Yamagawa
Table-2 Chemical analysis of scale (Yamagawa)

The turbine water washing equipment takes water from the hot well pump outlet , pressurizes it with a pump and injects it into the main steam line. The injected water dissolves and removes scale deposited on the first stage nozzles. Chemical analysis of the scale in Yamagawa is shown in Table 2. The ratio of water soluble scale components such as Na and Cl was high, so water washing was considered effective. Water washing was carried out 2 years after the initial commercial operation. If the injected water flow rate is too high, there ia a possibility of erosion, so water at 1-2 wt% of main steam flow was injected. As a result, the nozzle blocking ratio decreased as shown in Fig.10, and water washing was sufficiently effective to remove scales. At present a high availability is maintained by periodic water washing.

Fig-15 System diagram of turbine water washing
Fig-16 Effect of turbine water washing

(2) Effectiveness of water-cooled nozzle

As mentioned in section 2, water-cooled nozzles were adopted in Sumikawa for the first time in the world. Overhaul inspection after initial operation show scale deposited on the first-stage nozzles was minimal, indicating that thewater-cooled nozzles were effective. Nozzle surface temperature at the nozzle throat is lower than that of the steam flow, so it was found that a liquid film which was formed on the nozzle surface is effective in washing away scale (particularly NaCl). Table-3 shows chemical analysis of scale. The main component of the scale is SiO2, and NaCl was less than 1%. This also indicates that water cooled nozzles were more effective to remove water soluble scale components.

Fig-17 First stage nozzle (Sumikawa)
Table-3 Chemical analysis of scale (Sumikawa)

5-2. Maintenance against Corrosion

In the 4 plants, the following maintenance was adopted against corrosion in order to maintain a high availability for a long period.

(1) Shot peening

Geothermal steam contains corrosive gases such as H_2S and impurities such as Cl and so the turbine rotor is exposed to corrosive environments as well as centrifugal stress, which can cause stress corrosion cracking(SCC). Shot peening is carried out as an effective measure against SCC by reducing tensile stress in the rotor surface which is one of the factors of SCC. Shot peening is carried out by striking small steel balls to the rotor to apply compressive stress of about 30kg/cm2 at a depth of 100-150m from the rotor surface, thereby reducing the local surface tensile stress occurring in the rotor.

(2) Coating of rotor gland

The rotor gland of a geothermal turbine is exposed to steam containing corrosive gas and air(oxygen) entering from outside as well as highly corrosive fluid. So the rotor gland is given a special coating at every periodic inspection to prevent corrosion.

6. Conclusion

Japan is located in a volcanic zone where there are widespread and valuable geothermal energy resources with huge amount of latent energy. For effective utilization of this rich and re-cyclable natural energy, we endeavor to improve the economy and reliability by applying the technologies described in this paper and invigorate the market for geothermal power generation in Japan by developing new technologies.

Acknowledgments

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Fig-1 Locations of recent geothermal power plants

Fig-2 Sumikawa geothermal power plant

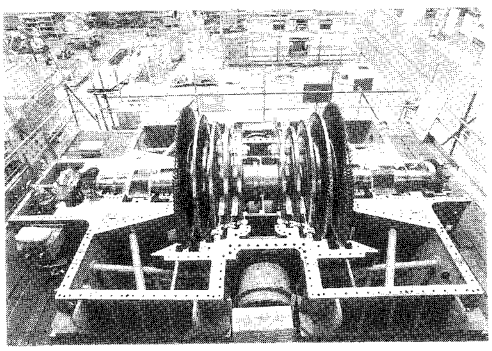

Fig-3 MODULAR-50

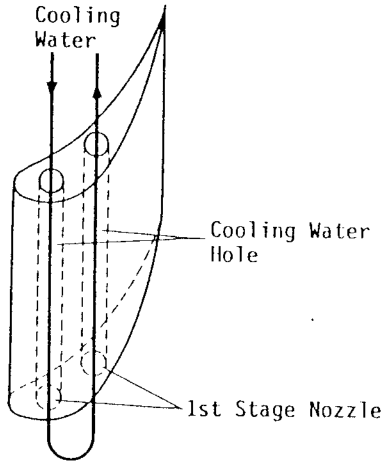

Fig-4 Water cooled nozzle

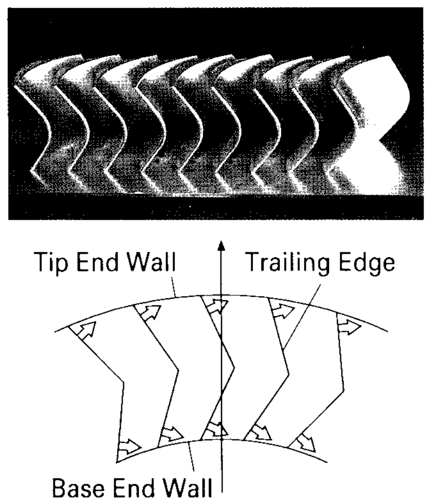

Fig-5 Bow nozzle

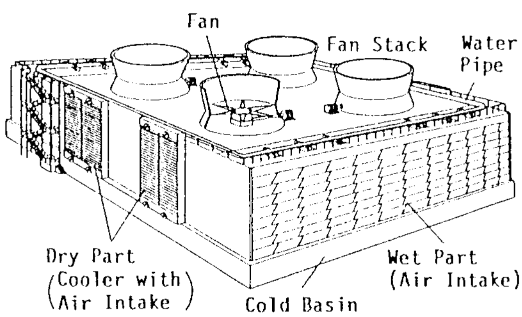

Fig-6 Dry- and wet-type cooling tower

Fig-7 Yamagawa geothermal power plant

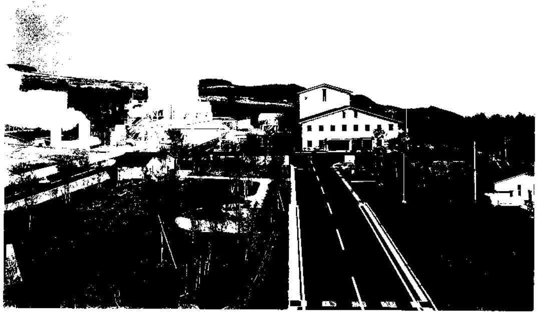

Fig-8 Ogiri geothermal power plant

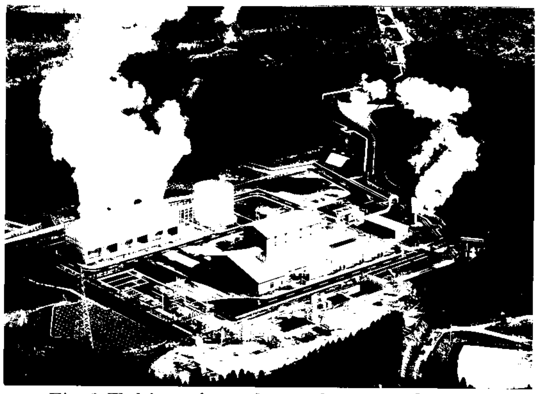

Fig-9 Takigami geothermal power plant

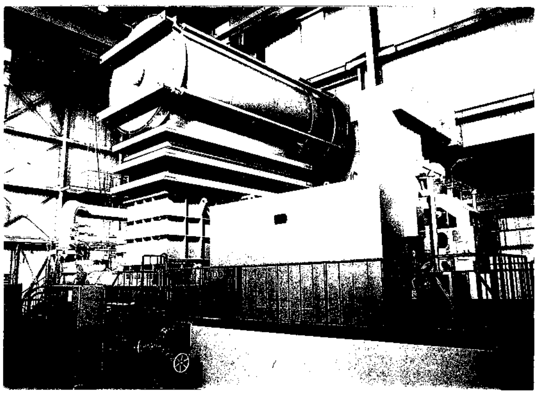

Fig-10 MODULAR-25 turbine generator

Fig-11 Integral shroud blade

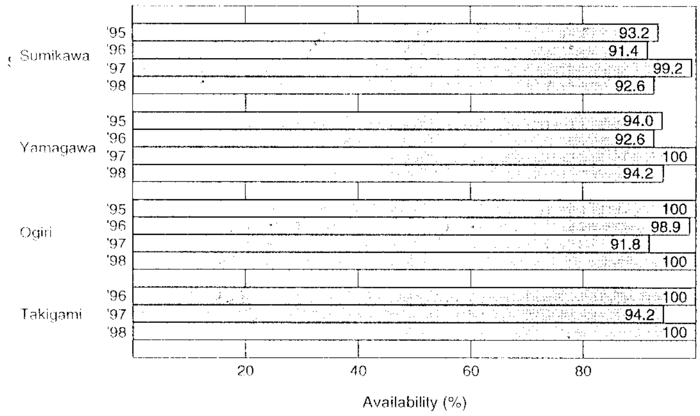

Fig-12 Availability of 4 recent plants

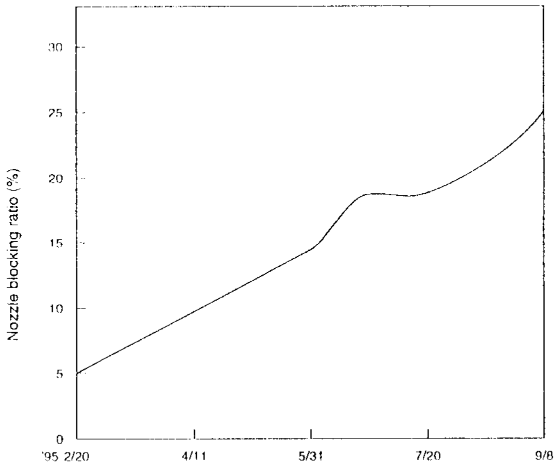

Fig-13 Nozzle blocking ratio in Yamagawa

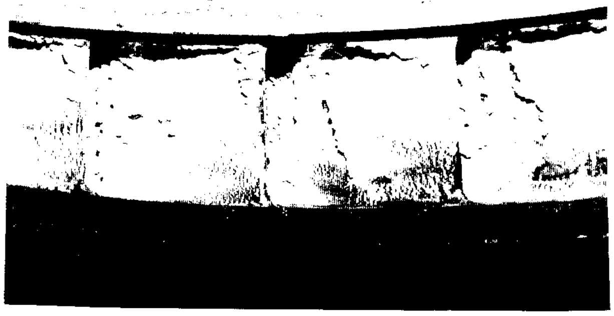

Fig-14 Scaling on first stage nozzle in Yamagawa

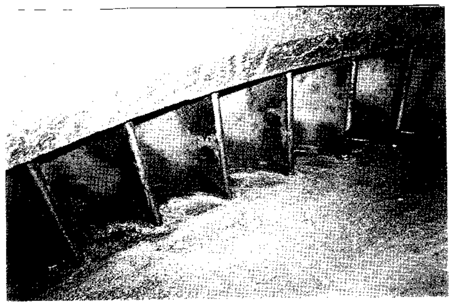

Fig-17 First stage nozzle (Sumikawa)

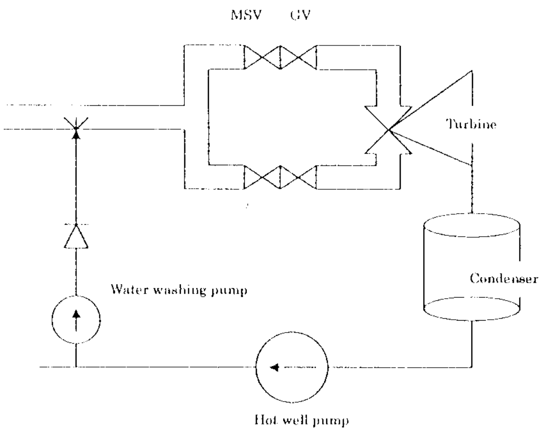

Fig-15 System diagram of turbine water washing

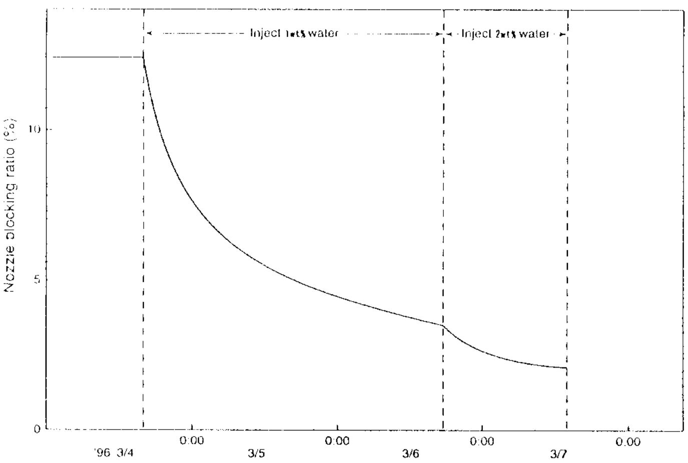

Fig-16 Effect of turbine water washing

Table-1 Design specification of recent geothermal power plants

	Item	unit	Sumikawa	Yamagawa	Ogiri	Takigami
	Beginning of construction		Apr. 1993	Sept. 1993	Nov.1994	Jun. 1995
	Commissioning		Mar. 1995	Mar. 1995	Mar. 1996	Nov. 1996
Turbine	Type		Single pressure single flow condensing turbine	Single pressure single flow condensing turbine	Single pressure single flow condensing turbine	Single pressure single flow condensing turbine
Turbine	Rated output	kW	50,000	30,000	30,000	25,000
Turbine	Speed	rpm	3,000	3,600	3,600	3,600
Turbine	Steam condition					
Turbine	Pressure	MPa	0.49	1.08	0.29	0.25
Turbine	Temp	℃	151.1	183.2	132.9	126.8
Turbine	Gas content	wt%	0.17	0.5	0.12	0.3
Turbine	Steam consumption	t/h	389	216	293	254
Turbine	No. of stage		5 x 2	6	4	4
Turbine	Last blade	inch	23	25	25	25
Generator	Type		Air cooled generator	Air cooled generator	Air cooled generator	Air cooled generator
Generator	Capacity	kVA	55,600	34,000	34,000	28,000
Condenser	Type		Spray type jet condenser	Spray type jet condenser	Spray type jet condenser	Spray type jet condenser
Condenser	Vacuum	bara	0.098	0.132	0.108	0.108
Condenser	Cooling water temp	℃	22.0	33.5	29.0	32.0
Condenser	Hot water temp	℃	43.5	49.4	45.3	45.3
Condenser	Water Quantity	t/h	9,100	6,550	9,370	9,870
Cooling tower	Type		Dry and wet type of cross flow mechanical draft	Wet type of counter flow mechanical draft	Wet type of counter flow mechanica l draft	Wet type of counter flow mechanica l draft
Cooling tower	No. of cell		4	2	3	3
Cooling tower	Design wet bulb temp	℃	14.0	26.0	21.0	24.0
	Type of gas extraction system		Two stages of steam jet ejector	Two stages of steam jet ejector	Hybrid type(Ejector+vacuum pump)	Hybrid type(Ejector+vacuum pump)
	Type of hot well pump		Vertical centrifugal double suction	Vertical centrifugal double suction	Vertical centrifugal double suction	Vertical centrifugal double suction

Table-2 Chemical analysis of scale (Yamagawa)

	pH (1g/100 mlH_2O)	SiO_2 (%)	Fe (%)	T-S (%)	SO_4 (%)	CO_3 (%)	Cl (%)	B (%)	Ca (%)	Na (%)
No.1	8.8	25.1	0.3	0.5	1.0	16.9	19.1	< 0.1	15.2	11.7
No.2	—	11.1	3.2	0.9	—	—	—	—	22.4	—
No.3	8.9	26.4	0.5	0.4	1.0	12.6	22.2	< 0.1	11.6	13.5

Table-3 Chemical analysis of scale (Sumikawa)

	pH	SiO_2	$A\ell_2O_3$	T-Fe	Cℓ	Cℓ	B	B	SO_4	T-S
	g/100mℓH_2O	%	%	%	%	mg/kg	%	mg/kg	%	%
Nozzle inlet (upper, Gen side)	7.1	78.2	0.5	4.9	0.1	–	–	–	0.2	0.8
Nozzle outlet (lower, Gov side)	8.2	74.9	0.4	2.6	1.1	–	1.1	–	0.9	1.0
Nozzle outlet (upper, Gen side)	8.3	71.7	0.5	2.6	0.9	–	–	–	1.4	0.8