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DEVELOPMENT OF SCALE DEPOSIT INHIBITION TECHNOLOGY USING TURBINE WATER-COOLED NOZZLE

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ABSTRACT

The scale deposition onto turbines in geothermal power stations is usually regarded as unavoidable whereas this is one of the most serious concerns which can affect the interval of periodical inspections.

In common practice, scale is removed manually and mechanically during periodical inspections of power stations, but there are some cases of geothermal power stations where scale is removed from the turbines without stopping turbines by practicing the turbine washing operation.

The jointly developed technology by Tohoku Electric Power Co., Ltd. and Mitsubishi Heavy Industries, Ltd. in the present work, is a technique capable preventing scale deposition and precipitation by water-cooling the turbine first stage nozzle subjected to the highest deposition of scale and its effect has been confirmed through its model in the field test.

This paper presents these test processes and the test results.

FORMATION AND DEPOSITION OF SCALES IN TURBINES

Scale depositing points in geothermal turbines tend to concentrate on the first stage nozzle, as shown in the example in Figure 1.

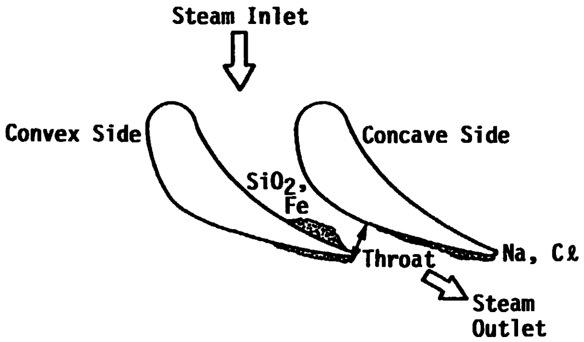


Figure 1. Scaling Phenomenon on First Stage Nozzle

As schematically shown in Figure 1, scales are likely to gather in the trailing edge area on both concave and convex sides. On the convex side, the scale deposition tends to concentrate at the downstream side from the throat.

Tables 1 and 2 show analysis results of the chemical composition of scales depositing on the first stage nozzle.

Table 1. Chemical Composition of Scale on First Stage Nozzle

Plant		Chemical Composition (wt.%)					
		SiO_2	Ca	Cℓ	T-S	Fe	Na
HATCHOBARU 1U Japan 55 MW		53.7	1.7	23.0	1.1	1.0	15.2
ONUMA Japan 10 MW		52.8	1.7	—	11.0	4.9	—
KAKKONDA 1U Japan 50 MW		0.05	Trace	50.5	—	Trace	36.2
SMUD GEO. U.S.A. 78 MW		83.0	0.37	Trace	3.1	3.3	—
BEOWAWE U.S.A. 17 MW		54.6	Trace	1.0	2.1	0.6	—
KAMOJANG Indonesia 55 MW		40.7	—	—	—	37.9	1.3
LEYTE Philippines 37.5 MW		13.9	7.5	7.5	17.4	11.4	10.3
MAK.BAN. 3U Philippines 55 MW		70.7	1.8	5.3	—	2.4	3.7
MILOS Greece 2 MW	Sat. Steam	9.3	5.8	7.2	0.8	24.4	—
	Super-heated Steam	25.9	19.8	2.6	7.8	4.4	—

A specific tendency was noted in the depositing location, nemely that SiO_2 and Fe tend to deposit on the concave side, and Na and Cℓ on the convex side.

Table 2. Chemical Composition of Scale on First Stage Nozzle (on Leyte, Philippines)

	Sampling Point	Chemical Analysis (wt.%)						X-Ray Diffraction (Main Constituent)
		SiO_2	Na	Ca	Fe	Cℓ	T-S	
1	1st Stage Upper Nozzle Concave	13.8	2.3	6.6	24.2	3.3	10.0	$CaSO_4$(Anhydrite), NaCℓ(Halite), Fe_3O_4(Magnetite), α-Fe_2O_3(Hematite), β-FeO(OH)(Akaganeite), FeS
2	1st Stage Lower Nozzle Concave	13.9	7.5	7.5	17.4	11.4	10.3	$CaSO_4$, NaCℓ, Fe_3O_4, α-Fe_2O_3, FeS
3	1st Stage Upper Nozzle Convex	1.7	29.2	1.8	3.3	49.8	1.3	NaCℓ, KCℓ(Sylvite), $CaSO_4$
4	1st Stage Lower Nozzle Convex	2.1	28.1	1.8	1.7	51.1	1.4	NaCℓ, KCℓ, $CaSO_4$

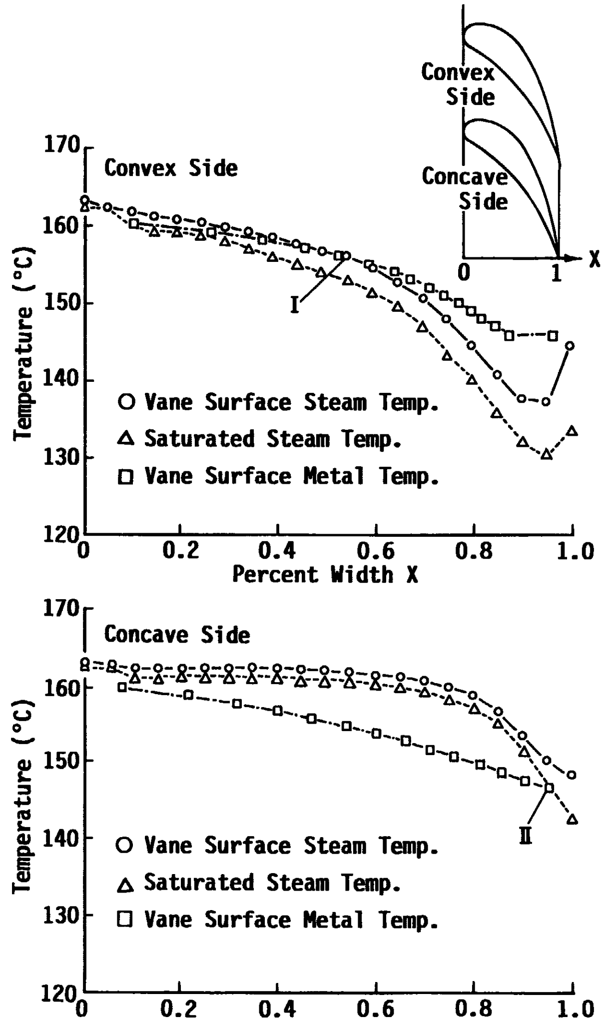


Figure 2. Results of Estimation of Temperature Distribution on Nozzle Vane Surface (Mean Section)

ESTIMATION OF PRECIPITATING AND DEPOSITING MECHANISM OF SCALES

The internal flow in the first stage nozzle passage (mean section) in a specific condition was evaluated by three-dimensional flow numerical analysis, and the temperature distribution on the metal surface of the first stage nozzle was estimated by using the estimated results of the static pressure distribution of steam on the nozzle vane surface, temperature distribution, and flow velocity distribution. In estimating the metal surface temperature distribution, the following turbulent flow plate heat conduction formula was used as the thermal conductivity (Heat Conduction Engineering Data, 1975, ed. by the Japan Society of Mechanical Engineering).

$$Nu = 0.023\, Re^{0.8} Pr^{0.4} \quad \text{..............} \quad (1)$$

where Nu: Nusselt number
Re: Reynolds number
Pr: Prenatal number

Figure 2 shows the relation of steam and metal temperature distribution on the nozzle vane surface.

The following points were clarified from the diagram.

(1) Convex Side

In the downstream portion of about 55 % from the nozzle front edge, the metal temperature is higher than the vane surface steam temperature.

For this reason, the drain is re-evaporated from the metal (vane) surface, and NaCℓ precipitates and deposits. SiO_2 also precipitates, but is likely to migrate to the steam side. After dispersing in the steam flow, it hardly deposits on the nozzle convex side.

(2) Concave Side

In the range up to the point II, the metal (vane) surface temperature is lower than the vane surface steam temperature, and change of steam into drain is promoted on the vane surface. However, the drain is not re-evaporated, and hence NaCℓ does not precipitate.

On the other hand, SiO_2 precipitates near the trailing edge after the point II as SiO_2 in the drain is concentrated due to re-evaporation and exceeds solubility.

PRINCIPLE OF SCALE PRECIPITATION IN ACTUAL TURBINE

Steam, which is usually saturated steam (point A in Figure 3) containing impurities such as SiO_2, Fe, Na and $C\ell$ is controlled by a control valve as shown in the steam table (h-s Diagram) in Figure 3.

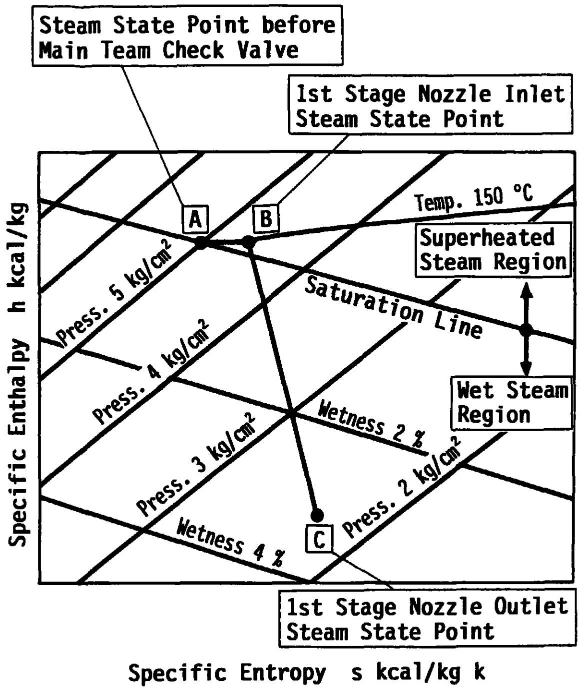


Figure 3. Steam Expansion Diagram

Accordingly, the point of steam condition is moved from point A to point B in the control valve, and at the inlet side of the first stage nozzle (point B), it is slightly superheated steam.

The main steam expands in the process of passing through the first stage nozzle (changing from point B to point C), and becomes wet steam. Impurities contained in the steam are then abundantly dissolved in concentrated form in the drops of water formed by condensation.

When the water drops come in contact with the nozzle metal surface which has been heated by higher temperature steam at the nozzle inlet side, they are re-evaporated, and their impurity concentration is further increased.

As a result, impurities precipitate as scales near the nozzle throat, which thereby becomes clogged.

SCALE DEPOSITION PREVENTIVE TECHNOLOGY

(1) Present Measures

At present, the latest technology is the water washing method of scales depositing on the nozzle, whereby geothermal condensate is injected into the inlet steam piping of turbine.

While good effects are obtained in plants in which overheated steam flows in some geothermal turbine, the method does not work effectively in other plants. The effectiveness may be dependent on the characteristic of the scale.

(2) Scale Deposit Prevention in Steam Turbines

On the basis of results of studies on the scale precipitation and deposition mechanism, a method of preventing scale precipitation on the nozzle was devised by lowering the metal temperature on the nozzle surface, and inhibiting re-evaporation and concentration of drain on the nozzle surface.

Precipitation or deposition of $NaC\ell$ on the nozzle convex side is thought to occur when the drain on the nozzle surface is re-evaporated. Precipitation or deposition of SiO_2 on the nozzle concave side is thought to occur when SiO_2 is concentrated in the drain near the trailing edge of the nozzle, thereby exceeding its solubility.

Thus, by inhibiting such re-evaporation and concentration of drain, it appears to be possible to arrest precipitation of $NaC\ell$ and SiO_2, which may be achieved by lowering the metal tmperature of the nozzle surface.

Accordingly, by arranging a cooling passage in the nozzle and passing cooling water from outside, a method of lowering the metal temperature of the nozzle surface was devised (this is called water-cooled nozzle, see Figure 4).

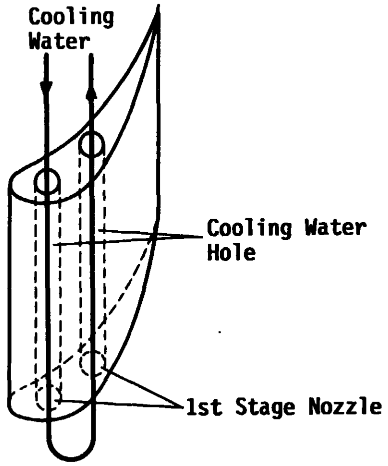


Figure 4. Structure of Water-Cooled Nozzle

INDEPENDENT ELEMENT TEST OF WATER-COOLED NOZZLE

To verify the results of studies on the mechanism of scale precipitation and deposition discussed in the preceding chapter, an independent element test of a water-cooled nozzle was conducted for two months, using actual geothermal steam.

The test was conducted in the Sumikawa Geothermal Field (Hachimandaira, Akita, Japan) with total cooperation from Mitsubishi Material Co., which is the steam supplier for the Sumikawa Geothermal Power Plant.

(1) Test System

To compare the new measures with existing nozzles, the test system consisted of three lines as specified below. The test system configuration is shown in Figure 5.

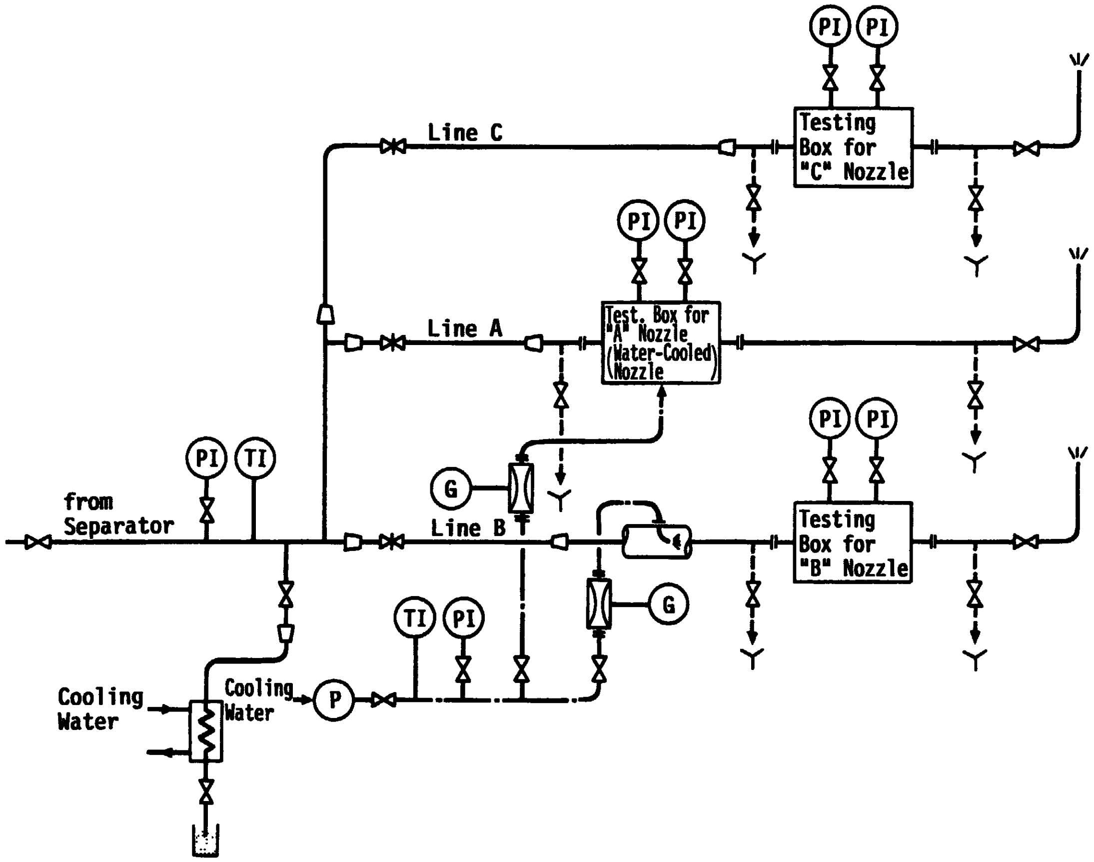


Figure 5. Nozzle Scale Deposit Test System Diagram

Line A:
Verification line of the scale deposit preventive effect of a water-cooled nozzle

Line B:
Verification line of the conventional method (water washing) by washing the nozzle in water, by spraying water on to the steam line

Line C:
Conventional nozzle assembly line without scale deposit preventive measures

The field test was conducted from August 9 through October 22, 1991, and the net test duration was 66 days. The field test process is shown in Table 3.

To observe the scale deposit state on the nozzle, open inspections were conducted three times during the test.

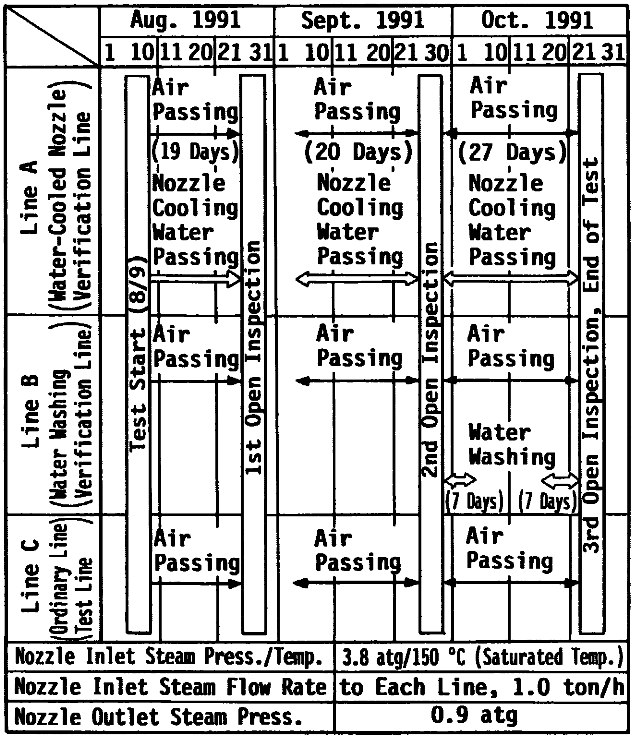
First open inspection:
August 28, 1991 (after 19 days of continuous operation)

Second open inspection:
September 24, 1991 (after operation of 39 days in total)

Third open inspection:
October 22, 1991 (after testing for 66 days in total)

The results of the measurement of purity of steam used in the test are summarized in Table 4.

Table 3. Scale Deposit Field Test Process



	Aug. 1991 1 10 / 11 20 / 21 31	Sept. 1991 1 10 / 11 20 / 21 30	Oct. 1991 1 10 / 11 20 / 21 31
	Test Start (8/9); 1st Open Inspection	2nd Open Inspection	3rd Open Inspection, End of Test
Line A (Water-Cooled Nozzle) (Verification Line)	Air Passing (19 Days) Nozzle Cooling Water Passing	Air Passing (20 Days) Nozzle Cooling Water Passing	Air Passing (27 Days) Nozzle Cooling Water Passing
Line B (Water Washing) (Verification Line)	Air Passing	Air Passing	Air Passing Water Washing (7 Days) (7 Days)
Line C (Ordinary Line) (Test Line)	Air Passing	Air Passing	Air Passing
Nozzle Inlet Steam Press./Temp.	3.8 atg/150 °C (Saturated Temp.)		
Nozzle Inlet Steam Flow Rate	to Each Line, 1.0 ton/h		
Nozzle Outlet Steam Press.	0.9 atg		

Table 4. Steam Purity Measurement Results at Test Apparatus Inlet

Date	pH	Cℓ (ppm)	SiO2 (ppm)	Fe (ppm)	T-S (ppm)
8/10 (A.M.)	–	< 0.01	0.10	< 0.1	–
8/10 (P.M.)	–	< 0.01	0.10	< 0.1	–
8/11 (A.M.)	4.5	< 0.01	0.17	< 0.1	9

(2) Test Results

The scale deposit states of lines A, B, and C after operation for two months are shown in Figure 6. Lines A, B, C are shown in Photos A, B, C.

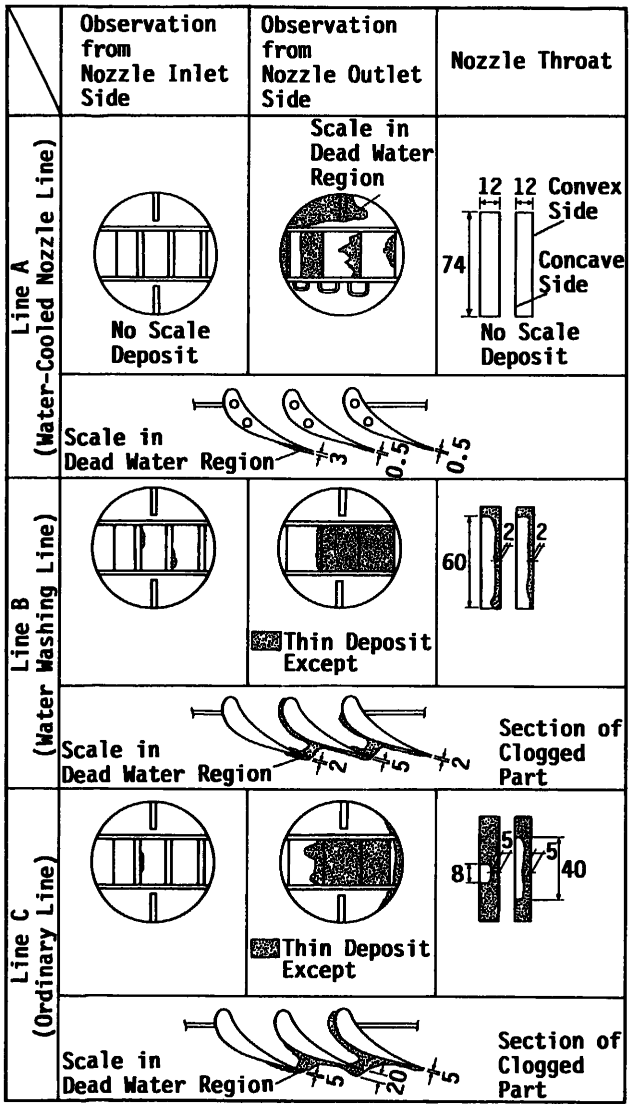
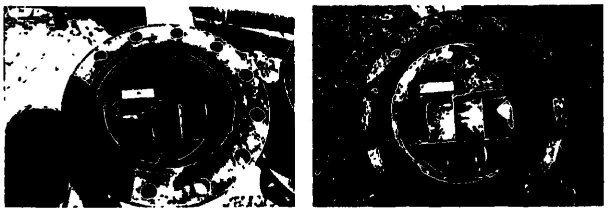


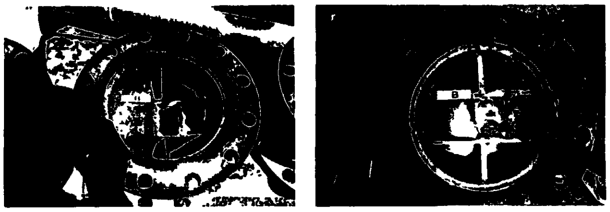
Figure 6. Scale Deposit State at Third Inspection



Taken from Nozzle Inlet Side Taken from Nozzle Outlet Side

after Operation for 39 Days in Total
(Open Inspection on Sept. 24, 1991)

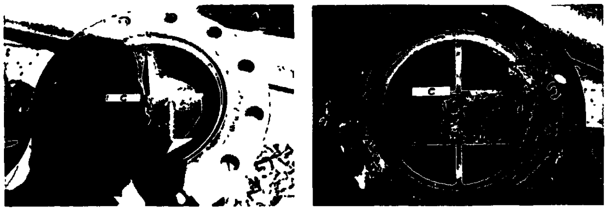
Photo A. Scale Deposit State
(Line A: Water-Cooled Nozzle Line)



Taken from Nozzle Inlet Side Taken from Nozzle Outlet Side

after Operation for 39 Days in Total
(Open Inspection on Sept. 24, 1991)

Photo B. Scale Deposit State
(Line B: Water Washing Line)



Taken from Nozzle Inlet Side Taken from Nozzle Outlet Side

after Operation for 39 Days in Total
(Open Inspection on Sept. 24, 1991)

Photo C. Scale Deposit State
(Line C: Ordinary Nozzle Line)

1) On the water-cooled nozzle, almost no scale deposited during the test period of about two months, and cooling of the nozzle proved to be extremely effective for preventing scale deposition.

It is thought that scale precipitation and deposition was prevented as a result of inhibition of re-evaporation and concentration of drain on the nozzle surface by cooling of the nozzle.

2) Removing effects of deposited scale by water washing were confirmed. However, after massive scale deposition, it was not effective in removing the majority in the 7-day water washing period of the present study.

3) In a conventional nozzle without preventive measures, about 1/3 of the nozzle throat was clogged with scale in a short period of 19 days.

VERIFICATION TEST IN ACTUAL TURBINE

On the basis of the field test results, the scale deposit preventive nozzle (water-cooled nozzle) was applied for the first time in the first stage nozzle of a turbine with a rated output of 50 MW at the Sumikawa Geothermal Power Plant owned and operated by Tohoku Electric Power Co., Ltd.

In this geothermal power plant, steam was initially admitted to the turbine on December 5, 1994, the initial synchronization was on December 13, and commercial operation was started on March 3, 1995.

(1) Verification Plan

Turbine Structure

Figures 7 and 8 show the structure of the geothermal turbine with rated output of 50 MW, and a general view of the turbine just before shipping from factory.

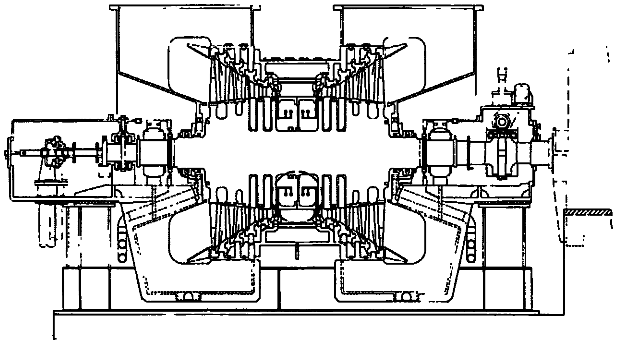


Figure 7. Cross Section of Sumikawa Turbine (Rated Output 50 MW)

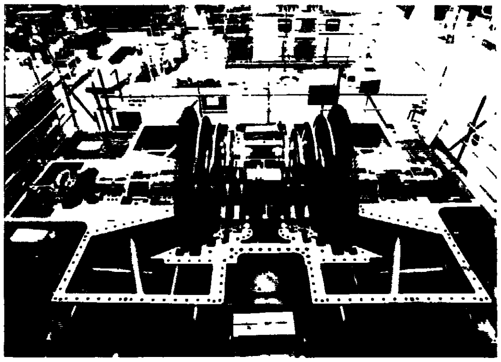


Figure 8. General View of Geothermal Turbine with Rated Output of 50 MW (Just before Shipping from Factory)

(2) Intermediate Report

After five months of turbine operation, the first stage nozzle was inspected, and almost no scale deposit was detected, as shown in Photo D.

Photo D. First Stage Nozzle Inlet of Turbine (Sumikawa Geothermal Power Plant Turbine)

CONCLUSIONS

As a method of preventing scale deposit in turbines that is a absolutely essential for maintaining the performance and reliability of geothermal turbines, cooling the first stage nozzle was found to be very effective, as proved by theoretical analysis, an independent element test of a water-cooled nozzle, and a field test in an actual plant.

We shall continue our efforts to supply electric power stably by enhancing the reliability of geothermal power plants.

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