Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

SILICA SCALE ABATEMENT SYSTEM ON THE UENOTAI GEOTHERMAL STEAM TURBINE

Kenji Takayama[1], Naori Komiyama[2], Yoshinobu Takahashi[3] and Nobuhiko Shakunaga[4]
[1]Tohoku Electric Power Co., Inc., 291 Nakano, Yuzawa-shi, Akita, Japan
[2]Toshiba Corporation, 4-36-5 Turumichuo Turumi-ku ,Yokohama-shi, Kanagawa, Japan
[3]Akita Geothermal Energy Co., Ltd., 21 Shimono, Yuzawa-shi, Akita, Japan
[4]Japan Metals & Chemicals Co., Ltd., 1-3-6 Saien Morioka-shi, Iwate, Japan

Key Words: silica scaling, geothermal turbine

ABSTRACT

As suspected from a continuous rise in the turbine inlet pressure, severe silica-rich scaling was found on the turbine nozzles during an inspection conducted after three months from the start of commercial operation.

Careful investigation of the scaling mechanism revealed that, as a significant pressure rise occurred in the turbine housing, silica-rich scaling was formed by precipitation through evaporation, flashing and super-saturation of water droplets carried over from the production-well separators. The following systems, therefore, were added on the existing facility to reduce silica scaling.

A very encouraging test result was obtained from the "turbine water injection system" which was installed immediately upstream of the turbine to de-superheat steam in the turbine chest by intermittently injecting condensate water into the steam line. This system was very successful in reducing the formation of silica scale and in washing out the scale deposits from the turbine nozzles .

A "scrubbing/mist-eliminator system" was also installed upstream to improve the steam quality before the steam entered the turbine. The mechanism is to purify the steam by continuously injecting condensate water through a venturi tube, and to separate the mist by two separators (mist eliminators).

Step-by-step field tests have been conducted to find out the most effective "turbine water injection" and "scrubbing/mist-elimination" operation procedure.

Currently, a combination of the above systems is satisfactorily working to minimize silica scaling in the turbine.

1. INTRODUCTION

The Uenotai Geothermal Power Station (28.8 MW; upgraded from 27.5 MW in February 1997) is located in Yuzawa City, Akita Prefecture. It was a joint development of Tohoku Electric Power Co., Inc. and Akita Geothermal Energy Co., Ltd. Tohoku Electric Power Co. was responsible for the generating equipment, and Akita Geothermal Energy Co. for the steam equipment. Commercial operation started on March 4, 1994.

Soon after the start of commercial operation, the opening of the main steam governing valve increased rapidly when operating at the rated output, and the generator output finally decreased. The results of an overhaul inspection of the steam turbine indicated that scale had formed around the first-stage nozzles of the steam turbine and around the strainer of the main stop valve, etc.

Removing the scale requires an overhaul inspection and a cleaning of the steam turbine about once every three months. This led us to develop the silica scaling abatement system.

2. CONFIRMING THE STATUS OF SCALE ADHERENCE

2.1. Turbine operation change

The pressure of the turbine inlet governing valve and the pressure at the turbine inlet increased rapidly soon after the start of commercial operation. On April 12, 1994, the forty-first day of operation, the aperture of the steam governing valve of the turbine inlet was 69%, and this was a great increase compared to the 48% when the operation started. Judging from similar experience at the other geothermal power stations, the cause was assumed to be scale adhering to the turbine nozzle. In order to identify the type of scale and to accurately determine the location of the scale, the steam turbine was subjected to an overhaul inspection from April 12 to 24, 1994.

2.2. Analysis of the scale

A white scale, composed of silica and a few salts (NaCl, etc.), was found in significant quantities at the first-stage nozzle of the steam turbine and, to some extent, at the main stop valve, sub-stop valve, strainer etc. A black scale, mainly composed of iron compounds, was found at the scale separator that was installed to remove solid material from the well production steam (Table 1).

The location where the scale formed almost coincided with the location where the pressure and temperature changed rapidly as a result of the change in the diameter of the steam line. The first-stage nozzle of the turbine was where the pressure and temperature changed most rapidly and where scale formation was consequently most noticeable.

3. MECHANISM OF SILICA SCALE FORMATION

The iron-compound scale was noticeably found, but an analysis of the hot water revealed a very small amount of iron.

It is possible that the surface of the well casing had corroded, because each of the wells had been out of service for more than two years before operation. Consequently, the iron-compound scale was judged to have come from this corrosion.

If the production wells are used continuously, the iron causing the scale would decrease, and therefore no special countermeasures were deemed necessary. Similarly, salts were not thought to be a problem because of their small amounts. Therefore we considered that the countermeasures against scale should be focused on silica.

3.1. Mechanism of silica carry-over into steam

Carry-over

The results of chemical analyses (Table. 2) indicated that the steam before the turbine inlet contained 0.7 mg/l of silica. The steam was formed by separation from the two-phase fluid brought to the surface from a production well at the well pad using a cyclone separator. The separation efficiency of a cyclone separator is generally 99.90 to 99.99 wt.%, and the steam after the separation process contains 0.01 to 0.10 wt.% of mist. The silica concentration in the mist is considered to be equal to that of the hot water (ca. 8.900 mg/l), and thus the concentration of silica in the steam is calculated based on the separation efficiency, i.e., 0.8-0.9 mg/l.

Selective carry-over

Selective carry-over is more significant at higher steam temperatures. At Uenotai, since the temperature of the two-phase fluid is not high (below 180°C), the silica originating in selective carry-over is negligible.

3.2. Mechanism of silica precipitation in the steam

The following are possible mechanisms of precipitation for the silica that is carried over into the steam:

· Precipitation due to over-saturation
Fig. 1 shows the relationship between the solubility curve of non-crystal silica and the silica concentration in the hot water after the cyclone separator process. The figure shows that the hot water after having passed through the separator is over-saturated with respect to silica. This implies that the mist contained in the steam after separation is over-saturated, or nearly over-saturated, with silica. Therefore, if the temperature decreases, and flashing, boiling etc. occur in the mist, even slightly, over-saturation will lead to silica precipitation. Some of the silica scale observed at Uenotai is thought to originate in over-saturation, but it is difficult to qualitatively estimate how much silica scale is produced by this mechanism.

· Precipitation due to flash
Small pressure drops occur at the main stop valve, the sub-stop valve and the strainer, and this causes flashing of the hot water mist. This flash probably produces much of the silica scale adhering to these areas. Repeated precipitation of silica in the mist leads to progressive silica scale forming on the surfaces.

· Precipitation due to boiling
Numerical simulation and field experiments using real geothermal steam confirmed that the temperature of the first-stage turbine nozzle at the steam outlet side is higher that the steam temperature (Amagasa, 1995). This causes the mist covering the nozzle surface to boil; its water content vaporizes, and the dissolved components in the mist, such as silica, precipitate and solidify on the nozzle outlet.

4. CONFIGURATION OF SCALE ABATEMENT SYSTEM

4.1. Turbine Water injection system

Theory

Over-saturation, flash and boiling of the mist are possible mechanisms for scale adherence. In these three cases, injecting water into the steam is effective in raising the wetness of the steam (preventing flash and boiling) and in lowering the concentration of the silica in the mist (preventing over-saturation). Washing off of the accumulated scale is also expected

Turbine Water injection equipment

The turbine water injection equipment directly atomizes the circulating water (steam condensed water) through the injection nozzle into the main steam piping. The injection nozzle is positioned some distance before the main stop valve, and the distance allows the injected water and steam to thoroughly mix before they reach the steam turbine inlet. To prevent the steam turbine from corroding, wetness measuring equipment was installed before the turbine inlet (Fig. 2).

Turbine Water injection test result

Turbine water injection tests were conducted at the site for more than seven months. The injection time varied from one hour to 14 days, and the amount of water injected ranged from 1.11 to 4.2 t/h.

The results were:

· With water injection rate, the scale accumulated when the amount of water was below 2.0 t/h, but stopped accumulating when it was over 2.0 t/h.
· With a long injection time of two weeks, the aperture of the main steam governing valve continuously reduced, which indicated in some cases an apparent washing off of refractory scale, including silica scale.
· The overhaul inspection of the steam turbine conducted after the water injection test indicated that when the wetness of the steam was below 2% (designed allowable value), long-term injection did not produce negative results such as turbine body corrosion.
· In every test case, the aperture of the main steam governing valve reduced soon after starting water injection. This supposes that water-soluble scale, such as NaCl, was washed off.

Preferable operation with the turbine water injection equipment

The results of the turbine water injection tests indicated that water injection for two hours every two weeks was the most preferable, and the station is currently operating stably with this routine.

4.2. Mist separator system

Theory

It is difficult to efficiently separate minute mist particulates in the steam without changing their state. However, if the injected water is directly atomized into the steam line and the relatively large water droplets thus produced catch the mist particulates, it is easy to separate them downstream. This permits reducing the amount of mist in the steam and leads to a considerable decrease in the scale-adherence rate to the turbine nozzle, etc.

Mist separating equipment
The equipment (Fig. 2) has ten nozzles, which directly atomize circulating water into the main steam piping, and two mist eliminators, which efficiently remove the injected water.

Water injection is accomplished with a venturi tube configuration. The mist separating equipment will be abbreviated as MSP (Mist Separator).

Water injection test result
A five-month continuous running test of the MSP, varying the amount of water injected in five stages (0 to 18 t/h), was conducted.

The results were:

- The MSP pressure loss was estimated at about 0.06 MPa in total.
- The separation efficiency of the mist eliminator is, with a water injection rate of 6 t/h, above 99%, and increasing the water injection rate permits raising the efficiency.
- As shown in Fig. 3, the minute mist particulates removal efficiency is, with a water injection rate of 6 t/h, about 50% (estimated from the Cl^- concentration of in the steam before and after the MSP), and increasing the water injection rate permits increasing the efficiency.
- Increasing the separation rate of the hot water mist to improve the purity of the steam is effective, although increasing the amount of injected water results in increasing the steam loss. To counter this, it is better to deal with the shape and location of the water injection nozzle.
- In a follow-up test dealing with the rate of variation of turbine steam inflow (Fig. 4), as shown below, it is presumed that continuous water injection at 15 t/h allows extending the overhaul inspection interval to two years. Considering steam loss and joint operation of the turbine water injection equipment leads to an optimal water injection rate of 6-9 t/h.

  Rate of variation of turbine maximum steam inflow (%) = $\{(Q' - Q_0) / Q_0\}$
  Q_0 =theoretical turbine maximum steam inflow under the pressure before the turbine inlet (t/h)
  Q' = actual turbine maximum steam inflow under the pressure before the turbine inlet (t/h)

5. CONCLUSION

To reduce scale formation at the Uenotai Geothermal Power Station, turbine water injection equipment was installed. Water injection tests indicated that water injection of 2.0 t/h is effective in preventing scale accumulation and in removing it. The steam turbine can be operated satisfactorily without causing shaft vibration, corrosion and so on.

By installing and operating the MSP upstream, the purity of the steam was improved, and significant improvements in the prevention of scale accumulation were achieved.

These two methods each have a significant effect in preventing scale from accumulating. (Fig. 5)

As a result, the overhaul inspection interval was greatly extended from once every three months to once every two years.

The noticeable effects of running the mist separating equipment and the water injection equipment are: reduced reconditioning costs for scale removal and avoiding output reductions.

The turbine water injection system is now also running at our Yanaidu-nishiyama Geothermal Power Station and Kakkonda Geothermal Power Station Unit 2 and is contributing to continuous, stable operation and reduced maintenance costs.

REFERENCES

Mimura,T., Adachi, Y., Shida,Y., Saito,Y., Komiyama, N., Asatsu, S., Nakano,Y., Fujishima, H., and Takahashi, T. (1996). Scaling Protection Technology for Uenotai 27.5MW Geothermal Steam Turbine. JOURNAL OF THE JAPAN GEOTHERMAL ENERGY ASSOCIATION, Vol. 33, No. 3 (Ser.No.143) 1996, pp.181-191.

Amagasa, S., Saito, S., Yoshida, K., and Sakanashi, H. (1995).Scaling Protection Technology for Sumikawa 50MW Geothermal Steam Turbine. JOURNAL OF THE JAPAN GEOTHERMAL ENERGY ASSOCIATION, Vol. 32, No. 2 (Ser.No.137) 1995, pp.108-132.

Table 1 Turbine overhaul inspection results and scale composition (April 1994)

Scale Accumlation Status		Mean thickness	Composition
Turbine	Scale stuck to all blades, inside out outside the circumference wall and horizontal fittings surface of the first-stage nozzle inlet and outlet.	1-3 mm (Max. 10 mm)	Mainly SiO_2 (83%) Fe (6%) (Na, Cl, S, etc.)
	Scale stuck to all blades and horizontal fittings of the second-stage nozzle outlet.	Below 1.5 mm	As above
	Scale stuck to all blades of the 3-5 stage nozzle outlets	Below 0.5 mm	As above
	Vanes at every stage and inside and outside the shroud. The amount of scale sticking was less on the rearward vanes.	Below 0.5 mm	As above
Main stop valve and other	Surface sheet of the main stop valve and sub-stop valve and valve rods. Steam inlet portion of the strainer closed by 10%.	Below 0.5 mm	Mainly SiO_2
Scale separator	Black and magnetic material deposits at the access hole.	20-30 mm	Mainly Fe
Steam piping	Almost free of scale sticking (using only an analytical reagent allowed sampling the scale).		Mainly Fe

Table 2 Analysis of the steam condensation water before the turbine inlet

Sampling date	Turbidity	Conductivity (μS/cm)	pH	SiO_2 (mg/l)	Cl (mg/l)	Fe (mg/l)
June 25, 1994	2.1	44.2	4.31	0.69	0.3	19.5
July 1, 1994	<1.0	41.8	4.41	0.73	0.2	-

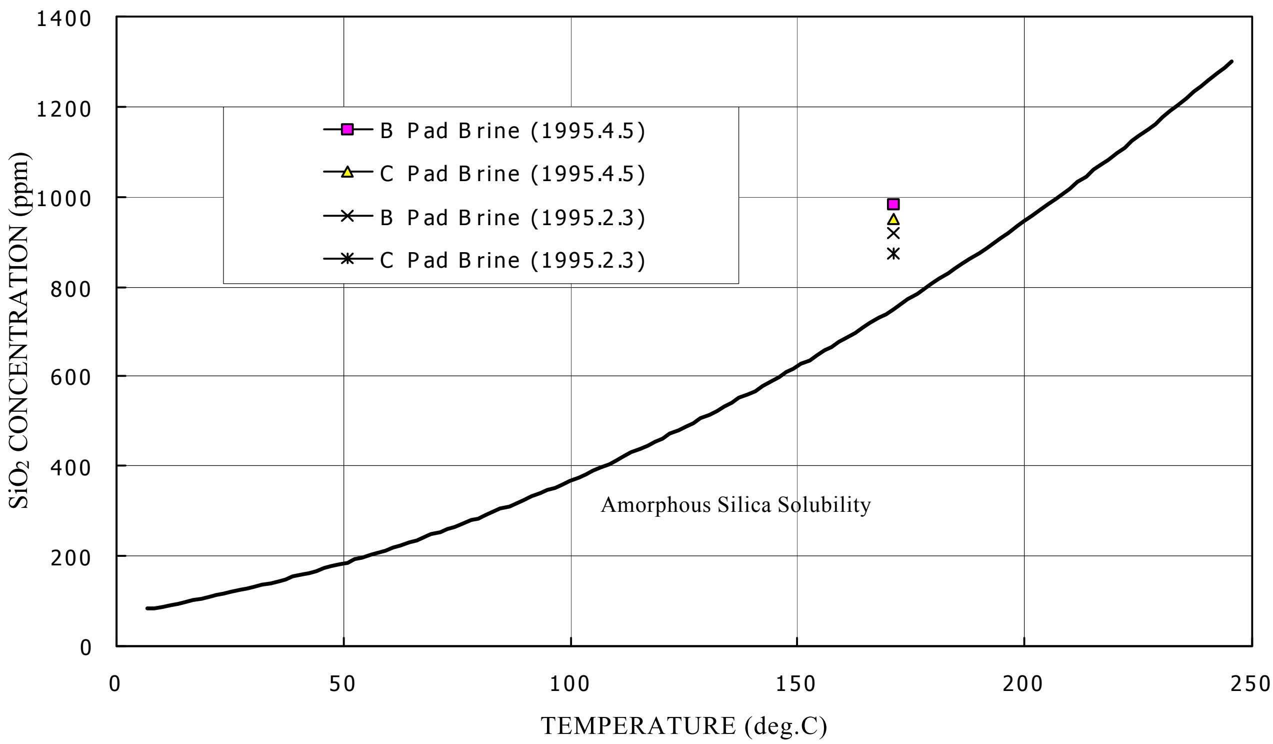

Fig.1 Relationship between SiO2 concentration of brine and amorphous silica solubility

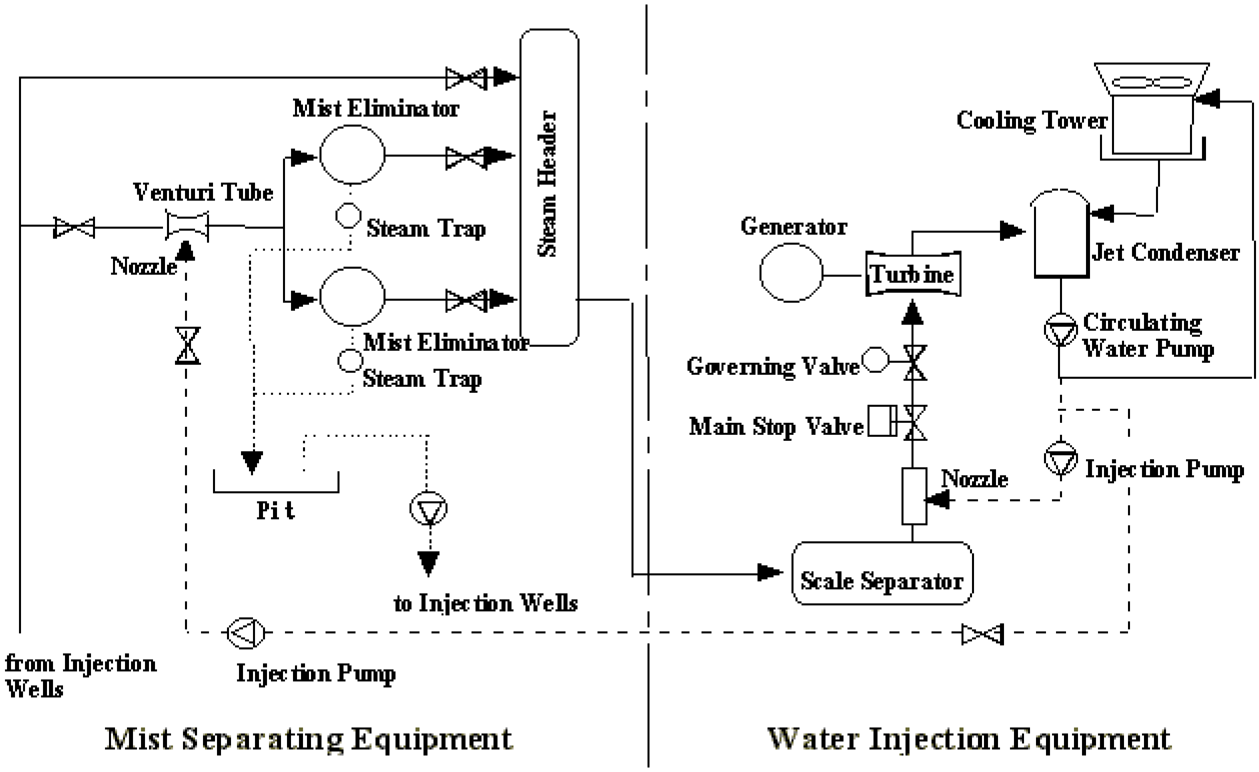

Fig.2 Mist Separating and Water Injection Equipment

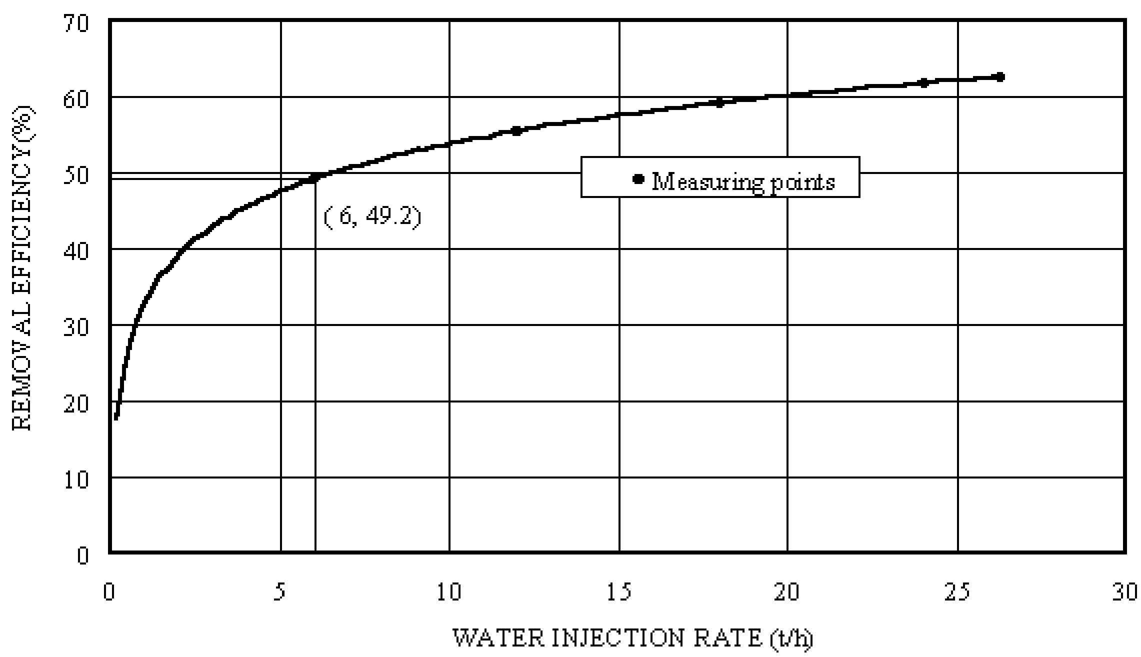

Fig.3 Removal efficiency by water injection into the main steam piping with a venturi

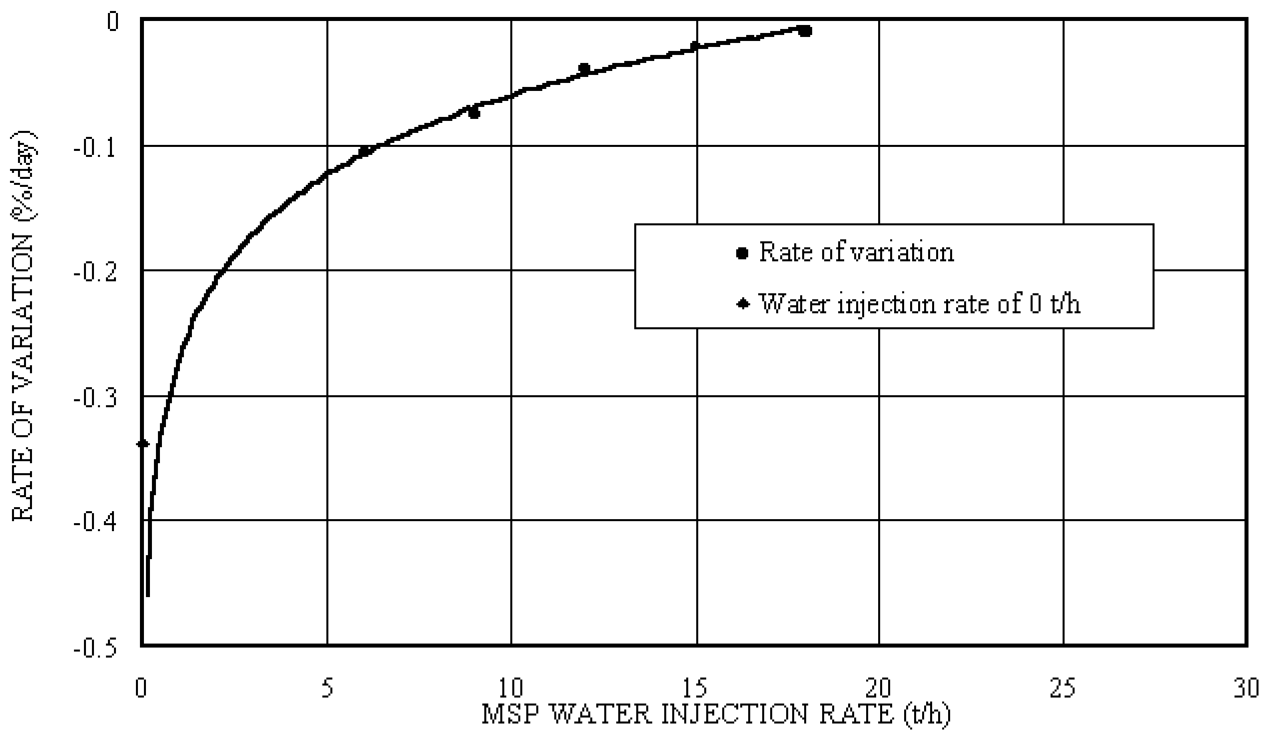

Fig.4 Rate of variation of turbine steam inflow.

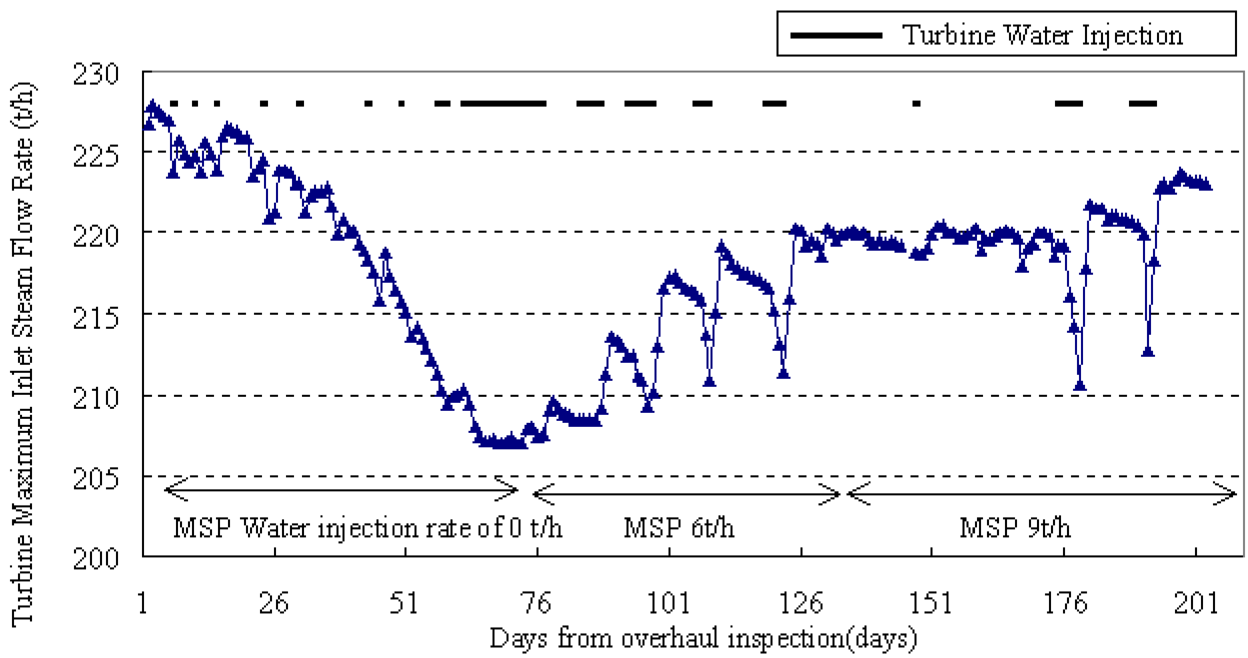

Fig5 Turbine maximum inlet steam flow rate
at theTurbine inlet