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STEAM PURITIES OF GEOTHERMAL PLANT

Yutaka Hibara Nobuhiko Hara Hidenori Sakanashi

Mitsubishi Heavy Industries, Ltd.

1-1 Akunoura Nagasaki, Japan

ABSTRACT

Geothermal power plants today are said to number more than 200 units, and their steam conditions and steam purity are varied. Steam purity of a geothermal power plant is a factor which has a great influence on the reliability of the power plant. Particularly a steam pressure rise due to scaling of a turbine governs the interval of overhauls.

This paper discusses the relationship between steam purity and turbine scaling on the basis of steam purity data collected from geothermal power plants in the world. It also refere to turbine water washing which is performed in plants in which turbine scaling cannot be prevented by improvement in steam purity alone.

STEAM PURITIES IN THE WORLD

Steam purity is influenced by quantity of impurities (Fe, Cl^-, SiO_2, etc.) of geothermal fluid and efficiency of steam gathering system. Because of the limited separating capability of a saparator made by the existing technology, steam purity falls down in proportion to an increase in the absolute quantity of impurities.

Table 1 shows steam impurities in the world. Steam impurities are not particularly high in any power plant.

Turbine scaling, which is influenced by steam purity, is most critical in the first stage nozzles.
Scaling in the first stage nozzles reduces nozzle area, making it necessary to raise pressure to keep the turbine output, and if scaling advances, scales come in contact with the rotor (moving blades or disc, etc.), and damage the rotor.
Against such a background, a study was made paying attention to the scaling of the first stage nozzles.

The higher the main steam pressure, the more the weight flow of steam at the same steam purity. This makes scaling likely to take place, so impurities flow ratio of the first stage nozzles area were calculated as shown in Figure 1. From the results, the absolute quantity of impurities in unit area of the first stage nozzles are found.

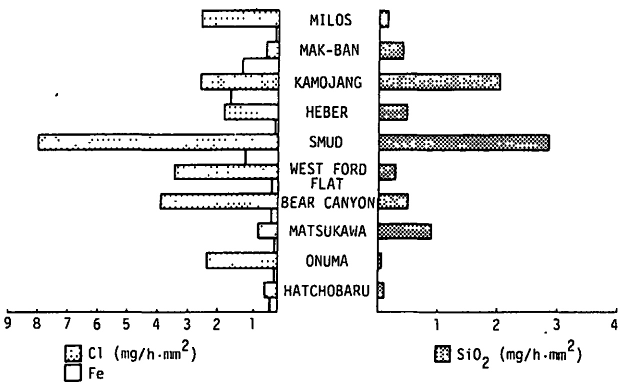


Fig. 1 IMPURITIES FLOW RATIO OF 1ST STAGE NOZZLE AREA

Figure 2 shows scaling speed derived from actual operation results. It is seen that all scale loads of SiO_2, Cl and Fe are high in Smud Geo. P/S. In actual operation, too, scaling rate was high, and steam pressure sharply increased in a short period.

Under the circumstances, the turbine is water-washed with condensate water of steam which is injected in the steam line during the rated load operation, thereby making three-years continuous operation possible. This method is referred to later.

In Kamojang P/S, silica content is high, and the interval of overhauls is one year.
Scaling rate is high as shown in Figure 2. To operate turbine safely it would be necessary to improve steam purity or shorten the interval of overhauls than one year.

In Onuma P/S an overhoul is conducted every year. This is not because of scaling but a standard practice of the power station.

In Matsukawa P/S, too, silica content is high, and an overhaul is carried out every six months. As a rule of thumb, an overhaul is made when 4% steam pressure rise or turbine bearing vibration takes place.

The above observations show that there is a relation between scaling rate and steam impurity load passing through unit area of the first stage nozzles.

Table 1 STEAM IMPURITIES IN THE WORLD

Name of Power Station		Kyushu Electric Power Co., Hatchobaru	Mitsubishi Metal Co., Onuma	Touhoku Electric Power Co., Kakkonda	Nihon Jyukagaku Co., Matsukawa	Hokkaido Electric Power Co., Mori	Freeport Geothermal Resource Company Bear Canyon	Freeport-Mcmoran Resource Portners West Ford Flat
Operation Date		June,1977	Nov.,1973	May,1978	Oct.,1966	Nov.,1982	Sep.,1988	Dec.,1988
Kind of Plant Cycle		Double Flash	Single Flash	Single Flash	Dry Steam	Double Flash	Dry Steam	Dry Steam
Type of Turbine		Double Pressure Double Flow Impulse-Reaction	Single Flow Impulse-Turbine	Double Flow Impulse-Turbine	Single Flow Impulse-Turbine	Double Pressure Double Flow Impulse-Reaction	Single Flow Impulse-Reaction	Single Flow Impulse-Reaction
Rating Output (kW)		55,000	10,000	50,000	22,000	50,000	17,100	11,000
Revolution (rpm)		3,600	3,000	3,000	3,000	3,000	3,600	3,600
Steam Condition	Pressure (kg/cm^2g)	5.52/0.43	1.5	3.5	3.53	6.0/1.0	8.01	8.01
	Temperature (°C)	161.3/109.4	127	147.4	200	162.4/119.6	171.7	175.5
	Gas Content (wt%)	0.45	0.1	0.03	0.5	10	0.4	0.1
Impurities in Steam (ppm)	Cl (ppm)	0.1	1.85	0.28	0.3	0.01	< 1.0	< 1.0
	SiO_2 (ppm)	0.03	0.01	0.06	0.4	0.01	0.13	<0.08
	Fe (ppm)	0.1	0.08	0.01	0.04	0.03	0.05	0.04
	TS (ppm)	-	-	-	-	-	35	60
Steam Load for 1st Stage Nozzle	Weight Flow ($kg/h \cdot mm^2$)	3.44	1.26	-	2.27	-	3.89	3.44
	Volume Flow ($m^3/h \cdot mm^2$)	0.89	1.03	-	1.09	-	0.95	0.84
Overhaul Interval (month)		24	12	12	6	24	* 24	* 24

Name of Power Station		Sacramento Municipal Utility District SMUD GEO. #1	Beowawe Geothermal Power Co., Beowawe	Heber Geothermal Company Heber	PLN Sector Kamojang Kamojang U3	National Power Co., Leyte U3	National Power Co., Mak-Ban U3	Public Power Co., Milos
Operation Date		Dec.,1983	Dec.,1985	July,1985	Sep.,1987	Nov.,1983	Apr.,1980	Under-testing
Kind of Plant Cycle		Dry Steam	Double Flash	Double Flash	Dry Steam	Single Flash	Single Flash	Single Flash
Type of Turbine		Quadruple Flow Impulse-Reaction	Double Pressure Single Flow Cond. Portable Turbine	Double Pressure Double Flow Impulse-Reaction	Double Flow Impulse-Reaction	Double Flow Impulse-Reaction	Double Flow Impulse-Reaction	Single Flow Geared Cond. Portable Turbine
Rating Output (kW)		78,000	16,600	52,000	55,000	33,500	55,000	2,000
Revolution (rpm)		3,600	3,600	3,600	3,000	3,000	3,000	9700/1500
Steam Condition	Pressure (kg/cm^2g)	8.09	3.45/0.1	2.85/0.07	5.63	5.32	6.8	7.0
	Temperature (°C)	189	145.5/99.1	141.6/101.7	161.9	163	164	169.6
	Gas Content (wt%)	0.055	0.024	< 0.1	0.5	0.8	0.41	1.0
Impurities in Steam (ppm)	Cl (ppm)	1.4	-	0.95	0.82	0.28	0.1	0.7
	SiO_2 (ppm)	0.50	0.70	0.25	0.65	0.07	0.1	0.04
	Fe (ppm)	0.2	<0.02	0.02	0.50	0.05	0.3	0.01
	TS (ppm)	114	-	6.5	4	13	7.5	3
Steam Load for 1st Stage Nozzle	Weight Flow ($kg/h \cdot mm^2$)	5.71	1.96	1.87	3.16	2.91	3.99	3.70
	Volume Flow ($m^3/h \cdot mm^2$)	1.40	0.86	0.92	0.92	0.90	1.02	0.89
Overhaul Interval (month)		* 36	* 24	24	12	12	* 12	* 12

Remarks:

* with turbine washing operation

- no data

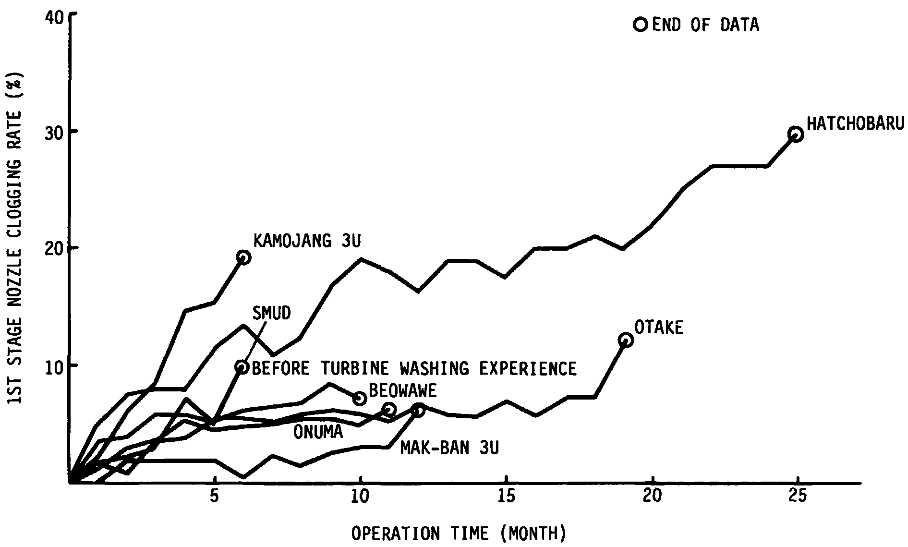


Fig. 2 SCALING SPEED ON THE 1ST STAGE NOZZLE

DIFFERENCE BETWEEN DRY STEAM AND SATURATE STEAM

Most of the plants in which scaling rate is high are plants using dry steam. The turbine of Greece Milos P/S was operated on both dry steam and saturate steam. Figure 3 shows the steam chest pressure during the operation. Operating conditions are not the same in both cases because of large changes in demand, but there is a tandency that scaling rate is higher during dry steam operation.

In both cases of 1 and 2 , the turbine was shut down. In the case of saturate steam, scales peeled off during the shut down and steam chest pressure dropped, while there was no such change with dry steam. It is considered that this is because scales produced by saturated steam peeled off on account of contraction due to temperature drop.

SCALING PHENOMENON ON 1ST STAGE NOZZLES

Photo 1 shows scales on the first stage nozzles of Greece Milos turbine after three months operation.
From this photo, it is seen that scaling took place on the concave side of the nozzles. Impurities (solids) in steam entering the first stage nozzles tend to gather on the nozzle concave side because of cantrifugal force.

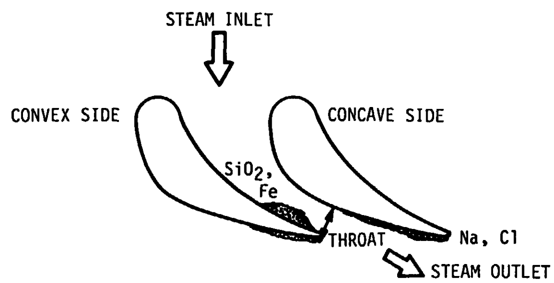


Fig. 4 SCALING PHENOMENON ON 1ST STAGE NOZZLE

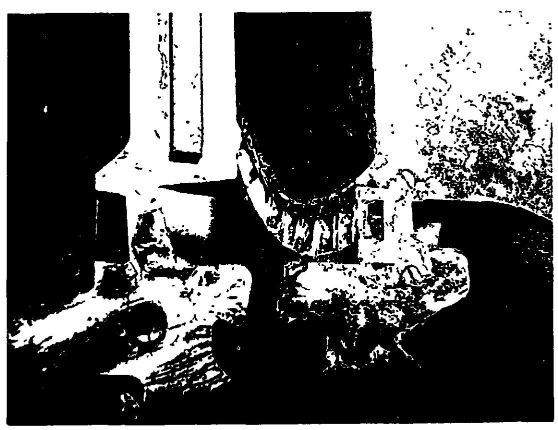


Photo 1 1ST STAGE NOZZLE SCALING OF MILOS GEO. (3 MONTH OPERATION)

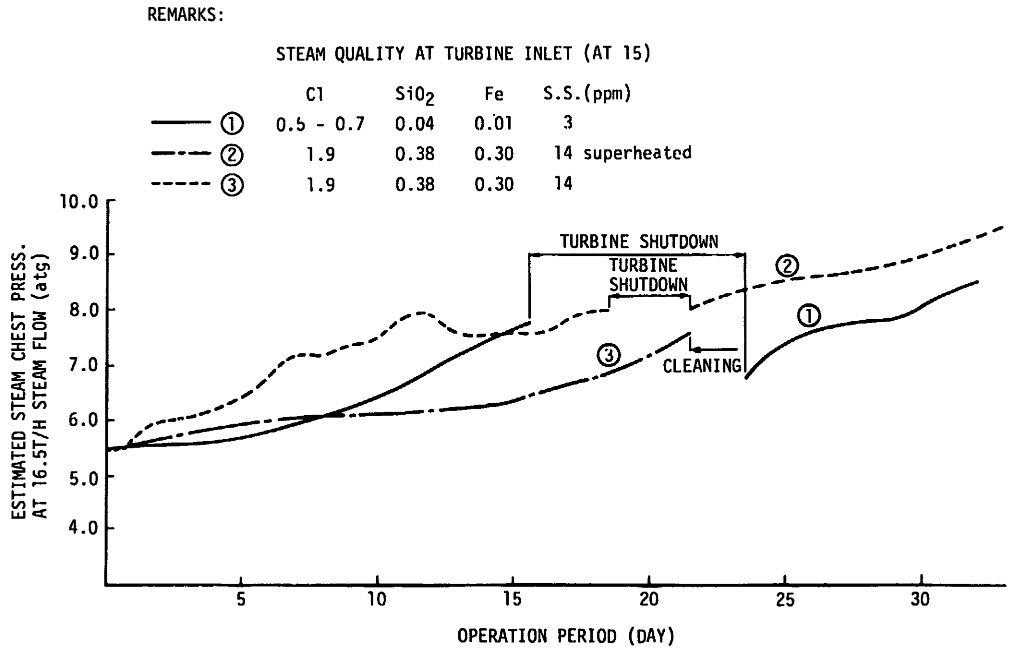


Fig. 3 COMPARISON TABLE OF STEAM CHEST PRESS. RISING CURVE WITH VARIABLE STEAM CONDITION AT MILOS GEO.

On the other hand, scales on the nozzle convex side are formed at the nozzle throat and downstream. The nozzle throat and downstream area is an unstable region where wet and dry conditions take place. This seems to accelerate deposition of water-soluble impurities such as Na and Cl contained in steam mist.

This phenomenon is verified by an analysis of the first stage nozzle scales in Philippine, Leyte geothermal power plant shown in Table 3, too. In all plants, main component is silica, which seem to have deposited on the nozzle concave side.

PLANT		Chemical Composition (wt%)					
		SiO_2	Ca	Cl	T-S	Fe	Na
HATCHOBARU 1U JAPAN 55MW		53.7	1.7	23.0	1.1	1.0	15.2
ONUMA JAPAN 10MW		52.8	1.7	-	11	4.9	-
KAKKONDA 1U JAPAN 50MW		0.05	Trace	50.5	-	Trace	36.2
SMUD USA 78MW		83.0	0.37	Trace	3.1	3.3	-
BEOWAWE USA 17MW		54.6	Trace	1.0	2.1	0.6	-
KAMOJANG INDONESIA 55MW		40.7	-	-	-	37.9	1.3
LEYTE PHILIPPINES 37.5MW		13.9	7.5	7.5	17.4	11.4	10.3
MAK-BAN 3U PHILIPPINES 55MW		70.7	1.8	5.3	-	2.4	3.7
MILOS 2MW GREECE	Sat. Steam	9.3	5.8	7.2	0.8	24.4	-
	Superheated Steam	25.9	19.8	2.6	7.8	4.4	-

Table 2 CHEMICAL COMPOSITION OF SCALES ON 1ST STAGE NOZZLE

Table 3 CHEMICAL COMPOSITION OF SCALE ON TURBINE OF LEYTE

	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, $CaSO_4$

IMPROVEMENT IN STEAM PURITY

Needless to say, raising the efficiency of steam gathering system is directly related to improvement in steam purity. Normally a steam gathering system is provided with a cyclone separator, demister, etc.

To obtain steam of even higher quality, a venturi scrubber would be an effective means.

The principle is to cause mist to adsorb solids by inertial collision between impurities and water injected in a venturi. A separator has to be provided downstream the venturi.

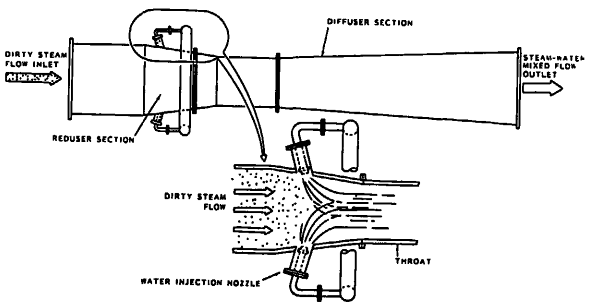


Fig. 5 DETAIL OF VENTURI WATER INJECTION NOZZLE

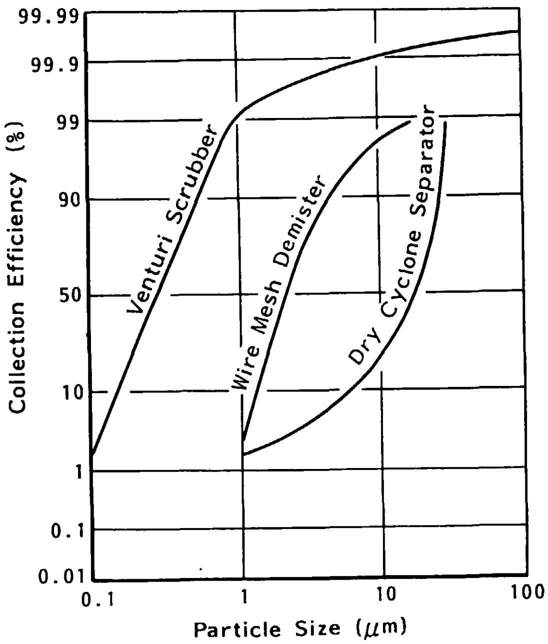


Fig. 6 COLLECTION EFFICIENCY OF VENTURI SCRUBBER

If a long-term continuous operation of a plant cannot be made possible by an improvement in the steam gathering system alone, turbine water-washing would be effective.

This method, which has recently been practiced in various parts of the world, is to inject steam condensate water before the turbine and water-wash scales mainly on the first stage nozzles.

Table 4 shows the record of water-washing and Figure 7 gives the operation results. As seem from Figure 7, water-washing is effective in some plants and is not very effective in others, but it is effective in dry steam plants.

Particularly it is very effecive in SMUD, where it is conducted every month.

In Milos, water-washing was sufficiently effective though saturated steam is used. The reason is that the plant is operated on a partial load becouse of demand, so the governor valve is throttled and steam is dry in the steam chest.

The mechanism of water-washing should be studied further in future.

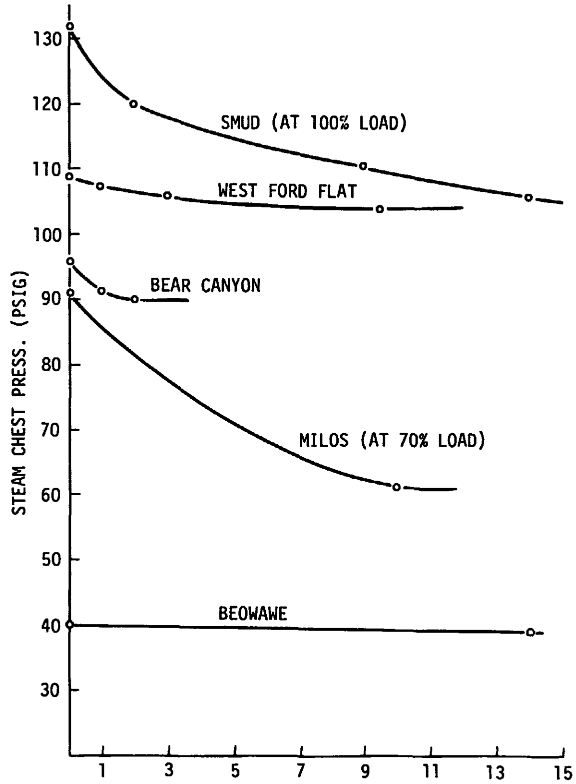
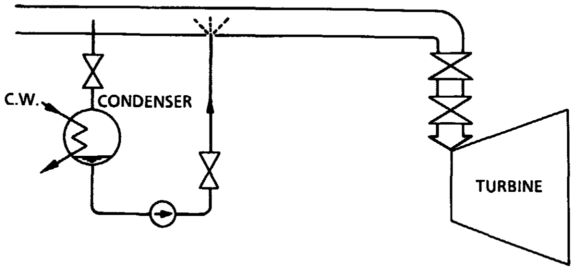


Fig. 7 ACTUAL RESULTS OF WATER WASHING OPERATION



TURBINE WASHING SYSTEM

Table 4 TURBINE WATER WASHING OPERATION

	Interval of Washing	Term (day)	Injected Water Flow,wt. Rate(%)	Injected Water Temp. (°C)	Kind of Washing Water	Results
SMUD	Monthly	2	1.8	45	Direct Steam Condensate	Excellent
BEAR CANYON	Monthly	2	3.7	51.7	ditto	Effective
WEST FORD FLAT	Monthly	2	2.6	45	ditto	Effective
BEOWAWE	Various	1	1.3	28	ditto	Some improvement but not complete removal
MAK-BAN	Continuous	Continuous	3	48.9	ditto	ditto
MILOS *	Monthly	2	2	60	ditto	Excellent

* under testing operation

CONCLUSION

1. Measurement of steam purity is made by the uniform velocity suction sampling method using a nozzle, but it is dirable to use analysis of steam taken from pipe wall, too. This makes it possible to take actions at an early stage because the absolute quantity makes a great change when hot water is carried over from the steam generating equipment due to change of down hole condition, etc. For this purpose, it is recommended to make measurements every day. Measurement of steam purity should include measurement of total solids.

2. Scaling rate of a turbine can be estimated by the absolute quantity of impurities (SiO_2, Cl, Fe) passing through unit area of the first stage nozzles. Particularly the effect of silica is great. Plants of a high steam pressure has a high possibility of scaling.

3. According to the experience of Mitsubishi, heavy contact between moving blades and scales is observed at nozzle clogging ratio of 20 ~ 25%. An overhaul for cleaning of a turbine should be carried out at nozzle clogging ratio of 15% as a general rule.
   For this purpose, it is necessary to know the tendency of steam chest pressure rise and pay attention to the condition of scaling.

4. More dry steam type power plants have a scaling problem than saturated steam type power plants.

5. Unsoluble substances (SiO_2, Fe) deposit on the concave side of the first stage nozzles while water-soluble substances (Na, Cl) deposit on the convex side at the nozzle throat and downstream.

6. Water-washing is an effective way to remove scaling from 1st stage nozzle during turbine operation.

REFERENCE

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