RELIABILITY OF GEOTHERMAL POWER GENERATION AND EXPERIENCE OF TROUBLE

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INTRODUCTION

A quater century has passed since technology started development stage of practical use of geothermal power generation.

There are some geothermal power plants, which have remained in successful operation over twenty years with extreamly high level of availability. On the other hand, many kinds of troubles peculiar to geothermal power generation have been experienced by not a few geothermal power station in service.

Important to preventing severe geothermal power plants troubles, therefore, are not only careful material selection at design stage but also timely inservice inspection and complete metallurgical inspection at every overhaul.

Geothermal power generation needs no fuel. So the economical power generation with geothermal power station should result from high reliability of plant operation.

CORROSIVE AND EROSIVE CONDITION WITH IMPURITIES

Since geothermal brine dissolves many chemical components, flashed geothermal steam contains many impurities such as mud or sand particles, Calcium carbonate ($CaCO_3$), Silica (SiO_2), Iron (Fe), Chloride (XCl), etc. Geothermal steam is also accompanied by geothermal gas composed of corrosive elements, such as Hydrogensulfide (H_2S) and Carbon dioxide (CO_2), etc.

A major problem associated with the geothermal power generation is the severely corrosive atmosphere created by geothermal gas and brine impurities. The high corrosiveness of brine is attributable to the presence in it of a large amount of salts, dissolved carbon dioxide and hydrogen sulfide, plus a substantial amount of silica.

Another difficult problem arises from scale formation caused by the impurities. During a prolonged period of operation, scale deposits peculiar to geothermal steam can accumlate on the turbine internals.

Impurity concentration in the turbine takes place at the first- or second-stage blading. The solubility of impurities in dry saturated steam decreases as the steam temperature goes down with expansion. Then the impurities, such as sodium chloride, kalium chloride, etc., deposit themselves at the first stage blading because steam expands across the saturation line into the wet zone. At this point, steam undergoes alternately wet-dry cyclic changes with the turbine starts and stops.

This wet-dry cyclic change in steam phase, when repeated, results in significant concentration of chloride in narrow channels especially in the groove of blade root.

In the wet zone beyond wilson-line of steam in turbine stages the drifting droplets are diluted and the corrosive impurities are washed away. The turbine blade, especially the long blade, should nevertheless cope with the stress corrosion cracking and corrosion fatigue cracking which are caused by corrosive gas in geothermal steam.

Also geothermal steam is contaminated with organic or inorganic acids. Very low levels of acid in the steam can result in acidic solution in the early moisture region existing in the first stage blading of geothermal turbine.

TROUBLE PECULIAR TO GEOTHERMAL POWER PLANT

Scaling and corrosion experiences have been reported from a number of operating geothermal power plants around the world. These power plants utilize vapor- or liquid-dominated soruces, and an unique subsystem is being contemplated in each instance to address particular corrosion problems peculiar to each plant.

Silica is the major substance that tends to be left deposited in the steam turbine.

The decreasing power output with the increasing scale deposits on the nozzles is a problem encountered by the turbines.

The silica scale deposit, though not corrosive itself, retains the corrosive elements like acid and chloride, and porous in appearance as sponge cake. Beneath the deposit, nozzle and blade surfaces are etched by acid and chloride.

Among the troubles experienced by geothermal power plants in the world, those with the turbines are most serious because they are rotatory machines.

The Corrosion problem in most cases is that of corrosion fatigue or stress corrosion cracking of turbine blades at the first or second stage due to deterioration caused by the wet-dry cyclic concentration of impurities.

MAJOR TROUBLES AT THE GEOTHERMAL POEWR PLANTS

For the geothermal power engineering the most important information comes from previous experiences gained at other similar plants. It clearly tells which components and systems failed, and more importantly, which components and systems and what designs proved successful.

A summary of problems experienced under peculiar circumstances at respective geothermal power plants in the world follows.

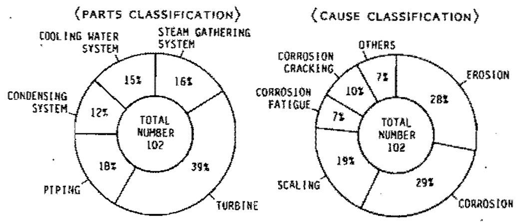

FIG. 1 FAILURE MODE ANALYSIS OF GEOTHERMAL POWER PLANTS

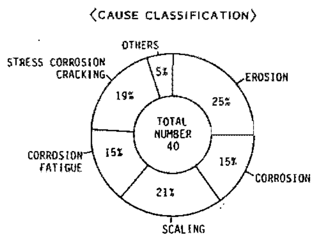

FIG. 2 FAILURE MODE ANALYSIS OF ROTATORY PARTS OF GEOTHERMAL TURBINES

TABLE 1 TROUBLE EXPERIENCE IN THE GEOTHERMAL POWER PLANTS

Equipment \ Geothermal Plants		JAPAN				
		MATSUKAWA	OTAKE	OHUMA	ONIKOBE	HATCHOBARU
Turbine	Moving Blade	1st stage erosion (With fling backing ring) 4th stage broke (Dust attack) 3rd stage broke (Micro-crack with dust attack) 2nd stage (CFC)	A blade at 1st stage broke	A blade at 1st stage broke Blade roots at 1st stage cracked (CFC due to wet and dry concentration)	1st stage blades broke (Rubbing with scale)	3rd stage shroud dumper cracked (SCC)
Turbine	Rotor		Gland corrosion		Gland corrosion	
Equipment \ Geothermal Plants		**EL SALVADOR**		**MEXICO**	**U.S.A.**	
		AHUACHAPAN 1,2T	AHUACHAPAN 3T	CERRO PRIETO	GEYSERS	VULCAN
Turbine	Moving Blade		Erosion	Last stage erosion (Drain attack) 1st stage erosion (Solid particle attack) Last stage scaling	1st and 2nd stages blades & shrouds broke off (CFC due to wet and dry concent-ration)	HP LP rotor 1st stage blade tenons & shrouds crack (SCC by chemical washing)
Turbine	Rotor		Vibration with blade erosion	Gland corrosion	Shaft-to-wheel radius surface sulfide stress cracking	
Equipment \ Geothermal Plants		**ITALY**	**ICELAND**	**PHILIPPINES**		**NEW ZEALAND**
		LARDERELLO	KRAFLA	TIWI	MAK.BAN.	WAIRAKEI
Turbine	Moving Blade	1st stage broke (SCC due to wet and dry concent-ration) Blade root corrosion New stellite shielded last blades replace after 9 years	2nd & 1st stages erosion (Heavy dust)	4th stage blades & shrouds broke (2nd steam impurity, 1~4T) 5th stage shrouds crack (5~6T)	1st stage shroud broke (Rubbing with heavy scaling, 1T)	Last blade erosion (No stellite shield) Blading of LP turbine replace (15 years) 1st and 2nd stages of IP turbine blades broke
Turbine	Rotor	Corrosion			1st stage disc cracked at 1T (Rubbing with heavy scaling)	Rotor and diaphragms stand by corrosion

IMPORTANCE OF STEAM PURITY

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

Typical troubles of geothermal turbine are valve sticking, blade erosion, corrosion, cracking of the stainless steel.

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.

To explain the effect of geothermal steam purity on the reliability of geothermal power station, typical troubles of geothermal power station are introduced in the following.

In case of steam dominated type geothermal power station, superheated steam normally enters the turbine directly. Therefore, geothermal steam has much impurities in case of steam dominated type.

Most of impurities are solid particles, and this will cause the erosion called the solid erosion. The cause of solid erosion is insufficiency of capacity and low efficiency of steam clean-up system. And in addition, well characteristic of the superheated steam changes suddenly, and occasionally wet steam enters the turbine. This will cause the drain erosion and scaling, same as in case of hot-water type.

Considering the above, we recommend to install the fainal separator and demister in the steam line just before the turbine to prevent both solid erosion and drain erosion.

RECOMMENDED LIMITS OF STEAM IMPURITY

It is recommendable to monitor continuously the steam purity with the steam quality monitoring device, and also operators shall develop and watch the change in turbine inlet steam pressure logging curve to check for the scale clogging.

To protect turbine from scaling troubles, recommendable limits of steam impurity are as follows.

Operation mode / Impurities	(1) For continuous normal operation	(2) Abnormal operation	(3) Turbine should not be operated.
TS (Total Solid)	< 0.5 ppm	0.5 ~ 5 ppm	> 5 ppm
Cl (Chlorine)	< 0.1 ppm	0.1 ~ 1 ppm	> 1 ppm
SiO_2 (Silica)	< 0.1 ppm	0.1 ~ 1 ppm	> 1 ppm
Fe (Iron)	< 0.1 ppm	0.1 ~ 1 ppm	> 1 ppm

In Operation Mode (2), the decrease in output with scale accumulation is to be expected.
In Operation Mode (3), quick scale accumulation will cause the rubbing between nozzles and discs.

The limits are determined as the operation criteria for the steam turbine in the ordinary geothermal field which has almost similar contents of both chlorine and silica. Little more chlorine content may be allowed at the geothermal field which has a lot of chloride concentration ratio in the brine.

PRECAUTION AGAINST OPERATIONAL TROUBLE

In prolonged operation, scale deposit peculiar to geothermal steam can accumulate on the turbine nozzles and moving blades.

Scale deposit on turbine blades or nozzles occasionally causes not only reduction of turbine output but also abnormal steam thrust to the rotor that can result in wear of the thrust bearing.

Operating data in the operation log require to be carefully checked to see whether there is any abnormal pressure rise in the steam chest or in the first stage of the turbine.

Pressure rise in the steam chest due to scale deposit generally stops, being saturated, at a certain point (+0.5 to 1.0 kg/cm^2). If it should continue to rise, it is abnormal and an immediate inspection is needed.

When a gradual change in turbine performance is perceived, it is important to fully understand the physical situation of the plant, i.e., to see whether there are any changes in long-term steaming characteristics of the wells, climatic influences on the cooling conditions of the cooling tower, etc.

If there is any gradual change in turbine performance with time, it must be confirmed that such a change can be rectified by adjustment at the time of overhauling of the unit.

In case of a sudden change in turbine performance, it is important to check all related operation data to see what part of the unit is wrong and to take proper measures considering every possible cases including shut-down and overhaul of the plant.

WASHING OPERATION

Low rotating speed washing operation was often tried at conventional steam turbine. Results were probably reported as unadequete cleaning method for the hard scale like silica with low speed running.

At SMUDGEO No.1 Unit, washing operation at full load was tried to clean up the scale deposit on the first stage nozzles in August 1985.

1.4% of deaerated pure water was sprayed into the main steam flow and desuperheated the steam temperature from 4°C super heat to abuot 1.5% wetted region.

The effect appeared gradually with continuous washing operation for 17 days, and steam chest pressure of turbine was reduced from 130 psig to 105 psig with the same steam quantity, which is the original set pressure at commissioning.

Washing operation, especially at full load, requires to be done carefully, considering heat shock, rotor vibration, erosion in the turbine, etc.

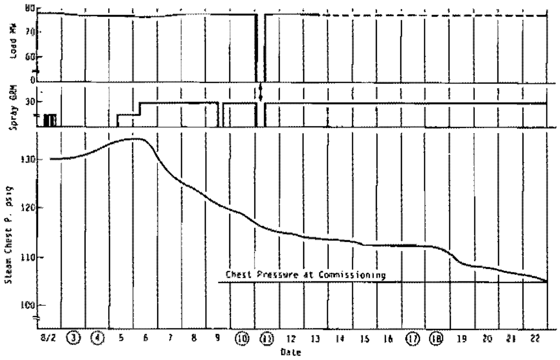

FIG. 3 WASHING OPERATION RESULT AT SMUDGEO #1 UNIT

RECOMMENDATION FOR PERIODIC OVERHAUL AND AGED DETERIORATION INSPSECTION

For successful and efficient operation of the geothermal power plant, it is important not only to develop and implement satisfactory routines for operation but also to carry out periodic overhaul and inspection based on recent technology and experiences gained from operation of the geothermal power plants in the world.

Therefore, such as periodic check and inspection for the maintenance of geothermal power plant should be paying attention to the equipment and machines, particularly about such points as degree of scale deposit, progress of corrosion and deterioration, life of paints, uneven sink, etc.

As the life of each equipment is greatly affected by corrosive atomosphere in geothermal fluid, it is necessary to conduct a thorough inspection periodically for prevention of deterioration by aging.

Intervals of overhaul depend on the operating conditions and other conditions of individual plants, but the following may be recommended for the geothermal power plant.

TABLE 2 OPERATION FACTOR OF GEOTHERMAL POWER STATION

OTAKE 12.5MW Power Station

Years	Operating Days	Operating Hours (H)	Availability Factor (%)	Note
1967	August 12 Start of Operation			Overhaul After 1,600 hrs.
	208	4,848	87.1	
1968	353	8,352	95.1	1st Inspection
1969	354	8,416	96.1	2nd Inspection
1970	365	8,666	98.9	
1971	352	8,335	94.9	3rd Inspection
1972	366	8,692	99.0	
1973	347	8,229	93.9	4th Inspection
1974	365	8,694	99.2	
1975	346	8,231	93.7	5th Inspection
1976	366	8,658	98.6	
1977	345	8,224	93.9	6th Inspection
1978	365	8,689	99.2	
1979	345	8,105	92.3	7th Inspection
1980	364	8,713	99.5	
1981	344	8,201	93.6	8th Inspection
1982	347	8,324	95.0	9th Inspection
1983	365	8,757	100.0	
1984	366	8,782	100.0	
1985	312	7,464	85.2	10th Inspection
1986	335	7,979	91.1	
1987	349	8,355	95.4	11th Inspection

HATCHOBARU 55MW Power Station

Years	Operating Days	Operating Hours (H)	Availability Factor ( )	Note
1977	191	4,573	99.8	
1978	334	8,012	91.5	1st Inspection
1979	352	8,447	96.4	
1980	344	8,236	93.8	2nd Inspection
1981	358	8,585	98.0	
1982	345	8,273	94.4	3rd Inspection
1983	365	8,740	99.8	
1984	352	8,380	95.4	4th Inspection
1985	365	8,740	99.8	
1986	350	8,379	95.7	5th Inspection
1987	365	8,712	99.5	

The first overhaul - 6 months after commencement of service operation
The second overhaul - 12 months after the first overhaul

After that, overhaul requires to be made every two years unless otherwise required.

After 3 years or 5 years of operation, it is strongly recommendable to make the metallurgical inspection, using recent technologies, of the turbine rotor and blade including removal of several blades from the rotor.

After that, 3 or 4 years intervals are suitable for metallurgical inspection according to overhauling condition of each individual geothermal plant.

CONCLUSION

Steam gathering system, especially steam separator in the hot-water dominated geothermal field, is a key factor in maintaining successful geothermal power plant operation. Chloride in geothermal steam, carried over as fine drift of brine, corrodes ferrous alloy.

Washing operation, especially at full load, is as effective to prevent output decrease by scale piling at first stage nozzles, but it shall be done carefully.

Important to preventing severe geothermal power plants troubles, therefore, are not only careful material selection at design stage but also timely inservice inspection and complete metallurgical inspection at overhaul.