Identification of Failure Modes and their Effects in Geothermal Power Plants

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Introduction

Geothermal power plant components can experience issues during operation which can reduce the efficiency of the plant and increase the over all cost of operation. Erosion, corrosion and scaling are among problems that can be faced and Figure 1 shows resulting damage that can be encountered. The methods that can be used to minimize the effects of these issues include adjustment of the fluid properties and/or material selection. The use of higher grade alloys can for instance protect components from erosion and corrosion damages but making components out of solid high grade alloys can be expensive. The use of coatings can therefore increase tolerance against common issues at a potentially lower cost than using solid higher grade material. The *Geo-Coat* project focuses on development of high enthalpy alloys, cermets and duplex coatings applied through high velocity oxy fuel (HVOF), laser cladding, electrospark deposition and electroless plating, with the intention of protecting geothermal power plant components from erosion, corrosion and scaling. To identify where such solutions can be the most effective, a failure mode and effect analysis (FMEA) was performed based on experience from geothermal power plant operators.

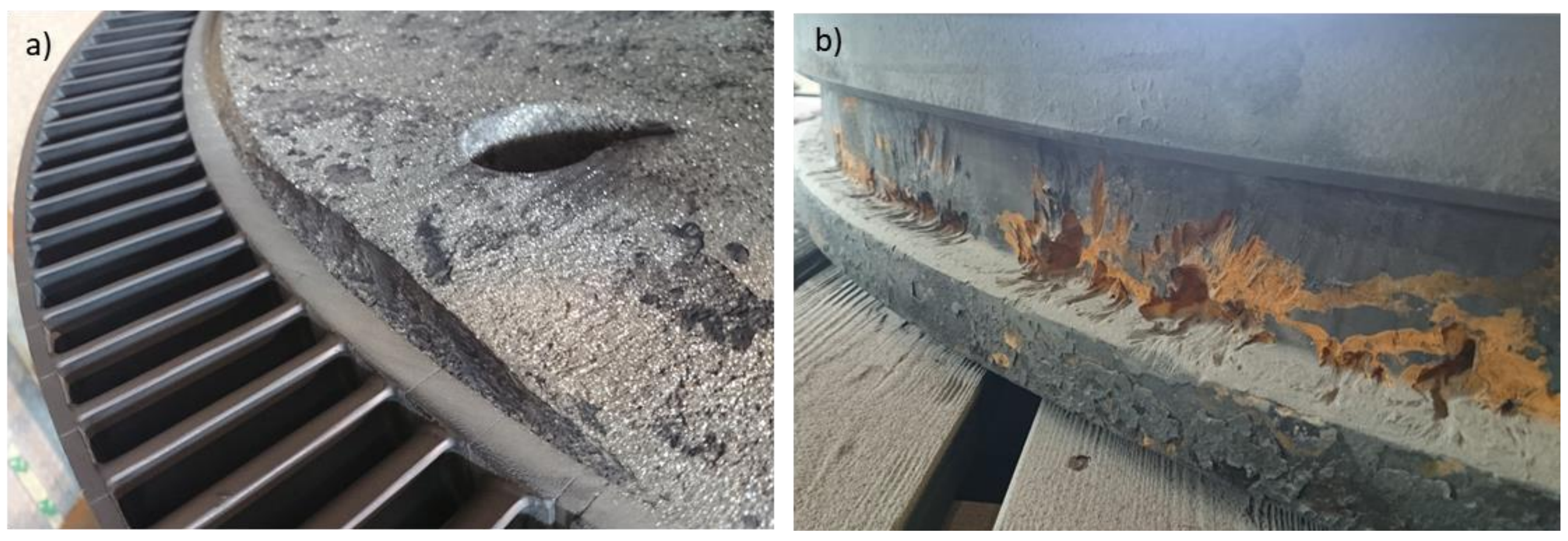

Figure 1: Erosion damages to a) a rotor disc and b) outer edge of a turbine diaphragm.

Method

Failure mode and effect analysis (FMEA) is a tool that is used to identify and prevent product and process failure before it occurs [1]. In this sense, failure can either refer to how a process or component fails or its capability is reduced, as was the case for this study. Once identified, the failure modes can then be rated based on the severity (S) of each effect, the frequency of occurrence (O) and its detectability (D). Multiplying the values for S, O and D then gives the *Risk Priority Number* (RPN) which can be used to rank the problems encountered. Focusing exclusively on the RPN can however be misleading when identifying potential issues to be minimized. The RPNs, S and D scales, and the *criticality* (S*O) were therefore all considered when determining the results. The scales used for the severity and the occurrence are shown in Table 1.

Table 1: The severity and occurrence ratings designed for the project.

	Value	Definition	Description
Severity	10	Hazardous	Catastrophic failure that can cause severe damage to property or people
	9	Critical	System inoperable and failure can lead to substantial damage of other equipment in the system
	8	Very high	System inoperable and requires immediate maintenance
	7	High	System operable with considerable reduction in performance of the system
	6	High	System operable with notable reduction in performance of the system
	5	Moderate	System operable with slight reduction in performance of the system
	4	Low	System operable, only slightly reduced capability of the component and minor effects to other parts of the system
	3	Very low	System operable and only slightly reduced capability of the component without it effecting other parts of the system
	2	Minor	System operable and no significant effect on the component
	1	None	No effect
Occurrence	10	Extremely high	Failure is likely to occur in 6 months
	9	Very high	Failure is likely to occur in 9 months
	8	High	Failure is likely to occur in a year
	7	High	Failure is likely to occur in 2 years
	6	Moderate	Failure is likely to occur in 3 years
	5	Moderate	Failure is likely to occur in 4 years
	4	Low	Failure is likely to occur in 6 years
	3	Low	Failure is likely to occur in 8 years
	2	Very low	Failure is likely to occur in 10 years
	1	Remote	Failure is unlikely to occur under 10 years

Results

The FMEA questionnaire focused on the effects caused by corrosion, erosion and scaling in geothermal systems. Answers to the FMEA were received from 6 operators of different geothermal power plants along with comments from others. The top results are shown in Table 2. The plants in question were mainly single flash, double flash and binary.

According to the RPN number the most critical failure mode throughout the system is considered to be due to corrosion. At the top of the list is corrosion of the coil for downhole pumps, followed by leaking of different pipelines throughout the system due to corrosion. Scaling in pipes and erosion to turbine components and valves are close runner-ups. The most severe effects are considered to be inoperability of valves due to scaling and erosion, along with leaking of pipes and other components from corrosion, material reduction of casing and vessels, vibration in turbine and pump components due to erosion and corrosion, clogging of pipes and turbine components due to scaling, and reduced efficiency in pumps due to corrosion. Leaking in pipelines, operating issues with valves, and reduced efficiency due to scaling in condensers and corrosion/erosion in pumps and turbine components were among the most frequent occurrences.

Table 2: The highest rated components for each system from the combined FMEA based on RPN, S and O.

System	Component	Part	Failure mode	Effect	S	O	RPN
Steam production	Wellhead	Casing	Corrosion	Material reduction	9	1	54
		Ring tool joint	Erosion-corrosion	Leaking	5	4	120
	Pipes	Liner	Scaling	Reduced flow	8	3	144
		Casing	Scaling	Reduced flow	4	6	48
	Valves	Control valve - seat	Erosion	Can't seal	4	6	144
		Master valve - seat	Erosion	Can't seal	7	3	126
		Master valve - stem	Corrosion	Can't seal	6	7	84
	Pumps	Coil	Corrosion	No inhibitor injection , no measurement of dynamic water level	8	10	480
Steam transmission	Pipes	H2S removal	Corrosion	Leaking	10	7	280
		2 phase	Cracking	Leaking	4	10	40
		2 phase - inlet	Cracking	Leaking	4	10	240
		Steam pipe	Cracking	Leaking	4	10	240
	Valves	Working fluid valve - pin	Wear/abrasion	Can't seal	9	4	144
		Level control valve	Scaling	Sticking	10	1	10
		Ball check valve	Scaling	Sticking	4	10	80
	Pumps	Working fluid - shaft	Wear/abrasion	Vibration	8	3	48
		Working fluid - bowl/barrel	Corrosion	Reduced efficiency	8	2	48
	Steam cleaning/ separating	Separator - vessel	Erosion, corrosion	Strength reduction	8	8	128
		Steam scrubbing	Erosion, corrosion	Strength reduction	8	8	128
		Stack	Corrosion	Leaking	8	2	96
		Mist eliminator - wire mesh	SCC	Breaking	8	5	40
	Turbine	Labyrinth seals	Scaling	Stock up	8	6	192
		Labyrinth seals	Erosion	Reduced efficiency, leaking	4	7	56
		Diaphragm	Erosion	Vibration, cracks	7	8	192
		Rotor	Erosion	Imbalance, vibration	4	7	84
		Rotor	Corrosion and erosion	Reduced efficiency	5	1	10
		Rotor blades	Cracking	Breaking of blades	9	3	108
		Rotor blades	Erosion	Vibration, cracks	9	5	45
		Rotor blades	Scaling and corrosion	Clogging, material reduction	7	7	49
		Casing	Scaling/corrosion	Reduced strength	7	7	49
		Casing	Erosion	Steam bypass	4	8	32
	Heating/cooling	Pre-heater - tubes	Scaling/corrosion	Clogging/leaking	7	3	105
		Pre-heater – water caps	Corrosion	Leaking	8	4	96
		Vaporizer - tubes	Erosion/fatigue	Leaking	7	3	105
		Condenser	Scaling	Reduced efficiency	2	10	80
		Air cooling condenser - tubes	Corrosion	Leaking	6	2	72
		Air cooling condenser – supports	Corrosion	Material reduction	2	3	12
Reinjection	Pipes	Brine pipelines	Clogging	System upset	8	6	192
		Brine pipelines	Corrosion	Leaking	8	8	320
		Brine pipelines	Corrosion under insulation	Leaking	8	3/2	6/5
		Casing	Scaling	Reduced capacity	8	8	64
		Casing	Corrosion	Leaking	8	2	80
	Valves	Seat	Erosion	Can't use to regulate	4	6	144
		Brine check valve - pin	Wear/abrasion	Can't close	9	4	144
		At wellhead - seat	Scaling	Sticking	8	10	80
		Pressure retention valve - body	Corrosion	No significant	2	8	16
		Check valve – body	Corrosion	No significant	2	8	16
		Check valve – disc	Corrosion	Inoperable	7	7	147
	Pumps	Impeller	Cavitation/scaling	Reduced efficiency - no fluid	8	8	128

Conclusion

Despite the limited number of answers, the results from the FMEAs show that erosion, corrosion and scaling influence components in all the plants and this supports the need for corrosion and scaling resistant solutions in geothermal power plants. Other conclusions that can be summarized from the FMEA results are the following:

- The most critical cases in the systems according to the RPN is leaking of pipes, generally caused by corrosion.
- Scaling leads to reduced efficiency of the plants in general but can also become detrimental if accumulated in valves, leading to them being inoperable.
- Scaling mainly affects valves, well equipment, heating/cooling equipment (i.e. condenser) and turbine components.
- Corrosion problems can be found in the majority of components and while the most serious cases generally appear to be connected to pipes they are also present in turbine components, steam cleaning/moisture removal equipment and valves.
- There are numerous components which could potentially benefit from the use of more erosion resistant material including turbine components, valves, the wellhead, pipes and pumps.

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