

The main challenges in operation and maintenance of geothermal power plants

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ABSTRACT

The operation of geothermal power plants has many challenges in terms of maintenance. These challenges can in some cases be specific to geothermal power plants. The specific problems faced by operators of geothermal power plants can be divided into several categories but in general the main causes for operational issues are related to a) scaling, b) corrosion, and c) erosion. For ON Power, the operator of the Hellisheiði and Nesjavellir power plants in Iceland, problems associated with scaling are most frequently observed in piping components and mechanical parts. These are parts ranging for example from control valves at production wellheads to stuck gland steam seals and valves throughout re-injection systems. Heat exchangers in contact with the geothermal brines are prone to scaling if mitigation is not in place. A substantial emphasis is placed on the maintenance of turbine parts, in particular on diaphragms and rotors. There, erosion can be accelerated with the insufficient removal of condensed droplets from the steam collection system and the condensation of steam while travelling through the turbine towards the condenser. Corrosion is mainly observed when temperatures are below 100°C and moisture within insulations is not evaporated rapidly. There, corrosion of pipes is observed where moisture penetrates the claddings protecting insulation materials. Corrosion is also observed in the gas collection system. In recent years, ON Power has been involved in research on specialized coatings for corrosion protection as well as studying steel alternatives to 316L. In this paper ON Power's results from a) acidifying geothermal water before heat exchange to prevent scaling, and b) from developing repair techniques for erosion corrosion damage that significantly reduce downtime will be presented. The acidification of the geothermal water with carbon dioxide and hydrogen sulfide has reduced scaling in heat exchangers by 75% and the long term reconstruction of diaphragm assembly surfaces within the turbines has resulted in no observable erosion damage over the last few year.

1. INTRODUCTION

ON Power operates two geothermal power plants; the Nesjavellir Power Plant and the Hellisheiði Power Plant. The Nesjavellir Power Plant has four 30 MW_e electricity generation units from Mitsubishi Heavy Industries Ltd. (MHI), a total of 120 MW_e, and a capacity for a thermal production of up to 300 MW_{th}. The power plant came online in 1990 with thermal production to provide hot water for district heating in the city of Reykjavik. In 1999 electricity production commenced. The turbines at Nesjavellir are single flow generation units with eight steps and condensers beside the units.

The Hellisheiði Power Plant has six 45 MW_e electricity generation units from MHI and one 33 MW_e unit from Toshiba, a total generation capacity of 303 MW_e, and a capacity for thermal production of up to 133 MW_{th}. The Power Plant came online in 2006 with a 90 MW_e electrical production and ramped up to its full production capacity of 303 MW_e by 2011.

In this paper the main challenges faced at the power plants related to corrosion, erosion and scaling will be covered along with the repair solutions and mitigations that have been developed and used at ON Power's power plants. The development covered has been a collaboration through the years between different people at ON Power as well as being the result of successful cooperation with Innovation Center Iceland, a number of universities, contractors and many other people within the geothermal industry.



Figure 1: The two power plants operated by ON Power; Nesjavellir (left) and Hellisheiði (right).

1.1 Maintenance challenges related to scaling, corrosion, and erosion corrosion

In the operation of geothermal power plants many challenges arise in relation to maintenance. These problems can be roughly divided into the categories of scaling, corrosion, and erosion corrosion.

1.1.1 Scaling

Scaling can occur in a number of places in geothermal power plants; in boreholes, steam pipe systems, heat exchangers, turbines, reinjection pipe systems, and reinjection boreholes. The most extensive scaling problem dealt with at the Hellisheidi Power Plant has been scaling in heat exchangers, reinjection piping, and reinjection boreholes. The heat exchangers are used to extract as much energy as possible from the geothermal water, but Silica scaling can be induced with the temperature drop of the geothermal water in the heat exchanger. A careful balance between extracting as much energy as possible while keeping the heat exchangers clean to prevent a drop in heat exchanger efficiency has to be maintained. The heat exchangers at Hellisheidi have been cleaned on a yearly basis since operations commenced. The mass of scale removed has been on the order of 600 kg from each heat exchanger every year. Two years ago, as a part of the CarbFix and SulFix projects (Gislason et al., 2018), the injection of condensate with dissolved carbon dioxide and hydrogen sulfide pH 3,5 into the geothermal water before the heat exchange process began. The injection of the gas rich condensate causes acidification of the geothermal water and thus a significant decrease in scale formation in the heat exchangers. During last years heat exchanger clean out the scale from each heat exchanger was about 150 kg, only 25% of the scale in previous years.

Some scaling problems have occurred in the turbines, specifically in one case when a particularly powerful and dry borehole was connected to the engines. Scale formed in one of the turbines at Hellisheidi but the problem was mitigated by rearranging the stem pipe system connections to mix dry and wet steam before the separators. Another scaling issue that has been experienced at Hellisheidi relates to the operation of a complex system with multiple boreholes connected together to a power plant. Scaling in the power plant and piping is prevented by keeping the pressure of the system above the saturation point for silica. However, single boreholes have different amounts of dissolved silica and thus a different saturation point. This can result in scale formation in piping leading from boreholes to the combined piping leading to the power plant.

1.1.2 Corrosion

Corrosion can occur in piping systems, especially in locations where the temperature is around or below 100°C. The carbon steel piping systems at Hellisheidi and Nesjavellir are insulated with rockwool. If a leak occurs the rockwool insulation can absorb the moisture and create ideal conditions for corrosion. To prevent this cladding is kept in good condition, and in some high-risk areas aluminum coating is applied to the pipes. A corroded pipe from ON Power's piping system can be seen in Figure 2.



Figure 2: A corroded pipe from ON Power's piping system.

1.1.3 Erosion corrosion

Erosion corrosion can occur in control valves for boreholes, in pipe bends close to boreholes, and in turbines. The erosion corrosion close to boreholes is often due to high flow rates or because the borehole was prematurely put online, too soon after drilling. Erosion corrosion in turbines happens because the steam is moving through the turbine at a high velocity while going beyond the saturation point, thus getting wetter while it travels through the turbine unit. The steam collides with precipitated water droplets and causes erosion corrosion (Morris & Robinson, 2015). This process cannot be eliminated. It takes place in several places in the turbine unit; among those are the diaphragm, the rotor, the turbine casing and assembly surfaces. In the diaphragm the erosion corrosion takes place on the assembly surfaces, between the blades, and in the seat for the casing.

In Figure 3 a highly eroded casing seat can be seen. Noticeably, there is old welding repair work made with 309Mo alloy in the seat and that part has not been eroded away in the same way as the surrounding material of the seat. This example clearly confirms the importance of choosing the right metals for equipment construction in the first place, especially in critical places like the casing seat of the diaphragm.



Figure 2: Erosion corrosion in turbine; between blades in the diaphragm (left) and in the casing seat for the diaphragm (right).

The erosion corrosion in the turbine mainly occurs where there is a pressure difference between sections and where the steam flows at a high velocity through the turbine. This happens because turbines in geothermal power plants are operated at fairly low pressures; the Hellisheidi power plants has turbines operating at pressures as low as 7 bars and close to saturation. During energy extraction, with such a low pressure and close to saturation, the steam will inevitably condense to some extent, forming water droplets. These water droplets are the main reason for erosion corrosion in turbine parts. In both Hellisheidi and Nesjavellir many modifications have been made to the system in an effort to avoid these problems. Holes have been drilled between the diaphragm through the casing to collect condensate which is subsequently lead to the condenser.

2. REPAIR TECHNIQUES AND DEVELOPMENT

To deal with the problems listed in the previous section several repair techniques have been developed in our workshop in Hellisheidi, in cooperation with our contractors. This is in addition to the mitigation techniques applied that were discussed above, such as the acidification of geothermal water in the heat exchangers to prevent scaling, the careful selection of boreholes for mixing of geothermal fluid to prevent scale formation in the turbine, and the aluminum coating of critical parts of the piping system to prevent corrosion. The repair techniques covered here deal with erosion corrosion in the diaphragm, the casing, and the rotor. In the case of the diaphragm the assembly surfaces have been rebuilt with 309Mo alloy over a nine year period with very good results. There has been no observable erosion on the assembly surfaces with five years of operation from the time they were repaired (Figure 4).

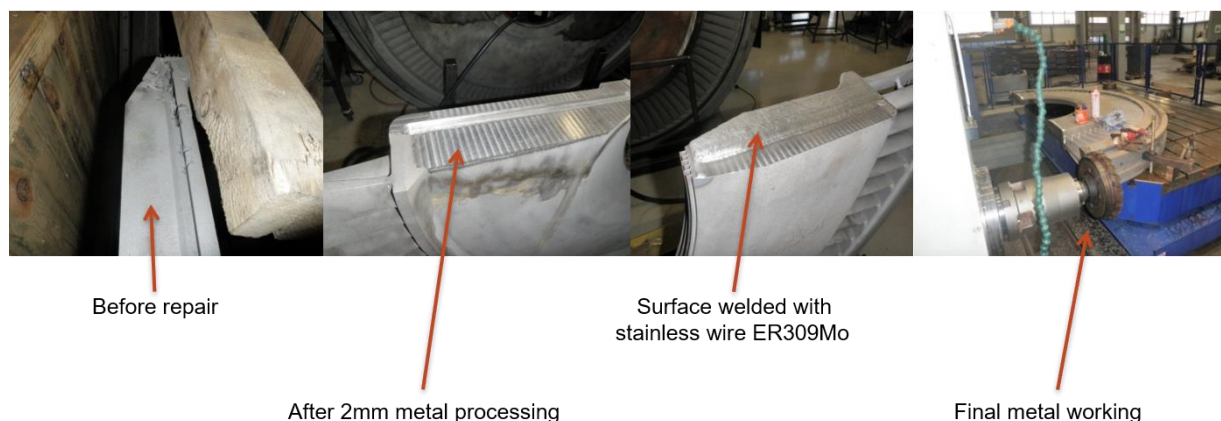


Figure 4: Assembly surface repairs in diaphragm.

The casing seat for the diaphragm is prone to corrosion due to the leak of wet steam between the steps of the turbine. This type of erosion is present in steps one to four of the turbine, and the damage needs to be repaired because it creates a path for the steam to go through the turbine, eventually going through the casing to the engine area. In cooperation with ON Power's workshop contractor a machine to repair this critical area has been developed. The general concept of the machine is to enable repairs on the eroded area in the same way erosion in the assembly surfaces has been repaired. The machine removes about 2 mm of the welded area and then the

seat is welded with 309Mo. The machine is carefully aligned with the rotor so that the seats for the blades will be exactly perpendicularly to the rotor once machined.

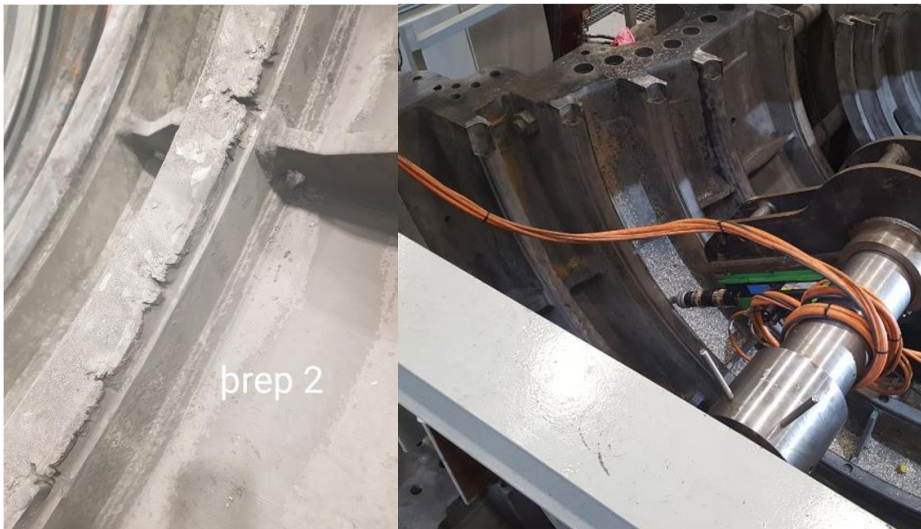


Figure 5: Diaphragm seat repair.

2.1 Erosion corrosion in turbine rotor and repair development

Geothermal turbine rotors need regular maintenance due to erosion corrosion, especially in areas where there is a pressure difference, like in the gland seal area. The rotors at the power plants have been repaired after twelve years in operation due to erosion in the gland seal area and after fifteen to eighteen years in operation a blade repair was necessary due to erosion corrosion caused by water droplet formation on the blade edge. The major affected areas have been in the first two steps, which have required a complete rebuild with 410 NiMo alloy while the later steps are more intact although we still see erosion corrosion in the blades for all steps. The erosion corrosion takes place in balancing holes and the area close to the blades. Originally all repairs on the turbine rotor and blades were sent out but since 2014 a turbine workshop has been operated in the Hellisheidi Power Plant. Up until now, seven rotors have been rebuilt in cooperation with the workshop contractor, Deilir.

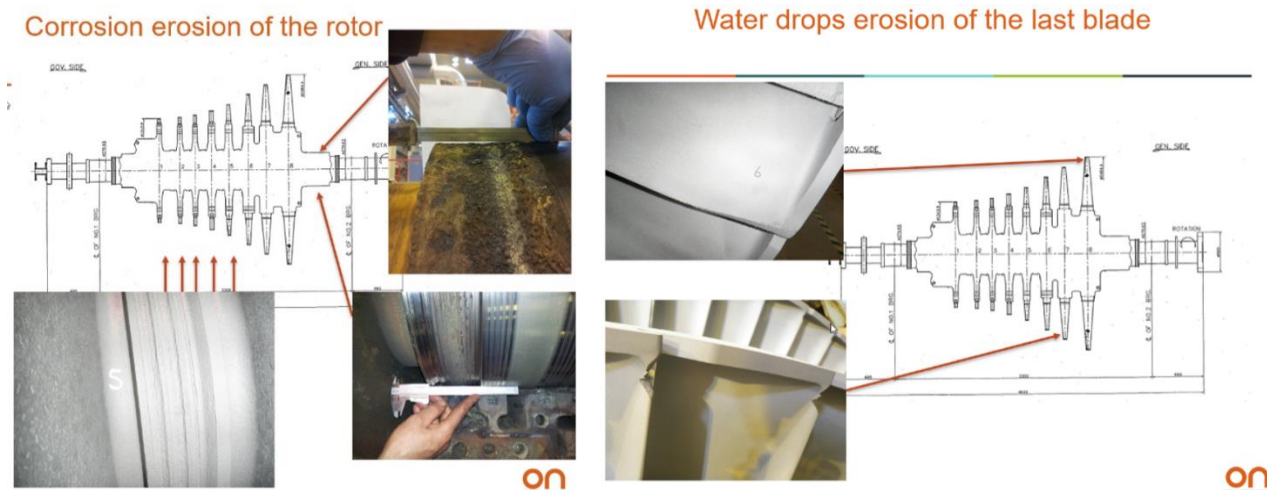


Figure 6: Turbine rotor corrosion erosion and water drop erosion on rotor blades.

Rotor repair example



Figure 7: The turbine workshop in the Hellisheidi Power Plant.

3. CONCLUSIONS AND DISCUSSION

For the effective and reliable operation of a geothermal power plant all the mechanical parts need to be in good condition. The first line of action is the proper design of parts. The second line of action is the prevention or mitigation of problems that inevitably arise, like was done by acidification to reduce scaling. The third line of action is the analysis of where problems occur and the fortification of machinery in key problem areas. In this paper the choosing of the right materials for the right places was covered, specifically relating to the prevention of erosion corrosion problems. All of these measures extend the time between the overhauling and repair of turbines, in ON Power's case from overhauling every four years to overhauling every six years due to all of the analysis and development of repair techniques. This has resulted in increased days of operation on our units per year, which is safer for employees, economically advantageous for the company, and significantly more convenient for all parties.

Further work in repair technique development and problem mitigation by ON Power includes work on coating techniques to make the metal in the power generation units resistant to the erosion corrosion load. Many problems can arise for example in cladding with welding on turbine parts, bending, and stress, during the repair work. A project addressing these issues called Geo Coat, which started as a collaboration with Innovation Center Iceland, Velvik, Metav, and Politehnica University of Bucharest, has now gone on to be funded by Horizon 2020. In this project many types of coating will be tested in a real geothermal power plant, hopefully with good results that can benefit all of the geothermal industry in preventing and mitigating erosion corrosion problems.

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