Some Analysis of Major Impact of Geothermal Fluid Components in Power Plant Equipment

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Abstract. This paper presents the results from a some analysis and major impact of geothermal fluid composition on the equipment in use in geothermal power plant. The structural analysis of material deposition improve the direct influenced of chemical composition of steam and waters included CaO, MgO, Al2O3 and SiO2 incorporated in the molten phase and the deposits in the scales formed due to equipment. The steam turbine corrosion damage, particularly of blades, discs and pomp s, has long been recognized as a leading causes of reduced availability in the geothermal power plant. The corrosion process depends on temperature, pressure, chemisty and vaporous carryover by diversity of impurity. The experimental analysis procedure involves characterization of the fluid geothermal composition. Detailed information about surfaces morphological modification of the power plant components are obtained by electron microprobe analysis EDX and SEM investigation. References selection are obtaining by X-ray diffractometer patterns of the specimen.

1. Introduction

Geothermal steam contains various solid particles resulting in particle erosion and scale deposits. Geothermal steam contains hydrogen sulphide (H2S) and carbon dioxide (CO2). Both components are highly corrosive can promote heavily corrosion. The steam impurities could be easily transferred to the metal surface through this process may generate greater concentration of corrosive impurities and massive silicides and salts deposits. Aggressive corrosion in steam geothermal condition may be defined as an accelerated corrosion, resulting from the presence of many salt contaminants such as Na2SO4, NaCl, and silicates forming molten deposits, with a damaging impact on the protective surface of geothermal plant components [1,2]. Specific chemistry of geothermal steam include: high non-condensable gas contents, high content of solids salts dissolved in steam and corrosive chemical composition [3]. High H2S content generally promotes metallurgical problems: stress corrosion, cracking and metal fatigue [4]. The high CO2 content in geothermal fluid below 200°C, accelerate calcite scaling and promote active corrosion. Also one of the most commonly problems regarding high gas content in the geothermal steam are high non-condensable gas contents, sulphur deposition and corrosion due to low pH and oxygen into the geothermal power components steam [5]. For example
the most commonly problems concerning high gas content in the geothermal steam are: high Cl- 10,000 ppm as 1.8% NaCl and CO2 300 ppm and SO4 50 ppm as Na2SO4). This paper aims to present our current understanding, a new class of investigation and experimental data to provide a broader view on the effects of geothermal water and steam composition in Hellisheiði-Iceland geothermal power plant.

2. Materials and methods
The Hellisheiði geothermal field is located on the Hengill area. The Hengill geothermal system is in southwest part of Iceland on the Mid-Atlantic Ridge and comprises of Hellisheiði (Figure 1) geothermal power plant (there are four 40MWe/units and 45MWe/units steam Mitsubishi Heavy Industry turbines). The temperature in the Hellisheiði system change with drill depth; the maximum temperature is 180°C, found at 200-600m, but at 2 km, the temperature drops to 220-260°C. This suggests that a cooling process is taking place in the deepest part of the drill in Hellisheiði geothermal system. The geothermal steam that is produced from the Hellisheiði system contains dissolved CO2 and H2S gases. However, the concentration of non-condensable gases in the steam is quite low (<0.5%), when compared to other high temperature in Icelandic geothermal systems.

![Figure 1](image1.png)

**Figure 1.** Hellisheiði power plants on a Hengill area in Iceland.

The concentration of CO2 is similar or lower than usual, and we suppose that this is the case for insufficient supply of this gas to the fluid, to saturate it with calcite. The steam from the well then goes through the separator before entering the turbine. Table 1 present the chemical composition of the steam in turbines 1 to 6 in the Hellisheiði power plant.

| Turbine no. | H2 [mg/kg] | N2 [mg/kg] | CH4 [mg/kg] | H2S [mg/kg] | CO2 [mg/kg] |
|------------|------------|------------|-------------|-------------|-------------|
| 1          | 31.14      | 28.85      | 4.43        | 804.27      | 1864.60     |
| 2          | 23.78      | 32.45      | 6.17        | 741.86      | 3087.17     |
| 3          | 29.35      | 22.71      | 5.04        | 928.50      | 2261.80     |
| 4          | 23.92      | 26.74      | 3.81        | 634.27      | 1725.63     |
| 5          | 15.92      | 82.93      | 7.58        | 472.50      | 4687.05     |
| 6          | 40.91      | 37.86      | 6.22        | 976.88      | 4551.85     |

Table 2 show examples of the chemical composition of the condensate/separator water. The temperature and pressure for some of the steam turbines that are operational at Hellisheiði power plant is 170-175°C. The temperature and pressure is similar between turbines no.1–4 with the average temperature 170.8°C and pressure 7.17 bars. When the geothermal steam goes through the turbine, the steam temperature and pressure decrease. The steam pressure for the turbine is 7.21bar and temperature 170.8°C and after the turbine the pressure will be around 0.095 bars and temperature...
45.5°C. The concentration of CO₂ is similar or lower than commonly, it is hypothesized that the cause is insufficient supply of this gas to the fluid to saturate it with calcite. The steam from the well then goes through the separator before entering the turbine. The concentration of H₂S and CO₂ in the steam are the highest. This aspect was expected due to the fact that they are common non-condensable gases dissolved in geothermal steam. Both H₂S and CO₂ are highly corrosive therefore are capable of aggressive corrosion in steel and alloys used in geothermal systems.

**Table 2.** Chemical composition ions of the steam and pH value of the separator and condensate water at Hellisheiði power plant.

| Location [in water] | Na  | K   | Ca  | Mg  | Fe  | Al  | Cl   | SO₄ | F | pH  |
|---------------------|-----|-----|-----|-----|-----|-----|------|-----|---|-----|
| Separator [ppm]     | 208.8 | 36.1 | 1.054 | 0.025 | 0.05 | 1.851 | 179.03 | 54.59 | 1.37 | 9.23 |
| Condensate [ppm]    | 0.15 | 0.2  | 0.01 | 0.001 | 0.011 | 0.003 | 1     | 0.2  | 0   | 6.32 |

It is important to get exact type of materials in the most relevant components of geothermal turbines power plants operated, as well as the most critical material damages of turbine components [6,7]. In a corrosive geothermal environment careful design and material selection is required to protect different parts of a turbine, particularly from: erosion, corrosion fatigue and Stress Cracking Corrosion (SCC). Surface damages such as corrosion and erosion depends not only on the steel type but also on the material condition as hardness of the steel and tempering process.

Turbine rotor at Hellisheiði power plant (figure 2) is manufactured by Mitsubishi Heavy Industry (MHI). Attention must be made to low-stress designs and applying rotor materials with low stress cracking corrosion susceptibility. The steel used for turbine components in power plant is a 12Cr steel and is a precipitation hardening martensitic stainless steel type 17-4 PH /AISI 630 (is the specification for martensitic stainless steel A17Cr-4Ni-3Cu; or Japan JIS G4303 (SUS 630). The producer MHI has developed two types of materials (Table 3) for the geothermal turbine rotors and chemical composition as shown in Table 4. The material 10325 MGB has a low SCC susceptibility because it contains extremely low levels of sulphur and impurity and GSR 1 is a 12% Cr-5 Ni material applied to turbine rotors exposed to highly corrosive geothermal steam. The steel used for turbine blades in Hellisheiði power plant is a 10325 MGB (low alloy ferrite steel of Cr, Mo,V type). In Fig.2 are shown examples of erosion and abrasion (index A), damages in blades (detailed index B) and rotor (detailed index C).

**Table 3.** Components turbine materials at Hellisheiði power plant and mechanical properties.

| Components | Metallurgical characteristics | Yield strength $R_{0.2}$ [N/mm²] | Tensile strength $R_{m}$ [N/mm²] |
|------------|------------------------------|-----------------------------------|----------------------------------|
| Turbine blades 10325MGB | Forged low alloy ferrite steel | ≥635                              | ≥740                             |
| Turbine rotors GSR 1 | 12Cr precipitation hardening martensitic stainless steel | ≥635 | ≥740 |

**Table 4.** Chemical composition of geothermal turbine materials.

| Material | Chemical composition (% of mass) |
|----------|----------------------------------|
| Turbine blades 10325MGB | C 0.23-0.3, Mn 0.7-1.0, P ≤0.015, S ≤0.005, Si 0.2-0.4, Ni ≤0.5, Cr 1.0-1.3, Mo 1.0-1.3, V 0.21-0.29 |
| Turbine rotors GSR 1 | C ≤0.06, Mn ≤1.0, P ≤0.015, S ≤0.005, Si ≤0.30, Cr 5.0-5.5, Mo 11.5-12.5, V 0.8-1.2 |

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Method analyses of scales and deposits of the turbine components were examined using complex analyses. The samples were taken from different parts of the equipment used in Hellisheiði. The authors performed a series of tests on the samples to find the morphology and composition of scales/deposits. The method laboratory proposed three kinds of laboratory testing: a) Scanning Electron Microscopy (SEM) was used to evaluate the morphology of structure of the scale deposited materials; b) Energy Depressive Spectroscopy (EDS analysis) was used to analyse the composition of deposited materials; c) X-Ray Diffraction (XRD analysis) was employed to quantitative analyse of the compounds in the scales/deposited materials [8].

3. Results and discussions
High CO$_2$ content in geothermal fluid below about 140°C accelerates calcite scaling and promotes very active corrosion of geothermal plant components. The solids content and composition is varied, particularly regarding chloride and different trace elements, as: boron, fluoride etc. The effects of geothermal steam is providing nucleation seeds which may further develop into an acidifying early condensate and the formation of concentrated solutions generating impurity deposits with accentuated corrosion effects [9,10]. Experimental evidence shows that the deposit on the surface exposed to steam consists of many constituents with 0.5 microns to millimetre particles, small crystals and silicide particles with absorbed ionic impurities and their effect is to create strong adhesion and corrosion on the turbine components surface.

Figure 2. Turbine MHI rotor at Hellisheiði power plant and examples of erosion (B) and abrasion (C) damages.

Figure 3. Massive chemical deposits in the geothermal power equipment caused by high salts concentration in the geothermal steam.
Active corrosion occurs when metals are heated in the temperature range 200-280°C, in the presence of sulphate deposits formed as a result of the reaction between sodium chloride and sulphides compounds in the phase solutions (figure 3). Figure 4 reveals result of EDX analyse of Smart Phase Map collected at 30.00kV resolution, clearly showing the seven different phases in the samples and the spectra basis for the O, Al, Si, S, K, Ca and Fe elements analysis. Phase mapping uses spectra as the basis for characterizing the elemental association and distribution by tracing variation in component peak intensity. This approach provides the fine correlation of the data between phases. The results are one single phase image describing the overall chemical map of the sample. Geothermal steam contains various solid particles which cause erosion and scale deposits. Special design and resistant material are needed to reduce the damage of Solid Particle Erosion (SPE). Wet steam can lead to droplet/moisture impact erosion. At Hellisheiði power plant erosion seems to be the main reason for damages of turbine parts, probably due to droplet impact erosion and solid particle erosion. In addition to silica the results of laboratory tests showed that there was also a small ion of Na, Ni and Fe particles and S and Si oxides.

![Figure 4. EDX micrography of the complex materials scaling deposition of the separator geothermal equipment.](image)

Full knowledge of the droplet size and number spectrum is vital for assessment of the droplet impact turbine erosion process. The droplet impact pressure as well as the droplet impact angle is confirmed to be driving parameters affecting a material’s volume loss, and volume loss increases exponentially with increasing perpendicular component of the droplets’ impact velocity. The deposit also accumulated on the leading and trailing blades edges. Similar to the turbine diaphragm, the rotor and the blades experienced similarity problems (Figure 5 and Figure 6).

![Figure 5. Electronic SEM micrography in surface erosion of blades (x 500).](image)

![Figure 6. Optical image of the (a) corrosion and (b) erosion rotor surface.](image)
The deposit thickness was reduced to 0.5-0.7 mm. Scaling and deposition occur also in the steamstainer (Figure 7), steam separator (Figure 8 and Figure 9), scrubber (Figure 10) and demister (Figure 11) elements. The demister’s purpose is to capture water that is in the steam. Steam flows through the demister’s elements and the resulting wet steam is depressed and water removed. The cleaning method of chisel chipping and fine grinding were used to remove the deposit from turbine blades.

Figure 7. Steamstainer with materials scaling deposition on its interior side.

Figure 8. EDX mapping micrography of the complex materials scaling deposition of the separator geothermal equipment. Examples of EDX showing seven different element phases of: O; Na; Si, S; Cl; Fe; and Ni in the samples.
Figure 9. SEM image of the separator accumulated deposit (x 400).

Figure 10. SEM image of the scrubber accumulated deposit (x 400).

Figure 11. SEM image of the demister equipment surface deposits (x 2000).

Figure 12. Scaling deposits X-ray diffraction pattern (Cu Kα).

Figure 13. Identification and the colors code in the RDX scaling deposits difractogram for the major compounds distribution.

In this experiment the RDX analysis is a technique for the rapid determination of the ions in the samples. It displays the spectrum of composition existing in a given relative homogeneous phases from the shape of diffraction peak broadened (Figure 12 and Figure 13) by a range of lattice parameters in the phase.

5. Conclusions
Hellisheiði geothermal system is composed of basaltic hyaloclastites layers and other rock types, that is located within the Hengill central volcano where the volcanism is most intense. The maximum
recorded temperature is around 280°C in the Hellisheiði system. Material analyses (SEM, EDX and XRD) showed that the problem of scaling deposit did not originate from corrosion. Supposed steam-carried particle were the main source of deposited material. The system contains dissolved CO₂ and H₂S gases. However, the concentration of non-condensable gases in the steam is quite low (<0.5%), in comparison to other geothermal systems in Iceland. Wet steam can lead to droplet/moisture impact erosion. At Hellisheiði power plant erosion seems to be the main reason for damages of turbine parts, probably due to droplet impact erosion and solid particle erosion. The deposits, consisting of mainly SiO₂, FeS and NaCl were found in the main equipment used for steam passing, including the separator, scrubber, demister and on the turbine blades.

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References
[1] Cuevas-Artega C, Rodriguez J A, Clemente C M and Rodriguez J M 2014 Pitting Corrosion Damage for Prediction Useful Life of Geothermal Turbine Blade American Journal of Mechanical Engineering 2(6) pp164-168
[2] Mazur Z, Garcia R, Aguirre J and Perez N 2008 Steam Turbine Blade Failure Analysis Engineering Failure Analysis 15(1-2) pp 129-141
[3] Regenspurg S, Wiersberg T, Brandt W, Hueges E and Saadat A 2010 Geochemical Properties of Saline Geothermal Fluids from the in–Situ Geothermal Laboratory Chemie der Erde-Geochemistry 70(3)
[4] Stefánsson A, Arnórsson S, Gunnarsson I, Kaasalainen H and Gunnlaugsson E 2011 The geochemistry and sequestration of H₂S into the geothermal system at Hellisheiði, Iceland Journal of Volcanology and Geothermal Research 202(3-4) pp 179-188
[5] Ahned M and Sürken N 2009 Experimental assessment of droplet impact erosion resistance of steam turbine blade materials Wear 267(9-10) pp 1605-1618
[6] Stapleton M 2002 Scaling and Corrosion in Geothermal Operation Power ChemTechnology pp15-18
[7] Corsi R 1886 Scaling and Corrosion in Geothermal Equipment: problems and preventive measures, Geothermics 15 (5–6) pp 839–856
[8] Adiprana R, Yuniarto E and Salak G 2010 Geothermal Power Plant Experience of Scaling/Deposit: Analysis, Root Cause and Prevention Proceedings World Geothermal Congress Bali, Indonesia 25-29
[9] Armannsson H, Gudmundsson A and Steingrimsson B S 1987 Exploration and development of the Krafla geothermal area Jökull 37 pp13-30
[10] Karlsdóttir S.N 2012 Comprehensive Renewable Energy Elsevier Ltd pp 239-257