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In-Situ Material and Corrosion Studies at the Soultz-sous-Forêts (France) EGS Site

Julia Scheiber[1], Guillaume Ravier[2], Nicolas Cuenot[1] and Albert Genter[1]

[1]GEIE, "Exploitation Minière de la Chaleur", Route de Soultz, 67250 Kutzenhausen, France

ES-Géothermie, 3A Chemin du gaz, 67500 Hagenau, France

scheiber@soultz.net

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ABSTRACT

At the Soultz EGS site a scientific and technical monitoring is associated with power plant operation. Material selection and testing of suitable materials became an essential part of the Soultz research program. Intensive in-situ material studies, involving scaling issues as well as corrosion and coating tests, were conducted. Saline Na-Ca-Cl brine of about 100 g/l Total Dissolved Solids is produced at 160°C/20 bars from a naturally fractured granitic reservoir. Measurements of the redox potential show reducing conditions and brine pH of 4.8 is slightly acidic. Gas Brine Volume Ratio is close to 1 with CO_2 concentration >85%. In consequence, a pressure of 20 bars is maintained in the surface installations in order to avoid degassing and calcite precipitation.

Selection of suitable materials for this aggressive environment focuses on stress resistance against chemical and mechanical attack, on durability and on cost effectiveness. It was recognized during those studies that material assessment needs to consider production and injection conditions as well as static and dynamic conditions. Volume of scale deposition and intensity of scale adherence as a function of surface roughness and electrochemical properties of applied metals turned out to be a crucial issue in Soultz especially for the heat exchanger unit and the re-injection side. Soultz scales are classified as NORM (Naturally Occuring Radioactive Material). Therefore, scale formation and scale deposition needs to be reduced not only by chemical scale inhibition but also by appropriate material selection. Static conditions seem to increase electrochemical corrosion for low alloyed metals contrary to dynamic conditions where a relatively low corrosion rate of 0.2 mm/year was observed at the re-injection side, 70°C/18 bars. Polymer coatings were found to be a promising option for metal surface protection but careful selection for specific power plant equipment is required and wrong selection can result in fatal consequences as observed for the heat exchanger unit at Soultz.

Besides corrosion and material studies at operating power plant equipment, in-situ material test were conducted using bypass systems installed at the production and re-injection side, the High Temperature Skid (HTS) and the Low Temperature Skid (LTS). Metal coupons, straight pipes, T-shaped pipes and single heat exchanger pipes were installed at in-situ conditions and tested during circulation. In-situ experiments at the high and low temperature side of the Soultz geothermal loop provide unique opportunities to test and select materials based on their durability and cost effectiveness for geothermal applications with Upper Rhine Valley type fluids.

1. INTRODUCTION

The geothermal power plant of Soultz-sous-Forêts is located in the NE of France, 50 km NE of Strasbourg, at the western rim of the Upper Rhine Graben (URG). The project started in 1987, with the aim to develop heat exploitation of deep reservoirs in hot dry rocks (HDR) by creating an artificial deep heat exchanger in a closed environment, Gérard and Kappelmeyer (1987). Therefore, one exploration well, EPS-1, and four deep wells, GPK-1 to GPK-4, were drilled between 1987 and 2005 down to the crystalline basement of the Rhine Graben. During drilling and well testing it became obvious that native brine was circulating through the fracture network of the naturally fractured granite, Genter and Traineau (1992), Genter et al. (2010). The original HDR design was found to be obsolete. Nevertheless, permeability of the reservoir decreased with increasing depth and the initially low permeability was improved by several hydraulic and chemical stimulations, creating an Enhanced Geothermal System (EGS), Gérard et al. (2006).

The Soultz EGS site operates a naturally fractured granitic reservoir percolated by Na-Cl-Ca brine with Total Dissolved Solids (TDS) up to 100 g/L. Geothermal brine is produced at 160°C/20 bars and is re-injected at 70°C/18 bars. For power production an Organic Rankine Cycle (ORC) was designed and installed between 2007 and 2009 with an estimated gross capacity of 2.2 MWe.

Economic feasibility of geothermal power plants relies on continuous and constant operation of the geothermal loop. Constraints of operational performance like unscheduled shut-down periods, intense maintenance operations and follow-up costs reduce their reliability. Binary power plants depend urgently on effective operation of down-hole pump and heat exchanger unit. Inappropriate performance or malfunctioning of one of these systems affects consequently the complete system. Reasonable material selection is required for surface and subsurface installations of the geothermal loop based on geochemical and physical parameters like brine and gas chemistry, production/injection temperature and pressure and transport of suspended particles.

The three-year research program (2010-2012) of the Soultz site was associated with a scientific and technical monitoring during geothermal exploitation. Several hydraulic circulation tests have been performed in this time and those tests were used for intensive in-situ material studies concerning corrosion, coating and scaling which resulted in an improved design for a corrosion skid at the high temperature side of the geothermal power plant. Circulation of geothermal brine affects material performance of equipment which is in direct contact with the geothermal brine. The high salt content, 97 g/l, of the Na-Cl-Ca brine (Sanjuan et al., 2010) and the production of cuttings from the reservoir causes not only corrosion but also abrasion issues at surface and subsurface installations of the geothermal loop. Additionally, scale formation which is partially related to corrosion processes, complicate proper material performance of the surface equipment, for example at the heat exchangers. Intensive mechanical cleaning procedures were required in the past in order to remove the inorganic deposits, mainly made of strontium rich barite ($Ba_{0.6}Sr_{0.4}SO_4$), galena (PbS) and minor fractions of mixed sulfides ($(Fe,Sb,As)S_x$), Sanjuan et al., (2010), Sanjuan et al., (2011), Scheiber et al., (2012) and Nitschke, (2012). For material protection and improving cleaning procedures for heat exchanger cleaning, it was decided to apply a polymer coating with beginning of the ORC operation in 2008. The anti-adhesive properties of the coating surface decrease scale adherence. Those surface properties should help to improve cleaning efficiency of the high-pressure water jetting procedure which worked out well in the beginning but with time efficiency decreased due to step-wise degradation of the coating. First damages of the coating and consequently corrosion related deposits as well as damages of the heat exchanger tubes were observed in the beginning of 2013 resulting in serious damages of the whole ORC heat exchanger system.

Another focus of the in-situ material experiments at Soultz is related to the performance of materials utilized for the down-hole pump. These materials have to stand high temperature and pressure at rotation rates of 1500 – 2000 rpm which creates high flow velocities and turbulences at the hydraulic part of the LSP. Based on the geochemical conditions, electrochemical corrosion due to the impact of oxygen is negligible during production due to the anoxic conditions of the geothermal brine. Arsenic needs to be considered as an important redox species, it is involved in the formation of brittle iron-arsenic layer on the impeller and bowl surfaces. Moreover abrasion issues due to the transport of suspended particles at certain flow rates have a very negative impact on LSP material performance.

On-site tests in bypass systems at in-situ conditions on the production and the injection side were found to be powerful tools for material studies before application of certain materials at operating equipment.

2. MATERIAL STUDIES ON OPERATIONAL EQUIPMENT

During the 2010-2012 technical monitoring program of the Soultz geothermal power plant the material performance of applied materials was evaluated. Especially the ORC tubular heat exchangers and the production pump were monitored carefully. Two case studies are presented which discuss specific operational conditions of the equipment, material selection, type of failure and improvement of the equipment.

2.1 Case Study I: Heat Exchanger

Energy production in Soultz is carried out in an Organic Rankine Cycle (ORC). The ORC heat exchanger system constitutes, of three low alloyed tube heat exchangers, the ORC Evaporator, Preheater 1 and Preheater 2, Figure 1.

Figure 1: ORC tubular heat exchanger system of the Soultz geothermal power plant: ORC Evaporator, Preheater 1 and Preheater 2, (Picture: GEIE).

Repeated cleaning procedures were required due to the presence of inorganic deposits at the geothermal side of the heat exchangers. Those scales are formed due to the temperature decrease in the heat exchanger and act as isolation material. With increasing deposit thickness, the heat transfer between geothermal brine and organic fluid decreases significantly, Scheiber et al., (2012). The scale formation was the main reason to apply a polymer coating on all tube exchangers at the ORC system before beginning of the ORC operation in 2008. Based on the anti-adhesion properties of the coating surface, scale adherence on the polymer surface was very low and instead of milling, high pressure water jetting was applied as cleaning procedure.

Directly after application of the coating in 2008 the cleaning procedures worked out very well. With time, the anti-adhesion properties start slowly to degrade and more and more of the scales could not be removed anymore. Formation of blisters was observed and finally, the first spalling of the polymer coating occured in November 2012 when the ORC heat exchanger system was opened for inspection and cleaning.

The polymer coating showed different signs of degradation in the ORC Evaporator and the two Preheaters:

- loss of anti-adhesion properties
- formation of blisters
- mechanical spalling and exposure of the low alloyed metal tubes

Water jetting can only remove scales which have a weak adherence on the polymer surface. Originally, scales were not strongly attached to the polymer surface but the poor efficiency of the water jetting cleaning implies that the anti-adhesive properties of the coating start to degrade. As a consequence, the scales are much stronger attached to the surface and cleaning becomes much more intensive which also stresses the polymer surfaces more and more. It is possible that surface roughness increased during cleaning operations which provides convenient conditions for scale deposition. After cleaning, a thin layer of grey scales cover most of the heat exchanger surfaces in 2012, Figure 2 (left). Based on this observation it can be expected that a permanent scaling layer at the heat exchanger surface grow slowly but continuously and form an inorganic insulation layer on the polymer coating. The efficiency of the heat exchange will decrease continuously as a function of the scaling thickness.

Blister formation, especially in heat exchanger caps, indicate a loss of thermal stability and decreasing diffusion resistance against dissolved gases like CO_2, Figure 2 (middle). The hydraulic regime in the caps is very rough due to high turbulences when the fluid flow is turned by 180°. If gases manage to diffuse through the coating to the metals surface at 20 bars, these gases tend to expend their volume if heat exchanger operation is stopped and atmospheric conditions are allowed to adjust due to pressure decrease. This basically mechanical driven phenomenon pushes the coating from the metals surface and results in blister formation.

At various locations, spalling of the coating was observed and metal was exposed to the geothermal brine, Figure 2 (right).

Figure 2: Surfaces of the ORC Evaporator front side <u>after</u> water jetting *(left)*. Blister formation in heat exchanger cap *(middle)*. Coating spalling and exposure of metal surface to the geothermal brine *(right)*. After Scheiber et al. (2013a)

Fragments of the polymer coating were found in samples of scale particles. Interestingly, front and back side of the coating surface were covered with different deposits, Figure 3 (left). Both deposits were investigated by optical microscopy (Stemi D4, Zeiss), and electron microscopy, combined with qualitative energy dispersive X-ray fluorescence (ESEM XL 30 FEG, Philips, equipped with an EDAX system).

The front side of the coating particle was in contact with the geothermal fluid and is completely covered by grey and black scales. Morphology and elemental composition correlate with former studies, they consist mainly of strontium rich barite ($Ba_{1-x}Sr_xSO_4$), minor amounts of galena (PbS) and trace fractions of mixed sulfides ($((Fe,Sb,As)S_x)$), Sanjuan et al., (2010), Sanjuan et al., (2011), Scheiber et al., (2012) and Nitschke, (2012).

The back side was in contact with the metal surface and is partly covered by a homogeneous and light yellow deposit. In the backscattered mode of the electron microscope two different deposits were observed, Figure 3 (middle): First, a dense layer of iron and oxygen rich minerals with similar morphology. Based on the elemental analysis, this deposit consists either of iron oxides or iron hydroxides and/or of iron carbonates, Figure 2 (right). Both types of minerals, iron oxides/hydroxides and iron carbonates, are indicators for electrochemical corrosion of the metal surface of the heat exchanger tubes. The second deposit is made of single, lead and sulfur rich grains which are irregular distributed at the surface. Here it was not clear if the particles were formed at the back side of the coating or if they were deposited there by accumulation in the heat exchanger cap and scale sampling.

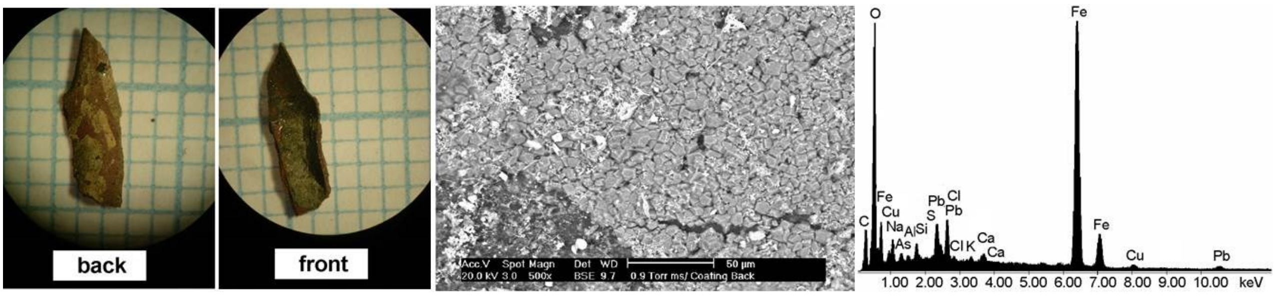

Figure 3: Back and front side of one coating particle sampled from the ORC evaporator. The particle is displayed on paper with millimeter gradations *(left)*. Electron microscope exposure and EDX analysis of iron rich deposits formed on the back side of the coating fragment *(middle & left)*. After Scheiber et al. (2013a).

Spalling of the coating exposed the low alloyed metal of the heat exchanger tubes to geothermal brine and aggressive in sub-surface corrosion and probably pitting corrosion was triggered. Finally, the mechanical strength of the heat exchanger pipes decreased to a complete breakdown. Geothermal brine broke to the isobutene cycle and polluted seriously the whole binary system. Soultz heat exchangers are fully damaged and have to be replaced. Several metals and alloys are now in discussion for the new ORC heat exchanger system. For this equipment, coating will not be considered in the near future, consequences of failures are too serious.

Nevertheless coatings are still of interest for the regular surface pipe network to decrease surface roughness and reduce scale adherence. In Soultz coatings are only applied in the future after extensive in-situ tests for their resistance in the aggressive Soultz brine. The presented case study of Soultz showed that coatings do have a real potential for material protection but products have to be selected very carefully based on the specific geochemical and physical operational conditions.

2.2 Case Study II: Material performance of the Line Shaft Pump (LSP)

Another focus of the in-situ material experiments at Soultz is related to the performance of materials utilized for down-hole pumps. In GPK-2 Line Shaft Pump (LSP) technology is applied for the production of geothermal brine. These materials have to stand high temperature and pressure at rotation rates of 1500 – 2000 rpm which creates high flow velocities and intense turbulences at the hydraulic part of the LSP. The presented case study focuses on electrochemical and mechanical resistance on the cast iron impellers of the LSP. A detailed study concerning the LSP history and improvement of the LSP in 2012 and 2013 is presented in Ravier et al. (2015).

In 2012 a newly manufactured hydraulic part of the LSP was installed and operated between March and April. Serious vibrations were observed by speeding up the pump and after dismantling, severe damage of all impellers and the inner parts of the bowls was discovered.

- material removal especially at the end ring section of the impellers
- crater-shaped pits at the end ring section and at the impeller blades
- broken off pieces (in the size of 1-2 cm)
- plate-like deposits cover all surfaces
- rust particles cover all surfaces of impellers and bowls

One part of an impeller blade was cut off to investigate the transition between metal and deposit, corrosion depth and morphology and elemental composition of the surface layer by electron microscopy, Figure 4a-d. Therefore, a part of the blade which showed deep crater-shaped pits was selected. The elemental composition of the metal and of the surface layer was identified by energy dispersive X-ray fluorescence (ESEM XL 30 FEG from Philips, equipped with an EDAX system).

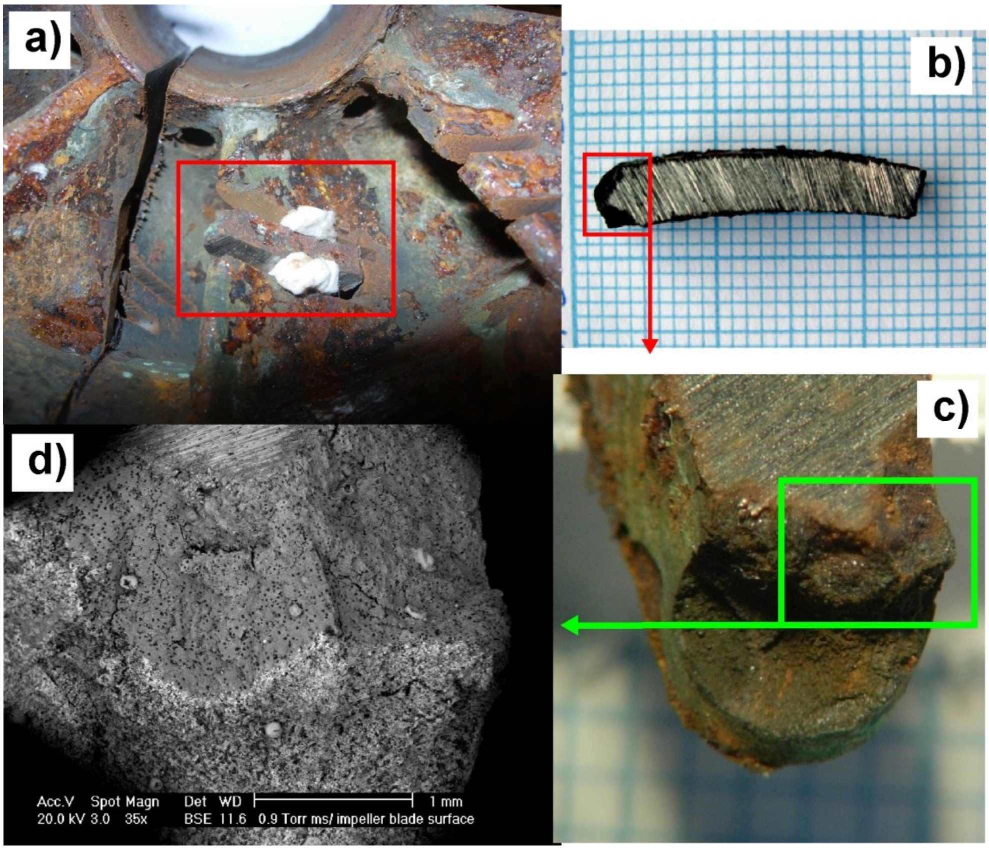

Figure 2: ***a)*** **Cutted section of an impeller blade from impeller N°16. Size: 22x5x5 mm.** ***b)*** **Close-up view of the cross section.** ***c)*** **Close-up view of the crater shaped pits.** ***d)*** **Exposure of the impeller blade surface by electron microscopy.**

The blades of impeller 16 show crater-shaped pits of different sizes, 1 – 4 mm. In Figure 5a the cross section of cast iron to the crater-shaped pits is located in the top of the electron microscope exposure. Two small crater-shaped pits at the top are covered with iron oxides, Figure 5b and EDX 2. It is very likely that those carbon spheres belong originally to the cast iron. Dots of pure carbon, 10 to 15 µm in diameter (EDX 1) are distributed irregular in deposit 1. Their presence in the iron oxide layer is a strong indication for a transformation of the metal surface by electrochemical corrosion as a result of the exposure of the cast iron to the geothermal fluid. A second deposit, present in the lower crater-shaped pit consists mainly of iron and arsenic with small amounts of sodium, chloride and silicon (EDX 3). Carbon spheres are also present in this deposit, Figure 5c which gives evidence for a transformation of the cast iron surface by electrochemical processes. Thickness of the iron-arsenic layer is larger than the one of iron oxide layer.

The boundary between deposit 1 (iron oxide) and deposit 2 (iron arsenic) is very distinctive; Figure 5 a & c. Shape and depth of the crater-shaped pits indicate an origin by high turbulences or even cavitation. It is possible that the formation of the arsenate deposit is a step by step process which starts with the formation of iron oxides by electrochemical corrosion of the cast iron followed by a transformation of the iron oxide layer to the iron arsenic layer, the Soultz brine contains 11 mg/l As, Scheiber et al. (2013b). Therefore arsenic has to be considered as important redox species.

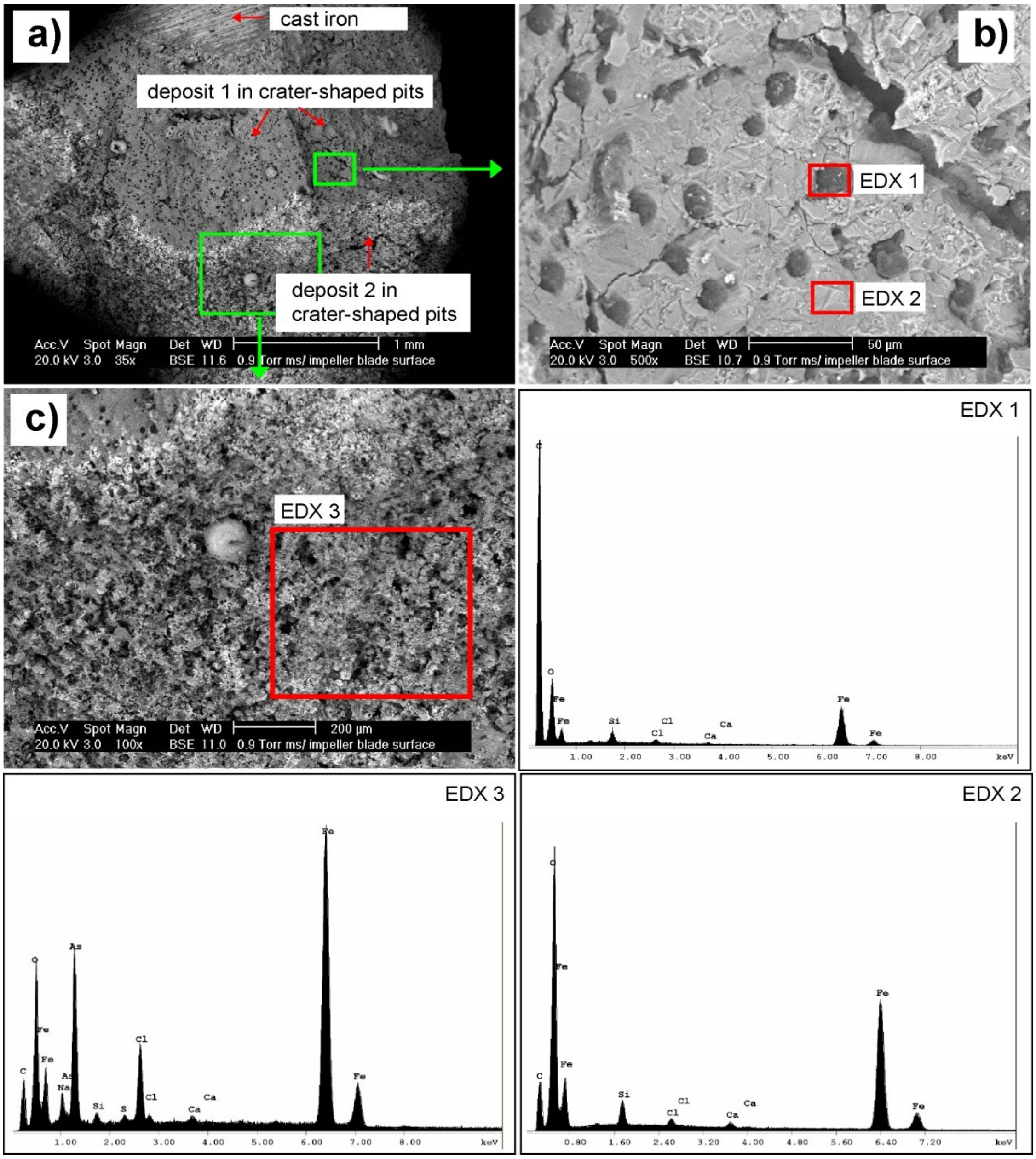

Figure 5: ***a)*** **Electron microscope exposure of the bulk metal and the deposits 1 and 2. Circles and squares mark the respective areas where elemental analyses were conducted.** ***b)*** **Close-up view of the transition zone between cast iron and deposit 1. EDX 1: Elemental analysis of one carbon sphere which is embedded in deposit 1. EDX 2: Elemental analysis of deposit 1 which is highly enriched in iron and oxygen. c) Close view on deposit 2. EDX 3: Elemental analysis of deposit 2 which is highly enriched in arsenic and iron.**

Chemical attack in combination with high rotation velocities at the hydraulic part of the Long Shaft Pump (LSP) creates a highly aggressive environment for materials in use in the GPK-2 production well. Moreover, cuttings and suspended particles are transported to the surface at production flow rates >23 l/s, Genter et al. (2012). Cuttings are mainly made up of sharp-edged quartz and feldspar particles with sizes up to 2 mm. Mechanical resistance of cast iron is very low and the iron arsenic layer which is formed due to electrochemical processes by brine/cast iron interaction shows no mechanical resistance against the cuttings at all.

Cast iron is no suitable material for down-hole pump application at the Soultz location for LSP impellers. Mechanical and chemical resistance is too low for continuous and reliable operation in this highly aggressive environment. In 2013 a new hydraulic section of the LSP was tested successfully after improving the applied material, Ravier et al., (2014).

3. MATERIAL STUDIES IN BYPASS SYSTEMS AT IN-SITU PRODUCTION AND INJECTION CONDITIONS

Corrosion studies are conducted in Soultz since 1994. First studies involved corrosion inhibitors for casing protection during drilling. The first material study was conducted in a simple bypass system equipped with five chambers in 1997. During a 4 month circulation, metal coupons of carbon steel, stainless steel, austenitic stainless steel and Ni-based alloy were exposed to the geothermal brine. Uniform corrosion was observed at the carbon steel sample but no corrosion was visible at the stainless steel or Ni-based alloy coupons, Baticci and Faucher, (2008). In 2008 a simple, three chamber bypass system, the Low Temperature Skid (LTS), was installed and in 2013 a more sophisticated bypass, the High Temperature Skid (HTS) began to operate.

Due to repeated interruption of the fluid circulation due to pump and heat exchanger breakdown, only some data from corrosion experiments at the Low Temperature side are presented in this study. Investigations of samples from the High Temperature Skid are still ongoing and results will be available this year.

3.1 Bypass Injection Side: Low Temperature Skid (LTS)

Corrosion experiments at this bypass system focused on material research at in situ conditions of 70°C and 18 bars. Metal coupons were exposed in three different chambers which were made of PEEK (Polyether Ether Ketone). Corrosion rate and type of corrosion were investigated on metal coupons made of carbon and stainless steels. Sample selection was based on those materials which were already in use in the surface and subsurface installations of the geothermal power plant in order to identify the weakest points at the power plant. For mild steels uniform corrosion were observed mainly at corrosion rates up to 0.2 mm/year. Pitting corrosion dominate at stainless steel samples. The more noble the material is the minor was the impact of the geothermal brine on the metal. The formation of a strong adhesive scaling was recorded especially for carbon steels, Baticci, (2009), Baticci et al., (2010), Mundhenk et al., (2012), Mundhenk et al., (2013), Scheiber et al. (2012).

Figure 6: Low temperature skid (LTS) is located downstream of the heat exchanger before injection well GPK-3 at the reinjection side of the geothermal loop at Soultz. After Scheiber at al., (2013a).

3.2 Bypass Production Side: High Temperature Skid (HTS)

The ongoing challenge is to conduct material tests at in-situ conditions at the hot side of the geothermal loop. Therefore, an innovative high temperature skid (HTS) has been designed, built and assembled in the hottest zone of the surface installations of the Soultz geothermal site. The HTS was calculated and designed by O. Sontot in cooperation with the scientific and technical team of GEIE in 2010, Sontot, (2010), Figure 7. This tool operates at 160˚C and 20 bars. Flow, temperature and pressure are monitored continuously during skid operation and an internal window provides the direct observation of the inside flow conditions at the upper part of the skid.

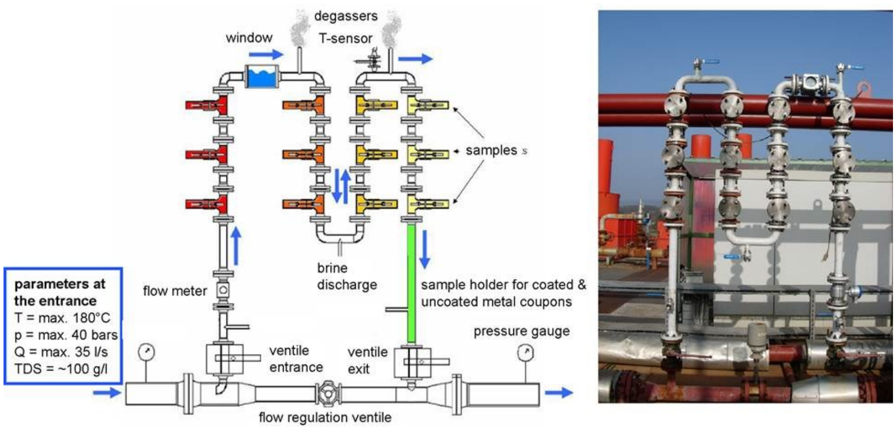

Figure 7: Scheme of the high temperature skid (HTS) after Sontot, 2010 *(left)* and the installed skid at the Soultz geothermal power plan *(right)*, after Scheiber et al., (2013a).

Samples of the HTS are a part of the pipe network of the skid itself. Metal coupons can be tested in a specific coupon sample holder system, green pipe in Figure 7. This setup is very different from former bypass systems where corrosion studies were conducted at metal coupons only which were placed in PEEK chambers. Pipe-samples will be assembled in four different vertical lines, represented by 4 different colors in Figure 7. Three samples can be inserted in every line but in fact, every straight pipe of the skid can be replaced by a sample of similar geometry. Every piece of the skid can be assembled and disassembled without complete de-installation.

The main objective of the skid design was to mimic the physical and geochemical conditions as close as possible. Temperature and pressure of the geothermal fluid is measured before entering and after leaving the HTS. The installation of the bypass system HTS for material studies on site at GPK-2 provides the opportunity to investigate the material resistance of various materials at in situ production conditions at adjustable flow rates. Therefore, a flow meter measures the flow rate which can be adjusted manually to the respective production conditions of the geothermal cycle. A window, placed between the first and the second line of the skid, provides direct observation of the current state of the geothermal fluid.

Corrosion experiments in the bypass system HTS focuses on materials which are applied at the hot side of the geothermal loop at 160°C and 20 bars like the down-hole pump, inhibitor injection system, filters, surface pipe network and ORC evaporator. For corrosion experiments, a specific pipe design, T-samples, will be tested in the skid. Those T-samples mimics regular components of the power plant like installation places of sensors or dead end filtration. The shape of those samples was chosen due to the observation that corrosion rates in static systems (stagnant brine) are higher than in dynamic systems (flowing brine). The straight part of the T-sample is placed in the flow direction, simulating the dynamic conditions. In the rectangular part of the T-samples the static conditions will be formed. Two metal coupons of the same composition like the T-sample are mounted in the linear and the rectangular part. Three T-samples of the same material are installed at the same time and removed from skid as a function of the experiment duration. The first tests are carried out with 1.0425 (P265GH) and 1.4404 (316L).

Corrosion and coating in-situ experiments at the high temperature side of the geothermal loop in Soultz provide unique opportunities to test and select materials based on their durability and cost effectiveness for geothermal applications with Upper Rhine Valley type fluids. Different metals will be tested to investigate the corrosion rate in stagnant and dynamic flow conditions and the type of corrosion, either uniform or pitting. Moreover, corrosion products and scaling layers on the metal surface will be characterized. Besides the corrosion study of metals, the test of different polymer coatings concerning their thermal stability, their abrasion resistance against mechanical attack by quartz and feldspar particles, produced from the granitic reservoir, and the formation of scales on the metal and polymer surface are under investigation.

4. CONCLUSIONS

Economic feasibility of geothermal power plants relies on continuous and constant operation of the geothermal loop. Constraints of operational performance like unscheduled shut-down periods, intense maintenance operations and follow-up costs reduce their reliability. Binary power plants depend urgently on effective operation of down-hole pump and heat exchanger unit. Inappropriate performance or malfunctioning of one of these systems affects consequently the complete system. Reasonable material selection is required for surface and subsurface installations of the geothermal loop based on geochemical and physical parameters like brine and gas chemistry, production/injection temperature and pressure and transport of suspended particles.

Materials at geothermal power plants have to stand a wide range of operational parameters and therefore they have to be specifically selected based on the operational purpose, on their durability and cost efficiency. Materials which are applied in geothermal sites have to perform under specific geochemical and physical conditions. At the geothermal power plant in Soultz-sous-Forêts, a Na-Ca-Cl brine with a TDS of ~97 g/l and a pH of 4.8 is produced from a granite reservoir. The brine is produced at 160°C and 20 bars and injected with 70°C and 18 bars, measured at the wellheads respectively. The presented case study of coating performance in the Organic Rankine Cycle (ORC) heat exchanger system showed that coatings do have a real potential for material protection but products have to be selected very carefully based on the specific geochemical and physical operation conditions.

Chemical attack in combination with high rotation velocities at the hydraulic part of the Long Shaft Pump (LSP) creates a highly aggressive environment for materials in use in the GPK-2 production well. Moreover, at flow rates >23 l/s suspended particles and cuttings from the reservoir are carried along with the produced brine. Abrasion resistance of down-hole pump needs to consider this fact for material selection as it was recognized in Soultz. Cast iron is no suitable material for down-hole pump application at the Soultz location for LSP impellers. Mechanical and chemical resistance is too low for continuous and reliable operation in this highly aggressive environment. In 2013 a new hydraulic section of the LSP was tested successfully after improving the applied material.

Corrosion experiments at the Low Temperature Skid (LTS) focus on material research at in situ conditions of 70°C and 18 bars. Mild steels and stainless steels were tested. For mild steels uniform corrosion were observed mainly at corrosion rates up to 0.2 mm/year. Pitting corrosion dominated at stainless steel samples. In general, the more noble the material is the minor was the impact of the geothermal brine on the metal. The formation of a strong adhesive scaling was recorded especially for carbon steels.

Based on material studies at the Low Temperature Skid (LTS) bypass system, an improved test skid at the hot side of the geothermal loop was designed and installed. The first experiments on this High Temperature Skid (HTS) started during the last production period in 2013. Corrosion studies and coating studies were carried out in pipes which are part of the HTS equipment. In fact, every linear pipe of the skid can be replaced by testing material of similar construction. Metal coupons, coated and uncoated, can be installed in two different conditions: dynamic flow and stagnant conditions. A coupon holder at the exit of the skid provides places for 22 coupons at the same time. Moreover, pipes for tubular heat exchanger can be tested directly in the skid concerning their material performance. Characterization of material performance at samples from the HTS is divided in analysis of corrosion type and corrosion rate (metal coupons) and surface analysis of the exposed material as well as chemical and mineralogical analysis of the corrosion products on the pipe samples. Additionally polymer coatings were tested at the HTS. The adherence of coating to the metal surface and formation of scales on the coating surface were in focus of these experiments. Evaluation of the experiments is ongoing and results will be available in the next few months.

For a direct comparison of the corrosion and coating experiments at the geothermal loop, the Low Temperature Skid (LTS) will be improved based on the current design of the high temperature skid (HTS). Experiments at high and low temperature conditions can be conducted in parallel and the results can be compared directly.

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