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First Year of Operation from EGS geothermal Plants in Alsace, France: Scaling Issues

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ABSTRACT

The Upper Rhine Graben is an area of interest for geothermal energy since 1990's where the European EGS pilot plant has been developed at Soultz-sous-Forêts, North East of France. The thermal gradient anomaly coupled with a dense naturally fractured network represents a good potential for geothermal brine production from sediment-basement interface and even fractured basement. In the French part of the Upper Rhine Graben, two industrial geothermal plants in Soultz-sous-Forêts and Rittershoffen were commissioned in 2016 and have been successfully in continuous exploitation since then. The Soultz-sous-Forêts power plant is producing electricity using an Organic Ranking Cycle, with an installed gross capacity of 1.7 MW_e. The Rittershoffen geothermal plant is providing superheated water for industrial needs, with an installed capacity of 24 MW_{th}. The commissioning and further exploitation of both plants have been followed notably by a physico-chemical monitoring of the produced geothermal brine. Indeed, geothermal brine is a Na-Ca-Cl fluid with a Total Dissolved Solids content of about 100 g/L and a Gas Liquid Ratio of about 1. Electrical conductivity, pH, and elementary chemistry, are monitored periodically. Results of this monitoring campaign show the stability of the brine chemistry and identified common trends for both sites, suggesting that geothermal reservoir exploited at Soultz and at Rittershoffen are connected. Based on the Soultz-sous-Forêts plant experience, the geothermal brine production generates sulfate and sulfide precipitations. These deposits can trap radioactive elements, like ^{226}Ra and ^{210}Pb. Within the aim to reduce radioactivity levels and also OPEX costs (maintenance stop for cleaning and waste disposal management), both geothermal plants are continuously using scaling inhibitors during exploitation. Surface facilities have been opened once at maintenance stops for both plants one year after commissioning. Grey-black deposits, in small quantity, were observed and have been chemically analyzed, highlighting lead, arsenic and antimony sulfide deposits into heat exchangers. Some barium sulfate deposit has been highlighted at Soultz geothermal site and is present as traces in Rittershoffen surface facilities. These analyses highlight the efficiency of scaling inhibitors used at geothermal plants, reducing the barium sulfate precipitation, but promoting metallic sulfides growth, however without impacting mainly the production. Research and monitoring are ongoing as well as quantification of radioactive elements within these scaling in order to select best chemical treatment ensuring the durability of geothermal loop and energy production, and preserving from environmental and safety at work issues.

1. INTRODUCTION

The Upper Rhine Graben (URG) is a part of European Cenozoic rift system. The resulting thermal gradient anomaly coupled with a dense naturally fractured network represents a good potential for geothermal brine production from sediment-basement interface and even fractured basement (Genter et al., 2010, Vidal et al., 2015). In the 1990's, exploration for geothermal energy started with drilling of wells at Soultz-sous-Forêts, within the frame of Hot Dry Rocks European project (i.e. creating artificial deep reservoir), which rapidly became obsolete, due to the presence of natural brine at depth (Gérard and Kappelmeyer, 1987). The concept was then named, Enhanced Geothermal System (EGS), and the Soultz geothermal site, became the European EGS pilot site (Gérard et al., 2006). During these last years, the technology has been more largely developed in the Upper Rhine Graben, with development of geothermal plants in France and Germany.

In the French part of the URG, two industrial geothermal plants in Soultz-sous-Forêts and Rittershoffen were commissioned in 2016 and have been successfully in continuous exploitation since then (Figure 1). The Soultz power plant is producing electricity using an Organic Ranking Cycle, with an installed gross capacity of 1.7 MW_e. The Rittershoffen geothermal plant is providing superheated water for industrial needs located close to the Rhine River, at Beinheim, with an installed capacity of 24 MW_{th}. ES Géothermie is operating both industrial plants in Alsace, for the companies EEIG Heat Mining and ECOGI, owning the Soultz and Rittershoffen plants respectively.

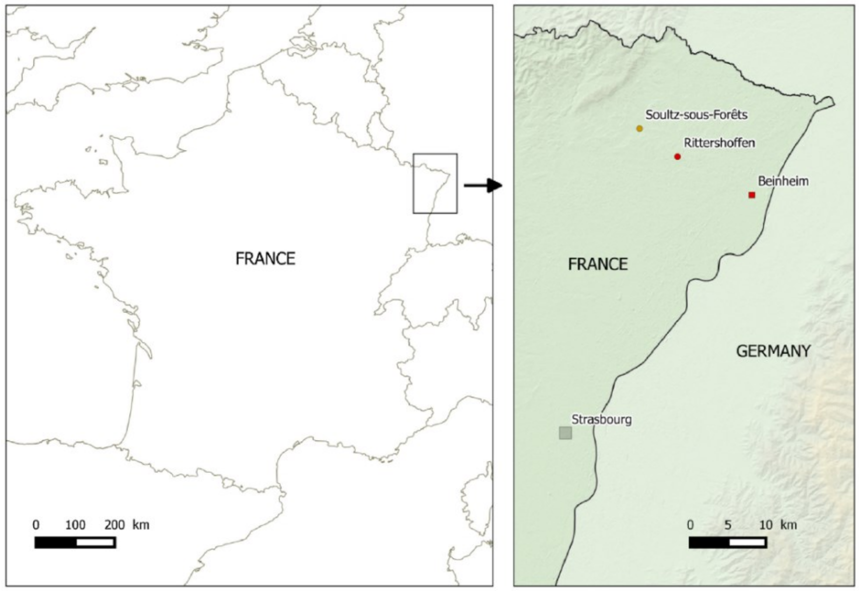


Figure 1: Location of both geothermal sites in Alsace, France (Baujard et al., 2017)

The geothermal fluid in both sites is a Na -Ca - Cl brine, with a Total Dissolved Solids of about 100 g/l (Sanjuan et al., 2016). The brine is also enriched in dissolved gases, mainly CO_2. The thermodynamic changes occurring in the surface installations, in terms of pressure and temperature, result in corrosion and scaling issues. Indeed, Scheiber et al, (2012) and Nitschke (2012) identified scalings in the heat exchangers from first geothermal power plant at Soultz (Genter et al., 2012). Scaling are mainly strontium rich barite ((Ba, Sr)SO_4), containing also minor fraction of galena (PbS), and traces amount of sulfide minerals ((Fe, Sb, As) S). Quantity of scaling is a real issue in the frame of surface installations cleaning and waste management as well as toxic and radioactive nature of the scaling. Indeed, Radium and Lead radioactive isotopes, (e.g. ^{226}Ra and ^{210}Pb, respectively) are monitored, due to their presence into barite and galena (Cuenot et al., 2013). Scheiber et al., (2013) conducted research on available scaling inhibitors on the market that could be used in the Soultz operational conditions, avoiding the sulfate precipitation (Scheiber et al., 2013, Haas-Nüesch et al., 2018). Few chemical treatments have been then tested at lab scale and when compatibility with the geothermal brine and efficiency on sulfate scaling inhibition were proven, chemical injection started on site. Both geothermal sites in operation have been using chemical treatments. Few months tests are conducted for both geothermal sites using some market-ready scaling inhibitors. Starting the industrial exploitation of both geothermal plants, status of deposit types and location occurrence are then periodically monitored, as well as the geothermal brine chemistry, to ensure the durability of the exploitation.

2. OPERATIONAL GEOTHERMAL PLANTS IN ALSACE

2.1 Soultz Geothermal Plant

The Soultz-sous-Forêts geothermal project started in 1987, and is the cradle of the geothermal energy European research in granitic and fractured systems. After almost 30 years of research, the geothermal site is exploiting the fractured basement at 5 km depth, under industrial conditions, for the EEIG Heat Mining. The installed gross capacity of the plant is about 1.7 MW_e. The actual geothermal system is made up of three wells: one production well named GPK2 and two injection wells named GPK3 and GPK4 (Figure 2, Figure 3). GPK1 is an old reinjection well, and EPS1 is an exploration well. The geothermal brine is coming at the wellhead at 150°C/23 bars, reaching the surface with a flow rate of 30 kg/s provided by a production Line Shaft Pump. The geothermal brine is then flowing through a system of six consecutive tubular heat exchangers supplying heat to a secondary loop, i.e. Organic Ranking Cycle, in order to produce electricity. The geothermal brine is then fully reinjected at around 70°C, and the volume of reinjected brine is shared between two wells, one third in GPK4 and two third in GPK3 without reinjection pumps. The reinjection temperature is linked to the conversion process. Under Horizon 2020 DESTRESS Project, a program for soft stimulation would be applied in GPK4 well, improving the injectivity of the well (Mouchot et al., 2017a). The geothermal plant has been successfully producing electricity since September 2016 under industrial conditions.

Figure 2: Geothermal plant of Soultz– EEIG Heat Mining, France.

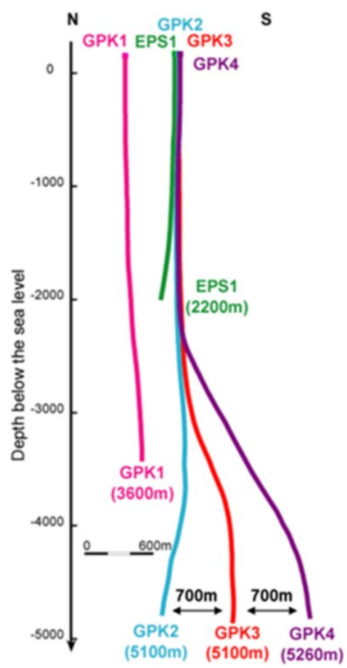


Figure 3: Schematic N-S vertical view of wells at the Soultz geothermal site, Dezayes et al. 2015.

The geothermal brine is highly saline, 96 g/L, mainly dominated by Na-Ca-Cl elements, with a Gas Liquid Ratio of 1.03 Nm^3/m^3 in standard conditions (T= 273.15 K, P= 1.01325 hPa) (Figure 4). Due to the high amount of dissolved CO_2, surface installations are operated under a pressure of 23 bars to avoid CO_2 degassing, steam flashing and corrosion issues. Average electrical conductivity is about 125 mS/cm and pH ranges between 4.9 and 5.3 (Scheiber et al., 2012; Sanjuan, 2011).

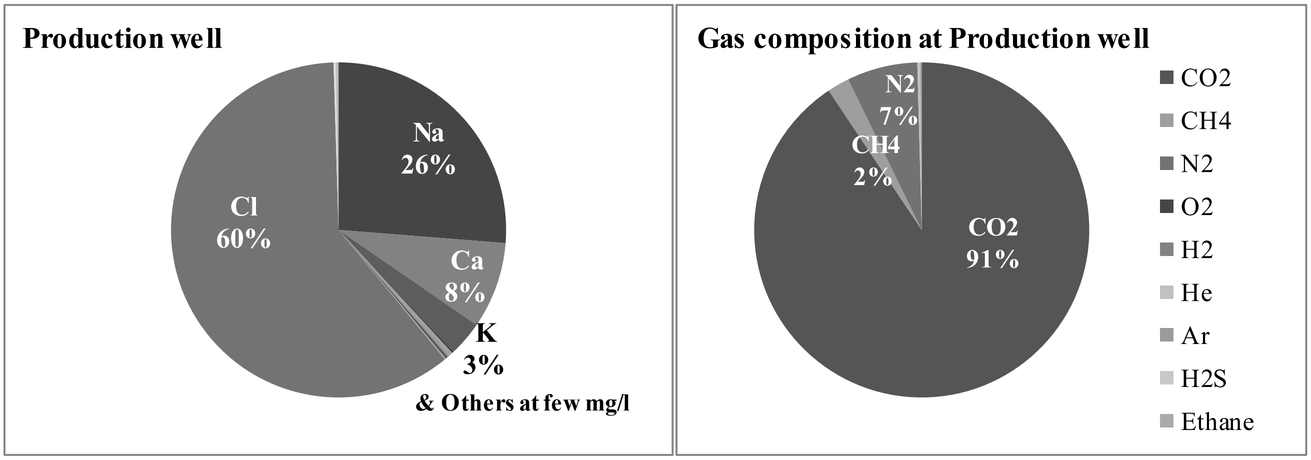


Figure 4: On the left, brine chemistry from GPK2 sampling in 2016, ICP –MS measurement under SUBITO project. On the right, gas composition of the brine from GPK2 sampling in 2016.

2.2 Rittershoffen Geothermal Plant

Use of geothermal energy was born at Rittershoffen following discussion with Roquette Frères Company, a bio-refinery with 100 MW_{th} heat needs for industrial processes, located in Beinheim, France (Figure 1). The geothermal heat plant, of an installed capacity of 24 MW_{th}, is then providing totality of its heat production to this company *via* an isolated heating transport loop of 15 km length (Figure 6). The geothermal brine is coming up to the surface at 170°C/25 bars, from a production well at 2700 m depth, into Triassic sedimentary layers and the top crystalline fractured basement interface (Baujard et al., 2015, Baujard et al., 2017). The geothermal brine is flowing through a system of 12 consecutive tubular heat exchangers, (Ravier et al., 2016, Ravier et al., 2017), and is fully reinjected without pump, at 80°C into one injection well, at 2500 m depth. The temperature is linked to the return temperature of the transport loop. The flow rate of the brine is regulated at 70-75 kg/s by a Line Shaft Pump. The geothermal plant has been successfully producing heat since June 2016 under industrial conditions (Figure 5).

Figure 5: Rittershoffen geothermal plant. On the forefront, the production (right) and the reinjection well (left). The heat exchangers system is located inside the building.

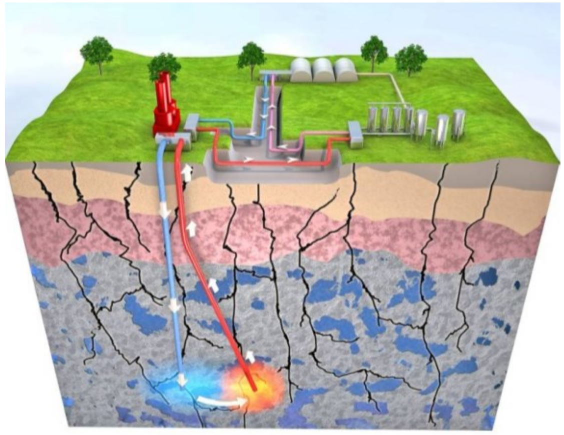
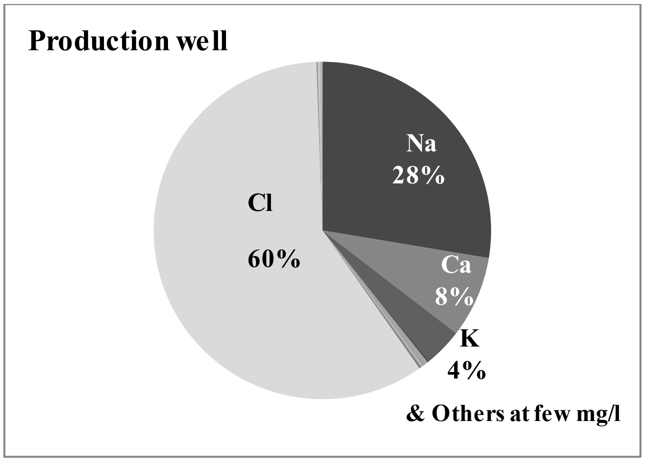


Figure 6: Schematic design of Rittershoffen geothermal plant and transport loop to Beinheim.

The geothermal brine is highly saline with TDS of about 100 g/L, mainly dominated by Na-Ca-Cl elements, with a Gas Liquid Ratio of 1.2 Nm^3/m^3 in standard conditions (T= 273.15 K, P= 1.01325hPa) (Figure 7). Due to the high amount of dissolved CO_2, surface installations are operated under a pressure of 25 bars to avoid CO_2 degassing, linked flashing and corrosion issues.



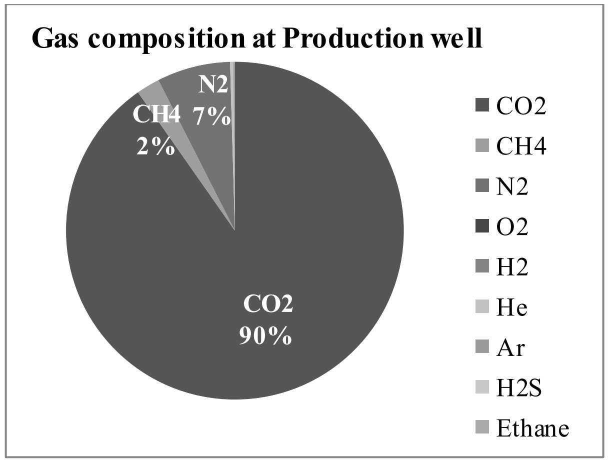


Figure 7: On the left, brine chemistry from GRT2 sampling in 2016, ICP –MS. On the right, gas composition of the brine from GRT2 sampling in 2016.

3. GEOCHEMICAL MONITORING - METHODS

Starting the exploitation phase at geothermal plants, brine and any deposit occurring in surface installations are monitored, periodically under production and at installation maintenance and cleaning phases. Within the aim to inject scaling inhibitors and apply a soft stimulation program into GPK4 well (DESTRESS Research program), a geochemical baseline acquisition and periodic monitoring are required to (i) detect any changes in terms of chemistry, (ii) assess the efficiency of these operations, and (iii) identify their consequences for the geothermal production loop. Applied methodologies are given here after.

3.1 Geothermal Brine Monitoring

At both sites, Soultz and Rittershoffen, geothermal brine can be monitored at pipes connected to production and injection wellheads. A small heat exchanger is connected to the pipe, enabling the cooling and the sampling of few liters per second of geothermal brine, at variable temperatures and flow rates. Physical parameters like pH and electrical conductivity are then measured by electrodes placed into a flow-through Plexiglas cell (Figure 8). Brine sampling is always realized at same temperatures, around 60-70°C, to be comparable between production and reinjection sites and from one site to another.

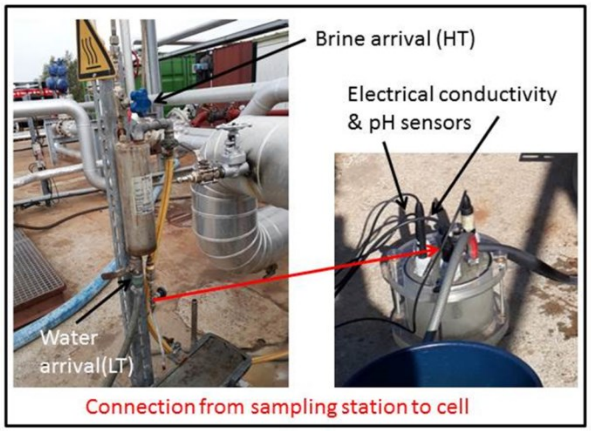


Figure 8: Sampling station and electrodes for pH and electrical conductivity monitoring, connected at GPK2 well, Soultz site.

Elementary chemistry and Total Dissolved Solids are monitored for geothermal brine at production and reinjection sides. Main elements are analyzed by Inductively Coupled Plasma Spectrometry (ICP-MS): Na, Ca, K, Mg, Fe, Sr, Mn, As, Zn, Ba, Cs, Rb, Li, SiO_2, Si, B, Cl, HCO_3, SO_4, P, F, Br, I are quantified in mg/l. Traces elements like Al, Cr, Cu, Ni, Se, Cd, Sb, Hg, Pb, U are analyzed in µg/l. Dissolved gases have been sampled with a vacuum chamber and brought to the laboratory for gas composition analyses, in terms of CO_2, CH_4, N_2, Ar, He, H_2S, and O_2.

3.2 Geothermal Scaling Monitoring

Production and reinjection filters are good witnesses of chemical processes occurring into the surface installations, in which any deposit can be easily monitored. When surface installation, such as heat exchangers, are opened for cleaning (periodic maintenance), any deposit can be sampled and analyzed from the warmest to the coldest heat exchanger. Main elements are analyzed by ICP-MS: Na, Ca, K, Fe, Sr, Mn, As, Zn, Ba, Si, S, Cu, Ti, Hg, Pb, Sb, Cd, and Th, expressed in mg/kg. Radiological isotopes are measured by gamma-spectrometry: ^{226}Ra, ^{228}Ra, ^{210}Pb, ^{210}Po, ^{228}Th, and ^{40}K. At each monitoring step, quantity, total radioactivity and structure of each deposit are referenced.

4. RESULTS AND DISCUSSION

From August 2016 to present - January 2017, both geothermal plants Rittershoffen and Soultz have been successfully running under fully industrial conditions and both were cleaned once, giving the opportunity to image all kinds of deposit / location couples from surface installations. Brine has been sampled to follow the quarterly evolution of chemistry for the Soultz plant, under the SUBITO project. At Rittershoffen geothermal plant, two analyses are available, one from the commissioning and a second twelve months later. Results from the fluid and scaling analyses are given here after for both geothermal sites.

4.1 Fluid Analyses

Data from Soultz brine chemical analyses have been gathered from Scheiber et al.(2012), Scheiber et al. (2013), Scheiber et al. (2014), and report analyses under SUBITO project (Figure 9). The chemical spectrum corresponds to GPK2 wellhead brine analysis.

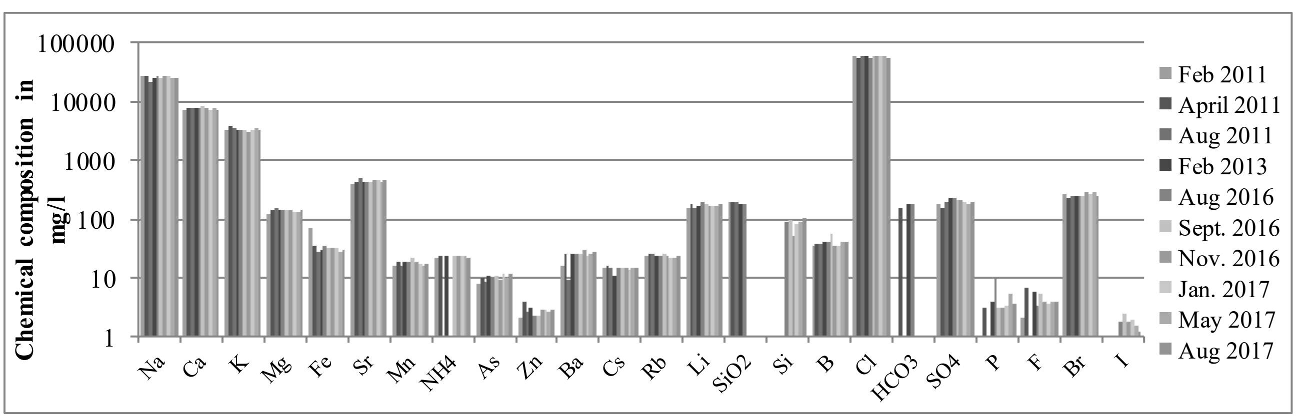


Figure 9: Chemical spectrum of the brine produced from GPK2 and sampled from February 2011 to August 2017. All light grey charts correspond to geothermal plant operation under fully industrial conditions.

Chemistry of the brine is dominated by Na, Ca, Cl and K elements. We noticed the non-negligible As content into the brine, reaching 12 mg/l, for both sites, Soultz and Rittershoffen. The evolution of Ba, Sr, SO_4, Fe, Zn, Si, and As are particularly monitored, for their deposition abilities in the surface facilities and reinjection wells.

Chemical element contents are quite stable with time, and especially under this first year of full exploitation. The main elements, Na Ca Cl appear very stable. The behavior of minor elements, Fe, Zn, Ba, SO_4, Mn, P, and F is more variable, without any clear trend of increase or decrease. These elements are present only at minor concentration and, their variability could be explained by analytical uncertainties and/or mixing into the geothermal reservoir. Next monitoring data would give more feedback on the fluid chemistry evolution under exploitation, especially with the monitoring performed in the frame of the soft stimulation program for GPK4 well under DESTRESS project (Mouchot et al., 2017b). Figure 10 presents the coefficient of variation for brine sampled at GPK2 and GPK3 wellheads between August 2016 and August 2017.

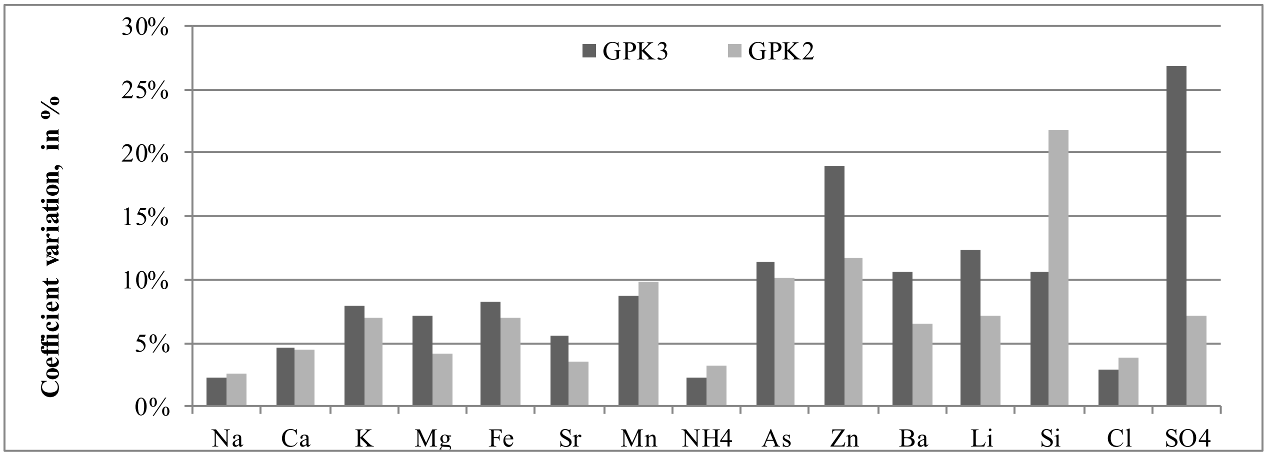


Figure 10: Coefficient of variation (standard deviation/average value) between brine chemical analyses from August 2016 to August 2017 for GPK2 and GPK3 wellheads sampled brine.

We notice that the variability is minor for the majority of cations and anions of the brine, inferior to 10%, even inferior to 5% for Na, Ca, and Cl, giving a good chemical stability of the geothermal brine at Soultz. The highest coefficient of variation is observed, for example, for Zn, Si, Ba, As, and SO_4, involved into sulfate and sulfide scaling, and could be explained by different efficiencies of tested scaling inhibitors. Concerning inhibitor efficiency, Figure 11 presents the chemical brine composition between production and reinjection wells, sampled in January 2017. Traces elements of Soultz brine at GPK2 are given in Figure 13.

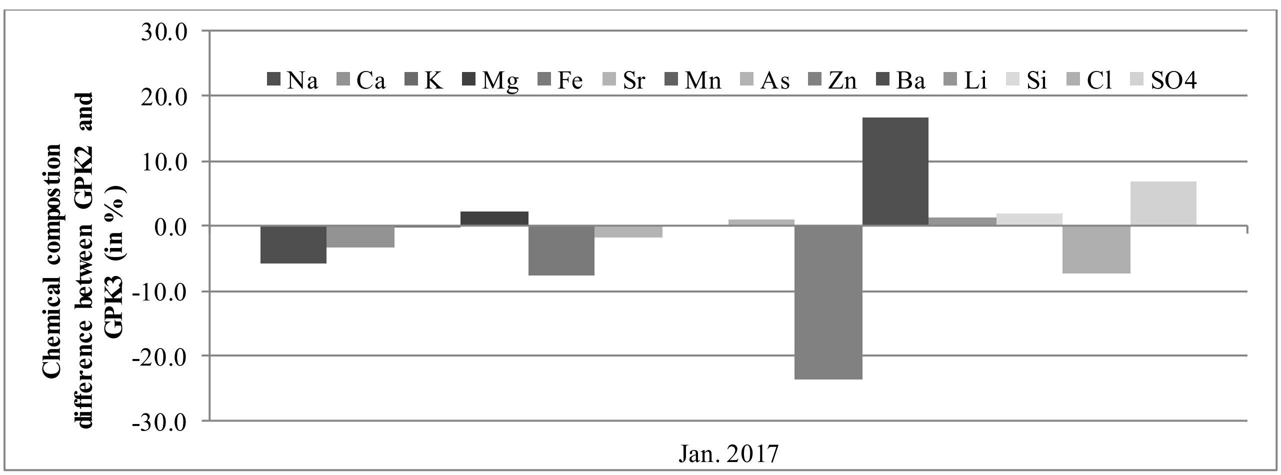


Figure 11: Brine chemical analysis comparison between production side GPK2 and reinjection side GPK3, one example from January 2017. Under SUBITO project.

In Figure 11, a decrease of Zn content is observed, approaching 25% that could be explained by some metallic sulfide deposition into heat exchangers. Same behavior is observed for the Fe content. Increase of 15% of Ba content and 7.5% for SO_4 content can be linked to barium sulfate inhibitor injection, releasing into solution some scaling, issued from previous deposition.

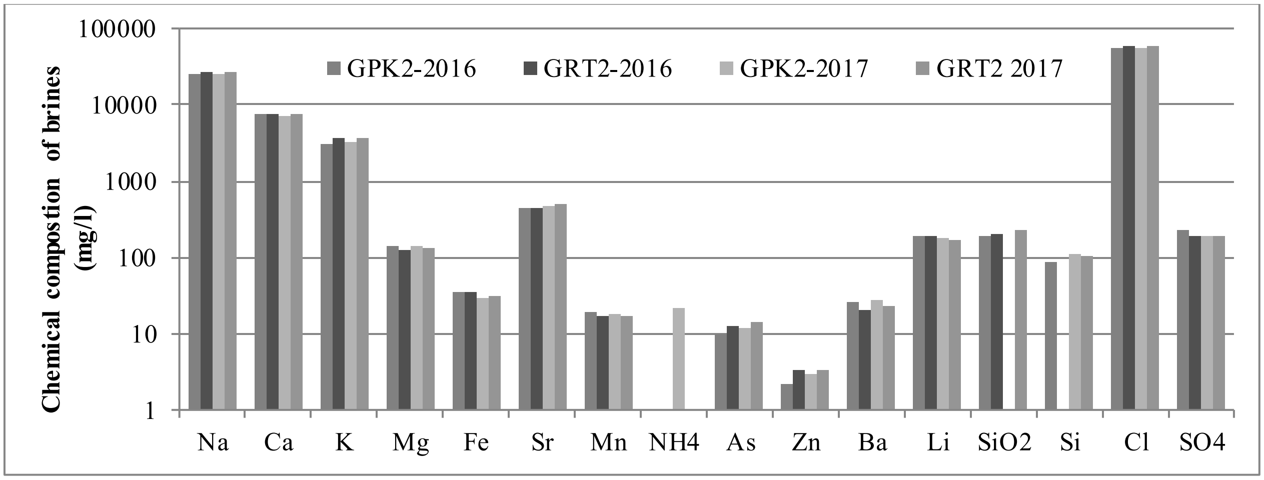


Figure 12: Chemical analyses of geothermal brine sampled from GPK2 and GRT2, in August 2016 and August 2017.

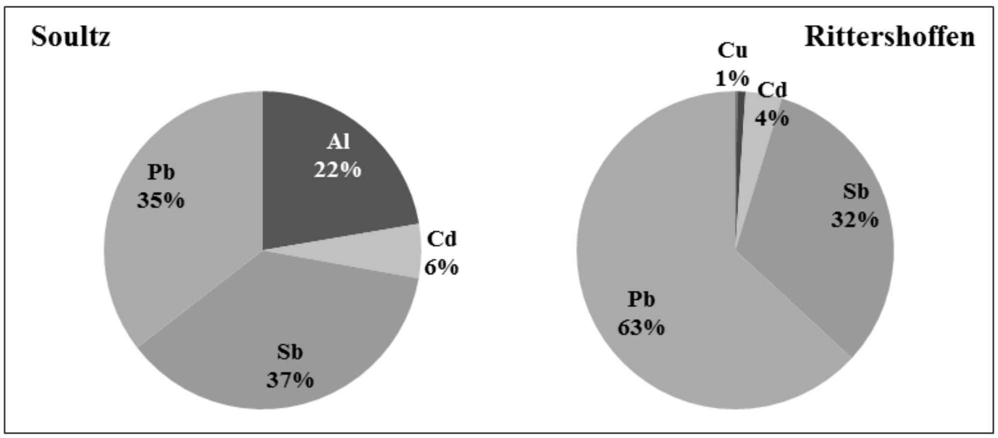


Figure 13: Traces element monitored into the geothermal brines from GPK2 and GRT2, data from August 2017.

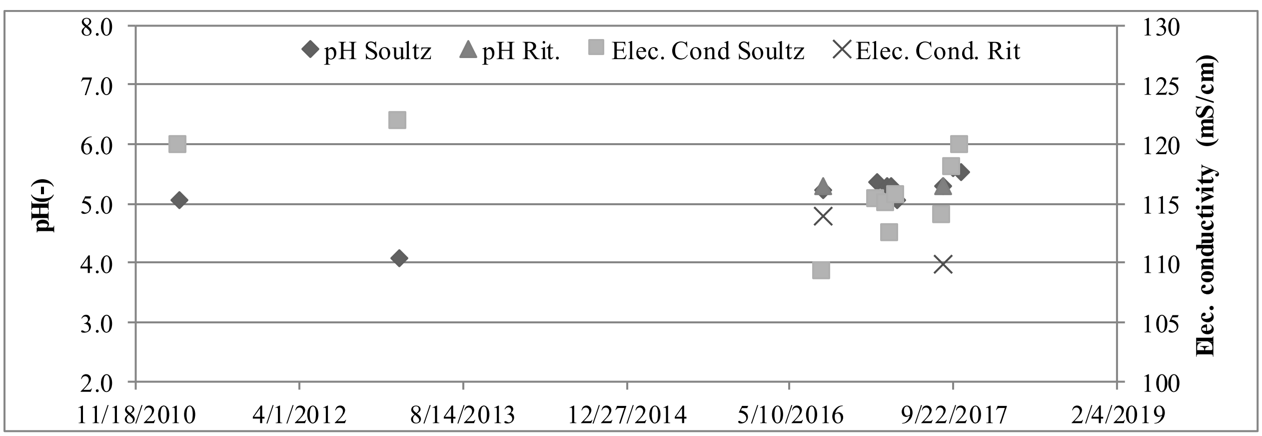


Figure 14: Physical parameters monitoring from GPK2, Soultz, and from GRT2, Rittershoffen. Under DESTRESS project and Scheiber et al. (2013).

The geochemical monitoring from Rittershoffen implies two full analyses, the first one performed in August 2016, two months after plant commissioning and the second one, twelve months later, in August 2017. We compared the brine chemistry sampled at the production wellhead from Rittershoffen and from Soultz sites. Figure 12 gives the chemical spectrum for Rittershoffen and Soultz plants at same sampling dates in 2016 and in 2017. We observe that the chemistry is very close, from one site to the other. The Total Dissolved Solid is higher of few grams per liter at Rittershoffen, of about 100g/L compared to 96 g/L for Soultz. The small difference can be explained by a higher content of Na, Ca, K and Cl in the Rittershoffen brine. From August 2016 to August 2017, Figure 12 shows some common features between chemical analyses from Soultz and from Rittershoffen brines:

- Constant values for Na, Ca, Cl, K, Mg, Cs, and Rb for GPK2 (2016- 2017) and GRT2 (2016- 2017);
- Li, Si, Fe and Mn contents are equal for both sites at the same sampling date;
- An slight increasing trend in As, Zn, Si and Sr for both sites from 2016 to 2017;
- A decreasing trend for Li content from 2016 to 2017.

These observations could indicate a connected reservoir between Rittershoffen and Soultz-sous-Forêts. Geothermal resources are produced from a multiscale clustered fractured and faulted basement, suggesting that reservoirs at a distance of 7 km could be connected. This is a subject of ongoing evaluation and need further investigations like tracer tests.

Traces elements from Soultz and Rittershoffen are given in percentage in Figure 13, showing that lead and antimony are present in hundreds of micrograms per liter. Part of this little content in Lead and Antimony from the brine, associated to Arsenic (~10mg/l - Figure 9) will precipitate with Sulfur as metallic sulfide into the surface facilities.

In addition to the chemical monitoring, physical characteristics of the brines are monitored periodically. Figure 14 shows the evolution of pH and electrical conductivity for Soultz and Rittershoffen (dataset from publications and internal monitoring). We note that pH values and electrical conductivity measurements are similar for Soultz and Rittershoffen at the same sampling date (August 2016 and August 2017). We could observe a slight increase of the pH since the commissioning of Soultz plant. This trend remains to be confirmed or not with a new monitoring campaign, starting soon with new electrodes and new calibration.

4.2 Scaling Analyses

The heat exchangers from Soultz geothermal plant were opened in September 2017, one year after commissioning. We observed at the opening grey-black deposits in the heat exchangers from the second one to the last one (Figure 15-left). All deposits have been sampled to illustrate all kinds of deposits that could be encountered in the surface facilities after one continuous year of brine circulation.

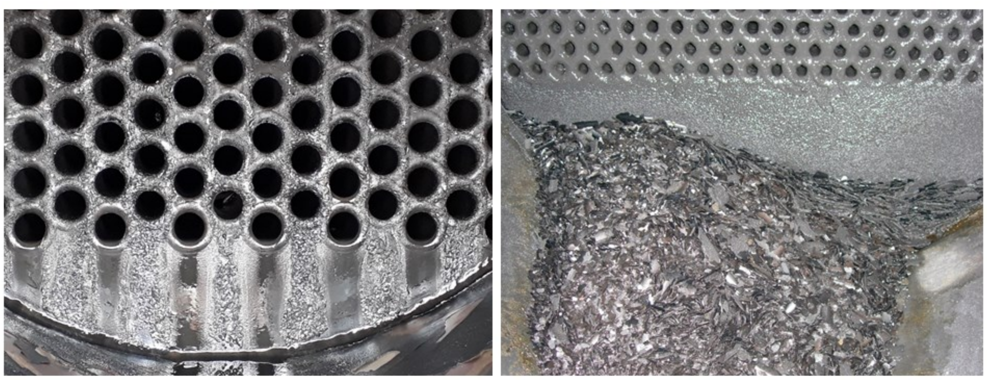


Figure 15: (Left) Black deposit sampled in the 6th heat exchanger of Soultz geothermal plant at ~65°C. (September 2017). (Right) Black and grey deposits sampled from the 12th heat exchanger at Rittershoffen at ~80°C (July 2017).

The quantity of scaling was quite low in the heat exchangers; the homogeneous thickness of the deposits was about 1 mm maximum. The high quality steel of the tubes was clean under the deposit. No corrosion has been identified. Other equipment, such as pipes in the reinjection line and filters were also opened. Figure 16 gives the chemical analyses of the deposit sampled from the second heat exchanger (internal ring on figure 16), in which the brine temperature is around 135°C. Intermediate internal rings represent chemical analyses from deposits sampled from the fourth and sixth heat exchanger, in which the brine temperature is around 100°C and 68°C respectively. The external ring corresponds to the chemical analysis of the black deposit sampled from the reinjection filter, in which the brine is around 65°C (Figure 16-left). We observe that:

- Pb is the main element, ranging from 30 to 70%, increasing with the temperature decrease;
- Sb is stable in all deposits at 10%;
- S content is decreasing with the temperature, from 17 to 4%;
- As content, as well as Fe content, increases with temperature decrease, ranging from 4 to 9% for As and from 1 to 2% for Fe;
- Cu is present at 20% in the second heat exchanger deposit, and only few percent in the others;
- Ba (2%) and Sr (1%), witnesses of barium sulfate scaling, occurs in the second heat exchanger deposit and in the reinjection filter;
- Na, Ca, K and Si are present in few percent, probably associated to salt and silica precipitation.

The heat exchangers in Rittershoffen geothermal plant were opened in July 2017, one year after commissioning. We had access to heat exchanger n°8, 9, and 12, in which the brine circulates at 135°C for the 8th and decreases down to 80°C in the 12th. We observe at the opening black and grey deposits. In comparison to observation at Soultz, the quantity was much higher. The homogeneous thickness of the deposits was about a few millimeters (Figure 15-right). Figure 16 (right) gathers the chemical analyses of the deposits from the heat exchangers at Rittershoffen: from the eighth - internal ring, from the ninth - intermediate ring, from the twelfth for the second intermediate ring and external ring. Indeed two types of deposits have been sampled in the 12th heat exchanger, one grey, homogeneous, and a second, more black with a pad structure. Results can be summed up as follows:

- As and Pb are the main elements, ranging from 25 to 40% and from 20 to 29 % respectively, both with the decrease of the temperature;
- Sb is quite stable at 7%, and increases slightly in the black pad deposit;
- S content increases from 8% to 30% with the temperature decrease;
- Zn, Cu and Fe are present ranging from 1 to 8% with a peak at 21% for Copper;
- Ba and Sr are absent from these deposits;
- Na, Ca and K are presents in a few percent.

We observe that the deposit are mainly lead sulfide, and containing, some metal -rich deposits (As, Cu, Sb, Zn, Fe) sulfide, in various ratio for both geothermal plants; This could be linked to different parameters, e.g. the injected inhibitors, flow rates, sampling practices. Both geothermal plants do not use scaling inhibitor from the same provider. In Rittershoffen surface facilities deposit, the content in As is slightly higher than in Soultz deposit, as shown also from the brine chemical analyses in Figure 12. Some strontium rich barite scaling is also present at Soultz, in the reinjection filter and in the second heat exchanger. Radiological analyses are ongoing, in order to identify at least ^{210}Pb and ^{226}Ra contents in these deposits.

These chemical analyses reveal that the scaling inhibitor injection reduces the barium sulfate precipitation at Soultz plant, even avoids it at Rittershoffen plant. However the precipitation of metallic sulfides is favored. Metallic sulfides could be linked to electrochemical interaction between brine and steels. The use of corrosion inhibitor (filming agent) could protect the steel surfaces, and then reduce interaction and scaling issues. Corrosion inhibitor injection was started at Soultz geothermal site after the maintenance stop in October 2017 and in November 2017 at Rittershoffen site. Heat exchangers next opening will confirm or not this hypothesis.

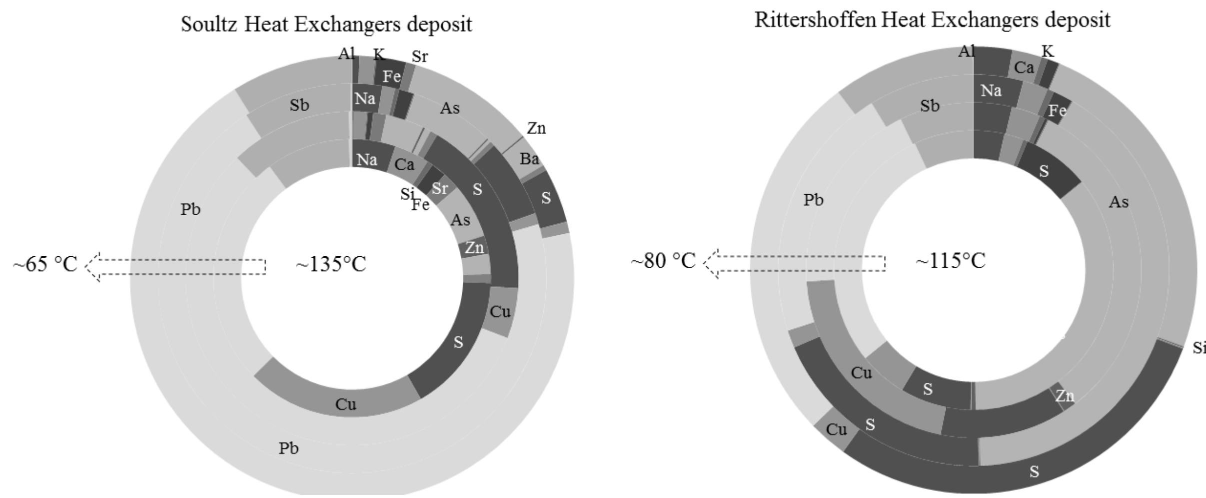


Figure 16: (Left) Relative chemical composition of scaling sampled from Soultz heat exchangers and reinjection filters, (Right) from Rittershoffen heat exchangers.

In addition to the relative chemical composition of scaling given in Figure 16, Figure 17 shows the chemical spectrum of deposits sampled from heat exchangers at Soultz and at Rittershoffen site, wherein the brine circulates at around 100°C. We note that the chemistry is quite similar for these two deposits and follows the same trends given in Figure 16: lead and antimony sulfides dominate the scaling chemistry at Soultz, and arsenic and lead are dominant elements at Rittershoffen. Ba and Sr are present at Rittershoffen, as traces (e.g. a few mg/kg).

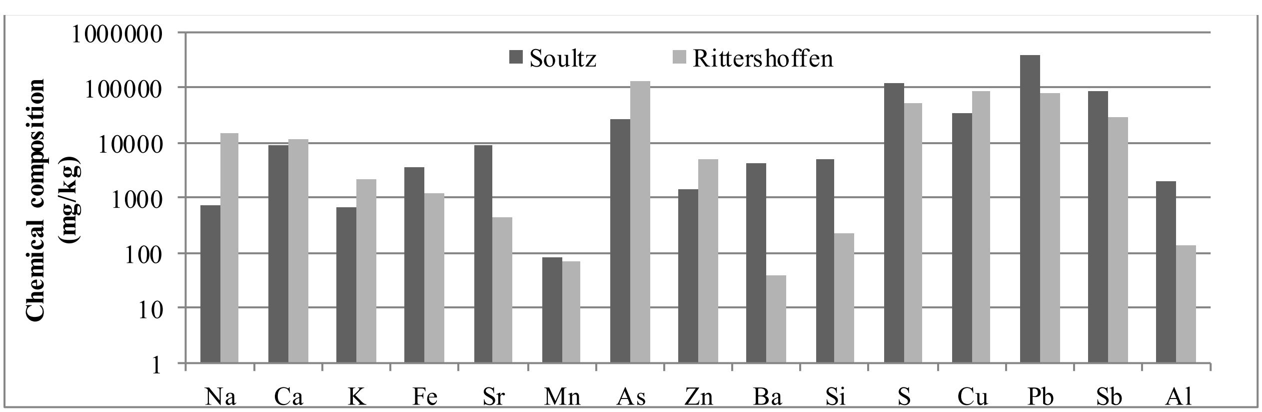


Figure 17: Chemical spectrum and composition expressed in mg/kg. One example from deposits sampled at Soultz and at Rittershoffen geothermal sites.

5. CONCLUSION

Geothermal energy has been developed at industrial scale in two plants in Alsace, North East of France. Both plants were commissioned in 2016, one producing electricity and the second providing heat for industrial needs. Both sites exploit a geothermal resource coming from a fractured basement into which natural brine (100g/L and GLR of ~1) circulates. Temperature of the brines range from 150°C to 170°C at the production wellheads and after flowing through heat exchangers, geothermal fluids are fully reinjected at depth at temperatures ranging from 80°C to 65°C. Geothermal fluids from Soultz and Rittershoffen plants present close chemistry and physical characteristics. In these geothermal conditions and following processes at the surface, barium sulfate and metallic sulfides precipitates into the geothermal loop, based on the feedback from Soultz studies. Then, since the commissioning of both plants, scaling inhibitors have been continuously injected. A geochemical monitoring has been applied at both sites, to follow the brine chemistry and any scaling occurrence into surface facilities. During maintenances stops of the surface facilities, heat exchangers from both plants were opened, into which black deposits, lead sulfides with other metal -rich (As, Sb, Cu, Zn, Fe) sulfides, cover homogenously the tubes wherein the brine circulates at temperatures ranging from 135°C to 65°C. This first year of monitoring highlights:

- The stability of main brine chemistry and physical parameters, like pH and electrical conductivity;
- Slight variable trends of brine chemistry highlighted in both plants, suggest that fractured basement locally exploited could be connected in a common, large geothermal reservoir;
- Barium sulfate has been successfully reduced with the injection of scaling inhibitor at both geothermal sites;
- Metallic sulfides growth is promoted, in which lead sulfide dominates, associated with antimony and arsenic sulfides for both geothermal sites. Arsenic sulfide dominates in the Rittershoffen heat exchangers deposits;
- Slight variation in scaling chemistry from one plant to the other could be linked to the use of different inhibitor, but also to the different production flow rate, or the different sampling practices.

Then, injected scaling inhibitors show a good efficiency on Barium sulfate inhibition but progresses on the metallic sulfides inhibition are still needed. Research and monitoring are ongoing as well as quantification of radioactive elements within these scaling. From a general operational point of view, volume of scaling present in the surface installations didn't have a major impact on the geothermal heat and electricity production in this first year. As the injection of a combined chemical treatment for both scaling and corrosion inhibition has been started since a few months, next maintenance stops would bring a valuable feedback for both geothermal plants. For any safety – radioprotection-, environmental issues and costs-controlled maintenance, some research is still ongoing to select the best chemical treatments, in order to manage geothermal brine-steel electrochemical interaction to solve scaling and corrosion issues, as well as ensure the durability of the geothermal loop.

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