Deep Geothermal Plants Operation in Upper Rhine Graben: Lessons Learned

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Keywords: Soultz-sous-Forêts, Rittershoffen, scaling, corrosion, inhibitors, maintenance costs, availability factor

ABSTRACT

Deep geothermal energy is being successfully produced in France since 2016 marked by the commissioning of two deep geothermal plants, at Soultz-sous-Forêts and Rittershoffen, North East of France, Upper Rhine Graben (URG). Both sites exploit highly saline brine at a temperature up to 170°C and rich in dissolved CO_2. The Soultz site is producing electricity with a capacity of 1.7 MW_e and the Rittershoffen site is producing industrial heat with a capacity of 24 MW_{th}.

In this geochemical context, scaling and corrosion processes occur on surface facilities, inducing technical issues and treatments. Chemical treatment is part of the operational costs, just like the electrical consumption of the production pump. From an operational point of view, the two geothermal plants, commissioned mid-2016, present an exceptional availability factor, which is above 90% throughout the year of 2017 and 2018.

After more than two years of successful commercial operation, the two geothermal plants allowed learning many lessons, which could be useful for the geothermal sector, and especially for future projects in this area, like the Illkirch geothermal project in the Strasbourg area that is currently in the drilling phase.

1. INTRODUCTION

Geothermal potential has been identified in the URG since decades thanks to the research on the Enhanced Geothermal System pilot plant at Soultz-sous-Forêts, 50 km to the North of Strasbourg, France. On the French side of the URG, two plants have been commissioned in 2016, producing heat and electricity under industrial conditions. The two sites are presented and operational feedbacks are given hereafter.

1.1 Soultz-sous-Forêts geothermal site

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 commercial conditions, for the EEIG Heat Mining (Figure 1). The installed gross capacity of the plant is about 1.7 MW_e.

The actual geothermal system is made of three wells: one production well named GPK-2 and two injection wells named GPK-3 and GPK-4. The geothermal brine is produced at a temperature of 150°C, reaching the wellhead with a nominal flow rate of 30 kg/s provided by a Downhole production Line Shaft Pump (Baujard et al., 2018).

The geothermal brine is then flowing through a system of three consecutive double-pass tubular heat exchangers supplying heat to an. Organic Ranking Cycle (ORC), 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 the two injection wells, one third in GPK-4 and two third in GPK-3 without using reinjection pumps. The reinjection temperature is linked to the conversion process. The geothermal plant has been successfully producing electricity since September 2016 under commercial conditions (Genter et al., 2018).

Figure 1: Soultz-sous-Forêts geothermal site

1.2 Rittershoffen geothermal site

The heat plant of Rittershoffen has been developed in order to supply Roquette Frères Company, a bio-refinery, with geothermal heat for their industrial processes. This industrial user, located in Beinheim, France, totals 100 MW_{th} of thermal needs. The geothermal heat plant, with an installed capacity of 24 MW_{th}, is then providing the totality of its heat production to this company via an isolated heating transport loop of 15 km length (Ravier et al., 2017). The geothermal brine is produced at a temperature of 170°C from a production well, GRT-2 at 2700 m depth, penetrated 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 twelve consecutive tubular heat exchangers, (Ravier et al., 2016), and is fully reinjected without additional pumps at 80°C into one injection well, GRT-1, at 2500 m depth (Figure 2). The reinjection 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 Downhole production Line Shaft Pump. The geothermal plant has been successfully producing heat since June 2016 under commercial conditions.

Figure 2: Rittershoffen geothermal site

After more than two years of operation under industrial conditions, some technical issues, such as corrosion and scaling deposit, were encountered during plant operation. This article presents the lessons learned from the experience obtained during the operation of more than two years, along with the remediation methods and their performance indicators.

2. SCALING CONTEXT AND MANAGEMENT

2.1 Scaling Context

Geothermal fluids produced from Rittershoffen and Soultz sites are both brines with a Total Dissolved Solid content of about 100 g/L, Na –Ca – Cl type. The chemical analysis of major and minor elements is given in Figure 3. In traces, both brines present mainly lead, aluminium and antimony. During the heat transfer in both plant, liquid-solid equilibrium are changing, inducing the precipitation of barium sulphate and metal-rich (Pb, Fe, As, Sb) sulphides (Scheiber et al., 2012, Mouchot et al., 2018). These scales are strongly attached to the pipes and tubes, and cause depositions and clogs that will reduce energy production. Furthermore, they also imply a trimestral maintenance stop for cleaning, which is also unfavourable considering the loss of production during the downtime. Additionally, quantities of scaling to be managed on-site as toxic wastes are not negligible. Moreover, these precipitations trap natural radionuclides like $^{226/228}Ra$ and ^{210}Pb in sulphates and sulphides deposits respectively. Waste management as a NORM class (Cuenot et al., 2013) induces specific regulation rules for safety and environment protection as well as high operational costs.

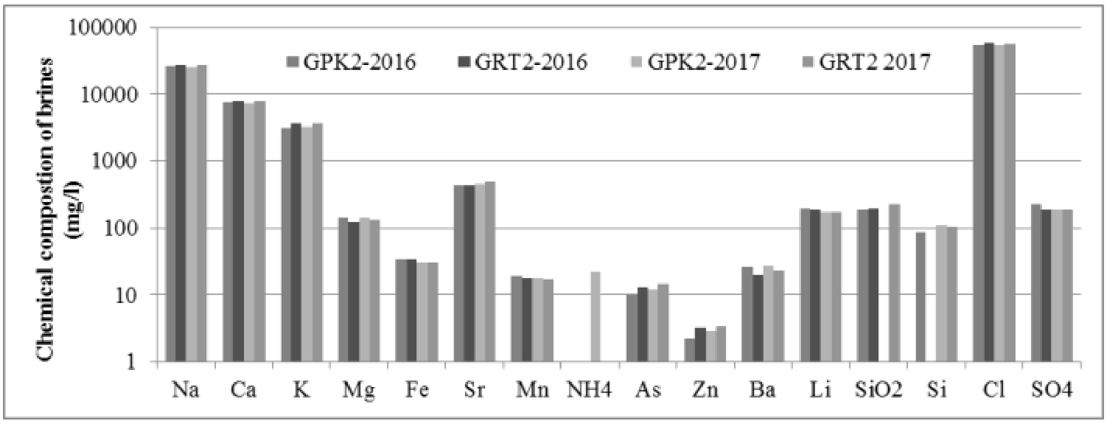

Figure 3: GPK2 and GRT2 geothermal brines composition, (Mouchot et al., 2018)

2.2 Scaling management

Surface installations are operated at 20 bar or above to keep dissolved gases above the Gas Break Out pressure and avoid carbonate precipitation.

However, other precipitation like barium sulphate could occur during the thermal transfer in the heat exchangers. To reduce the impact of such deposits, it has been recommended to use inhibitors. Acids with dispersive properties have been selected to be injected on-site. The scaling management performed using this method is described in Figure 4.

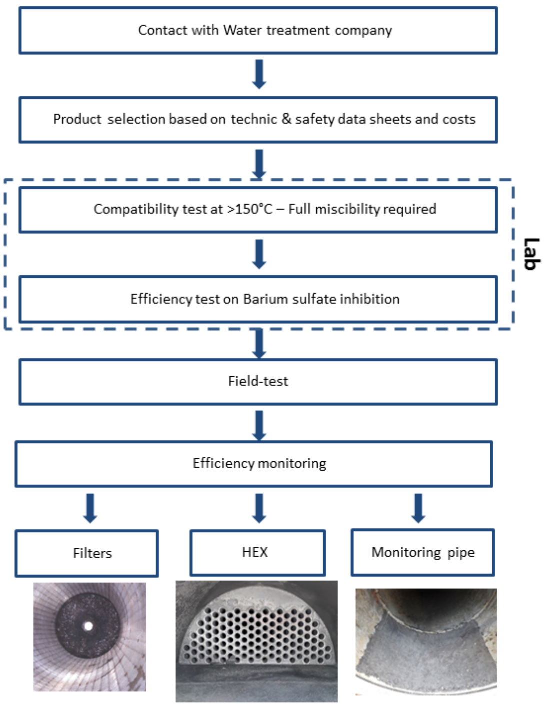

Figure 4: Scaling management

2.3 Performance Indicator

With the aim of identifying the proper cleaning frequency of the heat exchangers and efficiency of applied chemical treatments, pressure drops and heat transfer coefficient are both monitored.

In context of scaling monitoring pressure drops of the heat exchangers gives indicator of scaling deposition on the inner walls of the tubes. Given a constant flow rate, an increase in pressure drops suggests a thicker layer of deposits in the tubes. An analysis is made on the monthly evolution of pressure drop trends on the three sets of exchangers in Rittershoffen heat plant.

Furthermore, scaling depositions also reduce the efficiency of heat exchanges, which can be observed by monitoring the heat transfer coefficient expressed in $W/m^2.K$. Understandably, a decrease this coefficient suggests a thicker layer of deposits. An analysis is made on the trends of the U-values of the three sets of exchangers in Rittershoffen heat plant.

Examples of monitoring data are given in Figure 5 and Figure 6 for the hottest and the coldest heat exchanger series respectively at Rittershoffen geothermal plant.

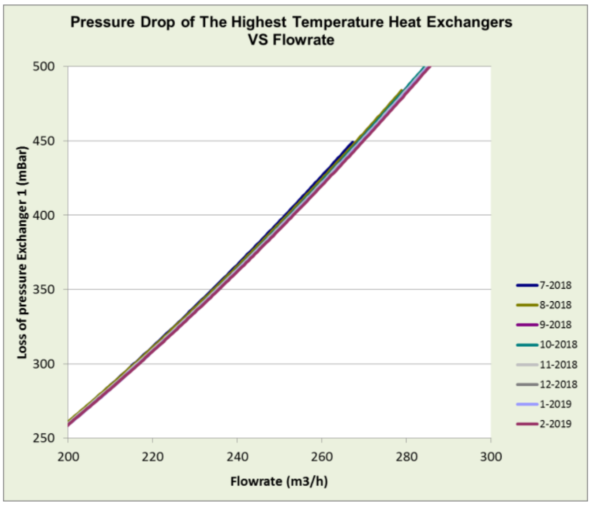

Figure 5: Example of pressure loss on the hottest heat exchangers

From July 2018 to February 2019, Figure 5 highlights the constant relation between pressure losses and flowrate. This trend is witness of good efficiency of chemical treatments injected on the geothermal plant to inhibit scaling formation.

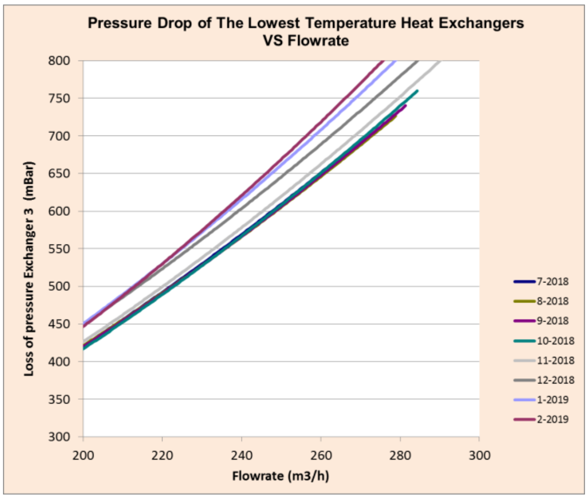

Figure 6: Example of pressure loss on the coldest heat exchanger

From July 2018 to February 2019, Figure 6 highlights the increasing trend by month of pressure loss versus production flowrate. From July to September 2018, trends are quite constant, revealing good efficiency of chemical product and dosage. October 2018, the dosage of scaling inhibitor has been reduced of 15%, with the same efficiency. In November 2018, due to good results, the dosage has been reduced of 15%. Graph shows that pressure loss increases with a constant flowrate, indicating a progressive fouling of coldest heat exchangers. Consequently, dosage has been adjusted since January 2019.

3. CORROSION CONTEXT AND MANAGEMENT

3.1 Corrosion context

Geothermal fluids exploited at both plants, are rich in dissolved gases, with a gas liquid ratio of 1 -

1.2 Nm^3/m^3 in standard conditions. Carbon dioxide is the main component of the gas mixture as described in Figure 7.

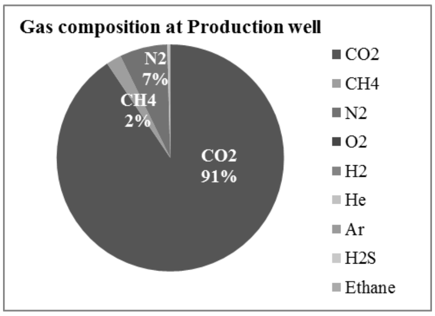

Figure 7: Gas composition of geothermal fluid from GPK2. (Mouchot et al., 2018)

The pH of fluid is slightly acidic, of about 5.2 at 60°C. All these parameters induce generalized corrosion of steel material. A generalized corrosion rate of about 0.15-0.3mm/year has been measured at 70-80°C by electrochemical analysis at lab scale and on field-test (Mundhenk et al. 2013, Baticci et al., 2010).

The heat exchangers are made of 1.4410 stainless steels for their corrosion resistive properties. Pipes are made of carbon steel, and could suffer more corrosion processes. Particularly in restrictions and elbows zones, localized corrosion could occur more easily. For example, at Rittershoffen plant, carbon steel reinjection line has been damaged by localized corrosion (Figure 8). Indeed, this part of the line is at GRT1 wellhead pressure. Due to good injectivity, wellhead pressure was below the Gas Break Out at 80°C inducing CO_2 degassing.

Figure 8: Localized corrosion on the reinjection pipe at Rittershoffen plant.

3.2 Corrosion management

A corrosion control program has been applied at both geothermal sites: (i) a chemical treatment injection and on-site monitoring, (ii) a coating reinjection pipe line and (iii) a pressure control at injection wellhead.

Corrosion inhibitor has been selected based on methodology given in Figure 9.

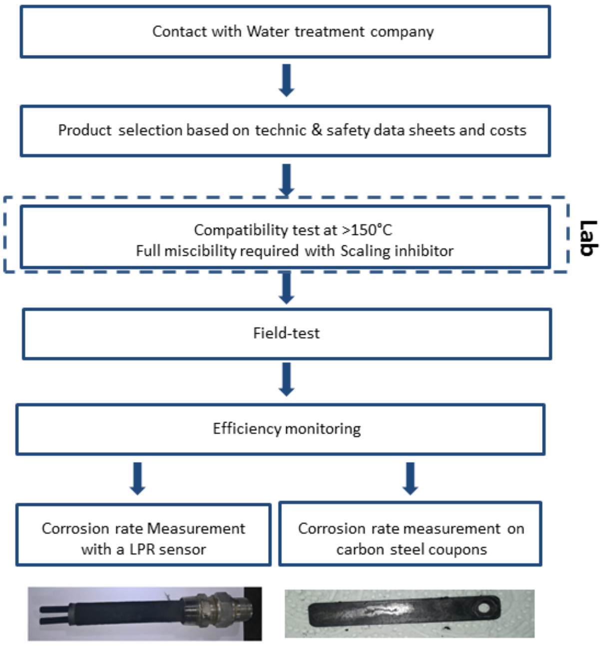

Figure 9: Methodology of corrosion inhibitor selection and efficiency assessment.

The second and third actions of corrosion control are coupled. They consist on coating the reinjection pipe under wellhead pressure, and increase the wellhead pressure by adding an injection column with smaller diameter.

A 4’’1/2 13.5 lbs/ft injection column and 160 m length has been inserted into the GRT1 well, during the 2018 annual maintenance shut-down of Rittershoffen geothermal plant (Figure 10). The column, as well as a part of the reinjection line has been coated with an EPOXY polymer for corrosion and erosion issues. The column is composed of 14 tubes with special DHT-HTC coupling in order to have a continuous internal coating (Figure 11).

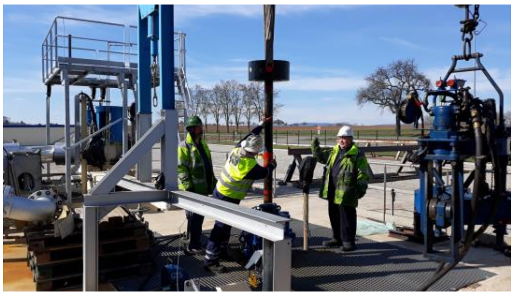

Figure 10: Injection column inserted at Rittershoffen plant. April 2018.

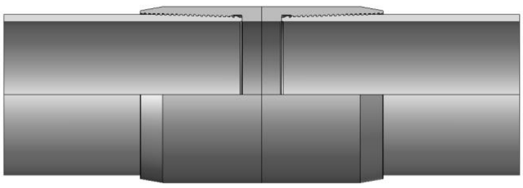

Figure 11: Drawing of DHT-HTC coupling

3.3 Performance indicators

Performance indicators of each action are described hereafter.

Corrosion rate monitoring performed before and during inhibitor injection highlights the good efficiency of tested products. Indeed, corrosion rate has been reduced of about 50%-80% even reaching value of about 0.015mm/year (Mouchot et al., 2019).

The column installation in the injection well has strongly reduced the loss of charge after the regulation valve, avoiding CO_2 degassing and corrosion issues. Figure 12 highlights also the benefit of such coating on the scaling quantity and adherence.

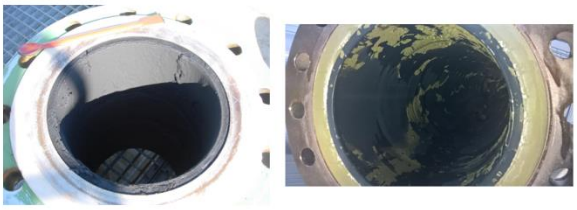

Figure 12: Comparison of coated and non-coated pipes. Rittershoffen plant

Since the installation of the column, GRT-1 wellhead pressure increased from 7 bars to 15 bars at nominal flowrate (Figure 13). After one year of operation, the injection column gives satisfying results. It will be inspected in March 2020 during casing inspection of GRT-1.

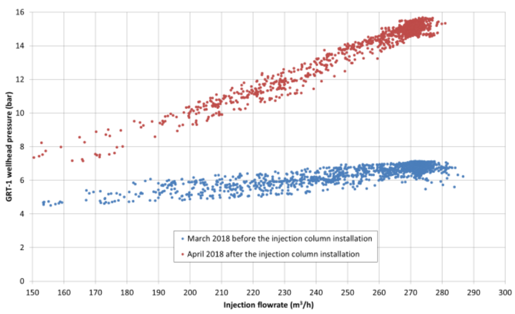

Figure 13: Comparison of GRT-1 wellhead pressure in function of the flow before (blue dots) and after the injection column installation (red)

4. AVAILABILITY AND OPERATIONAL COSTS

4.1 Availability factor

4.1.1 Soultz-sous-Forêts geothermal power plant

The commissioning of the new geothermal power plant of Soultz-sous-Forêts spanned over June 2016 for the geothermal downhole Line Shaft Pump, and over July and August 2016 for both the geothermal loop and the ORC unit. The performance test and test run of the ORC unit were performed mid-August 2016 and its commercial operation started in September the same year.

The total plant availability reached 90% in 2017 and 95.9% in 2018. The lower availability in 2017 was mainly due to a longer maintenance stop in September 2017 during which routine operations where performed as well as an acid cleaning of the LSP hydraulics. When considering the ORC unit itself, the availability with regard to the geothermal loop operating time rises to 99.8% for both 2017 and 2018, with an overall availability since the beginning of its commercial operation of 99%.

In 2017, the net annual efficiency of the Soultz ORC unit was 11.5%. The gross electrical production of the Soultz geothermal plant in 2017 was nearly 9.7 GWh and the total electrical consumption, including ORC auxiliaries and production pump, was around 3.7 GWh, resulting in an overall net electrical production for the whole plant of 5.9 GWh. In 2018, these figures were relatively stable and reach 9.6 GWh for the gross electrical production and auxiliaries consumptions of 3.9 GWh, hence the overall net electrical production for the whole plant reached 5.7 GWh.

4.1.2 Rittershoffen geothermal heat plant

Commissioning of the Rittershoffen geothermal plant started mid-May 2016. The vacuum process for the pipe-in-pipe transport loop was completed 3 months afterwards. The required pressure of 2.5 mbar was obtained inside this 15 km long pipe. The plant was subsequently put in commercial operation in September 2016, and the heat demand of the heat user increased step by step to in the following month. Plant was shut down mid-November 2016 for 3 weeks to replace all the water of the transport loop due to a leak on a process plate heat exchanger at the bio refinery. Availability was about 92.9% all over the year in 2017 and 92.2% in 2018 (Figure 14). The Rittershoffen geothermal plant was shut down two times in 2017 to replace a part of the injection line due to CO_2 corrosion damages and to clean the heat exchangers. In 2018, availability of the plant was impacted by heat exchangers cleaning and by damage on a bearing of the electrical motor of the downhole production pump.

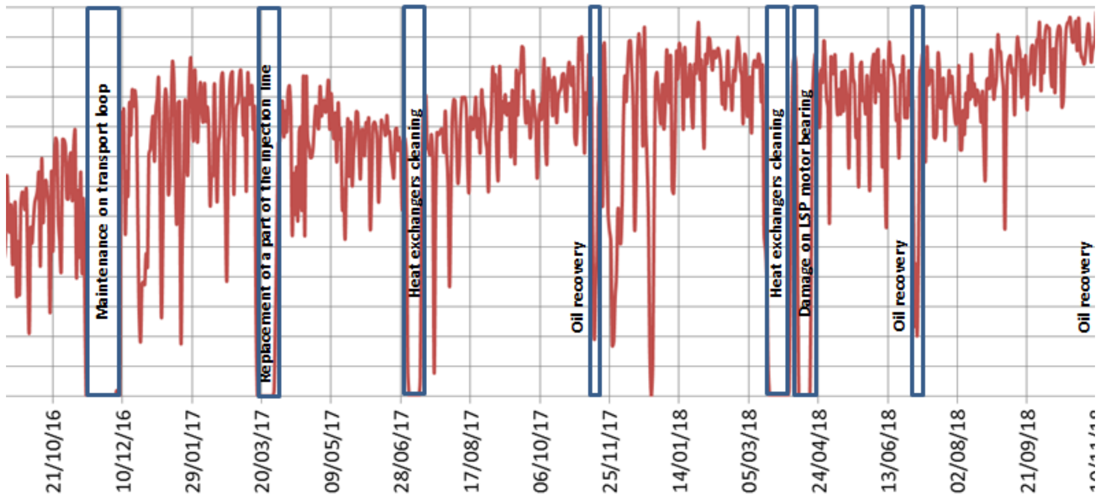

Figure 14: Daily average thermal heat demand of the bio-refinery from the 1st of September 2016 to the 31sth of December 2018 and maintenance shut down

In 2017 and 2018, about 1 960 000 m^3 and 2 124 000 m^3 of brine at 168°C was pumped in order to produce respectively 155.6 GWh and 181.7 GWh of heat. Since it is not technically feasible to transport brine to the factory due to its corrosion characteristic, the heat is transferred to Beinheim via a transport loop containing fresh water which is formerly heated via twelve heat exchangers having only 4°C of pinch (Ravier et al., 2016). Temperature at the inlet of the transport loop is currently reaching 164.4°C and temperature at the inlet of the bio-refinery is 160,5°C, that means that thermal loses on the transport loop pipe in pipe are lower than 4°C. The heat supplied to the bio-refinery was 142.8 GWh in 2017 and 167.8 GWh in 2018 which substituted a portion of its natural gas consumption. This resulted in saving about 34 600 tons of CO_2 in 2017 and 41 700 tons in 2018 (Pratiwi et al, 2018). Global thermal efficiency of the transport loop was 91.7% in 2017 and increased to 92.3% by reducing the vacuum pressure to 1.5 mbar.

In 2017, the total electrical consumption of the Rittershoffen geothermal plant and of the transport loop was about 4.8 GWh. Moreover, total heat supply in 2017 to the industrial user was 142.8 GWh, giving a ratio between the geothermal heat energy supplied with the electrical energy consumption of nearly 30.

4.2 Auxiliary consumption

4.2.1 Soultz-sous-Forêts geothermal power plant

In Soultz geothermal power plant, a Line Shaft Pump is installed in the artesian well GPK-2 to enhance the production flow and maintain the production pressure above the bubble point of the brine at the production temperature. This pump is set at a depth of 350.9 m, and consumed about 170 kW to produce about 30 l/s.

Annual oil consumption was about 50 drums in 2017 and 54 in 2018. The oil injected for bearings lubrication is dispersed into the cased wellbore, floats on top of the water level and is usually recovered every three to four months during a half day of shut down.

Chemical treatments for scales and corrosion control are still under investigation at Soultz-sous-Forêts and Rittershoffen geothermal plants. Dosages of both treatments are in the ppm scale. Nevertheless, it represents about 6 IBC containers per year of scaling inhibitor and about 4 IBC containers per year of corrosion inhibitor. These chemical treatments currently represents an operational expenditure of nearly 2.9c€/m^3 of geothermal brine for both geothermal plants. The effort to reduce this operational expenditure is ongoing.

4.2.2 Rittershoffen geothermal heat plant

Even though the production well GRT-2 is artesian, the brine is pumped by a downhole production Line Shaft Pump with oil-lubricated line shaft installed at 480.6 m depth. After nearly 3 years of operation, the electrical consumption of the LSP is about 502 kW at 82.7 L/s and 420 m of head. Global efficiency of the Downhole production Line Shaft Pump including the electrical motor and surface cables is nearly 70%.

Annual oil consumption was about 29 drum in 2017 and 48 drums in 2018. The oil for lubrication represents an operational expenditure of nearly 16 k€ per year including oil recycling.

Total electrical consumption of the Rittershoffen geothermal plant and of the transport loop was about 4.8 GWh in 2017 and 5.9 GWh in 2018. Ratio between the heat energy supplied to the bio-refinery and the electricity consumption was nearly 29.8 in 2017 and 28.3 in 2018. This ratio is an excellent indicator of energy performance of the Rittershoffen geothermal plant.

Chemical treatments represent about 12 to 14 IBC containers per year of scaling inhibitor and about 6 IBC containers per year of corrosion inhibitor.

5. CONCLUSION

For decades, development of deep geothermal energy in Upper Rhine Graben has been facing some challenges to demonstrate the commercial feasibility of such energy production in the region.

These challenges include managing the fluid production of high temperature, high salinity, and with dissolved gas issues

The commissioning and daily productions of two geothermal plants in Alsace, French part of the Upper Rhine Graben, provided the following feedbacks from the operational context during these two years:

- Methodologies have been developed to monitor the operation, notably in terms of corrosion and scaling issues;

- Remediation measures have been applied when corrosion and scaling issues occurred on-site;

- Performance indicators have been identified to monitor the efficiency of the remediation methods.

Main outcomes are the following:

1. Thanks to the combined use of scaling and corrosion inhibitors, generalized corrosion rate has been decreased and the quantity of scaling encountered in the surface installation has been significantly reduced as well.

2. Localized corrosion and degassing issues have been managed by applying a coating on the carbon steel pipes and increasing the injection wellhead pressure thanks to the injection column.

3. After two years of full operation, the feasibility of geothermal energy production has been demonstrated as baseload energy production under commercial conditions, as shown by the availability factor of higher than 95%.

4. These two years of operation have given some feedbacks on operational costs linked to auxiliary consumptions, like oil, chemical treatments and electricity, 2.5-3% of CAPEX per year.

Optimization of this energy production is still a topic for research and development, under different axes, operational cost environment impact management and on energy production. Some projects are ongoing on the two geothermal plants at Rittershoffen and Soultz-sous-Forêts focusing on:

- Apply appropriate dosage of inhibitors managing both scaling and corrosion issues at controlled costs, and in balance with the quantity and type of encountered scaling in surface installations.

- Use of environmentally friendly inhibitors at high temperature, to protect casing and downhole production pump from corrosion issues frame work of the GEOTHERMICA project ZODREX.

- Valorize full geothermal energy from the fluid by increasing the temperature differences between production and reinjection for thermal and/or electricity production in the frame work of the H2020 project MEET.

Due to the context, deep geothermal energy production in the Upper Rhine Graben can be a challenge. Thanks to research and industrial development, guidelines could be issued and exchanges on feedbacks are needed to continue the increase on the learning curve.

REFERENCES

ASTM standard practice G1-90: Standard practice for preparing, cleaning, and evaluating Corrosion test Specimens, Annual Book of Standards Vol. 03.02 American Society for Testing and Materials, s.35-41.

Baticci F., Genter A., Huttenloch P., Zorn R., 2010. Corrosion and Scaling Detection in the Soultz EGS Power Plant, Upper Rhine Graben, France. Proceedings World Geothermal Congress 2010. Bali Indonesia, 25-29 April 2010 11pp.

Baujard C. Genter A., Maurer V., Dalmais E., Graff J-J., 2015. ECOGI, a new deep EGS project in Alsace, Rhine Graben, France. In: World Geothermal Congress, Melbourne, Australia 19-25 April 2015.

Baujard C., Genter A.,Dalmais E., Maurer V., Hehn R., Rosillette R., Vidal J., Schmittbuhl J., 2017. Hydrothermal characterization of wells GRT-1 and GRT-2 in Rittershoffen, France: Implications on the understanding of natural flow systems in the Rhine Graben, Geothermics, 65, 255-268.

Baujard C., Genter A., Cuenot N., Mouchot J., Maurer V., Hehn R., Ravier G., Seibel O., Vidal J., 2018. Experience from a successful soft stimulation and operational feedback after 2 years of geothermal power and heat production in Rittershoffen and Soultz-sous-Forêts plants (Alsace, France), Geothermal Resource Council, GRC2018, October 14-17, Reno, Nevada, USA.

Cuenot N., Scheiber J., Moeckes W., Guéry B., Bruzac S., Sontot O., Meneust P., Maquet J., Orsat J., Vidal J., 2013. Evolution of the natural radioactivity within the Soultz geothermal installation. Proceedings of the European Geothermal Congress 2013, Pisa, Italy, (2013), 10 pp

Genter A., Baujard C., Cuenot N., Hehn R., Maurer V., Mouchot J., Seibel O., Vidal J., 2018.

Exploiting fractured granites for producing heat or electricity: dream or reality? 80th EAGE Conference & Exhibition 2018, Copenhagen, Denmark, 11-14 June 2018.

Mouchot J., Cuenot N., Bosia C., Genter A., Seibel O., Ravier G., Scheiber J.: First year of operation from EGS geothermal plants in Alsace, France: scaling issues, Stanford Geothermal Workshop 2018, Stanford, California, USA, 12-14 February 2018.

Mouchot J., Scheiber J., Jähnichen S., Seibt A., Florencio J., 2019. Scale and Corrosion control program, Example of two geothermal plants in Operation in the Upper Rhine Graben. European Geothermal Congress 2019, The Hague, 11-14 June 2019.

Mundhenk N., Huttenloch P., Sanjuan B., Kohl T., Steger H., Zorn R., 2013. Corrosion and scaling as interrelated phenomena in an operating geothermal power plant. Corrosion Science 70, 17-28.

Ravier G., Huttenloch P., Scheiber J., Perrot V., Sioly J-L., 2016. Design, manufacturing and commissioning of the ECOGI's heat exchangers at Ritterhsoffen (France): a case study. European Geothermal Conference 2016, Strasbourg, France, 19-24 Sept. 2016.

Ravier G., Harders V., El Aoud M., 2017. Rittershoffen geothermal heat plant. First geothermal heat plant for industrial uses worldwide, EuroHeat&Power, 3/2017 (9973).

Scheiber J., Nitschke F., Seibt A., Genter A., 2012. Geochemical and mineralogical monitoring of the geothermal power plant in Soultz-sous-Forêts (France). Proceedings, Thirty-Seventh Workshop on Geothermal Reservoir Engineering. SGP-TR-194.

Pratiwi A., Ravier G., Genter A., 2018. Life-cycle climate-chnage impact assessment of enhanced geothermal system plants in the Upper Rhine Valley. Geothermics 75 (2018) 26-39.

Acknowledgements

The authors acknowledge EEIG Heat Mining for the Soultz site access and ECOGI for the Rittershoffen site access. This work was done in the framework of the EGS Alsace project cofunded by ADEME and Electricité de Strasbourg. This work is partly cofounded by the Geothermica – ZoDrEx project supported by the European Unions's Horizon 2020 research and innovation program under grant agreement N°731 117. The ZoDrEx project is also supported at the French level by the "Investments for the Future" managed by ADEME.