Main achievements from the multi-well EGS Soultz project during geothermal exploitation from 2010 and 2012

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ABSTRACT

A research program based on a scientific and technical monitoring of the EGS Soultz power plant has been achieved during geothermal exploitation between 2010 and 2012. Several hydraulic circulation tests have been performed that involve one production well, GPK-2 and two reinjection wells, GPK-1 and GPK-3: a long term circulation for about 11 months in 2010, and two short term circulation tests in 2011. In 2012, a short term circulation test sharply stopped due to a serious down-hole pump failure.

During the 2010 exploitation, geothermal fluid discharge from GPK-2 reached a volume of about 500 000 m^3 by producing at 18 L/s for a temperature of 164°C. Tracer test was conducted and showed the good connection between GPK-3 and GPK-2. In 2010, more than 400 induced micro-seismic events of low magnitude occurred. In 2011, geothermal fluid discharge from GPK-2 reached a volume of about 300 000 m^3 by producing at 24 L/s for a temperature of 159°C. The strategy was to increase the reinjection flow rate in the shallow well GPK-1 (3.6 km) and simultaneously minimize it in GPK-3 in order to decrease reinjection pressure. Induced seismic activity was seriously decreased with less than 10 micro-earthquakes in 2011. In 2012, GPK-4 well, a former production well was converted into an injection well but for a rather short period, due to the failure of the down-hole production pump. New improvements about Line Shaft Pump (LSP) technology were done and another pump was designed and tested before its setting in GPK-2. In parallel, many research works have been carried out for characterizing scaling and the natural radioactivity derived from natural brines circulating within a deep fractured granite reservoir.

Down-hole pump technology was also tested in various geothermal conditions during exploitation. In 2010, the LSP worked for more than 300 days without any trouble. In 2011, occurrences of cuttings at higher flow rate, generated abrasion of the pump reinforcing its damaging. In 2012, serious damages occurred on its hydraulic part in terms of abrasion and corrosion. Environmental nuisances were also investigated in order to evaluate their impact on the local population and then on public acceptance. An opinion survey was conducted in close cooperation with the two neighbouring villages of Kutzenhausen and Soultz-sous-Forêts showing the permanent need of information and communication at local scale.

1. INTRODUCTION

1.1 Site presentation and main outcomes

The Soultz geothermal site which is located within the Upper Rhine Valley in Northern Alsace about 50 km NNE of Strasbourg, is the first EGS (Enhanced Geothermal System) demonstration site producing electricity in France (Fig. 1).

Figure 1: The Soultz power plant with the village of Kutzenhausen in the back.

Several deep wells from 2200 to 5000 m depth have been drilled, stimulated and circulated within deep naturally fractured granite showing poor initial permeability evidenced by the occurrence of a very saline geothermal fluid (100 g/L) circulating through a naturally fractured granite (Genter et al., 2010).

This EGS site is under development since the 90-ties when a preparatory phase and a preliminary exploration phase have been conducted in the upper reservoir (top basement, from 1400 to 2200 m) by the drilling of GPK-1 and the coring of EPS-1 (Table 1).

Table 1: Main outcomes of the Soultz project from exploration to power plant monitoring.

1984-1987	1987-1991
Preparatory phase	***Exploration phase***
Literature compilation	Drilling GPK1 at 2000 m
Seismic survey reinterpretation	Hydraulic testing in GPK1
Permitting and drilling preparation	Coring EPS1 at 2227 m
1991-1998	**1999-2007**
Creation of the 2 well system GPK1/GPK2 at 3600 m	***Creation of the 3 well system GPK2/GPK3/GPK4 at 5000 m***
Deepening of GPK1 at 3600 m and stimulation	Deepening of GPK2 at 5080 m and stimulation
Drilling of GPK2 at 3880 m and stimulation	Drilling of GPK3 at 5100 m and stimulation
Circulation test between the 2 wells GPK1/GPK2 (4 months)	Drilling of GPK4 at 5270 m and stimulation
	Circulation test between 3 wells (5 months)
	Complementary chemical stimulations
2007-2009	**2010-2012**
Construction of the ORC unit 2.2 MWe gross	***Scientific and technical monitoring of the power plant***
Power plant construction	Hydraulic, seismic, fluid geochemistry, and corrosion monitoring
Installation and test of the LSP in GPK2 pump at -250 m	LSP tests in different flow conditions (from 18L/s to 26 L/s)
Installation and test of the ESP in GPK4 pump at -500 m	Integration of GPK1 as a reinjection well
Power plant preliminary tests	Circulation test between 3 wells (11 months)
Interwell circulation tests	Power plant tests
	Connected to the grid from early 2011

In the following phase, a doublet development within the intermediate reservoir was achieved at 3600 m by the deepening GPK-1 and the drilling of GPK-2 (Table 1). After their stimulation, a successful two-well hydraulic circulation was carried out showing the promising potential of fractured granite reservoirs (Baumgartner et al., 1998). In the next step, it was decided to assess a deeper level of the basement by a triplet concept (lower reservoir). The creation of this well triplet was initiated by the deepening of GPK-2, and the drilling of GPK-3 and GPK-4 from the same pad, to 5100 and 5270 m depth, respectively (Table 1, Fig. 2). At this depth, a temperature of 200 °C was observed. During this phase, those deep wells were hydraulically and chemically stimulated leading to felt seismicity with a local magnitude of up to ML=2.9 in June 2003. After this phase of reservoir development, a large-scale hydraulic circulation was achieved successfully in 2005 and the design and the construction of a binary power plant initiated with an installed gross power capacity of 2.2 MWe.

1.2 The "Phase III" framework

Following the installation of the power plant, a three-year research program (2010-2012), the so-called "Phase III", associated with a scientific and technical monitoring during geothermal exploitation of the Soultz-sous-Forêts EGS power plant was conducted (Table 1).

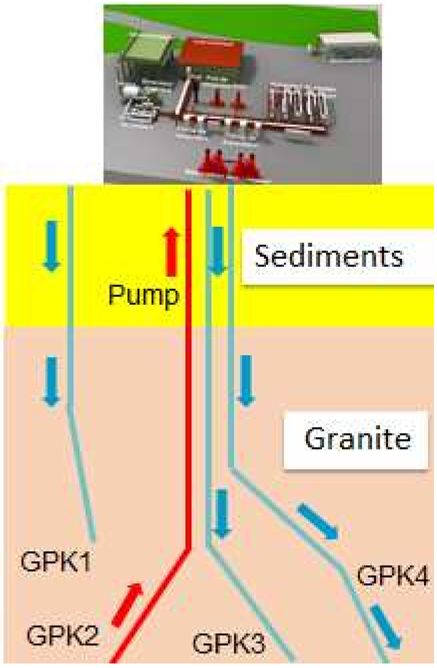

Figure 2: The Soultz power plant on surface and the multi-well system in the ground. A down-hole pump is deployed in the production well GPK-2. Injection wells are plotted in blue.

A scientific and technical team is thus operating an EGS multi-well system with one production well GPK-2 equipped with a down-hole pump and three possible reinjection wells (GPK-1, GPK-3, GPK-4) in order to monitor, measure and manage the geothermal system during exploitation (Fig. 2). In addition to on-site operations, many scientific and technical partners from Germany, France and Switzerland are involved for conducting research activity. The scientific and technical research program is supported by the French and German governments via ADEME and BGR/BMU, and by a French-German industrial consortium.

This research program was organized around three main folds such as reservoir performance, power plant technology and environmental nuisances related to exploitation. The main results and achievements are presented hereafter.

2. MAIN ACHIEVEMENTS IN THE RESERVOIR DURING EXPLOITATION

2.1 Reservoir study with tracer test done in 2010

For reservoir study, several hydraulic circulation tests were executed by producing mainly from GPK-2 and re-injecting in one or two re-injection wells (GPK-1, GPK-3) simultaneously: a long-term circulation with duration of about 11 months in 2010 was followed by short-term circulation tests in 2011 and 2012. Due to its limited hydraulic performance, GPK-4 was not used anymore during Phase III. The hydraulic tests from 2011 and 2012 were sharply stopped due to down-hole pump failure under operational conditions. In terms of reservoir, production flow rate was increased from 18 to 25 l s^{-1}.

During the 2010 exploitation, geothermal fluid discharge from GPK-2 reached a volume of about 500,000 m^3 at 18 l s^{-1} and a temperature of 164 °C. The injection into GPK-3 was done at an initial flowrate of about 17 L/s, and then decreased to 15 L/s, when a part of the produced fluid was injected into GPK-1 (flowrate: <2 L/s). GPK-2 wellhead pressure was kept at 18 bar, while GPK-3 wellhead pressure was maintained with an injection pump to about 55 bar, then 40 bar when reinjection was performed simultaneously into GPK-1. GPK-3 pressure kept slightly increasing until the end of the test. A tracer test was conducted and showed the good connection between GPK-3 and GPK-2. As for previous tracer tests done at Soultz (Sanjuan et al., 2006), an organic compound from the naphthalene sulfonate family such as 1,3,5-nts was used because of its properties of quasi-ideal tracer. This compound is inexpensive, environmentally safe, highly soluble in water (200 g/L), non-adsorptive and non-interactive with rocks and minerals of the fractures, thermally stable up to 340°C (Rose et al., 2000), detectable at low concentrations (down to 0.25 µg/L) and absent from natural geothermal fluids.

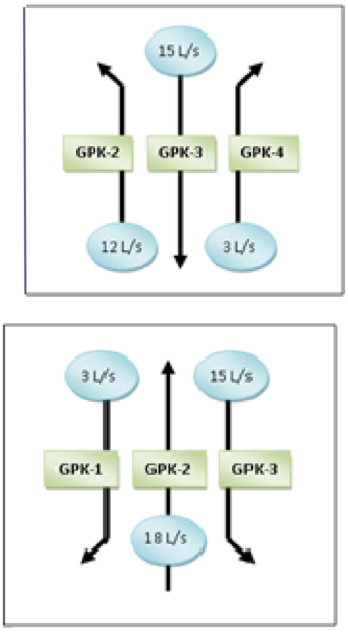

Figure 3: Geothermal well configuration for 2005 (top) and 2010 (bottom) tracer tests at Soultz.

In order to understand flow redistribution between the geothermal wells during geothermal circulation, a modeling work has been done by using 2005 and 2010 tracer data respectively. Many tracer modeling works have already been published with 2005 datasets (Sanjuan et al., 2006, Gentier et al., 2011; Radilla et al., 2012; Vogt et al., 2012). During the 2005 tracer test, reinjection was done in GPK-3 and production was done by both GPK-2 and GPK-4 (Fig. 3). The cumulated production flow was 15 L/s. There was no production down-hole pump during this test. During the 2010 tracer test, reinjection was done in both GPK-1 and GPK-3 and production was done with a down-hole LSP pump from GPK-2 (Fig. 3). The cumulated production flow was 18 L/s. Thus, a specific modeling work has been carried out for taking into account the tracer recycling due to reinjection in those tests as well as for better understanding the reservoir properties (Sanjuan, 2012).

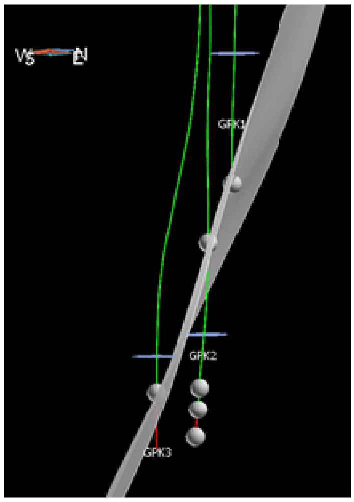

Figure 4: 3D fault model used for tracer interpretation. Spheres represent main flow inlets or outlets involved in 2010 tracer tests. The large-scale fault crossing GPK-3 at 4770 m MD is plotted with a grey shaded area (Sausse et al., 2010). Blue disks represent the casing shoe locations of the geothermal wells.

Based on various well data, a conceptual model of the main fracture flow contribution has been built for the 2010 tracer tests (Fig 4). By taking a given well as a 1D-tube reference, there are one main flow exit in GPK-1 and GPK-3 and 3 main flow entrances in GPK-2 (Fig 4). Sanjuan et al. (2006) had already identified two connecting loops in the deep geothermal systems between the wells GPK-2 and GPK-3: one direct and shorter loop and one indirect and longer loop. A third large-scale loop which poorly connects hydraulically GPK-3 and GPK-4 was also described in their conceptual model (only 1.8% of recovered tracer). The main outcomes of this 2005 tracer test is that the total fluorescein recovery in the fluid discharged from GPK-2 was estimated to 23.5% (15.6% for the loop 1 and 7.9% for the loop 2), the maximum and mean linear fluid velocities were 8.1 m/h and between 0.3 and 1.1 m/h (depending on the paths traveled by the fluid), respectively. Radilla et al. (2012) and Sanjuan (2012) found similar mean linear velocities (between 0.4 and 2.2 m/h) but with slightly different tracer recovery rates and distribution (6.3 and 14.1% for loops 1 and 2, and 11.1 and 4.8%, respectively). The 2010 tracer data give similar maximum linear velocities (7.9 m/h) between GPK-3 and GPK-2 (Sanjuan et al., 2011).Based on several modeling software for tracer curve analysis and interpretation, 2005 and 2010 tracer datasets and their recycling analysis have been evaluated with the same methodology (Sanjuan, 2012). For 2010 tracer test, only the loops between GPK-3 and GPK-2 were studied. The first step is to take into account the recycling of the tracer by using signal deconvolution calculation (Fig. 5) due to the fact that the geothermal fluid is reinjected in one well in 2005 (GPK-3) and two wells in 2010 (GPK-1, GPK-3). The second step is to take into account the flow contribution of each main outflow zones in a given well. Typically, in GPK-2, the short and direct loop and the long and indirect loop are modeled by using flow calculations in porous media (Fig. 5). Flow location in the wells is derived from the Soultz structural 3D model set up with Gocad by Sausse et al. (2010) (Fig. 4).

The modeling results of 2010 and 2005 tracer breakthrough curves are respectively presented on Figure 6 and Figure 7 and show that experimental data with recycling and simulated results are quite close. For 2010 tracer test, the contribution in terms of volume between GPK-2 and GPK-3 has been calculated for each loop (short and long) and compared with tracer test results from 2005 (Sanjuan et al., 2006; Radilla et al., 2012). It turns out that the cumulative volume of the 2 loops had increased by a factor 3 in 5 years (Table 2).

Table 2: Comparison between the different swept volumes in m^3 for each loop calculated by various studies for 2005 and 2010 tracer tests.

Study	Tracer test	Short loop volume	Long loop volume	Cumulated volume of the 2 loops
Sanjuan 2006	2005	3,900	6,500	10,400
Radilla 2012	2005	1,137	10,983	12,120
Sanjuan 2012	2010	5,701	29,942	35,643

The short loop represents a smaller volume but is faster whereas it is the opposite behavior for the longest loop. It was estimated that about 17.8% of the injected tracer was recovered through the short and faster loop (70% of recovered tracer) and 7.6% through the longest loop (30% of recovered tracer; Sanjuan, 2012). The total tracer recovery (25.4%) is higher than in 2005 (15.9% according to Sanjuan, 2012, or 23.5% according to Sanjuan et al., 2006).

The increasing of the injection/production flows from 12 L/s in 2005 to 18 L/s in 2010 as well as the effect of chemical stimulations in 2006 and long-term circulation duration between 2008 and 2010 which represents about 20 months and 660 000 m^3, was pointed out as major causes of such an evolution of the geothermal reservoir performances.

2.2 Hydraulic circulation post 2010

In 2011, geothermal fluid discharge from GPK-2 reached a volume of about 300,000 m^3 at 24 l s^{-1} and a temperature of 159 °C (Fig. 8).

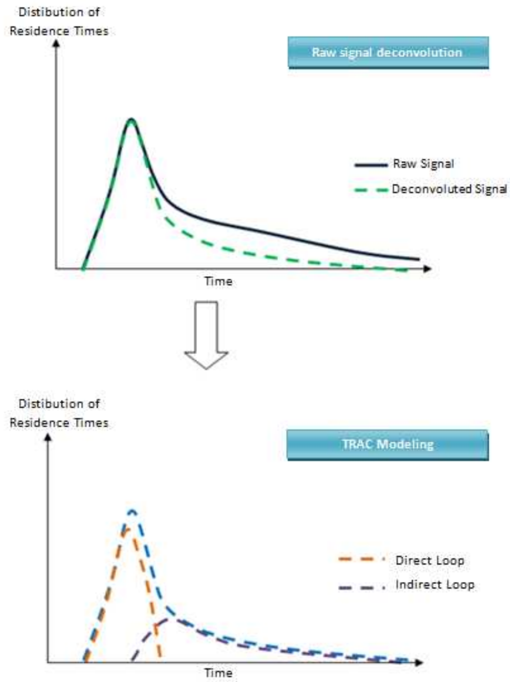

Figure 5: Major steps illustrating the deconvolution method for evaluating tracer recycling during reinjection

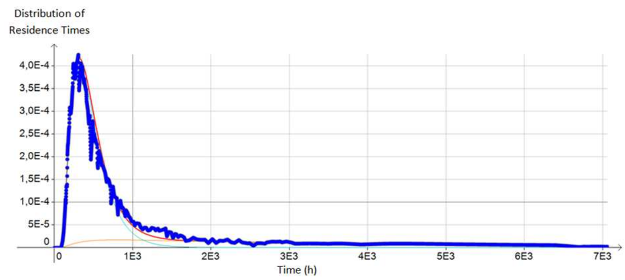

Figure 6: Distribution of residence time of the 2010 tracer test at Soultz. In dark blue, experimental data, in red, orange and light blue, modeling results.

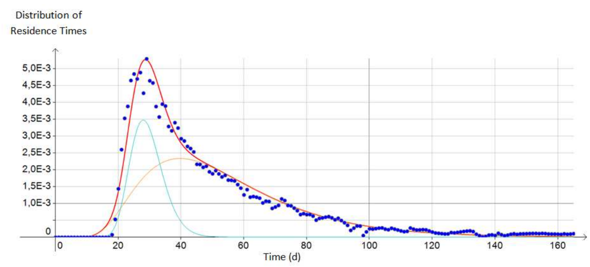

Figure 7: Distribution of residence time of the 2005 tracer test at Soultz. Dark blue dots correspond to experimental data. Red curve is the sum of the main flow contributions (orange, light blue) based on modeling results.

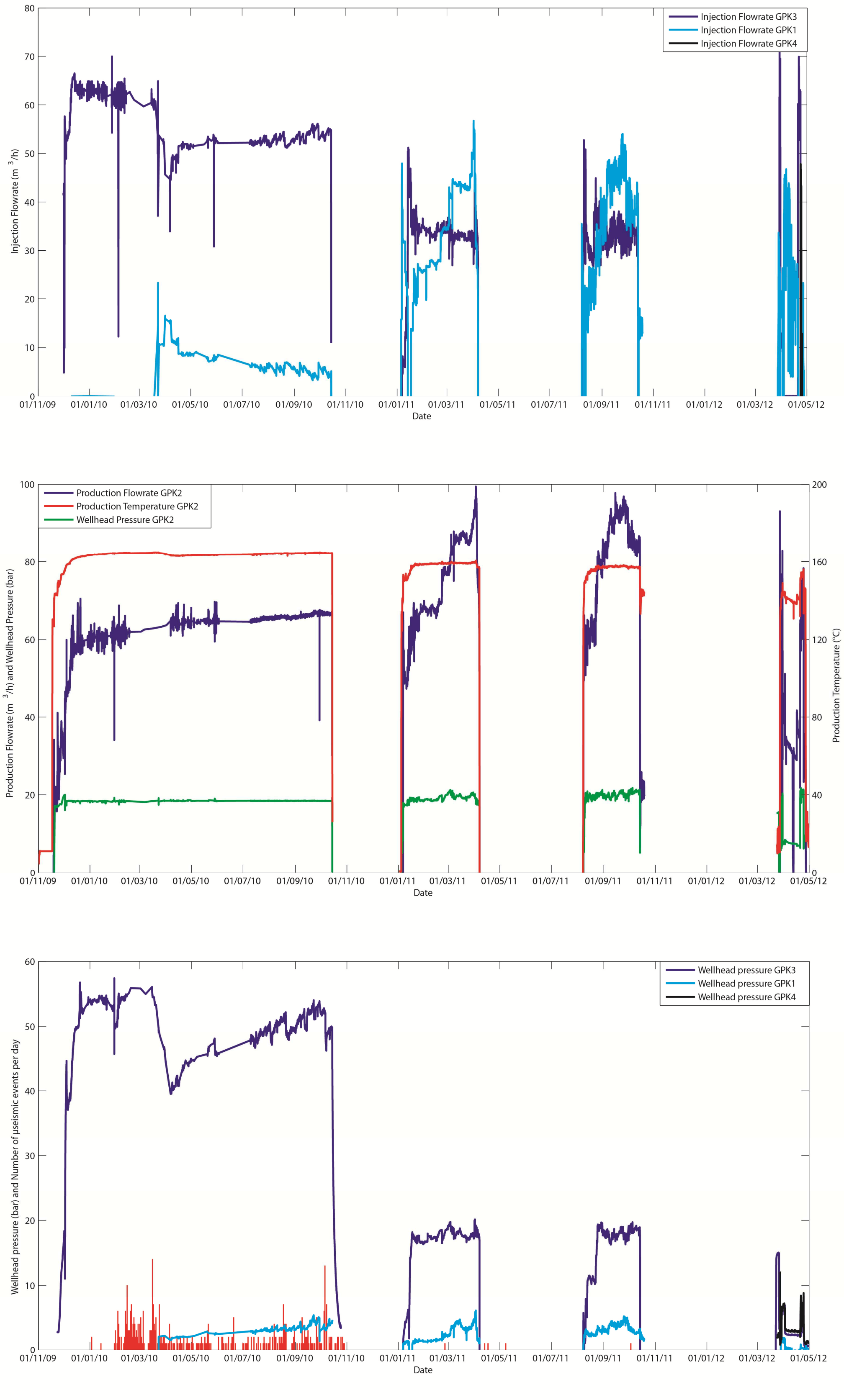

Figure 8: Geothermal activity at Soultz between November 2009 and May 2012. Reinjection flow rate in m^3/h in GPK-1, GPK-3 and GPK-4 (top). Production flow rate in m^3/h, production temperature and wellhead pressure from GPK-2 (middle). Wellhead pressure in GPK-1, GPK-3 and GPK-4 (bottom) and induced microseismicity frequency distribution versus time (bottom, in red)

The strategy was to increase the re-injection flow rate in GPK-1 and simultaneously minimize it in GPK-3 in order to decrease reinjection pressure (Fig. 8). Consequently, induced seismic activity was very low with a total number of only 5 micro-earthquakes in the entire year of 2011. The observed improvement of well productivity is interpreted as a self-cleaning of the fracture network during geothermal production. In 2011, occurrences of cuttings made of granite particles generated at high flow rate, abrasion of the production pump reinforcing its damaging.

In 2012, the geothermal circulation started in artesian mode on March, meaning that around 10 L/s of geothermal fluid were produced from GPK-2. It was planned to re-injected first during a shortest period in GPK-1 and later only in both, GPK-3 and GPK-4 in order to minimize the temperature cooling effect observed at GPK-2 related to a simultaneous reinjection into GPK-1. The temperature of the discharged water from GPK-2 was around 140°C, and the fluid was re-injected with 50 to 60°C. On the 20th of April, LSP was then started at a frequency of 30 Hz and the production flow rate increased up to 21 L/s. The production temperature increased from around 140°C to 156°C and the well-head pressure from 10 to 20 bar. The fluid was still reinjected in GPK-3 and GPK-1 with 50 to 60°C. The wellhead pressure in GPK-3 was around 8 bar at a reinjection flow rate of ~15 L/s (wellhead pressure in GPK-1 was below 1 bar). On the 23rd of April, it was started to reinject around 12 L/s into GPK-4. One day later, on the 24th of April, LSP had to be stopped because of a high torque on the line shaft of the LSP. It was suspected that parts of the hydraulic body of the pump were seriously damaged. The total geothermal volume circulated in 2012 was 25 000 m^3. After this major incident, a new down-hole pump was fully redesigned, built, tested and then redeployed at 292 m in GPK-2 early 2013.

2.3 Microseismicity activity and hydraulic circulation

A detailed analysis of the seismic monitoring of the Soultz site during hydraulic circulation between 2010 and 2012 has been extensively presented in Cuenot et al. (2011a). In 2010, about 400 microseismic events were detected during the 2010 circulation test. The highest activity was observed during the first phase of the test, when reinjection was performed into GPK-3 only (Fig. 8). Once a part of the geothermal fluid was reinjected into GPK-1, making GPK-3 wellhead pressure decreasing, the microseismic activity remained at a low level (between 0 and 5 events per day). Only near the end of the test, the activity seemed to increase a bit, maybe in relation to the continuous rise of GPK-3 injection pressure. A small activity had remained for 15 days after the end of the test. Magnitudes are in the range -0.3 to 2.3. 25 earthquakes reached a magnitude equal or larger than 1. Among them, 7 were above magnitude 1.8 and 4 reached magnitude higher than 2 (Cuenot et al., 2011a).

In term of location, as for previous hydraulic tests done between 2008 and 2009 (Fig. 9, Fig 10), the same zones concentrate the seismicity: in the area on the West/South-West of GPK-3, events are located at depths between 4.9 and 5.3 km (Fig. 9, Fig. 10); in the area between GPK-2 and GPK-3, hypocenters are located a bit deeper and in the northern part of GPK-2 where the larger events (M>2) are located. As already observed in the previous tests, no seismicity is located around GPK-4, which was not used here, and around GPK-1, into which reinjection took place at a low flow-rate (Cuenot et al., 2011a).

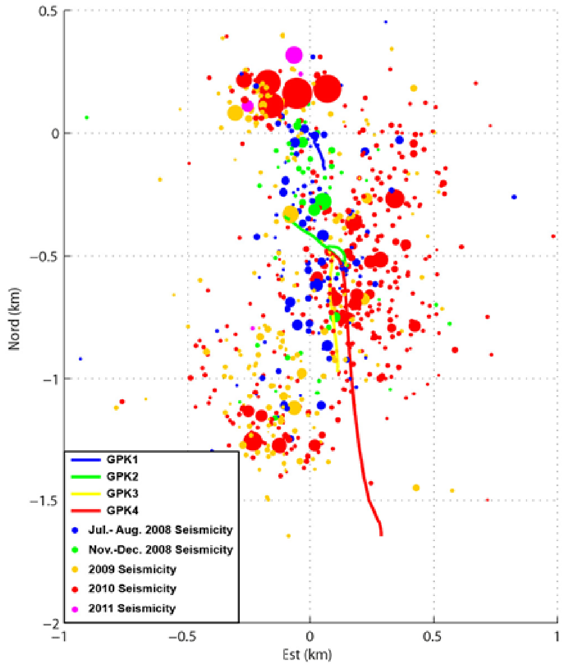

Figure 9: Plane view of location of microseismic activity observed between 2009 and 2010 (red circles) during geothermal circulation. Diameters of circles are proportional to magnitude.

Contrary to what was observed during the 2010 circulation, very few micro-earthquakes occurred in 2011 (Fig. 8): only 4 during the circulation of January-April 2011 and only 1 during the circulation of August-October 2011 (Genter et al., 2012). The reinjection strategy in 2011 was to equally re-inject in both GPK-3 and GPK-1 (Fig. 8). During the early 2011 circulation, only one event occurred during the circulation period itself; the three others took place after the stop of the pump, that is, during the shut in period. The largest earthquake reached a magnitude of 1.7. Another was of magnitude 1.3. Both were not felt by the population. In October 2011, the microseismic event occurred during the circulation time when the flow-rate reinjection was mainly concentrated in GPK-1 (Fig. 8). In 2011, no earthquake reached a magnitude higher than 2 and the microseismic activity was significantly reduced. This trend may be explained by the reinjection strategy: since 2009, the borehole GPK-1 has been more and more used to re-inject a part of the geothermal fluid so that the reinjection has been shared between GPK-1 and GPK-3 (Fig. 8). In 2011, a larger proportion of the fluid has been reinjected into GPK-1, allowing to reinject into GPK-3 without the use of pump. The consequence of this strategy is a lower injection pressure (around 20 bar in 2011), which led to a minimum microseismic activity, both in number and magnitude.

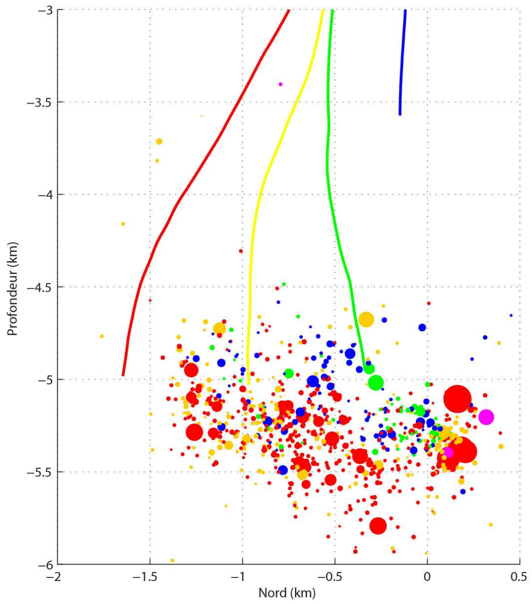

Figure 10: N-S vertical cross-section of the microseismic event locations induced by geothermal circulation (same legend than Fig. 9.

Figure 9 and Figure 10 show the location of the microseismic events, in planar view and North-South vertical cross-section respectively. 3 events from the first tests (including the largest ones) are located in a zone on the North of GPK-2 bottom hole at great depth. This zone was already active during the previous circulation experiments and already hosted the largest events. The event occurred during the second test is located rather deep on the East of GPK-2-GPK-3 inter-well area. The last one, which was the first occurred in 2011, exhibits an unexpected location: its depth is very shallow (3.4 km). Thus we could have expected that this event would be located in the vicinity of GPK-1, because its depth corresponds to the depth of GPK-1; but on Figure 10, it is clearly located on the West of GPK-2-GPK-3 inter-well region, thus, far from GPK-1 bottom hole. In 2012, due to the short term circulation test, no seismicity was observed.

2.4 Fluid composition during exploitation

Geochemical monitoring of the fluid discharged from GPK-2 indicates that with on-going production, the chemical composition of this fluid approaches the composition of the Native Geothermal Brine (NGB) with a salinity of 100 g/L. Continuous fluid geochemical monitoring from the corrosion skid (Fig. 12) has allowed obtaining and confirming, at temperatures close to 60-80°C and pressure of 20 bar, the most representative values of pH (4.7±0.1) and Eh (-215±15 mV) relative to the NGB which could never be determined (Mundhenk et al., 2013). Punctual geothermal fluid samples (geothermal water and associated incondensable gases) were collected on-site for a more detailed geochemical and isotopic characterization (major species, trace elements, stable isotopes) in the BRGM laboratories. The geochemical monitoring of the discharged water shows an evolution of its chemical and isotopic composition toward that of the NGB (Sanjuan et al., 2010; 2011).

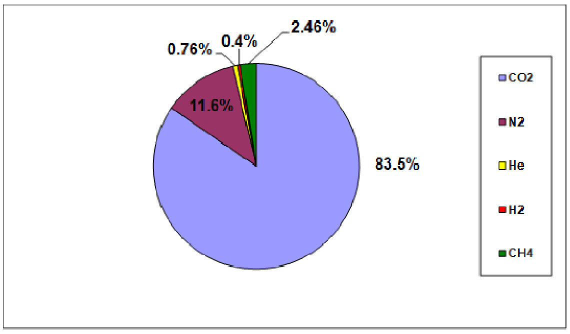

Figure 11: Chemical composition for gas sample collected from the well GPK-2 (Sanjuan et al., 2011).

About 92-96% of NGB were estimated in the water discharged from GPK-2 between May and October 2010 and 96-99% of NGB in February 2011. The Gas-Liquid Ratio (GLR) and the chemical composition of the associated incondensable gases were very different from those previously determined (Sanjuan et al., 2010). The GLR measured in February 2011 using a phase micro-separator indicates a value of about 104% in volume, or 0.18% in mass (Sanjuan et al., 2011), and the chemical composition of the corresponding gas sample in which CO_2 is dominating (Fig. 11) is probably the most representative.

3. SURFACE TECHNICAL ACHIEVEMENTS

Surface and sub-surface technical investigations with a major focus on corrosion, scaling, and down-hole pump technology were conducted.

3.1 On-Site Corrosion Monitoring

On-site corrosion experiments are conducted with a Low Temperature Skid (LTS), located between the heat exchanger and the reinjection well GPK-3 (70°C, 20 bars). The skid is equipped with three separated chambers for the exposure of metal coupons under in-situ conditions. This LTS was designed, installed and tested from 2008. Corrosion resistance, corrosion rate by mass loss and specific corrosion behavior like pitting or uniform corrosion are currently investigated. On-site short term (4 weeks) and long term experiments (several months) are conducted in cooperation with our scientific partners (Mundhenk al., 2013). Several kinds of materials with mild and high alloyed steels are currently tested. Main results of the on-site experiments for iron steels show a corrosion rate of 0.2 mm per year. In order to investigate corrosion in high temperature conditions, a construction of a High Temperature Skid (HTS) has been designed, built and is currently tested (Scheiber et al., 2013). This equipment is located between GPK-2 and the filter at the production side at a maximum temperature of 180°C and a maximum pressure of 40 bar (Fig. 12). Various materials related to the geothermal equipment used on the plant (casing, pump piece, heat exchanger) are currently tested in high temperature conditions. In parallel, different kinds of coatings are also tested in the same conditions (Scheiber et al., 2013).

Figure 12: Corrosion and coating study with the High Temperature Skid installed on the Soultz plant (picture GEIE).

3.2 Scaling Studies

The cooling of highly saline geothermal brine (100 g/L) could generate scaling within the surface installations. During exploitation, scaling has been sampled for a whole geochemical and mineralogical characterization. They correspond to black deposits which are preferably located within the ORC heat exchangers, the geothermal pipes, and the filtering system at reinjection side (Fig. 13).

Figure 13: Black scaling observed within the heat exchanger during exploitation.

They correspond mainly to sulfates such as barito-celestine ((Ba, Sr) SO_4) and sulfides such as galena (PbS) (Sanjuan et al., 2011). As those minerals are able to trap radionuclides (barium can exchange with radium), research work for the application of a chemical inhibitor has been launched. It includes the selection of an appropriate crystalline inhibitor for sulfates which started with laboratory test with some specific chemicals chosen for their potential of scale inhibition in the geothermal fluid (Scheiber et al., 2012).

3.3 Down-Hole Pump Technology: LSP

The first line shaft pump was installed in Soultz on May 2008 and operated from June 2008. This first LSP was built with line shaft bearings lubricated with fresh water. The LSP was made of standard cast iron metallurgy. Since its start-up in June 2008, the LSP assembly has been removed and reinstalled six times due to different operational and technical failures. Before redeploying the pump in the well and in order to protect its hydraulic part from corrosion, several pieces were treated with a special metal treatment with boron. First failure in August 2008 was caused by carbonate scaling due to the injection of fresh water for lubrication, which blocked the bearing lubrication leading to a breakdown of the line shaft. The fresh lubrication water was then replaced by purified water by osmosis. Following failures had several origins such as, blocking shaft after grid fault, stress corrosion in enclosing tubes and centralizers, performance losses due to sand particle erosion and corrosion or severe wear on alternative tested bearing material. Each time that the pump was removed, impellers and bowls of the pump were highly eroded and corroded because of the very aggressive geothermal conditions in Soultz. Cast iron is not a suitable material in such an environment (Fig. 14). Unfortunately, the supplier of the first generation of bowl unit could not offer proper technical solution for the Soultz well conditions (deviated well, corrosive highly saline fluid and abrasive cuttings (granite particles) carry over in the pumped water).

Figure 14: Status of the hydraulic part of the LSP pump after the pull operation of April 2011 (left) and picture of the new hydraulic LSP pump (right).

Then, a new slim-hole bowl unit done in a more appropriate material able to resist erosion, abrasion and corrosion was designed and built (Fig. 14). With this new bowl, it will be easier to manage thermal and mechanical elongation of the shaft. This new bowl was first tested in a shallow well and then installed in the GPK-2 well at 292 m depth early January 2013 (Fig. 14).

4. ENVIRONMENTAL STUDY

Environmental nuisances such as noise, seismic activity, and natural radioactivity have been investigated and coupled with an acceptability study in order to evaluate their impact on the local population (Lagache, 2012). A lot of research has been dedicated to natural radioactive isotopes because the geothermal Soultz fluid is circulating within a fractured granite reservoir. Thus, a specific monitoring of natural radioactivity on the geothermal site has been carried out in order to follow precisely its evolution within the geothermal installation. The first goal of this study is to ensure the protection of workers against potential radiations. Thus, nine measurement campaigns have been carried out since 2009 to observe and characterize the natural radioactivity evolution during hydraulic circulation tests (Cuenot et al., 2011b). As the goal is mainly radioprotection, the measured parameter is the dose rate, expressed in micro-Sievert per hour (µSv/h). Around 350 contact measurements, i.e. 1 cm from the installations were regularly sampled both on GPK-1 and GPK-2 platforms. For all measurement campaigns, the results show a general increase of the dose rates with the circulation volume and the highest values were found mostly on the reinjection line, where the temperature is lower (~70°C). This indicates a correlation between the observed radioactivity and the scaling processes inside the installation: some newly formed minerals are able to trap radionuclides (sulfides, sulfates). For example, for the campaign done in October 2011, the average dose rate contact value measured on GPK-2 platform is about 2 µSv/h (Cuenot et al., 2011b).

5. COMMUNICATION AND DISSEMINATION

Finally, large effort was dedicated to public dissemination. Between 2010 and 2012, about 6000 people visited the geothermal Soultz site including politicians, industry, universities, research organization and schools. Many scientists attended national and international conferences or published their results in peer-reviewed journals that represent a total of about 200 references. A special geothermal conference dealing with deep geothermal energy within the Upper Rhine Graben and grouping 150 participants was done at Soultz in 2011. A specific website written in three different languages (German, English, and French) is now on-line.

In order to fill the gap between academy and industry in France, a jointed research project in deep geothermal energy called LabEx (Laboratoire d'Excellence) has been granted by public funding. This Labex G-EAU-THERMIE is leaded by Strasbourg University (EOST) and strongly supported by Electricité de Strasbourg (ES) and GEIE EMC. This research project aims to strengthen relationships between scientists and engineers in deep geothermal energy within the Upper Rhine Valley. The main research topic is the understanding of hydrothermal convective cell in Northern Alsace.

In parallel, an opinion survey about acceptability of EGS has been carried out (Lagache, 2012). More than 200 individual interviews were conducted in summer 2012 with a representative sampling of the local population of the neighbouring villages of Kutzenhausen and Soultz-sous-Forêts. A questionnaire of about 80 questions was presented in order to test the sensibility of the local population about this rather new technology. Moreover, the mayors of Kutzenhausen and Soultz were involved and informed about the consultation launched in their villages.

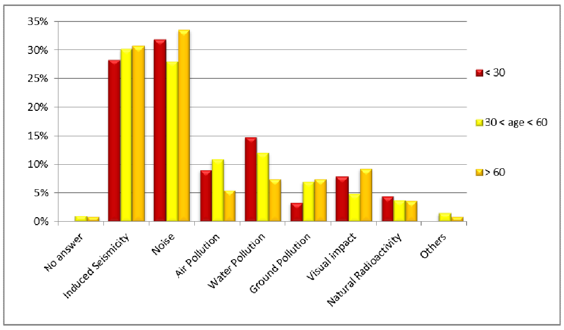

Figure 15: Main potential nuisances of deep geothermal energy versus age known from local population (Lagache, 2012).

More than 200 adults fulfilled the questionnaire and detailed answers were collected and analysed. The biggest causes of nuisance are the noise generated by the technical equipment of the power plant and induced seismicity. Thus, geothermal energy is felt like a rather favourable technology by the local population, even if there are always some reluctant people. The risks related to the geothermal exploitation are rather accepted as a whole. The results of this acceptability study thus show that the feeling of lack of information of the population is unquestionable although there is a new website online since 2011 and an average of 2000 visitors per year. Thus, the knowledge of deep geothermal energy and its challenges are limited. The biggest cause of trouble is the noise generated by the plant equipment (Fig. 15). Other risks, such as induced seismicity, pollution or natural radioactivity do not seem much concerned residents. The older people pay more attention to induced seismicity than the younger (Fig. 15). It is due to the fact that the largest felt earthquake occurred in June 2003 that means 10 years ahead before the opinion survey.

6. CONCLUSIONS

Over the period 2010-2012, many scientific and technical results have been obtained during the geothermal exploitation of the Soultz plant. A lot of achievements have been done for reducing the micro-seismicity activity induced by the exploitation, for understanding scaling process and the related natural radioactivity occurrence, and for measuring corrosion rate in severe geothermal conditions. This three year program clearly demonstrated to have more reliable down-hole pump technology. Because Soultz is one of the first EGS geothermal power plant in Western

Europe, many challenges have been outlined, new scientific and technical expertise is raising and will benefit to the French-German consortium for transferring the results to some new geothermal projects through the Upper Rhine Valley.

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