Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Integrated Fluid-chemical Monitoring Systems for Geothermal Applications

Harald Milsch, Ronny Giese, Mathias Poser, Simona Regenspurg and Stefan Kranz

GFZ German Research Centre for Geosciences, Potsdam, Germany

milsch@gfz-potsdam.de

Keywords: Geothermal Fluid, Fluid Chemistry, Monitoring, Scaling, Corrosion

ABSTRACT

Two versatile fluid-chemical monitoring units have been developed for both low and high enthalpy geothermal systems. They enable online and in-situ measurements of a variety of physico-chemical parameters at different locations of a geothermal fluid loop above ground. The scientific and technical purposes of the systems are (a) to monitor a compositional variability of the produced fluid and (b) to understand chemical processes potentially occurring within a geothermal plant. The latter may result from reactions between fluid and surrounding materials and/or mineral precipitation, e.g. in the course of a temperature decrease or oxygen contamination. This information is of paramount importance as so induced reactions might lead to failure of plant components through corrosion and scaling and/or damage the reservoir's permeability upon fluid reinjection and thus decrease injectivity.

Within the fluid loop above ground a number of locations can be defined where fluid-chemical monitoring is of interest, e.g. before and after the degasser, the filters and the heat exchanger. The monitoring units can be set up close to these installations and permit selective fluid bypass and monitoring through solenoid valves. The fluid passes through tubings from one device or sensor to another until it is pumped back into the main fluid line right before the injection pump. Sensors are provided for pressure, temperature, volumetric flow-rate, density, sonic velocity, turbidity, pH-value, redox potential, oxygen content and corrosion monitoring. Additionally, fluid samplers have been installed to collect fluid and analyze the solution composition. All analytical devices are mounted on racks allowing easy transfer of the apparatuses to other geothermal sites. The maximum operating pressure and temperature of the units are up to 20 bar and 200°C, respectively. Both apparatuses can also be connected to allow stand-alone detailed process investigations on in situ or synthetic fluids at defined pT-conditions.

1. INTRODUCTION

The sustainable development and use of geothermal sites, particularly those within sedimentary basins, faces severe challenges due to often highly saline fluids additionally containing an abundance of other dissolved ionic species (e.g. Huenges et al. 2010). An example of such a system is the geothermal research platform Groß Schönebeck, at approximately 60 km northeast of Berlin, Germany. At this site within the Northeast German Basin (NGB) a geothermal doublet has been installed accessing a Lower Permian sandstone reservoir at approximately 4300 m depth (Moeck et al. 2009). Within the reservoir section in both wellbores stimulation treatments have been performed to enhance productivity (Enhanced Geothermal System, EGS) (Zimmermann et al. 2010). Reservoir and wellbores were complemented with above-ground components (e.g. a gas separator, coarse and fine filters, and an injection pump) as well as an Organic-Rankine-Cycle (ORC) binary power plant (Frick et al. 2011). At reservoir depth the temperature and pressure of the geothermal fluid are approximately 150°C and 45 MPa, respectively. The fluid itself is a highly saline basinal fluid of Na-Ca-Cl type containing 265 g/L of total dissolved solids (Regenspurg et al. 2010).

For both sustainable operation of the plant and related scientific research a comprehensive physico-chemical and compositional fluid variability has to be monitored under above-ground in situ conditions. A commercial system fulfilling these tasks, to date, is not available. In the framework of the geothermal research platform Groß Schönebeck a mobile fluid-chemical monitoring unit (FluMo-1) has been developed for this purpose (Milsch et al., 2013). In the framework of a cooperative project with Indonesia funded by the German Federal Ministry for Education and Research a second system (FluMo-2) is currently being set up having an even higher temperature resistance ($T < 200°C$) addressing high-enthalpy geothermal systems and permitting comprehensive investigations on scaling processes, corrosion monitoring, and sensor evaluation.

2. FLUMO-1

Before starting the setup a number of requirements were defined regarding the technical capabilities the system should have. (1) Measurements should be possible at various locations of the plant above ground. (2) Measurements should be possible simultaneously for a number of defined physico-chemical parameters. (3) Data should be acquired and saved automatically. (4) Fluid sampling should be possible under in situ conditions in parallel to the measurements. (5) Despite economic compromises to be made the fluid wetting parts of the system should be selected as corrosion resistant as possible. (6) The device should be mobile to allow transport and installation at other geothermal sites.

The ports at which fluid is tapped were defined along the above-ground main fluid line in connection with the various installations outside and within a hall. **Fig. 1** illustrates these locations labeled A through G and R. Port A, outside the hall and close to the production well, serves only for fluid sampling. Ports B through G refer to the locations inside the hall before the degasser, after the degasser, before the coarse filters, before the power plant, after the power plant, and after the fine filters, respectively. At port R the fluid is fed back into the main line.

At the main line the ports consist of horizontal DN 50 / PN 40 T-flanges with a 1/2” tube connector complemented each with one electrical ball valve and one manual plug valve for additional safety. From there a combination of flexible PFE-lined high pressure hoses and 1/2" 316L stainless steel tubing, both isolated, are guided to the permanent location of the device within the hall. The six fluid lines from ports B through G are then connected to the device individually. Identically, at the unit's outlet, the fluid is guided back to port R at the main fluid line. Additionnally, electric cables installed along the tubing allow centralized and remote control of the ball valves from the monitoring system. **Fig. 2** illustrates these connections as well as the individual components of the unit's flow-through line.

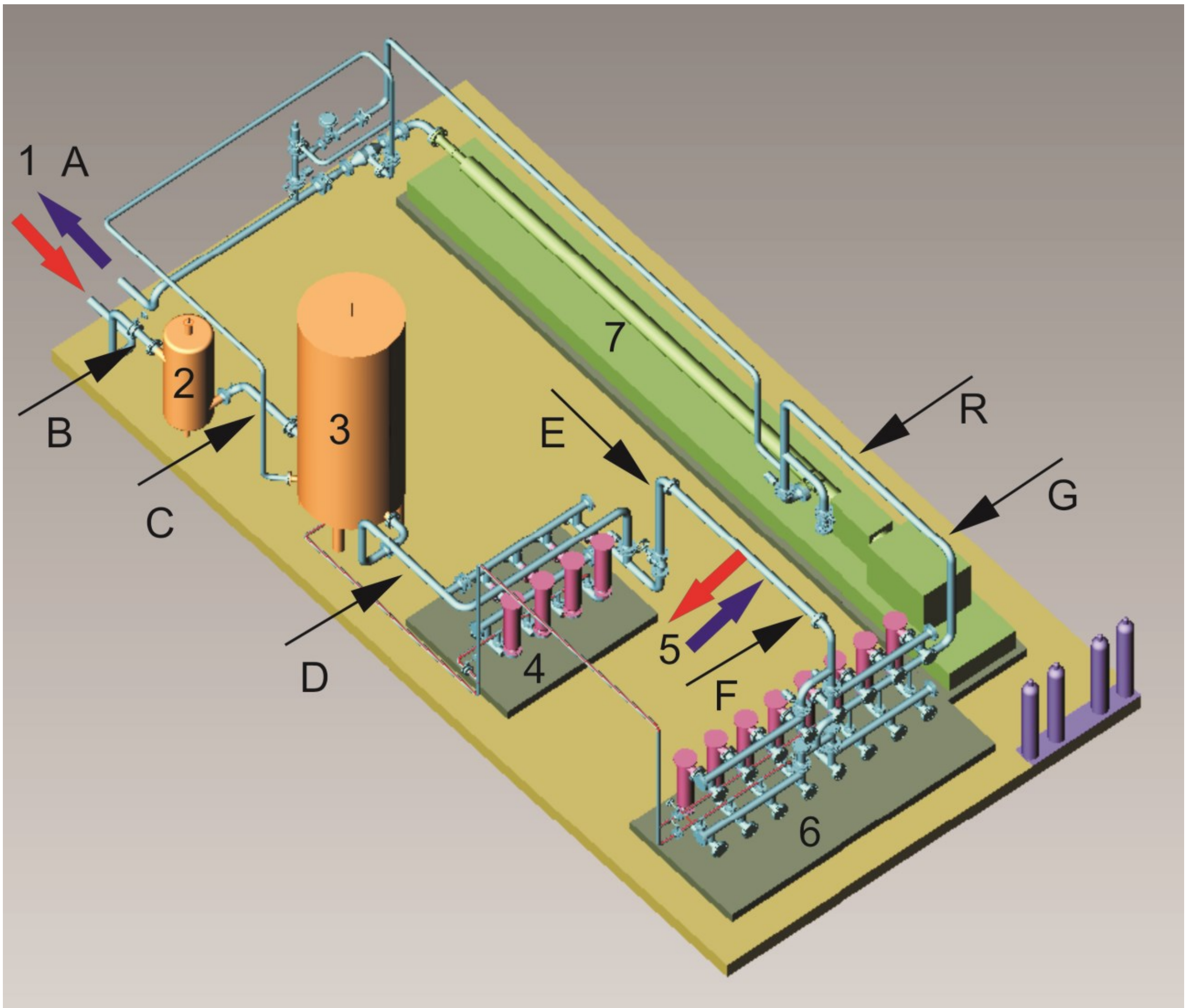

Figure 1: Schematic of the main fluid line and surface installations at the geothermal research platform Groß Schönebeck, Germany. Bold arrows indicate the in and outgoing fluid directions from/to the wells (1) and the power plant (5), respectively. The other numbers denote the degasser (2), an expansion tank (3), the coarse filters (4), the fine filters (6), and the injection pump (7). Arrows and letters inside the hall (B-G, R) denote the locations at which fluid can be selected for online and in situ monitoring with FluMo-1.

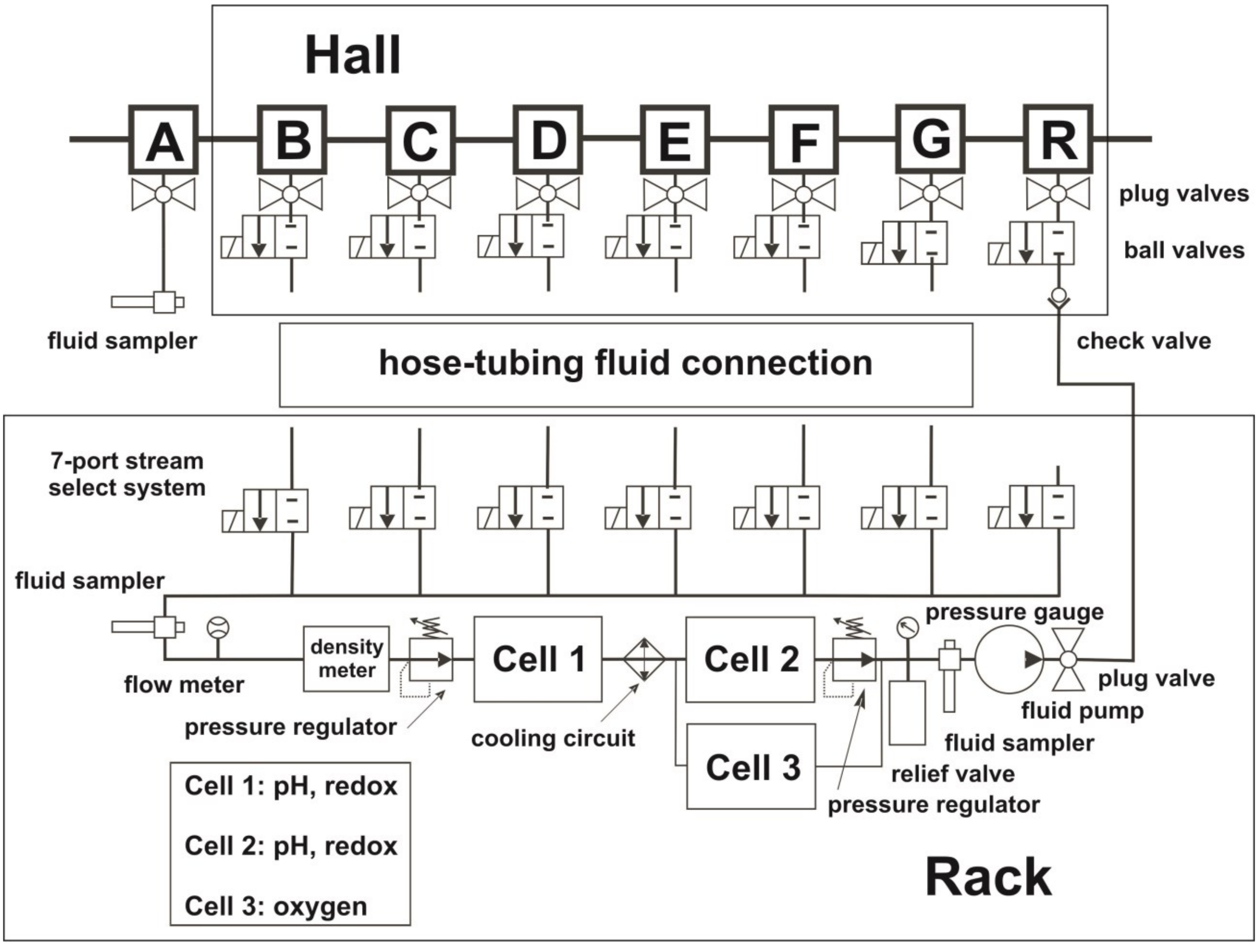

Figure 2: Schematic of both the fluid ports on the main line and the flow-through line within FluMo-1 including the different analytical components.

From the stream-select system the fluid first passes a BIAR sampling system to collect fluid at in situ pressure and temperature. Then, an Endress+Hauser PFA-lined flow meter is installed into the line. After the subsequent Anton Paar density meter with a Hastelloy C-276 vibrating tube and an integrated Pt100 thermo-sensor the fluid pressure is reduced from the one in the main line (≈ 15 bar) to 10 bar by a first pressure regulator with up- and downstream analog manometers. Afterwards, the fluid enters the first flow-through cell to measure pH-value and redox potential. Commercially, no pH-probe was found to be available covering the temperature range of interest between approximately 150°C and 70°C, which are the upper and lower temperature margins for production and injection, respectively. Therefore, at the high temperature side in flow-through cell 1, a ZrO2-based pH-probe is installed complemented with a platinum redox-probe working against the same external pressure balanced Ag/AgCl reference-probe, all from Corr Instruments with Hastelloy C-276 insertion tube. In addition, a Pt100 thermo-sensor is inserted into the flow-through cell from below. This solid state pH-probe only operates properly at temperatures above approximately 90°C. Consequently, for lower temperatures, another type of pH-sensor had to be selected. To cope with individual specifications of the probes in flow-through cells 2 and 3 the fluid has to be cooled by means of a circuit. In flow-through cell 2 Endress+Hauser pH and redox glass-based electrodes, both with Ag/AgCl internal reference and the pH-sensor additionally with an NTC-thermistor, are installed. Set in parallel, a third flow-through cell accommodates an Endress+Hauser oxygen-probe with a titanium insertion tube and an integrated Pt100 thermo-sensor. After the junction of flow-through cells 2 and 3 a second BIAR sampling system is installed to collect fluid from the low temperature side. Finally, the fluid is pumped back into the main line by means of a frequency controlled Verder gear pump with 316L stainless steel pump housing and PEEK gear wheels.

All components are mounted on a movable rack and are arranged at three different levels as shown in **Fig. 3**. The upper level holds the control and data acquisition system. In the center, all sensors and analyzers as well as two fluid samplers are installed. Finally, at the bottom level, the pump driving the fluid and a cooling circuit is located. Fig. 3 shows FluMo-1 as implemented at the geothermal research platform Groß Schönebeck.

Figure 3: FluMo-1 as installed and operational at the geothermal research platform Groß Schönebeck, Germany. Control and data acquisition system (top). Sensors, analyzers, and fluid samplers (centre). Fluid pump and cooling circuit (bottom).

3. FLUMO-2

In terms of analytical and conceptual capabilities FluMo-2 goes beyond FluMo-1 also addressing high-enthalpy applications. In addition to fluid monitoring within geothermal surface installations this system permits comprehensive process investigations on scaling and corrosion as well as integrated sensor evaluations at pressures up to 20 bar and temperatures up to 200°C. Central to the device are two reactor vessels made of duplex steel 1.4462. These can hold up to 50 L of fluid each and sensors can be introduced through the top or bottom lid. The reactors can be operated individually (fluid monitoring), connected (stand-alone device) or joint with FluMo-1 making the device a truly versatile research tool (**Fig. 4**). Both reactors can be stirred and can be actively heated with mantle heaters up to 200°C. **Fig. 5** shows a list of the unit's individual components and analytical systems that partly are designated as add-ons for specific investigations. As in FluMo-1, one fluid sampler is provided for each reactor. Permanent installations comprise one high temperature density meter as well as one combined density-sonic velocity meter and two sets of high temperature pH, redox, and conductivity probes. Add-ons are, for each reactor, one sonic velocity and one corrosion monitoring probe. Also, fibre-optic sensor evaluation can be conducted with a complete spectrometric system. Finally, two high precision syringe pumps permit fluid injection to provoke precipitation of solid particles in connection with defined investigations on scaling processes. **Figs. 6 and 7** present the technical assembly design of the unit and its present state as of Mai 2014.

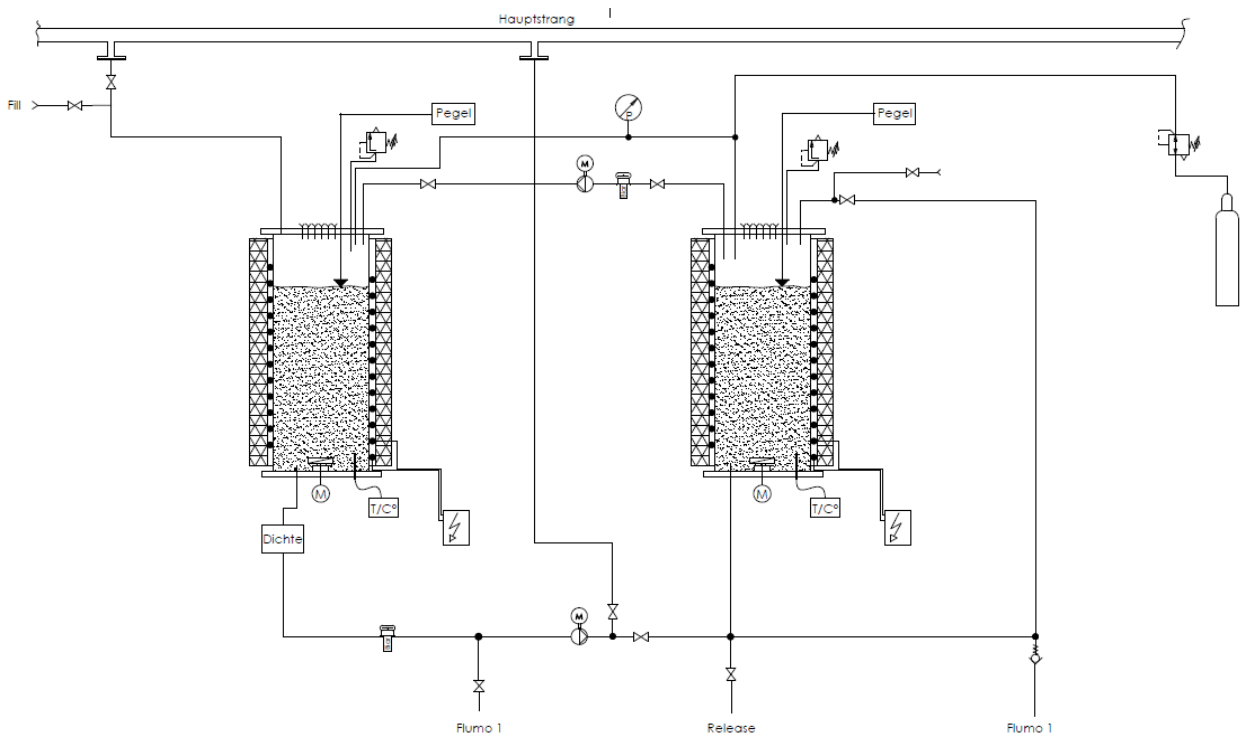

Figure 4: Conceptual lay-out of FluMo-2 with tubings and valves allowing for different operation options of the unit.

- 2 reactor vessels (Kempe) with 50 L each in duplex steel 1.4462
- 2 mantle heaters (Horst) for T_{max} = 200°C
- 2 gear pumps (Verder)
- 2 magnetically-coupled stirrers (DST) in titanium
- 2 fluid sampling systems (BIAR)
- 2 sets of pH, redox, and conductivity probes (CI) in Hastelloy C276
- 1 density and 1 density-sonic velocity meter (Paar) in Hastelloy C276
- 2 sonic velocity probes (SensoTech) in titanium
- 2 corrosion monitoring probes (Pepperl+Fuchs) in Hastelloy C276
- 1 VIS/NIR turbidity system (Endress+Hauser)
- 1 fibre-optic testing system (Yokogawa, Opto-Link)
- 2 Isco fluid injection pumps (Teledyne-Isco) in Hastelloy C276

Figure 5: Components and analytical devices of FluMo-2.

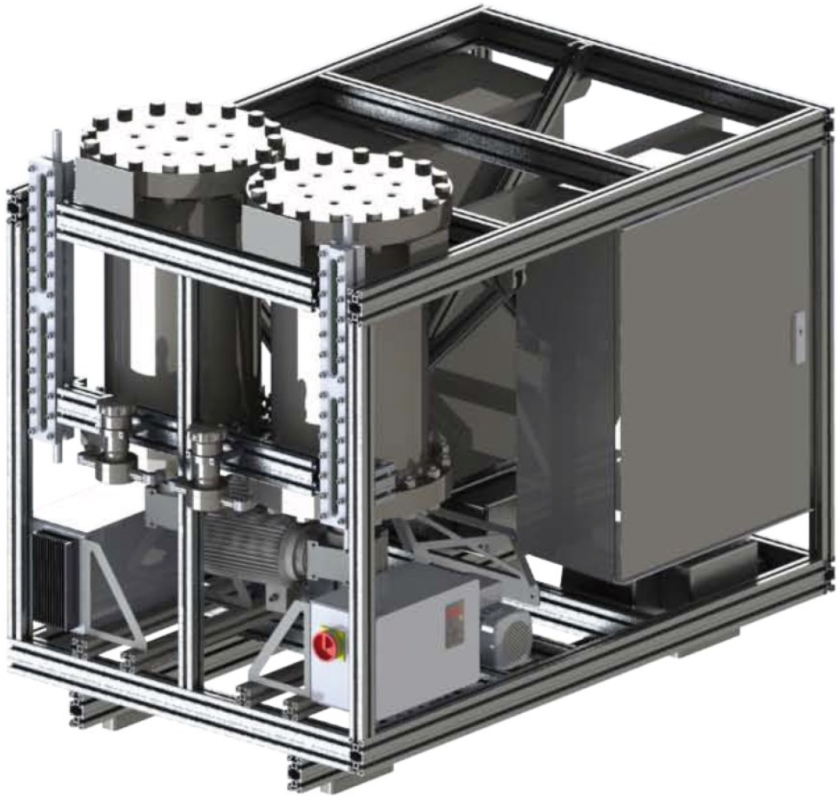

Figure 6: Technical design of FluMo-2 as currently being set up.

Figure 7: Present state of FluMo-2 as of Mai 2014.

4. CONCLUSIONS

In the framework of two different geothermal projects addressing deep and both high and low-enthalpy systems two versatile fluid-monitoring devices (FluMo-1 and 2) have been and are currently being set up. FluMo-1 has been in operation since (Feldbusch et al., 2013) and proved very functional and reliable. Improvements need only to be considered regarding the low-temperature pH-probe and finding the optimum sensor will continue to be an ongoing issue and very likely a matter of future research and development. Here and in addition to improving classical techniques, solutions based on fiber-optics and/or spectrometry might be an option. FluMo-2, designed for even more extreme pT-conditions and comprehensive process understanding with respect to scaling and corrosion in geothermal systems will be in test operation by fall 2014.

ACKNOWLEDGMENTS

The authors thank Andreas Kratz and Tanja Ballerstedt for substantial technical support. Discussions with Wulf Brandt and Erik Spangenberg led to technical improvements and are greatly acknowledged. FluMo-1 was financially supported by the GFZ-Potsdam and a grant in the framework of the German Economic Stimulus Plan II (2009). FluMo-2 was made possible by a grant from the German Federal Ministry for Education and Research (03G0753A).

REFERENCES

Feldbusch, E., Regenspurg, S., Banks, J., and Milsch, H.: Alteration of the fluid composition during the initial operation of a geothermal plant - results from in-situ measurements in Groß Schönebeck, Environ Earth Sci., doi: 10.1007/s12665-013-2409-9 (2013).

Frick, S., Regenspurg, S., Kranz, S., Milsch, H., Saadat, A., Francke, H., Brandt, W., and Huenges, E.: Geochemical and process engineering challenges for geothermal power generation, Chem. Ing. Tech., **83** (12), 2093-2104, doi: 10.1002/cite.201100131 (2011).

Huenges, E. (Ed.): Geothermal Energy Systems: Exploration, Development and Utilization, Wiley-VCH, Weinheim, p. 463 (2010).

Milsch, H., Giese, R., Poser, M., Kranz, S., Feldbusch, E., and Regenspurg, S.: Technical paper: FluMo - a mobile fluid–chemical monitoring unit for geothermal plants, Environ Earth Sci., doi: 10.1007/s12665-013-2408-x (2013).

Moeck, I., Schandelmeier, H., and Holl, H.-G.: The stress regime in a Rotliegend reservoir of the Northeast German Basin, Int. J. Earth. Sci., **98** (7), 1643-1657, doi: 10.1007/s00531-008-0316-1 (2009).

Regenspurg, S., Wiersberg, T., Brandt, W., Huenges, E., Saadat, A., Schmidt, K., and Zimmermann, G.: Geochemical properties of saline geothermal fluids from the in-situ geothermal laboratory Groß Schönebeck (Germany), Chemie der Erde - Geochemistry, **70** (Suppl. 3), 3-12, doi: 10.1016/j.chemer.2010.05.002 (2010).

Zimmermann, G., Moeck, I., and Blöcher, G.: Cyclic waterfrac stimulation to develop an enhanced geothermal system (EGS): Conceptual design and experimental results, Geothermics **39** (1), 59-69, doi: 10.1016/j.geothermics.2009.10.003 (2010).