

PERFORM

Deliverable D3.1

Report on stability and effectivity of particle filters in lab and field

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PERFORM is one of nine projects under the GEOthermica – ERA NET. The overarching target of PERFORM is to improve geothermal system performance, lower operational expenses and extend the life-time of infrastructure by the concept of combining data collection, predictive modelling, innovative technology development and in-situ validation. The improvement of geothermal plant performance from the proposed work is expected to result in an increase of the energy output by 10 to 50%. In order to reach this goal PERFORM will establish a single and shared knowledge database, build predictive models and demonstrate new and improved, cost-effective technologies which will reduce or even eliminate flow-obstructive scaling, clogging, and resistance to fluid (re-)injection at eight geothermal plants across Europe.



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About PERFORM

Despite years of experience with geothermal systems, the geothermal sector still faces a significant number of underperforming doublets, posing a strong limitation on a region's growth of geothermal energy utilization. A key operational challenge in geothermal energy production is restricted flow. Major obstacles for geothermal flow are scaling (mineral deposition), clogging (solid micro-particle deposition), corrosion and inefficient injection strategies. These issues result in high and mostly unforeseen costs for workovers, and additionally reduce production. In order to overcome these challenges, the consolidation and sharing of knowledge, including validated strategies for prevention and mitigation needs to be in place.

Therefore a consortium consisting of De Nationale Geologische Onderzoekingen voor Denemark og Grønland (GEUS) and FORCE Technology from Denmark, Helmholtz Centre Potsdam German Research Centre for Geosciences (GFZ) and Hydroisotop GmbH from Germany and Ammerlaan Geothermie B.V., Greenwell Westland B.V., Wageningen Food & Biobased Research and ECN part of TNO from the Netherlands proposed a GEOTHERMICA project PERFORM, which has been granted. The overarching target of PERFORM is to improve geothermal system performance, lower operational expenses and extend the life-time of infrastructure by the concept of combining data collection, predictive modelling, innovative technology development and in-situ validation. The improvement of geothermal plant performance from the proposed work is expected to result in an increase of the energy output by 10 to 50%. In order to reach this goal PERFORM will establish a single and shared knowledge database, build predictive models and demonstrate new and improved, cost-effective technologies which will reduce or even eliminate flow-obstructive scaling, clogging, and resistance to fluid (re-)injection at eight geothermal plants across Europe.

Based on experiences from operating geothermal sites within the EU, PERFORM will establish a single knowledge database containing information on operational, chemical and physical aspects of geothermal energy production. The database enables sharing experiences from operating geothermal doublets located in various countries and comparing the performance of the different geothermal reservoirs.

PERFORM builds predictive models that allow for pinpointing the most likely sources and causes of failure, as well as the best options for injectivity improvement. The integrated models will provide forecasting for scaling, productivity, and injectivity on short- and long- time scales, supporting early warning and planning of mitigation measures. Coupled thermo-hydro-mechanical-chemical simulators will allow for evaluation of injection temperature that apart for increasing flow will also increase the energy output.

Data and knowledge gathering and technology demonstration is planned for eight geothermal plants across Europe. Demonstration of new and improved, cost-effective technologies will allow for the reduction or even elimination of flow-obstructive scaling, clogging, and resistance to fluid (re-)injection. The technologies include low-cost cation extraction filters, self-cleaning particle removal appliances, H₂S removal technology and soft-stimulating injection procedures (thermal and CO₂-injection). The goal is to provide a set of new and improved, low-cost and environmentally friendly technology alternatives.

PERFORM integrates the knowledge database, predictive modelling and advanced technologies into a design and operation toolbox, which will be tied to economical calculations. The toolbox will enable stakeholders and specifically geothermal operators to plan future operations, mitigate existing obstructions, and optimise production/injection procedures, thus ensuring maximum energy production when needed.

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1 Introduction

Within the PERFORM project different technical approaches were developed and evaluated to avoid an enrichment of particles and precipitations, which decrease flow and injectivity of geothermal plants.

The main objective of WP 3.1 was to test and evaluate a newly developed self-cleaning particle filter for their application and stability at geothermal conditions. This self-cleaning filter system was developed earlier in the frame of a nationally funded project (HydroGeoFilt). Within the PERFORM project the HydroGeoFilt filter system was tested for application and efficiency in field tests at several geothermal sites. Altogether three tests were conducted: One at the thermal spa Oberlaa in Vienna Austria (in combination with WP 3.3) and two at the geothermal site of Insheim, Germany (one of which in combination with WP1, testing of adsorption material).

The particle filter development was closely related to WP 3.1 and 3.3. The main objective of workpackage 3.2 is on the development (lab and field tests) of methods of the adsorptive removal of dissolved metals, which cause a main risk for the formation of scaling and corrosion in geothermal plants. Due to an operational effected oversaturation, these metals tend to precipitate as insoluble compounds. Therefore, different adsorption materials, such as granular ferric hydroxide (GFH), zeolites and chitosan, which are already used for wastewater treatment, were first tested in the lab for the removal of metal cations. Within workpackage 3.2 the most promising adsorption materials were tested at the geothermal site in Insheim in a bypass experiment while simultaneously applying the HydroGeoFilt filtration system to remove the particles (including the adsorption materials). Additionally, in WP 3.3, fine-grained GFH as adsorption material and FeCl_3 as flocculation media were tested onsite to remove H_2S as a main corrosion factor from thermal water. For the onsite experiments, the different adsorption and flocculation materials were first added to the thermal water in a reaction container and afterwards filtered through the filter system HydroGeoFilt.

2 Site descriptions

2.1 Geothermal site in Insheim, Germany

The geothermal site Insheim located in southwest Germany in the Upper Rhine Valley is operated by Pfalzwerke geofuture GmbH since 2012. A hydrothermal reservoir is used for power generation using a binary ORC plant while the residual heat is used for local heating. At Insheim the thermal water pumped from a depth of 3.600 m has a temperature of about 160 °C.

The operational challenges at the geothermal plant in Insheim are the formation of sulphate and lead precipitations after the heat exchanger which can cause corrosion. In order to avoid scaling and corrosion, the operators use scaling and corrosion inhibitors.

In March 2019 personal from Hydroisotop (HI) and GFZ visited the geothermal plant in Insheim and took water samples from the production and injection well. These water samples were analysed for their dissolved constituents, radionuclides, and stable isotopes by Hydroisotop. According to the analytical results, the thermal water of Insheim is a highly mineralized Na-Ca-Cl type water (Table 1). Table 2 and 3 show the concentrations of trace and heavy metal elements and the activity concentrations of radionuclides. The most interesting parameters concerning the removal of metal cations using adsorption materials were **barium, lead, copper and iron**. Adsorption of **arsenic** was additionally investigated.

The dissolved gas contents, with a total of 0.7 L_{gas}/L_{H₂O} are dominated by carbon dioxide, nitrogen and methane (Table 4). The concentrations of organic parameters are summarized in table 5. The dissolved organic carbon (DOC) content is higher in the thermal water sample after heat exchanger due to the addition of scaling and corrosion inhibitors.

The stable isotopes $\delta^{18}\text{O}$, $\delta^2\text{H}$, $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ of water and dissolved constituents (dissolved inorganic carbon (DIC), sulphate, sulphide, carbon dioxide and methane) show typical values for thermal waters of the Upper Rhine Valley (Table 6).

The aim of the onsite experiments at Insheim was the test of alternative methods to reduce the heavy metal content (13-46 mg/L) from the thermal water. The used adsorption materials fine-grained iron hydroxide, zeolite and chitosan were afterwards removed from the thermal water by the HydroGeoFilt filter system.

Table 1 Organoleptic and physico-chemical parameters, main and trace cations and anions

Lab.-no.		324459	324460
		Production well	Injection well
Date of sampling		13.03.2019	13.03.2019
Temperature at head of well	°C	163	65
Pressure at head of well	bar	19,3	17
Degassing pressure	bar	15,5	15
Colour		colourless	colourless
Smell sensoric		organic	organic
Temperature at sampling	°C	18,1	19
Spec. electr. conductivity (25 °C) on-site	µS/cm	140400	140500
Spec. electr. conductivity (25 °C) Lab.	µS/cm	138600	138600
pH value at sampling		4,9	4,9
pH value Lab.		4,9	5,2
Dissolved oxygen content	mg/l	<0,1	< 0,1
Redox potential ORP (calculated)	mV	93	125
Base capacity (pH 8,2)	mmol/l	25,5	36,6
Alkalinity (pH 4,3) on-site	mmol/l	2,9	2,7
Alkalinity (pH 4,3) Lab.	mmol/l	2,46	2,46
Sodium (Na ⁺)	mg/l	29000	30000
Potassium (K ⁺)	mg/l	4000	4300
Calcium (Ca ²⁺)	mg/l	7100	7500
Magnesium (Mg ²⁺)	mg/l	70	72
Ammonium (NH ₄ ⁺)	mg/l	39,2	39,9
Barium (Ba ²⁺)	mg/l	26	26
Strontium (Sr ²⁺)	mg/l	130	160
Lithium (Li ⁺)	mg/l	167	180
Hydrogen carbonate (HCO ₃ ⁻)	mg/l	150	150
Chloride (Cl ⁻)	mg/l	61000	63000
Sulphate (SO ₄ ²⁻)	mg/l	140	150
Nitrate (NO ₃ ⁻)	mg/l	1,6	1,2
Bromide (Br ⁻)	mg/l	181	205
Fluoride (F ⁻)	mg/l	< 1	< 1
Iodide (I ⁻)	mg/l	< 1	< 1
Deviation cation to anion sum	%	0,51	0,72

Table 2 Other trace element concentrations

Lab.-no.		324459	324460
		Production well	Injection well
Date of sampling		13.03.2019	13.03.2019
Total phosphate	mg/l	-	0,96
Ortho-phosphate (PO_4^{3-})	mg/l	-	0,96
Antimony	mg/l	0,33	0,23
Molybdenum	mg/l	-	< 0,001
Silicon	mg/l	73,4	72,4
Aluminium	mg/l	< 0,005	< 0,005
Iron total	mg/l	26,3	28,4
Manganese total	mg/l	30,7	30,6
Arsenic	mg/l	16	18
Lead	mg/l	1,6	1,7
Copper	mg/l	0,024	0,13
Nickel	mg/l	< 0,001	< 0,001
Uranium	mg/l	< 0,0001	< 0,0001
Zinc	mg/l	8,8	9,5
Sulphide total (H_2S , HS^- , S^{2-})	mg/l	< 0,1	< 0,1

Table 3 Dissolved radionuclide activity concentrations

Lab.-no.		324459	324460
		Production well	Injection well
Date of sampling		13.03.2019	13.03.2019
Radium-226 (*226Ra)	Bq/kg	15,7 ± 0,8	35,4 ± 1,8
Radium-228 (*228Ra)	Bq/kg	10,9 ± 0,7	25,5 ± 1,3
Radon-222 (*222Rn)	Bq/kg	20,9 ± 2,3	23,2 ± 7,1
Lead-210 (*210Pb)	Bq/kg	21,0 ± 6,0	21,0 ± 6,0
Uranium-234 (*234U)	Bq/kg	< 0,01	< 0,01
Uranium-238 (*238U)	Bq/kg	< 0,01	< 0,01
Polonium-210 (*210Po)	Bq/kg	< 4,5	< 4,5

Table 4 Dissolved gas composition

Lab.-no.		324459	324460
		Production well	Injection well
Date of sampling		13.03.2019	13.03.2019
Hydrogen	Nml/kg	< 0,3749	< 0,3469
Oxygen	Nml/kg	< 0,01	< 0,01
Nitrogen	Nml/kg	67,7	44,9
Carbon dioxide	Nml/kg	660	631
Methane	Nml/kg	16,87	13,18
Ethane	Nml/kg	0,1994	0,1499
Propane	Nml/kg	0,0165	0,0104
Butane	Nml/kg	0,0082	0,0035
Pentane	Nml/kg	0,0082	0,0014
Ethene	Nml/kg	-	-
Propene	Nml/kg	-	-
Helium	Nml/kg	1,12	0,972
Argon	Nml/kg	0,35	0,3
Sum of gases	Nml/kg	746	691

Table 5 Organic parameters

Lab.-no.		324459	324460
		Production well	Injection well
Date of sampling		13.03.2019	13.03.2019
DOC	mg/l	1,5	5,1
Hydrocarbons	mg/l	< 0,05	-
Naphthalene	µg/l	3,4	-
1-Methylnaphthalene	µg/l	1,6	-
2-Methylnaphthalene	µg/l	1,6	-
Acenaphthylene	µg/l	< 0,1	-
Acenaphthene	µg/l	< 0,1	-
Fluorene	µg/l	< 0,1	-
Phenanthrene	µg/l	1,3	-
Anthracene	µg/l	< 0,1	-
Fluoranthene	µg/l	< 0,1	-
Pyrene	µg/l	< 0,1	-
Benzo(a)anthracene	µg/l	< 0,1	-
Chrysene	µg/l	< 0,1	-
Benzo(b)fluoranthene	µg/l	< 0,1	-
Benzo(k)fluoranthene	µg/l	< 0,1	-
Benzo(a)pyrene	µg/l	< 0,1	-
Dibenz(ah)anthracene	µg/l	< 0,1	-
Benzo(ghi)perylene	µg/l	< 0,1	-
Indeno(1,2,3 cd)pyrene	µg/l	< 0,1	-
Sum of PAH	µg/l	7,9	-

Table 6 Stable isotopes of water and dissolved constituents

Lab.-no.		324459	324460
		Production well	Injection well
Date of sampling		13.03.2019	13.03.2019
Oxygen-18 ($\delta^{18}\text{O}$)	‰	-1,49	-
Deuterium ($\delta^2\text{H}$)	‰	-44	-
Deuterium-excess	‰	-32,08	-
Carbon-13 ($\delta^{13}\text{C-DIC}$)	‰	-3,6	-
Sulphur-34 ($\delta^{34}\text{S-SO}_4$)	‰	14,4	-
Sulphur-34 ($\delta^{34}\text{S-H}_2\text{S}$)	‰	12,9	-
Oxygen-18 ($\delta^{18}\text{O-SO}_4$)	‰	7,2	-
Carbon-13 ($\delta^{13}\text{C-CO}_2$)	‰	-4,6	-4,5
Carbon-13 ($\delta^{13}\text{C-CH}_4$)	‰	-34,1	-34,8
Deuterium ($\delta^2\text{H-CH}_4$)	‰	-148	-148

2.2 Thermal spa Oberlaa in Vienna, Austria

The thermal bath Oberlaa is located in the South of Vienna in Austria. Thermal water used for heating the recreation area is produced from two wells (TH1 and TH2) which are drilled into a fault system within the Vienna Basin. The geological setting and hydrochemical composition of the thermal water are summarized in the PERFORM deliverable WP3 (M18) ("Report on evaluation of the H₂S removal technique") prepared by GFZ and HI.

Nowadays stripping and the use of chlorine are the common methods for thermal water treatment containing high sulphide contents. The aim of the onsite experiments at Oberlaa was the test of an alternative, effective, sustainable and environmentally friendly method to reduce the high sulphide content (13-46 mg/L) from the thermal water. The used iron based micro adsorption material, flocculations and precipitations applied for the removal of H₂S were removed by the HydroGeoFilt filter system.

3 Construction of the HydroGeoFilt filter system

The innovative development of the HydroGeoFilt filter system is the self-cleaning function. Clogged filter candles can be cleaned mechanically by using the ultrasonic device installed in the center of the filter and afterwards the particles can be removed by back flushing the filter. Filter systems, which work after a similar main principle are already used in the field of drinking and process water treatment. The aim of the HydroGeoFilt project was to adapt an existing filter system to applications in the field of extreme deep geothermal conditions (high working pressure, water temperature and flow rate and complex water chemistry).

Figure 1 shows the adapted filter concept with implemented filter candles and an installed casing for the ultrasonic device. The ultrasonic device runs stable up to a temperature of about 80 °C. For the use at temperatures higher than 80 °C the ultrasonic device has to be cooled by a continuous flow of cooling water.

Five filter candles are placed radially around the ultrasonic device casing within the filter (Figure 1). Currently filter candles with five different mesh sizes (5, 10, 25, 50 and 100 µm) are available for filtering precipitated particles and/or used adsorption and flocculation materials. Depending on the application field, filter candles with finer or coarser mesh sizes can be produced and installed in the filter. The filter candles have a smooth filter fabric and are non-pleated to reduce the clogging potential. In order to test the five filter candles independently the single filter candles can be opened and closed by a valve. Further, samples can be taken after flow through each single filter candle to evaluate the filter capacity.

During operation the flow rate of each filter can be measured through a flow rate measuring sensor. Clogging of the filter candles is monitored by measuring the pressure difference between the entrance and exit of the filter by a barometer.

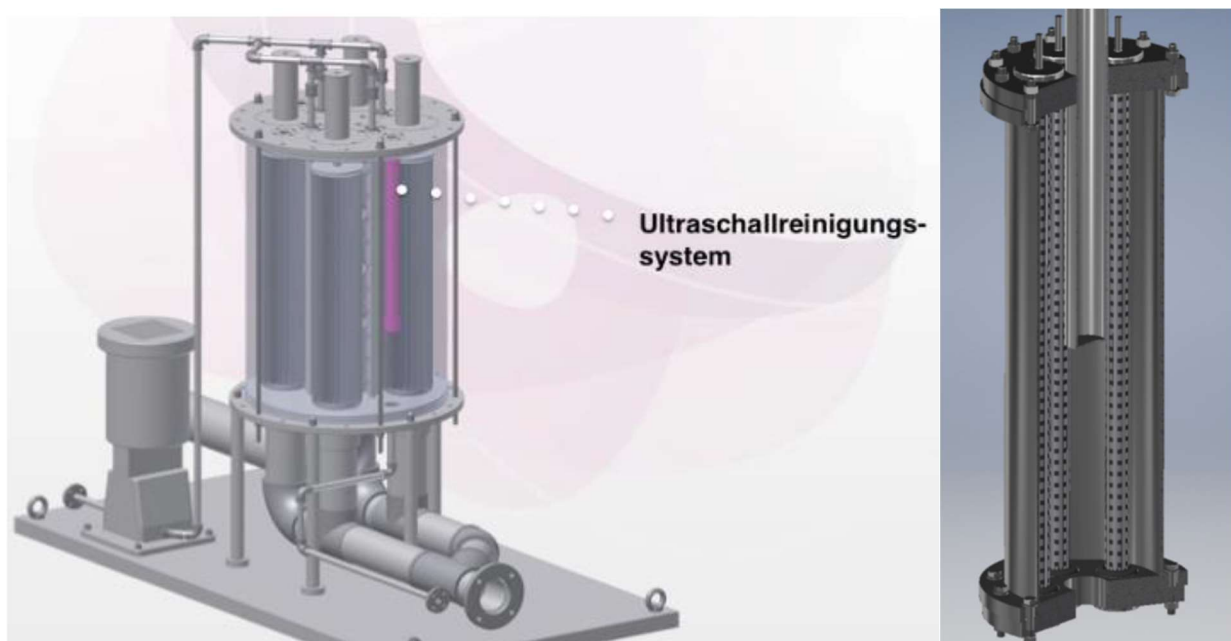


Figure 1 Schematic presentation of the HydroGeoFilt system (left) and CAD model – Longitudinal section through the filter system with implemented filter candles and installed casing for the ultrasonic device (right).

For the development of the new filter system, materials that comply with extreme requirements such as operational stability at high working pressures and temperatures, chemical resistance and oxidation resistance were selected. The chromium-nickel steel material 1.4401 with an additive of

molybdenum was selected for the cylindrical shaped filter casing and cover plates. This stainless, austenitic steel material has a high corrosion, temperature and pressure resistance. Stainless steel was also used for other filter components such as filter candles and flanges.

The whole filter system was designed and tested for a maximum working pressure of 13 bar and a maximum temperature of 120 °C.

For the application of the filter system at geothermal plants thermal water can be pumped into the filter through a mobile bypass system. However, for the onsite tests performed during the project time the different adsorption and flocculation materials were first added to the thermal water in a reaction container and afterwards the suspension was pumped into the filter to remove the particles.

4 First commissioning and onsite filter tests

The function and tightness of the filter system was tested at the ground of Hydroisotop (Figure 2).

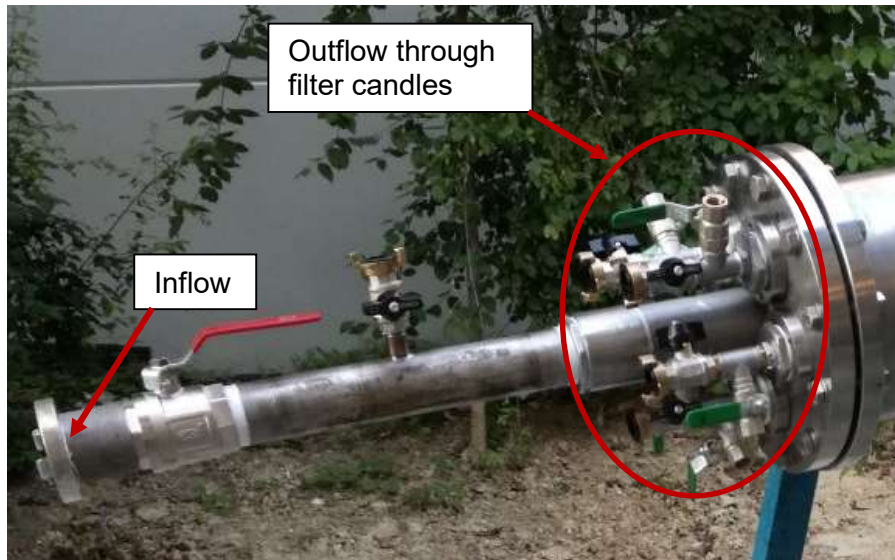


Figure 2 Construction of the filter system HydroGeoFilt

For the application in Oberlaa and Insheim, the peripheral devices were designed and installed according to the occurring conditions, which are max. 65°C and 10 bars.

4.1 Set-up and results of the particle filter tests at the thermal spa Oberlaa in Vienna

In the frame of onsite experiments at the thermal spa in Oberlaa GFH with a grain size of <0.2 mm and Fe(III)-chloride were added to the thermal water to test an alternative method for the reduction of the high sulphide content (13-46 mg/L) (WP3.3, Regenspurg et al. 2020). Figure 3 and 4 show the schematic experimental setup of the sulphide removal and particle filter tests in Oberlaa.

Thermal water produced from two thermal water wells (A: wells TH1, TH2, relation 1:1) was discharged into an IBC-container (B: reaction container). Iron(III)-bearing additives (GFH and Fe(III)-chloride) were added to the sulphide containing thermal water in the reaction container aiming to reduce Fe(III) to Fe(II) and to bind the sulphur as Fe-sulphide (FeS/FeS_2) or to fix the sulphur on the surface of GFH. The suspension of thermal water with the additives GFH or Fe(III)-chloride in the IBC was circulated by a pump and mixed with a stirrer (Figure 5) as long as the sulphide content decreased. The sulphide content was measured photometrically during the reaction process until the sulphide concentration was below the detection limit. Further, pH-value, spec. el. conductivity, redox potential and dissolved oxygen content were measured periodically using electrodes installed in a flow through cell. Either during the whole experiment or after the reaction was completed, the suspension was pumped from the IBC into the HydroGeoFilt filter system (C) for the removal of precipitates and GFH. After measuring the pH-value, spec. el. conductivity, redox potential and dissolved oxygen content (D: Fluid monitoring by FluMo) the treated thermal water was either discharged into the sewage system or connected to the IBC to ensure circulation of the thermal water. Thermal water samples were collected at the sampling connection at the IBC (Figure 5) or after the filter and fluid monitoring.

The experiments showed that H_2S could effectively be removed with both GFH and Fe(III)-chloride (WP 3.3, Regenspurg et al., 2020).

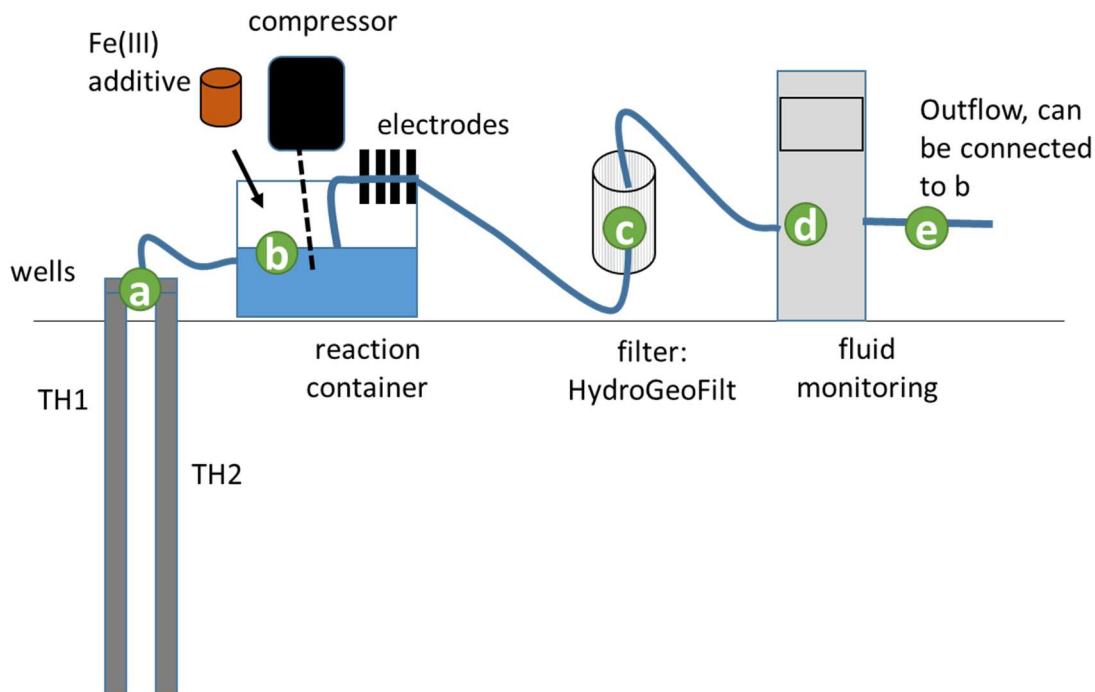


Figure 3 Schematic experimental setup at the thermal spa Oberlaa in Vienna, Austria (Regenspur et al., 2020).

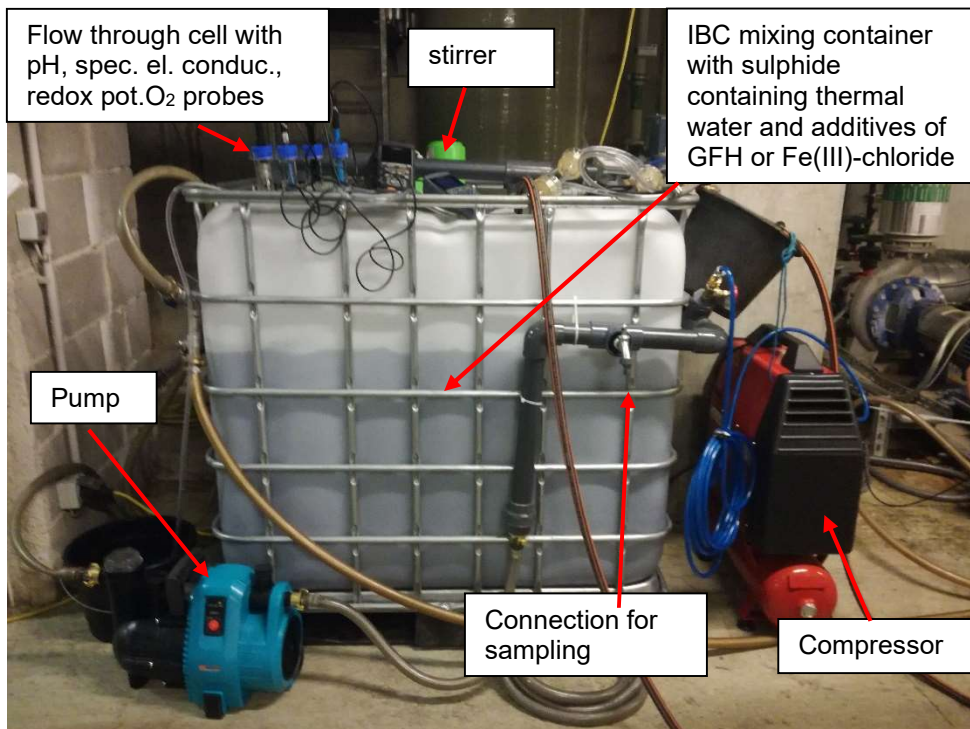


Figure 4 Experimental setup of H₂S removal experiments with the additives GFH and Fe(III)-chloride at the thermal spa Oberlaa in Vienna.

For the use of GFH as an additive, filter candles with mesh sizes of 5 and 10 µm and for the use of Fe(III)-chloride as an additive the filter candle with a mesh size of 5 µm was used. One thermal water sample was taken at the inflow of the filter system at the starting time of filtration. Further samples were collected after flow through the HydroGeoFilt filter system. In order to evaluate the

efficiency of the filter system to filtrate the Fe(III) bearing additives and reaction products the total iron concentration of the collected thermal water samples was analysed in the lab of Hydroisotop. The total iron concentration at the inflow of the filter (6.7 mg/L) is assumed to be constant due to a continuous homogenous mixing in the reaction container. During the experiment with GFH a constant flow over time of 0.24 m³/h and for the experiment with Fe(III)-chloride a continuous flow rate of 0.47 m³/h was measured by the flow meters (Figure 5). During the different experiments, a water volume of 1.15 m³ was filtered using the 5 µm filter candle and 0.63 m³ using the 10 µm filter candle. The temperature of the suspension was about 44-50 °C during filtration.



Figure 5 Application of HydroGeoFilt at the thermal spa Oberlaa in Vienna

The following diagrams show the analytical results (total iron concentration) with respect to the efficiency of particle filtration for both experiments (addition of GFH and filtration through 5 µm filter candle and addition of Fe(III)-chloride with filtration through 10 µm filter candle) (Figure 6). The orange parts of the bars show the total iron concentration of the filtrate (samples collected after

flow through filter system) and the whole bars show the total iron concentration in the thermal water sample taken at the inflow of the filter. The analytical results of the experiment with GFH show that iron bearing particles were filtrated with the 5 μm filter candle from the treated thermal water samples. At the flocculation experiment with Fe(III)-chloride iron bearing particles were not completely filtrated with the 10 μm filter candle in the beginning of the reaction process. With progressing reaction and filtration time total iron was also completely removed from the treated thermal water. It is assumed that a filter cake was formed around the filter candle with progressing filtration time which improved the efficiency of filtration. The relatively low filtration efficiency at the beginning of the filtration process might be due to the larger mesh size of 10 μm used for the experiment with Fe(III)-chloride . Further it is considered that at the beginning of the reaction process very fine grained iron hydroxide (Fe(OH)_3) flocculates are precipitated which are growing in size during the reaction process and can then be filtrated by the 10 μm filter candle. After finishing the experiments the filter candles were flushed back successfully using the ultrasonic device (Figure 7).

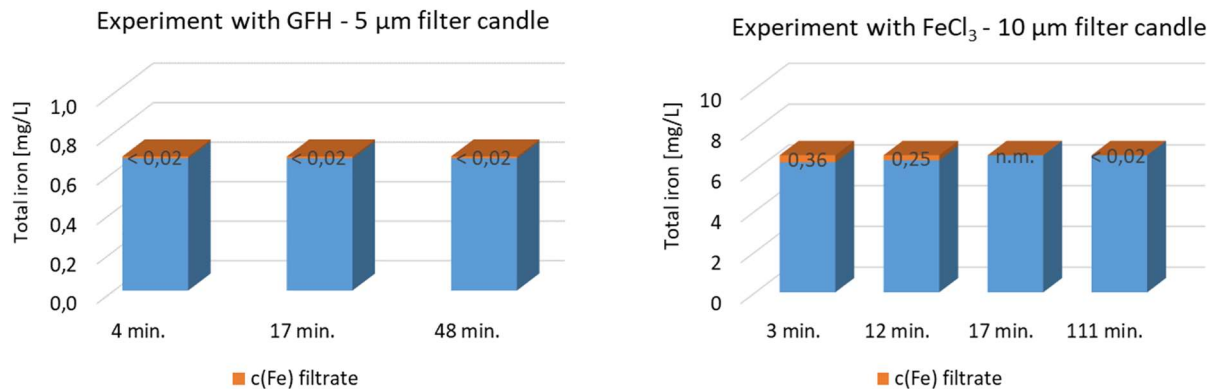


Figure 6 Total iron concentrations of treated thermal water samples at the inflow of the filter and after flow through the filter system in dependency of reaction time; Orange part of the bar: Total iron conc. of filtrate, whole bar (orange + blue): Total iron conc. of thermal water at the inflow of the filter



Figure 7 Left: Back flushing of the filter candles; Right: Generator of the ultrasonic device

4.2 Set-up and results of the particle filter tests at the geothermal site in Insheim

A test operation of the HydroGeoFilt filter system was conducted at the geothermal site Insheim on the 27th and 28th of November 2019 (Figure 8).

The HydroGeoFilt filter system was connected to a sampling connection after the heat exchanger and a continuous flow of thermal water (T about 62 °C and spec. el. conductivity of about 140 mS) through the filter was adjusted.

During this filter test, all filter candles (mesh sizes of 5, 10, 25, 50 and 100 µm) were tested. The filter system was operated successfully for 5 hours without clogging of the filter candles. Further, the flow rates measured with the single flow meters did not decrease during operation. The filtered water volume was 2.19 m³ for the 5 µm, 1.97 m³ for the 10 µm, 2.03 m³ for the 25 µm, 1.64 m³ for the 50 µm and 2.40 m³ for the 100 µm filter candle. In total, a thermal water volume of 10.23 m³ was pumped through the filter. The varying flow volumes of the filter candles are probably due to the high volume of gas bubbles within the thermal water. It could be observed that flow through the 50 µm filter candle was disturbed by gas bubbles resulting in the lowest filtered water volume, whereas the 100 µm filter candle showed the highest filtered water volume. However, it is necessary to conduct long-term filter tests in order to evaluate the working efficiency and stability of the filter system and to test the different mesh sizes of the filter candles.

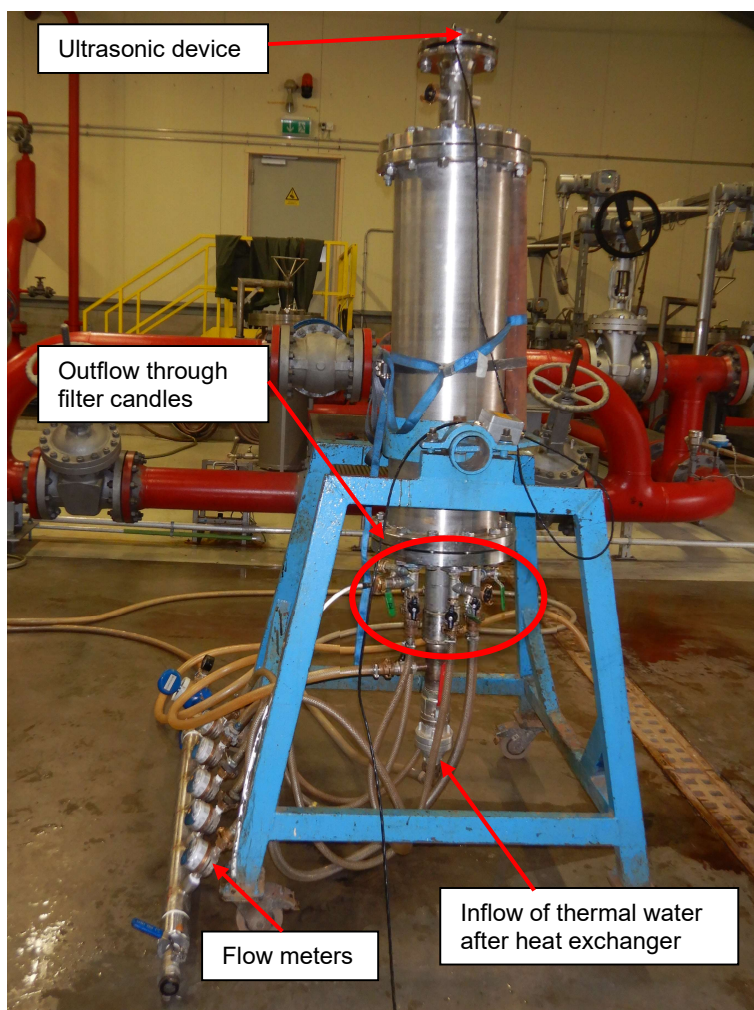


Figure 8 Test operation of the HydroGeoFilt filter system at the geothermal site in Insheim

Between June 14 and 18, 2020 HI and GFZ conducted a second onsite adsorption and filter test at the geothermal site in Insheim.

For the adsorption experiments (in total 4), hot thermal water from the production well was cooled down by two heat exchangers to about 45 °C and filled into a PE reaction container under N₂-atmosphere (Figure 10). Afterwards GFH (<0.2 mm), zeolite (<0.2 mm) (100 g added to 250 L of thermal water) or chitosan (16 g added to 225 L of thermal water) were added to the thermal water in the reaction container and the suspension was stirred by a mixer. After a reaction time of 30 minutes, the suspension was pumped through the HydroGeoFilt using the 5 µm filter candle and the Fluid monitoring device. The total volume filtered by the HydroGeoFilt through the four experiments was 0.68 m³. During each of the four experiments, a constant flow over time was determined (Figure 10).

Filtered and unfiltered fluid samples (0.45 µm filters) were taken before and during the reaction process at the reaction container and after filtration at the outflow of the fluid monitoring device (Figure 9). In order to evaluate the efficiency of filtering GFH from the suspension, the Fe(III) concentration was calculated from the total iron concentration measured on an unfiltered sample and the Fe(II) concentration measured on a filtered fluid sample taken after filtration. The calculated concentration difference between total Fe and Fe(II) of 0.2 mg/L lies within the analytical uncertainty. Hence, it could be estimated that GFH particles were efficiently filtered from the suspension by the HydroGeoFilt filter system.

After each experiment, the filter system was flushed back successfully by using the ultrasonic device.

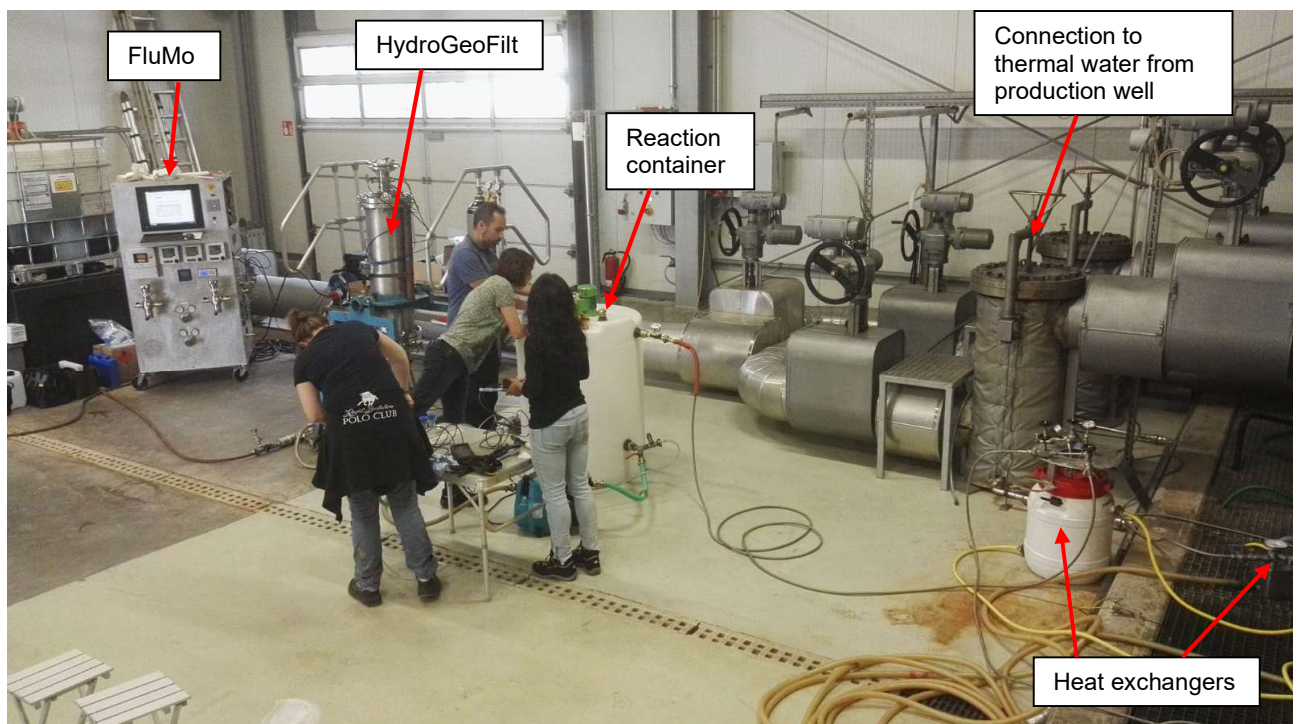


Figure 9 Application of HydroGeoFilt filter system during onsite adsorption experiments

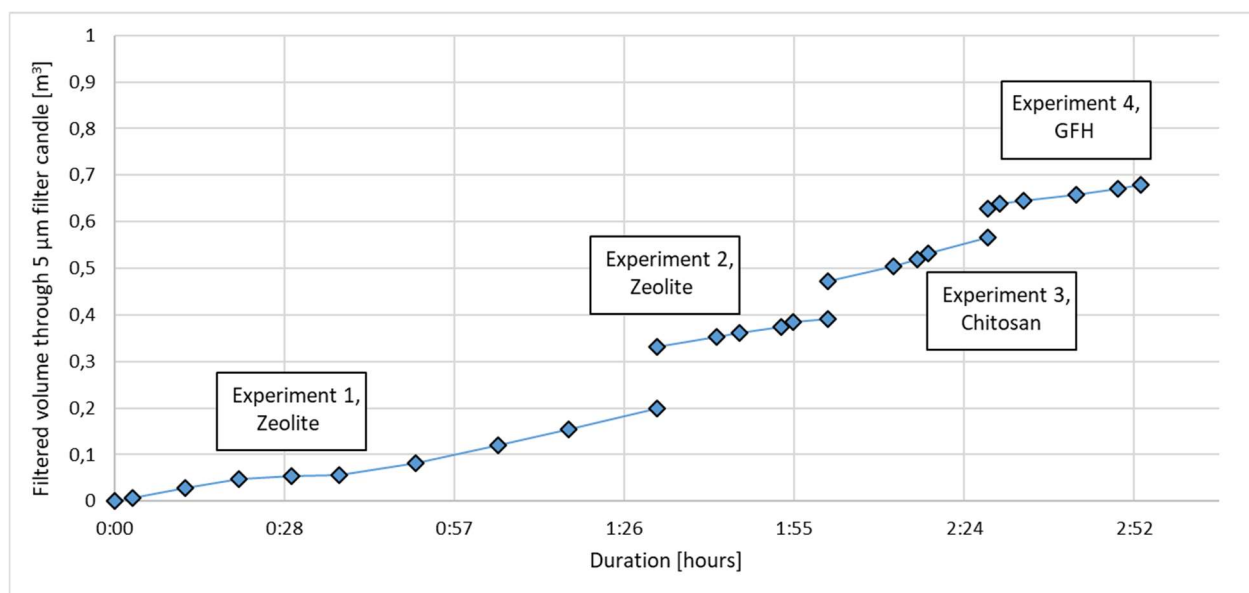


Figure 30 Constant flow rate through the HydroGeoFilt during the four experiments

5 Summary and outlook

Within the frame of the research project HydroGeoFilt the HydroGeoFilt filter system was developed for geothermal applications. Within the Perform project, the HydroGeoFilt filter system was tested under moderate geothermal conditions at a temperature of 50 °C at the thermal spa Oberlaa in Vienna, Austria and twice at the geothermal site Insheim, Germany (T = 45-62 °C). During those tests, it was shown that no corrosion or material changes of the filter components and no leakages were observed during the experiments. By using the HydroGeoFilt filter system, particles, added adsorption materials and flocculates could be efficiently filtered from the thermal water. In addition, back flushing by using the ultrasonic device was conducted at the geothermal sites Oberlaa and Insheim. The conducted onsite tests demonstrate that the HydroGeoFilt filter system was successfully installed and operated in the frame of bypass experiments for small-scale at moderate geothermal conditions. Hence, the HydroGeoFilt filter system was elevated to a TRL of 7.

However, the filter efficiency and stability and the self-cleaning function of the filter system still have to be evaluated by long-term onsite tests.

For the use at geothermal plants with higher temperatures and working pressures, the filter system still has to be improved.