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Construction of a Reactor for the Supply of Geothermal Fluids Under Laboratory Conditions (GECO Project)

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ABSTRACT

GECO (Geothermal Emission Control) is an international research project that started in 2018, funded by the EU through the H2020. Its core is the limitation of emissions from geothermal plants through the condensation and re-injection of gases.

In Germany, the Bochum Metropolitain Underground Laboratories (MULE) are operated by the International Geothermal Centre (GZB). For GECO, GZB is testing the effects of injection of CO2-rich hydrothermal fluids on sedimentary reservoirs. The interactions of fluids and rocks or components under artificial reservoir conditions are quantified and qualified in pilot-plant scale. For this purpose, geothermal fluids at exact defined composition, pressure and temperature are provided by a geo-fluid/gas reactor (FGR).

In this reactor, components such as Cl-, Na+, K+, Ca2+, Mg2+ or CO2 are added into a water flow loop. Furthermore, this arrangement, including a flow loop, allows precise control of the temperature, the pressure, as well as the mass flow due to constant pressure differences over a mass flow controller. Thus, the FGR can be operated in combination with experimental reactors as well as with boreholes.

1. INTRODUCTION

1.1 Project Description

The aim of the GECO project is to reduce emissions of non-condensable gases (NCG) from conventional geothermal plants. These gases, mainly CO2 and H2S, are harmful to the climate, sometimes toxic and odour-intensive. They are removed from the subsoil during the uplift of geothermal fluids and separated from the water content prior to the power plant process for performance reasons. Their emission lowers the acceptance of geothermal energy among the population and contributes directly to global warming. (Darkwah et al. 2018, Gökçen and Yildirim 2008)

As part of the CarbFix project, project partner Reykjavik Energy (OR) has developed, built and commissioned a pilot plant at the Hellisheidi site (Iceland) for reinjection of the NCGs. This plant demonstrates that returning the NCGs to the underground is technically feasible and practicable. The knowledge gained in Iceland is now to be expanded in the GECO project for further locations with different reservoir conditions. See table 1. (Berstad and Nord 2016)

Table 1: Injection sites in GECO.

Country	Reservoir	Rock Type	Temperature Level
Iceland	Hellisheidi	basaltic reservoir	high temperature
Italy	Castelnuovo	gneiss reservoir	high temperature
Turkey	Kızıldere	volcano-clastic reservoir	high temperature
Germany	Bochum	sedimentary reservoir	low temperature

Furthermore, project partners from France, Great Britain, the Netherlands, Norway and Spain support the implementation of the project.

1.2. Tasks of the International Geothermal Centre (GZB)

The task of the GZB is to characterize the Bochum reservoir with regard to the suitability of a possible reinjection of NCGs. By a geological model the influence of an injection on porosity and permeability shall be predicted. This is based on laboratory experiments on the reactivity of the predominant sandstone with synthetic geothermal fluids. Further experiments on a pilot scale will simulate the flow of rock under real conditions.

Finally, experiments in the underground between two boreholes with a synthetic brine are to record the effects in the reservoir in order to refine the model. The synthetic geothermal fluids will be generated on site using a geo-fluid/gas reactor (FGR), which will be used both in the pilot plant and at the borehole.

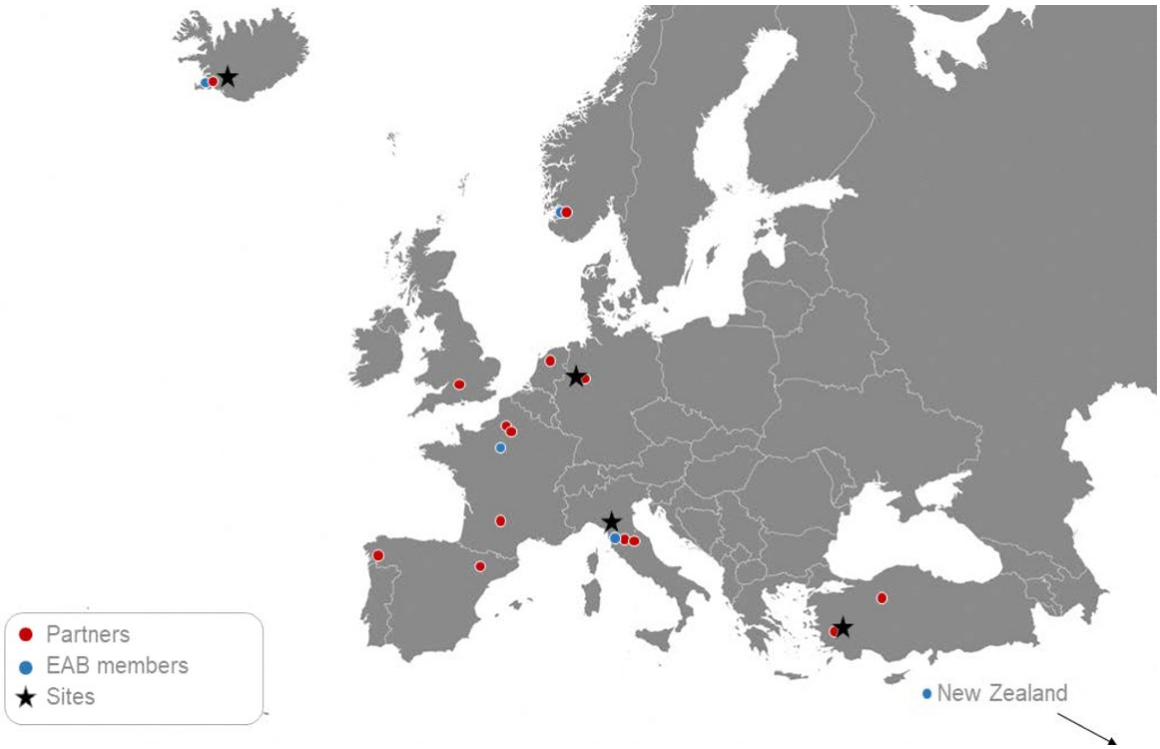


Figure 1: Map of the locations of all GECO project partners.

2. ENGINEERING OF THE FLUID REACTOR

2.1 Requirements

The requirements on the FGR strongly depend on the test procedure. It should fill the volume of the complete test plant of approx. 1 m³ abruptly with stored brine and deliver flow rates of 5 l/min to 400 l/min. The brine should have temperatures of up to 180 °C and reach pressures of up to 63 bar within the FGR or up to 1000 bar behind a downstream pump.

In the FGR, the ions of chlorine, sodium, potassium, calcium and magnesium are to be added in the form of acids or alkalis. High and low pH values are therefore essential. Furthermore, CO2, as well as H2S in subsequent tests, up to a mass fraction of up to 10 % is to be reached. See a list of the requirements in table 2.

In the case of endurance tests, such as corrosion tests, the composition should be continuously readjusted. Since crystallization in the reactor can also be assumed, this must already be taken into account in the planning.

2.2 Process Development

The core component of the FGR is a buffer and mixing tank. Brines of different composition are to be prepared in it and stored at almost test pressure. An internal flow loop ensures both continuous mixing and constant heat input. It is driven by a pump and tempered by a heating system. The pressure control system in the flow loop ensures the constant pressure between control valve and pump. Thus, fluid supply at constant pressure or with constant mass flow can be achieved in any case with different filling levels in the tank and varying backflows from the test setup. This arrangement enables the FGR to operate robustly even with fluctuating fluid consumption of the external test setups.

The return flow from the test setup into the FGR takes place on the low-pressure side behind the pressure control valve. Therefore no further pump is necessary for tests below the FGR pressure. The dosing of fresh water, acids and alkalis takes place in the return flow of the flow loop. The subsequent mixing in the tank and a residual flow in the pressure regulator during each mode of operation ensure uniform mixing of all added components.

The gas dosing unit as well as the safety devices against overpressure are connected directly to the mixing tank. See the process in the block flow diagram, figure 2.

Table 2: List of requirements of the FGR.

Requirement	Value
fill hole test station at once	Buffer volume of 1 m³
Vary flow rate	From 5 l/min to 400 l/min
Provision of fluids of elevated temperature	Up to 180 °C
Provision of fluids of high pressure	Up to 63 bar (higher pressures by additional pump)
Provision of fluids containing defined ion concentrations	Cl- up to 271000 mg/l
	Na+ up to 175000 mg/l
	K+ up to 1000 mg/l
	Ca2+ up to 11000 mg/l
	Mg2+ up to 2200 mg/l
Provision of fluids containing defined gas mass fractions	CO2 up to 10 %
	H2S up to 10 %
resist extreme pH value	of 1 to 14
resist particle formation by crystallisation	Up to 1 mm

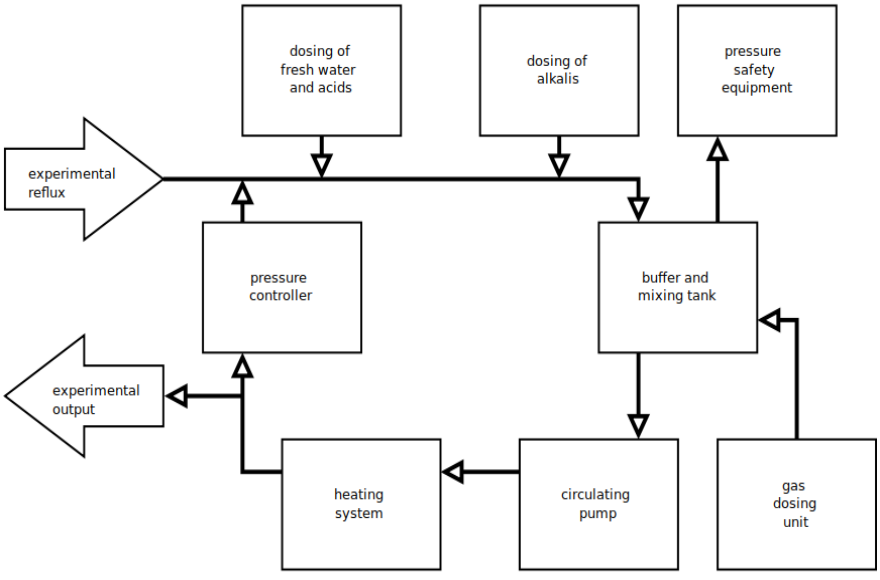
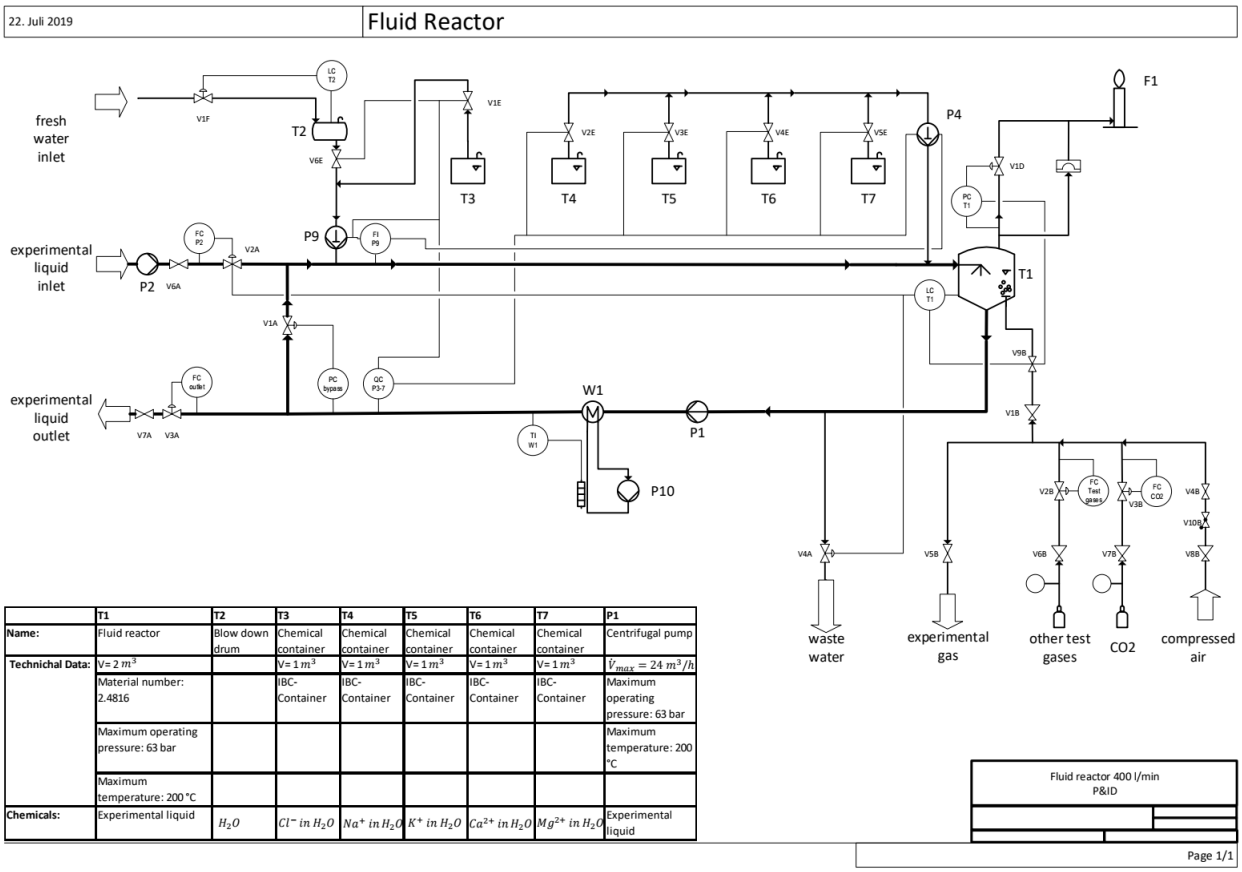


Figure 2: Block Flow Diagram of the FGR, own representation.

In the Pipe and Instrument Diagram, the plant components are located in the same arrangement as the Block Flow Diagram. See figure 3.

The flow loop runs from tank T1 through pump P1, heat exchanger W1 and the pressure regulating valve V1A back to the tank. The test setup is located parallel to the pressure regulating valve in the flow loop. For safety reasons, the dosing unit is divided into two assemblies. Fresh water and HCl are metered from T2 and T3 via pump P9. The caustic solutions are added from T4, T5, T6 and T7 via pump P4. In addition to a valve, a bursting disc in direct connection to the holding tank is used to secure the pressure. The gas is dosed via pressure reducing valves from the compressed air system or gas cylinders. The mass flow control valves V2B

and V3B can be used for the defined provision of a gas mixture. In the case of dosing clean gases or premixed gas mixtures, the corresponding flow controller is not used for control.



	T1	T2	T3	T4	T5	T6	T7	P1
Name:	Fluid reactor	Blow down drum	Chemical container	Chemical container	Chemical container	Chemical container	Chemical container	Centrifugal pump
Technichal Data:	V= 2 m^3		V= 1 m^3	V= 1 m^3	V= 1 m^3	V= 1 m^3	V= 1 m^3	$\dot{V}_{max} = 24\ m^3/h$
	Material number: 2.4816		IBC-Container	IBC-Container	IBC-Container	IBC-Container	IBC-Container	Maximum operating pressure: 63 bar
	Maximum operating pressure: 63 bar							Maximum temperature: 200 °C
	Maximum temperature: 200 °C							
Chemicals:	Experimental liquid	H_2O	$Cl^- in\ H_2O$	$Na^+ in\ H_2O$	$K^+ in\ H_2O$	$Ca^{2+} in\ H_2O$	$Mg^{2+} in\ H_2O$	Experimental liquid

Figure 3: Pipe and Instrument Diagram, own representation.

2.3 Material Selection

Depending on the composition, pressure and temperature, the requirements on the materials used for the pipes and instruments differ. The highest temperature in the FGR and pressures of up to 63 bar are in tank T1 and in the flow loop. Since realistically simulated geothermal fluids with this pressures are to circulate in this area, the highest requirements for corrosion resistance apply here.

This applies not only to the protection of the FGR but also to possible falsifications of test results when increasing the iron content in the fluid provided. The use of high-alloy steels should therefore be viewed critically. Nickel alloys have proven to be very corrosion resistant for these requirements. The alloy 2.4816 with a nickel content of 72 % and an iron content of 6 to 10 % is to be used for T1 and flow loop. (Schmid et al., 2017)

Commercially available IBC containers are used in areas with low pressures and lower temperatures such as the tanks T3 to T7 of the dosing units. The highest pressures in the FGR are in the gas dosing unit. Since no water is present in these pipes, they can be made of conventional high-alloy steel.

2.4 CAD Model

In order to be able to use the FGR at any location, the complete system is to be integrated into a conventional 20-foot container frame. For space reasons, the flow loop is arranged horizontally. All inlets and outlets are on one side. The IBC containers of the dosing components as well as the dosing pumps are sorted by acid and alkali. This eliminates reactive mixing in the event of leakage. In the event of a malfunction, a basin in the bottom of the container frame protects against the ingress of chemicals into the environment. In order to prevent this basin from overflowing, the FGR should be installed under the roof if possible. A housing must be avoided for safety reasons due to possible gas accumulation in the event of a leakage. See the CAD model in figure 4.

CONCLUSIONS

The provision of synthetic geothermal fluids for tests in laboratories and pilot plants places high demands on the FGR. A wide range of variations in pressure, temperature, volume flows and composition are required for a wide variety of test set-ups. Extreme values of pressure, temperature and pH value require a high resistance of the material used for pipes and instruments. The particularly corrosion-resistant nickel alloy 2.4816 is to be used here. Using an internal flow loop, composition, pressure and temperature can also be achieved at different levels of the buffer tank. The dosing units for fresh water, acids and alkaline solutions

are connected to this flow loop. The dosing units for gases or gas mixtures as well as the safety devices against overpressure are directly connected to the core piece of the FGR, the buffer and mixing tank.

Due to this arrangement of all components in a container frame, the plant remains mobile even for use at other locations.

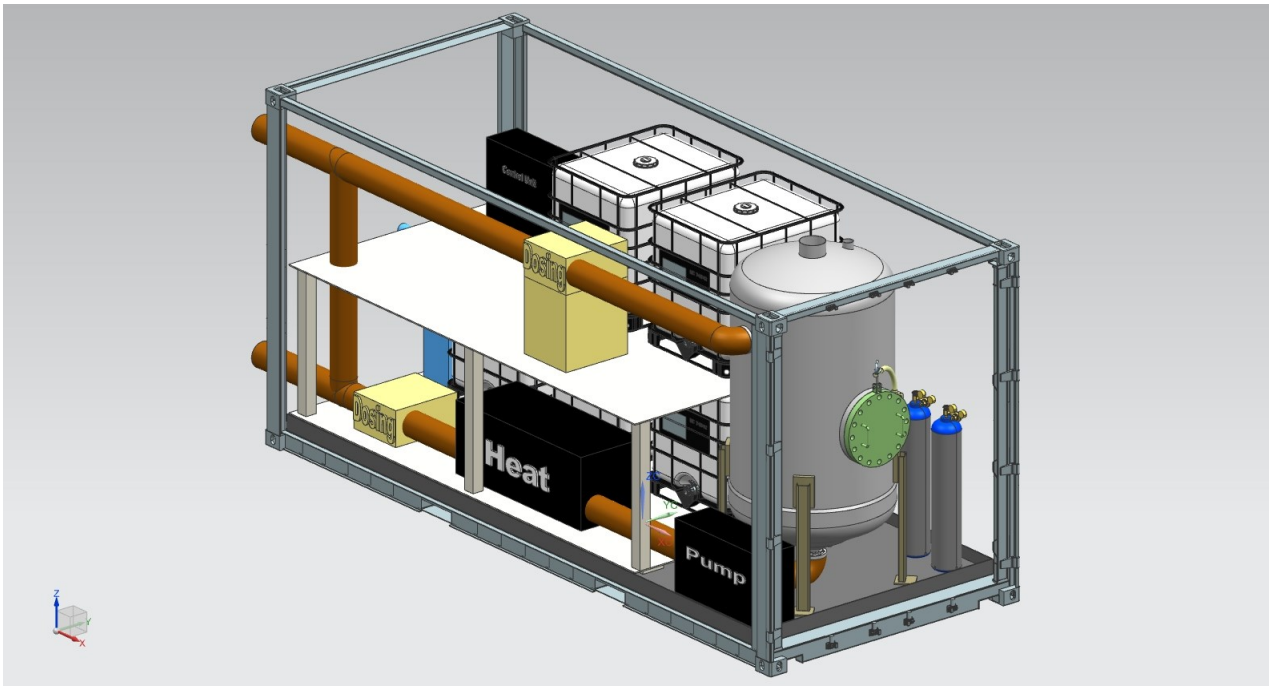


Figure 4: CAD Model of the FGR, own representation.

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