REFLECT DELIVERABLE D6.11

FACTSHEETS

Summary:
This document is a collection of the REFLECT factsheets produced for promoting the project results.

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1 EXECUTIVE SUMMARY

This document is a compilation of the REFLECT Factsheets which explain the project objectives and the results to different stakeholder groups.

Following our dissemination strategy, the factsheets were supposed to mainly target the scientific community, but geothermal operators and the general public were a secondary target. All factsheets contain a simple description of the specific project objective and the most relevant results, and offer further information via links to scientific publications, conference presentations or project deliverables.

Five factsheets have been prepared, published on the website and printed 150 times:

1. Downhole Sampler for high-temperature geothermal
2. Experiments for improving the efficiency of geothermal
3. European Geothermal Fluid Atlas
4. Role of microbiology in geothermal operations
5. Predictive modelling for geothermal

The REFLECT Final Conference on 19 Oct 2022 and the European Geothermal Congress 2022 were the first events during which the printed copies were distributed. The factsheets will also be used to promote REFLECT results on social media.

DOWNHOLE SAMPLER FOR HIGH-TEMPERATURE GEOTHERMAL WELLS

FACTSHEETS

REFLECT: Redefining geothermal fluid properties at extreme conditions

In the REFLECT project a **downhole sampler and fluid transfer system for high-temperature geothermal wells (>200°C)** has been developed (Fig. 1). The sampler is designed to tolerate harsh environments at high pressures and elevated temperatures, capable to sample from individual feed zones at specific depths giving information that is otherwise lost once the fluid flashes and/or mixes with shallower feed zones while flowing up the well. The objective is to be able to use the sampler to sample various phases (liquid, steam and two-phase steam) at low to high temperatures using the same methodology on the surface as high-temperature geothermal wells using well logging slick-line equipment and a lubricator pipe (Fig.2).

When feed zones of deep wells at high temperatures blend with colder inflow zones in the upper sections of the well, the local fluid conditions can cause corrosion and/or scaling in the perforated liner and production casing (Fig. 3). Consequently, the lack of knowledge about fluid properties of distinct aquifers leads to long-term and high-cost geothermal utilisation problems. Downhole sampling of the fluid at depth provides information on the fluid composition that enables optimal design of downhole and surface installations to prevent operational problems.

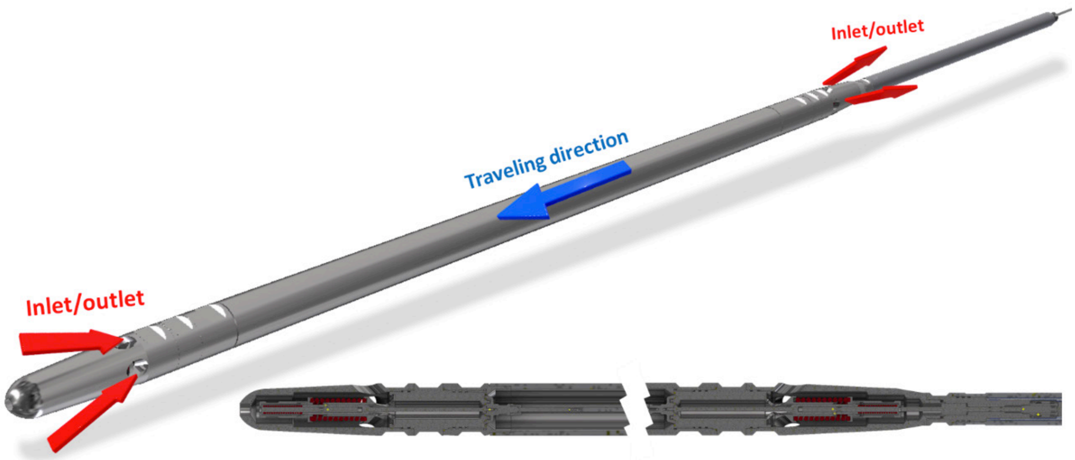

Figure 1: *REFLECT downhole sampler that has been developed to be able to sample various phases (liquid, two-phase, steam) at low to high temperature/high pressure superheated/supercritical conditions in geothermal wells.*

The fluid sampler developed in REFLECT will be able to sample high-temperature geothermal wells of 200-300°C, but **the more ambitious aim is to adapt the design even for higher temperatures (up to 400°C) and supercritical pressures**. A flow-through design has been selected as the most reliable principle (Fig.1). A special emphasis is put on the selection of corrosion resistant and leak-tight materials and parts suitable for construction of the downhole sampler.

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Since the sealing of the sampler will be one of the most crucial mechanisms, different materials for seals have been chosen, which can be adapted to the temperature/pressure conditions aimed for during sampling.

A first proof-of-principle sampling test will be performed by the REFLECT team at a low-temperature well in October 2022.

Figure 2: *The methodology of well sampling of high-temperature geothermal wells using well logging slick-line equipment and a lubricator pipe.*

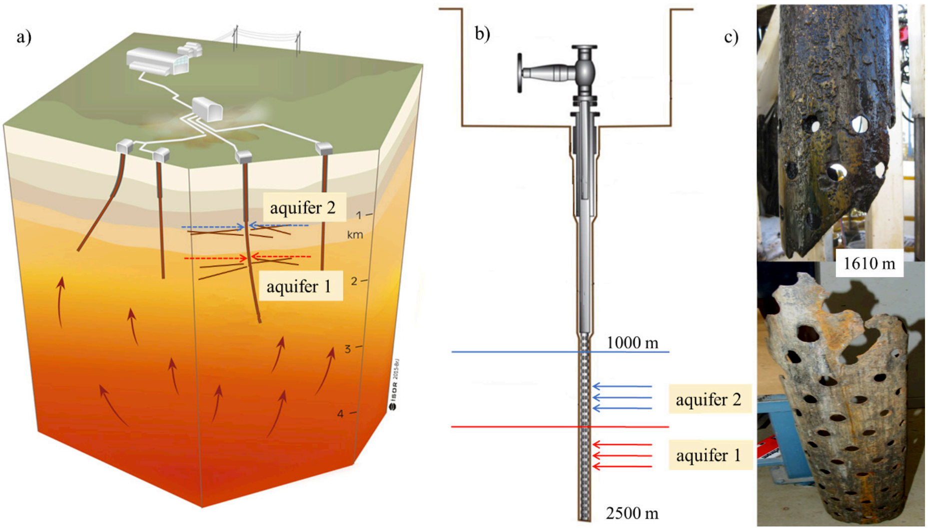

Figure 3: *Schematic drawing of a high temperature geothermal system (a) and a well bore with two feeding aquifers (b) for demonstration of a liner corrosion (c) at 1610 m depth within well KJ-39 (Krafla, Iceland). Extensive damage of the liner was caused by mixing between high temperature fluids from aquifer 1 (hot steam containing HCl gas) and aquifer 2 (colder instream) causing formation of HCl acid and corroding 12 mm liner down to 0 mm in few months. Surface samples showed no corrosive properties.*

Further information

Abstract EGU22 ERE2.4 Session: *Geochemical monitoring of the geothermal reservoirs using a high-temperature downhole sampler*

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EXPERIMENTS FOR IMPROVING THE EFFICIENCY OF GEOTHERMAL

REFLECT: Redefining geothermal fluid properties at extreme conditions

The key to improving geothermal efficiency is **preventing or controlling deleterious physical and chemical reactions** such as degassing and mineral precipitation that result in corrosion and scaling. Within the framework of the REFLECT project, investigations and experiments have been carried out to prevent these reactions.

DEGASSING EXPERIMENTS

The formation of free gas bubbles (**degassing**) during the production of geothermal waters can cause various issues like **scaling and blockage of reservoir pores**.

Within REFLECT, the aim has been to gather new data regarding degassing and its effect on fluid production from geothermal reservoirs.

Experiments performed within this study show good agreement with solubility theory of the conditions where free gas starts to form.

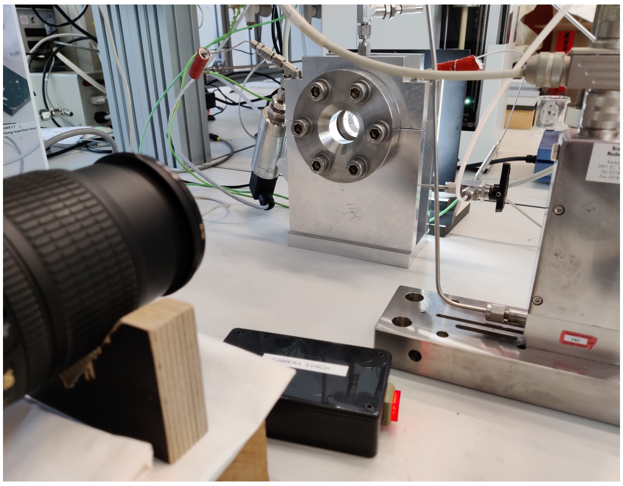

Figure 1: *The bubble point pressure is determined for gas-liquid mixtures at high pressure, temperature and salinity by visualising the degassing process in a pressure cell*

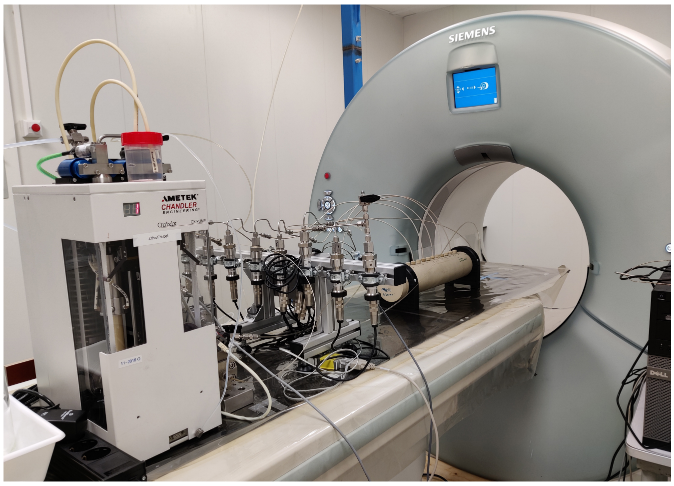

Figure 2: *A series of CT assisted coreflood experiments are performed to assess the extent to which free gas is limiting water flow inside rocks*

Further information

- *Abstract EGU21 SSS6.1 Session: Experimental investigation of degassing properties of geothermal fluids*
- *Abstract EGU22 ERE5.4 Session: Degassing kinetics of high salinity geothermal fluids*
- *Presentation from the REFLECT Geothermal Stakeholder Workshop: CO_2 degassing kinetics in bulk and porous media*

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SCALING INVESTIGATION AT TWO TURKISH SITES

A REFLECT team has been studying scaling issues at two geothermal power plants in the Western part of Turkey: the **Germencik and Tuzla plants**. The **antimony-based mineral stibnite** is the major problem in Germencik (Figure 4), while **silica-based scaling** is observed in Tuzla (Figure 3).

Within the framework of the project, scientists continue their work on both geothermal plants. Their main goal is to solve the scaling issues with 3D modelling, geochemistry studies and complementary work in the fields and laboratories.

The observations from the field have been repeated in well-controlled lab experiments as well as by modelling approaches to gain a full understanding of the precipitation process. Based on these observations, the most suitable solution would be to **use inhibitors by dosing specific compounds in the geothermal plants**. Caustic soda (NaOH) dosing could be a solution for the Germencik power plant. A systematic study to develop inhibitor molecules for the minimisation of scale formation in Tuzla is underway. The results of these examinations will yield valuable information on scaling formation.

Figure 3: *Silica based scaling in the Tuzla Power Plant*

Figure 4: *Stibnite scaling in the preheater system of the Germencik Power Plant*

Further information

- *REFLECT Webinar:* *Experiments for improving the efficiency of geothermal plants*
- *Scientific publication:* *Characterization of Sb scaling and fluids in saline geothermal power plants: A case study for Germencik Region (Büyük Menderes Graben, Turkey)*

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EUROPEAN GEOTHERMAL FLUID ATLAS

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REFLECT: Redefining geothermal fluid properties at extreme conditions

In the REFLECT project, geochemical and physical data of geothermal fluids are visualised through the European Fluid Atlas. **Fluid data** are collected from **21 European countries**. In the Atlas, the layers provide point feature information presented on a base map, including **geography, geology and depth range, as well as physical, chemical and microbial properties of fluids**. Data of wells, rocks and reservoirs are also available. The focus is on fluids used for electricity generation (> 100 °C), but data from heat projects are also included.

For the Atlas, a free and **open-source cross-platform** is used, in which the geographic information system provides the environment to view, edit and analyse geospatial data. The interface includes **query and filtering tools** to explore the database with a map based visualisation.

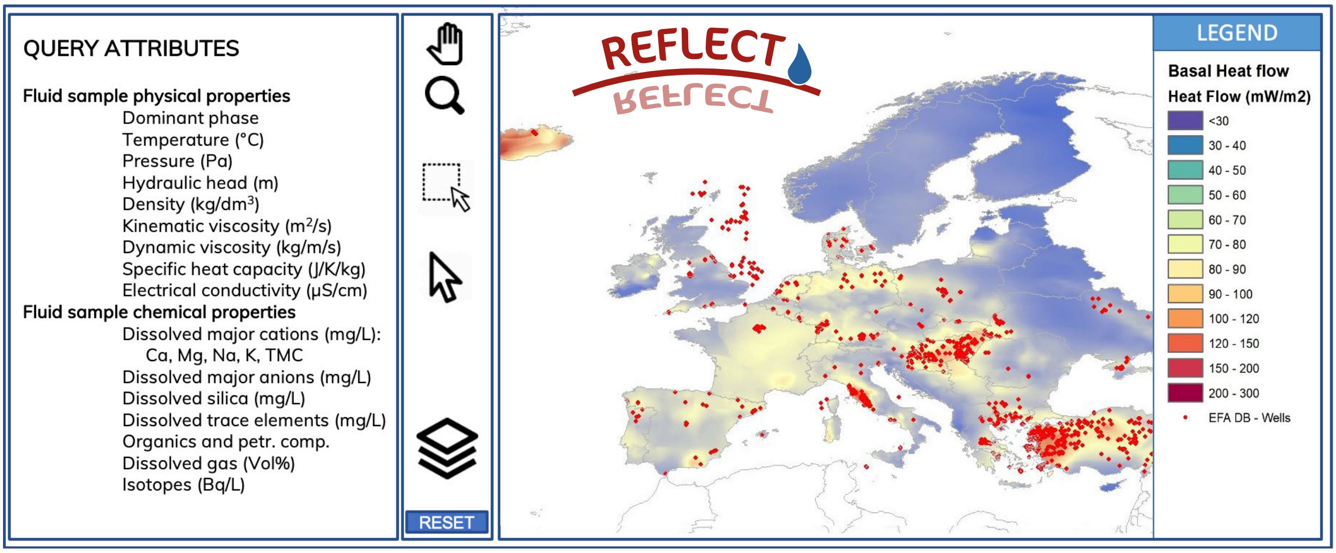

Figure: *Location and query attributes of the 2400 wells where formerly existing well, fluid, rock and reservoir data have been collected.*

With the Atlas, **operators can rapidly assess what kind of fluids might be expected at a certain location**, and thus have an improved view of the associated risks when installing a geothermal power plant. The compositional maps are developed into risk maps for the different operational issues in combination with numerical modelling. The Fluid Atlas can be later integrated into other databases, thus it can be an addition to already existing initiatives of geological data collection.

Further information available on the Results Section of the REFLECT website

- *Deliverable 3.1:* *Report on the collection of data on geothermal fluids at a European level*
- *Deliverable 3.2:* *Data compilation by REFLECT partners*

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ROLE OF MICROBIOLOGY IN GEOTHERMAL OPERATIONS

REFLECT: Redefining geothermal fluid properties at extreme conditions

Microorganisms are present in most ecosystems on Earth, and despite the extreme environmental conditions in geothermal fluids, these systems are also home to microbial life (Figure 1).

Inside power plant systems, **microorganisms can be involved in microbially induced corrosion** (MIC), **form biofilms or induce mineral precipitation**. One striking example of the impact of microorganisms on power plants is the induced precipitation of silica by bacteria, which strongly decreases the efficacy of a power plant [1].

However, other than in specific cases [1,2,3], knowledge of the diversity and prevalence of microbial life in deep geothermal reservoirs is still scarce. In order to fill in this knowledge gap, surveys of environmental DNA and cultivation of microorganisms under laboratory conditions (Figure 2) can be used to assess the diversity of microorganisms present in different power plants.

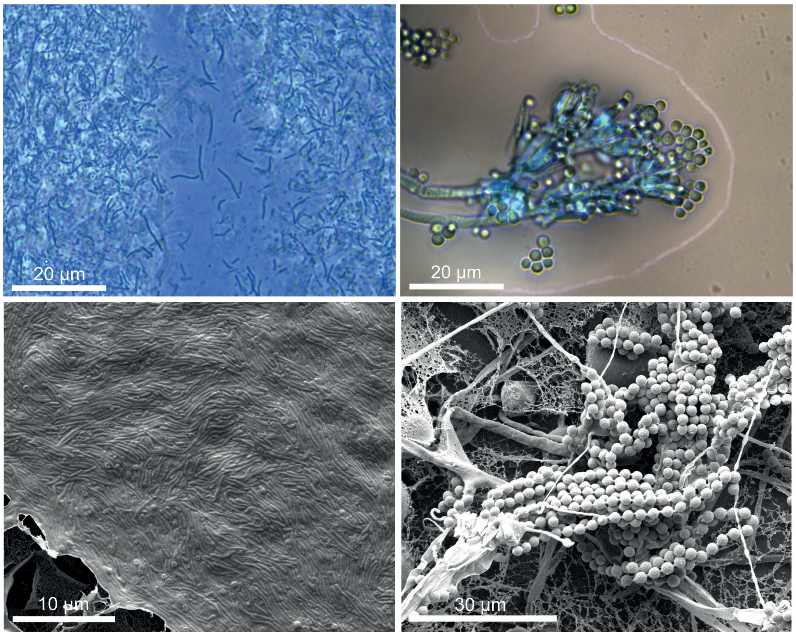

Figure 1: *Microscopical images of two microbial strains isolated from geothermal power plants. The two images on the left: Bacteria (Up: Optical microscopy, Bottom: Electronic Microscopy (Made by PME, UniL). The two images on the right: Fungus (Up: Optical microscopy, Bottom: Electronic Microscopy (Made by PME, UniL).*

Moreover, these studies should consider a broad spectrum of microbial groups, thus including simultaneously Bacteria, Archaea, and Fungi. A better knowledge of the microbial diversity present in these systems, as well as determining the conditions under which these microorganisms can grow, could allow to avoid problems generated by microorganisms in the pipes such as MIC.

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Furthermore, as the use of geothermal fluids to produce electricity changes the environmental conditions present in the fluids and in the reservoir, a better understanding of the microorganisms circulating in the power plants could allow to predict changes in the microbial population and its effects on the system in the long term.

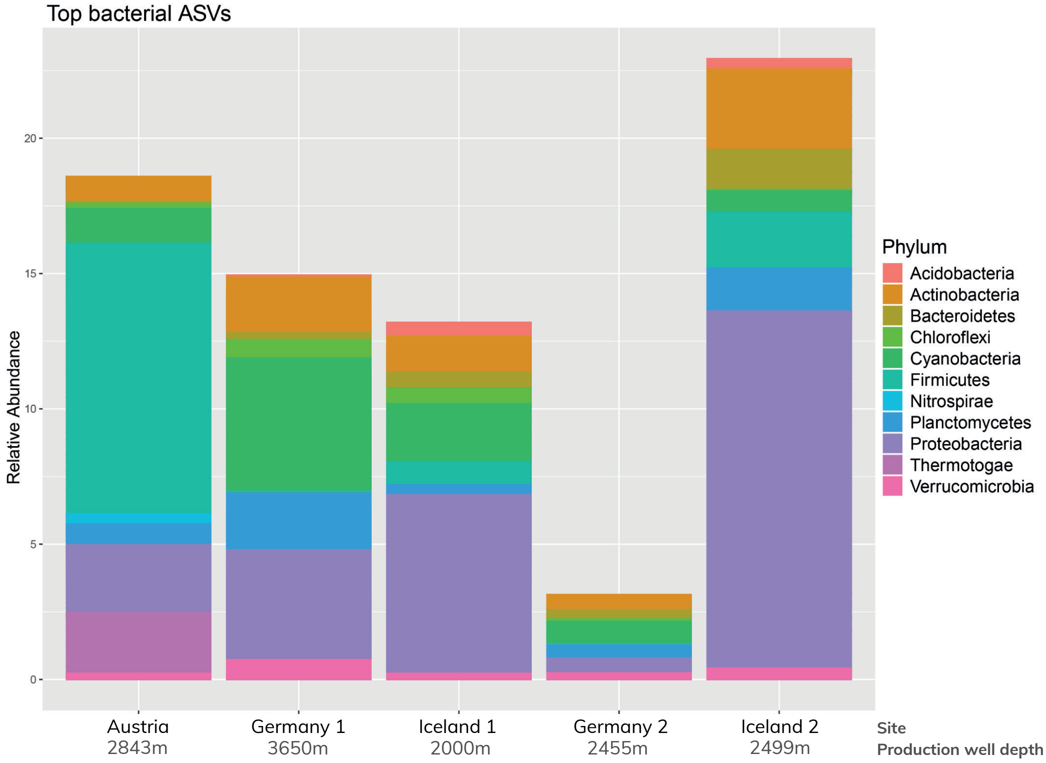

Figure 2: *Relative abundance of the top 100 bacterial species (ASVs) present at different power plants, grouped at the Phylum level.*

[1] Inagaki, F., Motomura, Y. and Ogata, S. (2003), *Microbial silica deposition in geothermal hot waters.* doi: 10.1007/s00253-002-1100-y

[2] Filippidou, S. et al. (2016), *Anoxybacillus geothermalis sp. nov., a facultatively anaerobic, endospore-forming bacterium isolated from mineral deposits in a geothermal station.* doi: 10.1099/ijsem.0.001125

[3] Westphal, A. et al. (2019), *Change in the microbial community of saline geothermal fluids amended with a scaling inhibitor: effects of heat extraction and nitrate dosage.* doi: 10.1007/s00792-019-01080-0

Further information

- *Scientific publication:* *Dissolved organic compounds in geothermal fluids used for energy production: a review*
- *Presentation from the REFLECT Geothermal Stakeholder Workshop:* *Studying microbial life in deep geothermal reservoirs*

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PREDICTIVE MODELLING FOR GEOTHERMAL

REFLECT: Redefining geothermal fluid properties at extreme conditions

In a geothermal system, brine is transported from aquifers - subsurface water reservoirs - to the surface, with the aim of extracting its thermal energy. However, on the fluid's way towards the surface, its chemical equilibrium is disturbed, potentially causing **scaling** in the facilities.

The numerical code **porousMedia4Foam** has been developed in order to **predict** these scaling risks. It is an **open-source, multi-scale and multiphase package**, where **OpenFOAM®** is coupled with the **PHREEQC code*** to investigate hydro-geochemical interactions. The flow, transport of chemical species, evolution of porous media properties and temperature are handled by solving equations implemented in OpenFOAM® (Figure 1) whereas, the chemistry is exclusively handled by PHREEQC.

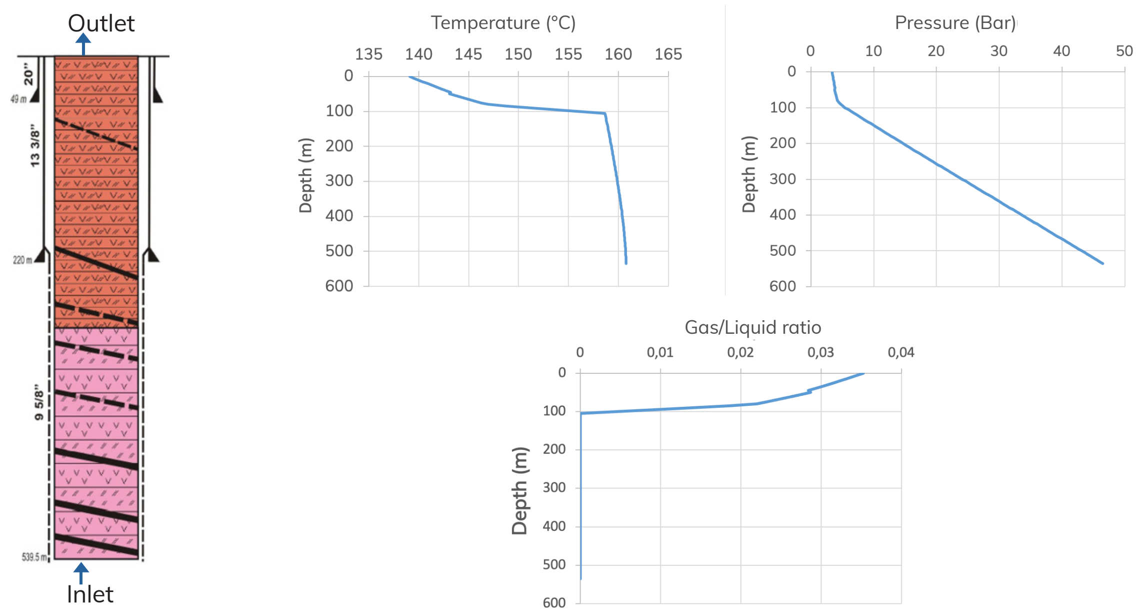

Figure 1: *Temperature, pressure and gas/liquid ratio profiles in a geothermal production well*

An accurate prediction of the scaling amount and location in the geothermal systems depends heavily on (1) the **characterization of the geothermal fluid**, which is impacted by the uncertainties in the fluid sampling and analysis and (2) the **interaction between flow hydrodynamics and precipitation**.

* Parkhurst, D.L., Appelo, C.A.J., 2013, *Description of input and examples for PHREEQC version 3 - A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations:* U.S Geological Survey Techniques and Methods, book 6, chap. A43: https://pubs.usgs.gov/tm/06/a43

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PREDICTIVE MODELLING FOR GEOTHERMAL

A workflow was developed and tested for uncertainty quantification in the fluid composition and its impact on scaling. A **full coupling between the PHREEQC code and hydraulic model** was made and the model was tested for two example conditions (flow in the pipes and wells and flow in heat exchangers), considering fluid composition uncertainties (Figure 2). The current workflow is being extended to different types of scaling, including calcite and lead. A software implementation for integrating uncertainty quantification workflow with geochemistry modelling is available ('Example D4.3' in the Further Information section). This workflow will enable operators to make a better decision about the operational settings and mitigation measures.

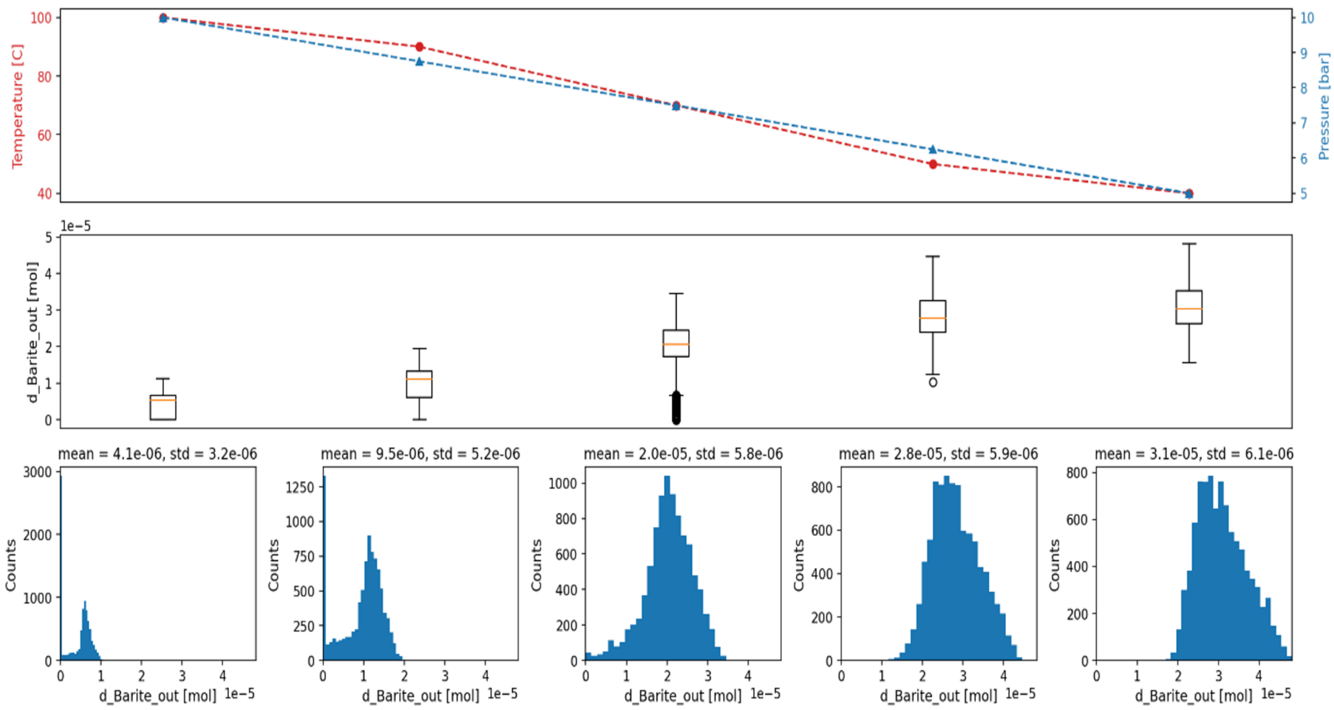

Figure 2: *Distribution of barite deposition layer considering geothermal brine composition uncertainties. Results are given at five different locations along a simplified heat exchanger pipe*

Further information available on the Results Section of the REFLECT website

- *Scientific publication: porousMedia4Foam: Multi-scale open-source platform for hydro-geochemical simulations with OpenFOAM®*
- Deliverable 4.2: Coupled hydro-thermal-chemical software porousMedia4Foam
- Deliverable 4.3: *Impact of geochemical uncertainties on fluid production and scaling prediction*
- *Example D4.3: Example code to perform uncertainty quantification with geo-chemistry modelling using PHREEQC*

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