

Amorphous silica (SiO_2) precipitation or scaling has been identified as one of the most common problems in geothermal systems and is one of the factors limiting the production of geothermal energy. The precipitates can lead to the clogging of pipes and wells, shorten lifetime of equipment such as pumps and turbines and can increase the operational hazards, e.g. due to the need of higher operational pressures. The scales also impair the financial performance of a geothermal power plant due to the reduction in power generation, increased operating costs and longer downtimes required for cleaning and maintenance of the system. However, up until now, no universally applicable solution to prevent silica precipitation in geothermal systems is available. In order to improve mitigation techniques, the understanding of the pathways and mechanisms of amorphous silica precipitation has to be advanced. In this study we report detailed observations of microstructures and compositional characteristics of silica-dominated precipitates from the Hellisheiði geothermal power station in south-west Iceland.

The precipitates were characterised on stainless steel scaling plates (5 x 2.5 cm) that were inserted into the flow path of the geothermal fluid at different locations within the power plant for 6 weeks (Figure 1). After retrieval, the plates were imaged using a scanning electron microscope (SEM) and analysed using energy dispersive spectroscopy (EDS) and X-ray diffraction (XRD) to obtain compositional information.

The precipitates showed distinct microstructures that span from fan-shaped to wave-like to individual flakes or even ridge-shaped precipitates (Figure 1). The dominant component on all plates was amorphous silica which occurs as spherical nanoparticles. They form most likely through homogeneous nucleation in the supersaturated geothermal fluid (SiO_2 concentration: 800 to 1000 ppm) and are deposited onto the plates subsequently. Along the rim of the plates where the precipitates broke off, likely during sampling, transport or sample preparation, the imaging revealed one additional, distinct mineral layer underlying the silica precipitates. This was a corrosion layer composed of fine grained, often idiomorphic Fe-sulphide crystals. The iron was sourced from the corrosion of the plates *in-situ* as the total iron concentrations in the separated water are very low (< 0.02 ppm). The sulphur for the Fe-sulphides on the other hand originated from the geothermal fluid where it occurs as H_2S at concentrations just below 30 mg/kg $_{\text{H}_2\text{O}}$. The fact that the corrosion layer is covered by silica precipitation indicates that corrosion is fast and prior to the precipitation of amorphous silica. Once the plates are covered by precipitates, further corrosion is likely to be minimal. Hence, the formation of a layer of amorphous silica could passivate the surface of the pipes and help limit corrosion of the steel. The metal plates, where exposed, are composed of Fe-oxides, mostly hematite. These result from oxidation of the metal plate upon exposure to atmospheric oxygen after removal from the separated water.

These results provided the first detailed description of silica-rich scales from the Hellisheiði power station. The microstructure and composition of the precipitates vary considerably depending on the ambient physico-chemical conditions in the power plant pipelines. However, how and why particular physico-chemical conditions lead to a variety of microstructure in the silica precipitates is poorly understood. Nevertheless, our work demonstrates that a quantitative understanding of silica scales in low-salinity geothermal systems can be gained through the detailed analyses of microstructures and composition of the precipitates. Combined with fluid chemical data and information about fluid flow will allow us to derive a first comprehensive model for understanding and maybe even reducing silica scaling in geothermal systems.

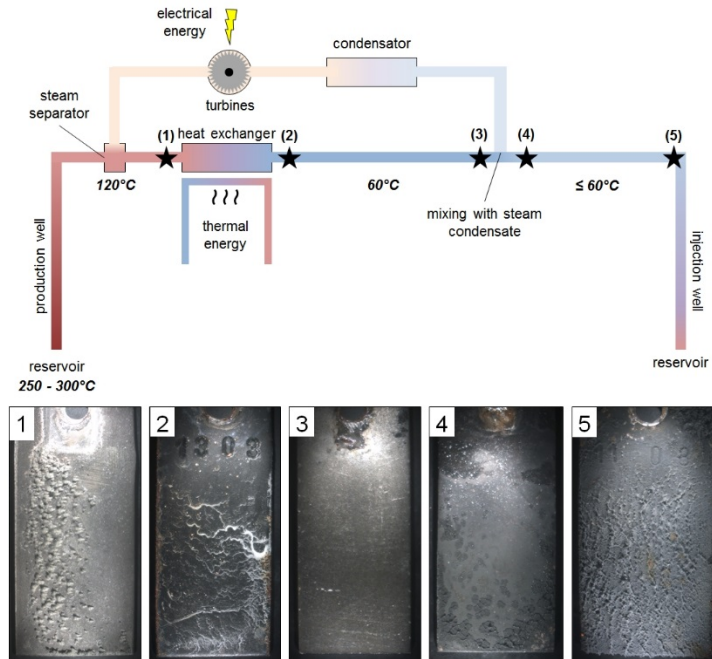


Figure 1 Top: Simplified operational scheme of the Hellisheiði power station with the location of the scaling plates used in this study (1 – 5). Bottom: Photographs of individual scaling plates depicting the different structures of the amorphous silica precipitates. Each photograph is about 2.5 cm wide.