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## An integrated experimental approach to study corrosion and scaling in simulated geothermal environments

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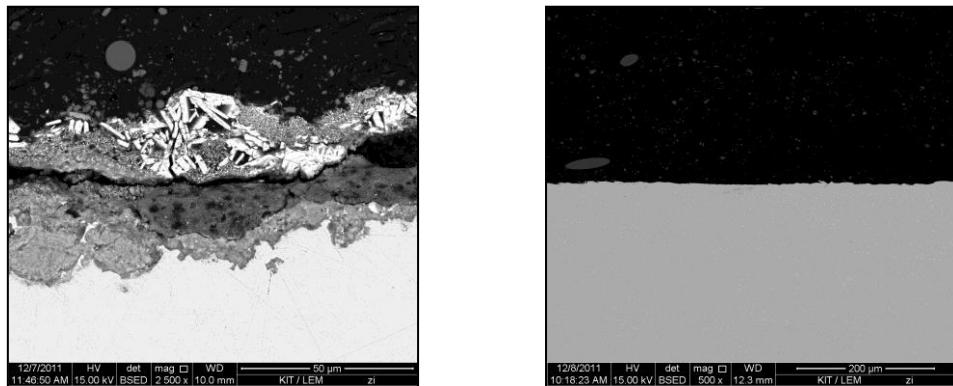
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### ABSTRACT

In this research outline I present a collection of ideas in the field of corrosion and scaling. It does not contain any results but rather serves as a basis for a further scientific discussion.

### 1. INTRODUCTION

Corrosion and scaling are becoming an issue in almost every situation where deep-seated natural fluids come in contact with engineering materials at elevated temperatures (e.g. geothermal energy production, CO<sub>2</sub> storage, nuclear waste disposal). These geothermal fluids are complex multi-component solutions (often CO<sub>2</sub>-rich Na-Ca-Cl brines) being close to equilibrium with respect to the mineralogy of the rock formation in which they reside for long times. Depending on the geological boundary conditions a wide variety of geothermal fluids can be encountered, each with individual properties in terms of corrosivity and scaling-affinity. Most studies, however, either focus on corrosion or on scaling neglecting their strong interrelation that is strongly affected by varying environmental conditions (pressure, temperature, and flow). Consequently, the resistance and the corrosion behavior of a given material have to be regarded as a system property, rather than a material property. For instance, previous studies demonstrated that bare and smooth metallic surfaces exposed to geothermal fluids impede the formation of adherent scales. As opposed to this, corroded metallic surfaces promote the formation of scales that have a stronger bonding to the substrate. Whether or not scales will form and what properties they have is therefore directly linked to the corrosion resistance of the substrate material. An example for this behavior is shown in the SEM images in Figure 1. These show the difference in the corrosion and scaling behavior of unalloyed and alloyed materials.

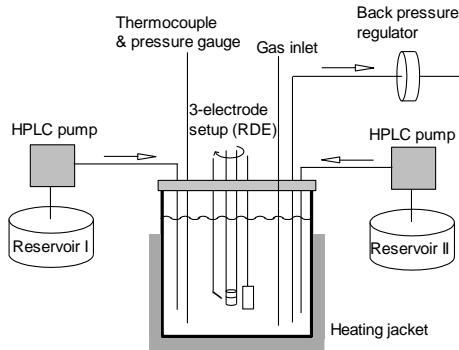


**Figure 1: SEM images of post-exposure samples; (left) mild steel N80 with siderite and barite scales, (right) CrNiMo-alloy 904L with no scaling deposition.**

### 2. APPROACH AND EXPERIMENTAL

Bridging the gap between corrosion and scaling this study is an integrated experimental approach to study the material-fluid interaction in simulated geothermal environments. The experiments will be conducted in a heatable flow-through autoclave that is equipped with a 3-electrode setup (Fig. 1). The ideal goal is to adjust the experimental conditions to the parameters found in natural subsurface or industrial process environments. Depending on the research question posed, the corrosive medium in the cell can be either a simple salt solutions or a solution prepared on the basis of geothermal fluids that are withdrawn from wells. The pressure can be controlled by a back pressure regulator. The temperature and the pressure can be constantly monitored. Rotating disc electrodes (RDE) are ideal to create turbulent flow conditions on the material-fluid interface. Attached to the autoclave are two HPLC pumps that provide a constant feed of scaling-affine

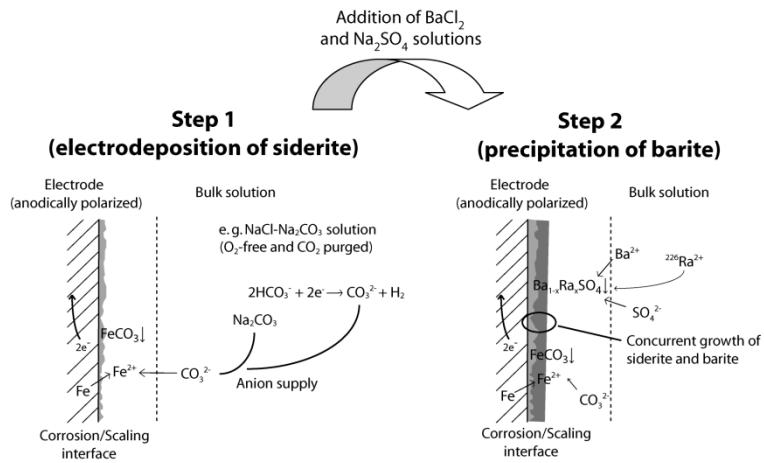
reactants (e.g.  $\text{BaCl}_2$ ,  $\text{SrCl}_2$ ,  $\text{Na}_2\text{CO}_3$ ,  $\text{Na}_2\text{SO}_4$ ) into the reactor. The respective geochemical modeling (speciation, solubility, saturation states) will be performed with PHREEQC (USGS).



**Figure 2: Flow-through reactor equipped with a 3-electrode setup for the electrochemical experiments (RDE: rotating disc electrode)**

The material of interest (mild steels, CrNiMo-alloys, metallic glasses (?) etc.) will be kept under potentiostatic or -dynamic control while it is exposed to a scaling-affine environment. The idea is to trigger the corrosion process and the buildup of scaling under controlled laboratory conditions at various P and T. A way to generate scales on a polarized Fe electrode is illustrated in Fig. 2. Two types of scales are typically encountered in subsurface environments: (i) Siderite-rich carbonate ( $\text{FeCO}_3$ ) often represents the most stable corrosion product of Fe-based materials under reducing conditions. While a dense layer is capable to inhibit corrosion to a certain extent, loose layer are known to promote localized corrosion. Hence, the characteristics of the newly formed siderite layer are essential to predict the material behavior. (ii) Barite/celestine ( $(\text{Ba}, \text{Sr})\text{SO}_4$ ) is often deposited as a consequence of a temperature decrease and is known to incorporate naturally occurring radioactive nuclides (e.g.  $^{226}\text{Ra}$ ) into its crystal lattice.

In the envisaged research program we aim to measure the electrochemical response while the electrode is exposed to a corrosive and scaling-affine environment. It involves the application of diverse electrochemical (in-situ) methods and analytical (ex-situ) techniques. Linear polarization resistance (LPR) is capable to derive time-resolved corrosion rates and is useful to monitor corrosion. Passivation and localized corrosion are best studied by cyclic potentiodynamic polarization, imposing a high potential perturbation. Electrochemical impedance spectroscopy (EIS) involves the application of a time-varying voltage (AC) and measurement of the current response. EIS is a powerful method and generally represents a fuller description of an electrochemical system, relative to DC methods. The combination of these methods provides a comprehensive description of the chemical and electrochemical reactivity of the material-fluid interface. The in-situ measurements will be complemented by various ex-situ techniques (e.g. XRD, SEM/EDX, VSI, and AFM) to study the deterioration process of the reacted sample and to analyze and characterize the newly formed products.



**Figure 3: Schematic sketch of the deposition of scaling on a non-inert Fe electrode. During the exposure to the corrosive environment and scale deposition the electrical response will be recorded by various methods, such as potentiodynamic and -static polarization, electrochemical impedance spectroscopy (EIS), and linear polarization resistance (LPR).**

### 3. EXPECTED OUTCOME

The envisaged study fuses basic with applied research and opens a field of research between geochemistry/mineralogy, electrochemistry, material-, and corrosion sciences. The outcome of this research establishes a deeper understanding of material-fluid interaction in natural subsurface environments and can give valuable support in the material selection process for various applications.