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Preliminary Investigation of the Formation Mechanism of Amorphous Silica Scale in Cold Reinjection Systems at Berlin Geothermal Field, El Salvador

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ABSTRACT:

This study investigates the preliminar formation mechanism of silica scale in part of the Cold Reinjection System (CRS) at the Berlin Geothermal Field (BGF), which has a total installed capacity of 109.2 MW. BGF is currently operated using 17 production and 25 reinjection wells. At the TR-4 platform, two-phase fluid from production well TR-4B and TR-4C at ~180°C respectively are separated by two Cyclone separator (CS train A and CS train B) Separated steam is used for power generation, while the separated brine is routed to hot reinjection and/or binary system. Some steam is released through silencers, condenses, and flows into weir boxes where silica supersaturation and polymerization occur. One weir box from (WTrainB, 89.2°C) is treated with 50% citric acid. After injection, Citric acid 50% concentration range is 35 to 55ppm in 90ml-120ml/min in range of discharge approximated of 18-22 L/min, while another weir box (WTrainA, 60.3°C) remains untreated. These brines are mixed with the others in a reinjection pond (~50–70°C) before being injected into cold reinjection well TR-4R (max 30 kg/s) or redirected to TR-9 and TR-11s. This setup forms a part of CRS at BGF.

The aim of this research is to propose a preliminary silica scale formation mechanism on site experiments of polymerization and adsorption of SiO2
The XRD results confirmed the presence of amorphous silica in both acid-treated and untreated systems, along with smectite, magnetite, halite, and traces of quartz. These findings reinforce that citric acid injection did not fully inhibit silica scale formation under high-temperature geothermal conditions. This is consistent with previous mineralogical studies in geothermal systems, which shows that amorphous silica frequently precipitates in both treated and untreated brine due to persistent supersaturation, thermal activation, and colloid-rich conditions. After mixing in the reinjection pond and resting in the cold reinjection system (CRS), deposition of SiO_2 occurs regardless of prior citric acid treatment.

1. Introduction

Silica scaling is a major operational issue in geothermal power plants, particularly in cold reinjection systems, where supersaturation of silicic acid (H_4SiO_4) and its polymerization into colloidal and amorphous silica can lead to rapid scale formation. This reduces reinjection well capacity, increases maintenance costs, and limits long-term field sustainability [1–3].To mitigate this, several chemical treatments have been investigated, including pH adjustment and organic acid addition. Citric acid, in particular, has shown the ability to delay silica polymerization under certain conditions by reducing pH and complexing with silicate anions [4–6]. However, its effectiveness in complex field environments specially where treated and untreated waters mix—is not fully established.
Recent studies have shown that citric acid slows but does not entirely prevent colloid formation and silica deposition in field settings [3].

This study investigates the preliminary formation mechanism of amorphous silica scale in the Cold Reinjection System (CRS) at the Berlin Geothermal Field, El Salvador, analyzing polymerization and adsorption behavior over time in treated, untreated, and mixed brines, this work aims to provide a kinetic perspective on silica behavior and scale development under operational geothermal conditions.

2. Methodology

Time-resolved batch experiments were conducted to evaluate the polymerization and adsorption behavior of dissolved silica under three geothermal brine conditions from the Berlin Geothermal Field: Weirbox A (WTrainA, untreated; 60.3 °C, pH 6.4), Weirbox B (WTrainB, treated with 50% citric acid; 89.2 °C, pH 5.7), and the Reinjection Mix pond (62.1 °C, pH 4.51). Each condition involved two parallel experiments: one for polymerization and another one for adsorption, microsphere silica gel was added to simulate silica interaction with solid surfaces [5]. The geothermal water was immediately transferred to 1 L polyethylene bottles. One of them has 1 g of CM-D-50-1000AW serving as batch reactors and immersed in a thermostatic bath maintained at 90 °C. 50 mL of water was syringe using an ADVANTEC syringe and filtered through 0.45 µm cellulose acetate membranes. For 120 minutes at time intervals of 0, 10, 20, 30, 45, 60, 75, 90, 105, and 120 minutes. Monomeric silica (m-SiO_2) was analyzed onsite via UV-Vis spectrophotometry at 400 nm based on the molybdosilicic acid method, where geothermal water was reacted with 0.1 M HCl and 5 wt% ammonium molybdate, and absorbance was measured using a HACH DR-1900 spectrophotometer [4], while the samples filtrated were collected in 50 mL polyethylene bottles pre-treated with 0.5 mL of 1 M HCl to prevent post-sampling polymerization, following Wanyonyi et al. [5], [4]. Total silica (T-SiO_2) was analyzed using ICP-AES (Perkin-Elmer Optima 5300DV) using the same acidified, filtered 50 mL samples. In parallel, scale samples were collected from brine pipelines, cyclone separators, and weirboxes. X-ray Diffraction (XRD) was

carried out using a Rigaku UltimaIV diffractometer with Cu Kα radiation over a 2θ range of 5°–65°

3. Results

The polymerization and adsorption experiments revealed that m-SiO_2 concentrations decreased over time while T-SiO_2 remained relatively stable across all sites. In WTrainA, polymerization experiments showed m-SiO_2 values ranging from ~260 to 400 ppm and T-SiO_2 from ~700 to 770 ppm, indicating gradual polymerization. Adsorption experiments yielded a mild decrease in m-SiO_2 (~320 to ~250 ppm), suggesting weak surface interaction with silica particles. In WTrainB, mSiO_2 declined more rapidly (from ~630 to 600 ppm), while T-SiO_2 dropped slightly from ~760 to 670 ppm, even with citric acid treatment. The reinjection mix exhibited intermediate behavior: m-SiO_2 dropped from ~440 to 370 ppm (polymerization) and from ~550 to ~400 ppm (adsorption), while T-SiO_2 stayed near ~600–670 ppm. These trends reflect site-specific temperature and pH conditions influencing reaction rates. XRD analysis confirmed the presence of amorphous silica, magnetite, smectite, halite, and minor quartz in all systems, with amorphous silica dominant in both treated and untreated conditions. XRF analysis showed SiO_2 as the major component (often >80 wt%) with associated oxides like Fe_2O_3, Al_2O_3, and Na_2O, consistent with mineral deposition reported in other geothermal systems 【1,3,4】.

4. Discussion

The polymerization and adsorption experiments revealed that mSiO_2 concentrations decreased over time while tSiO_2 remained relatively stable across all sites. In WTrainA, polymerization experiments showed mSiO_2 values ranging from ~260 to 400 ppm and tSiO_2 from ~700 to 770 ppm, indicating gradual polymerization. Adsorption experiments yielded a mild decrease in mSiO_2 (~320 to ~250 ppm), suggesting weak surface interaction with silica particles. In WTrainB, mSiO_2 declined more rapidly (from ~630 to 600 ppm), while T-SiO_2 dropped slightly from ~760 to 670 ppm, even with citric acid treatment. The reinjection mix exhibited intermediate behavior: mSiO_2 dropped from ~440 to 370 ppm (polymerization) and from ~550 to ~400 ppm (adsorption), while T SiO_2 stayed near ~600–670 ppm. These trends reflect site-specific temperature and pH conditions influencing reaction rates. XRD analysis confirmed the presence of amorphous silica, magnetite, smectite, halite, and minor quartz in all systems, with amorphous silica dominant in both treated and untreated conditions. XRF analysis showed SiO_2 as the major component (often >80 wt%) with associated oxides like Fe_2O_3, Al_2O_3, and Na_2O, consistent with mineral deposition reported in other geothermal systems 【1,3,4】.

5. Conclusions

- Silica scale formation in the Berlin Cold Reinjection System occurs through time-dependent polymerization and colloid development, as confirmed by both monomeric and total silica trends.
- Citric acid treatment slightly delayed monomeric silica depletion but did not prevent colloidal silica formation under high-temperature conditions (~89 °C), demonstrating limited inhibition effectiveness.
- Adsorption onto silica gel had only minor effects on monomeric silica levels, indicating limited natural adsorption capacity in brine.
- The dominant factors driving silica scaling in the CRS are supersaturation, temperature, and mixing of multiple brine streams, not solely pH or chemical dosing.
- These findings suggest that effective long-term mitigation of silica scale will require integrated strategies that combine chemical treatments, temperature control, and brine management.

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