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Laboratory Evaluation of Chemical Dissolution on Complex Geothermal Binary Plant Scales

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INTRODUCTION

Geothermal binary plants operating in high-silica brine environments face persistent scaling challenges that reduce heat exchanger efficiency and increase maintenance costs. Scaling occurs when dissolved minerals—primarily silica—precipitate during brine cooling, forming scale deposits on heat transfer surfaces (Brown, 2013). These deposits not only impair thermal performance but also increase pressure drop across heat exchangers, as demonstrated at the Wairakei binary plant (Zarrouk et al., 2014).

Chemical mitigation approaches, including pH modification and silica inhibitors, have been widely applied, each with distinct advantages and limitations. While pH modification can suppress silica precipitation, it introduces corrosion risks and secondary scaling (Gill & Jacobs, 2018). Silica inhibitors offer improved heat recovery but require precise formulation and dosing. Traditional mechanical cleaning methods often prove inadequate for complex scales composed of amorphous silica, metal silicates, and corrosion products (Grassiani, 2000).

Recent advancements in chemical dissolution strategies have shown promise for mitigating scale without plant shutdown. Online treatments have successfully restored reinjection well capacity by dissolving silica and iron-based deposits in situ (Gica, 2020; Monterozo et al., 2022). These findings underscore the potential of tailored chemical programs as a viable alternative or complement to mechanical cleaning in geothermal binary systems, and this study evaluates the performance of different dissolvers on heat exchanger scales.

METHODS

Scale samples were collected from multiple heat exchanger locations from the binary plant. Each sample was analyzed for mineralogical composition using petrographic microscope and X-ray Diffraction (XRD), and X-Ray Fluorescence.

Laboratory dissolution tests were conducted under controlled conditions (Figure 1). Experiments were performed at 80°C using a certain solid-to-liquid ratio. Multiple dissolvers were evaluated, including organic acid blends, inorganic acids, and alkaline formulations. Scale samples were immersed in the solution for 24 hours, and weight measurements were taken to monitor weight loss.

Dissolution performance was quantified based on percentage weight loss.



Figure 1. Scale sample in analytical balance and in solution.

RESULTS

Initial screening tests were conducted on a representative heat exchanger scale predominantly composed of amorphous silica and corrosion products (Fe-sulfides and Fe-oxides) to select the best dissolver. Dissolution performance varied significantly, with organic acid blends achieving the highest removal (up to 52%) compared to inorganic acids and single-component treatments (Figure 2). Using the best dissolver (organic acid blend 2), further testing on other scale samples from different heat exchanger locations were conducted. These samples exhibited diverse compositions, ranging from silica-rich deposits to corrosion-product-dominated scales. Dissolution efficiency ranged from **11% to 65%**, with the highest performance observed on LT Preheater scales containing a balanced mix of silica and corrosion products (Table 1). Visual comparisons of pre- and post-treatment samples (Figure 3) revealed significant fragmentation.

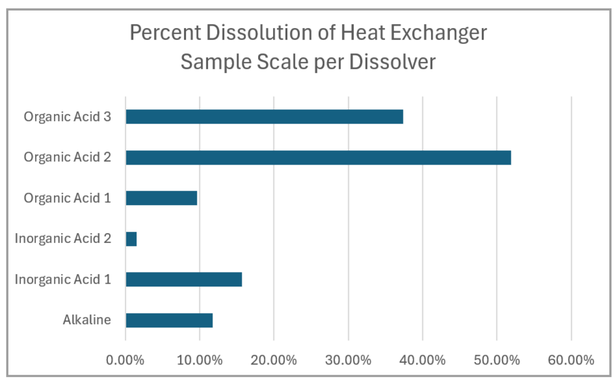


Figure 2. Percent dissolution of different dissolvers on a representative heat-exchanger scale sample predominantly composed of amorphous silica, Fe-oxides and Fe-sulfides.

Table 1. Solubility results using the organic acid blend 2 on different binary plant scales.

#	Temperature Regime	Scale Composition	% Dissolution
1	170 - 140 °C	87% amorphous silica, 5% corrosion products, 5% amorphous clays, 3% impurities	41%
2	140 - 80 °C	25% amorphous silica, 10% corrosion products, 65% metal fragments	11%
3a	110 - 80 °C	50% amorphous silica, 40% corrosion products, 7% amorphous clays, 2% formation materials	39 to 63%
3b	110 - 80 °C	50% amorphous silica, 40% corrosion products, 7% amorphous clays, 2% formation materials	15 to 46%
4	80 °C	45% amorphous silica, 40% corrosion products, 10% amorphous clays, 4% formation materials, 1% % metal fragments	65%

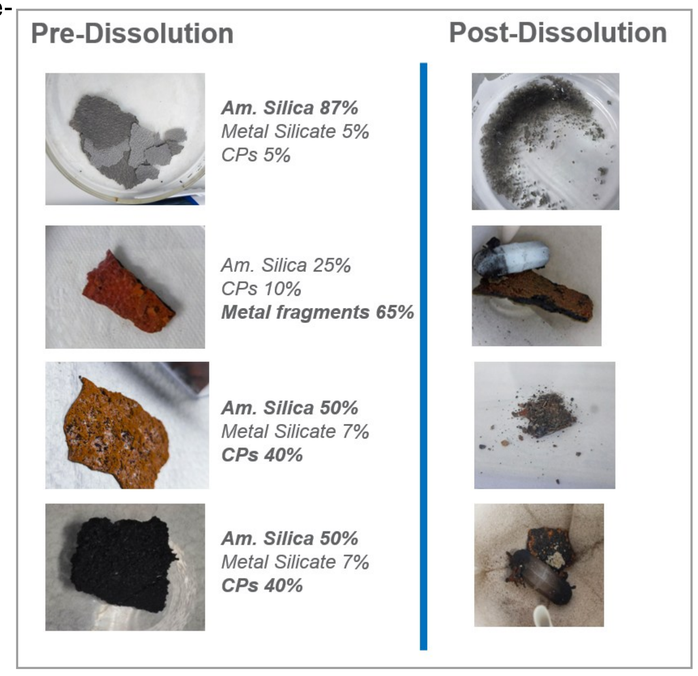


Figure 3. Photos of scale samples before and after soaking.

DISCUSSION

Elemental Analysis by X-ray Fluorescence — **Test Method: CP17000**

The sample preparation was: Dried at 105 °C

Silicon (SiO2)	66 wt %
Sodium (Na2O)	6 wt %
Magnesium (MgO)	5 wt %
Aluminum (Al2O3)	4 wt %
Iron (Fe2O3)	2 wt %
Sulfur (SO3)	2 wt %
Potassium (K2O)	1 wt %
Total From XRF:	**88** wt %

The following elements were not detected or were below the reporting limit (< 0.5%):
Sb As Ba Bi B Br Cd Ca Ce Cs Cl Cr Co Cu Dy Er Eu F Gd Ga Ge Au Hf Ho In I Ir Fe La Pb Li Lu Mn Hg Mo Nd Ni Nb Os Pd P Pt Pr Re Rh Rb Ru Sc Sm Se Ag Sr S Ta Te Tb Sn Tm Ti W Tl Th U V Yb Y Zn Zr

The dissolution results highlights the reaction of different scale formations to different chemical formulation. Initial screening showed that organic acid blends achieved the highest removal (up to 52%) compared to inorganic acids and single-component treatments

- Silica-rich scales responded significantly (39 –52%) to organic acid blends especially to organic acid blend 2. Metal fragment-dominated scales showed minimal dissolution (11%).
- The best-performing formulation is the organic acid blend 2)to work on scale sample mainly composed of both amorphous silica and corrosion products, confirming the benefit of synergistic action different components of the blend, but the percent dissolution has a wide range depending on the dominant scale composition and degree of heterogeneity.
- Some organic acids such as citric and sulfamic were less effective for high-silica deposits, consistent with literature on silica's low solubility in weak acids.

XRF elemental analysis confirmed high residual SiO_2 content (≈66 wt%), along with metals (MgO, Al_2O_3, Fe_2O_3).

CONCLUSION

Organic acid blend chemical dissolution offers a promising alternative or complement to mechanical cleaning for geothermal binary plant heat exchangers, achieving up to 65% dissolution on scales containing both silica and corrosion products while maintaining non-corrosive properties. However, the study also highlights critical considerations:

- Effect of treatment conditions: Scale deposit composition is influenced by the plant's scale mitigation method.
- Organic acid blend performance: While the optimized organic acid blend delivered the best results in this study, it may not be universally applicable across all geothermal binary plants due to differences in brine chemistry, and dominant scale deposit composition.
- Residual silica challenge: Post-treatment analysis confirmed persistent crystalline silica phases, indicating that single-step cleaning is insufficient for complete removal.

Recommendations: Consider multi-stage dissolution strategies, combining alkaline and acidic treatments or sequential chemical-mechanical approaches for severe scaling. Laboratory simulation is only the first step. Pilot -scale testing to confirm effectiveness and operational viability.

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