Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026

Scaling in Obama onsen geothermal plant, Japan: microstructure analysis and its imitation in a laboratory environment

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Keywords: Scaling, Magnesium silicate, Calcium carbonate, Imitation method

INTRODUCTION

Japan has many hot spring (onsen) sites with high volumes and temperatures around 100 ˚C. Obama Town in Nagasaki Prefecture is one of the most notable areas, where about 70% of the geothermal water is extra-hot, with an estimated potential of 42 MWt (Muraoka, 2007). This large thermal potential suggests a strong possibility for use in a geothermal binary power plant. They conducted a feasibility study for a binary-type geothermal plant. In the results, scaling appeared after the wellhead. We have been studying the texture and developing an artificial-scale synthetic method. This paper reviews a series of studies on texture analysis of actual scale and laboratory imitation of silicate scales, aiming toward anti-scaling technologies.

1 METHODS & RESULTS

1.1 Layered Structure of Scale

Carbon steel pipes with scaling before and after the aeration tank were collected. The textures of the scales were analyzed using SEM/EDS, XRD, and FT-IR, and the microstructure and phases were identified. Figure 1 shows the layered structure. In the compositional images, the dark gray area is resin. From optical microscopic observation, the scale before aeration consists of five layers, while the scale after aeration has two layers. Each layer was named L1, L2, etc. The L1 layers in both pipes are divided into two parts based on SEM/EDS analysis. Iron corrosion products initially formed on the carbon steel pipe. Magnesium silicate (Mg-silicate) formed overall on their corrosion products. Iron corrosion products readily reacted with silica in the solution, promoting silicate scaling (Koyama et al., 2022). A calcium carbonate ($CaCO_3$) layer developed on the magnesium silicate pipe before aeration, but was not observed after aeration. The formation of calcium carbonate heavily depends on the degassing of carbon dioxide (CO_2). This suggests that the aeration tank causes CO_2 degassing, which inhibits calcium carbonate precipitation afterward. The initial phase originated from mineral elements in the geothermal brine was magnesium silicate, whereas calcium carbonate did not precipitate directly on the corrosion product, as observed area.

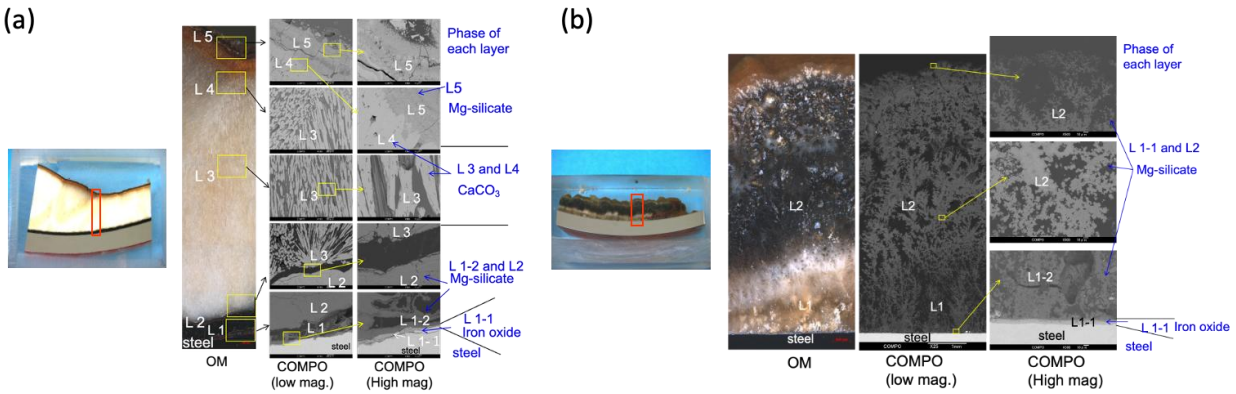


Figure 1. The layered structure of scale on the surface of the pipe (a) before aeration and (b) after it at the Obama Onsen binary power plant. The left-side figures are sectional photographs of the pipes with scale embedded in resin, and the red squares indicate the observation areas examined by optical microscopy and SEM/EDS. Both optical microscopic and compositional images are shown. The phases of the layers were identified. (Modified from Morita and Umezawa (2016) and Morita and Motoda (2021a))

1.2 Temporal Change of Thickness and Substance of Scale

A stainless steel pipe (nominal diameter: 100A) was installed in the piping for the Orange Bay source at Obama onsen. We checked its appearance and thickness approximately every two weeks (Figure 2). The surface color initially changed from metallic gray to black over time, and this growth continued until 35 days. White $CaCO_3$ was visible after 42 days, with the growth rate rapidly increasing, then slowing down around 90 days. The surface color finally changed to black. The results indicated that Mg-silicate grows much more slowly than $CaCO_3$; therefore, preventing Mg-silicate growth could delay scaling. Stopping Mg-silicate scaling early is especially important in this case.

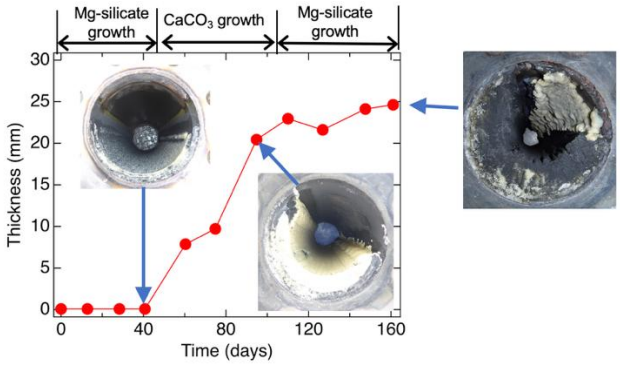


Figure 2. Changes over time in the thickness of the scale before aeration and the development of the scale.

1.3 Artificial-Scale Synthetic Method

To address the scaling issue at the Obama onsen binary power plant, the development of anti–scaling technology should be accelerated. We have created the artificial-scale synthetic method. The geothermal fluid contains magma gas and dissolved oxygen, but the effects of these gases should be considered. We prepared degassed water, then added CO_2 gas, N_2 gas, or atmospheric air, heated the water to around 100°C, and finally added chemicals (Morita et al., 2021). The test solutions flowed through a carbon steel pipe. Figure 3 shows the XRD patterns for the scales sampled from the pipe surface. The scale synthesized under atmosphere and N_2 conditions consisted of iron corrosion products. In contrast, the scale synthesized under CO_2 conditions was mainly Mg-silicate, with peak positions similar to those at the Obama binary power plant.

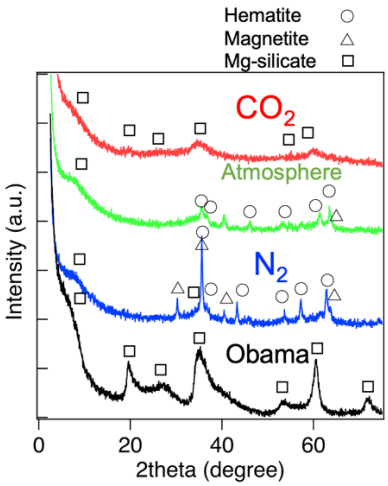


Figure 3. XRD patterns of the artificial scales synthesized in a CO_2 gas atmosphere and a N_2 gas environment, and the scale sampled on the surface of a pipe after aeration at the Obama binary power plant. (Modified from Morita *et al.*, 2021b)

2 DISCUSSION & CONCLUSIONS

The scales observed at the Obama onsen binary power plant indicate that magnesium silicate initially forms on the carbon steel with iron corrosion products. The aeration tank helps control CO_2 degassing, thereby reducing $CaCO_3$ precipitation in the piping downstream. During the initial stage of scale formation at the Obama onsen binary power plant, magnesium silicate scaling dominates over calcium carbonate scaling.

The growth rate of Mg-silicate scale is much slower than that of $CaCO_3$. Once a silicate layer forms, it promotes $CaCO_3$ scaling, causing rapid growth. Therefore, the best way to prevent scaling is to stop the initial formation of Mg-silicate.

The artificial scale synthesis method has successfully replicated Mg-silicate in the scale sampled from the pipe after the aeration tank at the Obama onsen binary power plant. Under N_2 gas or atmospheric conditions, instead of Mg-silicate, iron corrosion products mainly form on carbon steel. The strong correlation between the artificial scales and field-collected scales highlights the effectiveness of the laboratory method for simulating geothermal scaling processes under controlled conditions. This approach provides a foundation for developing anti-scaling technologies suitable for binary power plants.

Acknowledgements

We sincerely thank the New Energy and Industrial Technology Development Organization (NEDO) for its valuable support of the "Geothermal Power Generation Technology Research and Development" project. This study was also supported by the JSPS KAKENHI (Grant Numbers 19H02453 and 23K23074) and by a research grant from the Moritani Scholarship Foundation.

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