

GEOCHEMICAL STUDY OF THE CHARACTERISTICS, FORMATION MECHANISMS, AND CONTROLS OF SILICA SCALING AT THE OLKARIA GEOTHERMAL FIELD, KENYA

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SCALING AT THE OLKARIA GEOTHERMAL FIELD, KENYA
(ケニア・オルカリア地熱地帯におけるシリカスケールの特徴・生成機構・
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論 文 内 容 の 要 旨

Scaling and corrosion have been reported as the biggest utilization problems in developing geothermal resources worldwide. In Olkaria, comprehensive geochemical characterization of silica scaling to understand the mechanisms of formation and deposition at the different levels has yet to be done. Therefore, this study could serve as a guiding reference for future studies on the types of scaling in the alkaline geothermal environment.

Chapter 1 introduces the background to silica scaling problems, the motivation and significance of this research in Olkaria, and the study's main objectives.

Chapter 2 provides a comprehensive geochemical characterization of the geothermal fluid in Olkaria, especially related to the wells or locations that have the most proliferation to silica scaling. The analysis of the saturation state with respect to quartz and chalcedony showed that quartz controls the concentration of silicic acid in the reservoir fluid. The calculated pH at the reservoir is above neutral, while the pH at discharge is, on average, greater than 9. From chemical modeling, mineral precipitation was mostly guided by rapid fluid cooling from boiling within the wells and in the aquifer, zones surrounding the geothermal wells.

Chapter 3 provides a comprehensive geochemical characterization of the scale deposits at Olkaria and suggests a formation and deposition model. Silicic acid in solution exists as monosilicic acid $[\text{Si}(\text{OH})_4]$ and monosiliate ion $[\text{Si}(\text{OH})_3\text{O}^-]$ depending on pH. The deposits in Olkaria are majorly siliceous, comprising pure amorphous opal-A scales, aluminum-rich opal-A scales, aluminosilicates and quartz. The mechanism for quartz precipitation is such that monosilicic acid or monosilicate ion is adsorbed on the surface of a solid, and the critical nucleus of quartz is formed and grows to crystalline quartz by continuous adsorption of $[\text{Si}(\text{OH})_4]$ or $[\text{Si}(\text{OH})_3\text{O}^-]$ by homogenous nucleation. Amorphous aluminosilicates form as the fluid flashes to $> \text{pH } 9$, and a rapid reaction between $[\text{Si}(\text{OH})_4]$ or $[\text{Si}(\text{OH})_3\text{O}^-]$ and $[\text{Al}(\text{OH})_4]^-$ occurs to form opal-A.

Chapter 4 discusses the physiochemical processes controlling silica colloid formation and deposition. The results showed that the polymerization involved a monosilicic to monosilicic acid, monosilicic to polysilicic acid and polysilicic to polysilicic acid reactions. Aluminum and fluoride ions in solution played a key role in accelerating the rate of silica precipitation. The

percentage of polysilicic particles was high at the very early stages, which would be regarded as a first-order addition of monomers to instantly formed discrete polysilicic particles. The percentage of polymer particles was a strong driving force for aggregation. The ionic strength influenced the rate of silica precipitation, where the rate was higher in wells with ionic strength > 0.03 M. The rate of colloid deposition for the 5th to 17th day was estimated at $1500\text{--}3000\text{ mg m}^{-2}\text{day}^{-1}$, which was considered an interaction at the plate fluid plate interface and contributed to by the nucleation and growth of silica.

Chapter 5 assesses the impact of high fluoride concentration in geothermal waters on silicic acid behavior. Processes that promote the enrichment of fluoride content in the geothermal water are related to sodium-bicarbonate facies that promote the release of F^- from fluorite and cation exchange reactions that enable Ca depletion in the geothermal water. Three processes are suggested for fluoride action on silicates under alkaline conditions: formation of complexes between F^- , O_2^- and some low and high field strength cations resulting in silicate polymerization, adsorption of fluoride with OH surface groups leading to enrichment in deposits, and shift in complexes from NaF to Na-Al-F kind of complexes, that promote polymerization of aluminosilicates.

Chapter 6 discusses applying the test piece immersion method as a laboratory screening technique for chemical inhibitors proposed for use in the Olkaria geothermal field. Initial results show that Si deposition on the test pieces was suppressed in the presence of the inhibitors tested (steam condensate, acetic acid, tiron, citric acid, EDTA, and boric acid). A proposal for a field and demonstration test has been given to be used with the selected inhibitors after a comprehensive laboratory test is concluded.

Chapter 7 presents the general conclusions and recommendations for future work. The growth of the critical silica particles was a series of processes controlled by supersaturation, the ions in solution, and the salt concentration. Amorphous silica could be deposited by heterogeneous nucleation on the fluid/surface interface after the initial homogenous nucleation of nanoparticles into critical sizes. Aggregation of the polymers was promoted by elevated concentrations of ions (Al, F) in solution as well as salts that increased ionic strength and reduced the electrostatic repulsion between the negatively charged polymers. Brownian forces and the hydrodynamic conditions in the flow channel may result in colloidal silica being attached to pipe walls.