

Scale Prevention by Ceramic Balls

Hideo Kawarada^{1,*} and Olivier Pironneau²

¹74-2, Sanjinsawa, Shimokajiro, Onahama, Iwaki, Fukushima,
970-0316, Japan.

²Sorbonne University, Boite 187, place Jussieu, F-75252 Paris
cedex 5, France.

Received 31 July 2018; Accepted (in revised version) 2 January 2019.

Abstract. We studied the influence of the arrays of ceramic balls on the hardness of water and discovered effects, which can possibly explain the correlation between the balls and the growth of calcite crystals of CaCO_3 . A model to compute the electric field at the surface of the balls is proposed. It is shown that the number of polarised nuclei contributing to scale prevention is considerably larger than in natural water. Numerical simulations for a two-dimensional macroscopic model show that the effect of ceramic balls can be reproduced in configurations studied experimentally and industrially. Summarising, we note that ceramic balls induce a polarisation in the calcite particles thus decreasing the surface tension energy of crystals in the vicinity of the ceramic balls.

AMS subject classifications: 68U20, 78A57, 97M50, 97E99

Key words: Water scale control, Poisson-Boltzmann equation, crystal lattice model, Helmholtz free energy, Navier-Stokes equation.

1. Introduction

Water pollution is a serious problem everywhere in the world. As a kind of water pollution, scale formations — i.e. hard grayish-white substance, often reduce the efficiency of cleaning systems and inflict severe damage on pipes and aqueous closed systems. Examples of such damage are shown in the left and central pictures in Fig. 1. Various anti-scale treatments have been developed — cf. Refs. [2, 3, 7–9, 11, 12, 14, 19, 20], one of which, a tight aggregate of ceramic spheres, is presented in the right picture in Fig. 1. Immersed in natural water, it prevents the scale formation [13]. The diameter of the ceramic balls is around 1 cm and their surface is covered by inorganic oxides, whose main ingredients are SiO_2 and Fe. The latter produce free electrons by the reaction $\text{Fe} \rightarrow \text{Fe}^{++} + 2e$. The electrons, in turn, are captured by the hydrogen ions in water $2\text{H}^+ + 2e \rightarrow \text{H}_2$ thus leaving a considerably thin layer of OH^- very near the surface of the balls.

*Corresponding author. *Email addresses:* kawarada0@nifty.com (H. Kawarada), olivier.pironneau@upmc.fr (O. Pironneau)



Figure 1: Unwanted effect of scale and the device studied here to cure it.

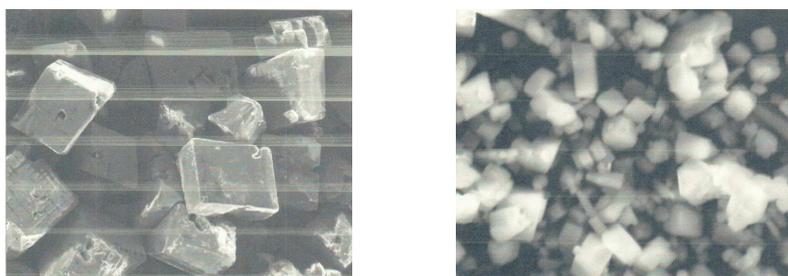


Figure 2: Left: CaCO_3 crystals in natural water. Right: same after 24h in contact with the spheres shown in Fig. 1.

Unlike chemical treatments, this approach does not change the water composition, only the size of the calcite aggregates — cf. the right picture in Fig. 2. However, in spite of encouraging outcome of various experiments, theoretical background of the method is open.

1.1. The process and the approach

What is the cause of scale formation? Calcite particles form crystals by a phase-change phenomenon. Scale is a more stable state for the crystal particles of calcium carbonate (CaCO_3 , calcite being its most stable crystal form) obtained by adhering to the surface of another material to release surface tension energy. Experimental measurements [22] show that the ceramic spheres in water generate an electric field near the layer caused by electrolytic solutions such as water containing Ca^{++} and CO_3^{--} ions: the layer of OH^- attracts Ca^{++} ions thus changing the crystal structure of calcite. The crystal particles close to the surface of a ceramic sphere are exposed to an electric field and store this additional polarisation energy which changes the crystal structure making scale formation less favourable energetically. Therefore, our investigation is focused on an electric field and also on polarisation energy with special emphasis on surface tension energy. This approach is referred to as the contact model.

Finally, as soon as it becomes clear that the slate-capable calcite concentration diminishes in the vicinity of the ceramic balls, the efficiency of various arrangements of ceramic spheres has to be studied. This is done by using a macroscopic model and an ad-hoc boundary condition for the calcite concentration. This last section is mostly numerical.