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Controlling the sequence of oxidation processes to enhance sand filter performance

EMIEL KRUISDIJK[1,2], FRANCESC CORBERA RUBIO[2], MICHELE LAURENI[2], BORIS M VAN BREUKELEN[2] AND DORIS VAN HALEM[2]

[1]Eawag - Swiss Federal Institute of Aquatic Science and Technology
[2]Delft University of Technology

Rapid sand filters are designed to remove iron (Fe^{2+}), manganese (Mn^{2+}), and ammonium (NH_4^+) from anaerobic groundwater to produce safe drinking water. Removal occurs through a combination of physicochemical and biological processes typically involving a series of uncontrolled simultaneous oxidation reactions. Transitioning to controlled sequential oxidation reactions enhances sand filter efficiency as conditions for each reaction can be optimized and negative interactions between reactions are eliminated. This ultimately results in higher flow rates, and reduced backwashing.

The potential for sequential oxidation of Fe^{2+}, Mn^{2+}, and NH_4^+ in separate filters was assessed through experiments conducted at a Dutch drinking water treatment site. Anaerobic groundwater treatment was studied in three treatment trains. Initially, Fe^{2+} was selectively oxidized and removed in a full-scale drinking water filter. The discharged water was then treated for Mn^{2+} and NH_4^+ in five pilot-scale filters under different conditions divided over the three treatment trains. The three oxidation processes were successfully separated by adjusting the oxygen concentrations and pH of the influent water through controlled aeration and base dosing. These adjustments also allowed us to modify the order of NH_4^+ and Mn^{2+} oxidation.

In a follow-up study, the sequential oxidation of Fe^{2+} and Mn^{2+} within a single filter was studied. Mineral coatings can significantly catalyse Fe^{2+} and, especially, Mn^{2+} oxidation playing a crucial role in rapid sand filters. Based on Gibbs free energy calculations, we expect Fe^{2+} to oxidize first in sand filters, followed by Mn^{2+} oxidation. This results in spatially separated layers with grains coated with Fe^{3+} precipitates in the top of the filter and Mn^{3+}/Mn^{4+} precipitates at the bottom. However, backwashing of the filter often leads to full mixing of the coated grains, initiating heterogeneous Mn^{2+} oxidation on Mn-coated grains that migrate to the top layer. This causes simultaneous oxidation of Fe^{2+} and Mn^{2+}. To maintain sequential oxidation, mixing of the grains must be prevented. This can be achieved using a dual-media filter or two separate filters, where complete Fe^{2+} oxidation occurs in the first layer/filter.