Dynamics of biofilm spatial-temporal heterogeneity in RSFs for ammonium and manganese removal from groundwaters

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Filtration through natural biofilms in Rapid Sand Filters (RSFs) is among the most used processes to remove ammonium and manganese from groundwaters. However, initial biofilm seeding is relatively slow, and little is known about the spatial-temporal distribution of the activities. The objectives of this work were to: (a) understand heterogeneity of microbial populations and activities in depth and time, (b) discover how it impacts the process, and (c) develop a mathematical model to propose and experiment enhanced “start-up” strategies.

A stainless-steel column filled with sand was fed with groundwater, with the possibility to modulate inlet temperature and substrate concentrations in “enhanced configuration”. Ammonium, nitrite and manganese concentrations were measured by spectrophotometry at the inlet, at several intermediate column heights and outlet of the RSF. A model was developed with Aquasim software where biological reactions, and evolutions of soluble compounds, free and attached functional microbial populations are described. Sand and water at different experiment stages and in RSF depths were sampled for DNA extraction and 16S rDNA sequencing, qPCR and metagenomic analysis.

Results shed light on heterogeneity in time of the activities: nitrification systematically begins before manganese oxidation. Analysis in all depth of the RSF, “profiles”, show that all activities are evenly distributed during the seeding and attachment of planktonic microorganisms. However, after the initial phase “start-up”, profiles indicate logically that the biological activities migrate to the inlet of the RSF where substrates are. Most of the substrates are oxidized on the first quarter of sand media depth.

Relative abundances of microorganisms indicate that active species changed from the start-up phase to the production phase: AOB Nitrosomonas species were dominant during ammonium oxidation, while commamonox Nitrospira species were mostly found in production.

The model fits pilot data in terms of elimination periods duration and distribution of the activities and allowed to estimate parameters to further simulate “start-up” configurations. By increasing temperature and substrates loading rate, effective nitrifying biofilm settlement was achieved 4.7 times faster than in conventional conditions. However, no significant improvement was observed for manganese oxidation.

At the end of the start-up phase, with both conventional and accelerated method, the filters hosted similar communities. The model, confronted to experiments in production time, validated that the spatial heterogeneity in depth of the RSF ensures robustness of the biological process to punctual over charge of ammonium and manganese.

Our study showed that (a) spatial-temporal heterogeneity is linked to growth of different microbial
populations in time, but also related to local conditions in time and depth, and (b) heterogeneity in depth is a characteristic of RSFs and is responsible for robustness and resilience of the process.

REFERENCES

