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Assessing and optimizing biofilter performance in drinking water treatment

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ABSTRACT

Biological filtration is a widely used treatment barrier in drinking water treatment plants to ensure the biological stability of treated water in distribution systems. Biofilters remove particulate and dissolved organic matter (DOM) and biodegradable organic matter from water. However, biofilters are difficult to study at full-scale where they are influenced by many factors that vary over time. Furthermore, there are multiple DOM removal processes occur simultaneously within BAC filter biofilms including adsorption, desorption and biodegradation. This research examined how optical properties of DOM (e.g. fluorescence spectroscopy and absorbance) can be used as an advanced characterization method to provide novel insights into performance and fundamental mechanisms of drinking water treatment via biological filtration processes.

A full-scale study involving experimental manipulation of parallel biofilters with non-adsorptive media allowed the study of DOM removal as a function of empty bed contact time (EBCT). By continuously monitoring effluent turbidity from the filters and measuring DOM removal via fluorescence spectroscopy, it was shown that turbidity and protein-like DOM removal increased linearly with increasing EBCT up until at least 80 min EBCT. Removal of refractory humic-like DOM removal improved, although to a smaller extent. This was contrary to the prevailing view that there is a negligible improvement in DOM removal efficiency at contact times longer than 30 min. Striking a good balance between DOM removal by biofiltration and the cost of longer EBCT can in turn result reduced operational costs while improving finished water quality.

This research was also carried out to distinguish biotic (biological degradation) and abiotic (adsorption and desorption) processes occurring within biofilter media. To distinguish these requires a suitable abiotic control, i.e. filter media with the same chemical properties but no biology. To identify abiotic controls for BAC filter experiments, a batch-scale study was conducted using gamma irradiation as a sterilization method. However, by measuring DOM removal via fluorescence spectroscopy, it was possible to observe that the chemical properties of biofilter materials changed even at low gamma doses (2.5 kGy) and a dose-related release of protein-like fluorophores occurred, possibly from the biofilm. The gamma-irradiation method was therefore deemed to be unsuitable for producing abiotic controls for BAC studies.

In a further attempt to identify abiotic controls for BAC filter experiments, the temperature was utilized as an alternative control strategy. Depending on responses to temperature in batch experiments, it was deduced whether DOM removal predominantly occurred via adsorption (chemisorption/physisorption) or biological degradation. Under the particular experimental conditions, there was little evidence of biological removal; instead, removal of DOM fractions emitting at longer wavelengths ("humic-like", >430 nm) was consistent with chemisorption, removal of DOM emitting at intermediate wavelengths ("humic-like", 390-420 nm) was consistent with physisorption, and multiple mechanisms were indicated for "protein-like" (<380 nm) DOM. Abiotic mechanisms like adsorption are often assumed to be unimportant for aged BAC filters; however, these results suggest that abiotic processes may be important for some DOM fractions.

Ultimately, this research aims to inform the design and operation of full-scale biological filters under Nordic climate conditions. To that end, a simple and cost-effective operational strategy was investigated for improving short-term DOM removal in full-scale biological filters. The strategy involved replacing a small fraction of saturated filter media with new media. Relative to replacing the entire media, this approach required lower capital cost and shorter downtime and maintained conditions for biological filter functioning. The modified biological filters showed improved DOM removal lasting for several weeks.

The results of this thesis demonstrate that fluorescence spectroscopy, due to high analytical precision and sensitivity, is a sensitive method for tracking DOM removal via biological filters. Additionally, it suggests there are opportunities to improve drinking water treatment by promoting one or other of the removal mechanisms depending on the incoming water quality. For example, allowing longer contact time in summer when there is elevated biodegradable DOM removal or performing partial renewal of biofilter media after heavy rains when incoming water has relatively high organic pollutants. Overall, these results are relevant to water producers that aim to optimize biofilters performance under strained operating conditions.

Keywords: Biofilter, full-scale biofilters, optical properties, drinking water, dissolved organic matter, treatment optimization, sterilization.