Nitrification activity stratifies in a rapid sand filter for drinking water treatment - A study in two Danish waterworks

Tatari, Karolina; Smets, Barth F.; Gudbrand, T.; Nielsen, P. B.; Lind, S.; Albrechtsen, Hans-Jørgen

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K. Tatari[a], DTU Environment, B.F. Smets[a], DTU Environment, T. Gudbrand[a] , DTU Environment, P.B. Nielsen[b,], Krüger, S. Lind[c], Københavns Energi, and H.-J. Albrechtsen[a], DTU Environment*

Abstract
Rapid sand filters are widely used in groundwater treatment to remove ammonium, iron and manganese from the raw water. Typically, filter performance is evaluated based on effluent concentration leading to a "black box" approach with regard to the processes that take place in the filter. This lack of knowledge creates uncertainty about performance robustness and reasons for filter malfunctioning. Specific insight of the processes is needed to allow a detailed optimization and remedial strategy.

Ammonium is removed biologically by nitrifying microorganisms attached on the sand grain surface. Nitrification kinetics is the key parameter controlling ammonium removal in a filter and can therefore be a powerful diagnostic tool revealing potential process limitations. In this study, we used a lab scale biofilm assay to investigate nitrification activity in two Danish waterworks. The aim was to identify how nitrification activity distributes within a filter and whether this profile is consistent in filters performing differently. Plant 1 operates a single line of pre and after filters and has been well performing over the last years. Plant 2 consists of two separate lines, each one with pre and after filtration steps. Plant 2 has experienced challenges in removing ammonium below the 0.05 mg/L regulatory limit especially in one of the two lines. Sand core samples were taken from the after filter in plant 1 and each after filter line of plant 2. Core samples were divided according to depth and nitrification activity was measured with a biokinetic assay. The experimental set up consisted in small columns packed with the sand core subsamples. The columns were continuously loaded with ammonium, mimicking the respective full scale filter conditions. To investigate kinetics, the loading was increased in short time experiments and the effect on the effluent was monitored. Ammonium removal rate at full scale filter conditions and potential nitrification activity were derived for the different filter regions of the two treatment plants.

Nitrification activity was in all cases concentrated at the top 10 cm of filter depth, and maximum nitrification capacity was 7 g NH_4^+-N/ m^3 sand/h compared with 0.8-0.4 g NH_4^+-N/ m^3 sand/h in the middle and bottom layers. A water sampler was installed in the full scale filter of plant 1 to observe the ammonium profile with depth. Ammonium was removed within the upper 15 cm with a removal rate ranging of 3.6- 7.7 g NH_4^+-N/ m^3 sand/h. Full scale observations fit with the lab scale activity measurements showing that the upper layer of the filter is where nitrification mostly happens. Deeper layers that are less active, provide extra nitrifying capacity in case ammonium is not removed within the top 15 cm. This study showed that rapid sand filters are stratified in terms of biological activity. This can be an important consideration for process optimization and modeling considerations.

**kaot@env.dtu.dk*
[a]*Bygning 113, DTU, 2800 Lyngby, Denmark*
[b] *Gladsaxevej 363 Søborg, 2860 Denmark*
[c]*Ørestads Boulevard 35, 2300 Copenhagen S., Denmark*