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Stratification of nitrification activity in rapid sand filters for drinking water treatment

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Rapid sand filters used in groundwater treatment remove ammonium, iron and manganese from the water. Ammonium is removed biologically by nitrifying microorganisms attached on the sand surface. Nitrification kinetics and activity is strongly affected by filter design and operation, which are the key parameters in process optimization. Nitrification optimization needs a detailed insight of the process and the way it takes place in the filter. Filters are often considered in a "black box" approach, where data are only available for influent and effluent and the entire filter is assumed homogenous. The aim of this study is to investigate nitrification activity in a rapid sand filter, with focus on its homogeneity and how it relates to filter performance.

Two groundwater treatment plants in Denmark were selected for the experimental investigations. 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 the after filters in both lines of plant 2. Core samples were divided according to depth and nitrification activity was measured in a lab scale assay. The method consists in a continuous flow mini-column where influent and effluent are monitored for all nitrogen species. Kinetics and maximum nitrification capacity are derived and used to quantify nitrification activity.

Nitrification activity was 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. qPCR counts for ammonium oxidizing bacteria showed a decrease from $5*10^7$ cells /gr sand at the top of the filter to $2*10^5$ cells /gr sand in the lowest 20 cm. From this study results that rapid sand filters are not homogenous in terms of biological activity. This can be an important consideration when modeling these units and as a basis for process optimization.