Softening of drinking water – are other processes in the treatment affected?

Use of salty groundwater for toilet flushing to substitute drinking water - water and microbial quality

Biological treatment: Optimization of biological rapid sand filters for drinking water production

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Use of salty groundwater for toilet flushing to substitute drinking water - water and microbial quality

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Biological treatment: Optimization of biological rapid sand filters for drinking water production

Drinking water production from groundwater will often require removal of several compounds such as ammonia, manganese, ferrous iron, methane, sulphides or natural organic matter (NOM). In rapid sand filters this may be mediated through microbial processes. Sometimes the filters unfortunately fail to meet the design criteria, and a deeper insight in the underlying processes would provide a necessary platform to solve the problems. Efficient removal of potential microbial substrates is essential for production of biostable water which is required when the produced drinking water is stored and distributed without a disinfection residual as e.g. in Denmark. We have developed a toolbox including investigations of the presence of required microorganisms. To investigate the presence and density of various microbial fractions, qPCR-methods were established for quantification of ammonium oxidizing (AOB, AOA), nitrite oxidizing (NOB), iron oxidizing (IOB) and methane oxidizing (MeOB) microorganisms. In addition, pyrosequencing of the full microbiome of the sand filters revealed a high diversity, and especially the presence of a very large and dominating population of Nitrospira was surprizing. Nitrification was particularly investigated in full scale filters, and lab-scale CST-columns incubated with depth specific samples of filter material allowed for investigation of the depth specific kinetics and maximum removal capacity. Additionally, pilot scale column experiments allowed for investigation of e.g. increased load of ammonium due to increased hydraulic load versus increased concentration, physical space in the filter material and its surface qualities. A safe operational windows in terms of load was identified during short term up-shifts in the ammonium load to the different columns. This showed the importance of the total load no matter the increase was due to hydraulic load or concentration. Based on the obtained insight the functionality of the filters could be optimized. Addition of limiting micronutrients such as phosphorous or cupper (which specifically stimulating nitrification since cupper is an essential metal in the ammonium mono oxygenase) was able to increase nitrification rate, to overcome incomplete nitrification with accumulation of nitrite, and to reduce the startup time of the microbial processes in new filters. This presentation provides an overview of a number of research projects on biological rapid sand filters conducted during the last 5 years.

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Can pesticide degradation be connected with methane oxidation at waterworks?

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Contributors: Hedegaard, M. J., Lee, C. O., Albrechtsen, H.
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Methane oxidation and the degradation potential of the herbicide bentazone at Danish waterworks

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Organisations: Department of Environmental Engineering, Urban Water Systems
Contributors: Hedegaard, M. J., Lee, C. O., Albrechtsen, H.
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On-line monitoring of microbial drinking water quality – on site tests

Microbial contamination is a major threat to drinking water quality, and monitoring the microbial water quality is a way to ensure good and safe drinking water. However, grab sampling and long incubation times for growth based methods may lead to late responses (several days) which may be too late to allow for relevant correcting actions. This calls for methods which can provide results rapidly - ideally in nearly real times. Microbial water quality is not restricted to pathogens or indicator organisms, since increased microbial numbers and activity may reflect the management and functionality of microbial processes in the treatment such as back washing of biological rapid sand filters. Furthermore they may become essential in distribution systems to monitor the efficiency of the disinfection or in cases without disinfection residual where reparations of pipes, stagnant water or ingress of water in case of leakages challenge the water quality.

Several approaches have been taken to monitor the microbial water quality - one is a biochemical parameter Adenosine TriPhosphate (ATP), since it is an energy carrier molecule present in all living cells. Monitoring of ATP in drinking water is a promising technique because firstly, ATP is an indicator of total microbial activity, meaning that only active microorganisms are detected, and the detection is not restricted to a specific microbial type. Secondly, ATP analysis can provide results in few minutes, creating a great potential for real time monitoring. We have successfully demonstrated the use of ATP as a measure for ingress of contaminating water in the drinking water system, and to monitor the effect of backwashing rapid sand filters.

Another approach is to monitor enzyme activity in terms of Alkaline Phosphatase (ALP), which is produced in most microbial cells and which can use 4-Methylumbelliferyl-Phosphate (MUP) which is a Flourescent substrate. This is measured in a fully automated instrument BACTcontrol (microLAN) with a total measuring time of 40 minutes and where the phosphatase activity was determined by measuring the fluorescence associated with the formation of 4-methylumbelliferone (MUF).

We are comparing these two approaches: the BACTcontrol Total Activity online analyzer and ATP analysis as well as other viability assays through simultaneous measurement at two different water companies: Aigües de Barcelona (AB), and Cetaqua, Spain, and Nordvand, Gentofte, Denmark. The eight-month long investigation includes including both the drinking water treatment plant and the distribution network i.e. multi-source chlorinated tap water from Barcelona DN and three types of process water from DWTP (sandfiltered water, GAC-filtered water and treated water) as well as biologically treated ground water.

This project is an ongoing work and further validation and optimization are supported by the EU granted project Aquavalens.
Pesticide degradation potential of pesticides in biological rapid sand filters at 10 different waterworks

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Optimizing nitrification in biological rapid sand filters: Diagnosing and supplementing micronutrients needed for proper filter performance

Nitrification is an important biological process commonly used in biological drinking water filters to remove ammonium from drinking water. Recent research has shown that a lack of micronutrients could be limiting the performance of these filters. Because nitrification is a biological process, carbon, nitrogen, phosphorus and other micronutrients, such as copper, are required to ensure growth and activity. In nitrification, copper is a micronutrient that is needed in the amoA enzyme used by ammonia-oxidizers to oxidize ammonium to nitrite. Increasing nitrification performance is needed in many filters that are unable to meet ammonium guideline values for drinking water, and can also be used to optimize filter performance by increasing water treatment capacity. Although copper supplementation can increase nitrification in some filters with nitrification problems, it does not always work. Therefore, in order to avoid the time, expense, and regulatory hurdles of supplementing a filter with copper, there is a need to accurately diagnose copper limitations in these filters. To determine if copper addition could increase nitrification in filters with nitrification problems, a bench scale batch essay was developed and tested. Initial batch experiments showed that proper mixing was needed to avoid concentration gradients, and that caution should be taken when mixing to avoid damaging the filter coating. Initial experiments were used to determine the proper mixing regime, which was then applied to all further batch tests. A collaboration between DTU Environment, industrial partners, and different water works was established to test the batch essays at two different water works. Both water works had trouble meeting the Danish guideline value for ammonium (0.05 mg NH4/L). At the start of the batch essays, ammonium removal was determined at 3 different ammonium concentrations, both with and without copper addition (for a total of 6 different batch essays). This was done at both water works to determine the initial removal rates. After initial dosing, the ammonium to each batch set up was increased to 10 mg NH4/L to allow for a period of incubation. After a week, the batches were re-spiked to the 3 different ammonium concentrations examined initially. Copper supplementation did not show any observable difference in ammonium removal at the start of the batch essays. After the cultivation period, one of the water works showed increased ammonium removal with copper addition at all examined ammonium concentrations. This was also observed in the corresponding full scale waterworks. The addition of copper yielded no observed difference in ammonium removal at the second water works, which was also observed in the corresponding full scale filter. These findings are important as they show that the batch essays can be used as a diagnostic tool to determine if copper supplementation can increase nitrification performance. The developed batch essays have important practical implications in optimizing nitrification performance. They can not only be used to diagnose and improve nitrification in existing filters, but can also be used to determine if the nitrification capacity of a filter can be increased, which could optimize filter operation. The batch essays have the potential to be an important diagnostic tool that could decrease regulatory hurdles, and save time and money.

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Optimizing nitrification in biological rapid sand filters for drinking water production

Addition of phosphate or trace metals or better management e.g. in terms of ammonium load can improve the nitrification rate and efficiency in biological rapid sand filters.

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The impact of backwashing on nitrification in biological rapid sand filters under different ammonium loading conditions

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Monitoring microbial water quality in Nordhavn

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Phosphorus addition can increase nitrification in biological rapid sand filters for drinking water treatment

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Stimulation of Nitrification in Biological Rapid Sand Filters by Addition of Phosphorus and Trace Metals

General information
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Diagnostics in biological rapid sand filters treating groundwater – governing factors for nitrification
To improve the insight in the processes in biological rapid sand filters a range of methods were developed to diagnose the microbial mediated processes – particularly nitrification.

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Effects of dynamic operating conditions on nitrification in biological rapid sand filters for drinking water treatment
Biological rapid sand filters are often used to remove ammonium from groundwater for drinking water supply. They often operate under dynamic substrate and hydraulic loading conditions, which can lead to increased levels of ammonium and nitrite in the effluent. To determine the maximum nitrification rates and safe operating windows of rapid sand filters, a pilot scale rapid sand filter was used to test short-term increased ammonium loads, set by varying either influent ammonium concentrations or hydraulic loading rates. Ammonium and iron (flock) removal were consistent between the pilot and the full-scale filter. Nitrification rates and ammonia-oxidizing bacteria and archaea were quantified throughout the depth of the filter. The ammonium removal capacity of the filter was determined to be 3.4 g NH₄–N m⁻³ h⁻¹, which was 5 times greater than the average ammonium loading rate under reference operating conditions. The ammonium removal rate of the filter was determined by the ammonium loading rate, but was independent of both the flow and influent ammonium concentration individually. Ammonia-oxidizing bacteria and archaea were almost equally abundant in the filter. Both ammonium removal and ammonia-oxidizing bacteria density were strongly stratified, with the highest removal and ammonia-oxidizing bacteria densities at the top of the filter. Cell specific ammonium oxidation rates were on average 0.6 × 10⁻² ± 0.2 × 10⁻² fg NH₄–N h⁻¹ cell⁻¹. Our findings indicate that these rapid sand filters can safely remove both nitrite and ammonium over a larger range of loading rates than previously assumed.

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Processes effecting nitrification performance in biological rapid sand filters

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Stimulation of nitrification in biological rapid sand filters for drinking water treatment by trace metals

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Stimulation of nitrification in biological rapid sand filters for drinking water treatment by trace metals

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Examining biological sand filters for drinking water treatment as biofilm reactors: experimental and modeling approach

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Contributors: Tatari, K., Smets, B. F., Lee, C. O., Nielsen, P. B., Albrechtsen, H.
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Publication date: 2013
Phosphate limitation in biological rapid sand filters used to remove ammonium from drinking water

Removing ammonium from drinking water is important for maintaining biological stability in distribution systems. This is especially important in regions that do not use disinfectants in the treatment process or keep a disinfectant residual in the distribution system. Problems with nitrification can occur with increased ammonium loads caused by seasonal or operational changes and can lead to extensive periods of elevated ammonium and nitrite concentrations in the effluent. One possible cause of nitrification problems in these filters maybe due to phosphate limitation. This was investigated using a pilot scale sand column which initial analysis confirmed performed similarly to the full scale filters. Long term increased ammonium loads were applied to the pilot filter both with and without phosphate addition. Phosphate was added at a concentration of 0.5 mg PO4-P/L to ensure that it was not the limiting substrate. Preliminary results showed an increased nitrification capacity both with and without phosphate addition although the addition of phosphate doubled the ammonium and nitrite removal capacity of the filter compared to non-phosphate dosing conditions. Phosphate addition also increased the total number of ammonium oxidizing bacteria in the column. © 2013 American Water Works Association AWWA WQTC Conference Proceedings All Rights Reserved.

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Relating dynamic conditions to the performance of biological rapid sand filters used to remove ammonium, iron, and manganese from drinking water

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Increased insight in microbial processes in rapid sand filters in drinking water treatment (DW BIOFILTERS)
The aim of this research project is to improve our knowledge on biological rapid sand filters as they are present in thousands groundwater based water works. This includes molecular investigations of the microorganisms responsible for the individual processes (e.g. nitrification); and detailed monitoring and experiments in the filters and laboratory to provide insight in the process mechanisms, kinetics and effect of environmental factors. Management of the filters (e.g. backwashing, flow rate, carrier type) will be investigated at pilot and full scale, supported by mathematical models. The sustainability and climate friendliness are evaluated by life cycle assessment (LCA). Molecular methods based on qPCR are being developed and implemented to quantify bacteria in different functional groups, such as those responsible for nitrification. This allows for development of diagnostic tools to detect if essential or core members are present or absent in a malfunctioning filter. It is meaningful to optimize the management of the filter only if they are present at relevant concentrations. Furthermore, to get insight in the complexity of the microbial community, the full microbial community is being investigated by deep sequencing. This will also contribute to a verification of whether the selected qPCR probes include all important groups. Filters from three water works have been sampled and are currently being processed to investigate depth profiles and horizontal variation in filters. Assays for essential microbial processes such as nitrification and oxidation of manganese are currently being established. They will provide identification of controlling parameters, bottle necks or inhibition of microbial removal of the bulk compound and the effect of filter management. Finally, a pilot plant has been established at Islevbro Water Works (operated by Copenhagen Energy) with material from the full-scale afterfilter. After validation that the pilot plant is mimicking the full scale filter, it will be used to investigate processes at larger scales such as backwashing procedures and effect of increased load of e.g. ammonium, manganese and ferrous iron. This filter will also be used to validate the mathematical models build for the biological filters at full scale.

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Modeling the Performance of Biological Rapid Sand Filters Used to Remove Ammonium, Iron, and Manganese From Drinking Water
Although biological rapid sand filters are a well established technology for treating drinking water, there is still a lack of scientific understanding of the processes controlling their performance. For example, the distribution and role of microorganisms in contaminant removal in the filter has not been described. As a result, the design and operation of these filters is based on rules of thumb rather than firm scientific understanding. The goal of this research is to characterize the underlying processes that control the biological performance of biological rapid sand filters in order to link filter management to performance.

Biological rapid sand filters are used for the dual purpose of particle removal (including microorganisms) and contaminant removal through biological activity on the filter media. For drinking water treatment in the United States, biological filters use granular activated carbon and are often used following ozonation to remove additional biodegradable organics created during ozonation. In Europe, biological filters are also used to remove ammonium and reduced forms of iron and manganese. These compounds can cause biological instability in the distribution system and can lead to many problems including the growth of pathogens and aesthetic problems (taste, odor, and color). All of these compounds can be removed through chemical oxidation with oxidants such as chlorine, but biological filters can be used to remove these compounds and thereby reduce the need for chlorine addition following treatment. Under the normal conditions found in many water treatment plants, reduced iron can be oxidized through aeration and the precipitates can be captured by the filter media. Ammonium and manganese can be removed biologically.

This research uses both pilot and full scale studies to develop methods for how operating conditions affect the performance of the filters. Substrate concentrations, particle/precipitate accumulation, and biomass kinetics are monitored throughout the depth of the filter and over the operational cycle of the filter. Tracer tests, using a conservative salt tracer, are performed during an operational cycle of a filter to examine how the filter flow changes with time. The data is used to validate a mathematical model that can both predict process performance and to gain an understanding of how dynamic conditions can influence filter performance. The mathematical model developed is intended to assist in the design of new filters, set up of pilot plant studies, and as a tool to troubleshoot existing problems in full scale filters. Unlike previous models, the
model developed accounts for the effects of particle/precipitate accumulation and its effects on the biological performance of the filter.

Ozone and biofiltration as an alternative to reverse osmosis for removing PPCPs and micropollutants from treated wastewater
This pilot-scale research project investigated and compared the removal of pharmaceuticals and personal care products (PPCPs) and other micropollutants from treated wastewater by ozone/biofiltration and reverse osmosis (RO). The reduction in UV254 absorbance as a function of ozone dose correlated well with the reduction in nonbiodegradable dissolved organic carbon and simultaneous production of biodegradable dissolved organic carbon (BDOC). BDOC analyses demonstrated that ozone does not mineralize organics in treated wastewater and that biofiltration can remove the organic oxidation products of ozonation. Biofiltration is recommended for treatment of ozone contactor effluent to minimize the presence of unknown micropollutant oxidation products in the treated water. Ozone/biofiltration and RO were compared on the basis of micropollutant removal efficiency, energy consumption, and waste production. Ozone doses of 4–8 mg/L were nearly as effective as RO for removing micropollutants. When wider environmental impacts such as energy consumption, water recovery, and waste production are considered, ozone/biofiltration may be a more desirable process than RO for removing PPCPs and other trace organics from treated wastewater.
experience has shown that some filters have problems consistently meeting regulatory guidelines for compounds like ammonium and reduced forms of iron and manganese. These compounds can cause biological instability in the distribution system and can lead to many problems including the growth of pathogens and aesthetic problems (taste, odor, and color). When problems occur in these filters, current solutions are often based on rules of thumb and guess work rather than on firm scientific principle. The goal of this research is to characterize the underlying processes that control the biological performance of biological rapid sand filters in order to link filter management to performance.

This research uses both pilot and full scale studies conducted at Islevbro water works, a drinking water plant in west Copenhagen, to determine how operating conditions and substrate loading affect the performance of the biological rapid sand filters. The pilot columns consist of two columns that are run in parallel and fed with influent water from the water works. The sand in the pilot columns was taken from one of the full scale filters and matches the depth profile of the full scale filter. The pilot columns were initially operated for approximately 2 and a half months at similar operating conditions as the full scale filter to validate the performance of the pilot columns. After this, the pilot columns were fed with varying loading rates of iron, ammonium, and manganese. To fully examine the changes in filter performance several parameters were analyzed. Water and media samples were collected throughout the depth of the column and over the operational cycle of the columns. Substrate analysis included ammonium, nitrite, nitrate, iron, and manganese. Qpcr analysis were also performed to quantify ammonium oxidizing bacteria (AOBs), ammonium oxidizing archea (AOAs), nitrite oxidizing bacteria (NOBs), and total bacteria with both depth and time. Similar analyses were performed in the full scale filters. The data is used to validate a mathematical model that can both predict process performance and is used to gain an understanding of how dynamic conditions can influence filter performance. The results presented will show how these varying conditions affect both the biological distribution and performance of these filters and will increase the understanding of biological rapid sand filters used to treat drinking water. This research helps to extend the knowledge on the roles of both Ammonium oxidizing bacteria (AOBs) and Ammonium oxidizing archea (AOAs) in the biological removal of ammonium in rapid sand filters and how varying substrate loadings and operating conditions can affect the biological performance of these filters.

Role of peroxy chemistry in the high-pressure ignition of n-butanol - Experiments and detailed kinetic modelling

Despite considerable interest in butanol as a potential biofuel candidate, its ignition behaviour at elevated pressures still remains largely unexplored. The present study investigates the oxidation of n-butanol in air at pressures near 80 bar. Ignition delays were determined experimentally in the temperature range of 795-1200 K between 61 and 92 bar. The time of ignition was determined by recording pressure and CH-emission time histories throughout the course of the experiments. The results display the first evidence of the influence of negative temperature coefficient (NTC) behaviour which was not observed in earlier ignition studies. The high-pressure measurements show that NTC behaviour is enhanced as pressures are increased. The experimental results were modelled using an improved chemical kinetic mechanism which includes a simplified sub-mechanism for butyl peroxy formation and isomerisation reactions currently incompletely accounted for in n-butanol kinetic models. The detailed mechanism validated with the high-pressure ignition results for realistic engine in-cylinder conditions can have significant impact on future advanced low-temperature combustion engines. (C) 2011 The Combustion Institute. Published by Elsevier Inc. All rights reserved.