Transformations of Organic Carbon in Three Greywater Recycling Systems Employing Different Post-treatments

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Abstract
Full-scale BAMBi greywater recycling systems are currently being investigated, combining a gravity-driven membrane bioreactor with UV-185 nm, activated carbon and electrolysis post-treatments. The goal for each system is to recycle the same volume of water to hand-washing quality after repeated uses. Meeting this demand requires a series of chemical transformations and removals, where some compounds are broken into smaller pieces, or specific bonds are modified. Targeting such removals and transformations to the specific types of organics that contribute to color, or are easily assimilated by bacteria will efficiently alleviate these concerns in the produced water. Batch testing with permeate from a system operating without post-treatment allows us to investigate the concentrations and the chemical transformations that occur in organic carbon as a function of exposure to each post-treatment. Initial batch testing with UV-185 nm demonstrates rapid initial removals of dissolved organic carbon and color absorbance that slows as more-easily degraded compounds are removed. The first hour of batch treatment yields a removal of 11 mg/L DOC, but removing a second 11 mg/L removal requires an additional 3.5 hours. Size exclusion chromatography analysis of permeate, before and after UV-185 treatment, demonstrated a preference for removal of larger organic compounds. Generally larger compounds contribute to color, but smaller, more assailable compounds contribute to bacterial growth, which does not indicate that UV-185 would be as efficient at mitigating bacterial regrowth, as it is combatting color. Combining the mechanistic findings from batch experiments with performance data from full-scale operation will allow us to make informed decisions about post-treatments for future greywater recycling systems.

Keywords:
gravity-driven membrane, permeate quality, ultrafiltration, hydroxyl radical, regrowth

INTRODUCTION

An affordable system that can recycle greywater to a hand-washing quality, can improve access to hygiene for many people in the developing world. The Blue Diversion Autarky Toilet features a low-cost, low-energy water recycling biologically activated membrane bioreactor (BAMBi) that achieves ~95% removal of organics. The water produced in this system however, still contains a significant amount (~50 mg/L) of dissolved organic carbon (DOC) (Künzle, 2015). Understanding the correct conditions we need to achieve in treated water (such as an upper limit of DOC) to prevent bacterial regrowth remains a significant research question, and obstacle to developing water recycling systems that deliver water of hand-washing quality. The ability of pathogens to grow in water is not necessarily linked to the quantity of organics, but is instead dependent on having organics of the right chemical composition and structure that the bacteria prefer (Vital 2010). It has also been demonstrated that some post-treatments, such as ozone, can actually transform the organics such that regrowth is more easily achieved following treatment (Vital 2010). Three post-treatment technologies are being evaluated in batch experiments utilizing permeate from a BAMBi that does not have any post-treatment (to be completed January 2016). We will then evaluate each post-treatment simultaneously in full-scale systems (for 3 months beginning in February 2016). The goal of this research is to make a post-treatment design recommendation, based on the overall performance of full-scale operation and ability of specific post-treatment approaches to remove or transform DOC that contribute to color and the growth of bacteria. In this abstract we present the tools we are using to evaluate each post-treatment and the conclusions we can draw from our testing with UV-185 nm treatment.

METHODS AND MATERIALS

A schematic of the full-scale reactor is presented in Figure 1. Reactors contain: 150 kDa ultrafiltration membrane modules (Microdyn, Wiesbaden, Germany), UV-185 nm lamp (AlfaaUV, Mumbai, India), a boron-doped-diamond electrolysis unit (Condias, Itzehoe, Germany), granular activated carbon (GAC) ~1 mm diameter (Sigma, St. Gallen, Switzerland). Size exclusion chromatography (SEC) was performed using a Toyopearl TSK HW-50S 100–20,000 Da column (Tosoh, Tokyo, Japan).

RESULTS AND DISCUSSION

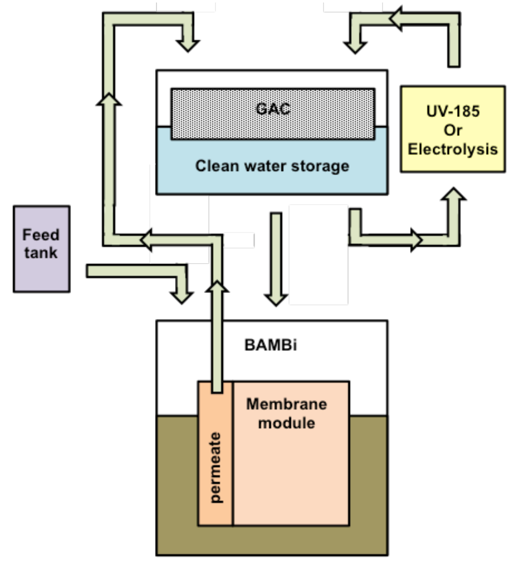
The removal of organic carbon and speciation of nitrogen during UV-185 nm batch treatment is presented in Figure 2, while Figure 3 presents the loss of absorbance. In each case, the loss of DOC or color starts rapidly and slows down as more-easily degradable compounds have been removed. DOC removal likely occurs by oxidizing carbon to CO_2. Loss of color is instead attributed to loss of specific color-contributing chemical structures, generally understood to be double bonds and aromatic groups more common on larger molecules. The distribution of organics, by SEC, in permeate water before and after UV-185 nm treatment is presented in Figure 4. The y-axis presents a relative signal on a carbon detector, and the x-axis represents the retention in the separation column. Larger, and more neutral molecules pass faster. We observe a preference for the removal of larger compounds during treatment. UV-185 nm is expected to be very effective at transforming organics because it can react directly by photodegradation and indirectly through the production of reactive species such as hydroxyl radical. Hydroxyl radicals are less selective than other oxidants, and it is then a bit surprising that the UV-185 nm is selectively transforming larger compounds, however this could be attributed to the direct photodegredation. While UV-185 nm treatment is effective at removing color, bacterial regrowth is generally linked to smaller more-assailable compounds (Vital 2000), indicating that UV-185 nm may not be as effective at this goal. We will verify this conclusion regarding what types of organic carbon bacteria prefer in our specific sample by comparing SEC profiles of permeate before and after bacteria are allowed to grow in the water. Greater microbilogy insights into the inactivation potential of different post-treatments on bacteria and the growth potential for actual pathogens following post-treatment is presented in the companion study “Growth of bacteria in treated greywater in the context of blue diversion autarky toilet”, submitted by M. Nguyen.

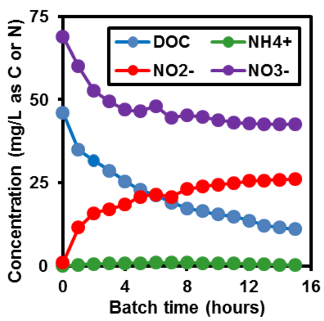
CONCLUSIONS

Three post-treatment technologies are being investigated, in batch tests to understand mechanisms of each treatment, and in full-scale membrane bioreactors to compare operational performance. We have demonstrated in this abstract, the ability to quantify changes in concentration and structure of organic carbon during post-treatment. In the case of UV-185 nm, we demonstrate a reduced ability to remove dissolved organic carbon and color absobance over batch treatment time. This treatment appears to be more effective on a portion of the organics and less effective on others. We have also demonstrated from SEC analysis that UV-185 nm has a preference for removal of larger compounds, over smaller compounds that are more-easily assimilated by bacteria. These results indicate that UV-185 may be better at removal of color than at preventing bacterial growth.

FIGURES

Figure 1 (right). Process schematic for the Blue Diversion Autary Toilet incorporating three possible post-treatment technologies. The term BAMBi stands for Biologically Active Membrane Bioreactor. A flush event triggers an addition of ~0.1 L of concentrated feed to the BAMBi, along with ~1.4 L of water from the clean water tank. Permeate water is driven through the biofilm on the membrane from the force of gravity, and then pumped up to the clean water tank. In the GAC configuration, the permeate water passes through a filter holding 6L of GAC as it enters the tank. In UV and electrolysis configurations, water is recirculated from and returned to the clean water tank. Four BAMBi units are currently assembled and will begin three-month operation in February 2016, after UV and electrolysis batch testing are complete (January 2016).





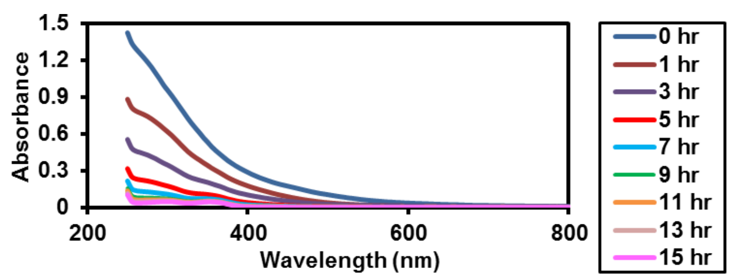


Figure 2 (left). Concentrations of DOC, total ammonia, nitrite and nitrate as a function of exposure time to UV-185 nm in batch. The initial material is membrane permeate from a BAMBi system that does not have any post-treatment. The speciation of Nitrogen is presented here because such additional reactions can reduce the efficiency of treating the organics, and puroducts such as nitrite are dangerous to the user.

Figure 3 (right). Absorbance spectra for membrane permeate as a function of UV-185 nm batch exposure. This data is from the same experiment as in figure 2.

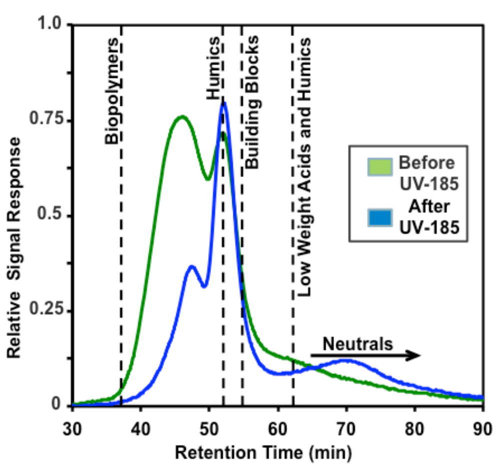


Figure 4 (left). Organic molecule distrubution by size exclusion chromatorgraphy of membrane permeate water before (green) and after (blue) 2.5 hours of batch treatment with a UV-185 nm lamp. The dashed lines indicate general retention times corresponding to biopolymers, humic substances, building blocks (components of humics) and lower weight compounds. Larger moleculs interact less with the column and are therefore eulted at shorter retention times. In this case we see a dramatic reduction in the peak between biopolymers and humics following UV-185 nm treatment.

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