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„Slow sand filtration of secondary effluent for wastewater reuse: Evaluation of performance and modeling of bacteria removal”

ABSTRACT
1,800 million people will be living in regions with absolute water scarcity by 2025. Wastewater is a valuable resource that is reliably available wherever water is consumed and collected for treatment. Appropriate technologies are needed for disinfection of wastewater to allow safe reuse. Slow sand filtration (SSF) is a simple process used for pathogen and particle removal in drinking water purification. It may be adapted for wastewater disinfection but only a few studies have been conducted on tertiary treatment of wastewater using slow sand filters. The purpose of this work was to evaluate the suitability and performance of slow sand filters at laboratory and pilot scale as a potential process for disinfection of secondary effluent. Fecal indicator bacteria removal during filtration was modeled and a filter-cascade tested. The performance of slow sand filters was evaluated in comparison to intermittent sand filters.
In the experiments the key process parameters hydraulic loading rate, sand grain size distribution and filter bed depth were systematically varied. The results showed that slow sand filters are promising for disinfection of wastewater, especially in arid developing countries, if reuse in agriculture is intended. They eliminated 1.9–2.6 $\log_{10}$-units of *E. coli* and 1.9–3.0 $\log_{10}$-units of intestinal Enterococci reaching effluent concentrations of 11–142 CFU per 100 ml of *E. coli* and 2–24 CFU per 100 ml of intestinal Enterococci at pilot scale. Bacteria removal was shown to be a function of sand surface area, dirt layer and supernatant water. The schmutzdecke and upper centimeters of the sand bed were a very efficient zone for bacteria removal whereas removal per filter length declined within deeper zones of the bed. Sand surface area per filter surface area should not be chosen below 2000 m^2/m^2. Slow sand filters removed 70–84% of total suspended solids reaching effluent concentrations of 1.2–2.3 mg/l and turbidity levels of 0.5–0.8 NTU. Average runtime was between 59 and 148 days.

The comparison of filters at laboratory scale and pilot scale fed with secondary clarifier effluent of the same wastewater treatment plant and operated at the same hydraulic loading rate showed that scale up did not significantly affect bacteria removal.
A slow sand filter achieved comparable or higher bacteria removal than an intermittent sand filter (ISF) even under challenging conditions in terms of BOD_5 and ammonium. The SSF eliminated 2.7–3.4 log-units of *E. coli* and 3.0–3.2 log-units of intestinal Enterococci. The ISF removed less bacteria: 1.8–2.5 log-units of *E. coli* and 1.6–2.8 log-units of intestinal Enterococci. A major advantage of the SSF compared to the established technology of ISF is the elevated hydraulic loading rate that can be used.
Bacteria removal in a rotating cascade consisting of four slow sand filter stages amounted to 1.7 log-units of *E. coli* and 1.9 log-units of intestinal Enterococci. The rotating cascade did not fulfil the expectations of increased bacteria removal due to the existence of four schmutzdecke layers. A cascade consisting of two slow sand filters was was used to treat effluent of a vertical flow constructed wetland. It achieved *E. coli* removal of 1.78 log-units in the first and 0.33 log-units in the second filter. This was comparable to typical removal in constructed wetlands so that SSF may be attractive because of lower land requirements.
A quantitative description of the processes leading to bacteria removal in slow sand filters for

tertiary treatment of wastewater was lacking. Therefore a model was developed for *E. coli* removal from secondary clarifier effluent in slow sand filters. Removal was successfully simulated for sands of variable grain size distribution and under a range of hydraulic loading rates compared to data obtained at pilot-scale filters. The most important process was retention of bacteria at the schmutzdecke and sand surface leading to an enrichment by a factor of up to 600 compared to the surrounding bulk phase. Bacteria elimination and inactivation both in the bulk phase and the schmutzdecke can be described by a first order kinetic.