Multiple objective treatment aspects of bank filtration

Sung Kyu Maeng[1*], Saroj Kumar Sharma[2] and Gary Amy[2,3]

1. Korea Institute of Science and Technology, PO Box 131, Cheongryang, Seoul130-650, South Korea
2. UNESCO-IHE Institute for Water Education, P.O. Box 3015, 2601 DA Delft, The Netherlands
3. King Abdullah University of Science and Technology, Thuwal, 23955-6000, Saudi Arabia

Abstract

The need for safe and good quality drinking water is growing rapidly worldwide, especially with increased urbanization and population growth. However, increasing pollution of surface waters, often by wastewater effluents, has made water treatment more difficult and expensive. Furthermore, most water resources, especially surface waters in industrialized and urban areas in developing countries, are quickly deteriorating as a result of uncontrolled waste discharges into receiving waters, which may also serve as drinking water sources. Consequently, this has led to the occurrence of potentially harmful organic micropollutants (OMPs) in drinking water treatment systems and ultimately in drinking water.

Bank filtration (BF) is a natural water treatment process which induces surface water to flow in response to a hydraulic gradient through sediment and into a vertical or horizontal well. It is a relatively cost-effective and robust technology. From a historical perspective, BF is first mentioned in the bible. In chapter 7 phrase 24 in Exodos, "all the Egyptians had to dig in the neighbourhood of the river for drinking water, since they could not drink the river water." BF has been recognized as a proven method for drinking water treatment in Europe. But these facilities have all been based on local experiences and thus far, there are no tools or a methodology that would help to transfer these experiences or the design and operation of a system from one place to another. Understanding the fate of effluent organic matter (EfOM) and natural organic matter (NOM) through BF is essential to assess the impact of wastewater effluent on the post treatment requirements of bank filtrates. Furthermore, their fate during drinking water treatment can significantly determine the process design.

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[*] *Corresponding Author: andrew.maeng@gmail.com*

Laboratory-scale batch and soil column experiments as well as analysis of the data from full-scale bank filtration and artificial recharge sites were conducted to obtain insight into the effect of source water quality (especially organic matter characteristics) and process conditions on the removal of organic micropollutants during soil passage. Figure 1 shows the schematic diagram of the soil column experimental setup. Wastewater effluent-impacted surface water and surface water were used as source waters in experiments with soil columns. Results showed the preferential removal of non-humic substances (i.e., biopolymers) from wastewater effluent-impacted surface water. The bulk organic matter characteristics of wastewater effluent-impacted surface water and surface water were similar after 5 m soil passage in laboratory column experiment. Humic-like organic matter in surface water and wastewater effluent-impacted surface water persisted through the soil passage. More than 50% of dissolved organic carbon (DOC) removal with significant reduction of dissolved oxygen (DO) was observed in the top 50 cm of the soil columns for both surface water and wastewater effluent-impacted surface water. This was due to biodegradation by soil biomass which was determined by adenosine triphosphate (ATP) concentrations and heterotrophic plate counts. Good correlation of DOC removal with DO and biomass development was observed in the soil columns
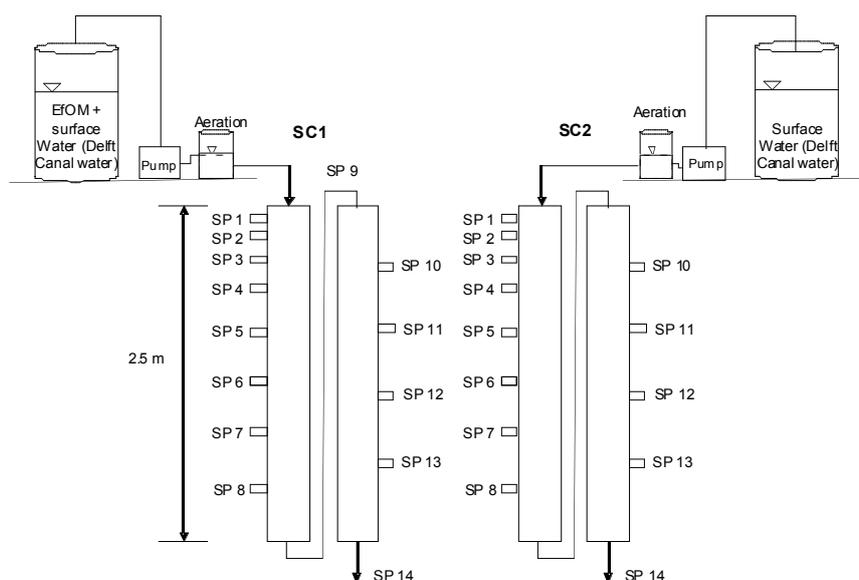

Figure 1. Schematic diagram of the soil column experimental setup

Track leaders should collect and submit the abstracts for their session to Seneshaw Tsegaye Managed aquifer recharge (MAR) systems such as BF have been recognized as a multi-objective (-contaminant) barrier to provide safe drinking water by attenuating endocrine disrupting compounds (EDCs) and pharmaceutically active compounds (PhACs). In this thesis, the fate of selected EDCs and PhACs during soil passage was investigated. Firstly, estrogen compounds (i.e., EDCs) were tested to determine if these compounds can be attenuated during BF. Adsorption and biodegradation are the two important removal

mechanisms for estrogen compounds (estrone, 17 β-estradiol and 17α-ethinylestradiol), but adsorption exhibited to be the important removal mechanism. 17β-estradiol and 17α-ethinylestradiol were removed 99% and 96%, respectively, in batch experiment under oxic conditions. Biomass associated with sand and redox conditions did not show any significant effects on the removal of 17β-estradiol. However, 17α-ethinylestradiol removals varied from 64% to 87% in soil columns fed with different sources of water. Biodegradation appears to be more important in the removal of 17α-ethinylestradiol. Estrogenic activity remaining under oxic conditions (13 ng estradiol-equivalents/L) was significantly lower than that of under anoxic conditions (97 ng estradiol-equivalents/L).

Secondly, batch studies were first conducted to investigate the removal of 13 selected PhACs from different water sources with respect to different sources of biodegradable organic matter. Column experiments were then performed to differentiate between biodegradation and sorption in the removal of these PhACs. Selected neutral PhACs (phenacetine, paracetamol and caffeine) and acidic PhACs (ibuprofen, fenoprofen, bezafibrate and naproxen) exhibited removal efficiencies of greater than 87% from different organic water matrices during batch studies (contact time: 60 days). In column studies, removal efficiencies of acidic PhACs (e.g., analgesics) decreased under biodegradable organic carbon-limited conditions. Removal efficiencies of selected acidic PhACs (ibuprofen, fenoprofen, bezafibrate, ketoprofen and naproxen) were less than 35% under abiotic conditions. These removals were attributed to sorption under abiotic conditions established by a biocide (20 mM of sodium azide), which suppressed microbial activity/biodegradation. However, under biotic conditions, removal efficiencies of these acidic PhACs compounds were greater than 78%, mainly attributed to biodegradation. Moreover, average removal efficiencies of hydrophilic (polar) neutral PhACs with low octanol/water partition coefficients (log Kow < 2) (paracetamol, pentoxifylline, phenacetine and caffeine) were low (< 12 %) under abiotic conditions. However, under biotic conditions, removal efficiencies of selected neutral PhACs were greater than 91%. In contrast, carbamazepine showed a persistent behavior under both batch and column studies. Overall, results of this study showed that biodegradation is an important mechanism for removing PhACs during soil passage.

This study also analyzed a comprehensive database of OMPs at BF and artificial recharge (AR) field sites located near Lake Tegel in Berlin (Germany). The focus of the study was on the derivation of correlations between the removal efficiencies of OMPs and key factors influencing the performance of BF and AR. At the BF site, shallow monitoring wells located close to the Lake Tegel source exhibited oxic conditions followed by prolonged anoxic conditions in deep monitoring wells and a production well. At the AR site, oxic conditions prevailed from the recharge pond along monitoring wells up to the production well. Long residence times of up to 4.5 months at the BF site reduced the temperature variation during soil passage between summer and winter. The temperature variations were greater at the AR site as a consequence of shorter residence times. Deep monitoring wells and the production well located at the BF site were under the influence of ambient groundwater and old bank filtrate (up to several years of age). Thus, it is important to account for mixing with native groundwater and other sources (e.g., old bank filtrate) when estimating the performance of BF with respect to removal of OMPs. Principal component analysis (PCA) was used to investigate correlations between OMP removals and hydrogeochemical conditions with spatial and temporal parameters (e.g., well distance, residence time, and depth) from both sites. At the BF site, principal component-1 (PC1) embodied redox conditions (oxidation reduction potential and dissolved oxygen), and principal component-2 (PC2) embodied degradation potential (e.g., total organic carbon and dissolved organic carbon) and the

calcium carbonate dissolution potential (Ca2+ and HCO3-). These two PCs explained a total variance of 55% at the BF site. At the AR site, PCA revealed redox conditions (PC1) and degradation potential with temperature (PC2) as principal components, which explained a total variance of 56%.

There is a need to develop assessment tools to help implement MAR as an effective barrier in attenuating different OMPs including PhACs and EDCs. In this study, guidelines were developed for different classes of OMPs, in which removal efficiencies of these compounds are determined as a function of travel times and distances. Guidelines are incorporated into Microsoft Excel spreadsheets and the water quality prediction tool was developed to estimate the removal of different classes of OMPs in MAR systems. Multiple linear regression analysis of data obtained from literature studies showed that travel (residence) time is one of the main parameters in estimating the performance of a MAR system for PhACs removal. Moreover, a quantitative structure activity relationship (QSAR) based model was proposed to predict OMP removals. The QSAR approach is especially useful for emerging compounds with little information about their fate during soil passage. Such an assessment framework for OMP removals is useful for adapting MAR as a multi-objective (-contaminant) barrier and understanding the fate of different classes of compounds during soil passage and the determination of post treatment requirements for MAR.

In general, this study showed that BF is an effective multiple objective barrier for removal of different contaminants present in surface water sources including organic micropollutants like PhACs and EDCs. The removal efficiencies of BF for these contaminants can be maximised by proper design of the recovery wells taking into consideration source water quality characteristics and local hydrogeological conditions.