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D3.2.1 Overview of MSc Studies on Soil Aquifer Treatment

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EU SWITCH Project
WP 3.2 Safe Water Reuse

D3.2.1 Overview of MSc Studies on Soil Aquifer Treatment

Introduction

Under SWITCH project WP3.2 Task 3.2.1, the effectiveness of Soil Aquifer Treatment (SAT), involving aquifer recharge (infiltration) and recovery of wastewater effluent was examined as a natural and sustainable advanced wastewater treatment process targeting multiple contaminants (chemicals and microbes) and serving as an effective barrier and environmental buffer in indirect potable reuse. The work involved testing of the SAT technology on various scales, both laboratory soil columns and field sites, for the removal of microbes and chemicals, both traditional and emerging contaminants that constrain potable reuse. This report provides an overview of 5 MSc studies conducted at UNESCO-IHE to analyze different aspects of SAT.

Summary of MSc studies on SAT

The five MSc studies on SAT conducted at UNESCO-IHE under SWITCH WP3.2 were as follows:

1. Chacha Harun (2007) Analysis of multiple contaminants during soil aquifer treatment. MSc Thesis 2007-18.

2. Ruua Al-Sakkaf (2008) Effect of SAT effluent on performance of MF/UF Membranes. MSc Thesis MWI 2008-01.

3. Manuel Fernando (2009) Effect of SAT pre-treatment on performance of NF Membranes. MWI MSc Thesis 2009-27.

4. Madiany Caballero (2010) Soil aquifer treatment as a pre-treatment for organic micropollutants removal during membrane filtration. MWI MSc Thesis 2010-05

5. Yona Nelson Malolo (2011) Effect of temperature and redox conditions on the removal of contaminants during soil aquifer treatment. MWI MSc Thesis 2011-09.

The first MSc study of Mr. Harun provided a literature review on removal of different contaminants during SAT which was then used to develop a framework for assessment of performance of SAT system. Soil column experimental setup (simulating 5 m of soil layer) was constructed at UNESCO-IHE which was used for four MSc studies to analyse removal of different contaminants during SAT. MSc study of Ms. Al-Sakaf and Mr.

Fernando analyzed the effect of SAT as a pre-treatment for membrane filtration systems. The effectiveness of SAT and Hybrid SAT systems on removal of selected organic micropollutants (pharmaceuticals) with or without ozonation pre-treatment was examined in the MSc study of Ms. Caballero. Finally, Mr. Malolo investigated how temperature and redox conditions influence the removal of bulk organic matter, nitrogen (ammonium and nitrate), phosphorus and pathogens from primary effluents from wastewater treatment plants.

These studies showed that SAT is a low-cost, robust and multi-contaminant removal technology which is effective for removal of bulk organic matter, nitrogen, pathogens and selected organic micropollutants. It was found that performance of membrane systems could be improved by using SAT as a pre-treatment for membrane filtration. In general, it can be concluded that SAT could be used for further polishing of both primary and secondary effluent treatment and SAT +NF hybrid system is an attractive technology for water reuse.

These MSc these can be downloaded from SWITCH website.
http://www.switch.watsan.net/page/4941

Abstracts of MSc Studies on SAT

Abstracts of each of these MSc studies are provided below:

1. Chacha Harun (2007) Analysis of multiple contaminants during soil aquifer treatment

Many SAT studies have been carried out around the world for the removal of different contaminants but there are no system tools or models available for the prediction of the removal of different contaminants namely organic matter, trace organics, phosphorus, ammonia, nitrate or microorganisms at different process conditions during SAT. This tool is very important for the design and operation of SAT systems, it can also save time in decisions making. However, the design of SAT is based on judgment and experience. Understanding processes and conditions controlling the fate of different contaminants during SAT and development of a tool for prediction of SAT effluent quality is the focus of this research.

This study was carried out by conducting extensive literature review on which relevant parameters influencing the removal of dissolved organic carbon (DOC), ammonia, nitrate, phosphorus, trace organics and microbes during SAT of primary, secondary and tertiary effluents were extracted. The parameters included travel distance, residence/travel time, pH, temperature, soil type, operating schedule, redox conditions and infiltration rates. The performance data for SAT (removal efficiency) with respect to travel distance and travel time were analysed after grouping them in bins. The first step was to do correlation analysis of different parameters on DOC removal. DOC was chosen

because it has influence on removal of other parameters such as ammonia and nitrate. The correlation analysis matrix showed a weak correlation among the parameters involved which suggested that SAT is case specific. The data were analysed further to find contaminant removal range, average and standard deviation on each bin. Three separate sets of guidelines were developed for estimation of removal of DOC, nitrogen species, trace organics, and microbes from primary, secondary and tertiary effluent respectively. The developed guidelines could be useful as a quick tool in making right judgments for preliminary designs of SAT systems and time in doing pilot studies will be saved. Also a framework for transfer of SAT technology and application of SAT technology has been proposed.

The most interesting finding of this study is that the average DOC concentration of SAT product water in field sites was <2 mg/L for both long term SAT of secondary and tertiary effluent which is below the average DOC found in drinking water supply which is 2.2 mg/L. Therefore, tertiary treatment prior to SAT may not be needed, though higher infiltration rate can be applied after tertiary treatment. In general, it can be concluded that SAT has the capacity to remove virtually all contaminants focused in this study from wastewater treatment plants effluents.

2. Ruua Al-Sakkaf (2008) Effect of SAT effluent on performance of MF/UF membranes

Soil Aquifer Treatment (SAT) is an the emerging managed aquifer recharge technology, which in combination with other available wastewater treatment technologies could produce effluent of acceptable quality for indirect potable reuse. The EfOM content of SAT effluent might influence the subsequent treatment processes in drinking water production namely MF/UF. The effect of SAT effluent on the performance of MF/UF membrane systems has not been fully understood, Organic matter present in SAT effluent may foul these membranes and influence their performance.

The main goal of this study was to develop the technology for reuse of wastewater by using SAT as pre-treatment of MF/UF membrane system. The specific objectives included analysis of DOC removal, MFI reduction and removal of different organic matter fractions by different types of membranes with or without SAT pre-treatment. Laboratory-scale soil column and stirred cell experiments were conducted using two types of water; (i) SE+DCW, (ii) SE, and different types of membranes: 0.1 μm pore size MF membranes and 100, 50, 10 kD UF membranes.

The average DOC removal from wastewater treatment plant effluents for different types of membranes alone ranged from 12 to 22%. SAT pre-treatment of these effluents increased the DOC removal by MF/UF membranes to 30 to 46%. SAT helps to improve performance of MF/UF by reducing the fouling up to 73% for SE+DCW and 57% for SE. The different types of membranes have characteristic for removal of organic matter and have different value of MFI. MFI reduction was bigger when the MWCO of the membranes was smaller. The maximum protein removal with 10 kD UF membrane was

30% without SAT, and for fulvic and humic-like organic matter removal is 22% without SAT pre-treatment.

This study clearly showed that SAT pre-treatment of wastewater treatment plant effluents not only improves the DOC removal by MF/UF membranes but also reduces the fouling potential of these membranes. Furthermore, combination of SAT and UF removes different organic matter fractions substantially thus increasing the potential for water reuse.

3. Manuel Fernando (2009) Effect of SAT pre-treatment on performance of NF Membranes

SAT represents a natural land treatment technology that has gained acceptance as an integral part of indirect potable reuse systems. However, removal of effluent organic matter (EfOM) in SAT systems is limited. Additional pre-treatment of secondary effluent (SE) is necessary to increase organic matter removal efficiency in SAT. In particular, ozone, which is a very strong oxidant, can be used as pre-treatment to SAT to convert the refractory organic compounds into more biodegradable form. Advanced membrane treatment such as RO and tight NF membranes are technologies prominently mentioned in the field of wastewater reclamation for potable reuse. However, the high organic matter content and suspended solids present in the effluent of conventional activated sludge necessitate the need for expensive pre-treatment to avoid excessive fouling rates. SAT can play an important role as an effective pre-treatment for membrane filtration to reduce considerably the problem of membrane fouling and thereby minimize the cost of pre-treatment for RO/NF membranes. This study, therefore, focused on the analysis of SAT pre-treatment on the performance of the NF membranes by investigating DOC removal and reduction in flux decline.

Laboratory-scale soil column studies were conducted using secondary effluent from a full-scale wastewater treatment plant and NF membrane setup was used. Different pre-treatment were applied to secondary effluent before SAT and performance of two different types of NF membranes were analysed. Soil column study showed that SAT can remove 24% of DOC in secondary effluent. With preozonation dose of 1 mg O3 to 1 mg DOC of SE, DOC removal improved to 26% by increasing the easily biodegradable fraction of DOC from 8% to 20%.

Two types of NF membranes (NF-270 and NF-90 from DOW FilmTec) were tested with four types of feed water (secondary effluent, SAT pre-treated secondary effluent, preozonated SE, and SAT pre-treated and ozonated SE). Rejection of DOC, TDS, and UVA254 were influenced more by the type of membrane rather than by the type of feed water. No significant change in DOC removal by NF membranes was observed with or without SAT pretreatment of wastewater treatment plant effluents. However, in terms of flux decline, the NF membrane, regardless of type, consistently performed better with SAT pre-treated feed water. The flux decline of NF-270 and NF-90 at equal delivered DOC were reduced by 2% and 18% respectively for SE as feed water and by 5% and 14% respectively for SE+O3 as feed water, due to SAT pre-treatment. The tighter NF-90

exhibited more flux decline compared with NF-270 with any type of feed water. In summary, this study showed that SAT followed by NF could be an effective technology for water reuse applications.

4. Madiany Caballero (2010) Soil aquifer treatment as a pre-treatment for organic micropollutants removal during membrane filtration

The effectiveness of SAT under given conditions depends on the effluent qualities, hydrogeologic conditions and process parameters applied. Furthermore, some organic micropollutants may not be completely removed during SAT. In this context, SAT pre-treatment of WWTP effluent followed by membranes for polishing is likely to provide water of required quality. However, the effect of SAT as a pre-treatment on performance of NF is not fully understood. To assess the effect of SAT as a pre-treatment for persistent organic micropollutants removal during membrane filtration, the removal of target compounds (gemfibrozil, diclofenac, bezafibrate, ibuprofen, fenoprofen, carbamazepine, acetaminophen, naproxen, clofibric acid, phenacetine, caffeine, pentoxifylline, ketoprofen, NDMA and 1,4-dioxane) during soil passage were analyzed in three different types of water samples before using NF membrane.

Laboratory-scale soil columns experiments were conducted at a hydraulic loading rate of 1.25 m/day using secondary effluent as feed water. High removals for most of the target compounds (> 70 %) were observed which can be linked to sorption onto soil particles or transformation through biodegradation. However, some compounds (clofibric acid, diclofenac, carbamazepine, NDMA and 1,4-dioxane) showed a persistent behavior with low removals due to their miscibility with water and resistance to biological degradation. On the other hand, soil passage in combination with ozone showed even higher removals for the majority of target compounds (<0.05 μg/L) in all the samples. Furthermore, an increase was observed in NDMA and 1,4-dioxane removals for pre-ozonated to secondary effluent during column studies (73% and 61% respectively).

Excellent rejections of target compounds by NF-90 were achieved (>98%), which was correlated with their physico-chemical properties and the influence of the amount effluent organic matter (EfOM) in the different water matrices, with the exception of NDMA that was poorly rejected (20%) independently of the water characteristics. However, SAT as a pre-treatment of NF has demonstrated its capability not only on providing significant reductions in emerging contaminants but also in the removal of organic matter content present in wastewater leading to reduction of fouling and an increase of the life-time of the membranes. Furthermore, the improved effect of preozonation on biodegradation of recalcitrant compounds followed by SAT and NF illustrate the benefits of this hybrid system as a promising technology for wastewater effluent reuse applications.

5. Yona Nelson Malolo (2011) Effect of temperature and redox conditions on the removal of contaminants during soil aquifer treatment.

Reuse of treated wastewater through groundwater recharge has emerged as an integral part of water and wastewater management in arid and semi arid regions of the world. The potential to augment existing water supplies and reduce reliance on imported surface waters using soil aquifer treatment (SAT) is restricted by lack of information to support rational design and operation of SAT systems. Elimination of uncertainties is necessary to utilize SAT as an alternative sustainable treatment and water resource management option.

Laboratory-scale batch and soil column studies were carried out to study the effect of temperature and redox conditions on removal of bulk organic matter, nutrients (nitrogen and phosphorous) and pathogens with primary effluent (PE) and secondary effluent (SE). PE and SE were collected from Hoek van Holland WWTP, the Netherlands. DOC removal in soil batch tests fed with PE was about 55% under aerobic conditions and about 40% under anoxic conditions. The DOC removal in batch reactors fed with SE was 25 % under aerobic conditions and 15% under anoxic conditions. Likewise in case of soil column studies with PE DOC removal was 46% under aerobic conditions and 31% under anoxic conditions whereas DOC removal was 19% for aerobic conditions and 13% under anoxic conditions in case with SE.

Oxygen availability was an important factor in nitrification (and denitrification) reactions and thus overall ammonium nitrogen removal from infiltrating water. Phosphorus removal efficiency was relatively low by SAT under aerobic and anoxic conditions though it was evident that aerobic conditions are advantageous over anoxic conditions. The removal of phosphorous ranged from 18 to 37% in batch experiments while in soil column experiments the removal ranged from 11 to 31% under both aerobic and anoxic conditions. Removal of pathogens in batch reactors was not substantially affected by redox conditions and ranged from 2.1 to 3.6 log removal. The soil columns were able to remove 2 to 3 log removals of *E-coli* and *total coliform* within 0.3 m column depth under both aerobic and anoxic conditions.

The DOC removal in PE at temperatures 15oC, 20oC and 25o C was 43%, 50% and 55% respectively. The DOC removal in SE at temperatures 15oC, 20oC and 25oC was 15%, 19% and 23% respectively. The performance of SAT at lower temperatures of 15oC in the soil passage did not significantly affect DOC removal but resulted in a diminished nitrification, denitrification rate and a reduced attenuation of nitrogen and phosphorous. It was observed that redox conditions and temperature influence the removal of DOC, nitrogen, phosphorous and pathogens during soil passage. The findings of this research confirm that SAT systems are able to act as a reliable barrier for DOC, nitrogen, and phosphorous regardless of seasonal and flow conditions during SAT providing a sufficient retention time is maintained.