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**MSc Thesis**

# Coupling Electroflocculation and Constructed Wetland Systems: An Integrated Approach to Tertiary Wastewater Treatment

**by**

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**-** The written thesis (in Hebrew) has not been submitted yet due to unfortunate personal problems of the student. Yet, the research work has been completed and reported in SWITCH and in IWA Wastewater Treatment and Reuse conferences.

## Abstract

Discharge of effluent into streams and rivers is a common practice worldwide. In arid lands competition for the freshwater for human use diminishes stream flow and effluents often make much of the base flow. In such situations stream health and rehabilitation highly depend on effluent quality. Strict standards for effluent disposal call for economic and efficient treatment alternatives. Various sources of wastewater contain growing concentrations of phosphorous and nitrogen cause eutrophication of natural water bodies. One of the consequences of eutrophication is decreasing of dissolved oxygen which adversely affects fish and other aquatic life, diminishing biodiversity.

Constructed wetland (CW) is an environmental friendly technology for treating wastewater or polishing effluent that is becoming increasingly popular in many parts of the world. It is designed and constructed based on natural marshes. CWs are often classified by the pattern of effluent flow in the system. In free-flow (surface flow) systems wastewater flows above the ground through emerged, submerged and floating aquatic vegetation. In subsurface flow systems wastewater moves through a porous medium such as gravel or aggregates, in which rooted hydrophytes grow. Subsurface systems are further classified into horizontal flow (HF), in which anaerobic conditions prevail, or vertical flow (VF) which maintains aerobic conditions. Low flow velocities coupled with the presence of roots and solid substrate, promote settling and filtration of particulate material. Biofilm of diverse microrganisms that develops on the porous medium is responsible for most of the biotransformation and mineralization of pollutants. CWs usually remove organic matter and nitrogen (N) compounds efficiently but are less efficient in removing phosphorous (P) compounds. .Retention of P in CWs includes peat/soil accretion (mostly in natural and free flow systems), soil adsorption, precipitation and plant uptake. In subsurface systems removal by plants is limited and requires plant harvesting annually.  The adsorption and chemical precipitation of phosphorus is much more vigorous at the initial operation stage because the process has finite capacity. As a result, CW capacity for phosphorous removal is quite limited. For the latter reason we considered coupling CW with physicochemical process that is expected to complement the naturally occurring processes by removing phosphorous efficiently.

Chemical precipitation is widely used for phosphate removal. The common precipitants used are aluminum sulphate and ferric chloride. Chemical treatment involves the addition of high amounts of chemicals resulting in undesirable ions residues and extra salinity being discharged in the treated wastewater. Electroflocculation (EF) is an electrochemical method that utilizes an electric current to separate and clear solid and dissolved pollutants from wastewater. This method enables

water treatment free of additional chemicals, thus offers an alternative to the use of metal salts. EF can be considered an alternative process to conventional flocculation, although they are somewhat different. The difference between these processes is manifested in the chemical and physical characteristics of the treated suspension and resulting aggregates. The flocs formed by EF are relatively large and contain less bound water. They are also more stable and therefore amenable to filtration. The overall goal of the investigation was to assess the utility of a tertiary treatment that couples a physicochemical process, i.e., electroflocculation, with natural processes taking place in constructed wetland, to facilitate compliance with stringent standards for river rehabilitation as well as for other uses of treated effluents. In this study we examine phosphorous removal applying iron electrodes and vertical flow CW treatment.

A pilot EF–CW system) was built at the Shafdan municipal, activated sludge wastewater treatment plant, comprising of the following components: (a) pre-strainer, (b) up-flow EF generator (EFector, TreaTec21 Industries Ltd.), 1.4 $m^3$ in volume, 1.25 m in diameter, containing 12 pairs of perforated iron electrodes, (c) granular filter, 1m bed depth and 0.6mm effective grain size, (d) 4 $m^3$ filtered water tank, used also for system backwash and flushing, and (e) a complex of CW ponds were constructed in the Shafdan WWTP (Tel-Aviv – Dan metropolitan area; Constructor Ofra Aqua Plants, modified by Moran consulting, design, & construction of aquatic ecosystem). The system included several series of three successive wetland ponds (ca. 35$m^2$ each), vertical or horizontal subsurface flow and one free flow. The results reported here relate to a treatment by a single VF pond. The VF ponds were packed from top to bottom with an 8cm layer of basalt (20-30mm); 9 cm of basalt (2-3mm); 8 cm basalt (5-10mm); 8 cm dolomite (8mm); 15 cm basalt (3-6 mm) and 20 cm of dolomite (50-60mm) at the bottom. *Cyperus papyrus*, *Canna sp.*, *Iris pseudoacorus*, *Phragmites australis* and *Juncus ensifolius* were planted, but by the third year *Cyperus papyrus* dominated the system.

'Shafdan' secondary effluents characteristics (annual average): turbidity–6.4 NTU, phosphate–2.7 mg/l as P, BOD–12 mg/l, COD–51 mg/l, nitrogen–9.2 mg/l as N, pH 7.35, Fe<0.1 mg/l.

*Turbidity removal* was best by CW alone, reaching a constant of more then 60% removal with 0.56–1.5 residual turbidity.

When CW preceded the electroflocculation unit, turbidity removal was around 47–58%, with lowest residual turbidity of 0.88 NTU. In this configuration, the constructed wetland reduced turbidity levels in 'Shafdan' secondary effluent from 1.8–3.9 NTU to a best level of 0.5 NTU. These low turbidity water continues through the EF system which adds iron ions to the effluent, at different concentrations (depending on current intensity), reaching turbidity levels of 10–50

NTU. After the effluent passes through the EFector, it continues through a double sand filter. This configuration yields turbidity levels similar to those reached by the CW alone.

When EF-GF preceded the CW gravel beds,, this combined treatment was very effective in turbidity and iron elimination, which could be attributed to efficient transport and attachment mechanisms of the colloids, provided by the flow and surfaces of the wetland porous media. Phosphate removal by EF–GF was up to 92% (lower detection limit was 0.4 mg/l $PO_4^{-3}$). Turbidity breakthrough correlated with high residual ferric concentrations, which could be explained by overdosing when raw turbidity was low (0.5 NTU).

When considering reverse flow (CW–EF–GF), the combined treatment lost its advantages. Filtrate turbidity deteriorated despite considerable reduction in coagulant dose, until the filter bed has been replaced with finer one. The new bed showed better turbidity removal efficiency, while the coarse grain showed a moderate head-loss development.

*Organic matter removal* was analyzed by two parameters: Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC). Fe concentration in 'Shafdan' secondary effluent was <0.1 mg/L (ICP measuring limit) with pH of 7.6-7.8. Organic matter removal by CW alone was tested with no added iron. TOC concentration in 'Shafdan' secondary effluent was 8.85-18.80 mg/L with an average of 12.22±2.33 mg/L. DOC concentration in 'Shafdan' secondary effluent was 8.3–17.3 mg/L with an average of 11.69±2.56 mg/L.

TOC removal by CW-EF-GF configuration was slightly better then the EF-GF-CW treatment, though results was similar with about 40% removal. DOC removal was at best at the CW-EF-GF configuration. TOC removal by CW alone is poor at 20% removal. When preceded by the EF-GF treatment, TOC and DOC removal reached an optimum of 50% removal, for Fe concentration of 14 mg/L. This configuration reached 28-53% TOC removal with an average of 37%±11.1% and 27--49% DOC removal with an average of 36.4%±10.34%.

Overall, all different treatments showed similar results for organic matter removal. None of the treatments reached TOC or DOC removal of over 50% with an average of 35% removal. TOC removal was at best when combining the CW and the EF-GF systems. DOC removal was similar for CW alone and when proceeded by EF-GF treatment. The latter configuration showed best results though it highly depended on a well designed sand filtration following the EFector.

*Phosphorous removal by EF-CW systems***.** Total phosphorous (TP) removal by different treatment configurations is studied. CW alone removed up to 20% of TP, while EF alone removed 10–-40% of TP regardless of Fe concentration. Filtration improved TP removal to an average of 90% when

Fe concentration exceeds 5 mg/l, with optimum 97% TP removal reaching TP concentration <0.3 mg/l. For Fe<5 mg/l TP removal by EF–GF–CW ranged 75–89% resulting in TP concentration <0.7 mg/l at all times. When EF-GF preceded CW treatment, TP removal depleted to a maximum of 83% removal for Fe>5 mg/l, with TP concentration of 0.3-0.7mg/l. Comparing the later with the above mentioned results indicate that CW consistently contributed additional phosphorous to the effluent; that could be explained by formation of a phosphorous 'reservoir' supplied by (a) Shafdan’s secondary effluent between EF treatments, and (2) plants decay, and released by water of lesser concentration.

CW–EF–GF configuration showed similar results to the EF–GF treatment, reaching an average of 90% TP removal, re-convincing that CW did not affect the TP level after granular filtration. Those results indicate that the latter is the best configuration for TP removal from wastewater. Still, it is possible that a long term flow of low phosphorous wastewater through the CW would have eliminated the phosphorous reserve and so would improve on the EF–GF–CW results. This long term operation could not have been carried out under current conditions for technical limitations. When observing residual Fe concentration after EF–GF, results show that only for initial Fe concentration >12 mg/l there is a 95% Fe removal by granular filtration and only for initial Fe concentration >15 mg/l there’s less then 0.5 mg/l Fe in the filtrate. This indicates that raising coagulant does effect both phosphorous removal and residual coagulant concentration. Raising coagulant dosage, with the enhanced conveying streams, induced by the increased current intensity, creates more opportunities for successful particle collisions and flocs formations, which can be further removed by the sand filter.

*Particles removal* capabilities of different treatments were analyzed by two parameters (other then turbidity): Total Suspended Solids (TSS) and particle distribution (cumulative and differential). Shafdan’ secondary effluent TSS concentration was variable between 1.7–10 mg/L with average concentration of 4.9 ± 2.6 mg/L.

Once the EF–GF treatment preceded the CW, TSS removal was similar and at times even better then CW alone. CW-EF-GF configuration showed TSS removal of 67–-87% with low TSS concentration of 0.33 mg/L and an average of 0.64±0.24 mg/L. The EF-GF system was supplied with low TSS effluent from the CW hence, the CW-EF-GF configuration reached similar results to the CW alone, despite adding Fe particles to the effluent.

It is shown that CW alone removes most of the particles from the effluent. Removal is slightly improved when adding the EF-GF system, especially at the low Fe concentrations. It is also shown that when the electroflocculation system is not polished by the CW, high Fe concentration of 17 mg/L added particles to the effluent in relation to the CW alone (since effluent flow through the CW system and onto the EF-GF system and samples were taken for the same incoming effluent, exiting CW and exiting GF).

Examining differential particle removal shows over 80% removal for all particle size and 99% removal of particle size >25µm for Fe concentration 2 and 4 mg/L. It is hypnotized that at low Fe concentrations not many large particles are created, thus particle removal is high tough turbidity and P removal are low.

Practically thinking, the EF unit (EFector) – constructed wetland hybrid system implies shorter residence time and better water quality, thus  reduces land, construction and maintenance costs of the constructed wetlands as well as water loss. Overall, the different configuration has different advantages in contaminates removal from the wastewater. The combination of the two treatments (electroflocculation and constructed wetland) contributed to the removal of contaminates in every inspected aspect. Contaminants removal was at best when the constructed wetland preceded the electroflocculation unit, but a good sand filtration is needed in order to remove turbidity. A full scale system may be in use both for river and lake rehabilitation and tertiary wastewater purposes. It can be modular, with relative small footprint and automatically controlled according to pre-set currents and backwash sequence.

Complementing CW treatment with a physicochemical process of electroflocculation can provide a tertiary treatment that effectively polishes secondary municipal effluent. While EF effectively reduces phosphate in both soluble and particulate forms CW treatment provides a transport-attachment trap to turbidity that escapes the electro-physico-chemical process and removes organic matter and N compounds.

The results strengthen previous indications that there is a slight improvement of the overall process of CW-EF-GF configuration over EF-GF-CW configuration.