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Discfiltration and ozonation for reduction of nutrients and organic micro-pollutants from wastewater – a pilot study

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Abstract

The combination of coagulation/flocculation and discfiltration with ozonation to reduce nutrients and organic micro-pollutants in secondary effluent was studied in pilot scale at Lundåkraverket wastewater treatment plant in Landskrona, Sweden. With a chemical dose of 4 gAl^{3+}/m^3 and 1.5 g/m^3 cationic polymer as active material effluent water quality with regards to total phosphorous (Tot-P), suspended solids and turbidity were 0.03, 2 mg/l and 0.5 Nephelometric Turbidity Units (NTU) in average. The effluent water quality was similar whether ozonation with an applied ozone dose of 2–9 gO_3/m^3 was performed prior to or after coagulation/flocculation/discfiltration. The results were corresponding to removal efficiencies for the coagulation/flocculation/discfiltration process of 94, 74 and 85% for Tot-P, suspended solids and turbidity, respectively. For organic micro-pollutants removal, it was found to be beneficial to perform coagulation/flocculation/discfiltration prior to ozonation as the ozone requirements were lowered for the dosing intervals applied. The removal was in the range of 38–98% depending on process configuration and ozone dose.

Key words: discfiltration, organic micro-pollutants, ozone, pilot-study

INTRODUCTION

In recent years the impact of organic micro-pollutants released from wastewater treatment plants on the environment has been of growing interest. At the same time, there is an ongoing eutrophication of the majority of the receiving water bodies caused by nutrient overload, where nitrogen and phosphorous play significant roles.

The European Union Water Framework Directive (2000/60/EC) for water, as well as agreements within the Baltic Sea Action Plan, will in due time result in more stringent effluent requirements on phosphorus for municipal wastewater treatment plants.

Organic micro-pollutants found in wastewater are mainly compounds originating from pesticides, flame retardants, personal care products, pharmaceuticals, detergents and plasticizers (Plósz *et al.* 2013). Conventional mechanical and biological wastewater treatment methods are known to be insufficient in reducing the more persistent components down to what is now thought of as acceptable levels thus an additional treatment step is needed. Tertiary oxidation and sorption are mentioned to be efficient in treating municipal wastewater effluent for the removal of these organic micro-pollutants (Lundström *et al.* 2010). Oxidation methods are usually involving ozone or chlorine dioxide whilst sorption is done with powdered activated carbon (Von Gunten 2003).

In applications when ozone is used for the removal of organic micro pollutants in secondary wastewaters, applied ozone dosages of 5 to 15 gO_3/m^3 are reported (Ternes *et al.* 2003).

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Ozone is a selective oxidant, primarily attacking electron density rich structures in molecules such as double bonds (Hewes & Davidson 1971). Furthermore, the free radicals HO_2 and OH· produced when ozone is decomposed are reacting rapidly with any impurities such as metal salts or organic matter in wastewater (Von Gunten 2003) The ozone and free radical oxidation efficiency is to some degree influenced by the suspended solids concentration, though results are somewhat contradictory (McCarthy & Smith 1974; Huber *et al*. 2005).

The two main objectives of the pilot study were (1) to test the combination of coagulation/flocculation/discfiltration and ozone for the removal of phosphorous, suspended solids and turbidity and (2) to investigate the effect of coagulation/flocculation/discfiltration on the ozonation efficiency to remove organic micro-pollutants. The pilot study was conducted at the Lundåkraverket wastewater treatment plants (WWTP) Landskrona, Sweden.

MATERIAL AND METHODS

Lundåkraverket WWTP

Lundåkraverket WWTP in Landskrona, Sweden is a municipal wastewater treatment plant designed for 38 600 PE and treating 580 m^3/h during normal operation with a peak capacity of 3,000 m^3/h. The treatment train consists of grit screens and sand removal followed by pre-sedimentation including in-line primary sludge hydrolysis for volatile fatty acids production. The water is further treated in a Bio-denipho® process where after water and sludge is separated in two parallel sedimentation basins and water is further treated via lamella sedimentation for effluent polishing. There is also a possibility of dosing aluminium before the lamella sedimentation for extended phosphorus removal.

Experimental setup

A schematic of the experimental setup is shown in Figure 1. Effluent from the two secondary sedimentation basins at Lundåkraverket WWTP was used as influent water to the pilot system. The study was conducted in two ways; (1) Performing coagulation/flocculation/discfiltration prior to ozonation and (2) ozonation prior to coagulation/flocculation/discfiltration. The ozone unit consisted of a

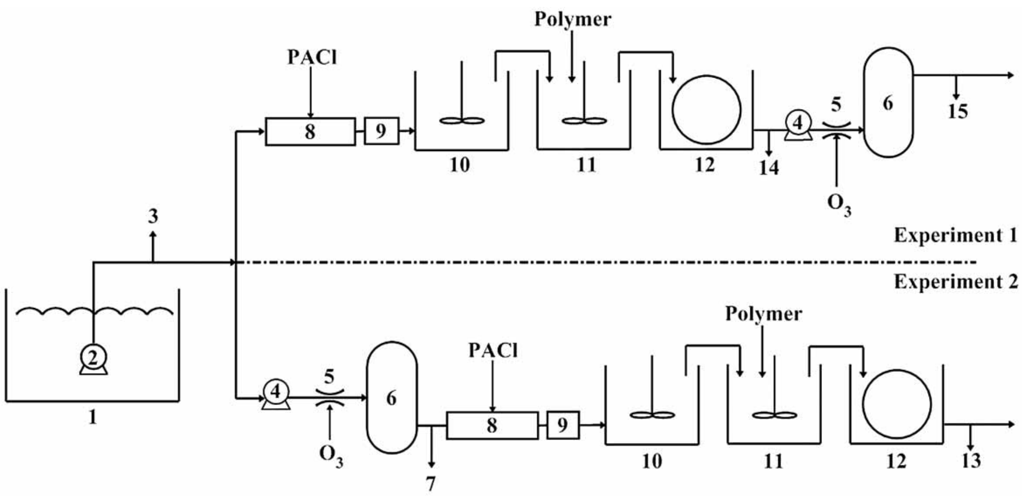

Figure 1 | Schematic diagram of the coagulation/flocculation/discfilter/ozone pilot unit. 1: Effluent from the secondary sedimentation basins, 2: Submerged centrifugal pump, 3: Influent to the pilot plant sampling point, 4: Booster pump, 5: Venturi-type ozone injector 6, Pressurized reaction tank, 7: Post ozonation sampling point, 8: Static mixer, 9: Flow meter, 10: Stirred PACl reaction tank, 11: Stirred polymer reaction tank, 12: Discfilter, 13: Post-discfiltration sampling point, 14: Post-discfiltration sampling point, 15: Post-ozonation sampling point.

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Primozone GM 2 ozone generator and a stainless steel pressurised reaction vessel. The ozone generator was operated with industrial grade oxygen gas. The total contact time in the ozone reaction vessel was 2.6 minutes. The ozone doses of 2, 5, and 9 gO_3/m^3 wastewater were used in both experimental setups. A discfilter (Hydrotech HSF1702/1-1F) with 10μm woven polyester media was used. The disc filter technology used in this study is described elsewhere (Persson *et al.* 2006). Squared polyethylene vessels with top mounted stirrers were used for coagulation and flocculation. The pilot plant was operated with a flow of 9.3–10 m^3/h with a hydraulic retention time in the coagulation and flocculation stages of 5.4–5.8 min each. For coagulation, 4 gAl^{3+}/m^3 polyaluminiumchloride (PAX XL 36, Kemira Kemi) was used. For flocculation, 1.5 g/m^3 (active material) of high molecular weight and medium-high charge cationic powder polymer of polyacrylamide base was used.

Sampling

Before samples were withdrawn, the process conditions were allowed to be stabilised for 1.5 h. For Experiment 1 (Figure 1) composite samples were withdrawn for organic micro-pollutants, Tot-P, SS and turbidity analysis at the influent (3), after filtration (14) and from ozone reactor effluent (15). For Experiment 2 (Figure 1), composite samples were withdrawn for organic micro-pollutants, Tot-P, SS and turbidity analysis at the influent (3), after ozonation (7) and effluent (13). All samples were 1.5 h composite samples from the respective sampling point, except for the influent samples for ozone dosage of 5 and 9 gO_3/m^3 for Experiment 1 which were collected during the whole day of the experiment. The samples were collected in DURAN® laboratory glass bottles.

Analytical methods

Analysis for total phosphorous (Tot-P), turbidity and suspended solids where made on site. The analytical methods for measuring Tot-P were Hach Lange LCK/LCS 349 cuvette tests (Hach Lange LZP 341 cuvetts) and Hach Lange DR2800 spectrophotometer. Turbidity was analysed with Hach 2100P turbidimeter and suspended solids according to standard method EN 872:2005.

The procedure for the analysis of the organic micro-pollutants was made accordingly to Hey *et al.* (2012). In short, samples of 100 mL were withdrawn and filtered using a 0.45 μm nitrite cellulose membrane filter and thereafter acidified to pH 3 using H_2SO_4. Prior to solid-phase extraction using OASIS HLB cartridge, an internal standard mix containing ^{13}C- and ^{2}H-labelled organic micro-pollutants was added. The extracts was analysed using LC/MS/MS. This method has also been used by Hörsing *et al.* (2011) and Grabic *et al.* (2012).

RESULTS AND DISCUSSION

Phosphorous, turbidity and suspended solids removal

Effluent water quality results with regards to phosphorous and turbidity were similar when performing coagulation/flocculation/discfiltration prior ozonation and vice-versa (Figures 2 and 3).

Total phosphorus was measured to be below 0.05 mg/l in all samples with an average of 0.03 mg/l meaning that a Tot-P reduction of about 94% was obtained in both Experiment 1 and Experiment 2. Turbidity was reduced by 85% as a mean value from the two experiments with an average of 0.52 NTU in the effluent.

Suspended solids (Figure 4) were reduced by 75% as a mean value for the two experiments with an average outgoing concentration of 2.1 mg/l. The average effluent suspended solids concentration in Experiment 1 was 2.6 mg/l (influent 7.2 mg/l) whilst in Experiment 2 it was 1.7 mg/l (influent

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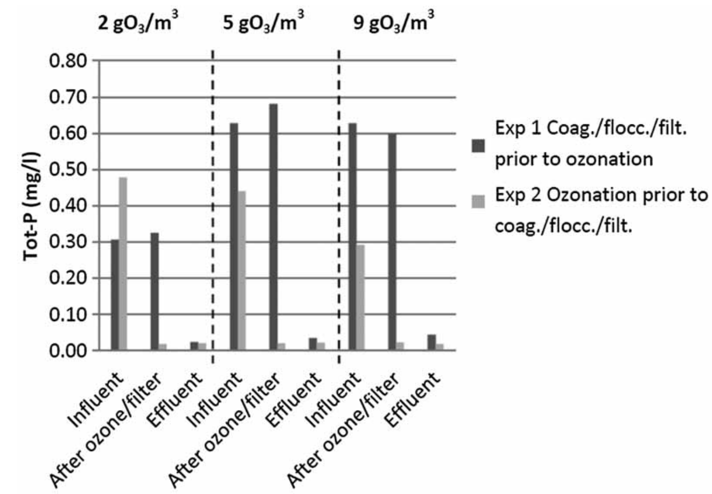

Figure 2 | Total phosphorus (Tot-P) test results from Experiment 1 and 2; Exp. 1 Coagulation/flocculation/discfiltration prior to ozonation and Exp. 2 Ozonation prior to coagulation/flocculation/discfiltration. (mg/l).

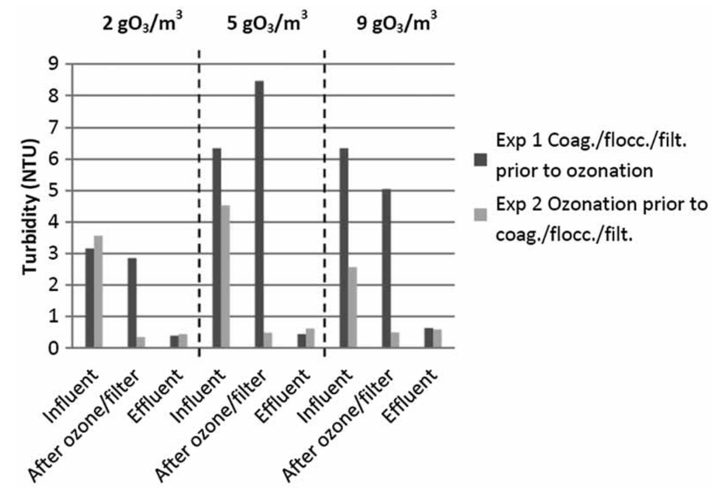

Figure 3 | Turbidity test results from pilot experiment 1 and 2; Exp. 1 Coagulation/flocculation./discfiltration prior to ozonation and Exp. 2 Ozonation prior to coagulation/flocculation/discfiltration. (NTU).

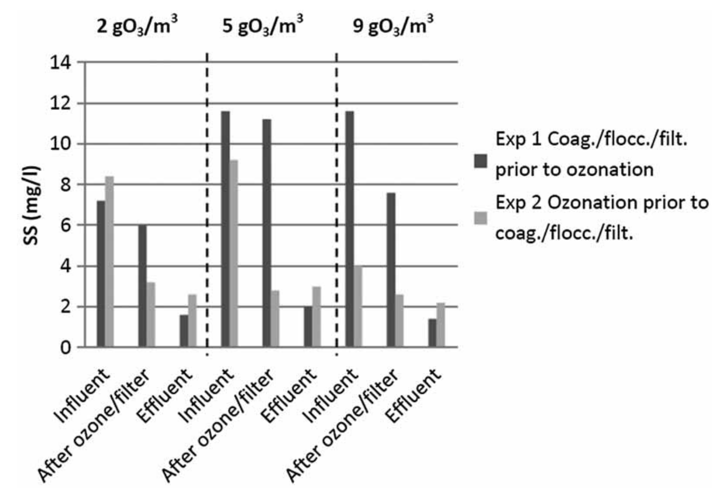

Figure 4 | Suspended solids (SS) test results from pilot experiment 1 and 2; Exp. 1 Coagulation/flocculation/discfiltration prior to ozonation and Exp. 2 Ozonation prior to coagulation/flocculation/discfiltration. (mg/l).

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10.1 mg/l). Saunier *et al*. (1983) have previously reported a coagulating effect by ozone. The suspended solids reduction displayed a slight improvement when ozone was applied prior to coagulation/flocculation/discfiltration, however, the total phosphorus and turbidity removal did not show the same improvement. Therefore, the effect of ozone on coagulation was not apparent in this study.

The results show that the coagulation/flocculation/discfiltration process is not effected by ozonation; similar effluent water quality was regarding total phosphorus, suspended solids and turbidity achieved both by performing ozonation prior to and after the process.

Organic micro-pollutants removal

Analysis of 46 different organic micro-pollutants was made. Twenty-four of these compounds were found consistently throughout the experiments. During the test period, the sum of the analyzed compounds in the influent water to the pilot plant ranged between 16 000 and 21 000 ng/l.

Ozonation after discfiltration

The results from Experiment 1 when the ozonation was performed after the discfiltration step are depicted in Figure 5. Overall, the removal efficiency is higher and more consistent than when the ozonation was conducted before the discfiltration step.

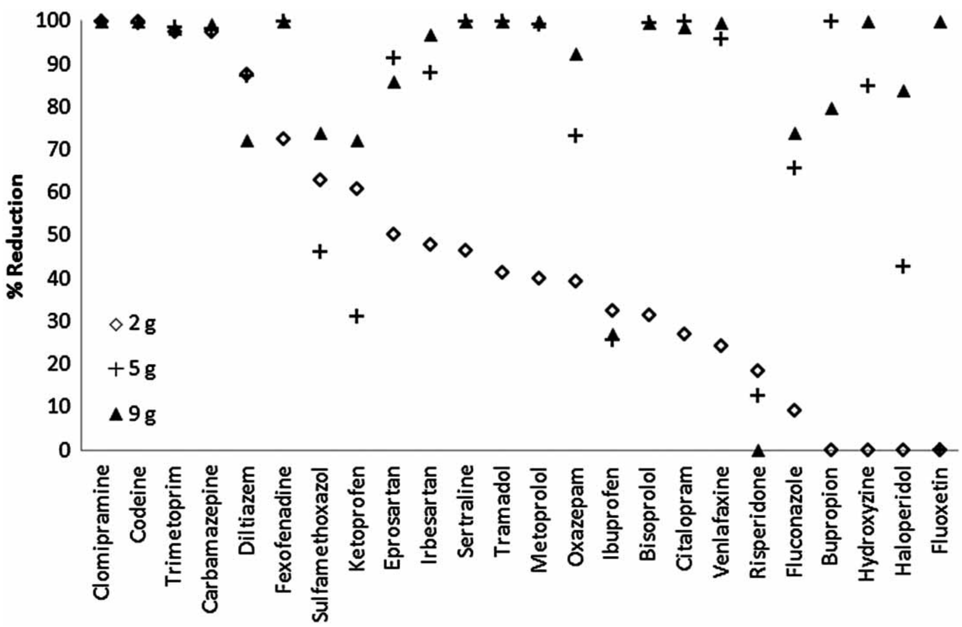

Figure 5 | Reduction of 24 organic micro-pollutants by ozone alone for each ozone dose (2, 5 and 9 gO_3/m^3) in Experiment 1, ozone after discfiltration.

The improved effect of ozone observed when adding ozone after discfiltration is thought to be due either to the removal of SS by the filtration step, enabling the applied ozone to react with dissolved organic micro-pollutants to a higher degree or possibly that some of the dissolved organic matter (DOC) is adsorbed onto the formed floccs thus lowering the DOC concentration.

Ozonation before discfiltration

Since the experiment was set up in such a way, the ozone and discfiltration steps can be evaluated independently. The removal efficiency of the twenty-four organic micro-pollutants by ozone alone

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when ozonation was conducted before discfiltration is depicted in Figure 6. Seven of the substances; Sertraline, Oxazepam, Ibuprofen, Risperidole, Haloperidol, Venlafaxine and Metoprolol was not removed when 2 gO_3/m^3 was applied. These substances were however removed to a greater extent (50–98%) when the ozone dose was increased to 5 and 9 gO_3/m^3.

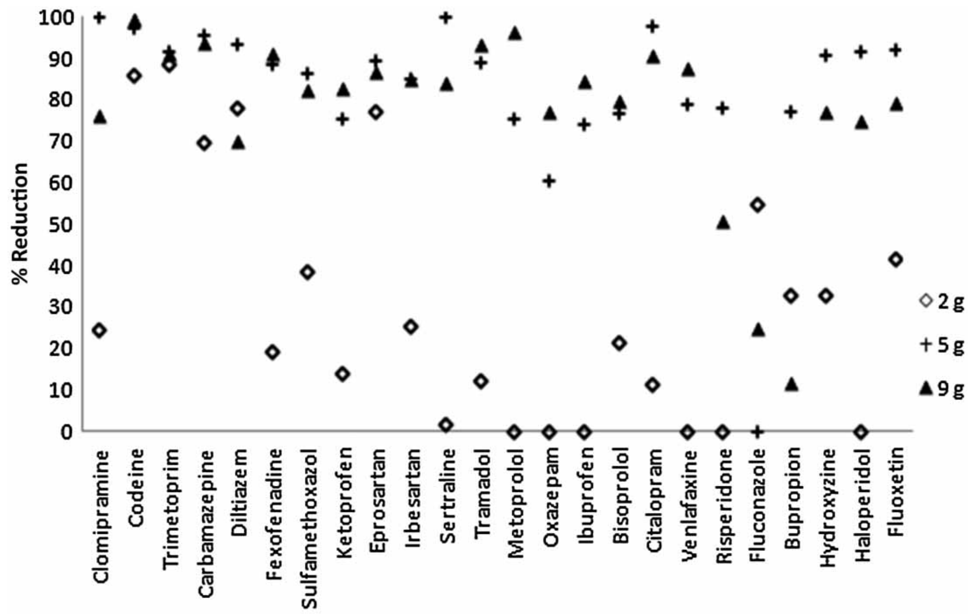

Figure 6 | Reduction of 24 organic micro-pollutants by ozone alone for each ozone dose (2, 5 and 9 gO_3/m^3) in Experiment 2, ozone before discfiltration.

Overall reduction of organic micro-pollutants

The total reduction calculated by summation of the concentrations of the 24 organic micro-pollutants measured in the influent (sampling point 3) and effluent (sampling points 13 or 15) is presented in Table 1. As can be clearly seen, the efficiency of the applied ozone dose increases when performed after the coagulation/flocculation/discfiltration process. For instance, the lowest ozone dose applied, 2 g/m^3 only reduces 10% of the total organic micro-pollutants when the ozone is introduced before the discfiltration. Whereas, if the same amount of ozone is applied after the filtration, the removal amounts to 48% thus ozonation should be applied after discfiltration of the chemically treated wastewater for more efficient ozone utilization.

Table 1 | Total reduction of 24 organic micro-pollutants for the two ozone setups presented as percentage

	Reduction	
Ozone dose ($g\ O_3/m^3$)	Ozone before discfiltration (%)	Ozone after discfiltration (%)
2	10	48
5	80	95
9	88	97

The effect of coagulation/flocculation/discfiltration process performance on organic micro-pollutants removal

Removal efficiency of the organic-micro-pollutants analyzed for the coagulation/flocculation/discfiltration process was evaluated for both experimental setups and all ozone doses, however, the

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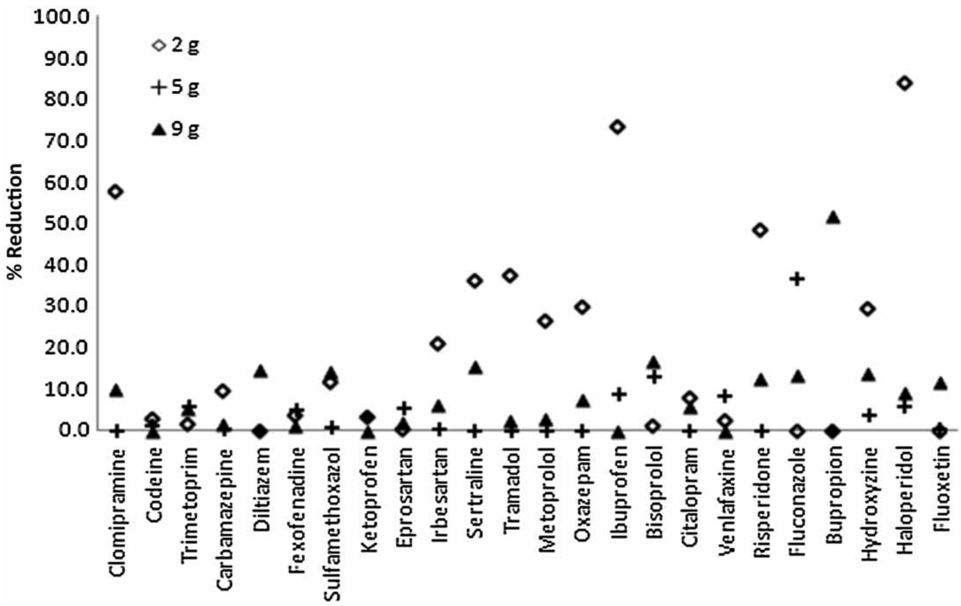

Figure 7 | Reduction of 24 organic micro-pollutants by the coagulation/flocculation./discfiltration process for each ozone dose (2, 5 and 9 gO_3/m^3) in Experiment 2.

results shown here is from experiment 2 (Figure 7). The removal efficiency varied between 0 and +24% which coincides with other research that has shown that enhanced coagulation/flocculation processes remove <20% of organic micro-pollutants in wastewater (Wert *et al*. 2011) and <50% for coagulation processes in drinking water treatment (Reungoat *et al*. 2010).

The study showed that the process combination coagulation/flocculation/discfiltration and ozone can be an attractive process combination if low Tot-P levels (<0.1 mg/l) and a reduction of trace organic micro-pollutants are desired. The coagulation and flocculation process might be further optimized in order to reduce the costs and toxicity assays would be needed for documentation of the toxicity reduction was similar and sufficient for the two process combinations.

CONCLUSIONS

- The process combination coagulation/flocculation/discfiltration and ozone can be an attractive process combination if low Tot-P levels of <0.1 mg/l) and a reduction of trace organic micro-pollutants are desired.
- Ozonation should be applied after discfiltration of the chemically treated wastewater for more efficient ozone utilization
- The coagulation/flocculation/discfiltration process is not effected by ozonation; similar effluent water quality was achieved both by performing ozonation prior to and after the process.

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