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Solutions to microplastic pollution – Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies

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ABSTRACT

Conventional wastewater treatment with primary and secondary treatment processes efficiently remove microplastics (MPs) from the wastewater. Despite the efficient removal, final effluents can act as entrance route of MPs, given the large volumes constantly discharged into the aquatic environments. This study investigated the removal of MPs from effluent in four different municipal wastewater treatment plants utilizing different advanced final-stage treatment technologies. The study included membrane bioreactor treating primary effluent and different tertiary treatment technologies (discfilter, rapid sand filtration and dissolved air flotation) treating secondary effluent. The MBR removed 99.9% of MPs during the treatment (from 6.9 to 0.005 MP L^{-1}), rapid sand filter 97% (from 0.7 to 0.02 MP L^{-1}), dissolved air flotation 95% (from 2.0 to 0.1 MP L^{-1}) and discfilter 40–98.5% (from 0.5 – 2.0 to 0.03–0.3 MP L^{-1}) of the MPs during the treatment. Our study shows that with advanced final-stage wastewater treatment technologies WWTPs can substantially reduce the MP pollution discharged from wastewater treatment plants into the aquatic environments.

1. Introduction

Microplastics (MPs) are defined as plastic particles < 5 mm. Primary MPs are intentionally manufactured in small sizes like virgin resin pellets, microbeads in personal care products, industrial scrubbers used in abrasive cleaning agents and plastic powders used for moulding, while secondary microplastics result from the fragmentation of larger plastic particles. Fragmentation can occur during the use of materials like textiles, paint and tyres, or once the plastics have been released into the environment. Both primary and secondary MPs are found from environmental samples (GESAMP, 2015). MPs have the potential to adsorb persistent organic pollutants (Rios et al., 2010; Chua et al., 2014) and heavy metals (Rochman et al., 2014) from the surrounding water environment. Further, variety of plastic additives, like flame retardants and plasticizers, are included in the plastics during manufacturing. It has been proposed that if MPs with their micropollutants enter food webs through digestion by biota, this may lead to ecosystem and human health impacts (Browne et al., 2013; Rochman et al., 2015; Miranda and de Carvalho-Souza, 2016).

Wastewater treatment plants (WWTPs) can act as a barrier but also as entrance routes for microplastics to aquatic environment. Conventional wastewater treatment with primary and secondary treatment processes can remove MPs from the wastewater up to 99% and most of the MPs are removed already during pretreatment phases (Carr et al., 2016; Murphy et al., 2016; Talvitie et al., 2017). Despite of the high reduction ability, conventional WWTPs may actually be a significant source of MPs given the large volumes of effluents that are discharged (Mason et al., 2016; Murphy et al., 2016; Mintenig et al., 2017; Talvitie et al., 2017).

During the last decades wastewater treatment has continuously been required to increase the quality of the final effluents. However, the technologies to improve the quality of the final effluent are not specifically designed to remove microplastics and do not necessarily remove MPs from the effluent (Mason et al., 2016; Talvitie et al., 2017). Few studies suggest, however, that with some advanced final-stage wastewater treatment technologies the removal of the MPs from effluents can be further improved (Carr

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et al., 2016; Mintenig et al., 2017; Ziajahromi et al., 2017).

The aim of this study was to examine the efficiency of different advanced final-stage treatment technologies to remove microplastics from effluent. This study includes tertiary treatments; discfilter (DF), rapid sand filtration (RSF) and dissolved air flotation (DAF) and membrane bioreactor (MBR). In addition, we examined which MP types (size and shape) were removed and which were left in the final effluent after the treatments. The study was repeated with 24-h automated composite samplers to include in-day variation to examination of MP removal and concentration. We performed comprehensive FTIR analyses to all and whole samples included in the study. In the end, we estimated the proportion of primary and secondary MPs in final effluents.

2. Materials and methods

2.1. Description of the selected WWTPs and advanced wastewater treatment technologies

The most commonly used advanced final treatment stage technologies were selected for our study. The tertiary treatments included different filtering (sand and cloth) and flotation techniques. Also, membrane bioreactor was selected.

Micro-screen filtration with discfilters (DF) was examined in Viikinmäki WWTP located at Helsinki, a metropolitan area of Finland. Viikinmäki WWTP process is based on primary clarification, conventional activated sludge (CAS) process and a tertiary denitrifying biological filter (BAF). More detailed characteristics of each WWTPs included in this study is given in supplementary data (SD. Table S1). The pilot-scale discfilter (Hydrotech HSF 1702 -1F) consists of two discs composing each of 24 filter panels. The pilot unit was so-called inside-out system where the influent water is introduced inside the filter panels. The particle removal is based on physical retention in filters and sludge cake formation inside the filter panels. The sludge cake formation decelerates the filtering, causing water level rise inside the cylinder. When water meets the level sensor, backwash is initiated. Backwash is performed with high pressure (in this case 8 bars) to rinse off the sludge cake. The particle and nutrient removal can further be enhanced with coagulants. In this study iron based coagulant and cationic polymer were used with dosages of 2 mg/L and 1 mg/L, respectively. Hydraulic retention time (HRT) in the pilot was 4 min and flow ~ 20 m^3/h. The overall filtration area was 5.76 m^2 and pore size of the filters was either 10 or 20 μm (Rossi, 2014).

Rapid (gravity) sand filters (RSF) as full-scale tertiary treatment was examined in Kakolanmäki WWTP (Turku Region Waste Water Treatment Plant), city of Turku, Southern Finland. In RSF, the wastewater is filtered through a layer of sand. The sand filter composed of 1 m of gravel with gain size of 3–5 mm and 0.5 m of quartz with grain size 0.1–0.5 mm. Apart from physical separation removing suspended solids, adhesion by microbes removes nutrients and microbes. Before the sand filter the process is based on CAS method.

Dissolved Air Flotation (DAF) as full-scale tertiary treatment was examined at Paroinen WWTP (Hämeenlinna Region Water Supply and Sewerage Ltd) located in city of Hämeenlinna, Southern Finland. In DAF, water is saturated with air at high pressure and then pumped to a flotation tank at 1 atm, forming dispersed water. The released air bubbles in dispersed water adhere to the suspended solids causing them to float to the surface, from where it is removed by skimming. Before the flotation, flocculation chemical Polyaluminium Chloride (PAX) is added to the wastewater with dosage of 40 mg/L to enhance flocculation. Before the DAF, the process is based on CAS process.

Membrane bioreactor (MBR) pilot unit was examined at Kenkäveronniemi WWTP, located in city of Mikkeli, South-East of Finland. Kenkäveronniemi WWTP is generally based on primary clarification, CAS process and secondary clarifier effluent on hygienization using peracetic acid solution. The MBR pilot included Submerged Membrane Unit (SMU) and ultrafiltration (UF) process (LF/KUBOTA SMUTM). The membrane system consisted of 20 flat-sheet membrane cartridges installed inside the filtration tank. During the filtration, the water is forced through membranes under negative pressure created by pumps and collected to the separate tank. MBRs are the combination of membrane filtrations processes with suspended growth biological reactors. This combination treats primary effluent containing suspended solids as well as dissolved organic matter and nutrients. Hence the MBR technology replaces secondary clarifiers in CAS systems. In the MBR pilot unit the effective membrane area was 8 m^2 and the nominal pore size of the membranes 0.4 μm. HRT values varied from 20 to 100 h and the flow between 40 and 90 l/h (Gurung, 2014).

2.2. Sample collection

Sampling at the four different WWTPs took place between April 2014 and August 2015. The actual sampling dates and times are given in supplementary data (SD. Table S2.). Samples with three replicates were collected before and after the treatments. The replicates consisted of three independent water samples. A custom made filtering device with in-situ fractionation was used (Talvitie et al., 2015). The mesh-sizes of the filters were 300, 100 and 20 μm, giving particle size fractions of >300 μm, 100–300 μm and 20–100 μm. Sampling full-scale treatments (RSF, DAF) was performed by pumping water (depth ~ 1 m) from the wastewater stream into the filtering device with an electric pump (Biltema art.17-953). In pilot-scale treatments (discfilters, MBR), the samples were collected from the taps designed for sampling, into the filter device. In addition, samples after the CAS in Kenkäveronniemi WWTP were collected to see the possible improved removal capacity provided by MBR method compared to CAS. Water sample volumes were measured with a flow meter (Gardena Water Smart Flow Meter) and varied with the wastewater quality and filter size (Table 1). The sampling was stopped before the filters were clogged with organic matter. After the sampling, the filters were collected to petri dishes and stored in room temperature.

Additional sampling was carried out with automated 24-h composite samplers. Composite samplers in each WWTPs took a sample proportionally and discretely at an interval of 15 min over a 24-h period before and after the treatment unit (Table 2). The samplers collected wastewater into plastic containers located in closed refrigerators. The discfilter was not included in the composite sampling as the WWTP was not able to provide the equipment.

2.3. Wastewater characteristics of the selected WWTPs

The main wastewater characteristics of the MP sampling sites are summarized in Table 3. The results were obtained from the analysis of 24-h composite samples collected for the weekly monitoring programs of plants. The samples were taken around the same time as those for the MP study.

2.4. Characterization of microparticles

All samples were visually examined using a stereo microscope (model EZ4 HD; Leica Microsystems GmbH, Wetzlar, Germany), with an integrated HD camera. All textile fibers and particles suspected as plastics were counted and the particles further classified as fragments, flakes, films and spheres, and their coloration