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How well is microlitter purified from wastewater? – A detailed study on the stepwise removal of microlitter in a tertiary level wastewater treatment plant

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ABSTRACT

Wastewater treatment plants (WWTPs) can offer a solution to reduce the point source input of microlitter and microplastics into the environment. To evaluate the contributing processes for microlitter removal, the removal of microlitter from wastewater during different treatment steps of mechanical, chemical and biological treatment (activated sludge) and biologically active filter (BAF) in a large (population equivalent 800 000) advanced WWTP was examined. Most of the microlitter was removed already during the pre-treatment and activated sludge treatment further decreased the microlitter concentration. The overall retention capacity of studied WWTP was over 99% and was achieved after secondary treatment. However, despite of the high removal performance, even an advanced WWTP may constitute a considerable source of microlitter and microplastics into the aquatic environment given the large volumes of effluent discharged constantly. The microlitter content of excess sludge, dried sludge and reject water were also examined. According to the balance analyses, approximately 20% of the microlitter removed from the process is recycled back with the reject water, whereas 80% of the microlitter is contained in the dried sludge. The study also looked at easy microlitter sampling protocol with automated composite samplers for possible future monitoring purposes.

1. Introduction

Litter has become a serious problem in aquatic environments worldwide. Litter includes both organic and inorganic materials like glass, metals, rubber, wood, paper, textiles and, for the most, plastics (OSPAR, 2014). Microlitter comprises litter particles smaller than 5 mm. Microlitter, and particularly its plastic subtype, microplastics, has received considerable attention over the past decade (Thompson et al., 2004; Barnes et al., 2009; Ladewig et al., 2015). Microplastics are of concern because of their durability and potential to be transferred within food webs (Cole et al., 2013; Setälä et al., 2014). Microplastics may cause mechanical stress when ingested, but also expose marine organisms to various hazardous substances, such as plasticizers (Fries et al., 2013), toxic metals (Rochman et al., 2014) and persistent organic pollutants (POPs) (Rios et al., 2010; Chua et al., 2014). These micropollutants are either added to the plastics during production or adsorbed from the surrounding water (Teuten et al., 2009). In aquatic environments, microplastics can also function as artificial "microbial reefs" and transport non-indigenous and possibly harmful species (Zettler et al., 2013). In addition to microplastics, also non-synthetic textile fibers has been proposed to have potential to transport chemical pollutants throughout the aquatic environment (Ladewig et al., 2015).

Microlitter consists of primary and secondary particles. Primary particles are intentionally microscopic in, e. g microbeads in peeling lotions and textile fibers, while secondary microlitter is fragmented from larger particles (Barnes et al., 2009). Both aquatic and land-based sources have been identified contribute to the amount of litter in marine environments (Law et al., 2010). Land base sources include public littering, poorly managed landfills, riverine transport, stormwater and untreated municipal sewage.

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Recently, wastewater treatment plants (WWTPs) have been suggested to act as one of the land base sources or entrance routes for microlitter to the aquatic environment (Magnusson and Norén, 2014; Talvitie et al., 2015; Murphy et al., 2016). First studies have shown that microlitter can be efficiently (>98%) removed from the wastewater during the wastewater treatment (Magnusson and Norén, 2014; Carr et al., 2016; Murphy et al., 2016). However, treated effluents still contain microlitter particles like plastic microbeads from toothpaste and textile fibers (Browne et al., 2011; Talvitie et al., 2015; Carr et al., 2016).

As vast volumes of effluent waters are discharged continuously into aquatic environments globally and the amounts are expected to grow due the population growth and urbanization (UN-Water, 2015), the role of WWTPs as an entrance route of microlitter to aquatic environments may be significant. At the same time, WWTPs can offer solutions to reduce the input of microlitter into the environment. Despite of this potential, very little attention has yet been drawn to the actual removal of microlitter during different type of wastewater treatment processes. Here we report detailed data on the removal of microlitter during different treatment steps in a large (population equivalent 800 000) advanced WWTP. The balance of microlitter in WWTP were estimated to further evaluate the removal and distribution of microlitter during the treatment processes. Also, the effect of microlitter size and shape on their removal in different treatment steps were determined. The further objective of this study was to establish an easy-to-use protocol for monitoring of WWTPs. In the end, we report the evaluation of microlitter and microplastic load discharged into the marine environment with effluents.

2. Materials and methods

2.1. Description of the selected WWTP

Selected WWTP (Viikinmäki, Helsinki Region Environmental Services Authority, HSY) is the largest wastewater treatment plant in Finland and the Nordic Countries, treating the wastewaters of ca. 800 000 inhabitants in the Helsinki metropolitan area. An average of 270 000 cubic meters of treated wastewaters are discharged from the WWTP into a Gulf of Finland, Baltic Sea every day. The treatment process in Viikinmäki WWTP is based on activated sludge method and has multiple treatment steps based on pre-, chemical- and biological treatment. The nitrogen removal has been enhanced with a tertiary denitrifying biological filter. In 2015, 95% of organic material (BOD_7), 98% of suspended solids (SS), 95% of total phosphorus (P-tot) and 90% of total nitrogen (N-tot) were removed during the treatment process of the selected WWTP.

Pre-treatment includes coarse screening (10 mm), grit removal, chemical treatment and primary sedimentation. In order to remove phosphorus, ferrous sulphate is dosed in the sand removal prior to secondary clarifier. In biological treatment biodegradable matter and nitrogen are removed from the wastewater with activated sludge method. Activated sludge process includes aeration tanks and secondary clarifiers. Hydraulic retention time in the process is approximately 25 h and sludge retention time varies between 6 and 12 days. Most of the activated sludge is recycled from secondary clarifiers into the aeration tanks as return activated sludge but part of it is also continuously removed from the process. This excess sludge is returned to primary sedimentation and sent to sludge treatment together with raw sludge. The nitrogen removal is further improved in tertiary treatment process with biologically active filter (BAF). During the BAF process, wastewater flows through tightly packed polystyrene beads. The beads provide a surface for micro-organisms to attach and grow. While growing, they consume organic material as well as phosphorus and convert nitrates to nitrogen gas.

Viikinmäki WWTP has also a solids handling treatment. Organic matter in the sludge is anaerobically digested to produce biogas, i.e. methane and consecutively used for the plant's own energy consumption. After the digestion, sludge is dewatered with centrifuges. For dewatering, the sludge is conditioned with flocculation chemical polyacrylamide (PAM). PAM induces a release of the water during dewatering by enhancing the aggregation of sludge particles into larger particle groups called flocs. Dewatering generates reject water, which is conducted via a settling tank into the beginning of the wastewater treatment process. The dried sludge is processed further in composting fields and used in green construction. The plant produces annually around 60 000 tonnes of dried sludge which has a dry solids (TS) content of 29%.

2.2. Sampling methods

The samples were collected from the plant influent, after pretreatment, after the activated sludge (AS) process, plant effluent, excess sludge, reject water and dried sludge (SD Fig. S1). Sampling was carried out during a seven-day period 14.9–20.9.2015 with three different sampling methods; grab sampling (here meaning one sampling occasion at a certain time), 24-h composite sampling and 24- hour sequential sampling (Table 1.).

2.2.1. Grab sampling of the wastewater and sludge

Grab samples from wastewater were collected from each sampling site in water process. Three replicates ($n = 3$) were taken from each sample types consecutively. Sampling was done by pumping water from the wastewater stream was (at depth ~ 1 m) onto the designated filter with an electric pump (Biltema art.17–953). Filtering set up previously designed for microplastic sampling in wastewaters was used (Talvitie et al., 2015). The respective filter mesh sizes were 300, 100 and 20 μm, giving size fractions of >300 μm, 100–300 μm and 20–100 μm (SD Fig. S2). The volume of each sample (Table 2.) was measured with a flow meter (Gardena Water Smart Flow Meter) attached to the pump. This volume of filtered water depended on the water quality and filter size. The volumes of replicate samples differed, since the water quality varied.

This sampling method is not applicable for influent water due to its high amount of organic material which rapidly clogs the filters allowing only small water volumes to pass. For the influent sampling a metallic beaker to collect water from the wastewater stream surface was used and the samples were later filtered in laboratory with the same filter set up.

Samples from the excess sludge and reject water were collected with the same method as influent samples, while dried sludge was collected by hands from the conveyor belt after dewatering process. All sludge and reject water samples were placed into pre-cleaned plastic containers and transported into the laboratory for filtering. The sludge and reject water samples were diluted before filtering by mixing subsamples of wet sludge (1 g), reject water (10 g) and dry sludge (0,2 g) with 1 L of tap water. Diluted sludge and reject water samples were then filtered with the filtering device as the wastewater samples. Details of different samples are presented in Table 2. To prevent contamination during the sampling, all equipment was rinsed carefully with tap water prior to sampling.

2.2.2. Composite sampling

24-h composite samples were collected from all sites in water process (Table 3.). Composite samplers (ISCO 3700) in each sampling location took flow proportional, discrete samples at regular 15 min Intervals over 24-h period of time. The samples were collected into plastic containers placed in refrigerators. Both, the