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Combined Sewer Overflow pretreatment with chemical coagulation and a particle settler for improved peracetic acid disinfection

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ABSTRACT

Full scale disinfection by peracetic acid (PAA) was achieved on Combined Sewer Overflow (CSO) water, which was pre-treated physically by a fast settling-filtration unit. Disinfection of untreated CSO water using PAA was compared to treatment using a particle separator (HydroSeparator®) and additional coagulation with poly-aluminum-chloride. Disinfection for *Enterococcus* increased with the applied dose of PAA and additional improvement was achieved when it was preceded by chemical coagulation with 5 mg L^{-1} poly-aluminum-chloride. When *Enterococcus* was reduced by treatment in the HydroSeparator, followed by PAA treatment during a CSO event, the treatment was sufficient to maintain microbial quality in the recipient water.

1. Introduction

Many old cities are drained by combined sewer systems, in which wastewater is mixed with rain water and transported to a wastewater treatment plant for processing. When significant rainfall events occur, design capacity of combined sewer systems can be exceeded, resulting in the discharge of untreated Combined Sewer Overflow (CSO) to nearby surface waters through prepared emergency structures. Discharge of untreated CSO gives rise to acute impacts on the quality of receiving waterbodies, as it contains a variable mixture of rain water, raw sewage, watershed run-off pollutants, variable pathogenic organisms, viruses, cysts, suspended solids, chemicals, and floatable materials [1]. In recent years, the impact of CSOs on water bodies used for recreational purposes has become an issue of concern in Europe. The European Union (EU) has strove to regulate bathing water quality by issuing a series of bathing water directives; one of which stipulates that in terms of good microbial content, the density of *E. coli* should not exceed 500 MPN and *Enterococcus* 200 MPN per 100 mL of water intended for recreational purposes, based upon 95 percentile evaluation. For bathing water of sufficient quality, the number of indicator organisms should not exceed 500 *E. coli* per 100 mL and 185 *Enterococcus* per 100 mL water intended for recreational purposes, based upon 90 percentile evaluation [2].

Safe bathing water quality, in terms of microbial load, can be maintained by disinfection of inflowing CSO water. According to Tchobanoglous et al. [3], an ideal disinfectant should guarantee maximum efficiency in pathogenic microorganism removal, without generating toxic and undesirable by-products. Furthermore, the disinfection process should be inexpensive and technologically compatible with other parts of the water treatment [3]. Various well known disinfectants are currently used in the water industry, such as hypochlorite and chlorine dioxide [4], which could be used to reduce contamination by microorganisms from CSO events. However, unfortunately the by-products of these compounds are of environmental concern [5–9]. Alternatively, the organic peroxide peracetic acid (PAA) is a strong disinfectant with a wide spectrum of antimicrobial activity, which was introduced to wastewater treatment approximately 30 years ago

Abbreviations: ABTS, 2,2″-azino-bis [3-ethylbenzothiazoline-6-sulfonic acid] diammonium salt; AUC*x*, area under the curve of disinfection concentration until *x* min of disinfection; COD, chemical oxygen demand; CSO, Combined Sewer Overflow; MPN, most probable number; PAA, peracetic acid; PAX, polyaluminium chloride; SS, suspended solids.

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[10–15]. Commercial PAA is available as an acidic quaternary equilibrium mixture of PAA, hydrogen peroxide, acetic acid, and water:

$$CH_3COOH + H_2O_2 \rightleftharpoons CH_3CO_3H + H_2O \quad (1)$$

The residues after PAA use are acetic acid, hydrogen peroxide, and water. Acetic acid is further biodegraded to carbon dioxide whilst hydrogen peroxide degrades to oxygen and water; neither of which is considered toxic to aquatic life [16]. Recently, we investigated at laboratory scale the potential to employ peracetic acid and performic acids for disinfection of CSO in terms of dosage, kinetics, and residual disinfectants [17]. Additionally, we previously demonstrated for the first time, full- scale use of performic acid disinfection of CSO by using a sea outfall pipe as reaction tank [18].

The efficiency of a disinfection method can be increased if CSO water is pretreated with physical and/or chemical processes, such as chemical coagulation or filtration. The primary purpose of physical chemical treatment is to reduce suspended solids and therefore any contaminants associated with them. Among various physical chemical treatment processes in wastewater technology, employment of chemical coagulation, followed by introduction of lamella clarifiers is most common. Suspended solids and other pollutants from wastewater can be removed by chemical coagulation, followed by lamella clarification; and the process is considered an essential component of wastewater treatment [3]. Lamella clarifiers (comprised of a series of inclined-plates) were designed to remove particulates from CSO water. When CSO water flows over lamella in a clarifier, particles settle on the inclined plates accumulating in the associated collection hopper, resulting in effective removal of suspended solids.

Chemical coagulation is the process of the formation of flocs (large particles) from finely divided and destabilized particles. Studies concerning chemical coagulation and lamella clarification of CSO have shown efficient removal of total suspended solids (~80%), COD (~60%), total phosphorus (~85%) [19–21] and heavy metals (~75%) [22]. A broad spectrum of pollutants from CSO water has also been treated by ballasted flocculation [23] and priority pollutants by lamella clarification [24]. Furthermore, coagulation followed by disc filtration has been used to remove polycyclic aromatic hydrocarbons associated with micro particles in storm water [25]. Finally, removal of suspended solids and *E. coli* from CSO water has been demonstrated by drum and disc filtration, followed by UV disinfection [26]. To our knowledge, there are no studies currently available in the literature concerning disinfection of CSO water by chemical coagulation followed by lamella clarification. The following article describes such a study.

Application of physico-chemical pretreatment of CSO effluent will likely lead to improved disinfection efficiency and alter the degradation kinetics of PAA. Clearly, it is important to quantify this process in order to operate a full scale CSO treatment facility efficiently and effectively. Thus, the aim of this study was to test a full scale PAA disinfection system for CSO in terms of its design and performance. The design of the study and system is based on our previous work in addition to chemical coagulation using real CSO water. Furthermore, this study also investigates the degradation kinetics of PAA in CSO water before and after chemical coagulation.

2. Materials and methods

2.1. Chemicals

ABTS (2,2″-azino-bis [3-ethylbenzothiazoline-6-sulfonic acid] diammonium salt), sodium thiosulfate, and catalase from bovine liver (2000–5000 units/mg protein) were all purchased from Sigma–Aldrich (Brøndby, Denmark). All chemicals were of reagent grade. PAA (CAS no: 79-21-0) solution containing 30–40% (w/w) of technical grade disinfectant was supplied by Sigma–Aldrich (Brøndby, Denmark). PAX-XL 100 solution containing 9.3% (w/v) Al with basicity 43 ± 2% was supplied from Kemira Water Denmark (Copenhagen, Denmark).

2.2. Chemical analysis

Turbidity, phosphate, and suspended solids were determined according to standard methods [27] and using standard operating procedures and control methods from the general water laboratory at Department of Environmental Engineering, Technical University of Denmark. PAA concentration was analyzed using the colorimetric method described by Chhetri et al. [17] based on selective oxidation of ABTS by PAA without interference from hydrogen peroxide.

2.3. Microbiological analysis

Samples were processed within 2 h after collection. Residues of PAA were neutralized in laboratory experiments by adding 100 mg L^{-1} sodium thiosulfate, followed by 50 mg L^{-1} catalase to destroy hydrogen peroxide [28]. *Enterococcus* were enumerated using the Enterolert methods from IDEXX (IDEXX laboratories, Maine, United States), as described by Chhetri et al. [17].

2.4. Site description

The HydroSeparator® CSO system (HydroSeparator) was installed in Kærby, a small city in Middelfart, Denmark to treat CSO from the towns of Båring and Asperup following extreme weather (i.e. significant precipitation events), which usually occurs at least several times a year. During these extreme events, treatment capacity of Nørre Aaby wastewater treatment plant is exceeded and CSO is consequently discharged to a surface water body. Prior to installation of the HydroSeparator, untreated CSO has been discharged to Kærbyholm canal, which flows to Pavebækken stream, which further flows into Storeå river before finally entering the sea near the towns of Varbjerg and Bro. The HydroSeparator is a patented and specialized system designed to effectively clean CSO, minimizing the environmental impact to receiving water bodies such as rivers, harbors, beaches etc. The HydroSeparator is equipped with lamella, followed by a filter with sieve size of 20 μm (Fig. 1). The HydroSeparator has a capacity to treat CSO water at a flow rate of 5–25 L s^{-1}. The principle use of the HydroSeparator is to remove suspended solids (SS) from CSO discharge during extreme weather events, which also, in turn reduces pollutants associated with them. At the Kærby site, particles greater than 4 mm present in the CSO are removed by a mechanical screen prior to flow into the HydroSeparator. Retention time of CSO water in the HydroSeparator is determined based on flow rate into the system. In maximal flow, the retention time of CSO water in the HydroSeparator is 7 min, whilst during minimum flow retention time is 35 min. To optimize removal of larger SS's during flow through the HydroSeparator, chemical coagulation was employed at the inlet. After treatment by flow-through of the HydroSeparator, CSO water is further disinfected with PAA in a reaction chamber, which then flows to a constructed wetland. In this study, any effects or processes associated with the constructed wetland following discharge of treated CSO were not investigated.

2.5. Experiment performed

This study was divided into three sub-experiments: Experiment I- study of disinfection, Experiment II- study of pre-treatment with chemical coagulation and Experiment III- study of full scale