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Salt stress in a membrane bioreactor: Dynamics of sludge properties, membrane fouling and remediation through powdered activated carbon dosing

L. De Temmerman [a,b], T. Maere [b], H. Temmink [a,c], A. Zwijnenburg [a], I. Nopens [b,*]

[a] Wetsus Centre of Excellence for Sustainable Water Technology, P.O. Box 1113, 8900 CC Leeuwarden, The Netherlands

[b] BIOMATH, Department of Mathematical Modelling, Statistics and Bioinformatics, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium

[c] Sub-department of Environmental Technology, Wageningen University, P.O. Box 17, 6700 AA Wageningen, The Netherlands

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ABSTRACT

Membrane bioreactors are a well-established technology for wastewater treatment. However, their efficiency is adversely impacted by membrane fouling, primarily inciting very conservative operations of installations that makes them less appealing from an economic perspective. This fouling propensity of the activated sludge is closely related to system disturbances. Therefore, improved insight into the impact of fouling is crucial towards increased membrane performance. In this work, the disturbance of a salt shock was investigated with respect to sludge composition and filterability in two parallel lab-scale membrane bioreactors. Several key sludge parameters (soluble microbial products, sludge-bound extracellular polymeric substances, supramicron particle size distributions (PSD), submicron particle concentrations) were intensively monitored prior to, during, and after a disturbance to investigate its impact as well as the potential governing mechanism. Upon salt addition, the supramicron PSD immediately shifted to smaller floc sizes, and the total fouling rate increased. Following a certain delay, an increase in submicron particles, supernatant proteins, and polysaccharides was observed as well as an increase in the irreversible membrane fouling rate. Recovery from the disturbance was evidenced with a simultaneous decrease in the above mentioned quantities. A similar experiment introducing powdered activated carbon (PAC) addition used for remediation resulted in either no or less significant changes in the above mentioned quantities, signifying its potential as a mitigation strategy.

* *Corresponding author*. Tel.: +32 0 9 264 5939.
E-mail addresses: lieven.detemmerman@ugent.be (L. De Temmerman), Ingmar.Nopens@ugent.be (I. Nopens).
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1. Introduction

The application of membrane bioreactors (MBRs) for wastewater treatment is not a novel concept. However, the significant investment and operational costs are still major hindrances for an increased widespread application. The specific energy use of MBRs is approximately 0.6–1.0 kWh m^{-3} compared to 0.3–0.4 kWh m^{-3} for conventional activated sludge (CAS) systems, depending on the configuration (Krzeminski et al., 2012; Verrecht et al., 2010). This substantiates the multitude of studies that have been conducted in order to determine a system to optimize the overall energy efficiency of MBRs, inter alia Barillon et al. (2012). A classification of energy consumption in MBRs indicates that approximately half of the total energy consumption of MBRs is associated with coarse bubble aeration which is applied to decrease membrane fouling through air scouring (Brepols et al., 2010).

Energy savings can be achieved in the area of fouling mitigation (aeration, backwashing, or membrane cleaning) or source control (monitoring and improving the biomass characteristics that are associated with fouling) (Le-Clech et al., 2006). Until recently, MBR research focused on discovering opportunities to decrease operational costs for fouling mitigation by optimizing the aeration demand and flux settings without compromising membrane performance. Newly designed aerators, intermittent aeration and adapted membrane configurations have certainly contributed to a gradual decrease in energy demand. However, these ameliorations have primarily been a result of trial and error experiments that do not explicitly target an accumulation of knowledge about fouling causes and mechanisms. This deficiency in understanding currently hinders further progress.

The source control approach is challenging, as it requires monitoring the sludge condition and its association with filterability and fouling. Activated sludge composition is complex as well as dynamic in nature, i.e., it depends on operational conditions such as sludge retention time, hydraulic retention time and wastewater characteristics (Drews, 2010; Le-Clech et al., 2006). Furthermore, MBRs experience influent dynamics in reference to flow rate, organic loading, temperature, salt concentrations, and toxic compounds (Theiss et al., 2006). These dynamics can be considered inflow disturbances as they will induce dynamics in the activated sludge matrix and subsequently impact its filterability in one or the other way (Drews et al., 2006; Rosenberger and Kraume, 2003; Van den Brink et al., 2011). Furthermore, a majority of the above mentioned dynamics can occur simultaneously, making their individual impact quantification difficult, if not impossible. Whereas the combined effect of inflow disturbances on fouling can be quantified, the exact cascade of mechanisms for each disturbance is not easily clarified (Van den Broeck et al., 2011).

One significant disturbance for both industrial and municipal wastewater treatment is the increase in the inflow concentration of monovalent salt, e.g., due to road application, discharge of industrial effluents, or sewer infiltration of intruded seawater in coastal areas. Monovalent salt modifies the influent's ionic strength as well as the balance between monovalent and multivalent ions. Elevated monovalent salt concentrations deteriorate sludge quality through deflocculation (Biggs et al., 2001; Sobeck and Higgins, 2002) by disturbing the multivalent cation bridging between extracellular polymeric substances (EPS) (Van den Broeck et al., 2010). While membrane fouling can be associated with an array of sludge parameters related to increased salinity, extracellular polymeric substances (EPS) and soluble microbial products (SMP) are often considered important contributors to fouling (Drews, 2010). On the other hand, multivalent ions and sludge-bound EPS are collectively beneficial for floc formation. A decrease in sludge quality resulting from increased salt concentration leads to worse sludge filterability and increased membrane fouling. The latter is most likely related to the increased fouling potential of EPS that is released into the bulk liquid (Reid et al., 2006; Sun et al., 2010; Van den Broeck et al., 2010). EPS comprises of proteins, polysaccharides, lipids, and other biopolymers bound to sludge, whereas SMP is considered to be the EPS counterpart in the bulk liquid. The balance between reduced EPS and increased SMP exhibited a substantial correlation with the intensity of a salt shock (Drews et al., 2008). However, lab-scale results for fouling are inconclusive regarding the importance of EPS and SMP as fouling agents (Van den Broeck et al., 2010), and full-scale evaluation did not demonstrate a significant impact of SMP on fouling (Fenu et al., 2010).

In addition to focusing on the cause of fouling and the individual impact of parameters, several authors have evaluated the efficiency of fouling reducers with encouraging results (Huyskens et al., 2012; Iversen et al., 2009; Koseoglu et al., 2008). In a comparative study of potentially beneficial fouling reducers, Huyskens et al. (2012) found beneficial effects depending on fouling reducer dosing rate and charge, the adsorption of small particles and floc strength. Currently, the dosing of fouling reducers is based on MLSS concentration as recommended by manufacturers, but Huyskens et al. (2012) concluded that this might not be the best dosing strategy. Indeed, different effects were found for municipal and industrial waste sludges. Mesoporous powdered activated carbon (PAC) was prominently ranked compared to cation-based polymers and starch (Iversen et al., 2009; Jamal Khan et al., 2012). The positive effect of PAC on sludge filterability was significant even at dosages as low as 0.5 g PAC per liter of sludge (4 mg PAC per liter of wastewater) during periods of high salinity (Remy et al., 2011). In the latter study, it was evidenced that PAC incorporated into the floc matrix induced the formation of stronger flocs. In similar studies regarding wastewater sludge, size exclusion analyses indicated the potential of PAC for adsorbing submicron particles such as biopolymers and low molecular weight acids and neutrals in the bulk liquid (Filloux et al., 2012; Jamal Khan et al., 2012; Kang and Choo, 2010). In addition, these PAC addition experiments demonstrated a reduction in membrane fouling. The importance of submicron particles for fouling has previously been suggested by many authors (Drews, 2010; Jiang et al., 2005; Le-Clech et al., 2006; Remy et al., 2011), but their dynamics during disturbances have not yet been intensely monitored in lab, pilot, or full-scale MBRs.

This paper intends to provide additional insight into membrane fouling and fouling mitigation during a salt shock.