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Sequential batch membrane bio-reactor for wastewater treatment: The effect of increased salinity

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HIGHLIGHTS

- A SB-MBR pilot plant treating wastewater subject to salinity increase was investigated.
- Salinity increase influenced the biological contribution of COD removal efficiency.
- Salinity increase did not exert a significant stress on heterotrophic bacteria.
- Significant reduction of the respiration rates of autotrophic species due to salt.
- The irreversible cake deposition was the predominant membrane fouling mechanism.

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ABSTRACT

In this work, a sequential batch membrane bioreactor pilot plant is investigated to analyze the effect of a gradual increase in salinity on carbon and nutrient removal, membrane fouling and biomass kinetic parameters. The salinity was increased by 2 g NaCl L^{-1} per week up to 10 g NaCl L^{-1}. The total COD removal efficiency was quite high (93%) throughout the experiment. A gradual biomass acclimation to the salinity level was observed during the experiment, highlighting the good recovery capabilities of the system. Nitrification was also influenced by the increase in salinity, with a slight decrease in nitrification efficiency (the lowest value was obtained at 10 g NaCl L^{-1} due to lower nitrifier activity). Irreversible cake deposition was the predominant fouling mechanism observed during the experiment. Respirometric tests exhibited a stress effect due to salinity, with a reduction in the respiration rates observed (from 8.85 $mgO_2\ L^{-1}\ h^{-1}$ to 4 $mgO_2\ L^{-1}\ h^{-1}$).

1. Introduction

Industrial saline wastewater is usually rich in organic matter and toxic compounds, meaning that it needs to be treated prior to discharge into the environment to prevent surface and ground water quality decreases (Jang et al., 2013).

Biological processes may represent an alternative and cost-effective solution for treating saline wastewater compared to commonly used physicochemical processes. Therefore, several authors have investigated the impact of high salinity on conventional activated sludge (CAS) processes (Campos et al., 2002; Rene et al., 2008). Researchers found that high salt contents produce negative impacts on the performance of CAS systems (e.g., compromised settling, cell plasmolysis, decrease of biomass respiration rates, etc.) (Kargi and Dincer, 1996; Campos et al., 2002; Mannina et al., 2016). To overcome the negative effect of salt, researchers have investigated using innovative biological technologies for treating saline wastewater (e.g., membrane bioreactor – MBR). The use of MBR technology provides considerable advantages over CAS systems including: higher effluent quality, lower footprint requirement, high sludge retention time (SRT), an almost complete absence of pathogenic bacteria in the effluent and faster biomass acclimation (Judd and Judd, 2010). Thus, the use of MBRs for treating high strength wastewater containing toxic compounds has been proven effective (Jang et al., 2013). However, it is crucial to investigate how biomass kinetics and activated sludge features affect the biological and physical performance of MBRs used to treat saline wastewater. With this in mind, several studies have been recently carried out on MBRs treating saline wastewater (Jang et al., 2013; Johir et al., 2013; Di Trapani et al., 2014; Luo et al., 2015). Jang et al. (2013) found a reduction of the ammonia removal and an increase in membrane fouling when treating high salinity wastewater was due to particular features of the microbial

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community. Johir et al. (2013) found a decrease in the dissolved organic carbon and ammonia uptake rate due to the inhibitory effect of the salinity. Di Trapani et al. (2014) compared the performance of a moving bed membrane bioreactor (MB-MBR) with a MBR system subjected to a gradual salinity increase (up to 10 g NaCl L^{-1}) and showed an increase of the pore fouling tendency with the increase in salinity in the MBR (Di Trapani et al., 2014). Very recently, Luo et al. (2015) investigated the effects salinity has on the characteristics of the biomass and membrane fouling in MBR systems. They found that ammonia removal efficiency decreased considerably at high salinities ($\geqslant$10 g $NaCl^{-1}$), especially immediately after the salinity shock load. Therefore, the autotrophic biomass suffers significantly when exposed to a high salinity environment. Nevertheless, several aspects still require further investigation to improve the efficiency of MBRs treating high strength saline wastewater.

Sequential Batch Reactors (SBRs), set up to treat industrial and civil wastewater in a single biological reactor and operated according to five discrete periods (fill, react, settle, draw and idle), were also investigated to treat saline wastewater (Artan and Orhon, 2005; Campos et al., 2002; Rene et al., 2008). Amin et al. (2014) recently found that treating saline wastewater in an SBR resulted in substrate consumption that is better described by a second-order kinetic rather than the Monod first order kinetic. Ye et al. (2009) found that the salinity exerted a significant impact on nitrifying bacteria in a SBR. Moreover, the bacterial wash-out due to salinity may promote an increase in the effluent turbidity (Amin et al., 2014). During the last decades, new approaches to designing and operating SBRs have been explored to achieve very high effluent qualities when treating non domestic wastewater (e.g., multiple tanks and innovative technologies such as membrane bioreactors – MBR, etc.). The use of multiple tanks enhances nutrient removal from non-domestic wastewater (Bernet et al., 2000; Ra et al., 2000). However, the adoption of MBRs enables good performance for organic matter removal and sludge separation (Yang et al., 2010). Specifically, the combined use of SBRs and MBRs might overcome the drawbacks associated with salinity. To explore the possibilities using SBRs and widening their potential applications, this paper investigates for the first time, a pilot plant scheme composed of a combination of anoxic/aerobic/external MBR tanks.

In detail, this paper was aimed at evaluating the short term effect of a gradual increase of the inlet salinity in terms of carbon and nutrient removal, membrane fouling tendencies and biokinetic behavior.

2. Methods

2.1. The pilot plant and sampling scheme

The SB-MBR pilot plant was built at the Laboratory of Sanitary and Environmental Engineering of Palermo University (Fig. 1). A 320 L filling tank used for the storage of wastewater taken from the sewer system (the hydraulic retention time of the filling tank was equal to 1 day). This was connected to a 40 L stirring tank, where salt was added to the wastewater prior to being fed to the pilot plant. The SB-MBR pilot plant was designed according to a pre-denitrification scheme and consisted of two reactors in series, one anoxic (volume 45 L) and one aerobic (volume 224 L) and a MBR compartment (50 L). Furthermore, an oxygen depletion reactor (ODR) was installed between the MBR compartment and the anoxic reactor (Fig. 1).

The membrane was periodically backwashed (every 9 min for 1 min) by pumping a volume of permeate back through the membrane module from the Clean-In-Place (CIP) tank. The extraction flow was equal to 20 L h^{-1}. The SB-MBR plant was operated according to the sequencing batch approach. In particular, 8 cycles per day were carried out. During each cycle, 40 L (Q_{IN}) of urban wastewater with salt addition was added to the pilot plant. The reaction period and the solid–liquid separation (settle + draw of classical SBR) phase were set to 1 h and 2 h, respectively. During the solid–liquid separation phase, a permeate flow of 20 L h^{-1} (Q_{OUT}) was continuously extracted. During the cycle, an 80 L h^{-1} flow (Q_{R1}) was continuously pumped from the aerobic tank to the MBR tank. Furthermore, a recycled activated sludge (Q_{RAS}) flow equal to 80 L h^{-1} during the reaction period and 60 L h^{-1} (Q_{R1}–Q_{OUT}) during the solid–liquid separation phase, was continuously recycled from the MBR to the anoxic tank through the ODR tank.

The SB-MBR pilot plant was started up with sludge inoculum, withdrawn from a CAS system of Palermo's wastewater treatment plant, to obtain an initial mixed liquor suspended solids concentration of 4000 mg L^{-1}. The pilot plant was operated for 3 months without sludge withdrawing (indefinite SRT). Table 1 summarizes the main wastewater characteristics (in terms of the average values and standard deviations – SD) as well as the pilot plant operational parameters. From Table 1, it is worth noting that the HRT and F/M values were set to enable biomass acclimation to the increasing salinity, in particular to the nitrifying species (Ammonia Oxidizing Bacteria-AOB and Nitrite Oxidizing Bacteria-NOB) that are known to be very sensitive to salinity variations.

The experiment was divided into six Phases, with each characterized by a different salt concentration in the feeding wastewater. In detail, the salt concentration was gradually increased from 0 to 10 g NaCl L^{-1} (Phase I: no salt addition, Phase II: 2 g NaCl L^{-1}, Phase III: 4 g NaCl L^{-1}, Phase IV: 6 g NaCl L^{-1}, Phase V: 8 g NaCl L^{-1} and Phase VI: 10 g NaCl L^{-1}). The NaCl dosing was increased 2 g NaCl L^{-1} per week. Phase VI had a longer duration (26 days) to investigate the biomass recovery, as discussed in the following.

During plant operations, the influent wastewater, the mixed liquor inside the anoxic and aerobic tanks and the effluent permeate were sampled and analyzed for total and volatile suspended solids (TSS and VSS), total chemical oxygen demand (COD_{TOT}), supernatant COD (COD_{SUP}), ammonium nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), phosphate (PO_4-P), total carbon (TC) and inert carbon (IC). All the analyses were carried out according to Standard Methods (APHA, 2005).

To discriminate between the removal effect that the biological processes had and the filtration provided by the membrane, two different removal efficiencies are calculated (Di Trapani et al., 2014; Mannina and Di Bella, 2012): the biological removal efficiency and the total removal efficiency.

The biological removal efficiency was calculated from the difference of the COD_{TOT} in the influent and the COD_{SUP} measured in the supernatant of the mixed liquor samples (filtered using a pore size of 0.45 μm) withdrawn from the MBR tank. Conversely, the total COD removal efficiency (including the membrane filtration removal effect) was determined from the difference of the influent and the permeate COD_{TOT}.

The capillary suction time (CST) measurement (Veselind, 1988) was carried out in accordance with the EN 14701-1:2006 International Standard to investigate the sludge dewaterability.

2.2. Respirometric batch test

Respirometric batch tests were conducted using a "flowing gas/static-liquid" type batch respirometer (Spanjers et al., 1996). The suspended biomass samples were taken from the aerobic bioreactor and diluted with permeate to obtain a mixed liquor concentration in the range of 2.0–3.0 g VSS L^{-1}. Before performing the respirometric test, each sample was aerated until endogenous conditions were reached. In the batch tests aimed at determining the