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Effect of salt concentration on membrane bioreactor (MBR) performances: Detailed organic characterization

M.A.H. Johir [a], S. Vigneswaran [a,*], J. Kandasamy [a], R. BenAim [b], A. Grasmick [c]

[a] Faculty of Engineering and Information Technology, University of Technology, Sydney, Broadway, NSW 2007, Australia
[b] Institute of Filtration and Technique of Separation (IFTS), Agen, France
[c] European Membrane Institute of Montpellier (UMR–CNRS 5635), Université Montpellier II, CC005, Place Eugène Bataillon, 34095, Montpellier Cedex 05, France

HIGHLIGHTS

- Effect of gradual loading of salt concentration on organic in MBR.
- Effect of salt concentration on SOUR by microorganism
- Organic characterization with different salt concentration.
- Cluster analysis of the effect of salt concentration on organic removal.

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ABSTRACT

The gradual increase of salt concentration (0 to 35 g-NaCl/L) on the performance of membrane bioreactor (MBR) was studied. The uptake rate of dissolved organic carbon and ammonia decreased from around 17.0 mg-DOC/g-MLVSS.d to 1.8 mg-DOC/g-MLVSS.d and from 8.2 mg-NH_4-N/g-MLVSS.d to 0 mg-NH_4-N/g-MLVSS.d respectively when salt concentration reached to 35 g-NaCl/L. Similarly the specific oxygen uptake rate (SOUR) reduced from 8 to 9 to around 0.3 mg-O_2/g-MLVSS.h. The removal of bio-polymers, humic acids, building blocks and low molecular weight neutral decreased with increase in salt concentration. The concentration of dissolved organic nitrogen (DON) in bio-polymer increased from 0.05 to 3.31 mg/L when the salt concentration reached to 35 g-NaCl/L. This study provides good information for understanding the effect of continuous increase of salt concentration in treating saline wastewater in a MBR process.

1. Introduction

The treatment of wastewater using membrane bioreactors (MBR) is becoming a more promising treatment technique due to process intensification and high effluent quality. The removal of organics and nutrients (such as ammonia, nitrate and phosphorus) by MBR is achieved through decomposition of these by microorganisms. The MBR system has also been effectively applied to the treatment of saline water such as seawater or saline effluent from food or leather industries, etc. The treatment of wastewater or saline wastewater by MBR is governed by microbial activity. Numerous studies had been conducted on the classification of microorganisms in saline water [1]. They stated that the growth range of microorganisms in terms of salt concentration is an important criterion in assessing the viability of the biological treatment under elevated salt conditions. They also reported that true halophilic microorganisms or halophiles grow in saline environment and require a certain minimum level of salt for continued existence. Halotolerant microorganisms grow better in freshwater environment but can be found in saline environment. Halotolerant micro-organisms are also able to tolerate high salt concentration. Woolard and Irvine [2] stated that non-halophilic bacteria grows well in a medium containing 1% salt and are the primary organisms in freshwater and terrestrial ecosystem. The microorganisms can be classified into four classes depending on the salt concentration as (i) Non-halophilic, <10 g/L NaCl, (ii) Marine or slightly halophilic, 10–30 g/L NaCl, (iii) Moderately halophilic, 30–150 g/L NaCl and (iv) Extremely halophilic, >150 g/L NaCl [1]. Many studies had

Abbreviations: AOB, Ammonia-oxidizing bacteria; A2O, Anaerobic/anoxic/oxic; BOD, Biological oxygen demand; COD, Chemical oxygen demand; DGGE, Denaturing gradient gel electrophoresis; DO, Dissolved oxygen; DOC, Dissolved organic carbon; DON, Dissolved organic nitrogen; FISH, Fluorescent in-situ hybridization; HOC, Hydrophobic organic compounds; HRT, Hydraulic retention time; LC–OCD, Liquid chromatography–organic carbon detection; MBR, Membrane bioreactor; MLSS, Mixed liquor suspended solids; MLVSS, Mixed liquor volatile suspended solids; N, Nitrogen; NOB, Nitrite oxidizing bacteria; OLR, Organic loading rate; OUR, Oxygen uptake rate; P, Phosphorus; PAN, Poly acrylonitrile; PCR, Polymerase chain reaction; RO, Reverse osmosis; RNA, Ribonucleic acid; SOUR, Specific oxygen uptake rate; TKN, Total Kjehldahl Nitrogen; TMP, Trans-membrane pressure; LMW, Low molecular weight.

* Corresponding author. Tel.: +61 2 95142641; fax: +61 2 95142633.
E-mail address: s.vigneswaran@uts.edu.au (S. Vigneswaran).

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been conducted on the classification of microbial communities at different salt concentrations. Bassin et al. [3] observed more pronounced change in microbial communities at shock salt loading compared to gradual loading of salt. They used a combination of denaturing gradient gel electrophoresis (DGGE) and sequence analysis of polymerase chain reaction (PCR)-amplified 16S ribosomal RNA (rRNA) gene fragments and fluorescent in-situ hybridization (FISH) to validate the PCR-based results and to observe the dominant bacterial populations. They found almost 27 bands of microorganisms which belonged to several phyla, such as α, β and γ Proteobacteria, Bacteroidetes, Chloroflexi, Firmicutes, and Actinobacteria. They reported that protozoa, nematodes, rotifers and filamentous bacteria could not withstand high salt concentrations.

From the classification of microorganism it is evident that there are large quantities of microorganisms that can tolerate high concentrations of salt. These groups of microorganisms contained a large number of aerobic heterotrophs that are able to biodegrade organic carbon matter from saline water [1]. Many aerobic treatments had been employed with different salt concentrations ranging between 10 and 150 g/L [4]. Lefebvre and Moletta [4] also stated that biological treatment of carbonaceous, nitrogenous and phosphorous pollution has proved to be feasible at high salt concentrations but its efficiency depends on proper adaptation of the biomass or the use of halophilic organisms. Therefore, MBR can be a useful pre-treatment option for saline wastewater, seawater or brackish water prior to reverse osmosis (RO) for the removal of carbonaceous, nitrogenous and phosphorous pollution. However, the operation of MBR is limited to operational parameters such as concentrations of salt, salt adaption strategy (shock or gradual loading of salt), acclimation period, and hydraulic retention time, etc. This may require proper acclimation of the biomass or the use of halophilic organisms [4].

Many studies had been conducted on the use of MBR to treat saline water. A study conducted by Visvanathan et al. [5] showed that a fluidised bed biological granular activated carbon, at 15 min empty bed contact time effectively removed nearly 100% biodegradable dissolved organic carbon (DOC) from seawater. They also investigated the effects of MBR on biodegradable organic content removal and biofouling control. The results show that MBR was able to remove 78% of DOC. They also found that the effluent from the MBR increased the permeate flux of RO by 300% more than untreated seawater. Artiga et al. [6] studied the performance of hybrid MBR for the treatment of saline wastewater from a fish canning factory (salt concentration was up to 73–83 g/L). They achieved 77–92% removal of chemical oxygen demand (COD) operated at organic loading rates from 0.3 to 1.4 kg COD/m^3 d. Dan et al. [7] achieved 80–90% removal of COD with two different types of MBR (yeast MBR and biological MBR) operated at a high salt concentration of 32 g/L. In their study they used osmo-tolerant yeast sludge which was then fed by two types of synthetic wastewaters (glucose-feed wastewater and protein-feed wastewater). In the protein feed wastewater, they have used commercially available tuna fish protein extract. The acclimation was conducted till the removal of COD reached 80%.

In contrast a change of salinity may also affect the removal of biological oxygen demand (BOD) and COD due to a change in organic loading rate (OLR) [8,9]. Yogalakshmi and Joseph [10] studied the effect of NaCl shock load on the removal efficiency of COD in a bench scale aerobic submerged MBR operated at steady state OLR of 3.6 g-COD/L/d and hydraulic retention time (HRT) of 8 h. They used activated sludge as feed biomass which was then fed with synthetic wastewater containing glucose, starch, etc. and was acclimatised for a period of 30 days. They found almost 95% removals of COD with NaCl shock loading of 5–30 g/L. The removal efficiency of COD at NaCl shock loading of 50 and 60 g/L were 77 and 64% respectively.

The addition of salt may also have effect on nutrient removal. Hong et al. [11] studied the effect of chloride concentration on the removal of nutrients by anaerobic/anoxic/oxic (A^{2}O) reactor. They used activated sludge collected from an aeration tank at the Taipa WWTP in Macau, as well as synthetic wastewater containing glucose monohydrate, KH_2PO_4, NH_4Cl, $NaHCO_3$, NaCl and tap water. In their study, the chloride concentration of real wastewater was gradually increased up to 2500 mg/L by adding NaCl. They found that the increase of chloride concentration from 150 to 5000 mg/L did not affect the removal of ammonia nitrogen but it affected the removal of phosphorus. Another study by Artiga et al. [6] showed that nitrification did not occur when the salt concentration was high (up to 84 g/L) although it did occur with a low salt concentration of 15 g/L. Uygur [12] observed a decreased removal efficiency of NH_4-N (from 3.0 to 0.80 mg NH_4-N /$g_{biomass}$.h) and PO_4-P (from 0.36 to 0.08 mg PO_4-P /$g_{biomass}$.h) when the salt content increased from 0 to 6% with experiments conducted with SBR. Uygur [12] used synthetic wastewater in their study which was inoculated with mixed microbial population composed of heterotrophic, autotrophic nitrifying organisms; anaerobic acid producers and excess phosphate up taking organisms (*Acinetobacter* sp.). Sharrer et al. [13] found 91.8 $\pm$ 2.9% to 95.5 $\pm$ 0.6% removal of total nitrogen at different salinity level of between 0 and 32 g/L. They also found that the removal of phosphate was affected by salinity. The removal efficiency of phosphate decreased from 96.1 $\pm$ 1.0% to 65.2 $\pm$ 5.4% when salinity increased from 0 to 32 g/L. They operated a MBR at a hydraulic retention time (HRT) of 40.8 h, a solids retention time of 64 $\pm$ 8 days and food: micro-organism ratio of 0.029 day^{-1}. Yogalakshmi and Joseph [10] observed a decrease in total kjehldahl nitrogen (TKN) removal efficiency from 95% to 23% with an increase in NaCl shock loads from 5 to 60 g/L. They also found an ammonia removal efficiency of between 84 and 64% with NaCl shock loads of 5–30 g/L, which further dropped to 13% at a 60 g/L shock load.

In this study, the gradual increase of salt concentration was tested to optimise a system where salty water can gradually leach into aerobic biological treatment systems such as a MBR process in coastal areas. Furthermore, many industrial sectors like food industries, petroleum and leather industries also produce wastewater containing high salinity and high organic matter [4]. These types of wastewaters can also affect the performance of MBR process. Thus, this study provides an understanding of the relative merits of the effect of a continual increase of salt concentration on the MBR process.

The effect of salt concentration was investigated in terms of organic and ammonia removal, and specific oxygen uptake rate (SOUR). The later represents the viability of micro-organism. Furthermore, a detailed organic characterization was conducted to better understand the effect of gradual increase of salt concentration along with cluster analysis of the DOC concentration of MBR effluent and mixed liquor.

2. Materials and methods

2.1. Continuous experiments in membrane bioreactor (MBR)

In this study, a MBR experiment was conducted with activated sludge to investigate the effect of gradual loading of salt (0–35 g-NaCl/L). The main focus of this study was to assess the short term effect of gradually increasing the salt concentration without the use of saline seed such as *Halobacteium halobium* to the biomass. As such, activated sludge was used as seed material. Here the activated sludge is the sludge seeded with mixed liquor (3 L) obtained from a domestic sewage treatment plant in Sydney which was acclimated for 45 days with synthetic substrate consisting of ethanol (0.05 ml/L), peptone (2.7 mg/L), beef extract (1.8 mg/L) as an organic source and NH_4Cl (0.01 mg/L), KH_2PO_4 (0.003 mg/L), $NaHCO_3$ (600 mg/L) as mineral salts. The ethanol (analytical reagent) was used as source of organic carbon which is easily bio-degradable. Analytical reagent inorganic salts were used as source of N (NH_4Cl) and P (KH_2PO_4). Analytical reagent $NaHCO_3$ was used to maintain the pH. The beef extract and peptone used in this study were also analytical reagent. The COD:N:P ratio of synthetic wastewater was maintained at 150:5:1 at an OLR of 0.25 kgCOD/m^3.d. The OLR in this study was low for the following reason. The HRT was kept high at 8 h to achieve superior nitrification and organic removal which resulted in