Effect of current density value and current application period on the wastewater treatment performance of Electrochemically Enhanced Self-Forming Dynamic Membrane Bioreactors (e-SFDMBRs)

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Abstract

The use of membrane reactor in wastewater treatment gained interest for the past years due to its high-quality effluent. However, expensive membranes and high operational costs due to membrane fouling limit the wide application of this process. Research on fouling control by combining membrane use with different techniques have been studied to address this challenge. This study particularly uses electrochemically-enhanced self-forming dynamic membrane bioreactor (e-SFDMBR). The main feature of the SFDMBR technology is that the biological filtering layer self-forms on a support of cheaper, inert coarse-pore membrane. This work focuses on describing the treatment performance of the bioreactor and the effect of lowering the current density and application period of electric current on the effluent quality and membrane fouling. Two systems of e-SFDMBR were operated and compared in terms of ammonium-nitrogen and orthophosphate removal and concentration of fouling precursors. The lower application period system (0.5 mA/cm2, 3 min ON/27 min OFF) posted 99.71% ammonium-nitrogen removal while the lower current density system (0.3 mA/cm2, 5 min ON/20 min OFF) achieved 99.68% removal. Both systems were able to completely remove phosphate and produce low concentration values of known fouling precursors.

Keywords: electrochemical process, membrane fouling, membrane bioreactor, dynamic membrane

1. Introduction

Freshwater availability has become greatly limited due to the rapid growth of world's population (Ma et al., 2015). Increase in population leads to industrialization which, consequently, result to more wastewater generated. However, not all of these wastewaters are treated, around 80% are dumped into the natural receiving waters and results to pollution (WWAP, 2017).

Currently, activated sludge process is the most widely used method in wastewater treatment. However, this process demands for high dissolved oxygen and additional carbon source. In addition to that, it requires high reactor volume, produces large amounts of excess sludge, and needs a final disinfection treatment for removal of pathogenic organisms (Ensano, 2016).

One of the more promising alternatives is the membrane bioreactor (MBR). This technology offers advantages such as higher effluent quality, smaller reactor volume, and less sludge production (Cicek, 2003). However, membrane fouling remains the biggest obstacle for widescale application of this technology.

One of the modifications of MBR technology is the use of dynamic membranes (DM). A cheaper, inert, and coarse-pore membrane having pore size in the range of tens if microns is used instead of microfiltration/ultrafiltration membranes while achieving the same effluent quality (Salerno, 2017; Sun, 2018). The cake layer that develops in this membrane has smaller porosity and is more selective than the membrane. This now serves as the main filtering layer therefore exploiting the mechanism of membrane fouling. This new "membrane layer" can be easily removed and reformed depending on the equilibrium conditions. This technology can reject most of the particles in the activated sludge and remove ammonia nitrogen and organic materials efficiently (Fan and Huang, 2002). While it greatly reduced the capital costs, maintenance costs remain high because of the frequent cleaning and other pollutants, like phosphate, are still present in considerable concentrations in the effluent (Millanar-Marfa, 2019).

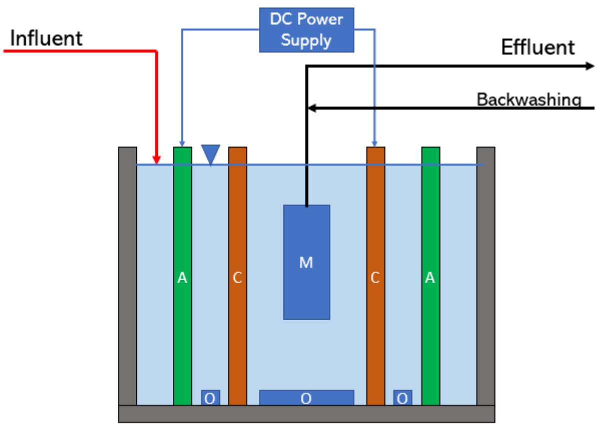
New studies focused on developing this technology involve combining it with electrochemical process to further reduce fouling and remove the need for periodic cleaning. Application of electric current has several advantages such as decrease in sludge production, less reagent used, and easier regulation. It also enhances the pollutant removal capabilities and fouling control of reactors (Wei et al., 2009).

Comparison between SFDM and e-SFDM was already done in previous studies (Castrogiovanni, 2019; Millanar-Marfa, 2020). As part of the investigation of the effects of different parameters in the performance of e-SFDMBRs, this study aims to determine the change in treatment performance and membrane fouling control of e-SFDMBR after changing the intermittent application period and current density in the reactors.

2. Materials and Methods

2.1. Experimental Setup

The experimental setup used in the study is shown in Figure 1. The e-SFDMBR is made with a cylindrical reactor with working volume of 17 L. The membrane module is made of Dacron with pore size of 30 microns and surface area of 0.02 m^2. It is inserted in a plexiglass for support. Perforated cylindrical aluminum anode and stainless-steel cathode were placed around the membrane module with radial distance of 6 cm from each other. The electrodes were connected to a digital external power supply through copper wires. Aeration system at the bottom of the reactor was installed to promote mixing and provide necessary oxygen.



"A" denotes anode and "C" are the cathodes. The blue boxed labelled as "O" are the oxygen diffusers, and the "M" represents the membrane module.

Figure 1. Experimental setup

2.2. Operating Conditions

The reactors were inoculated with fresh activated sludge from secondary clarifier at the conventional municipal treatment plant in Salerno. The inoculation lasted almost a month until operating parameters became stable. After inoculation, the reactors were continuously fed with synthetic wastewater with similar characteristics to those of real wastewater. The concentrations were based on the study previously done by Borea et al. (2017). Effluent was extracted by a metering pump at 30 LMH during the 33-day operation. The filtration cycle lasts 15 minutes composed of 14 mins 30 secs permeate production and 30 secs backwashing. Sludge was withdrawn only for necessary analyses.

The two reactors differ in amount of electricity applied and intermittence of operation. One reactor was operated at current density of 0.5 mA/cm^2 with 3 min ON/27 min OFF intermittent application of electricity and the other was at 0.3 mA/cm^2 with 5 min ON/20 min OFF which will be referred to as "e-SFDMBR-0.5" and "e-SFDMBR-0.3", respectively.

2.3. Analytical Methods

Dissolved oxygen, pH, temperature, conductivity, and redox potential of the influent, reactor, and effluent were taken every day using a multiparametric probe (Hanna Instruments, Padova, Italy. HI2838). The transmembrane pressure (TMP) of the membranes were recorded continuously through a pressure transducer (PX409-0-15VI, Omega) connected to a datalogger (34972A LXI Data Acquisition/Switch unit, Agilent).

Samples from influent, reactor, and effluent were taken about every 48 hours for analysis for COD, ammonia nitrogen, nitrate nitrogen, and orthophosphate concentrations using APAT and CNR-IRSA 2003 standard methods. Mixed Liquor Total Suspended Solids (MLTSS) and Mixed Liquor Volatile Suspended Solids (MLVSS) were measured using the same methods.

3. Results and Discussions

3.1. Effluent quality and conventional pollutant removal

The performance of the reactors in removing conventional pollutants is summarized in Table 1.

Table 1. Removal efficiencies (in %) using e-SFDMBRs.

Pollutant	e-SFDMBR-0.5	e-SFDMBR-0.3
COD	99.18	98.97
NH4-N	99.71	99.68
PO4-P	100.00	100.00

Both reactors achieved very high COD, NH4-N, and PO4-P removals. An explanation for this is that the studied parameters' values are not high enough to maintain the anoxic environment in the reactors and decreases the anoxic conversion of nitrate to nitrogen gas.

All e-SFDMBRs recorded 100% removal of phosphate compared to 14% of SFDMBRs (Millanar-Marfa, 2019). This proves that electrocoagulation is the main mechanism that contributes to phosphate removal and decreasing current density or current application period does not affect this process.

3.2. Membrane fouling

Aside from pollutant removal, another main concern in membrane bioreactor operations is membrane fouling. Fouling is determined by looking at one of the main parameters: transmembrane pressure (TMP)

The TMP of e-SFDMBR-0.5 around 1.0 kPa throughout the whole operation. On the other hand, e-SFDMBR-0.3 posted lower TMPs at 0.21 kPa at the start and increases around 0.01 kPa/day. This difference may be due to slower cake thickening in this reactor because of lower current density and slower production of aluminum ions for electrocoagulation. Both TMPs are far from the 50 kPa threshold value considered by other studies. No cleaning was done to any of the e-SFDMBRs proving its success in membrane fouling control.

4. Summary and Conclusions

The combination of electrochemical processes with self-forming dynamic membrane bioreactors greatly improved the removal of nutrient and organic pollutants. It also reduced the fouling experienced by the membrane bioreactors.

The results of this study showed that decreasing one of the parameters related to application of electricity, application period or current density, does not greatly impact the performance of e-SFDMBRs in terms of nutrient removals. However, lower current density or shorter application period lowers the conversion rate of nitrates to nitrogen gas in the reactors.

In terms of fouling control, e-SFDMBRs proved to be superior since cleaning was not needed throughout their operations and the transmembrane pressures remained at minimum. Changing one of the electricity application parameters also showed no significant difference in the concentration of membrane fouling precursors.

References

APAT and CNR-IRSA. (2003), Metodi analitici per le acque. Manuali e Linee Guida 29/2003

Borea, L., Naddeo, V., and Belgiorno V. (2017) Application of electrochemical processes to membrane bioreactors for improving nutrient removal and fouling control. Environmental Science and Pollution Research 24:321-333. doi: 10.1007/s11356-016-7786-7

Castrogiovanni, F., Borea, L., Millanar-Marfa, J., Napodano, P., Balakrishnan, M., Ballesteros, F., Hasan, S., Belgiorno, V., and Naddeo, V. (2019) Wastewater treatment and emerging contaminants removal in electro membrane bioreactor using self-forming dynamic membranes. International Conference on Environmental Science and Technology 2019

Cicek, N. (2003). A review of membrane bioreactor and their potential application in the treatment of agricultural wastewater. Canadian Biosystems Engineering 45, 637–649.

Ensano, B., Borea, L., Naddeo, V., Belgiorno, V., de Luna, M., and Ballesteros, F. (2016) Combination of Electrochemical Processes with Membrane Bioreactors for Wastewater Treatment and Fouling Control: A Review. Frontiers in Environmental Science Vol. 4, Article 57 doi: 10.3389/fenvs.2016.00057

Fan, B. and Huang, X. (2002) Characteristics of a Self-Forming Dynamic Membrane Coupled with a Bioreactor for Municipal Wastewater Treatment. Environmental Science and Technology Vol. 36, No. 23, 5245-5251 doi: 10.1016/j.biortech.2018.09.003

Ma., J., Wang, Z., Mao, B., Zhang, J., and Wu, Z. (2015). Electrochemical Membrane Bioreactors for Sustainable Wastewater Treatment: Principles and Challenges. Current Environmental Engineering, 2, 38-49 doi: 10.2174/2212717802011508311145842

Millanar-Marfa, J., Borea, L., Castrogiovanni, F., Napodano, P., Hasan, S., De Luna, M., Belgiorno, V., and Naddeo, V. (2019) Performance evaluation of a flat sheet self-forming dynamic membrane (SFDM) for municipal wastewater treatment containing organic micropollutants. International Conference on Environmental Science and Technology 2019

Salerno, C., Pompilio V., Berardi, G., and Pollice, A. (2017) Influence of air scouring on the performance of a Self Forming Dynamic Membrane BioReactor (SFD MBR) for municipal wastewater treatment. Bioresource Technology 223, 301-306 doi: 10.1016/j.biortech.2016.10.054

Sun, F., Zhang, N., Li, F., Wang, X., Zhang, J., Song, L., and Liang, S. (2018) Dynamic analysis of self-forming dynamic membrane (SFDM) filtration in submerged anaerobic bioreactor: Performance, characteristic, and mechanism. Bioresource Technology 270, 383-390 doi: 10.1016/j.biortech.2018.09.003

Wei, V., Oleszkiewicz, J., and Elektorowicz, M. (2009) Nutrient removal in an electrically enhanced membrane bioreactor. Water Science and Technology 60.12, 3159-3163

WWAP (United Nations World Water Assessment Programme) (2017). The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource