Chemosphere 97 (2014) 71–77

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Start-up period investigation of pilot-scale submerged membrane zelectro-bioreactor (SMEBR) treating raw municipal wastewater

Shadi W. Hasan [a,*], Maria Elektorowicz [b], Jan A. Oleszkiewicz [c]

[a] Department of Chemical and Environmental Engineering, Institute Center for Water and Environment (iWATER), Masdar Institute of Science and Technology, PO Box 54224, Abu Dhabi, United Arab Emirates
[b] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, QC H3G 1M8, Canada
[c] Department of Civil Engineering, University of Manitoba, Winnipeg R3T 5V6, Canada

HIGHLIGHTS

- SMEBR is a promising technology for wastewater treatment.
- Removal rates of NH_3^+-N, PO_4^{3-}-P, and COD were 99%, 99%, and 92%, respectively.
- No significant increase in the transmembrane pressure (0.02 kPa d^{-1}) was reported.
- SMEBR required small treatment footprint.
- SMEBR, potentially, can reduce the overall sludge management related cost.

ARTICLE INFO

Article history:
Received 14 July 2013
Received in revised form 4 November 2013
Accepted 6 November 2013
Available online 28 November 2013

Keywords:
Submerged membrane electro-bioreactor (SMEBR)
Nutrient removal
Membrane fouling
Electrokinetics
Energy consumption
Wastewater

ABSTRACT

Submerged membrane electro-bioreactor (SMEBR) is a new hybrid technology for wastewater treatment employing electrical field and microfiltration in a nutrient-removing activated sludge process. A pilot SMEBR system was located at the wastewater treatment plant in the City of l'Assomption (Quebec, Canada) with the objective of investigating the start-up period performance under variable organic loadings and environmental conditions with respect to effluent quality, membrane fouling, and sludge properties. The pilot SMEBR facility was fed with the raw de-gritted municipal wastewater. At steady state operation, the removal efficiencies of ammonia (as NH_3^+-N), phosphorus (as PO_4^{3-}-P), and COD were 99%, 99%, and 92%, respectively. No substantial increase in the monitored transmembrane pressure as 0.02 kPa d^{-1} was reported. The time necessary to filter 100 mL of the sludge sample has decreased by 78% after treatment whilst the sludge volume index averaged 119 mL g^{-1}. Energy requirements were in the range of 1.1–1.6 kW h m^{-3} of wastewater. It was concluded that the SMEBR is a very competitive technology when compared to conventional membrane systems as it can enhance treatment performance to an appreciable extent, remove phosphorus and reduce fouling.

1. Introduction

Several distinctive technologies have been used for wastewater treatment such as clarifier-based biological processes, membrane bioreactor filtration (membrane bioreactors, MBRs), and sometimes electrocoagulation (EC). Each process has drawbacks when operated separately. For instance, the membrane in MBR experiences reversible and irreversible fouling during filtration, which results in an increase in the transmembrane pressure (TMP) leading to lowering the reactor performance (Bourgeous et al., 2001). As a result, the membrane requires physical and chemical cleaning, increasing the cost of treatment and decreasing the life-time of the membrane. Many factors affect membrane fouling such as operating conditions, sludge properties, and membrane characteristics (Trussell et al., 2006; Drews et al., 2008). EC proved its efficiency in wastewater treatment compared to chemical coagulation. It has better removal efficiency of metals, colloids, solid particles, and soluble inorganic pollutants, lesser sludge production, and more importantly the prevention of transfer of undesired ions into the treated wastewater. For example, Mavrov et al. (2006) combined EC with submerged microfiltration flat ceramic membranes (mean pore size of 0.3 μm) in a bench scale for the removal of selenium from industrial wastewater. Results showed 98% removal of selenium after 20 min of treatment time with current density of 4.8 mA cm^{-2} applied continuously. Chen et al. (2007) have designed a bioreactor followed by an electro-reactor to investigate the influence of the electric field on membrane flux.

* Corresponding author. Tel.: +971 2 810 9237; fax: +971 2 810 9901.
E-mail address: swajih@masdar.ac.ae (S.W. Hasan).

0045-6535/$ - see front matter Crown Copyright © 2013 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.chemosphere.2013.11.009

They concluded that the addition of the electric field had major impact on the membrane flux. At an operation pressure of 0.1 MPa, membrane flux increased while voltage gradient ranged between 15 and 20 V cm^{-1}, and then kept almost constant. Cui et al. (2009) investigated the combined membrane bioreactor with EC process in a laboratory scale to enhance total phosphorus (TP) removal from synthetic domestic wastewater to reach 0.5 mg TP L^{-1} in the treated effluent. Wei et al. (2012) have studied the nutrient removal in an electrically-enhanced membrane bioreactor (EMBR) at room temperature (20 ± 2 °C) with synthetic feed and 2 months at 10 °C with real sewage. Results showed >99% of ammonium, >95% of dissolved COD, and >90% ortho-phosphorus removal in the EMBR. Wei et al. (2011) also found out that the bacterial viability was not significantly affected when the applied electric current density was less than 6.2 A m^{-2} after 4 h. They reported that the percentage of live cells dropped by 15% and 29% at 12.3 and 24.7 A m^{-2}, respectively.

The introduction of electrical DC field was involved in: (i) an electrolytic dissolution of the anode producing cationic species, which are transformed to large flocs coagulating colloidal substances, providing a large surface area for sorption, (ii) controling reaction of metals from the dissolved anode with phosphorous and its fate within the reactor, (iii) oxidizing organic components and making them potentially more bioavailable, (iv) removing membrane foulants (e.g. soluble extracellular polymeric substances, EPS), (v) controlling deposition of the remaining inorganic and organic wastewater components on electrodes, (vi) changing properties of the sludge in the reactor, (vii) controlling pH, (viii) controlling morphology of the flocs, (ix) affecting sludge viscosity and (x) influencing zeta potential (ZP) of the sludge in the reactor.

The combination of biological, electrokinetic and membrane filtration processes in one hybrid submerged membrane electro-bioreactor (SMEBR) was first investigated by Elektorowicz et al. (2009). Bani-Melhem and Elektorowicz (2010) conducted several experiments in a laboratory scale under constant TMP through which the basic constraints for designing such hybrid reactor were identified. Ibeid et al. (2010) investigated the change in the flocs morphology in a lab scale SMEBR system. The results were encouraging but all these investigations used synthetic wastewater.

The previous investigations on the SMEBR were limited to lab scale reactors fed with synthetic wastewater, hence the novelty of the research described in this manuscript is the transfer of the technology to a pilot scale reactor fed with pre-screened, de-gritted raw municipal wastewater (without primary settling) and subjected to the shifting of variables (temperature and nutrient load) occurring under standard operating conditions.

2. Materials and methods

The SMEBR pilot facility was located in the 20 mL d^{-1} municipal wastewater treatment plant (WWTP) in the City of l'Assomption (Quebec). The hybrid system consisted of a cylindrical PVC reactor 1.6 m high, and 0.5 m in diameter with a hollow fiber microfiltration membrane Microza – MUNC-600A (Table 1). Two cylindrical perforated electrodes (aluminum anode and stainless steel cathode) connected to a DC power supply were located centrically (Fig. 1). Compressed air was supplied through fine bubble air diffusers centered at the bottom of the reactor to: (i) allow complete sludge mixing in the rector, (ii) supply adequate dissolved oxygen for biological processes, (iii) and postpone membrane fouling. The SMEBR was continuously supplied with de-gritted and pre-screened raw municipal wastewater redirected from the sewage channel at a flow rate of 0.6 m^3 d^{-1}. The supplied wastewater in this study was subjected to variable temperature and daily variable loadings of COD, phosphorous, total suspended solids (TSS), ammonia and nitrates (average values along with standard deviations are shown in Table 2).

Table 1
Pilot-scale membrane module characteristics (Asahi Kasei Chemicals Corporation – Japan).

Item	Membrane characteristics
Membrane material	PVDF
Normal pore size	0.1 μm
Membrane surface area	12.5 m^2
Module diameter	0.167 m
Module length	1.131 m
Membrane configuration	Hollow fiber
Filtration mode	Filtration by submerged membrane
Maximum TMP	300 kPa
Maximum operating temperature	40 °C
pH range	1–10
Maximum designed flux	0.2–0.7 m^3 m^{-2} d^{-1}

In the SMEBR, wastewater entered into the biological treatment zone I (i.e. between the reactor wall and the outer electrode), then passed through the electrical zone II (i.e. between the electrodes), where it was exposed to electrokinetic phenomena and finally was filtered out through the membrane module. Operation conditions at the pilot scale were set based on the previous lab investigation (Hasan, 2011). Accordingly, the solids residence time (SRT) and hydraulic residence time (HRT) were set for 10 d and 11 h, respectively. The SMEBR system operated under complete mixed conditions where HRT was selected based on the entire volume of the reactor. The 11 h HRT was selected based on previous lab scale experiments through which the impact of HRT was investigated between 6 and 15 h. It was concluded that the SMEBR could operate at any selected HRT (between 6 and 15 h) depending on the objective the system is trying to achieve (water quality, membrane fouling or sludge properties). However, better results were achieved as HRT increased through which authors believed that the bacterial recovery occurred and contributed to the COD and nutrient removal efficiencies. Furthermore, longer HRT allowed longer exposure time of the wastewater to the electrical field thus increasing the positive impact of electrokinetics on the removal efficiency. Therefore, a suitable HRT (11 h) was chosen to achieve several objectives. Detailed lab scale runs can be found in Hasan (2011). The SMEBR operated under constant current density of 12 A m^{-2} intermittently supplied at 5 min ON: 10 min OFF. Investigations were conducted for 7 week. The inoculation was done with a sample of activated sludge from the WWTP in St. Hyacinthe – Quebec as the WWTP in l'Assomption is an aerated lagoon system and does not have activated sludge needed for inoculation. The acclimation process was carried out in the SMEBR for 1 month.

The SMEBR's performance was evaluated based on the changes observed in the sludge (biomass) characteristics in the reactor and the attained effluent quality. Fresh sludge samples were collected and analyzed for mixed liqour suspended solids (MLSS), mean particle size diameter (PSD), EPS, and ZP. Four samples from different locations; between the reactor wall and the anode, between electrodes, and between the cathode and the membrane module were collected weekly (assuming complete mixing and homogenity conditions within the SMEBR), then analyzed in duplicates and an average value along with standard deviation was recorded. Analytical methods were explained in details in Hasan et al. (2012a). Filterability test was carried out via filtering 100 mL of sludge while recording the filtration time. Sludge settleability test was done as 1 L of sludge was left to settle for 45 min, then sludge volume index (SVI) was calculated accordingly. COD, phosphorus and ammonia concentrations were measured using the Hach methods (TNT: 821, 822, 843, 844, and 832) and analyzed by Hach instrument (Hach-DR 2800). Dissolved oxygen (DO), pH, and temperature were measured using DO Meter (YSI, Model 52, USA).