DOMESTIC WASTEWATER TREATMENT EMPLOYING A NOVEL BAFFLED OSMOTIC MEMBRANE BIOREACTOR-MICROFILTRATION HYBRID SYSTEM

by

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

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I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. This research is supported by the Australian Government Research Training Program. In addition, I certify that all information sources and literature used are indicated in the thesis.

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LIST OF ABBREVIATIONS

AL-DS	Active layer facing draw solution
AL-FS	Active layer facing feed solution
AOB	Ammonia oxidizing bacteria
AS	Activated sludge
BNR	Biological nutrient removal
CEOP	Cake-enhanced osmotic pressure
CLSM	Confocal laser scanning microscopy
COD	Chemical oxygen demand
CP	Concentration polarization
CTA	Cellulose triacetate
DI	Deionised
DOC	Dissolved organic carbon
DS	Draw solution
ECP	External concentration polarization
EDGs	Electron donating groups
EDX	Energy dispersive X-ray spectroscopy
EPS	Extracellular polymeric substances
EWGs	Electron withdrawing groups
FDFO	Fertilizer drawn forward osmosis
FS	Feed solution
HA	Humic acid
HRT	Hydraulic retention time

ICP	Internal concentration polarization
LC-MS	Liquid chromatography mass spectroscopy
LC-OCD	Liquid chromatography-organic carbon detection
LMH	Litres per square meter per hour
MBR	Membrane bioreactor
MD	Membrane distillation
MF	Microfiltration
MLE	Modified Ludzak–Ettinger (MLE)
MLSS	Mixed liquor suspended solids
NaOAc	Sodium acetate
NF	Nanofiltration
NOB	Nitrite oxidizing bacteria
OCT	Optical coherence tomography
OLR	Organic loading rate
OMBR	Osmotic membrane bioreactor
OMBR-MF	Osmotic membrane bioreactor-microfiltration
OMPs	Organic micro-pollutants
PA	Polyamide
PAOs	Phosphorous accumulating organisms
PES-MF	Polyether sulfone-microfiltration
PPCPs	Pharmaceutical and personal care products
PRO	Pressure retarded osmosis
RO	Reverse osmosis
RSF	Reverse salt flux

RSFS	Reverse salt flux selectivity
SBR	Sequencing batch reactor
SEM	Scanning electron microscopy
SMP	Soluble microbial products
SND	Simultaneous nitrification and denitrification
SOA	Ammonium sulphate
SOUR	Specific oxygen uptake rate
SRSF	Specific reverse salt flux
SRT	Solid retention time
SWRO	Seawater reverse osmosis
TDS	Total dissolved solids
TDS	Total dissolved solids
TFC	Thin-film composite
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorous
TrOCs	Trace organic contaminants
TS	Total solids
UF	Ultrafiltration

Abstract

A novel baffled osmotic membrane bioreactor microfiltration (OMBR-MF) hybrid system was proposed for the domestic wastewater treatment with specific focus on nutrient and organic micropollutant (OMPs) removal. This baffled OMBR-MF hybrid system was first applied in laboratory scale conditions to treat simulated wastewater. Insertion of baffles in the aerobic reactor, created separate oxic and anoxic zones. In particular, simultaneous nitrification and denitrification (SND) was achieved in a single baffled OMBR-MF hybrid system. Thus, this reactor design enables both aerobic and anoxic processes reduce the process footprint and energy costs associated with pumping the mixed liquor in-between the oxic and anoxic tanks and chemical dosing costs for pH adjustment. The bioreactor was operated under four different oxic-anoxic cycle time at constant flux operation employing thin film composite-forward osmosis (TFC-FO) and polyether sulfone-microfiltration (PES-MF) membranes. At 65 d sludge retention time (SRT) 86-92 % COD, 63-76 % TN and 57-63 PO_4-P % removal was achieved during Run 1 to Run 4 in a bioreactor. The oxic-anoxic cycle time of 0.5-1.5 h appeared to be an appropriate choice for the process. Incorporation of MF membrane effectively alleviated salinity build up in the reactor, allowing stable operation of the system.

Based on outstanding SND performance using baffled OMBR-MF hybrid system test at different oxic-anoxic conditions long-term OMBR-MF hybrid system performance was evaluated at optimum oxic-anoxic (0.5-1.5 h) cycle time. The process performance was evaluated in terms of water flux, salinity build up in the bioreactor, organic and nutrient removal and microbial activity using synthetic reverse osmosis (RO) brine as draw solution (DS). The incorporation of MF membrane was effective in maintaining a

reasonable salinity level (612–1434 mg/L) in the reactor which resulted in a much lower flux decline (i.e. 11.48–6.98 LMH) as compared to previous studies. An average of 8.56 LMH FO flux was achieved during 38 days of continuous operation. The stable operation of the osmotic membrane bioreactor–forward osmosis (OMBR-FO) process resulted in an effective removal of both organic matter (97.84%) and nutrient (phosphate 87.36% and total nitrogen 94.28%), respectively. The dissolved oxygen profile during aerobic-anoxic cycle confirmed < 0.5 mg/L oxygen favourable for denitrification.

To further investigate novel baffled OMBR-MF system performance in particular the efficiency of OMPs removal under unique redox environment (oxic-anoxic conditions) were evaluated. The performance of OMBR-MF system was examined employing three different draw solutes (DS), and three model OMPs. The DS employed in this study were sodium chloride (NaCl), potassium chloride (KCl) and sodium acetate (CH_3COONa). Three model organic micropollutants used were caffeine, atenolol and atrazine respectively. The highest forward osmosis (FO) membrane rejection was attained with atenolol (100%) due to its higher molar mass and positive charge. With inorganic DS caffeine (94–100%) revealed highest removal followed by atenolol (89–96%) and atrazine (16–40%) respectively. All three OMPs exhibited higher removal with organic DS as compared to inorganic DS. Significant anoxic removal was observed for atrazine under very different redox conditions with extended anoxic cycle time. This can be linked with possible development of different microbial consortia responsible for diverse enzymes secretion. Overall, the OMBR-MF process showed effective removal of carbonaceous matter, nutrient and organic micropollutants (OMPs).

Membrane biofouling is an inevitable phenomenon in any membrane process. Therefore real-time membrane fouling characterization without affecting continuous operation would be helpful in devising efficient antifouling strategy. Further, real wastewater exhibits entirely different foultants and very diverse bacterial community. So, it would be more interesting to study foulant and microbial interaction with membrane employing real wastewater. So, in order to study the biofouling development on forward osmosis membranes optical coherence tomography (OCT) technique was employed. On-line monitoring of biofilm growth on a flat sheet cellulose triacetate forward osmosis (CTA-FO) membrane was conducted for 21 days with three different draw solutes. Further, the process performance was evaluated in terms of water flux, organic and nutrient removal, microbial activity in terms of soluble microbial products (SMP) and extracellular polymeric substance (EPS), and floc size. The measured biofouling layer thickness was in the order sodium chloride (NaCl) > ammonium sulfate (SOA) > potassium dihydrogen phosphate (KH_2PO_4). Very high organic removal (96.9 ± 0.8%) and reasonably good nutrient removal efficiency (85.2 ± 1.6% TN) was achieved. The sludge characteristics and biofouling layer thickness suggest that less EPS and higher floc size were the governing factors for less fouling.

Osmotic membrane bioreactor for wastewater treatment is very attractive and emerging process. It has shown very promising results for organic, nutrient and trace organics removal. With current technological advances, employing hybrid OMBR-MF have potential to produce fresh water at less cost than conventional desalination/water recovery technologies (i.e. ultrafiltration/RO systems). Main benefits of using baffled OMBR-MF hybrid system are better removal efficiency in terms of nutrient and micropollutants, saving in energy and pH adjustment costs, reduced process piping costs as SND takes place in single reactor and more flexible treatment unit.

The major challenges of OMBR to be a techno-economically viable technology are developing a high performance low cost forward osmosis membrane with higher flux and high selectivity with less internal concentration polarization (ICP) effect, and the availability of suitable draw solutions (to explore other divalent organic DS with lower RSF and lower fouling propensity and to compare their performance in baffled OMBR-MF system). It would be interesting to address microbial community dynamics in oxic and anoxic zone in the baffled bioreactor to elucidate its impact on nutrient and OMPs removal.

Besides, most of studies of OMBR have been performed at lab-scale. Therefore, more studies both in pilot and in full-scale plants are necessary to gain knowledge to achieve a better OMBR performance. In order to commercialise OMBR, full scale benchmarking and efficient process controls intensification are major challenges. Looking to the present progresses in FO membrane development (outer selective hollow fiber and nanomaterials made) in order to meet similar flux of existing porous membranes and very high performance of FO membranes in rejection of nutrients and micropollutants as compared to MF/UF membranes, OMBR can become techno- economically viable alternative for waster reuse applications in near future.

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