Development of specific membrane bioreactors for membrane fouling control during wastewater treatment for reuse

By

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CERTIFICATE OF ORIGINAL AUTHORSHIP

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Abbreviations

Symbol	**Description**
AC	Acylase
AFM	Atomic force microscopy
AnMBR	Anaerobic membrane bioreactor
AOB	Ammonium oxidizing bacteria
AOMBR	Anaerobic-oxic membrane bioreactor
A/O	Anoxic/oxic
A^2/O	Anaerobic/anoxic/oxic
BAP	Biomass-associated products
BNR	Biological nutrient removal
BOD	Biological oxygen demand
BPC	Biopolymer clusters
BPC_C	Polysaccharides in biopolymer clusters
BPC_P	Proteins in biopolymer clusters
CA	Cellulose acetate
CEB	Chemical enhanced backwashing
CEBs	Cell entrapping beads
CER	Cation exchange resin
CF	Concentration factor
CIOF	Combined inorganic-organic flocculant
CIP	Cleaning in place
CMBR	Conventional membrane bioreactor
COD	Chemical oxygen demand
C/N or COD/N	Carbon to nitrogen ratio
C/P	Carbon to phosphorus ratio
CST	Capillary suction time
DC	Direct current
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DOC’	Deoxycholate
DOM	Dissolved organic matter

DPB	Denitrifying-phosphate-accumulating bacteria
DTPA	Diethylenetrinitrilopentaacetic acid
ECPS	Extra-cellular polymers
e-MBR	Electro-membrane bioreactor
DTPA	Diethylenetrinitrilopentaacetic acid
EDTA	Ethylene diamine tetraacetic acid
EL	Electrostatic double layer
EMPS	Extra-microcolony polymers
EPS	Extracellular polymeric substances
EPS$_C$	Polysaccharides in extracellular polymeric substances
EPS$_P$	Proteins in extracellular polymeric substances
EPS$_P$/EPS$_C$	Protein to polysaccharide ratio in extracellular polymeric substances
F/M	Food to microorganisms ratio
GBF	Green bioflocculant
GF	Glass fiber
HIS	Hydrophilic substances
HMBR	Hybrid membrane bioreactor
HRT	Hydraulic retention time
KMT	Kaldnes MijiØteknologi, TØnsberg
LB-EPS	Loosely bound extracellular polymeric substances
LMW	Low molecular weight
Mag-S-MPS	Magnetically separable mesoporous silica
MBBR	Moving bed biofilm reactor
MBR	Membrane bioreactor
MBR-G	Membrane bioreactor with bioflocculant addition
MBBR-MBR	Moving bed biofilm reactor-membrane bioreactor
MCE	Mixed cellulose ester
ME	Mixed ester
MF	Microfiltration
MLE	Modified Luzack-Ettinger
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids

MRD	Membrane rejection degree
MW	Molecular weight
MWCO	Molecular weight cutoff
NLR	Nitrogen organic loading
NOB	Nitrite oxidizing bacteria
NPOC	Non-purgeable organic carbon
OHO	Ordinary heterotrophic organisms
OLR	Organic loading rate
OUR	Oxygen uptake rate
PAC	Powdered activated carbon
PACl	Polyaluminium chloride
PAC-MBR	Powdered activated carbon-membrane bioreactor
PAM	Polyacrylamide
PAN	Polyacrylonitrile
PAOs	Polyphosphate accumulating organisms
PC	Polycarbonate
PE	Polyethylene
PES	Polyethersulfone
PFC	Polymeric ferric chloride
PFS	Polymeric ferric sulfate
Phenex-NY	Phenex-Nylon
PN/PS	Protein to polysaccharide ratio
POC	Purgeable organic carbon
PP	Polypropylene
PSD	Particle size distribution
PSU	Polysulfone
PU	Polyurethane
PUS	polyurethane sponge
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride
PVDF$_H$	Hydrophobic polyvinylidene fluoride
QQ	Quorum quenching
QQMBR	Quorum quenching membrane bioreactor

RH	Relative hydrophobicity
SCMBR	Submerged conventional membrane bioreactor
SDS	Sodium dodecyl sulfate
SEM	Scanning electronic microscopy
S-MBBR	Moving bed biofilm reactor with sponge modified plastic carriers
S-MFC	Sludge microbial fuel cell
SMBR	Submerged membrane bioreactor
SMP	Soluble microbial products
SMP$_C$	Proteins in soluble microbial products
SMP$_P$	Polysaccharides in soluble microbial products
SMP$_P$/SMP$_C$	Protein to polysaccharide ratio in soluble microbial products
SND	Simultaneous nitrification and denitrification
SOUR	Specific oxygen uptake rate
SRT	Sludge retention time
SSMBR	Sponge-submerged membrane bioreactor
SSMBR-G	Sponge-submerged membrane bioreactor with bioflocculant addition
STP	Sodium tripolyphosphate
SVI	Sludge volume indexes
TB-EPS	Tightly bound extracellular polymeric substances
TCA	Trichloroacetic acid
TMP	Transmembrane pressure
TOC	Total organic carbon
TSAMBR	Thermophilic submerged aerobic membrane bioreactor
TSS	Total suspended solids
UAP	Utilization-associated products
UCT	The University of Cape Town
UF	Ultrafiltration
UTS	University of Technology, Sydney
WSW	Without sludge wasting
VFAs	Volatile fatty acids
VSS	Volatile suspended solids

Nomenclatures

Symbol	Description
ADIPAP KD 452 or KD452	Cationic polymers
$Al_2(SO_4)_3$	Aluminium sulfate
$CaCl_2 \cdot 2H_2O$	Calcium chloride
C_c	Concentration of potential cake forming particles in the bulk liquid (e.g. MLSS) which typically varies over time in membrane bioreactor
CGMS	Modified corn starch
$C_6H_{12}O_6$	Glucose
CO_2	Carbon dioxide
$CoCl_2 \cdot 6H_2O$	Cobalt chloride
CPE	Organic cationic polyelectrolyte
C_{SMP}	Time-dependent concentration of soluble particles entering the pores
$CuSO_4 \cdot 5H_2O$	Cupric sulphate
$d_{p,used}$	The initial pore diameter of the membrane in μm
dTMP/dt	Membrane fouling rate
f	The membrane's porosity
$FeCl_3$	Ferric chloride or Ferric chloride anhydrous
Fe-MBR	Electro-membrane bioreactor with stainless steel mesh as the anode
h_c	Variable depth of the cake layer expressed as a first order differential function in time, which relies on the attachment and detachment of cake layer
h_m	The membrane's effective thickness
H_2O_2	Hydrogen peroxide
H_2SO_4	Sulphuric acid
J	The permeate flux
k	The factor representing the detachment of the cake layer from the membrane surface
kDa	Unified atomatic mass unit

$K_2Cr_2O_7$	Potassium dichromate
KH_2PO_4	Potassium phosphate
$MLSS_e$	The MLSS concentration in the aqueous phase after emulsification
$MLSS_i$	The initial MLSS concentration of the mixed liquor sample
$m_{d,o}$	Outer membrane diameter
$m_{d,i}$	Inner membrane diameter
Mg	Magnesium
MGMS	Modified corn starch
$MgSO_4 \cdot 7H_2O$	Magnesium sulphate
MPE	Organic flocculant
MPE50	Organic flocculant (cationic polymers)
MPL30	Cationic polymers
$MnCl_2 \cdot 7H_2O$	Manganese chloride
NALCO MPE50	Cationic polymers
n_c	Cake fouling factor to explain the typically observed exponential rise of TMP due to the cake layer resistance especially at the final stage of operation of an MBR system
n_p	Pore fouling factor to explain the typically observed exponential rise of TMP due to the pore fouling resistance especially at the final stage of operation of an MBR system
NaCl	Sodium chlorite
NaClO	Sodium hypochlorite
$NaHCO_3$	Sodium hydrogen carbonate
$Na_2MoO_4 \cdot 2H_2O$	Sodium molybdate dehydrate
NH_2OH	Hydroxylamine
NH_4-N or NH_4^+	Ammonia nitrogen
$(NH_4)_2SO_4$	Ammonium sulphate
NO_2-N or NO_2^-	Nitrite
NO	Nitric oxide
N_2	Nitrogen gas
N_2O	Nitrous oxide
NO_3-N or NO_3^-	Nitrate
PAM-MGMS	Polyacrylamide-starch composite flocculant

pH	Power of hydrogen or potential hydrogen
PM30	A kind of polyethersulfone membrane
PO_4-P	Orthophosphate
Poly-1	Cationic polymers
Poly-2	Modified cationic polymers
r_p	Membrane pore radius
R80	Membrane bioreactor with 80 nm pore-sized ceramic membrane
R100	Membrane bioreactor with 100 nm pore-sized ceramic membrane
R200	Membrane bioreactor with 200 nm pore-sized ceramic membrane
R300	Membrane bioreactor with 300 nm pore-sized ceramic membrane
R^2	Squared value of correlation coefficient
R_C	Cake layer resistance
R_M	Intrinsic membrane resistance
R_{IR}	Irreversible fouling resistance
R_P	Pore blocking resistance
R_T	Total fouling resistance
SMP_{total}	Total soluble microbial products
t	The filtration time
T	Temperature
TATE & LYLE Mylbond 168	Starch
Ti-MBR	Electro-membrane bioreactor with titanium anodes
TN	Total nitrogen
$ZnSO_4 \cdot 7H_2O$	Zinc sulphate
x	Independent variable
y	Variable
$\Delta MLSS/\Delta t$	Biomass growth rate
ΔP	Transmembrane pressure gradient
$\Delta TMP/\Delta t$	Membrane fouling rate
YW 30	A kind of regenerated cellulose membrane

Greek symbols

Symbol	**Description**
α_c	Specific resistance of the compressible cake layer
α_p	Pore size reduction coefficient
γ	Shear rate
η_f	Average fraction of soluble particles that accumulate in membrane pores
ρ_c	Density of the cake layer
ρ_P	Density of biomass
τ	Shear stress
μ	Viscosity of the permeate

PhD DISSESRTATION ABSTRACT

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Abstract

In recent years, membrane fouling has become a critical issue of membrane bioreactor (MBR) in wastewater treatment. To resolve this obstacle, introducing biomass carriers or flocculants into submerged MBR (SMBR) has become one of the effective technologies for membrane fouling control. This study aims to provide an in-depth analysis on membrane fouling behaviour in SMBRs with sponge and/or the patented green bioflocculant by considering the properties of activated sludge and cake layer. A new functional media (sponge modified plastic carrier) was also developed to enhance the performance of integrated moving bed biofilm reactor-membrane bioreactor (MBBR-MBR) systems. The results suggested that sponge addition in a SMBR (SSMBR) or bioflocculant addition in a SMBR (MBR-G) reduced cake layer formation and limited pore blocking, thus effectively minimizing membrane fouling. Better sludge characteristics were obtained in both of the SSMBR and the MBR-G due to less soluble microbial products (SMP), lower biomass growth and sludge viscosity, higher protein to polysaccharide ratio in extracellular polymeric substances, higher zeta potential, greater relative hydrophobicity, larger floc size and better flocculation ability. The presence of sponge or bioflocculant in the SMBR also eliminated extracellular polymeric substances (EPS), SMP and/or biopolymer clusters (BPC) on membrane surface. Consequently, cake layer (R_C) and pore blocking resistance (R_P) were decreased in the SSMBR and the MBR-G. A modified resistance-in-series model proposed for the SMBR with and without bioflocculant could quantitatively demonstrate the impacts of sludge characteristics on membrane fouling. In the SSMBR, a longer hydraulic retention time (HRT) of 6.67 h permitted more considerably fouling reduction comparing to shorter HRTs (5.33 and 4.00 h). Moreover, lower R_P and R_C at the prolonged HRT were mainly ascribed to the elevated protein to polysaccharide ratio in SMP (SMP_P/SMP_C) of mixed liquor, together with the declined EPS and BPC in cake layer. SMP was not the primary membrane foulant when the SSMBRs were operated at different HRTs. Bioflocculant addition at the optimum HRT of 6.67 h further mitigated fouling in the SSMBR by improving activated sludge and cake layer characteristics. The integrated MBBR-MBR with the sponge modified plastic carriers showed better removal of DOC, NH_4-N, T-N and PO_4-P than the MBBR-MBR with plastic carriers only. Furthermore, the sponge modified plastic carriers also eliminated SMP of mixed liquor, and reduced SMP and BPC on membrane surface, which ameliorated membrane fouling, R_P and R_C as compared to the plastic carriers.

Keywords: Submerged membrane bioreactor (SMBR); Moving bed biofilm reactor (MBBR); Integrated MBBR-MBR; Sponge; Bioflocculant; Hydraulic retention time (HRT); Sponge modified plastic carriers; Membrane fouling; Nutrient removal; Cake layer; Modelling