

Addition of powdered activated carbon to anaerobic membrane bioreactor for fouling control

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under the supervision of Prof. Wenshan Guo
and the co-supervision of Prof. Huu Hao Ngo

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CERTIFICATION OF ORIGINAL AUTHORSHIP

I, Weonjung Sohn declare that this thesis, is submitted in fulfilment of the requirements for the award of Master of Engineering, in the School of Civil and Environmental Engineering/Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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LIST OF ABBREVIATIONS

Symbol	Description
AnMBRs	Anaerobic membrane bioreactors
AnFMBR	Anaerobic fluidized membrane bioreactor
AnCMBR	Anaerobic ceramic membrane bioreactor
AC	Activated carbon
AFCMBR	Anaerobic fluidized bed ceramic membrane bioreactor
AgNPs	Silver nanoparticles
AOX	Adsorbable organic halogen
ASVs	Amplicon sequence variants
BAC	Biologically activated carbon
BC	Biochar
BOD ₅	Biological oxygen demand
PAC	Powdered activated carbon
Cbz	Carbamazepine
COD	Chemical oxygen demand
CSTR	Continuously stirred tank reactor
Dcf	Diclofenac
DIET	Direct interspecies electron transfer
DOM	Dissolved organic matter
DOC	Dissolved organic carbon
EGSB	Expanded granular sludge bed
ENMs	Engineered nanomaterials
EPS	Extracellular polymeric substances
ETS	Erythromycin-tetracycline-sulfamethoxazole
FO	Forward osmosis
F/M ratio	Food to microorganisms ratio
GAC	Granular activated carbon
HRT	Hydraulic retention time
IAFMBR	Integrated anaerobic fluidized-bed membrane bioreactor
LCWW	Low-grade coal wastewater
LCFA	Long chain fatty acids

MBRs	Membrane bioreactors
MLSS	Mixed liquor suspended solids
MD	Membrane distillation
MF	Microfiltration
MW	Molecular weight
NF	Nanofiltration
NOM	Natural organic matter
OCPs	Organochloride pesticides
OLR	Organic loading rate
ORP	Oxidation-reduction potential
PAC	Powder activated carbon
PC-A	Polycitrate-Alumoxane
PE	Polyethylene
PET	Polyethylene terephthalate
PES	Polyethersulfone
PP	Polypropylene
PVA	Polyvinyl alcohol
PVDF	Polyvinylidene difluoride
PhACs	Pharmaceutically active compounds
PHAs	Polycyclic aromatic hydrocarbons
SAF-MBR	Staged anaerobic fluidized membrane bioreactor
SAF-CMBR	Staged anaerobic fluidized bed ceramic membrane bioreactor
SCFA	Short chain fatty acids
SS	Suspended solids
SRT	Solids retention time
SMs	Sulfonamide antibiotics
SMP	Soluble microbial product
SMX	Sulfamethoxazole
ST	Erythromycin-tetracycline
SMZ	Sulfamethazine
RO	Reverse osmosis
TC	Tetracycline
Tcs	Triclosan

TMP	Transmembrane pressure
Tmp	Trimethoprim
TOC	Total organic carbon
TS	Total solids
TP	Total phosphorous
UASB	Up-flow anaerobic sludge blanket
US CDC	United State Centre for Disease Control and Prevention
UF	Ultrafiltration
WWTPs	Wastewater treatment plants
VFAs	Volatile fatty acids
VSS	Volatile suspended solids
VS	Volatile solids
YW	Yeast wate
ZVI	Zero-valent iron

LIST OF SYMBOLS

Symbol	Description
$\text{Al}(\text{OH})_3$	Aluminum hydroxide
AlCl_3	Aluminum chloride
$\text{Al}_2(\text{SO}_4)_3$	Aluminum sulfate
Al_2O_3	Aluminum oxide
$\text{C}_6\text{H}_{12}\text{O}_6$	Glucose
Ca^{2+}	Calcium
CaCl_2	Calcium chloride
CO_2	Carbon dioxide
CO	Carbon monoxide
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	Cupric sulphate
Fe	Iron
FeCl_3	Ferric chloride anhydrous
FeS	Ferrous sulfide
H^+	Proton
H_2	Hydrogen
H_2O	Water
H_2S	Hydrogen sulfide
H_2SO_4	Sulphuric acid
K^+	Potassium
KOH	Potassium hydroxide
KH_2PO_4	Potassium dihydrogen phosphate
LMH	$\text{L}/\text{m}^2 \text{h}$
Mg^{2+}	Magnesium
$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	Magnesium sulphate
N_2	Nitrogen gas
Na^+	Sodium
NaClO	Sodium hypochlorite
NaNO_3	Sodium nitrate
NaHCO_3	Sodium bicarbonate

NaOH	Sodium hydroxide
NH ₄ ⁺	Ionized ammonia
NH ₄ ⁺ -N	Ammonium nitrogen
NH ₄ Cl	Ammonium chloride
NO ²⁻	Nitrite
NO ³⁻	Nitrate
NO ₂ -N	Nitrite nitrogen
NO ₃ -N	Nitrate nitrogen
O ₂	Oxygen gas
O ₃	Ozone
OH ⁻	Hydroxyl
PO ₄ ³⁻ -P	Hydrogen phosphate phosphorus
TiO ₂	Titanium dioxide
ZrO ₂	Zirconium dioxide
ZnSO ₄ ·7H ₂ O	Zinc sulphate

ABSTRACT

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Abstract

Membrane fouling remains a challenging issue which is the main obstacle of wider applications of anaerobic membrane bioreactors (AnMBRs). This is because the cake layer in AnMBRs is thicker and less removable than that in aerobic membrane bioreactors due to the different sludge characteristics. Pretreatment of feed wastewater can efficiently control membrane fouling by altering the feed water properties with the addition of fouling reduction enhancers, such as adsorbents and flocculants. Activated carbon, such as powdered activated carbon (PAC), which is comparatively simple and effective adsorbent, has been largely applied as an adsorbent to aerobic membrane bioreactors for membrane fouling mitigation. However, only a limited amount of research has focused on the application of PAC to AnMBRs. Although some studies have reported the effects of PAC addition on pollutants removal performance and fouling control of AnMBR system, few studies discussed the overall nutrient and organics removal performance as well as detailed membrane fouling behaviour regarding PAC addition at an ambient temperature. In addition, no study has been carried out on the effect of PAC on

microbial community in AnMBR. The long-term effects of the optimal PAC dosage, which was found to be 5 g/L from the short-term experiments, on conventional AnMBR performance with a hollow fiber membrane were investigated in this study. The optimal one-off PAC dosing could increase average COD and total organic carbon (TOC) removal rates up to 15.71% and 15.69%, respectively. The PAC addition exhibited not only lower transmembrane pressure (TMP) increase rate, but also reduction of soluble microbial product (SMP) and extracellular polymeric substances (EPS). High protein fraction of SMP as well as increased zeta potential in AnMBR with PAC addition could enhance hydrophobicity, which improved the flocculation ability of sludge. In addition, lower total membrane resistance and pore blocking resistance indicated that PAC addition could prevent both severe pore blocking and irreversible fouling, due to the lower amount of polysaccharide of SMP in cake layer. PAC addition could reduce the abundance of fouling-related bacteria such as *Cloacibacterium* and *Smithella*, which contribute to the biofouling development due to the high affinity to attach on membrane surface. This is because the high adsorption capacity of PAC could enabled 1.7-4.7 times lower abundance of those bacteria by inhibiting proliferation of them. These results demonstrated that PAC addition to AnMBR could effectively mitigate membrane pore blocking and irreversible membrane fouling as well as improve microbial community.

Keywords: Anaerobic membrane bioreactor; Membrane fouling; Enhancers; Powdered activated carbon