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

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Thesis submitted in fulfilment of the requirements for the degree of

Master of Engineering

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

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June 2021

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.

This research is supported by the Australian Government Research Training Program.

Production Note:
Signature: Signature removed prior to publication.

Date: 08. 06. 2021

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my principle supervisor Prof. Wenshan Guo for her patient guidance, and endless support. She also provided constant encouragement and mentorship for me all the way from the beginning of my master degree to the end of this degree. It was my pleasure to study under her supervision. I would like to appreciate my co-supervisor Prof. Huu Hao Ngo for his valuable encouragement and comments. I feel very fortunate to have been in his research group. I would like to extend my gratitude to my groupmates who always gave me their kindness, and especially to Dora for her great help to my experiment. Apart from my groupmates, I appreciate Allie for her great help in microbial community study, and Seongchul Ryu for his valuable life advice and help whenever I had difficulties. I am very grateful to my friends in Sydney who always support and encourage me. I was not able to successfully finish my study without their help to getting through the tough times during my study period. Finally, I would like to express my sincere gratitude to my family for financial support and endless love during my whole study time.

It was a big challenge for me to start an experiment, organizing data, and writing this master thesis. However, I was able to complete my master thesis as a result with my supervisor Prof. Wenshan guo’s constant guidance.

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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**
$Al(OH)_3$	Aluminum hydroxide
$AlCl_3$	Aluminum chloride
$Al_2(SO_4)_3$	Aluminum sulfate
Al_2O_3	Aluminum oxide
$C_6H_{12}O_6$	Glucose
Ca^{2+}	Calcium
$CaCl_2$	Calcium chloride
CO_2	Carbon dioxide
CO	Carbon monoxide
$CuSO_4 \cdot 5H_2O$	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	$L/m^2 \cdot h$
Mg^{2+}	Magnesium
$MgSO_4 \cdot 7H_2O$	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_4Cl	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
$ZnSO_4 \cdot 7H_2O$	Zinc sulphate

ABSTRACT

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Date: 08. 06. 2021

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

Faculty: Faculty of Environmental and Information Technology

School: Civil and Environmental Engineering

Supervisors: Prof. Wenshan Guo (Principal supervisor)

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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