ULTRAFILTRATION AND NANOFILTRATION HYBRID SYSTEMS IN WASTEATER TREATMENT AND REUSE

By

Hokyong Shon

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University of Technology, Sydney (UTS)

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CERTIFICATE

I certify that this thesis has not already been submitted for any degree and is not being submitted as part of candidature for any other degree.

I also certify that the thesis has been written by me and that any help that I have received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

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TABLE OF CONTENTS

CHAPTER 3

EXPERIMENTAL INVESTIGATION 3-1

CHAPTER 9

PHOTOCATALYSIS HYBRID SYSTEM IN THE REMOVAL OF ORGANIC MATTER FOR WASTEWATER REUSE 9-1

NOMENCLATURE

a’’	=	modified series resistance flux decline (MSRFD) constant with Langmuir
b’’	=	MSRFD constant with Langmuir
C	=	bulk organic concentration (ML^{-3})
C_b	=	bulk concentration (ML^{-3})
C_e	=	equilibrium organic concentration (ML^{-3})
C_m	=	interfacial membrane concentration (ML^{-3})
C_p	=	permeate concentration (ML^{-3})
C_s	=	saturation organic concentration (ML^{-3})
d	=	flux decline kinetic constant (T^{-1})
D	=	organic diffusion coefficient (L^2T^{-1})
d_h	=	equivalent hydraulic diameter (L)
D_s	=	surface diffusion coefficient of organic (L^2T^{-1})
H	=	adsorption constant, function of temperature
J	=	permeate flux at a given time of operation (MT^{-1})
J_0	=	pure water permeate flux (MT^{-1})
k	=	apparent photodegradation rate constant (T^{-1})
K	=	Talu reaction constant
k_0	=	flux decline potential which is dimensionless
k_1	=	rate constant (T^{-1})
k_f	=	external film mass transfer coefficient of organic (LT^{-1})
K_F	=	Freundlich constant
K_F’	=	series resistance flux decline (SRFD) constant with Freundlich constant
K_F’’	=	MSRFD constant with Freundlich isotherm constant
K_s	=	energy of adsorption
K_s’’	=	MSRFD constants with Sips
k_{SE}	=	Boltzmann constant ($ML^2T^{-2}K^{-1}$)
L	=	channel length (L)
L_p	=	pure water permeability ($MT^{-1}kPa^{-1}$)
M	=	weight of the adsorbent (M)
M_i	=	i is an incrementing index over all MW present (Da)
M_n	=	number-average molecular weight (Da)

M_w = weight-average molecular weight (Da)

M_z = z-average molecular weight (Da)

N_i = number of molecules having a MW

1/n = Freundlich constant

1/n' = SRFD constant with Freundlich constant

1/n'' = MSRFD constants with Freundlich isotherm constant

P = polydispersivity

q = measured amount organic adsorbed (MM^{-1})

q_m = sorption capacity (MM^{-1})

q_m'' = sorption capacity with Sips

R_{as} = resistance due to strong adsorption (L^{-1})

R_{aw} = resistance due to weak adsorption (L^{-1})

R_{cp} = resistance due to concentration polarization (L^{-1})

R_g = resistance due to the gel layer (L^{-1})

r_p = radius of adsorbent particle (L)

t = illumination (operation) time (T)

T = absolute temperature (K)

U = average velocity of the feed fluid (ML^{-1})

V = volume of the solution in batch reactor (L^3)

$\overline{q}$ = average adsorbed phase organic concentration (MM^{-1})

T_P = duration of permeate production cycle (T)

T_C = duration of cleaning cycle (T)

$C_{coefficient}^{baseline}$ = experimental value of the flux decline

$Flux_{net}$ = productivity of the cross-flow membrane system operating with periodic cleaning

$C_{coefficient}^{simulated}$ = simulated flux values for different model coefficients

μ = dynamic viscosity ($kPaT^{-1}$)

η = viscosity of the organic phase ($L^2N^{-1}T^{-1}$)

ξ = zeta potential (mV)

ρ_p = particle density of adsorbent (ML^{-1})

Ψ = concentration spreading parameter

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Wastewater reuse is increasingly seen as an essential strategy for making better use of limited freshwater resources, and as a means of preventing deterioration of the aquatic environment from wastewater disposal. Membrane processes are now being successfully used to obtain water of recyclable quality. However, membrane fouling is a critical limitation on the application of membranes to wastewater reuse. Pretreatment of biologically treated sewage effluent (BTSE) prior to membrane processes will reduce organic deposition and subsequent biogrowth on membranes due to dissolved organic matter. Pretreatment also reduces the need for frequent chemical cleaning, which is a major factor that impacts on membrane life. From these perspectives, pretreatment offers significant potential for improving the efficiency of membrane processes.

The main objectives in this study are i) to evaluate different pretreatment methods of removing effluent organic matter (EfOM) from BTSE and in reducing membrane fouling, ii) to investigate the variation in the ultrafiltration (UF) and nanofiltration (NF) membrane foulant characteristics in terms of molecular weight (MW) distribution of foulants and the characteristics of fouled membrane, iii) to examine the effect of semi flocculation and semi adsorption (with partial doses of flocculants and adsorbents, respectively) on the membrane filtration, iv) to study the phenomena of membrane filtration and pretreatment using different fractions (hydrophobic (HP), transphilic (TP) and hydrophilic (HL)) of BTSE, v) to assess the effect of hybrid hydrodynamic cleaning with high rate crossflow and relaxation modes in comparison with pretreatment to membrane, vi) to evaluate the merits/demerits photocatalysis hybrid system in comparison with NF and UF with pretreatment and vii) to develop different flux decline models to quantitatively compare different pretreatments.

The highest removal of organic matter was observed when flocculation followed by adsorption was used as pretreatment. The flocculation and adsorption removed 68.5% and 71.4% of hydrophobic organic matter. After the flocculation pretreatment, the majority of large MW EfOM was removed. The pretreatment of the flocculation followed by adsorption led to very high removal of both small and large organic matter. Further, this pretreatment led to practically no filtration flux decline. The weight averaged MW (M_w) of the organics in the foulant on the membrane surface was 510

daltons (UF) and 190 (NF) without pretreatment and 350 (UF) and 180 (NF) after pretreatment with flocculation followed by adsorption, respectively. The flux decline with the HP fraction was high compared with the TP and HL fractions. It was observed that a particular amount of flocculant and adsorbent to UF was necessary below which the UF membrane became heavily fouled. The detailed analysis of M_w indicated that the M_w values of organic matter in the synthetic wastewater and in the flocculated effluent were 29800 daltons (initial), > 25000 (after flocculation with 40 mg/L $FeCl_3$ or less) and < 1000 (after flocculation with 50 mg/L $FeCl_3$ or more). The M_w values suggested the reason why the permeate flux was decreased with 40 mg/L $FeCl_3$ semi flocculation followed by semi adsorption due to the remaining large M_w.

A detailed investigation of the utilisation of two automated cleaning techniques to reduce fouling problems was explored. The two cleaning techniques studied were periodic membrane relaxation and a periodic high rate cross-flow. The study found that an optimised usage of these two de-clogging techniques, with a 1 hour production period followed by a 1 minute relaxation period and then a 1 minute high cross-flow rate period resulted in a net productivity increase of 14.8%. Three different semi-empirical mathematical models were investigated to partially quantify the effects of different pressures and pretreatments. The three different models used were i) empirical flux decline (EFD) model, ii) series resistance flux decline (SRFD) model and iii) modified series resistance flux decline (MSRFD) model. The flux decline coefficient values determined from the EFD and SRFD models can be used as an index to assess flux decline and compare different operating conditions and pretreatments. With the MSRFD model, when flocculation of 21 mg-Fe/L was used as a pretreatment at a pressure of 300 kPa, the values of the bulk concentration (C_b), the concentration on the membrane surface (C_m) and adsorption resistance (R_a) significantly decreased by 4.4, 3.1 and 12.9 times, respectively. After 0.1 g/L adsorption as a pretreatment, the values decreased by 2.2, 2.0 and 1.8 times, respectively. Thus, pretreatment can significantly decrease membrane fouling.

Although pretreatment reduces flux decline caused by membrane fouling, it cannot completely prevent membrane fouling. Further, as time proceeds, membrane fouling by organic matter is converted into biofouling and the concentration from the retentate constantly increases. To resolve these problems, this study recommends three near-zero fouling systems with an integrated photocatalysis membrane hybrid system.