UNIVERSITI PUTRA MALAYSIA

PERFORMANCE OF MEMBRANE BIOREACTOR IN THE TREATMENT OF HIGH STRENGTH MUNICIPAL WASTEWATER

AHMED HUSSIEN BIRIMA

PERFORMANCE OF MEMBRANE BIOREACTOR IN THE TREATMENT OF HIGH STRENGTH MUNICIPAL WASTEWATER

By

AHMED HUSSIEN BIRIMA

Thesis Submitted To the School of Graduate Studies, Universiti Putra Malaysia, In Fulfilment of the Requirement for the Degree of Doctor of Philosophy

October 2008

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

PERFORMANCE OF MEMBRANE BIOREACTOR IN THE TREATMENT OF HIGH STRENGTH MUNICIPAL WASTEWATER

By

AHMED HUSSIEN BIRIMA

June 2008

Chairman : **Associate Professor Thamer Ahmed Mohamed, PhD**

Faculty : **Engineering**

In some parts of Malaysia, wastewater treatment plants (WWTPs) are located in industrial areas. These WWTPs receive wastewater mostly from these industrial activities regularly or occasionally. Therefore, their biochemical oxygen demand (BOD), chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N) are very high. Conventional biological treatment processes are incapable of producing desirable effluent quality with the increasingly stringent discharge requirement.

In this study, a laboratory-scale membrane bioreactor (MBR) was used for treating high strength municipal wastewater. Prepared synthetic wastewater samples which represent a high strength municipal wastewater as well as the actual high strength municipal wastewater were used in the study. The developed MBR was operated under different conditions using statistical experimental full factorial design with three factors and three levels. The factors were sludge retention time (SRT), feed temperature (T_f) and organic loading rate (OLR) and their respective levels were 25, 30 and 35 days; 20, 30 and 40 ^oC; and 1.73, 4.03 and 6.82 kg COD/m^3 .d .

To evaluate the performance of MBR under the different operating conditions, ten trials were carried out using the prepared synthetic wastewater samples. The MBR could cope with the different operating conditions with high accuracy on the experimental results. Permeate COD, BOD, NH_3-N and total suspended solids (TSS) varied from 0 to 32, 0.3 to 13.1, 0.004 to 0.856 and 0 to 26 mg/l respectively. The pH in the aeration tank increased significantly compared to that of the feeding tank. In addition, the increasing pH of the aeration tank was well correlated to that in the feeding tank. (R^2 = 0.8336 for low OLR trials and 0.9106 for high OLR trials).

To investigate the effects of the different operating conditions on membrane fouling, sustainable time (t_{sust}) was used as a measure to compare the different trials. Within the same OLR level, t_{sust} increased as SRT and T_f increased. Sustainable time was found to decrease as the ratio of mixed liquor volatile suspended solids to mixed liquor suspended solids (MLVSS /MLSS) increased with a correlation coefficient (R^2) of 0.808.

When MBR was used to treat the actual high strength municipal wastewater, the respective average removal efficiencies of COD, BOD and NH_3-N were 98.4, 99.7, and 99.9%. These were found to be comparable with those values obtained from the synthetic wastewater treated by MBR .

Empirical models were developed to predict the concentrations of permeate COD, BOD and NH_3-N. The predicted values were highly correlated with the observed values (R^2 of 0.9188, 0.9111 and 0.9899 respectively for the three parameters

mentioned). However the models of COD and BOD were found to be more accurate than the NH_3-N model.

Future work on the optimization of MLSS concentration and aeration rate as well as the improvement on the techniques for reducing the membrane fouling is recommended.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PRESTASI BIOREAKTOR MEMBRAN DALAM MENGOLAH AIR SISA DOMESTIK BERKEKUATAN TINGGI

Oleh

AHMED HUSSIEN BIRIMA

Jun 2008

Pengerusi : **Professor Madya Thamer Ahmed Mohamed**

Fakulti : **Kejuruteraan**

Di sesetengah tempat di Malaysia, loji olehan kumbahan airsisa terletak di kawasan industri. Loji-loji olehan kumbahan airsisa ini kebanyakannya menerima air sisa daripada aktiviti-aktiviti industri secara berterusan atau berkala. Oleh itu, tahap keperluan oksigen biokimia (BOD), keperluan oksigen kimia (COD) dan ammonia nitrogen (NH_3-N) adalah sangat tinggi. Proses olehan biologi konvensional tidak mampu menghasilkan kualiti effluen yang dapat memenuhi piawai kumbahan yang semakin ketat.

Di dalam kajian ini, satu bioreaktor membran skala makmal (MBR) telah direkabentuk, dibina dan diaplikasikan dalam mengolah air sisa domestik berkekuatan tinggi. Penyediaan air sisa sintetik yang mewakili air sisa domestik yang berkekuatan tinggi dan juga air sisa domestik sebenar yang berkekuatan tinggi telah digunakan di dalam kajian. MBR yang telah dibangunkan beroperasi di bawah keadaan yang berbeza dengan menggunakan rekabentuk faktorial penuh eksperimen statistik dengan tiga faktor dan tiga tahap. Faktor-faktor itu ialah masa tahanan enapcemar (SRT), suhu suapan makanan (T_f) serta kadar bebanan organik (OLR)

dan nilai-nilai tersebut ialah 25, 30 dan 35 hari; 20, 30 dan 40 ^{o}C; dan 1.73, 4.03 dan 6.82 kg COD/m^{3} .hari masing-masing.

Untuk menguji prestasi MBR di bawah keadaan operasi yang berbeza, sepuluh ujian telah dijalankan dengan menggunakan sample air sisa sintetik tersedia. MBR tersebut berupaya beroperasi di bawah keadaan operasi yang berbeza dengan ketepatan tinggi ke atas keputusan eksperiman. Turasan dengan nilai COD, BOD, NH_3-N dan Jumlah Pepejal Terampai (TSS) adalah berjulat dari 0 sehingga 32, 0.3 sehingga 13.1, 0.004 sehingga 0.856 dan 0 sehingga 26 mg/l masing-masing. Nilai pH di dalam tangki pengudaraan meningkat dengan ketara jika dibandingkan dengan tangki suapan makanan. Tambahan pula, peningkatan pH di dalam tangki pengudaraan dapat dikorelasikan dengan tangki suapan makanan (R^2 = 0.8336 untuk ujian OLR rendah dan 0.9106 untuk ujian OLR tinggi).

Untuk menyiasat kesan-kesan keadaan operasi yang berbeza ke atas penyumbatan membran, masa mampan (t_{sust}) telah digunakan sebagai sukatan bandingan bagi ujian-ujian yang berbeza. Di dalam lingkungan tahap OLR yang sama, t_{sust} meningkat apabila SRT dan T_f meningkat. Masa mampan telah didapati menurun apabila nisbah pepejal terampai meruap likuor campur kepada pepejal terampai likuor campur (MLVSS/MLSS) meningkat dengan pekali korelasi (R^2) 0.808.

Apabila MBR digunakan untuk mengolah air sisa domestik sebenar yang berkekuatan tinggi, purata keberkesanan penyingkiran untuk COD, BOD dan NH_3-N ialah 98.4, 99.7, dan 99.9% masing-masing. Keputusan ini didapati sejajar dengan

nilai yang telah diperolehi terlebih dahulu daripada model air sisa yang diolah dengan MBR.

Model empirikal telah dibangunkan untuk meramal kepekatan turasan COD, BOD dan NH_3-N. Nilai yang telah diramal adalah sangat berkorelasi dengan nilai sebenar (R^2 dengan 0.9188, 0.9111 dan 0.9899 masing-masing untuk tiga parameter yang telah disebut). Walaubagaimanapun, model untuk COD dan BOD didapati lebih tepat dibandingkan dengan model NH3-N.

Kajian masa hadapan ke atas pengoptimuman kepekatan MLSS dan kadar pengudaraan di samping pembaikan ke atas teknik untuk mengurangkan penyumbatan membran disarankan.

ACKNOWLEDGMENTS

Foremost, I am extremely grateful to most beneficent Allah, the Almighty, who bestowed me good health, strength, and courage in accomplishing this research. Above all, I believe in Allah's boundless love and grace that have filled my soul with hope and happiness and have inspired me to live through difficult times of my life.

I also wish to express my heartfelt gratitude and sincere appreciation to those whose contributions collectively were of immeasurable value in my educational pursuits. First I wish to extend special appreciation and thanks to my supervisor Associate Professor Dr. Thamer Ahmed Mohammed for his patience and understanding during the prolong period of my study; constructive suggestions and timely help which enable me to accomplishing the objective of this research in professional manner.

Deep gratitude and sincere appreciations also extend to other members of supervisory committee, Professor Suleyman Aremu Muyibi for his superb guidance, constructive suggestions and heartfelt cooperation. Professor Azni Idris for his professional assistance and help.

I would like to extend profound thanks and sincere appreciation to Associate Professor Ir. Megat Johari for ideas, limitless assistance and beneficial advice; and full support for the research. My gratitude for him is forever.

I would like to extend special thanks to Indah Water Consortium Sdn. Bhd. (IWK) for providing me the data of wastewater samples.

My father is the constant source of support and encouragement throughout my study period. I express the deepest sense appreciation to my father Hussien Birima and my mother's soul late Mustora Abdul Allah and dedicate this piece of work to both of them.

Thanks to many of my friends, colleagues, and technicians in public health engineering laboratory KAW, Ken, Fiona, and Leong for their cooperation and handy help during this study, En. Fairuz, En. Ameen, for the technical support.

Last but not least, my gratitude extends to my brothers, sisters and uncles.

I certify that an Examination Committee met on October 24th 2008 to conduct the final examination of Ahmed Hussien Birima on his doctor of philosophy thesis entitled "Design and Development of Membrane Bioreactor for Treating High Strength Municipal Wastewater " in accordance with Universiti Pertanian Malaysia (higher degree) Act 1980 and Universiti Pertanian Malaysia (higher degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Bujang B. K. Huat, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Abdul Halim Ghazali, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Salmiaton Bt. Ali, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mohd Razman Salim, PhD
Professor
Faculty of Civil Engineering
University Technology Malaysia
(External Examiner)

BUJANG KIM HUAT, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 19 February 2009

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of doctor of philosophy. The members of the Supervisory Committee are as follows:

Thamer Ahmed Mohammed, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Azni Idris, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Suleyman Aremu Muyibi, PhD
Professor
Faculty of Engineering
International Islamic University Malaysia
(Member)

HASANAH MOHD GHAZALI, PhD
Professor/Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9 April 2009

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

_____

AHMED HUSSIEN BIRIMA

Date:

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TOC	Total Organic Carbon
NH3-N	Ammonia Nitrogen
NO_2-N	Nitrite Nitrogen
NO_3-N	Nitrate Nitrogen
TKN	Total Kjehldahl Nitrogen
TS	Total Solids
TSS	Total Suspended Solids
ML	Mixed Liquor
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
TMP	Trans-Membrane Pressure
CASP	Conventional Activated Sludge Process
MBR	Membrane Bioreactor
SMBR	Submerged Membrane Bioreactor
MSBR	Membrane Sequencing Batch Reactor
UF	Ultrafiltration
MF	Microfiltration
SRT	Sludge Retention Time
T_f	Feed Temperature
OLR	Organic Loading Rate
VLR	Volumetric Loading Rate

F/M	Food To Microorganism Ratio
FC	Fecal Coliforms
CFV	Cross Flow Velocity
EPS	Extracellular Polymeric Substances
UBIS	Ultra Biological System
HRT	Hydraulic Retention Time
EBPR	Enhanced Biological Phosphorus Removal
Q_r	Recycling Flow Rate
Ec	Efficiency of Substrate
RMBR	Recirculated Membrane Bioreactor
CMF	Critical Membrane Flux
PAC	Powdered Activated Carbon
RBCOD	Readily Biodegradable Organic Substances
SMP	Soluble Microbial Products
DOE	Department of Environment
PE	Population Equivalent
DO	Dissolved Oxygen
TMP	Transmembrane Pressure
SP	Suction Pressure
J_c	Critical Flux
J_p	Permeate Flux
t_{sus}	Sustainable Time
SVI	Sludge Volume Index
FSIP	Flux- Suction Pressure Intersection Point