UNIVERSITI PUTRA MALAYSIA

SEWAGE CHARACTERIZATION AND INSEWER TRANSFORMATION OF SELECTED DETERMINANTS

HARLINA BINTI AHMAD

SEWAGE CHARACTERIZATION AND INSEWER TRANSFORMATION OF SELECTED DETERMINANTS

By

HARLINA BINTI AHMAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

MARCH 2010

SEWAGE CHARACTERIZATION AND INSEWER TRANSFORMATION OF SELECTED DETERMINANTS

By

HARLINA BINTI AHMAD

March 2010

Chair: Azni Idris, PhD, Professor

Faculty: Faculty of Engineering

A comprehensive sewage characterization was conducted to further understand the nature of sewage generated in three different catchments: domestic, commercial and industrial areas. It was revealed that the characteristic sewage generated in domestic areas resembled the typical sewage characteristic reported globally. However, sewage generated in industrial areas indicated interferences or adulteration from industrial processing effluents. The heavy metal characterization revealed that most STPs treated effluents complied with Standard B of Environmental Quality Act (EQA) 1979 in term of Ni, Cu, Zn, Fe, Pb and Cr.

The assessment of STPs performance grouped according to their locations discovered that STPs which served population exceeded the design population equivalent (PE) demonstrated poor performance due to overloading factor. The lower efficiency of COD, BOD_5 and SS removal of STPs located in industrial areas might be contributed to industrial processing effluents contamination. It was reported that 86.1% of BOD_5, 71.46% of COD

and 95.9% of SS of cumulative probabilities of treated effluent from STPs in domestic areas met the permissible limit in the Standard B of EQA. The cumulative probability of BOD_5, COD and SS of treated effluents of STPs in commercial areas to meet the Standard B were 95.4%, 80.0% and 97, 95% accordingly. The percentage of cumulative probability for the treated effluents of STPs in industrial areas portrayed lower values which were 68.61% (BOD_5), 56.0% (COD) and 77.3% (SS) respectively.

The screening of Persistent Organic Pollutants (POPs) in treated effluent of selected STPs revealed the presence of eight pollutants; phenol, naphthalene, bis(2-chloroisopropyl) ether, dimethyl phthalate, diethyl phthalate, ethyl benzene, 1, 4-dichlorobenzene and phenanthrene. The range of concentrations varied with phenol depicted the most abundance compound detected in all studied STPs' effluents

In the determination of reaction rate and order, it was found that all samples followed first order reaction and the rate, K varied from 0.00192 to 0.00336 L/mgMLVSS/day. The decay coefficient, b, obtained ranged from 0.167 to 0.3360 day^{-1}. The fitting of Monod and Haldane models produced sets of biokinetic constants. The fractionation study revealed that only 61% to 69% of total COD were truly biodegradable in nature. Meanwhile, the fraction of readily biodegradable ranged from 15% to 38%, the non-biodegradable ranged from 31% to 39% and the slowly biodegradable ranged from 23% to 44%.

The in situ characterization of sewerage network concluded that variation in the parameters analyzed between the sampling points. The course of degradation of COD, SCOD, phenol, anionic surfactants and sulphide were followed in aerobic and anaerobic conditions mimicked the in sewer environment. In aerobic condition, the zero-order rate of COD and

SCOD were 0.051mg/l/hr and 0.052 mg/l/hour respectively. In anaerobic condition, it was observed that there was negligible COD removal. However, SCOD concentration was observed to increase with incubation time with the rate of 0.010 mg/l/hr. Phenol concentration was observed to decrease with the rate of removal 0.021 hr^{-1} aerobically. Nevertheless, there was negligible removal of phenol concentration observed in anaerobic condition. Similarly, the removal of anionic surfactants with rate of removal of 0.0454 hr^{-1} aerobically was observed, however there was insignificant removal in anaerobic condition. Sulphide concentration was observed to decrease in aerobic condition, while the concentration of sulphide was observed to increase significantly in anaerobic condition. The regressed sulphide prediction equation in anaerobic condition was proposed with coefficient a = 0.0265 and b= 0.5 and the forecasting model became

$\Delta S = 0.0265\ C^{0.5}\ 1.07^{(T-20)}\ t_h\ (A/V)$.

The model simulation study revealed that the Toxic Substance Model developed for river flow can be used with certain assumptions to predict the fate of anionic surfactants along the sewerage network very well. However, the model was found inadequate to predict the distribution of phenol along the sewer.

KAJIAN PENCIRIAN SISA KUMBAHAN DAN TRANSFORMASI DETERMINAN TERPILIH DI DALAM SALIRAN PAIP PEMBENTUNGAN

Oleh

HARLINA BINTI AHMAD

Mac 2010

Pengerusi: **Azni Idris, PhD, Professor**

Fakulti: **Fakulti Kejuruteraan**

Kajian pencirian sisa kumbahan secara komprehensif dijalankan bagi memahami sifat-sifat kumbahan yang terhasil di dalam kawasan gunatanah domestik, komersial dan industri. Adalah didapati ciri-ciri kumbahan yang dihasilkan di dalam kawasan domestik dan komersial menyerupai ciri kumbahan tipikal. Walau bagaimanapun, kumbahan yang terjana di dalam kawasan industri menunjukkan terdapat percampuran daripada sisa pemprosesan industri. Kumbahan yang dihasilkan menunjukkan kepekatan COD, BOD_5 dan SS yang sangat tinggi melebihi nilai bagi kumbahan tipikal. Adalah didapati bahawa efluen terawat bagi loji rawatan kumbahan (STPs) menunjukkan kecenderungan melepasi had efluen yang telah ditetapkan di dalam piawai Malaysia.

Kajian pencirian terhadap logam berat telah mendedahkan bahawa hampir semua efluen terawat loji rawatan kumbahan mematuhi piawai ataupun standard B bagi Akta Kualiti Alamsekitar 1979 bagi parameter Ni, Cu, Zn, Fe, Pb dan Cr. Walau bagaimanapun, kajian yang dijalankan menunjukkan kepekatan Cd dan As di dalam efluen terawat melepasi had efluen yang dibenarkan.

Penilaian kecekapan loji rawatan kumbahan yang dikategorikan mengikut lokaliti telah dijalankan menggunakan parameter COD, BOD_5 dan SS sebagai asasnya. Loji rawatan yang menerima sisa kumbahan daripada kesetaraan penduduk (PE) melebihi nilai rekabentuk menunjukkan kecekapan yang sangat rendah kerana faktor lebihan beban. Kecekapan yang sangat rendah penyingkiran COD, BOD_5 dan SS bagi loji rawatan kumbahan di kawasan industri disumbangkan oleh faktor percampuradukan air sisa pemprosesan industri. Peratusan kebarangkalian kumulatif bagi efluen terawat bagi loji rawatan kumbahan di kawasan domestic mematuhi piawaian standard B (EQA) adalah 86.1% bagi BOD_5, 71.46% bagi COD dan 95.9% bagi SS. Peratusan kebarangkalian kumulatif bagi efluen terawat bagi loji rawatan kumbahan di kawasan komersial pula adalah 95.4% bagi BOD_5, 80.0% bagi COD dan 97.95% bagi SS. Manakala peratusan kebarangkalian kumulatif bagi efluen terawat bagi loji rawatan kumbahan di kawasan industri adalah 68.6% bagi BOD_5, 56.0% bagi COD dan 77.3% bagi SS.

Pencemar organic persisten (POPs) yang dikenalpasti di dalam efluen terawat empat loji rawatan kumbahan adalah fenol, naftalena, bis(2-kloroisopropil) eter, dimetil phthalat, dietil phthalat, etil benzena, 1,4-diklorobenzena dan phenanthren. Julat kepekatan sebatian-sebatian tersebut pelbagai dengan fenol hadir dalam kepekatan paling tinggi

Kajian penentuan darjah dan kadar tindakbalas, mendapati semua sampel menunjukkan darjah pertama dan julat kadar tindakbalas, K, adalah 0.0019-0.00336 $L(mgMLVSS)^{-1}(hari)^{-1}$. Padanan model Monod dan Haldane menghasilkan pemalar biokinetik yang berkenaan. Kajian fraksinasi COD menunjukkan 61%- 69% COD adalah boleh-

biodegradasi. Manakala COD sedia-biodegradasi adalah 15%-38%, COD nyah-biodegradasi 31%-39% dan COD biodegradasi-perlahan 23%-44%.

Kajian pencirian setempat jaringan saliran pembetungan menyimpulkan proses yang berlaku di dalam paip pembetungan adalah aerobik (kepekatan oksigen terlarut 1- 3 mg/L). Proses penguraian COD, SCOD, fenol, surfaktan anionik dan sulfida dijalankan di dalam makmal dengan simulasi keadaan di dalam saliran pembetungan. Dalam keadaan aerobik, kadar tindakbalas sifar COD dan SCOD adalah 0.051 mg/l(jam)$^{-1}$ dan 0.052 mg/l(jam)$^{-1}$. Kepekatan COD didapati malar di dalam keadaan anaerobik. Walau bagaimanapun, kepekatan SCOD bertambah dengan kadar 0.01 mg/l(jam)$^{-1}$ dalam keadaan anaerobik. Kepekatan fenol berkurangan dengan kadar 0.021jam^{-1} secara aerobik. Kepekatan fenol juga didapati malar dalam keadaan anaerobik. Kadar penyingkiran surfaktan anionik adalah 0.0454 jam^{-1} secara aerobik dan malar secara anaerobik. Kepekatan sulfida berkurangan dalam keadaan aerobik, manakala bertambah dalam keadaan anaerobik. Persamaan untuk bagi menganggarkan kepekatan sulfida yang diperolehi secara regresi tak linear dengan koefisien a = 0.0265 dan b = 0.5 adalah seperti berikut $\Delta S = 0.0265\ C^{0.5}\ 1.07^{(T-20)}\ t_h\ (A/V)$.

Simulasi model Toxic Substance yang diterbitkan bagi aliran sungai didapati mampu menganggarkan kepekatan surfaktan anionik di dalam saliran pembetungan dengan baik. Walau bagaimanapun, model tersebut tidak menunjukkan korelasi yang baik bagi penganggaran kepekatan fenol sepanjang saliran pembetungan yang dikaji.

ACKNOWLEDGEMENTS

First of all, all praises and thank to Allah the Most Gracious, the Most Merciful. I hereby would be much grateful to express my most sincere gratitude to the main advisor Prof. Dr. Azni Idris and supervisory committee members Prof. Dr. Mohd. Omar Abd. Kadir, Prof. Madya Dr. Salmiaton Ali and Dr. Norli Ismail for their excellent guidance and advice given throughout the project. Special thanks to Prof. Dr. Mohd Omar Abd. Kadir for his help and support in financing the research with short term grant from USM.

I would also like to thank Indah Water Konsortium for giving me the opportunity to do research on selected sewage treatment plants (STPs) and sewerage networks, the IWK staffs of Seberang Jaya Headquarter and the staffs of USM and UPM whom have been of great assistance to me. I would also like to express my up most gratitude to my colleagues whom without them, this research would not have been possible to complete.

Ultimately, I wish to thank my beloved husband Nazri bin Hashim, for giving me endless love, support and counsel. For my mother, Haminah Hashim, I would like to say that the success of this research was consequence of your never-ending faith, hope and prayer. Thank you mother. To my five princesses Nura Adiela, Nurin Sufiah, Nurul Ilyana, Nur Fatnin Hanisah and Nur Zahidah Amani, you are my source of inspiration and strength. Alfatihah and prayer for my beloved father, Allahyarham Ahmad Awang, there is no such word that could describe his love, patience and faith in me. His courage was my most inspiration.

I certify that an Examination Committee has met on date of viva to conduct the final examination of Harlina Binti Ahmad on her PhD of Environmental Engineering thesis entitled "Sewage Characterization and In Sewer Transformation of Selected Determinants" 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:

Luqman Chuah Abdullah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Ismail Yazis, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Internal Examiner)

Teh Beng Ti, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Rakmi Abdul Rahman, PhD
Professor
Faculty of Engineering and Built Environment
Universiti Kebangsaan Malaysia
(External Examiner)

_____

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

Date: 20 May 2010

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment for the degree of Doctor Philosophy in Environmental Engineering. Members of the Supervisory Committee were as follows:

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

Salmiaton Ali, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd Omar Abd Kadir, PhD
Professor
School of Industrial Technology
Universiti Sains Malaysia
(Member)

Norli Ismail, PhD
Lecturer
School of Industrial Technology
Universiti Sains Malaysia
(Member)

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

Date: 10 June 2010

DECLARATION

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

_____

HARLINA BINTI AHMAD

Date: 16 July 2010

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ABSTRAK	v
ACKNOWLEDGEMENTS	ii
APPROVAL SHEETS	ix
DECLARATION	xi
LIST OF TABLES	xiv
LIST OF FIGURES	xvi
LIST OF PLATES	xxii
LIST OF SYMBOLS	xxiii
LIST OF ABBREVIATIONS	xxv
CHAPTER	
1 INTRODUCTION	
1.1 Sewage management in Malaysia	1
1.2 Sewage pollution in Penang	7
1.3 Problem statement	12
1.3 Research Objectives	13
1.4 Significance of the Study	14
1.5 Research limitation	14
2 LITERATURE REVIEW	16
2.1 Sewage pollution	16
2.1.1 Sewage characterization	17
2.1.2 Effect of Sewage on Man and Environment	32
2.2 Advanced Sewage Treatment	36
2.2.1 Advanced oxidation processes (AOPs)	37
2.2.2 Membrane processes	39
2.2.3 Adsorption	41
2.3 Fate of pollutant in sewerage networks and sewage treatment plants	42
2.3.1 In sewer organic transformation and treatment potential	42
2.3.2 Fate of pollutant in sewage treatment plants	50
2.3.2.1 Fate of xenobiotics compounds in sewage treatment plants	52
3 **MATERIALS AND METHODS**	56
3.1 Sewage characterization on three different areas; domestic, commercial and industrial	56
3.1.1 Sampling locations	56
3.1.2 Sample analyses	59
3.1.3 Heavy metals	61

3.1.4 Persistent organic pollutants (POPs) charting and characterization in sewage effluents 61
3.2 Sewage biotreatability study 64
3.2.1 COD fractionation (determination of soluble and inert COD) using respirometric technique and total biological demand concept 65
3.2.2 Biokinetic constant determination using Monod and Haldane models 72
3.3 In sewer characterization and Modeling 77
3.3.1 In sewer characterization 77
3.3.2 Lab scale transformation of COD, anionic surfactants, Phenols and sulphide under Sewer conditions (aerobic/anaerobic) 87
3.3.3 In sewer modeling by Toxic Substances Model 89
3.4 Summary of research methodology 95

4 RESULT AND DISCUSSION 98
4.1 Sewage treatment plants evaluation and sewage characterization 98
4.1.1 General and conventional parameters 98
4.1.2 Assessment of Sewage Treatment Plants (STPs) performances 115
4.1.3 Persistent Organic Pollutants (POPs) 130
4.2 Biotreatability and COD fractionation 141
4.2.1 Biokinetic parameters determination 141
4.2.2 Monod and Haldane models analyses of the sewage influents 149
4.2.4 COD fractionation of sewages influents 156
4.3 In sewer characterization and evaluation 165
4.3.1 In situ characteristic of sewerage network 165
4.3.2 In sewer Lab-scale degradation study of pollutants in aerobic and anaerobic conditions 183
4.4 In sewer Modeling (Dry weather and diurnal flow) 199
4.4.1 Determination of dissolved fraction of phenol and anionic surfactants 199
4.4.2 Toxic substance model of anionic surfactant and phenol in sewer 201

5 CONCLUSION 209

6 RECOMMENDATION 213

REFERENCES 215
APPENDICES 238
BIODATA OF STUDENT 274
LIST OF PUBLICATIONS 275