UNIVERSITI PUTRA MALAYSIA

KINETICS AND PERFORMANCE OF SEWAGE SLUDGE TREATMENT USING LIQUID STATE BIOCONVERSION IN CONTINUOUS BIOREACTOR

ROSHANIDA BINTI A. RAHMAN

KINETICS AND PERFORMANCE OF SEWAGE SLUDGE TREATMENT USING LIQUID STATE BIOCONVERSION IN CONTINUOUS BIOREACTOR

ROSHANIDA BINTI A. RAHMAN

DOCTOR OF PHILOSOPHY
UNIVERSITI PUTRA MALAYSIA

2009

KINETICS AND PERFORMANCE OF SEWAGE SLUDGE TREATMENT USING LIQUID STATE BIOCONVERSION IN CONTINUOUS BIOREACTOR

By

ROSHANIDA BINTI A. RAHMAN

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

December 2009

DEDICATION

TO MY BELOVED FAMILY

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

KINETICS AND PERFORMANCE OF SEWAGE SLUDGE TREATMENT USING LIQUID STATE BIOCONVERSION IN CONTINUOUS BIOREACTOR

By

ROSHANIDA BINTI A. RAHMAN

December 2009

Chairman: Professor Dr Fakhru'l-Razi Ahmadun, PhD

Faculty: Engineering

Liquid state bioconversion (LSB), a novel biodegradation, bioseparation, biosolids accumulation and biodewatering process was applied for sewage sludge treatment. The LSB process has been proven to be non hazardous, safe and environmentally friendly method for ultimate sludge management and disposal. The study was developed by using mixed fungi of *Aspergillus niger* and *Penicillium corylophilum* to treat sewage sludge in a LSB bioreactor. Results of the LSB process performance in previous studies were excellent; however the studies were only conducted on a batch system. The shortfall of the LSB batch process was identified when the LSB process was about to be applied in an actual wastewater treatment plant. The continuous process is an alternative treatment to be applied due to its advantages to handle continuous sewage sludge in the wastewater treatment plant. Therefore, this research

was conducted in order to study the LSB process on the continuous system in terms of kinetic coefficients determination, process performance and process optimisation. For the continuous LSB process, a mathematical model was developed from the basic principles of material balance based on Monod equation. By investigating the kinetics of substrate utilisation and biomass growth, the kinetic coefficients of Y, K_d, K_s and μ_{max} were found to be 0.79 g VSS g COD^{-1}, 0.012 day^{-1}, 1.78 g COD L^{-1} and 0.357 day^{-1}, respectively. In addition, the LSB performance was analysed by employment of the adapted fungi on a continuous basis to evaluate the bioconversion performance, bioseparation and dewaterability characteristics of sewage sludge at different hydraulic retention times (HRTs). The evaluation of the performance of LSB continuous process showed an improvement in the percentage of MLSS (mixed liquor suspended solids), COD (chemical oxygen demand), turbidity and protein in supernatant from 87 to 98%, 70 to 93%, 97 to 99% and 44 to 82%, respectively compared to the untreated sludge. The characteristics of the treated sludge from LSB continuous process in terms of settleability and dewaterability showed that the process was highly influenced by fungi entrapment with an increase of biosolids accumulation at 80% and filterability improved from 76 to 97%. The sludge volume index (SVI) in the range of 34 to 43 obtained from the treated sludge showed a good indicator of compressibility and settleability of the sludge. The LSB continuous process was modelled and analysed using response surface methodology (RSM) for optimisation purposes. Two operating factors namely HRTs and substrate influent concentrations (S_0) were optimised in terms of sewage sludge dewaterability. The optimisation result showed that the optimum values were obtained at 3.62 days and

10.12 g L^{-1} of HRT and S_0, respectively. The results were verified at a pilot scale bioreactor using the data obtained from the optimisation process. The final biosolids accumulation of 6% (w/w) obtained from the initial ~1% (w/w) of the untreated sludge shows that the LSB continuous process enhanced the dewaterability and hence, provide better waste management.

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

KINETIK DAN PRESTASI RAWATAN ENAPCEMAR MENGGUNAKAN BIOPENUKARAN KEADAAN CECAIR DALAM BIOREAKTOR SELANJAR

Oleh

ROSHANIDA BINTI A. RAHMAN

Disember 2009

Pengerusi: Profesor Dr Fakhru'l-Razi Ahmadun, PhD

Fakulti: Kejuruteraan

Biopenukaran keadaan cecair (LSB) merupakan suatu proses baru bagi biodegradasi, biopemisahan, pengumpulan biopepejal dan biopenyahcairan telah digunakan untuk rawatan enapcemar. Proses LSB telah dibuktikan sebagai kaedah yang tidak berbahaya, selamat dan mesra alam bagi pengurusan dan pembuangan enapcemar akhir. Kajian ini telah dibangunkan dengan menggunakan campuran dua fungus iaitu *Aspergillus niger* dan *Penicillium corylophilum* untuk merawat sisa enapcemar di dalam sebuah bioreaktor LSB. Keputusan bagi prestasi proses LSB dalam kajian-kajian terdahulu amatlah memberangsangkan, namun, kajian hanya dijalankan dalam sistem kelompok. Kekurangan yang dikenalpasti dalam proses berkelompok LSB adalah apabila proses tersebut hendak dibangunkan di loji rawatan air sisa yang

sebenar. Proses selanjar merupakan rawatan alternatif yang boleh digunakan bagi mengatasi kekurangan tersebut disebabkan kelebihannya dalam menangani enapcemar selanjar yang terdapat di loji rawatan air sisa. Oleh yang demikian, kajian ini dijalankan bagi mengkaji proses LSB pada sistem selanjar dari segi untuk mendapatkan pekali kinetik, mengkaji proses prestasi dan juga proses pengoptiman. Bagi proses LSB selanjar, satu model matematik telah dibangunkan daripada prinsip asas imbangan jisim berdasarkan persamaan Monod. Daripada kajian kinetik ke atas penggunaan substrat dan pertumbuhan biojisim, pekali kinetik bagi Y, K_d, K_s, dan μ_{max} diperolehi masing-masing pada 0.79 g VSS g COD^{-1}, 0.012 $hari^{-1}$, 1.78 g COD L^{-1} dan 0.357 $hari^{-1}$. Di samping itu, prestasi LSB telah dianalisa dengan penggunaan fungus teradaptasi pada asas selanjar untuk menilai prestasi biopenukaran, biopemisahan dan ciri penyahcairan sisa enapcemar pada masa tahanan hidraulik (HRT) yang berbeza. Penilaian ke atas prestasi proses selanjar LSB telah menunjukkan peningkatan di dalam peratusan MLSS (campuran cecair pepejal terampai), COD (keperluan oksigen kimia), kekeruhan dan protein di dalam supernatan masing-masing daripada 87 kepada 98%, 70 kepada 93%, 97 kepada 99% dan 44 kepada 82%, berbanding dengan enapcemar tidak terawat. Ciri-ciri enapcemar terawat daripada proses selanjar LSB dari segi kebolehmendapan dan penyahcairan telah menunjukkan bahawa proses ini sangat dipengaruhi oleh pemerangkapan fungus dengan peningkatan pengumpulan biojisim pada 80% dan kebolehtelapan daripada 76 kepada 97%. Nilai indeks isipadu enapcemar (SVI) di antara 34 hingga 43 telah diperolehi daripada enapcemar terawat menunjukkan petanda yang baik ke atas kebolehmampatan dan kebolehmendapan enapcemar tersebut. Proses selanjar LSB telah dimodelkan dan dianalisa dengan menggunakan kaedah rekabentuk permukaan (RSM) bagi tujuan pengoptiman. Dua faktor operasi iaitu HRTs dan kepekatan subtrat awalan (S_0) telah dioptimakan dari segi kebolehnyahcairan enapcemar. Hasil pengoptiman menunjukkan HRT dan S_0 masing-masing mencatatkan nilai pada 3.62 hari dan 10.12 g L^{-1}. Keputusan tersebut telah disahkan pada bioreaktor skala loji dengan menggunakan data yang diperolehi daripada proses pengoptiman. Sebanyak 6% (w/w) pengumpulan biojisim akhir telah diperolehi daripada nilai awalan sebanyak ~1% (w/w) enapcemar tidak terawat telah menunjukkan bahawa proses selanjar LSB telah meningkatkan kebolehnyahcairan dan seterusnya dapat memberi faedah kepada pengurusan sisa yang lebih baik.

ACKNOWLEDGEMENTS

In the name of Allah, the most gracious and the most merciful. My deepest gratitude and sincere appreciation to Professor Dr. Fakhru'l-Razi Ahmadun, Chairman of my Supervisory Committee for providing invaluable technical advice, untiring assistance, encouragement, motivation and generous help that enabled me to accomplish the research and preparation of the thesis. Sincere appreciation is also due to Associate Professor Dr. Salmiaton Ali and Associate Professor Dr. Norhafizah Abdullah, members of the Supervisory Committee, for their constructive suggestions and guidance throughout my study period. I am indebted to Indah Water Konsortium (IWK) for supplying the sludge samples during the research period. Special thanks go to Miss Lim of IWK for her assistance in terms of sampling arrangements and discussions.

I am also grateful to all the staff of the Chemical and Environmental Engineering (KKA) Department of Universiti Putra Malaysia (UPM) especially the laboratory staff, Mr. Termizi, Mr. Ismail and Mr. Joha, for their assistance and cooperation. My appreciation and special thanks to my friend Hind for her advice, support and guidance throughout my experimental works and thesis writing. My thanks also to all my friends in the Engineering Faculty of UPM especially Liza, Zila, Sukaina, Alireza, Ferozeh, Asri, Hasni, Yanti, Dayang and Raja for their time, moral support and cooperation during my time in UPM.

My appreciation also goes to my family and in-laws, mother, father, sisters and brothers for their spiritual moral support and best wishes to achieve this prestigious degree. Lastly, my special thanks and gratefulness to my dearest husband, Captain (R) Hamon Rafiz and my children, Dania, Dosh and Darwisy, for their patience, inspiration, encouragement, and cooperation during the whole period of study.

I certify that a Thesis Examination Committee has met on 23rd December 2009 to conduct the final examination of Roshanida Binti A. Rahman on her Doctor of Philosophy thesis entitled "Kinetics and Performance of Sewage Sludge Treatment using Liquid State Bioconversion in Continuous Bioreactor" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

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

Robiah Yunus, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

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

K.B Ramachandran, PhD
Professor
Indian Institute of Technology (IIT)
Madras India
(External Examiner)

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

Date: 12 April 2010

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

Fakhru'l-Razi Ahmadun, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Norhafizah Abdullah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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

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

Date: 13 May 2010

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been 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 at any other institution.

ROSHANIDA BINTI A. RAHMAN

Date:

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A	Area of the filter paper, m^2
Adj R^2	Adjusted R^2
ANOVA	Analysis of variance
APHA	Air Pollution Health Association
COD	Chemical Oxygen Demand
COD_{sup}	COD removal in supernatant
CSTR	Completely stirred tank reactor
CV	Coefficient of Variation
D	Dilution rate, day-^{1}
D_{max}	Maximum dilution rate
F-test	Test for comparing model variance with residual variance
HRT	Hydraulic retention time, day
IWK	Indah Water Konsortium
K	Maximum specific substrate utilisation rate, g COD g VSS^{-1} day^{-1}
K_d	decay rate constant, day^{-1}
K_s	Limiting substrate concentration at which μ is half μ_{max}, g COD L^{-1}
LOF	Lack of Fit
LSB	Liquid State Bioconversion
MLSS	Mixed Liquor Suspended Solids
$MLSS_{sup}$	MLSS removal in supernatant
MLVSS	Mixed Liquor Volatile Suspended Solids
OD	Optical Density
OLR	Organic Loading Rate, g COD L^{-1} d^{-1}
P	Pressure of filtration, N m^{-2}
PDA	Potato Dextrose Agar
Prob>F	Probability of seeing the observed F value if the null hypothesis was true

P-value	Probability value
q	Specific substrate utilization rate, g COD g VSS^{-1} day^{-1}
Q	Flow rate, L day^{-1}
r	Specific resistance to filtration, m kg^{-1}
R^2	A measure of the amount of variation around the mean
R_m	Resistance on the medium, m^{-1}
rpm	revolution per minute
RSM	Response Surface Methodology
S_0	Substrate influent, g COD L^{-1}
$S_{removal}$	Substrate removal, g COD L^{-1}
SD	Standard Deviation
SEM	Scanning Electron Microscope
Sp.	Species
SRF	Specific Resistance to Filtration
SRT	Solid retention time, day
SSB	Solid State Bioconversion
SSV	Settled Sludge Volume, mL L^{-1}
STP	Sewage Treatment Plant
SVI	Sludge Volume Index
t	Filtration time, sec
t	Time, day^{-1}
V	Volume of filtration, m^3
V	Reactor volume, L
VSS/SS	MLVSS to MLSS ratio
vvm	volume per volume of substrate per minute
v/v	volume/volume
w/v	weight/volume
X, X_e	Biomass concentration (effluent), g VSS L^{-1}
X_0	Biomass in the influent, g VSS L^{-1}
X_1	Hydraulic retention time (HRT)

X_2	Substrate influent (S_0)
X_{eff}	Effluent biomass concentration, g VSS L^{-1}
Y	Growth yield coefficient, g VSS g COD^{-1}
c*	Weight of dry solids per volume of filtrate, kg m^{-3}
μ	Viscosity of filtrate, Ns m^{-2}
μ	Specific growth rate, day^{-1}
θ	HRT
μ_{max}	Maximum specific growth rate, day^{-1}
2FI	Two factor interaction

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Wastewater treatment plants are considered accomplished when impurities and organic content in liquid form were transformed into solid or sludge form and followed by separation of the sludge from the liquid. The solids or sewage sludge is produced as a slurry byproduct of wastewater treatment plant (O'Kelly, 2005; Mendez *et al*., 2005; Uggetti *et al*., 2009). On average, the wastewater treatment plant is estimated to generate at about 40 to 50 g dry weight of sewage sludge per person per day and up to 60 g dry weight when incorporating a secondary treatment step (Sanchez *et al*., 2007; Fuentes *et al*., 2008). For many years, wastewater treatment plants have produced a significant increment on sewage sludge production due to an increase in civilisation, urban development and limitations in the standard of wastewater and biosolids disposal (Metcalf and Eddy, Inc. 2004). A large amount of sludge is currently generated rapidly around the world and has not stopped increasing (Romdhana *et al*., 2009; Hong *et al*., 2009). However, sewage sludge management and disposal facilities are costly and usually represent nearly 60% of the construction cost of a wastewater treatment plant and 50% of the operating cost (Peavy *et al*., 1985; Xing *et al*., 2003; Neyens *et al*., 2004; Cleverson *et al*., 2007). As a result, proper and effective sewage sludge management is needed in order to overcome this serious environmental issue.

A reduction of sewage sludge volumes can reduce the cost significantly especially for its transportation and disposal. Therefore, dewatering process is necessary to be conducted in order to reduce the moisture content of sludge. Many previous works have been identified that dewatering of sludge is one of the most costly and least understood process due to the complexity and the dynamic of the sludge matrix (Katsiris and Kouzeli-Katsiri, 1987; Bruus *et al*., 1992; Neyens *et al*., 2004). Sludge from sewage treatment plant usually contains less than 1% (w/w) of mixed liquor suspended solid (MLSS). Hence, the sewage sludge contains 99% or more of water. Sewage sludge which is normally considered as biological sludge is relatively hard to be dewatered compared to primary sludge in the preliminary treatment of wastewater (Chang *et al*., 2001; Curvers *et al*., 2009). This is probably due to the mixture of the particle, microorganisms, colloids and organic polymer in the sludge (Jorand *et al*., 1995; Novak *et al*., 2003).

The water within the solid compound in the sludge have different properties in terms of vapour pressure, enthalpy, entropy, viscosity, density, solid-liquid chemical interaction and many other parameters (Katsiris and Kaouzeli-Katsiri, 1987; Vaxelaire and Cezac, 2004; Northcott *et al*., 2005). Current practices use various mechanical techniques for dewatering such as filtration, squeezing, capillary action, vacuum withdrawal and centrifuge. All of these conventional sludge treatment and dewatering technologies need intensive consumption of energy and they are costly (Uggetti *et al*., 2009). The cheapest method involved is the use of drying beds or lagoon but it still depends on availability of land (Hwa and Jeyaseelan, 1997). Besides the conventional process, effective dewatering requires treatment from microorganisms due to the fact that majority of these microbes live in aggregates such as films, flocs and sludges (Neyens *et al.,* 2004). Therefore, an alternative dewatering process that is environmentally friendly and safe using microorganism is a suitable method for future waste management strategy (Alam e*t al*, 2003b).

Bioremediation which involves the use of microbial treatment to degrade waste contaminants has received great attention in solving the increase of sewage sludge generation. This method has been used to convert sewage sludge into valuable product or energy and to clean up a polluted environment originating from wastewater treatment plant system (Liu and Tay, 2004; Larsen *et al*., 2009; Xia *et al*., 2008; Ichinari *et al*., 2008; Pramanik and Khan, 2008). The employment of microbial treatment through liquid state bioconversion (LSB) process is one of the alternative options to solve the increase in sludge generation and disposal (Alam, 2002; Hind, 2008). In the past, the LSB technique functions as a multiple treatment for sewage sludge, including biodegradation, bioseparation, biodewatering and biosolids accumulation and it has also produced environmentally friendly ultimate sludge disposal (Alam *et al*., 2001a; 2001b; 2003a; 2004a; Alam and Fakhru'l-Razi, 2003; Hind, 2008). Biodegradation and bioconversion processes involve a transformation of dissolved and organic substances by microbial communities to biomass and evolve gases. Among microbial communities, it is discovered that the fungi play an important role in optimising waste bioconversion from secondary sludge (Molla, 2002; Alam *et al*., 2003b). The filamentous fungi used in the LSB process is immobilised in the particle of sludge by a formation of flocs; therefore increasing the separation and filtration process significantly (Alam, 2002; Sarkar, 2006; Hind, 2008).

The LSB process of sewage treatment plant sludge has been conducted through several approaches at bench scale in a shake flask and a fermenter under sterilised condition (Alam, 2002). Subsequently, the microbial treatment of sewage treatment plant sludge or activated sludge has been evaluated by LSB batch process under non-sterilised, controlled conditions in terms of biodegradation and biodewaterability (Sarkar, 2006). Furthermore, another LSB batch process approach under natural (non-controlled) conditions has been discussed by Fakhru'l-Razi and Molla (2007) in terms of bioseparation and dewaterability using cultured inocula. Finally, the LSB batch process has been evaluated and compared between the bench and the large scale under non-sterilised, controlled conditions in terms of biodegradation, bioseparation and dewaterability (Hind, 2008). For the composting of sewage sludge or biosolids, a solid state bioconversion (SSB) process of sludge product from the LSB process has been proposed by Molla (2002). As a result, this LSB process has proven not only successful in enhancing the biodegradation, bioseparation and dewaterabilty of treated sludge but converting it into valuable biomass for compost purposes through the SSB process.

1.2 Problem Statement

Sewage sludge treatment and disposal, which are mainly of organic matter, is one of the most serious challenges environmental problems all over the world. Malaysia is not an exception where the management of the increasing volume of sewage sludge has been one of the primary environmental issues (Zain *et al.*, 2001). The increasing of the sludge volume throughout the country means a serious problem to the water resources, public health and the environment. In Malaysia, Indah Water Konsortium (IWK) Sdn. Bhd. operates and maintains most of the sewerage services. Presently, Malaysia produces approximately 7.5 million cubic meters of sewage sludge annually throughout the country. Indah Water also had spent more than RM 66 million for the sludge handling and management purpose. It is estimated that at least another RM 3.1 billion will be required to provide adequate sludge facilities by 2035 (IWK, 2007). The same increasing trend is observed all over the world, which shows the need for effective solutions for sludge management and disposal in order to overcome this problem.

An alternative sewage sludge treatment and disposal has been introduced by Alam (2002) and Molla (2002) through liquid state bioconversion (LSB) and solids states bioconversion (SSB) processes, respectively by using locally isolated fungi. The LSB is a biodegradation, bioseparation, biodewatering and biosolids accumulation process of the sewage sludge, while the SSB process produced environmentally friendly ultimate sewage sludge disposal through composting. The development of LSB process using a batch system has been studied by Alam (2002), Sarkar (2006) and Hind (2008). The LSB batch process performance also has been optimised using bench and pilot scale process and tremendous sludge volume reduction occurs by enhancing the settling and dewatering characteristics of sewage sludge (Hind, 2008). However, the main drawback of the batch process is in term of inoculums preparation. The preparation of inoculums is quite tedious due to the usage of pure culture from the mixed fungi. For every new cycle of the batch process, the inoculums has to be sub-cultured and prepared fresh before the inoculation process onto the sewage sludge. Furthermore, every inoculation for every batch process needs at least 3 days for the acclimatisation of the fungi. As a result, the process will not be practical to be implemented at an actual wastewater treatment plant which the sewage sludge is produced in huge amounts everyday.

From the economical viewpoint, the LSB batch process is not economic to be practiced at an actual treatment plant. Besides the cost of the inoculums for every cycle of the batch process, the operation cost also needs to be accounted. Every batch needs an operator to take out the LSB sludge before starting a new cycle. The process also includes feeding time for inoculums which is twice perday for 3 days for every batch. Although batch reactor is excellent on handling difficult materials and slow reactions process, however it is not economical to run the LSB process for sewage sludge treatment which is a waste and produced in a bulk at an actual wastewater treatment plant in the batch mode. Besides, a large volume of bioreactor is needed to cater the huge amount of sewage sludge at one time for batch process.

To overcome the shortage from this LSB batch process in order to apply it at an actual wastewater treatment plant, the LSB continuous process is proposed in this study. A continuously stirred tank reactor proposed for this study is an adaptation of a batch reactor in which the sewage sludge is added continuously to the bioreactor while the treated sewage sludge is removed at the same time. The advantage of the continuous process is one time inoculation procedure only needed for 3 days time and re-inoculation is not required. Therefore the cost for the inoculums and operator can be reduced significantly. A smaller reactor is needed compared to batch due to the continuous operation to cater a huge amount of sewage sludge which is continuously flowing at the wastewater treatment plant. The output of the treated sewage sludge also can be manipulated because the continuous reactor can be altered by varying the hydraulic retention time, thus increases operating flexibility for the wastewater treatment plant operators. Besides, less operation down time is required due to no necessity for plant shut down to start the new cycle as needed by the batch process.

Despite the overwhelming performance results on the LSB process from previous studies, information on the kinetics aspect has not yet been investigated. In a continuous process, certainly some of the parameters, condition and kinetics are different compared to the batch process. In the continuous process, an equilibrium concentration of substrate is established independently from microbial density and time which allow microbes to grow at a steady state by maintaining stable environment growth conditions and hence the same physiological state. Therefore, in an ideal continuous process, more precise and statistically relevant data can be collected compared to the batch culture

(Kovarova-kovar and Egli, 1998). Knowledge of kinetic coefficients is essential for biological wastewater system design, control process and optimisation of operational conditions (Nakhla *et al*., 2006). Consequently, this research is a continuation from a previous study on the LSB process in order to develop the LSB continuous process in terms of kinetic coefficients, performances, evaluation and optimisation of the operating parameters.

1.3 Objectives of Study

Based on the problem statement as discussed above, the objectives of this study are:

1. To develop a kinetics model for LSB process in a continuous bioreactor.
2. To evaluate the performance of sewage sludge using LSB continuous process.
3. To optimise the LSB continuous process of sewage sludge using Response Surface Methodology (RSM).

1.4 Outline and Scope of Thesis

The content of this thesis in the following chapters is divided into four parts. The first part is the literature review discussed in Chapter 2. It describes in general about sewage treatment plant sludge and in particular the LSB process. The second part of the thesis is Chapter 3 which is a discussion on the material and methods for the LSB process and analysis. The third part of the thesis deals with the results and discussions of the study. The discussions are divided into three chapters which are Chapter 4, 5 and 6 and are related to the objectives of the study. Each chapter has its own introduction, results, discussion and summary. The last part is the overall conclusion presented as Chapter 7 which summarises all results from the findings and discusses contribution of the thesis. The details are described as below:

i) In Chapter 2, a general introduction on aspects of sewage treatment plant sludge, problems, management and disposal is first reviewed. Secondly, the sludge treatment and disposal issues in Malaysia are discussed. Finally, other bioremediation techniques as well as the LSB process as an environmentally friendly sludge management and disposal is introduced and previous findings are presented.

ii) Chapter 3 describes the materials and methods which are considered as important procedures in operating the bioreactor of the LSB continuous process. The standard analysis procedure for the influent and effluent of the bioreactor is described as well with details explained in the Appendix A.

iii) Chapter 4 discusses the LSB continuous process and determination of the kinetic coefficients for sewage sludge. As this is a first study on the LSB continuous process of sewage sludge by applying the fungi inoculum, it is the aim of this study to provide a good overview on the microbial growth rate and substrate utilisation rate, biomass balance, substrate balance and assumption used in order to predict the continuous process at different hydraulic retention times. The mathematical model from the basic principles of material balance and Monod equation as introduced in Chapter 2 are used. The model used has discovered that the growth or degradation phenomena can be described satisfactory with the four coefficients of μ_{max}, K_s, Y and K_d. A detailed investigation of the obtained kinetic coefficients from the developed model on the experimental data is needed in order to verify the validation of the model for future design and control development applications.

iv) Chapter 5 evaluates the LSB continuous process on the bioconversion performance, bioseparation and dewaterability characteristics. The results involve fungi adaptation, supernatant analysis of the effluent, bioseparation and dewatering characteristics of sewage sludge at different hydraulic retention times. Discussion from the findings of the continuous basis is compared to the untreated sludge as well as the results on the batch basis by previous studies.

v) Chapter 6 analyses the LSB continuous process from sewage sludge using statistical techniques of RSM in order to maximise the performance of the process with respect to the simultaneous effects of two operating factors (hydraulic retention times and influent substrate concentrations). Nine interrelated parameters are also evaluated as responses. The study has been conducted in order to develop a continuous response surface of the operating factors with the hope of providing an optimal region which satisfies the operating specifications between all responses. The developed statistical model is verified with the pilot scale of experimental data.

vi) Chapter 7 is the concluding chapter which summarises the main results from the achievable objectives, comparison between the LSB batch and the LSB continuous process and finally the advantages and importances of the LSB process. Suggestion for future research and perspectives are also briefly suggested.

REFERENCES

Abouelwafa, R., Baddi, G.A., Souabi, S., Winterton, P., Cegarra, J. and Hafidi, M. (2008). Aerobic biodegradation of sludge from the effluent of a vegetable oil processing plant mixed with household waste: Physical–chemical, microbiological, and spectroscopic analysis. *Bioresource Technology* 99: 8571–8577.

Abu-Orf, M.M. and Dentel, S.K. (1997). Effect of mixing on the rheological characteristics of conditioned sludge: full-scale studies. *Water Science & Technology* 36(11): 51–60.

Abu-Orf, M.M. and Ormeci, B. (2005). Sludge network strength using rheology and relation to dewaterability, filtration and thickening— laboratory and full-scale experiments. *ASCE Journal of Environmental Engineering* 131(8): 1139–1146.

Ahlgren, G. (1987). Temperature functions in biology and their application to algal growth constants. *Nordic Society Oikos* 49(2): 177-190.

Ahluwalia, S.S. and Goyal, D. (2007). Microbial and plant derived biomass for removal of heavy metals from wastewater. *Bioresource Technology* 98: 2243–2257.

Ahmad, A.L., Wong, S.S., Teng, T.T and Zuhairi, A. (2008). Improvement of alum and PACl coagulation by polyacrylamides (PAMs) for the treatment of pulp and paper mill wastewater. *Chemical Engineering Journal* 137(3): 510-517.

Ait, Baddi, G., Alburquerque, J.A., Gonzalvez, J., Cegarra, J. and Hafidi, M. (2004). Chemical and spectroscopic analyses of organic matter transformations during composting of olive mill wastes. *International Biodeterioration and Biodegradation* 54: 39–44.

Aksu, Z, and Karabayir, G. (2008). Comparison of biosorption properties of different kinds of fungi for the removal of Gryfalan Black RL metal-complex dye. *Bioresource Technology* 99: 7730–7741.

Aksu, Z., Tatli, A.I. and Tunc, O. (2008). A comparative adsorption/biosorption study of Acid Blue 161: Effect of temperature on equilibrium and kinetic parameters. *Chemical Engineering Journal* 142: 23–39.

Alam, M.Z., Fakhru'l-Razi, A., Abd-Aziz, S. and Idris, A. (2001a). Bioconversion of wastewater sludge by immobilized microbial treatment. In *Proceedings International Water Association (IWA) Conference On Water and Wastewater Management for Developing Countries*, October 29-31, Kuala Lumpur, 344-353.

Alam, M.Z., Fakhru'l-Razi, A., Molla, A.H. and Roychoudhury, P.K. (2001b). Treatment of wastewater sludge by liquid state bioconversion process. *Journal of Environmental Science and Health* A36(7): 1237-1243.

Alam, M.Z. and Fakhru'l-Razi, A. (2002). Effect of agitation and aeration on bioconversion of domestic wastewater sludge in a batch fermenter. *Journal of Environmental Science and Health* A37 (6): 1087-1097.

Alam, M.Z., Fakhru'l-Razi, A., Abd-Aziz, S. and Idris, A. (2002). Bioconversion of domestic wastewater sludge by immobilized mixed culture of *Penicillium corylophilum* WWZP1003 and *Aspergillus niger* SCahmA103. *Journal of Art. Cells, Blood Subs., and Immobilization Biotechnology* 30(4): 307-318.

Alam, M.Z. (2002). Microbial treatment of domestic wastewater treatment plant sludge by liquid state bioconversion process. Ph.D. thesis, Faculty of Engineering, UPM, Malaysia.

Alam, M.Z. and Fakhru'l-Razi, A. (2003). Enhanced settleability and dewaterability of fungal treated domestic wastewater sludge by liquid state bioconversion process. *Water Research* 37: 1118-1124.

Alam, M.Z., Fakhru'l-Razi, A. and Molla, A.H. (2003a). Biosolids accumulation and biodegradation of domestic wastewater treatment plant sludge by developed liquid state bioconversion process using a batch fermenter. *Water Research* 37: 3569 3578.

Alam, M.Z., Fakhru'l-Razi, A., Abd-Aziz, S. and Molla, A.H. (2003b). Optimization of compatible mixed cultures for liquid state bioconversion of municipal wastewater sludge. *Journal of Water Air and Soil Pollution* 149: 113-126.

Alam, M.Z, Fakhru'l-Razi, A., Molla, A.H. (2003c). Optimization of liquid state bioconversion process for microbial treatment of domestic wastewater sludge. *Journal of Environmental Engineering Science* 2: 299-306.

Alam, M.Z., Fakhru'l-Razi, A. and Molla, A.H. (2004a). Evaluation of fungal potentiality for bioconversion of domestic wastewater sludge. *Journal of Environmental Science* 16(1): 132-137.

Alam, M.Z., Fakhru'l-Razi, A and Molla, A.H. (2004b). Treatment and biodegradation kinetics of microbially treated domestic wastewater sludge. *Journal of Environmental Science and Health* A39(8): 2059-2070.

Alam, M.Z., Muyibi, S.A. and Rosmaziah, W. (2008). Statistical optimization of process conditions for cellulase production by liquid state bioconversion of domestic wastewater sludge. *Bioresource Technology* 99: 4709–4716.

American Public Health Association (APHA). (2005). *Standard methods for the examination of the water and wastewater*, 19^{th} edition. Washington, DC.

Anderson, I.C., Parkin, P.I. and Campbell, C.D. (2008). DNA- and RNA-derived assessments of fungal community composition in soil amended with sewage sludge rich in cadmium, copper and zinc. *Soil Biology & Biochemistry* 40: 2358–2365.

Annadurai, G., Ling, L.Y. and Lee, J-F. (2008). Statistical optimization of medium components and growth conditions by response surface methodology to enhance phenol degradation by *Pseudomonas putida*. *Journal of Hazardous Materials* 151: 171–178.

Apaolaza, H.L., Gasco, J.M. and Guerrero, F. (2000). Initial organic matter transformation of soil amended with composted sludge. *Biology and Fertility of Soils* 32: 421– 426.

Bai, H-J., Zhang, Z-M., Yang, G-E. and Li, B-Z. (2008). Bioremediation of cadmium by growing *Rhodobacter sphaeroides*: Kinetic characteristic and mechanism studies. *Bioresource Technology* 99: 7716–7722.

Bailey J.E. and Ollis, D.F. (1986). *Biochemical Engineering Fundamentals*. New York: McGraw Hill.

Bajaj, M., Gallert, C. and Winter, J. (2008a). Anaerobic biodegradation of high strength 2-chlorophenol-containing synthetic wastewater in a fixed bed reactor *Chemosphere* 73: 705–710.

Bajaj, M., Gallert, C. and Winter, J. (2008b). Biodegradation of high phenol containing synthetic wastewater by an aerobic fixed bed reactor. *Bioresource Technology* 99: 8376–8381.

Banegas, V., Moreno, J.L., Moreno, J.I., García, C., León, G. and Hernández, T. (2007). Composting anaerobic and aerobic sewage sludges using two proportions of sawdust. *Waste Management* 27: 1317–1327.

Banerjee, A., Elefsiniotis, P., and Tuhtar, D. (1999). The effect of addition of potato-processing wastewater on the acidogenesis of primary sludge under varied hydraulic retention time and temperature. *Journal of Biotechnology* 72: 203–212.

Barker, D.J. and Stuckey, D.C. (1999). A review of soluble microbial products (SMP) in wastewater treatment systems. *Water Research* 33: 3063–3082.

Benefield, L.D and Randall, C.W. (1980). *Biological process design for the wastewater treatment*. New York: Prentice-Hall.

Bhaskar, Y.V., Mohan, S.V. and Sarma, P.N. (2008). Effect of substrate loading rate of chemical wastewater on fermentative biohydrogen production in biofilm configured sequencing batch reactor. *Bioresource Technology* 99: 6941–6948.

Bhatia, S., Othman, Z. and Ahmad, A.L. (2007). Pretreatment of palm oil mill effluent (POME) using *Moringa oleifera* seeds as natural coagulant. *Journal of Hazardous Materials* 145: 120–126.

Bhattacharyya, M.S., Singh, A. and Banerjee, C.U. (2008). Production of carbonyl reductase by *Geotrichum candidum* in a laboratory scale bioreactor. *Bioresource Technology* 99: 8765–8770.

Bhunia, P. and Ghangrekar, M.M. (2008). Statistical modeling and optimization of biomass granulation and COD removal in UASB reactors treating low strength wastewaters. *Bioresource Technology* 99: 4229–4238.

Blais, J-F., Meunier, N., Mercier, G., Drogui and P., Tyagi, R.D. (2004). Pilot Plant study of simultaneous sewage sludge digestion and metal leaching. *Journal of Environmental Engineering* 130(5): 516-525.

Borchardt, J.A., Redman, W.J., Jones, G.E. and Sprague, R.T. (1981). *Sludge and its ultimate disposal*. USA: Ann Arbor Science.

Borja, R., Banks, C.J. and Wang, Z. (1995). Effect of organic loading rate on anaerobic treatment of slaughterhouse wastewater in a fluidized-bed reactor. *Bioresource Technology* 52: 157-162.

Bradley, R.M. and Dhanagunan, G.R. (2004). Sewage sludge management in Malaysia. *International Journal of Water* 2(4): 267-283.

Bruce, A.M. and Evans, T.D. (2002). *Sewage sludge disposal: Operational and environmental issues.* U.K: Foundation of Water Research.

Bruus, J.H., Nielsen, P.H. and Keiding, K. (1992). On the stability of activated sludge flocs with implications to dewatering. *Water Research* 26(12): 1597-1604.

Cai, Q-Y., Mob, C-H., Wu, Q-T., Zenga, Q-Y. and Katsoyiannis, A. (2007). Concentration and speciation of heavy metals in six different sewage sludge-composts. *Journal of Hazardous Materials* 147: 1063–1072.

Cammarota, M.C. and Freire, D.M.G. (2006). A review on hydrolytic enzymes in the treatment of wastewater with high oil and grease content. *Bioresource Technology* 97: 2195–2210.

Carta-Escobar, F., Pereda-Marin, J., Alvarez-Mateos, P., Romero-Guzman, F. and Duran Barrantes, M.M. (2005). Aerobic purification of dairy wastewater in continuous regime Part II: Kinetic study of the organic matter removal in two reactor configurations. *Biochemical Engineering Journal* 22: 117-124.

Castillo, A., Llabres, P. and Mata-Alvarez, J. (1999). A kinetic study of a combined anaerobic-aerobic system for treatment of domestic sewage. *Water Research* 33(7): 1742-1747.

Cereti, C.F., Rossini, F., Federici, F., Quaratino, D., Vassilev, N. and Fenice, M. (2004). Reuse of microbially treated olive oil mill wastewater as fertilizer for wheat (Triticum durum Desf.). *Bioresource Technology* 91: 135-140.

CGER (Commission on Geosciences, Environment and Resources). (1996). *Use of reclaimed waster and sludge in food crop production*. Washington: The National Academies Press.

Chang, G.R., Liu, J.C. and Lee, D.J. (2001). Co-conditioning and dewatering of chemical sludge and waste activated sludge. *Water Research* 35(3): 786-794.

Chen, C.C, Lin, C.Y. and Chang, J.S. (2001). Kinetics of hydrogen production with continuous anaerobic cultures utilizing sucrose as the limiting substrate. *Applied Microbiology Biotechnology* 57: 56-64.

Cheng, J.P., Zhang, L.Y., Wang, W.H., Yang, Y.C., Zheng, M. and Ju, S.W. (2004). Screening of flocculant-producing microorganisms and flocculating activity. *Journal of Environmental Science-China* 16: 894–897.

Christensen, G.L. (1983). Units for specific resistance. *Water Pollution Control Federation* 55(4): 417-419.

Chu, C.P., Lee, D.J. and Chang, C.Y. (2005). Energy demand in sludge dewatering, *Water Research* 39: 1858–1868.

Chu, C.P., Lee, D.J., Chang, Bea-Ven, You, C.H., Liao, C.S. and Tay, J.H. (2003). Anaerobic digestion of polyelectrolyte flocculated waste activated sludge. *Chemosphere* 53(7): 757–764.

Cleverson, V.A., Von Speling, M., and Fernandez, F. (2007). Sludge treatment and disposal. Biological Wastewater Treatment Series 6. London: IWA Publishing.

Cokgor, E.U., Oktay, S., Tas, D.O., Zengin, G.E. and Orhon, D. (2009). Influence of pH and temperature on soluble substrate generation with primary sludge fermentation. *Bioresource Technology* 100: 380–386.

Coulibaly, L., Gourene, G. and Agathos, N.S. (2003). Utilisation of fungi for biotreatment of raw wastewaters. *African Journal of Biotechnology* 2: 620–30.

Coulibaly, L., Naveau, H., Agathos, S.N. (2002). A tanks-in-series bioreactor to simulate macromolecule-laden wastewater pretreatment under sewer conditions by *Aspergillus niger*. *Water Research* 36: 3941–3948.

Curvers, D. Usher, S.P., Kilcullen, A.R., Scales, P.J., Saveyn, H. and Van der Meeren, P. (2009). The influence of ionic strength and osmotic pressure on the dewatering behaviour of sewage sludge. *Chemical Engineering Science* 64(10): 2448-2454.

D'Annibale, A., Quaratino, D., Federici, F. and Fenice, M. (2006a). Effect of agitation and aeration on the reduction of pollutant load of olive mill wastewater by the white-rot fungus *Panus tigrinus. Biochemical Engineering Journal* 29: 243–249.

D'Annibale, A., Sermanni, G.G., Federici, F. and Petruccioli, M., (2006b). Olive-mill wastewaters: a promising substrate for microbial lipase production. *Bioresource Technology* 97: 1828–1833.

de Guardia, A., Petiot, C., Rogeau, D. and Druilhe, C. (2008). Influence of aeration rate on nitrogen dynamics during composting. *Waste Management* 28: 575–587.

Deng, S.B., Bai, R.B., Hu, X.M. and Luo, Q. (2003). Characteristics of a bioflocculant produced by *Bacillus mucilaginosus* and its use in starch wastewater treatment. *Applied Microbiology Biotechnology* 60: 588–593.

Dentel, S.K., (2001). Conditioning, thickening, and dewatering: research update/research needs. *Water Science and Technology* 44(10): 9–18.

Dziurla, M.A., Salhi, M., Leroy, P., Paul, E., Ginestet, Ph. and Block, J.C. (2005). Variations of respiratory activity and glutathione in activated sludges exposed to low ozone doses. *Water Research* 39: 2591-2598.

El Hajjouji, H., Baddi, G.A., Yaacoubi, A., Hamdi, H., Winterton, P., Revel, J.C. and Hafidi, M. (2008). Optimisation of biodegradation conditions for the treatment of olive mill wastewater. *Bioresource Technology* 99: 5505–5510.

El-Fadel, M. and Massoud, M. (2001). Methane emissions from wastewater management. *Environmental Pollution* 114:177-185.

Elibol, M. (2004). Optimisation of medium composition for actinorhodin production by *Streptomyces coelicolor* A3(2) with response surface methodology. *Process Biochemistry* 39: 1057–1062.

Fakhru'l-Razi, A., Alam, M.Z., Idris, A., Abd-Aziz, S. and Molla, A.H. (2002a). Domestic wastewater biosolids accumulation by liquid state bioconversion process for rapid composting. *Journal of Environmental Science and Health* A37(8): 1533-1543.

Fakhru'l-Razi, A., Alam, M.Z., Idris, A., Abd-Aziz, S. and Molla, A.H. (2002b). Filamentous fungi in Indah water Konsortium (IWK) sewage treatment plant for biological treatment of domestic wastewater sludge. *Journal of Environmental Science and Health* A37(3): 309-320.

Fakhru'l-Razi, A. and Molla, A.H. (2007). Enhancement of bioseparation and dewaterability of domestic wastewater sludge by fungal treated dewatered sludge. *Journal of Hazardous Materials* 147: 350-356.

Fan, T., Liu, Y., Feng, B., Zeng, G., Yang, C. and Zhou, M. (2008). Biosorption of cadmium(II), zinc(II) and lead(II) by *Penicillium simplicissimum*: Isotherms, kinetics and thermodynamics. *Journal of Hazardous Materials* 160 (2-3): 655-661.

Feng, H-J., Hu, L-F., Shan, D., Fang, C-R., and Shen, D-S. (2008). Effects of Temperature and Hydraulic Residence Time (HRT) on Treatment of Dilute Wastewater in a Carrier Anaerobic Baffled Reactor. *Biomedical and Environmental Sciences* 21: 460-466.

Fernandez, J.M., Plaza, C., Hernández, D. and Polo, A. (2007). Carbon mineralization in an arid soil amended with thermally-dried and composted sewage sludges. *Geoderma* 137: 497–503.

Forster, C.F. (2003). *Wastewater treatment and technology*. London: Thomas Telford.

Fouad, M. and Bhargava, R. (2005). A simplified model for the steady-state biofilm-activated sludge reactor. *Journal of Environmental Management* 74: 245-253.

Friedrich, J., Cimerman, A. and Perdih, A. (1983). The use of *Aspergillus niger* for bioconversion of apple distillery waste. *European Journal of Applied Microbiology and Biotechnology* 17: 243-247.

Friedrich, J., Cimerman, A. and Perdih, A. (1987). Mixed culture of *Aspergillus awamori* and *Trichoderma reesei* for bioconversion of apple distillery waste. *Applied Microbiology and Biotechnology* 26: 299-303.

Fu, Y. and Viraraghavan, T. (2000). Removal of a dye from an aqueous solution by fungus *Aspergillus niger*. *Water Quality Research Journal Canada* 35(1): 95-111.

Fu, Y. and Viraraghavan, T. (2001). Fungal decolorization of dye wastewaters: a review. *Bioresource Technology* 79: 251-262.

Fuentes, A., Llorens, M., Saez, J., Aguilar, M.I., Ortuno, J.F. and Meseguer, V.F. (2008). Comparative study of six different sludges by sequential speciation of heavy metals. *Bioresource Technology* 99: 517–525.

Fytili, D. and Zabaniotou, A. (2008). Utilization of sewage sludge in EU application of old and new methods—A review. *Renewable and Sustainable Energy Reviews* 12: 116–140.

Garcia, I.G., Pena, P.R.J., Venceslada, J.L.B., Martin, A.M., Santos, M.A.M. and Gomez, E.R. (2000). Removal of phenol compounds from olive mill wastewater using *Phanerochaete chrysosporium, Aspergillus niger, Aspergillus terreus* and *Geotrichum candidum. Process Biochemistry* 35: 751-758.

Gea, T., Barrena, R., Artola, A. and Sanchez, A. (2007). Optimal bulking agent particle size and usage for heat retention and disinfection in domestic wastewater sludge composting. *Waste Management* 27: 1108–1116.

Ghangrekar, M.M., Asolekar, S.R. and Joshi, S.G. (2005). Characteristics of sludge developed under different loading conditions during UASB reactor start-up and granulation. *Water Research* 39: 1123-1133.

Gmachowski, L. (2008). Free settling of aggregates with mixed statistics. *Colloids and Surfaces A: Physicochemical Engineering Aspects* 315: 57–60.

Gohil, A. and Nakhla, G. (2006). Treatment of tomato processing wastewater by an upflow anaerobic sludge blanket–anoxic–aerobic system. *Bioresource Technology* 97: 2141–2152.

Gong, W-X., Wang, S-G., Sun, X-F., Liu, X-W., Yue, Q-Y. and Gao, B-Y. (2008). Bioflocculant production by culture of *Serratia ficaria* and its application in wastewater treatment. *Bioresource Technology* 99: 4668–4674.

Grady, C.P.L., Dagger, G.T. and Lim, H.C. (1999). *Biological wastewater treatment*. 2nd edition. New York: Marcel Dekker, Inc.

Gray, N.F. (2004). *The biology of wastewater treatment*, 2nd edition. London: Imperial College Press.

Gray, S.R., Becker, N.S.C., Booker, N.A. and Davey, A. (2007). High floc strength with aged polyelectrolytes. *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 298 (3): 262-266.

Guest, R.K. and Smith, D.W. (2002). A potential new role for fungi in a wastewater MBR biological nitrogen reduction system. *Journal of Environmental Engineering Science* 1: 433-437.

Gupta, R., Beg, Q.K. and Lorenz, P. (2002). Bacterial alkaline protease: molecular approaches and industrial applications. *Journal of Applied Microbiology Biotechnology* 59: 15-32.

Hai, F.I., Yamamoto, K. and Fukushi, K. (2006). Development of a submerged membrane fungi reactor for textile wastewater treatment. *Desalination* 192: 315–322.

Hamdi, M., Ellouz, R. (1992a). Bubble column fermentation of olive mill wastewaters by *Aspergillus niger*. *Journal of Chemical Technology and Biotechnology* 54: 331–335.

Hamdi, M. and Ellouz, R. (1992b). Use of *Aspergillus niger* to improve filtration of olive mill waste-waters. *Journal of Chemical Technology and Biotechnology* 53: 195–200.

He, N., Li, Y. and Chen, J. (2004). Production of a novel polygalacturonic acid bioflocculant REA-11 by *Corynebacterium glutamicum*. *Bioresource Technology* 94: 99–105.

Henze, M., Harremoes, P. and la Cour J.A. (2002). *Wastewater treatment*. 3rd edition. Germany: Springerlink.

Higgins, M. and Novak, J. (1997a). Dewatering and settling of activated sludges: the case for using cation analysis. *Water Environmental Research* 69: 225-232.

Higgins M.J. and Novak J.T. (1997b). The effect of cations on the settling and dewatering of activated sludges: laboratory results. *Water Environmental Research* 69: 215–224.

Hind F.A.B. (2008). Optimisation of sludge settleability and dewaterability Using pilot scale liquid state bioconversion process Under non-controlled conditions. Ph.D. thesis, Faculty of Engineering, UPM, Malaysia.

Hjorth, M., Christensen, M.L. and Christensen, P.V. (2008). Flocculation, coagulation, and precipitation of manure affecting three separation techniques. *Bioresource Technology* 99: 8598–8604.

Hong, J., Hong, J., Otaki, M. and Jolliet, O. (2009). Environmental and economic life cycle assessment for sewage sludge treatment processes in Japan. *Waste Management* 29(2): 696-703.

Hsien, T.Y. and Lin, Y.H. (2005). Biodegradation of phenolic wastewater in a fixed biofilm reactor. *Biochemical Engineering Journal* 27: 95–103.

Hu, W.C., Thayanithy, K. and Forster, C.F. (2002). A kinetic study of the anaerobic digestion of ice-cream wastewater. *Process Biochemistry* 37: 965-971.

Huang, C. and Huang, C.P. (1996). Application of *Aspergillus oryzae* and *Rhizopous oryzae* for Cu(II) removal. *Journal of Water Research* 30: 1985-1990.

Huang, C., Pan, J.R., Fu, C-G. and Wu C-C. (2002). Effects of surfactant addition on dewatering of alum sludges. *Journal of Environmental Engineering* 128(12): 1121-1127.

Huang, X.W., Cheng, W. and Hu, Y.Y. (2005). Screening of flocculant producing strains by NTG mutagenesis. *Journal of Environmental Science-China* 17: 494–498.

Hwa, T.J. and Jeyaseelan, S. (1997). Conditioning of oily sludge with alum. *Environmental Monitoring and Assessment* 44: 263-273.

Ichinari, T., Ohtsubo, A., Ozawa, T., Hasegawa, K., Teduka, K., Oguchi and T., Kiso, Y. (2008). Wastewater treatment performance and sludge reduction properties of a digestion unit. *Process Biochemistry* 43: 722–728.

ILBS. (1999). *Laws of Malaysia. In Environment Quality Act 1974 (act 127) and Subsidiary Legislation. International Law Book Services (ILBS)*, Kuala Lumpur, Malaysia. 121p

Iscen, C.F., Kiran, I. and Ilhan, S. (2007). Biosorption of Reactive Black 5 dye by *Penicillium restrictum*: The kinetic study. *Journal of Hazardous Materials* 143: 335–340.

Isik, M. and Sponza D.T. (2005). Substrate removal kinetics in an upflow anaerobic sludge blanket reactor decolorising simulated textile wastewater. *Process Biochemistry* 40: 1189-1198.

Indah Water Konsortium (IWK) Corporate sustainability report 2007: *13 years of environmental accomplishment (1994-2007).* Kuala Lumpur: IWK

Jang, J.H., Ike, M., Kim, S.M. and Fujita, M. (2001). Production of a novel bioflocculant by fed-batch culture of *Citrobacter* sp. *Biotechnology Letters* 23: 593–597.

Jaouania, A., Guillen, F., Penninckxa, M.J., Martinez, A.T. and Martinez, M.J. (2005). Role of *Pycnoporus coccineus* laccase in the degradation of aromatic compounds in olive oil mill wastewater. *Enzyme and Microbial Technology* 36: 478–486.

Jarusutthirak, C. and Amy, G. (2006). Role of soluble microbial products (SMP) in membrane fouling and flux decline. *Environmental Science Technology* 40: 969–974.

Jarusutthirak, C., Amy, G. and Croue, J.P. (2002). Fouling characteristics of wastewater effluent organic matter (EfOM) isolates on NF and UF membranes. *Desalination* 145: 247–255.

Jenkins, D., Richard, M.G. and Daigger, G.T. (2003). *Manual on the causes and control of activated sludge bulking, foaming and other solids separation problems*, 3rd edition. Boca Raton: Lewis Publishers.

Jensen, J. and Jepsen, S-E. (2005). The production, use and quality of sewage sludge in Denmark. *Waste Management* 25: 239-247.

Jianlong, W., Xinmin, Z., Decai, D. and Ding, Z. (2001). Bioadsorption of lead (II) from aqueous solution by fungal biomass of *Aspergillus niger*. *Journal of Biotechnol*ogy 87: 273-277.

Jimenez, A.M., Borja, R. and Martin, A. (2003). Aerobic-anaerobic biodegradation of beet molasses alcoholic fermentation wastewater. *Process Biochemistry* 38: 1275-1284.

Jimenez, A.M., Borja, R., Martin, A. and Raposo, F. (2006). Kinetic analysis of the anaerobic digestion of untreated vinasses and vinasses previously treated with *Penicillium decumbens*. *Journal of Environmental Management* 80: 303–310.

Jin, B., van Leeuwen, H.J, Patel, B. and Yu, Q. (1998). Utilisation of starch processing wastewater for production of microbial biomass protein and fungal α-amylase by *Aspergillus oryzae*. *Bioresource Technology* 66: 201-206.

Jin, B., van Leeuwen, H.J., Patel, B., Doelle, H.W. and Yu, Q. (1999). Production of fungal protein and glucoamylase by *Rhizopus oligosporus* from starch processing wastewater. *Biochemistry* 34: 59–65.

Jin, B., Wilen, B-M. and Lant, P. (2003). A comprehensive insight into floc characteristics and their impact on compressibility and settleability of activated sludge. *Chemical Engineering Journal* 95: 221-234.

Jo, J.H., Lee, D.S., Park, D., Choe, W-S. and Park, J.M. (2008). Optimization of key process variables for enhanced hydrogen production by *Enterobacter aerogenes* using statistical methods. *Bioresource Technology* 99: 2061–2066.

Jorand, F., Zartarian, F., Thomas, F., Block, J.C., Bottero, J.Y., Villemin, G., Urbain, V. And Manem, J. (1995). Chemical and structural (2D) linkage between bacteria within activated sludge flocs. *Water Research* 29(7): 1639-1647.

Kabbashi, N.A., Fakhru'l-Razi, A., Ramachandran, K.B. and Idris, A. (2001). Composting: a solution to waste management problems. *In Proceedings: The International Water Association Conference on Water & Wastewater Management for Developing Countries*, (vol. 1), pp 715-725. 29-31 October 2001, Putra World Trade Centre, Kuala Lumpur, Malaysia.

Kalyandurg, I.B. (2003). Study of reaction kinetics of a submerged membrane activated sludge process. Ph.D. thesis, King Fahd University of Petroleum and Minerals, Saudi Arabia.

Kanat, G., Demir, A., Ozkaya, B. and Bilgili, M.S. (2006). Addressing the operational problems in a composting and recycling plant. *Waste Management* 26: 1384– 1391.

Kapdan, I.K. and Oztekin, R. (2006). The effect of hydraulic residence time and initial COD concentration on color and COD removal performance of the anaerobic–aerobic SBR system. *Journal of Hazardous Materials* B136: 896–901.

Kapoor, A., Viraraghavan, T. and Cullimore, D.R. (1999). Removal of heavy metals using the fungal *Aspergillus niger*. *Bioresource Technology* 70: 95-104.

Katsiris, N. and Kouzali-Katsiri, A. (1987). Bound water content of biological sludges in relation to filtration and dewatering. *Water Research* 21: 1319-1327.

Kaushik, P. and Malik, A. (2009). Fungal dye decolourization: Recent advances and future potential. *Environmental International* 35(1): 127-141.

Kesavan, P. and Law, V.T. (2005). Practical identifiability of parameters in Monod kinetics and statistical analysis of residuals. *Biochemical Engineering Journal* 24: 95-104.

Khalaf, M.A. (2008). Biosorption of reactive dye from textile wastewater by non-viable biomass of *Aspergillus niger* and *Spirogyra* sp. *Bioresource Technology* 99: 6631–6634.

Khuri, A.I. and Cornell, J.A. (1996). *Response Surfaces: Design and Analyses*, 2nd edition, New York: Marcel Dekker.

Kim, S-H., Han, S-K. and Shin, H-S. (2004). Feasibility of biohydrogen production by anaerobic co-digestion of food waste and sewage sludge. *International Journal of Hydrogen Energy* 29(15): 1607-1616.

Kim, Y.M., Park, D., Jeon, C.O., Lee, D. S. and Park, J.M. (2008). Effect of HRT on the biological pre-denitrification process for the simultaneous removal of toxic pollutants from cokes wastewater. *Bioresource Technology* 99: 8824–8832.

Klausen, M.M., Thomsen, T.R., Nielsen, J.L., Mikkelsen, L.H. and Nielsen, P.H. (2004). Variations in microcolony strength of probe-defined bacteria in activated sludge flocs. *FEMS Microbiology Ecology* 50: 123–132.

Knocke, W.R., Dishman, C.M. and Miller, G.F. (1993). Measurement of chemical sludge floc density and implications related to sludge dewatering. *Water Environmental Research* 65: 735-743.

Kolekar, Y.M., Pawar, S.P., Gawai, K.R., Lokhande, P.D., Shouche, Y.S. and Kodam, K.M. (2008). Decolorization and degradation of Disperse Blue 79 and Acid Orange 10, by *Bacillus fusiformis* KMK5 isolated from the textile dye contaminated soil. *Bioresource Technology* 99: 8999–9003.

Kotay, S.M. and Das, D. (2007). Microbial hydrogen production with *Bacillus coagulans* IIT-BT S1 isolated from anaerobic sewage sludge. *Bioresource Technology* 98(6): 1183-1190.

Kotsou, M., Kyriacou, A., Lasaridi, K. and Pilidis, G. (2004). Integrated aerobic biological treatment and chemical oxidation with Fenton's reagent for the processing of green table olive wastewater. *Process Biochemistry* 39:1653–1660.

Kouloumbos, V.N., Schaffer, A. and Corvini, P.F-X. (2008). Impact of sewage sludge conditioning and dewatering on the fate of nonylphenol in sludge-amended soils. *Water Research* 42: 3941-3951.

Kovarova-kovar, K., and Egli, T. (1998). Growth kinetics of suspended microbial cells: from single-substrate-controlled growth to mixed-substrate kinetics. *Microbiology and Molecular Biology Reviews.* 646-666.

Krumins, V., Hummerick, M., Levine, L., Strayer, R., Adams, J.L. and Bauer, J. (2002). Effect of hydraulic retention time on inorganic nutrient recovery and biodegradable organics removal in a biofilm reactor treating plant biomass leachate. *Bioresource Technology* 85: 243–248.

Krzywonos, M., Cibis, E., Miskiewicz, T. and Kent, C.A. (2008). Effect of temperature on the efficiency of the thermo- and mesophilic aerobic batch biodegradation of high-strength distillery wastewater (potato stillage). *Bioresource Technology* 99: 7816–7824.

Kulcu, R. and Yaldiz, O. (2004). Determination of aeration rate and kinetics of composting some agricultural wastes. *Bioresource Technology* 93: 49-57.

Kumar, A., Kumar, S. and Kumar, S. (2005). Biodegradation kinetics of phenol and catechol using *Pseudomonas putida* MTCC 1194. *Biochemical Engineering Journal* 22: 151–159.

Kumari, K. and Abraham, E. (2007). Biosorption of anionic textile dyes by nonviable biomass of fungi and yeast. *Bioresource Technology* 98: 1704–1710.

Kurian, R., Nakhla, G. and Bassi, A. (2006). Biodegradation kinetics of high strength oily pet food wastewater in a membrane-coupled bioreactor (MBR). *Chemosphere* 65: 1204–1211.

Langenhoff, A.A. M., Intrachandra, N. and Stuckey D.C. (2000). Treatment of dilute soluble and colloidal wastewater using an anaerobic baffled reactor: influence of hydraulic retention time. *Water Research* 34(4): 1307-1317.

Larsen, S.B., Karakashev, D., Angelidaki, I., and Schmidt, J.E. (2009). Exsitu bioremediation of polycyclic aromatic hydrocarbons in sewage sludge, *Journal of Hazardous Materials* 164(2-3): 1568 – 1572

Lee, H., Song, M., Hwang, S. (2003a). Optimizing bioconversion of deproteinated cheese whey to mycelia of *Ganoderma lucidum*. *Process Biochemistry* 38: 1685– 1693.

Lee, H., Song, M., Yu, Y. and Hwang, S. (2003b). Production of *Ganoderma lucidum* mycelium using cheese whey as an alternative substrate: response surface analysis and biokinetics. *Biochemical Engineering Journal* 15: 93–99.

Lee, H.S., Park, S.J. and Yoon, T.I. (2002). Wastewater treatment in a hybrid biological reactor using powdered minerals: effects of organic loading rated on COD removal and nitrification. *Process Biochemistry* 38: 81-88.

Lee, S., Yang, K. and Hwang, S. (2004). Use of response surface analysis in selective bioconversion of starch wastewater to acetic acid using a mixed culture of anaerobes. *Process Biochemistry* 39: 1131–1135.

Lee, S.E., Koopman, B., Bode, H. and Jenkins, D. (1983). Evaluation of alternative sludge settleability indices. *Water Research* 17(10): 1421-1426.

Leidig, E., Prusse, U., Vorlop, K.-D. and Winter, J. (1999). Biotransformation of Poly R-478 by continuous cultures of PVAL-encapsulated *Trametes versicolor* under nonsterile conditions. *Bioprocess Biosystem Engineering* 21(1): 5–12.

Lens, P.N.L., Bosch van Den, M.L., Hulshoff pol, L.W. and Lettinga, G. (1998). Effect of staging on volatile fatty acid degradation in sulphidogenic granular sludge reactor. *Water Research* 32(4): 1178-1192.

Li., M., Zhao, Y., Guo, Q., Qian, X. and Niu, D. (2008a). Bio-hydrogen production from food waste and sewage sludge in the presence of aged refuse excavated refuse landfill. *Renewable Energy* 33(12): 2573-2579.

Li, S-L., Whang, L-M., Chao, Y-C., Wang, Y-H., Wang, Y-F., Hsiao, C-J., Tseng, I-C., Bai, M-D., Cheng, S-S. (2010). Effects of hydraulic retention time on anaerobic hydrogenation performance and microbial ecology of bioreactors fed with glucose-peptone and starch-peptone. *International Journal of Hydrogen Energy* 35: 61-70.

Li, X-M., Liao, D-X., Xu, X-Q., Yang, Q., Zeng, G-M., Zheng, W. and Guo, L. (2008b). Kinetic studies for the biosorption of lead and copper ions by *Penicillium simplicissimum* immobilized within loofa sponge. *Journal of Hazardous Materials* 159(2-3) 610-615.

Li, X-Y. and Yuan, Y. (2002). Settling velocities and permeabilities of microbial aggregates. *Water Research* 36: 3110–3120.

Liew, A.G., Idris, A., Ahmadun, F.R., Baharin, B.S., Emby, F., Megat Mohd Noor, M.J. and Nour, A.H. (2005). A kinetic study of a membrane anaerobic reactor (MAR) for treatment of sewage sludge. *Desalination* 183: 439-445.

Lim, B.-R., Huang, X., Hu, H.-Y., Goto, N. and Fujie, K. (2001). Effect of temperature on biodegradation characteristics of organic pollutants and microbial community in a solids phase aerobic bioreactor treating high strength organic wastewater. *Water Science and Technology* 43 (1): 131–137.

Lin, C.Y. and Chen, C.C. (1999). Effect of heavy metals on the methanogenic UASB granules. *Water Research* 33(2): 409-416.

Lin, K.C. and Yang, Z. (1991). Technical review on the UASB process. *International Journal of Environmental Study* 39: 203-222.

Lin, S.D. and Lee, C.C. (2007). *Handbook of environmental engineering calculations*. 2nd edition. Netherland: McGraw-Hill.

Lin, T-C. and Chen, C. (2004). Enhanced mannanase production by submerged culture of *Aspergillus niger* NCH-189 using defatted copra based media. *Process Biochemistry* 39: 1103–1109.

Liu, D.H.F. and Liptak, B.G. (1997). *Environmental engineer's handbook*. 2nd edition. New Jersey: Lewis Publishers.

Liu, L., Wang, Z., Yao, J., Sun, X. and Cai, W. (2005). Investigation on the formation and kinetics of glucose-fed aerobic granular sludge. *Enzyme Microbiology Technology* 36: 712-716.

Liu, L.V, Nakhla, G. and Bassi, A. (2004). Treatability and kinetics studies of mesophilic aerobic biodegradation of high oil and grease pet food wastewater. *Journal of Hazardous Material* B112: 87-94.

Liu, Y-Q and Tay, J-H. (2004). State of the art of biogranulation technology for wastewater treatment. *Biotechnology Advances* 22: 533–563.

Liu, Y-Q and Tay, J-H. (2006). Variable aeration in sequencing batch reactor with aerobic granular sludge. *Journal of Biotechnology* 124(2): 338–346.

Liu, Y-Q. and Tay, J-H. (2007). Influence of cycle time on kinetic behaviors of steady-state aerobic granules in sequencing batch reactors. *Enzyme and Microbial Technology* 41: 516–522.

Loperena, L., Saravia, V., Murro, D., Ferrari, M.D. and Lareo, C. (2006). Kinetic properties of a commercial and a native inoculum for aerobic milk fat degradation. *Bioresource Technology* 97: 2160–2165.

Lowa, B-T., Ting, Y-P., Deng, S. (2008). Surface modification of *Penicillium chrysogenum* mycelium for enhanced anionic dye removal. *Chemical Engineering Journal* 141: 9–17.

Lowry, O. H., Rosebrough, N. J., Farr, A. L. and Randall, R. J. 1951. Protein measurement with the Folin Phenol Reagent. *Journal of Biological Chemistry* 193:265-275.

Lu, W.Y., Zhang, T., Zhang, D.Y., Li, C.H., Wen, J.P., Du, L.X. (2005). A novel bioflocculant produced by *Enterobacter aerogenes* and its use in defecating the trona suspension. *Biochemical Engineering Journal* 27: 1–7.

Lu, Y., Wu, X. and Gui, J. (2009). Characteristics of municipal solid waste and sewage sludge co-composting. *Waste Management* 29(3) 1152-1157.

Luyben, W.L. (2007). *Chemical reactor design and control*. New Jeysey, USA: A John Wiley & Sons, Inc., Publication.

Mahmoud, N., Zandvoort, M., Jules van Lier and Zeeman, G. (2006). Development of sludge filterability test to assess the solids removal potential of a sludge bed. *Bioresource Technology* 97: 2383–2388.

Mannan, S., Fakhru’l-Razi, A and Alam, M.Z. (2005). Use of fungi to improve bioconversion of activated sludge. *Water Research* 39: 2935-2943.

Manolov, R.J. (1992). Influence of agitation rate on growth and ribonuclease production by free and immobilized *Aspergillus clavatus* cells. *Applied Biochemistry Biotechnology* 33: 157–169.

Marcos, N.I., Guay, M., Dochain, D. (2004). Output feedback adaptive extremum seeking control of a continuous stirred tank bioreactor with Monod's kinetic. *Journal of Process Control* 14(7): 807-818.

Margesin, R., Cimadom, J. and Schinner, F. (2006). Biological activity during composting of sewage sludge at low temperatures. *International Biodeterioration & Biodegradation* 57: 88–92.

Maro´ stica Jr., M.R. and Pastore, G.M. (2007). Production of R-(+)-a-terpineol by the biotransformation of limonene from orange essential oil, using cassava waste water as medium. *Food Chemistry* 101: 345–350.

Martel, C.J. (2000). Influence of dissolved solids on the mechanism of freeze-thaw conditioning. *Water Research* 34(2): 657–662.

Martinez Nieto, L., Garrido Hoyos, S.E., Camacho Rubio, F., Garcia Pareja, M.P. and Ramos Cormenzana, A. (1993). The biological purification of waste products from olive oil extraction. *Bioresource Technology* 43: 215–219.

Martins, A.M.P., Pagilla, K., Heijnen, J.J. and van Loosdrecht, M.C.M. (2004). Filamentous bulking sludge – a critical review. *Water Research* 38: 793–817.

Massanet-Nicolau, J., Dinsdale, R. and Guwy, A. (2008). Hydrogen production from sewage sludge using mixed microflora inoculum: Effect of pH and enzymatic pretreatment. *Bioresource Technology* 99(14): 6325-6331.

McKinney, R.E. (2004). *Environmental pollution control microbiology*. New York: Marcel Dekker, Inc.

McNamaraa, C.J., Anastasiouc, C.C., O'Flahertyd, V. and Mitchell, R. (2008). Bioremediation of olive mill wastewater. *International Biodeterioration & Biodegradation* 61:127–134.

Mendez, A., Gasco, G., Freitas, M.M.A., Siebielec, G., Stuezynski and Figueiredo J.L. (2005). Preparation of carbon-based adsorbents from pyrolysis and air activation of sewage sludges. *Chemical Engineering Journal* 108: 169-177.

Mendil, D., Tuzen, M. and Soylak, M. (2008). A biosorption system for metal ions on *Penicillium italicum* – loaded on Sepabeads SP 70 prior to flame atomic absorption spectrometric determinations. *Journal of Hazardous Materials* 152: 1171–1178.

Metcalf and Eddy. Inc. (2004). *Wastewater Engineering treatment and reuse*, 4th edition. New York: McGraw Hill.

Mikkelsen, L.H. and Keiding K. (2002). Physico-chemical characteristics of full scale sewage sludges with implications to dewatering. *Water Research* 36: 2451-2462.

Mishra, B.K., Arora, A. And Lata. (2004). Optimization of a biological process for treating potato chips industry wastewater using a mixed culture of *Aspergillus foetidus* and *Aspergillus niger*. *Bioresource Technology* 94: 9–12.

Moeller, G. and Torres L.G. (1997). Rheological characterization of primary and secondary sludges treated by both aerobic and anaerobic digestion. *Bioresource Technology* 61:207-211.

Molla, A.H, Fakhru'l-Razi, A., Abd-Aziz, S., Hanafi, M.M., Roychoudhury, P.K. and Alam, M.Z. (2002). A potential resource for bioconversion of domestic wastewater sludge. *Bioresource Technology* 85: 263-272.

Molla, A.H. (2002). Solid state bioconversion of domestic wastewater treatment plant sludge into compost. Ph. D. thesis, Faculty of Engineering, UPM, Malaysia.

Molla, A.H. and Fakhru'l-Razi, A. (2004). Effects of compost produced through solid state bioconversion of domestic wastewater sludge on corn (*Zea mays*) growth. *The Agriculturist* 2(1): 18-28.

Molla, A.H., Fakhru'l-Razi, A., Hanafi, M.M. and Alam, M.Z. (2004). Optimization of process factors for solid-state bioconversion of domestic wastewater sludge. *International Biodeterioration & Biodegradation* 53: 49-55.

Mondala, A., Liang, K., Toghiani, H., Hernandez, R. and French, T. (2009). Biodiesel production by in situ transesterification of municipal primary and secondary sludges. *Bioresource Technology* 100(3) 1203-1210.

Monod, J. (1949). The growth of bacterial cultures. *Annual Review of Microbiology* 3:371-394.

Montgomery, D.C. (1991). *Design and Analysis of experiments*, 3rd edition. New York: Wiley.

Morgan-Sagastume, F. And Allen, D.G. (2003). Effects of temperature transient conditions on aerobic biological treatment of wastewater. *Water Research* 37: 3590–3601.

Morimura, S., Kida, K., Nakagawa, M. and Sonoda, Y. (1994). Production of fungal protein by *Aspergillus awamori* var. *kawachi* grown in *shochu* distillery wastewater. *Journal of Fermentation and Bioengineering* 78(2): 160-163.

Muralidhar, R.V., Chirumamila, R.R., Marchant, R. and Nigam, P. (2001). A response surface approach for the comparison of lipase production by *Candida cylindracea* using two different carbon sources. *Biochemical Engineering Journal* 9: 17–23.

Mustafa, I.K and Sponza, D.T. (2008). Anaerobic/aerobic treatment of a simulated textile wastewater. *Separation and Purification Technology* 60: 64–72.

Nakhla, G., Liu, V. and Bassi, A. (2006). Kinetic modelling of aerobic biodegradation of high oil and grease rendering wastewater. *Bioresource Technology* 97: 131-139.

Ndon, U.J. and Dague, R.R. (1997) . Effects of temperature and hydraulic retention time on anaerobic sequencing batch reactor treatment of low-strength wastewater. *Water Research* 31(10): 2455—2466.

Nellenschulte, T. and Kayser, R. (1997). Change of particle structure of sewage sludges during mechanical and biological processes with regard to the dewatering result. *Journal of Water Science and Technology* 36(4): 293-306.

Nelson, M.I., Balakrishnan, E., Sidhu, H.S. and Chen, X.D. (2008). A fundamental analysis of continuous flow bioreactor models and membrane reactor models to process industrial wastewaters. *Chemical Engineering Journal* 140(1-3): 521-528.

Neyens, E., Baeyens, J., Dewil, R. and De heyder, B. (2004). Advanced sludge treatment affects extracellular polymeric substances to improve activated sludge dewatering. *Journal of Hazardous Materials* 106B: 83-92.

Nguyen, T.P, Hilal, N., Hankins, N.P. and Novak, J.T. (2008). Characterization of synthetic and activated sludge and conditioning with cationic polyelectrolytes. *Desalination* 227: 103–110.

Nielsen, P.H., Thomsen, T.R. and Nielsen, J.L. (2004). Bacterial composition of activated sludge-importance for floc and sludge properties. *Water Science Technology* 49: 51–58.

Northcott, K.A., Snape, I., Scales, P.J. and Stevens, G.W. (2005). Dewatering behaviour of water treatment sludges associated with contaminated site remediation in antartica. *Chemical Engineering Science* 60: 6835-6843.

Novak, J.T., Sadler, M.E. and Murthy, S.N. (2003). Mechanisms of flocs destruction during anaerobic and aerobic digestion and the effect on conditioning and dewatering of biosolids. *Water Research* 37: 3136-3144.

O'Kelly, B.C. (2005). Mechanical properties of dewatered sewage sludge. *Waste Management* 25: 47-52.

Oleszczuk, P. (2008). The toxicity of composts from sewage sludges evaluated by the direct contact tests phytotoxkit and ostracodtoxkit. *Waste Management* 28: 1645–1653.

Oleszkiewicz, J.A. and Mavinic, D.S. (2002). Wastewater biosolids: an overview of processing, treatment and management. *Journal of Environmental Engineering Science* 1: 75-88.

Ormeci, B. (2007). Optimization of a full-scale dewatering operation based on the rheological characteristics of wastewater sludge. *Water Research* 41: 1243-1252.

Outwater, A.B. (1994). *Sludge characterization. In reuse of sludge and minor wastewater residuals.* USA: Lewis Publishers, CRC Press Inc.

Parshetti, G.K., Kalme, S.D. and Gomare, S.S. (2007). Biodegradation of reactive blue-25 by *Aspergillus ochraceus* NCIM-1146. *Journal of Biotechnology* 98: 3638–42.

Patel, R. and Suresh, S. (2008). Kinetic and equilibrium studies on the biosorption of reactive black 5 dye by *Aspergillus foetidus*. *Bioresource Technology* 99: 51–58.

Pazouki, M., Keyanpour-Rad, M., Shafie, Sh. and Shahhoseini, Sh. (2007). Efficiency of *Penicillium chrysogenum* PTCC 5037 in reducing low concentration of chromium hexavalent in a chromium electroplating plant wastewater. *Bioresource Technology* 98: 2116–2122.

Peavy, H.S., Rowe, D.R. and Tchobanoglous, G. (1985). *Environmental Engineering*. New York: McGraw Hill.

Pirt, S.J. (1975). *Principles of Microbe and Cell Cultivation*. Oxford: Blackwell Science Publication

Piyushkumar, M., Kiran, D. and Lele, S.S. (2007). Application of response surface methodology to cell immobilization for the production of palatinose. *Bioresource Technology* 98: 2892–2896.

Pramanik, S. and Khan, E. (2008). Effects of cell entrapment on growth rate and metabolic activity of mixed cultures in biological wastewater treatment. *Enzyme and Microbial Technology* 43: 245–251.

Prasertsan, P., Dermlim, W., Doelle, H. and Kennedy, J.F. (2006). Screening, characterization and flocculating property of carbohydrate polymer from newly isolated *Enterobacter cloacae* WD7. *Carbohydrate Polymer* 66: 289–297.

Puvaneshwari, N., Muthukrishnan, J. and Gunashekaran, P. (2002). Biodegradation of benzidine based azo dyes direct red and direct blue by the immobilized cells of *Psuedomonas fluoroscens* D41. *Indian Journal of Experimental Biology* 40: 1131–1136.

Qasim, S.R. (1999). *Wastewater treatment plants: planning, design and operation,* 2nd edition. USA: Technomic Publication.

Qin, L., Liu, Y. and Tay, J-H. (2004). Effect of settling time on aerobic granulation in sequencing batch reactor. *Biochemical Engineering Journal* 21: 47-52.

Radha, K.V., Regupathi, I., Arunagiri, A. and Murugesan, T. (2005). Decolorization studies of synthetic dyes using *Phanerochaete chrysosporium* and their kinetics. *Process Biochemistry* 40: 3337–3345.

Ramakrishnan, A. and Gupta, S.K. (2008). Effect of hydraulic retention time on the biodegradation of complex phenolic mixture from simulated coal wastewater in hybrid UASB reactors. *Journal of Hazardous Materials* 153: 843–851.

Ramesh, B., Reddy, P.R.M., Seenayya, G. and Reddy, G. (2001) Effect of various flours on the production of thermostable B-amylase and pullulanase by *Clostridium thermosulfurogenes* SV2. *Bioresource Technology* 76: 169- 171.

Reddy, P., Pillay, V.L., Kunamneni, A. and Singh, S. (2005). Degradation of pulp and paper-mill effluent by thermophilic micro-organisms using batch systems. *Water SA* 31(4): 575–580.

Ren, H., Chen, W., Zheng, Y. and Luan, Z. (2007). Reactive & Effect of hydrophobic group on flocculation properties and dewatering efficiency of cationic acrylamide copolymers. *Functional Polymers* 67: 601–608.

Ren, N., Chen, Z., Wang, X., Hu, D., Wang, A. (2005). Optimized operational parameters of a pilot scale membrane bioreactor for high-strength organic wastewater treatment. *International Biodeterioration & Biodegradation* 56: 216–223.

Romdhana, M.H., Hamasaiid, A., Ladevie, B., Lecomte, D. (2009). Energy valorization of industrial biomass: Using a batch frying process for sewage sludge. *Bioresource Technology* 100: 3740–3744.

Rosenani, A.B., Kala, D.R. and Fauziah, C.I. (2004). *Characterization of Malaysian sewage sludge and nitrogen mineralization in three soils treated with sewage sludge.* Supersoil 2004: 3rd Australian New Zealand Soils Conference, 5-9 December 2004, University of Sydney, Australia.

Ruggieri, L., Artola, A., Gea, T. and Sanchez, A. (2008). Biodegradation of animal fats in a co-composting process with wastewater sludge. *International Biodeterioration and Biodegradation* 62: 297–303.

Ruiz, T. and Wisniewski, C. (2008). Correlation between dewatering and hydro-textural characteristics of sewage sludge during drying. *Separation and Purification Technology* 61: 204–210.

Sakohara, S., Ochiai, E. and Kusaka, T. (2007). Dewatering of activated sludge by thermosensitive polymers. *Separation and Purification Technology* 56: 296–302.

Salehizadeh, H. and Shojaosadati, S.A. (2002). Isolation and characterization of a bioflocculant produced by *Bacillus firmus*. *Biotechnology Letters* 24: 35–40.

Salihoglu, N.K., Pinarli, V. and Salihoglu, G. (2007). Solar drying in sludge management in Turkey. *Renewable Energy* 32(10): 1661-1675.

Sandhya, S., Sarayu, K. and Swaminathan, K. (2008). Determination of kinetic constants of hybrid textile wastewater treatment system. *Bioresource Technology* 99: 5793–5797.

Sánchez, E., Borja, R., Travieso L., Martin, B. and Colmenarejo, M.F. (2005). Effect of influent substrate concentration and hydraulic retention time on the performance of down-flow anaerobic fixed bed reactors treating piggery wastewater in a tropical climate. *Process Biochemistry* 40: 817–829.

Sanchez, E., Travieso, L., Weiland, P., Borja, R. and Nikolaeva, S. (2002). Effect of influent strength changes on the performance of a down-flow anaerobic fixed bed reactor treating piggery waste. *Resources, Conservation and Recycling* 36: 73–82.

Sánchez, M.E., Martínez, O., Gómez, X. and Morán, A. (2007). Pyrolysis of mixtures of sewage sludge and manure: A comparison of the results obtained in the laboratory (semi-pilot) and in a pilot plant. *Waste Management* 27(10): 1328-1334.

Sarkar, A.M. (2006). Biodewaterability and liquid state bioconversion of activated sludge under non-sterilized conditions. M.Sc. thesis, Faculty of Engineering, UPM, Malaysia.

Saveyn, H., Curvers, D., Thas, O. and Van der Meeren, P. (2008). Optimization of sewage sludge conditioning and pressure dewatering by statistical modeling. *Water Research* 42: 1061-1074.

Scheumann, R. and Kraume, M. (2009). Influence of hydraulic retention time on the operation of a submerged membrane sequencing batch reactor (SM-SBR) for the treatment of greywater. *Desalination* 246: 444–451.

Schneider, O., Sereti, V., Eding, E.H., Verreth, J.A.J., Klapwijk, B. (2007). Kinetics, design and biomass production of a bacteria reactor treating RAS effluent streams. *Aquacultural Engineering* 36: 24–35.

Senan, R.C. and Abraham, T.E., (2004). Bioremediation of textile azo dyes by aerobic bacterial consortium. *Biodegradation* 15: 275–280.

Senthilnathan, P.R. and Sigler, R.G. (1993). Improved sludge dewatering by dual polymer conditioning. *Water Science Technology* 28: 53-57.

Shahvali, M., Assadi, M. and Rostami, K. (2000). Effect of environmental parameters on decolorization of textile wastewater using *Phanerochaete chrysosporium*. *Bioprocess Engineering* 23: 721-726.

Shayegan, J., Ghavipanjeh, F. and Mirjafari, P. (2005). The effect of influent COD and upward flow velocity on the behavior of sulphate-reducing bacteria. *Process Biochemistry* 40: 2305-2310.

Shedbalkar, U., Dhanve, R. and Jadhav, J. (2008). Biodegradation of triphenylmethane dye cotton blue by *Penicillium ochrochloron* MTCC 517. *Journal of Hazardous Materials* 157: 472–479.

Shioya, S., Marikawa, M., Kajihara, Y., Shimizu, H. (1999). Optimization of agitation and aeration condition for maximum virginiamycin production. *Applied Microbiology Biotechnology* 51: 164–169.

Shober, A.L., Stehouwer, C. and Macneal, E. (2003). On-farm assessment of biosolids effects on soil and crop tissue quality. *Journal of Environmental Quality* 32: 1873–1880.

Shuler, M.L. and Kargi,F. (2003). *Bioprocess Engineering-Basic concepts*. 2nd edition. Singapore: Pearson Education Pvt. Ltd,

Siegrist, H., Alder, A., Brunner, P.H. and Giger, W. (1988). *Pathway analysis of selected organic chemicals from sewage and agricultural soil*. EWPA/CEC Conference on Sewage Sludge Treatment and Use. Amsterdam.

Singh, R.K., Kumar S., Kumar, S. and Kumar A. (2008). Biodegradation kinetics studies for the removal of p-cresol from wastewater using *Gliomastix indicus* MTCC 3869. *Biochemical Engineering Journal* 40: 293-303.

Singh, R.P. and Agrawal, M. (2008). Potential benefits and risks of land application of sewage sludge. *Waste Management* 28: 347–358.

Sokoł, W. and Korpal, W. (2006). Aerobic treatment of wastewaters in the inverse fluidised bed biofilm reactor. *Chemical Engineering Journal* 118: 199–205.

Sonke, L. (2005). The model-data-overlap: A new approach to parameter estimation, model variation, selection and discrimination. [Electronic version]. Fu Berlin Digital Dissertation, Berlin.

Sponza, D.T. and Ulukoy, A. (2008). Kinetics of carbonaceous substrate in an upflow anaerobic sludge blanket (UASB) reactor treating 2,4 dichlorophenol (2,4 DCP). *Journal of Environmental Management* 86(1): 121-131.

Srivastava, S. and Thakur, I.S. (2006). Isolation and process parameter optimization of *Aspergillus* sp. for removal of chromium from tannery effluent. *Bioresource Technology* 97: 1167–1173.

Tan, I.A.W., Ahmad, A.L. and Hameed, B.H. (2008). Preparation of activated carbon from coconut husk: Optimization study on removal of 2,4,6-trichlorophenol using response surface methodology. *Journal of Hazardous Materials* 153: 709–717.

Tao, T., Peng, X.F., Lee, D.J. and Hsu, J.P. (2006). Micromechanics of wastewater sludge floc: force–deformation relationship at cyclic freezing and thawing. *Journal of Colloid and Interface Science* 298(2): 860–868.

Taseli, B.K., Gokcay, C.F. and Taseli, F. (2004). Upflow column reactor design for dechlorination of chlorinated pulping wastes by *Penicillium camemberti*. *Journal of Environmental Management* 72: 175–179.

Thanh, B.X., Visvanathan, C. and Aim, R.B (2009). Characterization of aerobic granular sludge at various organic loading rates. *Process Biochemistry* 44: 242-245.

Tsai, J-C, Kumara, M., Chen, S-Y. and Lin, J-G. (2007). Nano-bubble flotation technology with coagulation process for the cost-effective treatment of chemical mechanical polishing wastewater. *Separation and Purification Technology* 58: 61–67.

Tung, T.Q., Miyata, N., Iwahori, K. (2004). Growth of *Aspergillus oryzae* during treatment of cassava starch processing wastewater with high content of suspended solids. *Journal of Bioscience and Bioengineering* 97(5): 329–335.

Uggetti, E., Llorens, E., Pedescoll, A., Ferrer, I., Castellnou, R., and García, J. (2009). Sludge dewatering and stabilization in drying reed beds: Characterization of three full-scale systems in Catalonia, Spain. *Bioresource Technology* 100: 3882–3890.

UNEP (United Nations Environment Programme) (2000). *International Source Book on Environmentally Sound Technologies for Wastewater and Stormwater Management*. Osaka: Newsletter and Technical Publications.

UNEP (United Nations Environment Programme) (2002). *Biosolids Management: An Environmentally Sound Approach for Managing Sewage Treatment Plant Sludge*: Newsletter and Technical Publications.

Vanderhasselt, A. and Verstraete, W. (1999). Short-term effects of additives on sludge sedimentation characteristics. *Water Research* 33(2): 381-390.

Vasiliadou, I.A., Tziotzios, G. and Vayenas, D.V. (2008). A kinetic study of combined aerobic biological phenol and nitrate removal in batch suspended growth cultures. *International Biodeterioration & Biodegradation* 61: 261–271.

Vaxelaire, J. and Cezac, P. (2004). Moisture distribution in activated sludges: a review. *Water Research* 38: 2215-2230.

Vázquez, I., Rodríguez, J., Marañón, E., Castrillón, L. and Fernández, Y. (2006). Simultaneous removal of phenol, ammonium and thiocyanate from coke wastewater by aerobic degradation. *Journal of Hazardous Materials* B137: 1773–1780.

Verma, M., Brar, S.K., Tyagi, R.D., Sahai, V., Prevost, D., Valero, J.R. and Surampalli, R.Y. (2007). Bench-scale fermentation of *Trichoderma viride* on wastewater sludge: Rheology, lytic enzymes and biocontrol activity. *Enzyme and Microbial Technology* 41: 764–771.

Verma, M., Brar, S.K., Tyagi, R.D., Valero, J.R. and Surampalli, R.Y. (2005). Wastewater sludge as a potential raw material for antagonistic fungus (*Trichoderma* sp.): Role of pre-treatment and solids concentration. *Water Research* 39: 3587–3596.

Vesilind, P.A. (1994). The role of water in sludge dewatering. *Water Environmental Research* 66: 4-11.

Vesilind, P.A. and Hsu, C.C. (1997). Limits of sludge dewaterability. *Journal of Water Science Technology* 36(11): 87-91.

Viero, F.A, and Sant'Anna Jr., G.L. (2008). Is hydraulic retention time an essential parameter for MBR performance? *Journal of Hazardous Materials* 150: 185–186.

Vijayaraghavan, K., Ahmad, D. and Abdul Aziz, M.E. (2007). Aerobic treatment of palm oil mill effluent. *Journal of Environmental Management* 82: 24-34.

Wakeman, R.J. (2007). Separation technologies for sludge dewatering. *Journal of Hazardous Materials* 144: 614–619.

Wang, R., Law, R.C.S. and Webb, C. (2005). Protease production and conidiation by *Aspergillus oryzae* in flour fermentation. *Process Biochemistry* 40: 217–227.

Wang, S.G., Gong, W.X., Liu, X.W., Tian, L., Yue, Q.Y. and Gao, B.Y. (2007). Production of a novel bioflocculant by culture of *Klebsiella mobilis* using dairy wastewater. *Biochemical Engineering Journal* 36: 81–86.

Wang, Z.-W. and Liu, X.-L. (2008). Medium optimization for antifungal active substances production from a newly isolated *Paenibacillus* sp. using response surface methodology. *Bioresource Technology* 99(17): 8245-8251

Wei, Y. and Liu, Y. (2005). Effects of sewage SSC application on crops and cropland in a 3-year field study. *Chemosphere* 59: 1257–1265.

Wen, Z., Liao, W. and Chen, S. (2005). Production of cellulase/b-glucosidase by the mixed fungi culture *Trichoderma reesei* and *Aspergillus phoenicis* on dairy manure. *Process Biochemistry* 40: 3087–3094.

Whiteley, C.G. and Lee, D-J. (2006). Review: Enzyme technology and biological remediation. *Enzyme and Microbial Technology* 38: 291–316.

Wilen, B-M., Lumley, D., Mattsson, A. and Mino, T. (2008). Relationship between floc composition and flocculation and settling properties studied at a full scale activated sludge plant. *Water Research* 42: 4404-4418.

Wolny, L., Wolski, P. and Zawieja, I. (2008). Rheological parameters of dewatered sewage sludge after conditioning. *Desalination* 222: 382–387.

Wu, J., Xiao, Y-Z., Yu, H-Q. (2005). Degradation of lignin in pulp mill wastewaters by white-rot fungi on biofilm. *Bioresource Technology* 96: 1357–1363.

Wu, J-Y. and Ye, H-F. (2007). Characterization and flocculating properties of an extracellular biopolymer produced from a *Bacillus subtilis* DYU1 isolate. *Process Biochemistry* 42: 1114–1123.

Wu, R.M., Tsou, G.W. and Lee, D.J (2000). Estimate of sludge floc permeability. *Chemical Engineering Journal* 80: 37-42.

Xia, S., Zhang, Z., Wang, X., Yang, A., Chen, L., Zhao, J., Leonard, D. and Jaffrezic-Renault, N. (2008). Production and characterization of a bioflocculant by *Proteus mirabilis* TJ-1. *Bioresource Technology* 99: 6520–6527.

Xing, C-H., Wu, W-Z., Qian, Y. and Tardieu, E. (2003). Excess sludge production in membrane bioreactors: a theoretical investigation. *Journal of Environmental Engineering* 129(4): 291-297.

Xu, Z., Nakhla, G. and Patel, J. (2006). Characterization and modeling of nutrient-deficient tomato-processing wastewater treatment using an anaerobic/aerobic system. *Chemosphere* 65: 1171–1181.

Xua, P., Ding, Z-Y., Qian, Z., Zhaoa, C-X. and Zhang, K-C. (2008). Improved production of mycelial biomass and ganoderic acid by submerged culture of *Ganoderma lucidum* SB97 using complex media. *Enzyme and Microbial Technology* 42: 325–331.

Yamada, Y. and Kawase, Y. (2006). Aerobic composting of waste activated sludge: Kinetic analysis for microbiological reaction and oxygen consumption. *Waste Management* 26: 49–61.

Yang, K., Yu, Y. and Hwang, S. (2003). Selective optimization in thermophilic acidogenesis of cheese-whey wastewater to acetic and butyric acids: partial acidification and methanation. *Water Research* 37: 2467–2477.

Yim, J.H., Kim, S.J., Ahn, S.H. and Lee, H.K. (2007). Characterization of a novel bioflocculant, p-KG03, from a marine dinoflagellate, *Gyrodinium impudicum* KG03. *Bioresource Technology* 98: 361–367.

Zafar, S., Aqil, F. and Ahmad, I. (2007). Metal tolerance and biosorption potential of filamentous fungi isolated from metal contaminated agricultural soil. *Bioresource Technology* 98: 2557–2561.

Zain, S.M., Basri, H. Suja, F. and Jaafar, O. (2001). *In Proceedings: Land application technique for the treatment and disposal of sewage sludge.* The International Water Association Conference on Water & Wastewater Management for Developing Countries, (vol. 1), pp 401-407. 29-31 October 2001, Putra World Trade Centre, Kuala Lumpur, Malaysia.

Zain, S.M., Jaafar, O., Basri, H., Suja, F. and Rahman, R.A. (1999). *In Proceeding: Characterization of sludge from and extended aeration sewage treatment plant.* World Engineering Congress, pp. 359-362. Chemical and Environmental Engineering. Kuala Lumpur.

Zhang, M.L, Sheng, G.P. and Yu, H.Q. (2008a). Determination of proteins and carbohydrates in the effluents from wastewater treatment bioreactors using resonance light-scattering method. *Water Research* 42: 3464 – 3472.

Zhang, Z.Y., Jin, B., Bai, Z.H. and Wang, X.Y. (2008b). Production of fungal biomass protein using microfungi from winery wastewater treatment. *Bioresource Technology* 99: 3871–3876.

Zheng, Y., Ye, Z-L., Fang, X-L., Li, Y-H. and Cai, W-M. (2008). Production and characteristics of a bioflocculant produced by *Bacillus* sp. F19. *Bioresource Technology* 99: 7686–7691.

Zhu, H., Parker, W., Basnar, R., Proracki, A., Falletta, P., Béland, M. and Seto, P. (2008). Biohydrogen production by anaerobic co-digestion of municipal food waste and sewage sludges. *International Journal of Hydrogen Energy* 33(14): 3651-3659.

Zinatizadeh, A.A.L., Mohamed, A.R., Abdullah, A.Z., Mashitah, M.D., Isa, M.H. and Najafpour, G.D. (2006a). Process modeling and analysis of palm oil mill effluent treatment in an up-flow anaerobic sludge fixed film bioreactor using response surface methodology (RSM). *Water Research* 40: 3193-3208.

Zinatizadeh, A.A.L., Mohamed, A.R., Najafpour, G.D., Hasnain Isa, M. and Nasrollahzadeh, H. (2006b). Kinetic evaluation of palm oil mill effluent digestion in a high rate up-flow anaerobic sludge fixed film bioreactor. *Process Biochemistry* 41(5): 1038-1046.

Zorpas, A.A., Arapoglou, D. and Panagiotis, K. (2003). Waste paper and clinoptilolite as a bulking material with dewatered anaerobically stabilized primary sewage sludge (DASPSS) for compost production. *Waste Management* 23: 27-35.