



UNIVERSITI PUTRA MALAYSIA

**SEQUENCING BATCH REACTOR (SBR) TECHNOLOGY FOR
BIOLOGICAL TREATMENT OF SEWAGE**

LIM CHIN MING

FK 2001 49

**SEQUENCING BATCH REACTOR (SBR) TECHNOLOGY FOR
BIOLOGICAL TREATMENT OF SEWAGE**

By

LIM CHIN MING

**Thesis Submitted in Fulfilment of the Requirement for the
Degree of Master of Science in the Faculty of Engineering
Universiti Putra Malaysia**

August 2001



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirement for the degree of Master of Science

**SEQUENCING BATCH REACTOR (SBR) TECHNOLOGY FOR
BIOLOGICAL TREATMENT OF SEWAGE**

By

LIM CHIN MING

August 2001

Chairperson: Fakhru'l-Razi bin Ahmadun, Ph.D.

Faculty: Engineering

The sequencing batch reactor (SBR) has become popular in recent years since Irvine and Davis (1979) described its operation. The SBR achieves the processes in a framework of space compared to the conventional system, which achieves in terms of space. There are generally 5 operational steps in a SBR cycle namely Fill, React, Settle, Draw and Idle.

A bench scale SBR was studied at 2 different strategies. The study was conducted at different cycle times (6h, 8h and 10h) and different operational mode based on the ratio of anaerobic and aerobic period (1/2.7, 1/1 and 1.7/1). The study was undertaken to investigate the effluent quality, removal efficiency, SVI and kinetic growth coefficient.



Results from strategy A (different cycle time) showed that increases in cycle time led to decrease in the removal of TSS, COD and BOD₅. Best results were obtained for the system with the 6h-cycle time, followed by the 8h-cycle time and lastly was the 10h-cycle time.

Six hours cycle time was chosen for strategy B mainly due to the overall better removal efficiency on TSS, COD and BOD₅. There were 3 operational modes being examined in strategy B, they were 1/2.7 (longest aerobic period), 1/1 and 1.7/1 (shortest aerobic periods).

Best results were obtained from the 1/2.7 operational mode with the longest aerobic period (lowest *Li*, which was 1.22 mg/mg.d), followed by 1/1 operational mode and lastly was the 1.7/1 operational mode. The higher removal efficiency was associated with the longer aerobic period, the kinetic growth coefficient and SVI also increased with the increasing of aerobic period. Therefore, the 6h-cycle time and 1/2.7 operational mode appeared to be the most reliable option in this study.

For further studies, more work could be done to have a better understanding of the SBR system. For instance, inclusion of an anoxic period in the React step would enhance denitrification process to achieve better effluent quality. Moreover, kinetic growth model can be further explored by thymidine assay.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

**TEKNOLOGI REAKTOR TURUTAN SESEKUMPUL (SBR) UNTUK
RAWATAN AIR SISA SECARA BIOLOGIKAL**

Oleh

LIM CHIN MING

Ogos 2001

Pengerusi: Fakhru'l-Razi bin Ahmadun, Ph.D.

Fakulti: Kejuruteraan

Reaktor turutan sesekumpul (SBR) semakin popular sejak tahun kebelakangan ini setelah Irvine dan Davis (1979) mengemukakan operasinya. SBR dapat melaksanakan pemrosesannya dalam ukuran masa berbanding sistem pemrosesan tradisional yang memerlukan lapangan atau ruangan. Operasi SBR terdiri daripada lima mod, iaitu Isi, Tindabalas, Mendak, Salur dan Rehat.

Satu kajian SBR berskala makmal telah dijalankan berdasarkan dua strategi yang berlainan. Kajian ini telah dijalankan pada masa putaran yang berlainan (6 jam, 8 jam dan 10 jam) dan pada mod operasi yang berlainan (1/2.7, 1/1 dan 1.7/1). Kajian ini bertujuan untuk menyelidik kualiti sisa kumbahan selepas rawatan, kecekapan pengurangan, SVI dan juga koefisien kinetik pertumbuhan.

Keputusan daripada strategi A (masa putaran yang berlainan) menunjukkan bahawa penambahan masa putaran akan mengurangkan kecekapan pengurangan TSS, COD dan BOD₅. Bagi sistem berdasarkan masa putaran, 6 jam menunjukkan keputusan yang terbaik. Ini diikuti pula dengan 8 jam masa putaran dan akhir sekali 10 jam masa putaran.

Masa putaran 6 jam telah digunakan di dalam strategi B memandangkan kecekapan baik yang dipamerkan dari segi pengurangan TSS, COD dan BOD₅. Terdapat tiga mod operasi yang diselidik dalam strategi B. Mereka adalah 1/2.7 (masa aerobik yang terpanjang), 1/1 dan 1.7/1 (masa aerobik yang terpendek).

Keputusan yang terbaik diperolehi daripada mod operasi, 1/2.7 dengan masa aerobik yang terpanjang tetapi nilai L_t yang terendah iaitu 1.22 mg/mg.d. Ini diikuti oleh mod operasi 1/1 dan seterusnya mod operasi 1.7/1. Di samping kecekapan pengurangan yang tertinggi berkait rapat dengan masa aerobik yang lebih lama, malah nilai koefisien kinetik pertumbuhan dan SVI juga meningkat dengan peningkatan masa aerobik.

Kesimpulannya, sistem SBR beroperasi pada masa putaran 6 jam dan mod operasi 1/2.7 merupakan satu pilihan yang baik dalam penyelidikan ini.

Demi kajian lanjutan, banyak penyelidikan boleh diadakan untuk mendapatkan kefahaman yang lebih lanjut tentang sistem SBR. Satu selang anosik boleh diselit pada mod Tindakbalas untuk menggalakkan proses dinitrifikasi supaya

menghasilkan air sisa rawatan yang lebih berkualiti. Di samping itu, model kinetik pertumbuhan boleh diselidik dengan menggunakan assay pertumbuhan thymidine.

ACKNOWLEDGEMENTS

First of all, the author wishes to express her utmost thanks and deepest gratitude to supervisors, Dr. Fakhru'l-Razi bin Ahmadun, Associate Professor Dr. Saari Mustapha and Encik Abdul Ghani Liew Abdullah of Chemical and Environmental Engineering Department for their keen supervision, guidance and invaluable advises throughout the course of this project.

The author wishes to express her thanks to Miss Hii Siew Ling, Mr Ho Yun Kit, Mr Tan Ming Ying, Cik Maslinda and all members of Environment Engineering Laboratory who had contributed their idea and unreserved help to me. Furthermore, the author wishes to thank Mr Suria from IWK and all friends who have contributed their idea and help to her.

Last but not least, the author wishes to dedicate her gratefulness to her beloved husband, Mr Ng Perk Tsong and family for their support and encouragement throughout the project to the completion of this project and thesis.



TABLE OF CONTENTS

	Page
ABSTRACT	ii
ABSTRAK	iv
ACKNOWLEDGEMENTS	vii
APPROVAL SHEETS	viii
DECLARATION FORM	x
LIST OF TABLES	xiv
LIST OF FIGURES	xvi
LIST OF PLATES	xviii
LIST OF ABBREVIATIONS	xix
CHAPTER	
I INTRODUCTION	1
Objectives	4
II LITERATURE REVIEW	5
Definition of Sewage	5
Nature of Sewage	6
Sewage Composition	7
History of Wastewater Treatment	11
Description and Design of SBR	14
Advantages and Disadvantages of SBR	19
Basics of Sewage Treatment	21
Mass Balance in SBR	23
Mixed Liquor Suspended Solids / Mixed Liquor Volatile Suspended Solids (MLSS / MLVSS)	23
Mixed Cultures in SBR	24
Kinetic of Biological Growth	27
Biochemical Process in SBR	32
Biochemical Oxygen Demand (BOD) Removal	32
Biological Nutrient Removal	33
Chemical Oxygen Demand (COD) Removal	39
Application of SBR	42
Treatment of Domestic Waste by SBR	45
Current Status	47
Economic Comparison	48
SBR in Malaysia	49
III MATERIAL AND METHODS	51
Experimental Design	51
Experiment Procedure	52
Sample Collection	57
Analytical Techniques	57
Chemical Oxygen Demand (COD)	58



	Biological Oxygen Demand (BOD ₅)	59
	Total Suspended Solids (TSS) / Mixed Liquor Suspended Solids (MLSS)	60
	Mixed Liquor Volatile Suspended Solids (MLVSS)	61
	Ortho-Phosphorus (PO ₄ ³⁻ -P)	62
	Ammonia Nitrogen (NH ₃ -N)	62
	Sludge Volume Index (SVI)	63
	Kinetic Constant	63
IV	RESULTS AND DISCUSSION	67
	Results of Strategy A	67
	COD Removal	68
	TSS Removal	70
	BOD ₅ Removal	72
	NH ₃ -N and PO ₄ ³⁻ -P Removal	74
	Results of Strategy B	82
	COD Removal	83
	TSS Removal	85
	BOD ₅ Removal	87
	NH ₃ -N and PO ₄ ³⁻ -P Removal	89
	The effect of Loading Rate (<i>Li</i>) (based on the aerobic period during React step) on the Removal efficiency	92
	The effect of Loading Rate (<i>Li</i>) (based on the aerobic period during React step) on the SVI	97
	Kinetic Growth Coefficient at Different Operational Mode	98
V	CONCLUSION	107
	Recommendation	108
	REFERENCES	110
	APPENDICES	119
	A: Composition of Media and Solution	119
	A1: Composition of COD reagents	119
	A2: Composition of BOD reagents	121
	B: Data sheets of Strategy A	123
	B1: Daily influent and effluent concentration at 6h, 8h and 10h cycle time	123
	C: Data sheets of Strategy B	126
	C1: Daily influent and effluent concentration at 1/2.7, 1/1 and 1.7/1 operational mode	126
	C2: Track analysis of MLVSS and COD concentration at 1/2.7, 1/1 and 1.7/1 operational mode	129
	C3: Specific growth rate (μ) and specific substrate Utilisation rate (<i>U</i>) at 1/2.7, 1/1 and 1.7/1 operational mode	130



LIST OF TABLES

Table	Page
2.1 Typical composition of untreated domestic wastewater.	9
2.2 Types and numbers of microorganism typically found in untreated domestic wastewater.	10
2.3 Typical mineral increase from domestic water use.	11
2.4 Description of the operational steps for the SBR.	15
2.5 Advantages and disadvantages of SBR.	21
2.6 Types of waste treated by SBR.	44
2.7 The comparison of the economy of the main treatment system	49
2.8 List of SBR wastewater treatment plants in Malaysia	50
3.1 Summary of the conditions for Strategy A.	53
3.2 Summary of the average characteristics of the influent	55
3.3 Summary of the conditions for Strategy B.	56
4.1 Influent and effluent qualities for SBR operated with cycle time of 6, 8 and 10h.	67
4.2 Influent and effluent qualities for SBR operated with operational mode of 1/2.7, 1/1 and 1.7/1 (anaerobic and aerobic period ratio).	82
4.3 Summary of biological kinetic constant for different operational mode of 1/2.7, 1/1 and 1.7/1 (anaerobic and aerobic period ratio).	105
B1 Daily COD influent and effluent concentration at 6h, 8h and 10h cycle time.	123
B2 Daily BOD ₅ influent and effluent concentration at 6h, 8h and 10h cycle time.	123
B3 Daily TSS influent and effluent concentration at 6h, 8h and 10h cycle time.	124

B4 Daily NH ₃ -N influent and effluent concentration at 6h, 8h and 10h cycle time.	124
B5 Daily PO ₄ ³⁻ -P influent and effluent concentration at 6h, 8h and 10h cycle time.	125
C1 Daily COD influent and effluent concentration at 1/2.7, 1/1 and 1.7/1 operational modes.	126
C2 Daily BOD ₅ influent and effluent concentration at 1/2.7, 1/1 and 1.7/1 operational modes.	126
C3 Daily TSS influent and effluent concentration at 1/2.7, 1/1 and 1.7/1 operational modes.	127
C4 Daily NH ₃ -N influent and effluent concentration at 1/2.7, 1/1 and 1.7/1 operational modes.	127
C5 Daily PO ₄ ³⁻ -P influent and effluent concentration at 1/2.7, 1/1 and 1.7/1 operational modes.	128
C6 MLVSS and COD concentration at 1/2.7, 1/1 and 1.7/1 operational modes.	129
C7 Value of μ and U at 1/2.7, 1/1 and 1.7/1 operational modes.	130

LISTS OF FIGURES

Figure	Page
2.1 Sewage composition.	8
2.2 Typical operating sequences for a SBR.	16
2.3 Liquid volume versus time for one reactor.	19
2.4 Typical bacterial growth curve in terms of numbers.	25
2.5 $\ln X$ vs. time.	29
2.6 Plot of specific growth rate, μ vs. specific substrate utilisation rate, U .	31
2.7 Division of the total influent COD in municipal wastewater into its various constituent fractions.	40
3.1 Schematic of reactor.	51
3.2 Plot of $\ln X$ vs time.	64
3.3 Plot of specific growth rate, μ vs. specific substrate utilisation rate, U .	66
4.1 Daily influent and effluent COD at different cycle time.	69
4.2 Daily influent and effluent TSS at different cycle time.	71
4.3 Daily influent and effluent BOD ₅ at different cycle time.	73
4.4 Daily influent and effluent NH ₃ -N at different cycle time.	75
4.5 Daily influent and effluent PO ₄ ³⁻ -P at different cycle time.	76
4.6 Efficiency of COD, TSS, BOD ₅ , NH ₃ -N and PO ₄ ³⁻ -P removal at different cycle time.	78
4.7 Daily influent and effluent COD at different operational modes.	84
4.8 Daily influent and effluent TSS at different operational modes.	86
4.9 Daily influent and effluent BOD ₅ at different operational modes.	88
4.10 Daily influent and effluent NH ₃ -N at different operational modes.	90

4.11 Daily influent and effluent $\text{PO}_4^{3-}\text{-P}$ at different operational modes.	91
4.12 Efficiency of COD, TSS, BOD_5 , $\text{NH}_3\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ removal at different operational modes.	96
4.13 Profile for MLVSS and COD concentration at different operational modes.	98
4.14 $\ln X$ vs. time at different operational modes.	102
4.15 μ vs. U at different operational modes.	104



LIST OF PLATES

Plate	Page
3.1 Reactor used in the study.	52

LIST OF ABBREVIATIONS

μ	-	Specific growth rate
μ_{\max}	-	maximum specific growth rate
BOD	-	Biological / Biochemical Oxygen Demand
BOD ₅	-	Five days Biological Oxygen Demand
COD	-	Chemical Oxygen Demand
DO	-	dissolved oxygen
EPBR	-	enhanced biological phosphate removal
EQA	-	Environmental Quality Act
F/M	-	food to microorganism ratio
HDT	-	hydraulic detention time
IWK	-	Indah Water Konsortium
K	-	maximum substrate utilizing rate
k_d	-	endogenous decay rate
Li	-	loading rate
MGD	-	milligallon per day
ML	-	mixed liquor
MLSS	-	mixed liquor suspended solids
MLVSS	-	mixed liquor volatile suspended solids
PAO	-	phosphorus-accumulating organisms
PHB	-	poly- β -hydroxybutyrate
RBCOD	-	readily biodegradable Chemical Oxygen
r_g	-	bacterial growth rate

r_{su}	-	substrate utilization rate
S	-	substrate concentration
S_{bi}	-	biodegradable Chemical Oxygen Demand
S_{bpi}	-	particulate slowly unbiodegradable Chemical Oxygen Demand
SBR	-	Sequencing Batch Reactor
SCFA	-	short chain fatty acid
SS	-	suspended solids
S_{sbi}	-	soluble readily biodegradable Chemical Oxygen Demand
S_{ti}	-	total influent Chemical Oxygen Demand
S_{ui}	-	unbiodegradable Chemical Oxygen Demand
S_{upi}	-	particulate unbiodegradable Chemical Oxygen Demand
SVI	-	Sludge Volume Index
T or t	-	time
TDS	-	total dissolved solids
TKN	-	Total Kjeldahl Nitrogen
TOC	-	total organic carbon
TS	-	total solids
TSS	-	total suspended solids
U	-	specific substrate utilization rate
U.S. EPA	-	United States Environmental Protection Agency

UASB	-	Upflow Anaerobic Sludge Blanket
VFAs	-	volatile fatty acids
X	-	microorganism concentration
Y_x	-	cell growth yield

CHAPTER I

INTRODUCTION

Every community in this world produces both liquid and solid-wastes. Due to the development, the living standard of our nation is increasing. This will consequently cause the increment of the waste generation and the demand of the clean water.

A supply of clean water is an essential requirement for the establishment and maintenance of a healthy community. It acts not only as a source of potable water, but also provides valuable food supplements through supporting the growth of aquatic life and irrigation in agriculture.

As we know, water is universal; water is all around us. It represents the medium of life on earth and one of the four ancient “elements”. All body functions depend on water and plants and animals learn to adapt their body functions to humid and dry conditions of their environment.

Hence human and animal life cannot exist without a minimum amount of potable water. However, many biological and chemical contaminants have been known for years to be harmful to human and animal health. New contaminants have been discovered to be harmful in recent years.



Therefore, the immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment and disposal, is not only desirable but also necessary in an industrialised society. This is because if there is accumulation of untreated wastewater, the decomposition of the organic materials can lead to the production of large quantities of malodorous gases. It usually contains numerous pathogenic, disease-causing microorganisms that dwell in the human intestinal tract. In addition, wastewater also contains nutrients, which can stimulate the growth of aquatic plants and may contain toxic compounds.

Today, not only must a wastewater treatment plant satisfy effluent quality requirements, it must also satisfy many other environmental conditions. The purpose of the wastewater treatment before discharging is to convert the components in raw wastewater (its inherent characteristics) into a relatively harmless final effluent for discharge.

Presently, most of the unit operations and processes used for wastewater treatment are undergoing continual and intensive investigation from the standpoint of implementation and application. In order to meet the increasingly stringent requirements for environmental enhancement of watercourses, many modifications and new operations and processes have been developed and implemented.

Presently, there are many treatment systems such as activated system, anaerobic system, etc. A developing country like, Malaysia; there will be more alternatives to be chosen. One of them is the Sequencing Batch Reactor (SBR).

Meanwhile, SBR has emerged as an innovative technology in the wastewater treatment industry. This is because SBR can accomplish the tasks of primary clarification, biooxidation and secondary clarification within the confines of a single reactor. Furthermore, advances have occurred in sludge bulking control technologies using selector mechanisms.

Therefore, among the alternatives, Sequencing Batch Reactor (SBR) is becoming more and more popular due to the low land requirement and simpler than other activated sludge systems. Beside that, it requires small capital investment and minimum operational skills. It was also found that the biomass in an SBR would be subjected to high substrate tension that provides an effective means for the control of filamentous bacteria and, thus, sludge bulking. In addition, SBR is also effective in the removal of nitrogen and phosphorus.

A properly designed SBR process is a unique combination of equipment and software comprising a complete secondary wastewater treatment facility. There is a widespread belief that periodic processes (like SBR) are a recent development and still in a development stage. It can't be denied that SBR thus has its disadvantages. However, the advantages of its efficiency the in wastewater treatment can't be neglected.