UNIVERSITI PUTRA MALAYSIA

SIMULTANEOUS REMOVAL OF CARBON, NITROGEN AND PHOSPHORUS FROM DOMESTIC WASTEWATER BY SEQUENCING BATCH REACTOR

HO YUN KIT

SIMULTANEOUS REMOVAL OF CARBON, NITROGEN AND PHOSPHORUS FROM DOMESTIC WASTEWATER BY SEQUENCING BATCH REACTOR

By

HO YUN KIT

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

September 2001

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

SIMULTANEOUS REMOVAL OF CARBON, NITROGEN AND PHOSPHORUS FROM DOMESTIC WASTEWATER BY SEQUENCING BATCH REACTOR

By

HO YUN KIT

September 2001

Chairman: Dr. Fakhru'l-Razi Ahmadun

Faculty : Engineering

Sequencing Batch Reactor(SBR) had been found to be an alternative biological treatment for simultaneous removal of carbon, nitrogen and phosphorus from domestic wastewater. Nevertheless studies of this alternative treatment system are few in Malaysia. Thus, research has to be done to explore the potentials of such treatment in our country.

A bench scale SBR with a working volume of 2 L, was set up. The reactor had a stable flowrate of 1.4L/hr maintaining a food to microorganism ratio of around 0.16 and a minimum sludge age of 6-9 days. In this study, two major operational strategies were used in achieving the best removal of the three nutrients. In the first operational strategy where different total cycle hours were applied, the 6 hour total

cycle hour produced the best removal efficiency in terms of total suspended solids (TSS)[97%], biological oxygen demand (BOD)[85%], chemical oxygen demand (COD)[87%] and total Kjeldahl nitrogen (TKN)[>90%]. Nevertheless phosphorus removal seemed to be comparable with the other strategy operations, 8hr and 10hr total cycle time.

The next operational strategy involved the manipulation of various ratio of aerobic and anaerobic period. Three main ratio, anaerobic:aerobic(fill:react) ratio of 1:2.7, 1:1 and 1.7:1 were taken into consideration. Longer aerobic period (fill:react ratio 1:2.7) produced the best removal efficiency for TSS(95%), COD(89%), BOD(90%) and TKN (>90%). Total phosphate removal efficiency averaged about 38%. Hence, longer aerobic period strategy produced better overall nutrients removal efficiency.

In operational strategy involving fill:react ratio, the nitrification rates ranged from 1.2 to 2.4 mg.g^{-1} VSS day^{-1} which were comparable to previous studies(Palis & Irvine.,1985; Vuoriranta *et.al.*,1993; Rustrian *et.al.*, 1998). The denitrification rates ranged from 1.2 to 3.7 mg.g^{-1} VSS day^{-1} which were also comparable to previous works(Palis & Irvine, 1985; Vuoriranta *et.al.*,1993; Bortone *et.al.*, 1994; Rustrian *et.al.*, 1998). The P-release rates ranged from 0.018 to 0.027 mg P/g VSS/min while P-uptake rates ranged from 0.010 to 0.024 mg P/g VSS/min.

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

RAWATAN BERSAMA UNTUK KARBON, NITROGEN DAN FOSFORUS DALAM DARI AIR SISA KUMBAHAN DOMESTIK MELALUI 'SEQUENCING BATCH REACTOR'

Oleh

HO YUN KIT

September 2001

Pengerusi: Dr. Fakhru'l-Razi Ahmadun

Fakulti : Kejuruteraan

'Sequencing Batch Reactor'[SBR] telah mendapat perhatian meluas sebagai salah proses alternatif biologi dalam rawatan bersama elemen karbon, nitrogen serta fosforus dari air kumbahan domestik. Walau bagaimapun, proses ini kurang dikajiselidik oleh para saintis di negara Malaysia. Oleh yang demikian, kajian perlu dijalankan meggunakan proses ini dalam memenuhi keperluan negara.

Dalam kajian ini, sebuah reaktor kecil dengan isipadu berfungsi 2L telah digunakan. Reaktor ini berfungsi the kadar aliran masuk dan keluar yang mantap iatu 1.4L/hr serta mempunyai nisbah makanan kepada mikroorganisma sebanyak 0.16. Reaktor ini juga megekalkan umur enapan kumbahan selama 6-9 hari.

Dalam kajian ini, dua strategi operasi telah digunakan dalam rawatan air sisa kumbahan. Dalam strategi operasi pertama telah melibatkan jumlah masa proses

yang berlainan. Dalam jumlah masa proses SBR 6 jam, effisien pengurangan dalam rawatan adalah paling berkesan dari segi aspek jumlah pepejal terampai (TSS) [97%], penentuan permintaan oksigen biologi (BOD))[85%], penentuan permintaan oksigen kimia (COD) [87%], nitrogen (TKN)[>90%]. Namun begitu, rawatan untuk fosforus tidak setanding dengan strategi operasi yang lain.

Dalam operasi strategi yang berikutnya, manipulasi pelbagai nisbah masa aerobik serta anaerobik telah dijalankan. Dalam tiga nisbah yang dikaji iaitu anaerobik:aerobik 1:2.7, 1:1 dan 1.7:1, strategi yang mempunyai masa aerobik yang lebih tinggi iaitu anaerobik:aerobik 1:2.7 telah memperolehi rawatan yang terbaik. Strategi ini telah memperolehi effisien rawatan tertinggi bagi aspek TSS(95%), COD(89%), BOD(90%) and TKN (>90%). Namun begitu, rawatan untuk fosforus tidak setanding dengan strategi operasi yang lain. Ia hanya effisien rawatan pemulihan sebanyak 38%. Namun demikian perbezaan effisien rawatan adalah setanding the 2 strategi lain.

Dalam nisbah masa aerobik serta anaerobik, kadar nitrifikasi adalah dalam lingkungan 1.2-2.4 $mg.g^{-1}$ VSS day^{-1} setanding dengan kajian terdahulu (Palis & Irvine.,1985; Vuoriranta *et.al.*,1993; Rustrian *et.al.*, 1998). Bagi kadar denitrifikasi, kajian ini mendapat kadar dalam lingkungan 1.2-3.7 $mg.g^{-1}$ VSS day^{-1} juga setanding kajian lain (Palis & Irvine, 1985); Vuoriranta *et.al.*,1993; Bortone *et.al.*, 1994; Rustrian *et.al.*, 1998). Bagi kadar pelepasan fosforus adalah dalam lingkungan 0.018 – 0.027 mg P/g VSS/min dan kadar pengambilan fosforus ialah dari 0.010-0.024 mg P/g VSS/min.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my main supervisor, Dr. Fakhru'l-Razi for his constant guidance and advises throughout the period of my study.

In addition, I wish to thank members of my supervisory committees, Dr.Azni, En. Abdul Ghani Malik and Dr. Sa'ari, for their time and energy spent in making this a better work.

My appreciation also goes to the laboratory staff and lab members for their support and assistance throughout my stay in the laboratory.

TABLE OF CONTENTS

		Page
ABSTRACT		ii
ABSTRAK		iv
ACKNOWLEDGEMENTS		vi
APPROVAL SHEETS		vii
DECLARATION FORM		ix
TABLE OF CONTENTS		x
LIST OF TABLES		xii
LIST OF FIGURES		xiii
LIST OF ABBREVIATIONS		xiv
CHAPTER		
I	**INTRODUCTION**	1
	Objective	3
II	**LITERATURE REVIEW**	4
	Sequencing Batch Reactor	4
	Biological Nitrogen Removal	11
	Biological Phosphate Removal	16
	Kinetic Studies	21
	Maximum Cell Yield Coefficient & Endogenous Decay Coefficient	21
	Nitrification Rate	23
	Denitrification Rate	25
	Phosphate Release and Uptake Rates	26
	SBR in Malaysia	27
	Economic Comparison	29
III	**MATERIAL AND METHOD**	31
	Study Site	31
	Experimental Design	31
	Study Parameters	32
	Laboratory Analysis	34
	Storage of Wastewater and Samples	34
	Preservation	35
	Experimental Procedure	36
	SBR Cycle Strategies	42

IV	**RESULTS**	
	Preliminary Stage (Strategy A)	48
	Physical Parameters	46
	Chemical Parameters	53
	Advanced Stage (Strategy B)	62
	Physical Parameters	62
	Chemical Parameters	66
V	**DISCUSSIONS**	76
	Preliminary Stage (Strategy A)	76
	Physical Parameters	76
	Chemical Parameters	77
	Advanced Stage (Strategy B)	83
	Physical Parameters	83
	Chemical Parameters	85
	Kinetic Studies	99
VI	**CONCLUSION**	107
	Recommendation	108
REFERENCES		111
APPENDICES		
A	Experimental Data	116
B	Material and Method	134
BIODATA OF THE AUTHOR		145

LIST OF TABLES

Table		Page
2.1	Advantages and disadvantages of Sequencing Batch Reactor	10
2.2	List of SBR Wastewater Treatment Plants in Malaysia.	28
2.3	The comparison of the economy of the main treatment systems.	30
3.1	Summary of analysis used based on "Standard Methods For the Examination of Water And Wastewater 14 edition, 1975".	33
3.2	Form of Preservations	35
3.3	Summary of the conditions for Strategy A	37
3.4	Summary of the conditions for Strategy B	38
4.1	Influent and effluent characteristics for SBR systems with operational strategy of 6hr , 8hr and 10hr cycle time.	46
4.2	Influent and effluent characteristics for SBR systems with operational strategy based on different aerobic : anaerobic ratio.	47
5.1	Kinetic coefficient obtained from different operational strategy of fill:react ratio manipulating aerobic and anaerobic phase	99
5.2	Nitrification rate obtained from different operational strategies of Fill:react ratio manipulating aerobic and anaerobic phase	101
5.3	Nitrification rate obtained from different operational strategies of Fill:react ratio manipulating aerobic and anaerobic phase	102
5.4	Phosphate uptake and release rate obtained from different operational Strategies of fill:react ratio manipulating aerobic and anaerobic phase	105

LIST OF FIGURES

Figure		Page
2.1	Plot of specific growth rate, μ vs. specific substrate utilisation rate, U	23
3.1	An overall view of the experimental work done.	40
3.2	Experimental laboratory-scale SBR system.	41
3.3	Operational schedule for preliminary cycles	43
3.4	Operational schedule for fill:react strategies	43
4.1	Daily influent and effluent TSS at different cycle time.	50
4.2	Daily influent and effluent BOD at different cycle time.	55
4.3	Daily influent and effluent COD at different cycle time.	57
4.4	Daily influent and effluent ammonical nitrogen at different cycle time.	60
4.5	Daily influent and effluent orthophosphate at different cycle time.	62
4.6	Daily influent and effluent TSS at different operational strategy.	64
4.7	Daily influent and effluent BOD at different operational strategy.	67
4.8	Daily influent and effluent COD at different operational strategy.	69
4.9	Daily influent and effluent ammonical nitrogen at different operational strategy.	71
4.10	Daily influent and effluent orthophosphate at different operational strategy.	73
4.11	μ vs. U at different operational mode	75
5.1	Periodical studies of fill:react (1:2.7) strategy process	88
5.2	Periodical studies of fill:react (1:1) strategy process	89
5.3	Periodical studies of fill:react (1.7:1) strategy process	90
5.4	Cyclic studies of fill:react (1:2.7) strategy process	96
5.5	Cyclic studies of fill:react (1:1) strategy process	97
5.6	Cyclic studies of fill:react (1.7:1) strategy process	98

LIST OF ABBREVIATIONS

ASAP	As Soon As Possible
BOD_5	Biological Oxygen Demand of 5 days
COD	Chemical Oxygen Demand
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Suspended Solids
N	Nitrogen
na	Not Available
NO_3-N	Nitrate Nitrogen
NO_2-N	Nitrite Nitrogen
NO_x-N	Inorganic Nitrogen
Ortho	Orthophosphate
P	Phosphate
PVC	Polyvynilchloride
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphate
TSS	Total Suspended Solids
SBR	Sequencing Batch Reactor
SS	Suspended Solids
VFA	Volatile Suspended Solids
SVI	Sludge Volume Index

CHAPTER I

INTRODUCTION

As the world progresses into the new millennium, countries continue to move ahead seeking advancement and better living lifestyle. In the process, wastewater generates from all aspects of human activity increase in volume and diversity in characteristic. Hence, the preferred continuous flow treatment system would also become more complex in set-up and operation processes.

In addition, as treatment processes develop in complexity, land needed for treatment plant set-up would increase too. But in reality, not many countries could afford such a situation. Therefore, wastewater treatment systems presently in used worldwide, needed some diversification in set-up or better if new technologies are invented. Even if land factor is not a constraint, a complicated plant may need high capital investment. Treatment plant with many reactors and clarifiers and other equipment would normally increase cost in maintenance for the operational equipment. In addition, advanced technologies treatment plant would also need highly skilled operators. This would also definitely increase operation costs.

As years gone by, rules and regulation of wastewater treatment plant discharge has become more stringent. Such a development in regulation would continue in future. Therefore, more efficient and advanced treatments have to be developed in order to achieve the required standards. Another issue on hand is the eutrophication of lakes, rivers and other water resources, which is receiving worldwide attention. Nutrients like nitrogen and phosphorus are the primary causes of eutrophication It is therefore not unusual to realize that standard for both nutrients have been increasingly stringent over the past two decades Though existing biological and chemical processes can remove these nutrients, nonetheless it has not come in a simple way and it does increase the cost of treatment Therefore researchers are now working round the clock to search for better, simpler and cost effective solutions

One of the alternative treatments that surface, sequencing batch reactor (SBR) stands out for a few particular reasons. SBR is making a comeback as a choice of wastewater treatment for the future Though once neglected for various reasons, its popularity seems to increase owing to the fact that tremendous improvement and advancement in automation technology had taken place The strong point about SBR is that it does not need a train of reactors like continuous flow treatment systems All it does need is a single reactor in order to achieve a simultaneous removal of carbon, nitrogen and phosphorus from wastewater In short, SBR offers flexibility that not many treatments system could offer in performing many tasks at hand efficiently

Another advantage of the SBR system is that land space occupied is lower than the presently preferred continuous flow system Thus this would reduce the capital investment in setting up treatment plant With good computational software and automation technology, SBR could function effectively and easily be maintained Thus in the long term, operational and maintenance cost would also be lower

In short, though SBR thus has its own shortcomings, such as the need to has skilled operator, currently restricted to small and medium treatment plants, but the advantageous of a well managed and efficient SBR system cannot be overlooked. SBR stands out as a system that are space and cost effective with capabilities of removing nutrients such as nitrogen and phosphorus.

Objective

To investigate whether sequencing batch reactor can be an alternative process in managing simultaneous removal of carbon, nitrogen and phosphorus from domestic wastewater.

Scope of study:

i) To study the effects of nutrient removals on effluent quality through;

   a) The effect of different Cycle Time (6 hr, 8hr, 10hr).

   b) The effect of different Operational Mode (Anaerobic and Aerobic ratio), (1/2.7, 1:1 and 1.7/1)

CHAPTER II

LITERATURE REVIEW

Sequencing Batch Reactor

Activated sludge wastewater treatment system has evolved tremendously since Ardern and Lockett introduced it in 1914. The original activated sludge system introduced was operated in a batch mode (fill and draw type). From that point in history, the present day preferred continuous flow system were developed thereafter and since then it has replaced fill and draw treatment schemes. As continuous flow system gained popularity, batch mode schemes had taken a step backward in development. Batch processes usage have never reaches its capacity because of few design constraints (Hoepker & Schroeder, 1979):

1) High oxygen uptake rates during fill phase.
2) Aeration time necessary to achieve organic removal and nitrification.
3) Amount of denitrification that can be obtained through endogenous respiration.
4) Process stoichiometry and kinetics.
5) Effluent turbidity caused by dispersed (nonflocculant) cells.

Continuous-flow wastewater treatment, has since dominated in wastewater treatment process especially in biological waste treatment (Irvine, & Dennis, 1979; Irvine *et.al.*, 1979; Hoepker, & Schroeder,1979). Completely mixed activated sludge tank has become the standard for secondary waste treatment. However, continuous-flow systems were found later not to be as perfect as it should be. They are prone to suffer occasional upsets. Effluent quality from a secondary waste treatment plant in reality is not found to be as consistent and reliable as theoretically predicted by steady-state design equations. Fluctuations in influent flow-rate and influent waste strength were found to be the main culprits in causing inconsistency results when operate under steady-state (Irvine, & Dennis, 1979).

As countries become more advanced in technologies, wastewater characteristics around the world have diversified into more complex components. Without having really solved its initial drawbacks, continuous-flow activated sludge system became progressively more complex and sophisticated in synchrony with the progress and advancement achieved by countries (Fang *et.al.*, 1994). Under such circumstances, Irvine and co-workers (Irvine *et.al.*, 1979; Fang *et.al.*, 1994) had taken the chance to re-examine the fill-and-draw type batch operation, renaming it Sequencing Batch Reactor (SBR). This development is the second resurgence of this treatment since the first short-lived initial resurgence of SBR treatment by Eastern Regional Research Laboratory by Hoover *et.al.* in the early 1950's (Irvine *et.al.*, 1979).

The second resurgence by Irvine and co-workers has since open the eyes of many groups of other researchers. Since then SBR has made significant progresses especially with contribution by Irvine research group. The recent advances in process control and digital process computers have added to SBR progresses. Therefore, as the world move toward the new millennium, SBR has been hand-picked as one of the alternative treatment system that have much to offer as continuous-flow activated sludge had contributed in the last few decades.

Sequencing Batch Reactor (SBR) is a draw-and-fill activated sludge treatment system and thus the units involved are the same as conventional activated sludge system. SBR is a time-oriented system as compared to the space oriented conventional activated sludge system. There are five discrete operational periods during one cycle for each batch tank in a sequencing batch treatment facility. Each treatment cycle includes the following stages: fill, react, settle, draw/decant and idle (Irvine *et.al.*, 1979; Irvine, & Dennis, 1979; Irvine *et.al.*, 1993; Garzon-Zuniga & Gonzalez-Martinez, 1996).

The cyclic operation in SBR gives the option of mixing or/and aeration or vice versa producing aerobic or anoxic or anaerobic condition at different time of treatment. Each condition set-up in reactor will be in best interest of targeted influent characteristics (e.g. poly-p organisms need anaerobic condition follow by aerobic condition in order to have complete removal of phosphorus).

During the fill stage, the tank is fill with influent during a distinct period of time In the fill period, organism selection can be controlled by manipulating the actual specific growth rates of the microbes and by regulating the oxygen tension in reactor (e g from anaerobic to anoxic to anaerobic) [Irvine, *et.al.*, 1993] However, prior to a fill period, settled solids would be contained in the bottom portion of the reactor at a concentration of 8000 mg/l to 10 000 mg/l (Irvine, & Dennis, 1979, Irvine *et.al.*, 1979) As a result, the tank contains an active and sizeable organism population Therefore, bulk of the treatment may be completed prior to the end of fill stage unless measure is taken to slow down the reaction (e g elimination of aeration)

In some circumstances, tank reaches maximum liquid holding capacity prior to the cessation of wastewater flow for that day Hence, in a SBR system, two or more reactors would be required to accommodate a continuous flow of wastewater (Irvine, & Dennis, 1979) However, the flow profile for many rural municipalities and industries is such that little or no discharge occurs for an appreciable portion of the day Under these circumstances, a single tank should be sufficient (Irvine *et.al.*, 1979, Okada & Sudo, 1986)

The react period is the stage where the tank receives in no flow Mechanical mixing or/and air supply can be adjusted to complete the desired reactions The react period normally takes up about 35% of the total cycle time in a standard SBR system During the fill stage, much desired reaction can be brought to virtual completion (e g nitrification and denitrification) Nonetheless, react period, offers flexibility necessary to ensure that proper reactions are completed and a particular reaction would not have adverse effect on other reactions

The subsequent stage of treatment after react is settle period. During settle period, all mixing and aeration are stopped and the organisms are allowed to settle leaving the clarified treated water above. Settle period in standard SBR systems take up about 20% of the total cycle time. A prolonged settled period must be avoided since settled sludge may begin to float to the surface (Irvine *et.al.*, 1979).

After sufficient solids separation the clarified waters are discharged. The period of discharge is termed the draw/decant period. An idle period in system followed after the draw period while it awaits the return of the next cycle wastewater. Mixing and aeration may be an option during the idle period if necessary. In addition, solids can be wasted during the idle period. The frequency of wastage is determined by the net solids increase in the system each day and the capacity of mixing and aeration equipment (Irvine *et.al.*, Peavy *et.al.*, 1985).

Contribution of many works done on SBR system by researchers such as Irvine and co-workers has identified a number of advantages of SBR over conventional activated sludge systems:

i) cycling between anoxic and aerobic periods of operation (Dikshitulu *et.al.*, 1993).

ii) greater flexibility in meeting changes in feed conditions (Dikshitulu *et.al.*, 1993; Okada & Sudo, 1986).

iii) Reactions that must be physically separated in continuous-flow systems such as nitrification and denitrification can be carried out in a single tank. (Dikshitulu *et.al.*,1993; Okada, & Sudo, 1986).

iv) Better control over settling characteristics of the sludge (Dikshitulu *et al*.,1993)

v) Single tank batch system, sequencing on daily cycle provides low capital and operating costs (Irvine *et.al.*,1979)

vi) High mixed liquor solids concentration limits light penetration, thus preventing algae growth (Irvine *et.al.*,1979)

vii) Biomass in SBR, subjected to high substrate tension, provide effective means for control of filamentous bacteria and thus, sludge bulking (Fang *et.al.*,1993)

viii) Professional maintenance works are not necessary since configuration of SBR system is relatively simple (Okada, & Sudo, 1986)

ix) Effective simultaneous removal of nitrogen, carbon and phosphorus (Okada, & Sudo, 1986, Fang *et.al.*,1993, Subramaniam *et.al.*, 1994)

Table 2.1 Advantages and disadvantages of Sequencing Batch Reactor

Advantages	Disadvantages
1. Operational flexibility (variation of cycles).	1. High construction and operation costs.
2. Satisfactory N and possible P removal.	2. Higher installed power than other activated sludge systems.
3. Secondary settler and recycle pumps not necessary.	3. Need of sludge treatment and disposal (variable with conventional and extended mode).
4. Simpler than other activated sludge systems	4. Usually more competitive for smaller populations.
5. High efficiency in BOD removal.	
6. Low land Requirements.	

Source: (Marcos, 1996)