TREATMENT OF PHARMACEUTICAL WASTEWATER USING SEQUENCING BATCH REACTOR

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Treatment of Pharmaceutical Wastewater Using Sequencing Batch Reactor

by

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Dissertation submitted in partial fulfilment
of requirements for the
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(Civil Engineering)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the originality of the work is my own expect as specified in the references and acknowledgements, and that the originality work contained herein have not been undertaken or done by unspecified sources or persons.

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(NATASHA RAMDASS)

CERTIFICATION OF APPROVAL

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Approved by,

____

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ABSTRACT

The objective of this study was to determine the optimum operating conditions for the effective treatment of a pharmaceutical wastewater by sequencing batch reactor. The wastewater sample was obtained from a pharmaceutical company in Bangi, Kuala Lumpur. The characteristics of the wastewater: pH 4.36; BOD_5 765 mg/L; COD 1352mg/L; TSS 71.3 mg/L; NH_3-N 6.8 mg/L; NO_3-N 30 mg/L; total phosphorus 18.13 mg/L; sulphate 20 mg/L, sulphide 0.28 mg/L and TKN 44.34 mg/L. The wastewater was treated using sequencing batch reactor process that included the following five stages: Fill, React, Settle, Decant and Idle. Three different HRT values were tested (12 hr, 24 hr and 48 hr) with each cycle operating under high MLSS and low MLSS concentrations simultaneously. Both reactors operated with an organic loading rate of 1.35 kg COD/m^3. A 24 hr HRT showed the best performance. Optimum operating conditions resulted in the following effluent characteristics, COD 217±23.2 mg/L, BOD 46±9.8 mg/L, pH 7.7±0.2, TNK 23.35±17 mg/L, NO_3-N 0.21±0.08 mg/L and NH_3-N 4.4±2.1 mg/L. It is recommended to use a pre treatment by chemical or anaerobic process.

ACKNOWLEDGEMENT

Firstly, I would like to give thanks to God for blessing me with this opportunity and giving me guidance and strength in the past year. I am forever grateful and honored to have been able to complete my studies here in Universiti Teknologi Petronas.

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CHAPTER 1
INTRODUCTION

1.1 Background of the Study

Pharmaceuticals or medical substances are substances formulated with the intention of fulfilling a biological purpose of some sort. Pharmaceuticals present in receiving waters (after wastewater treatment) are a result of a number of sources such as pharmaceutical industries, animal and human excretion etc, as depicted in Fig 1.1

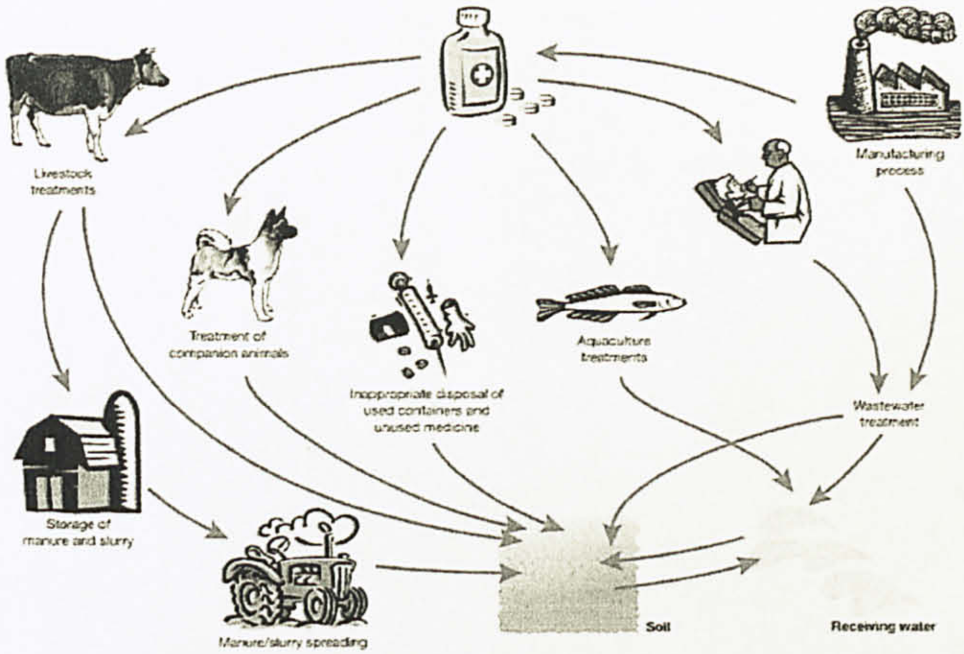

Fig 1.1. Sources of Pharmaceuticals in Environment

In the past, the presence of pharmaceuticals and chemicals in wastewater and environment was acknowledged but a challenge to quantify because of their low concentrations. As time progressed, more and more of these products are being used in hand with the developing world causing increasing concentrations noted in wastewater and environment.

The ability to quantify, however low levels of pharmaceuticals in environment are being documented, has alerted researchers of their threatening effects. Recent research confirms findings of low levels of pharmaceuticals in the environment and suggests that certain ingredients in the products could affect aquatic life and subsequently the ecosystem. Regardless of the level of wastewater treatment using conventional biological treatment, pharmaceuticals cannot effectively be treated due to the nature of the compounds. However, recent studies have shown promise in the use of Sequencing Batch Reactors (SBR).

Sequencing Batch Reactors are activated sludge processing tanks which operate under non steady conditions for the treatment of wastewater. The wastewater is treated in batches with aeration and settlement both occurring in the same tank. There are two major differences between SBR and continuous activated sludge system which are that the former carries out functions of equalization aeration and sedimentation in time sequence and is flexible to treatment of a wide range of influent volumes, whereas the latter functions on a conventional space sequence and is limited to a fixed influent flowrate. There are five basic stages of a SBR system : fill, react, settle, draw and idle. Aeration of the mixed liquor occurs in the first two stages, seeding the influent. Sludge is formed and ammonia is broken down into nitrites and nitrates. The settling stage settles the sludge created in aeration phase with the continued consumption of oxygen leading up to the process of denitrification (Burton et al, 2004).

1.2 Problem Statement

The difficulty in treatment of pharmaceutical industrial wastewater is its characteristic high content of organic matter, toxicity, deep colour and high salt content. This, as a result, prevents standards from being met with conventional biological processes alone. This study served to investigate the effectiveness of the treatment of pharmaceutical wastewater using sequence batch reactor (SBR).

1.3 Objectives and Scope of the Study

To subject the sample wastewater to biological treatment using sequencing batch reactor at three hydraulic retention times (HRT) at a high and low biomass concentrations to determine optimum operating conditions that meet specified effluent standards.

The scope of study for this project aims to fulfil the above mentioned objective, over a course of 12 months. These twelve months were divided into two semesters ie, FYP 1 and FYP 2. During semester one (June – December 2009) the work covered was centred mainly around literature search and planning. Literature search included the application of sequencing batch reactor to other industrial wastewater, treatment methods other than sequencing batch reactor that has been applied to pharmaceutical wastewater and cases of the use, in some way or the other, of sequencing batch reactor to a wastewater similar to wastewater from the pharmaceutical industry.

This study is relevant in analyzing the effectiveness of pharmaceutical wastewater treatment by SBR as compared to other treatment methods applied in industry. Preliminary characterisation of the wastewater sample in terms of BOD, COD, suspended solids, pH, sulphates, sulphides, ammonia nitrogen, nitrate nitrogen, total phosphorus and total kejeldahl nitrogen (TKN) was carried out. Semester two was allocated to experimental work which was drawn from research documented in semester one. Experimental work was carried out using a bench (lab) scale setup of sequencing batch reactor to treat wastewater from a pharmaceutical company in Bangi, Kuala Lumpur. All laboratory work was conducted in accordance to the Standard Methods (2005).

CHAPTER 2
LITERATURE REVIEW

2.1 Pharmaceutical Wastewater and Treatment

The pharmaceutical industry uses both inorganic and organic raw materials in production. A wide variety of products are produced which fluctuates the characteristics of the wastewater effluent. Generally, most of the waste is toxic to biological life and is characterized by a low BOD/COD ratio (Badawy et al, 2009).

The treatment of pharmaceutical wastewater has been a growing concern with an increase in their presence in receiving waters; however, treatment to the desired effluent standards is tricky with the wider variety on products being produced. The following presents some literature on pharmaceutical wastewater treatment using different process applications.

A case study in southern Taiwan explored a pilot scale study of pharmaceutical wastewater treatment by the membrane bioreactor (MBR) process. The membrane bioreactor system is becoming increasingly important in wastewater treatment as it offers several advantages like high biodegradation efficiency and smaller footprint. (Fan et al, 2005). The influent wastewater to the MBR system consisted of real pharmaceutical manufacturing wastewater and septic tank effluent. The MBR plant, at a 10 m^3/day capacity, consisted of an aeration tank and a membrane bioreactor to remove organic matter. The study demonstrated the field operation of pharmaceutical wastewater treatment by MBR. It was found that MBR system was capable of removing 95% COD and up to 99% BOD. Therefore, it is believed from the results that MBR system is a potential method of treating pharmaceutical wastewater with stable operation and satisfactory removal efficiency (Chang et al, 2008).

A pharmaceutical and chemical company in south-east of Cairo, Egypt discharges both industrial (6000 m^3/day) and municipal wastewater (128 m^3/day) into a nearby evaporation pond without any treatment. A treatability study was carried out for this wastewater. The characteristics of the generated raw wastewater were COD 4100–

13023 mg/L, TSS 20–330 mg/L and oil grease 17,4–600 mg/L in addition to refractory and priority compounds. It was decided that a pre-treatment was necessary before the effluent could be discharged into public sewer. In light of this, the application of the Fenton oxidation process as a pre-treatment to biological process improved the removal of pharmaceuticals from wastewater and appeared to be an effective solution to meet effluent standards as dictated by legislation law (Badawy et al, 2009).

Welly(2009) studied the treatment of a pharmaceutical wastewater by upflow anaerobic sludge blanket (UASB) and hybrid upflow anaerobic sludge blanket (HUASB) reactors. The highest COD and BOD_5 removals were achieved by the HUASB reactor – COD removal 90% (effluent COD 133 mg/L) and BOD_5 removal of 97% (effluent BOD_5 51 mg/L).

2.2 Sequencing Batch Reactor (SBR)

Sequencing Batch Reactor (SBR) has a flow through process. The installation consists of at least two identically equipped tanks with a common influent inlet that can be switched between them. SBR process commonly follows a five step sequence of fill, react, settle, draw and idle described in detail below:

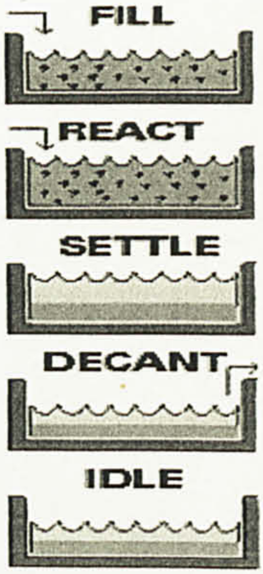

Fig 2.1 Steps in the SBR process

Fill - Wastewater fills the tank mixing with biomass that settles during the previous cycle.

React - Air is added to the tank to aid in biological growth and facilitate subsequent waste reduction.

Settle - Mixing and aeration stop in this phase to allow solids to settle to the bottom of the tank.

Decant - Clarified effluent is discharged.

Idle - If necessary, sludge removal occurs in this stage.

(http://www.waldeninc.com/SBR.htm)

The SBR process has been widely applied in the treatment of industrial wastewater with the ability to adjust to each application due to its flexible operating conditions. The following discusses some of the applications of the SBR system to treat wastewater from different industries.

The Department of Environmental Engineering in Turkey carried out a study on the treatment of mixed pharmaceutical industry and domestic wastewater by sequencing batch reactor process. The characteristics of the wastewater was BOD_5 90-130 mg/L, COD 200-300 mg/L, SS 900 mg/L, pH 6.4-6.8, temperature 20°C, NH_3 26 mg/L and PO_4^{-3} 8.5 mg/L. The objective of this study was to determine the optimum operating conditions of the SBR and the advantages that it brought to an activated sludge treatment process. Optimum treatment was achieved under 4 h aeration and 60 min of sedimentation time. Effluent characteristics from the SBR were BOD_5 13-18 mg/L COD 25-37 mg/L, SS 9-21 mg/L, pH 7.3-7.6, temperature 23°C, NH_3 1 mg/L and PO_4^{-3} 8.1 mg/L (Ileri et al, 2003).

The pulp and paper making industries are one of the largest industrial contributors to polluted wastewater. In China, this industry is one of the highest water consumers with serious pollution problems. A laboratory scale experiment to optimize biological treatment by optimizing operating conditions of the SBR process was conducted. These included mixed liquor suspended solids (MLSS) concentration, volumetric exchange rate (VER), aeration time, temperature and daily operation cycle on biological treatment of pulp and paper mill effluent was studied using 4 litre sequencing batch reactors. The results showed that chemical oxygen demand (COD) removal efficiency was up to 93.1 ± 0.3% and the volumetric loading reached 1.9 kg BOD/m^3/day under optimum operation. Treatment by activated sludge process encountered problems of filamentous bulking which the sequencing batch reactor process solved. The effluent quality met the discharge standard according to local authority and the sludge volume index (SVI) was improved to a healthy level as compared to treatment by activated sludge process. (Tsang et al, 2007).

In the treatment of dairy industry wastewater, the sequencing batch reactor was coupled with a membrane separation process which is a solid-liquid separation process. The combined system was named Membrane Sequencing Batch Reactor (MSBR). The process was optimized to run long term and the results showed BOD removal to be as high as 97–98% and stable. Membrane separation resulted in suspended solids free effluent. The main nutrient consumption was nitrogen for synthesis of new cells due to low influent concentrations. The removal efficiency reached 96% for nitrogen. Due to the limit of biological process, phosphorus removal was relatively low at 80% and depended on excess sludge wasting. (Bae et al, 2003)

In Poland, two lab scale aerobic Sequencing Batch Reactors (SBR) were investigated to co-treat landfill leachate and wastewater from a milk factory. The reactors were operated at 24 hour time cycles. It was found that treatment efficiency strongly depended on operating conditions such as duration of different phases, hydraulic retention time (HRT) and organic loading. The removal efficiency of the of the SBR system decreased with an increased organic loading or decreased HRT. The best effluent quality during co-treatment was achieved under 0.8kg BOD_5/m^3 d and HRT of 10 days (Neczaj et al, 2008).

In another study conducted in India, researchers investigated the treatment of a complex chemical wastewater in a sequencing batch reactor with an aerobic suspended growth configuration. A 24 h operating sequence was employed and studied with various organic loading rates (1 kg COD/m^3/day, 1.7kg COD/m^3/day and 3.5kg COD/m^3/day). The SBR performance was monitored under the following parameters: pH, oxidation-reduction potential, sludge volume, sludge volume index, suspended solids and volatile suspended solids. Application of the SBR resulted in a better performance as compared to the conventional ASP system in treating complex chemical effluent. This may be due to enforced unsteady state conditions coupled with periodic exposure of the micro-organisms to defined process conditions which facilitate the required metabolic conditions for treating complex chemical effluents (Mohan et al, 2005).

CHAPTER 3
METHODOLOGY

The pharmaceutical wastewater sample is obtained from a pharmaceutical company in Bangi, Kuala Lumpur. The sample is characterized according to the following parameters by methods outlined in the Standard Methods(2005)

Table 3.1 Characteristics of pharmaceutical wastewater sample

BOD_5	765
COD (mg/L)	1352
TSS (mg/L TNR)	71.3
NH_3-N (mg/L)	6.8
NO_3-N (mg/L)	30
Total Phosphorus (mg/L)	18.13
Sulphate (mg/L)	20
Sulphide (mg/L)	0.28
TKN(mg/L)	44.37
pH	4.36

As mentioned in preceding chapters, a Sequencing Batch Reactor will be used to in this experiment and the setup will operate as in Fig 3.1. A plan view of the setup is shown in Fig 3.2.

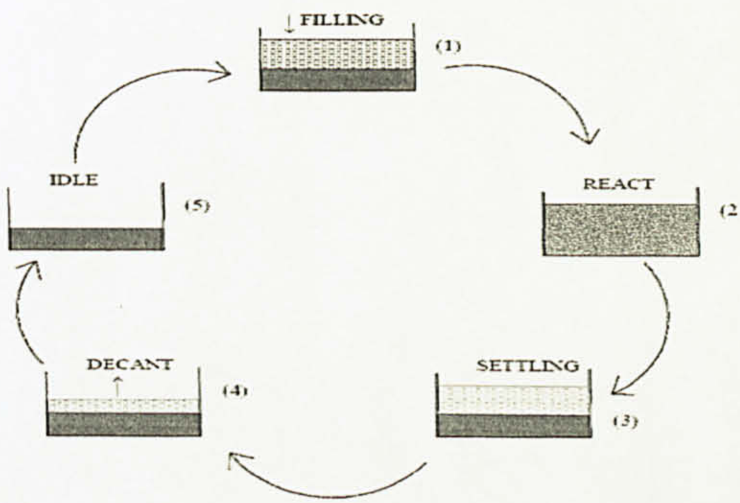

Fig. 3.1. Various stages in SBR cycle

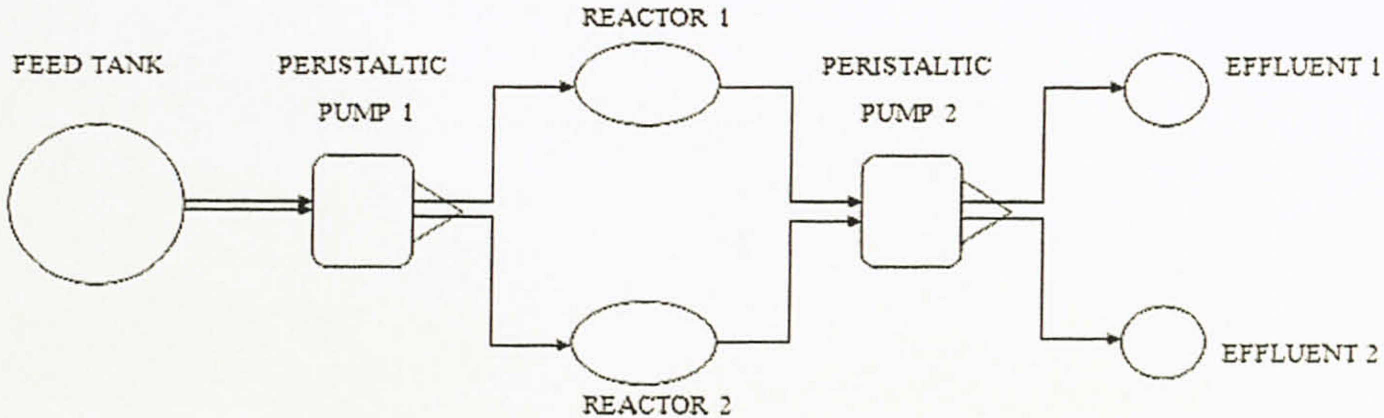

Fig 3.2 Plan View of Setup

Table 3.2 : Cycle periods for reactor

HRT (hour)	FILLING (min)	REACT (hour)	SETTLING (hour)	DECANT (min)	IDLE (min)
24	15	21.25	2	15	15
48	15	45.25	2	15	15

The low pH of the raw wastewater was adjusted to a range feasible to biological treatment using sodium bicarbonate before treatment. A reference to Fig 4.2 shows that the influent was kept at a pH between 6 and 7 and the effluent pH was between 7 and 9 which meets effluent standards.

The lab scale setup consists of two reactors, one with a high mixed liquor suspended solids (MLSS) concentration and the other with a low MLSS concentration. The reactor volume is 1.5 litres each. A mixing plate and an air diffuser (aerator) is used during the reaction phase of the cycle. A feed tank is filled with influent (untreated) wastewater. The pH is adjusted here before it is fed into the reactors. Feeding and decanting is done by two peristaltic pumps adjusted pump 1L per 15 min. Two effluent tanks are used for the resulting effluent from each reactor after settling. Aeration and mixing are done using an air diffuser and a mixing plate to facilitate reaction. The system was operated by an automatic timer for 12 hr and 24 hr HRT. For the 48 hr HRT manual feed and decant had to be done.

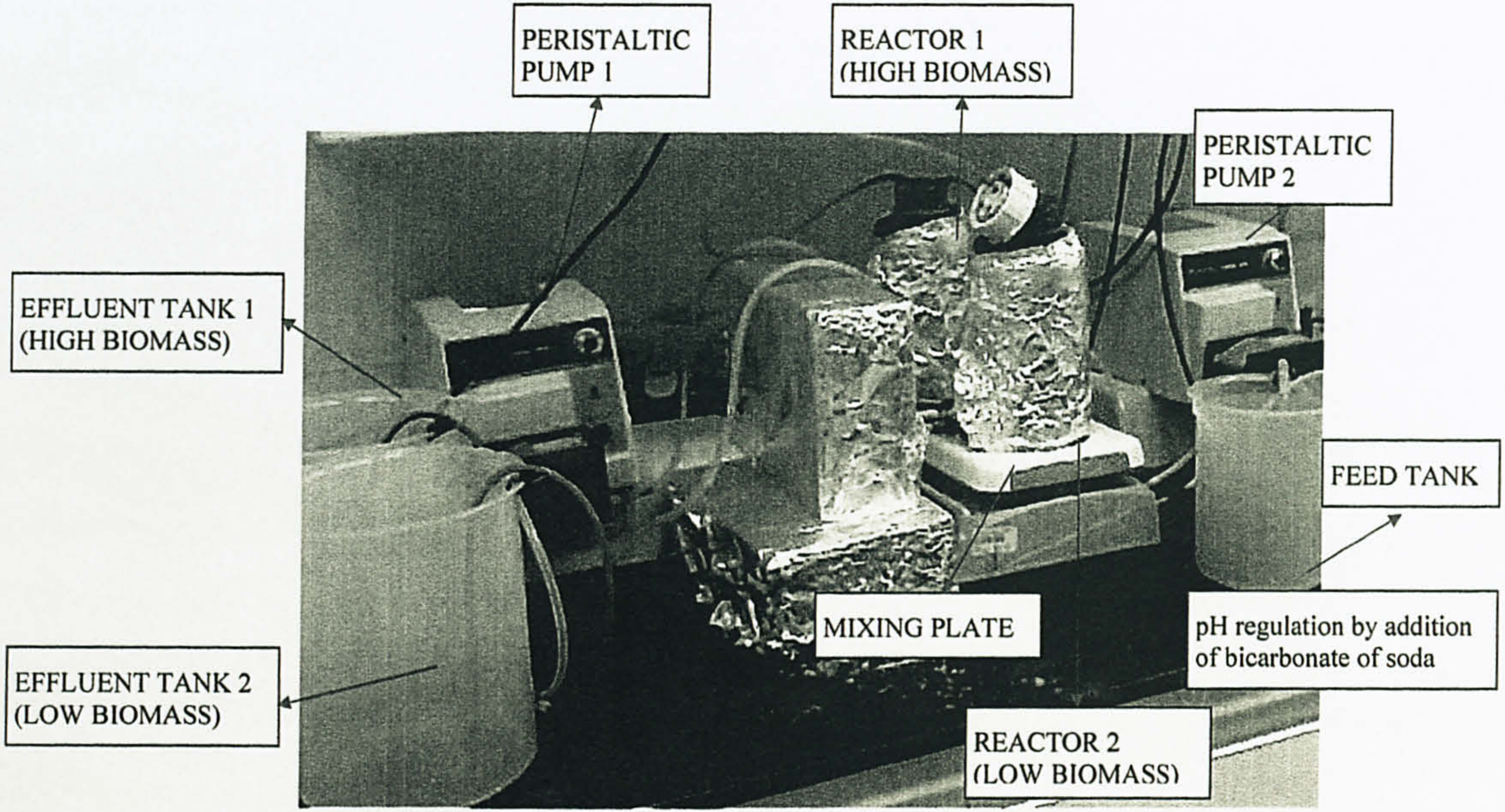

Fig 3.3. Bench Scale Setup of SBR

Acclimation was carried out over a period of 2 weeks with the following ratios of domestic wastewater / pharmaceutical wastewater: 75/25, 50/50, 25/75, 0/100. These ratios were each carried out for 3 days each until the bacteria was acclimatized to the environment of the pharmaceutical wastewater. After the acclimation period, the Hydraulic Retention Times (HRT = 12, 24 and 48 hours) were tested with two different mixed liquor suspended solids (MLSS) concentrations (low MLSS and high MLSS) (Table 3.1). During a cycle, the reactors had the following volumes (Fig 3.3)

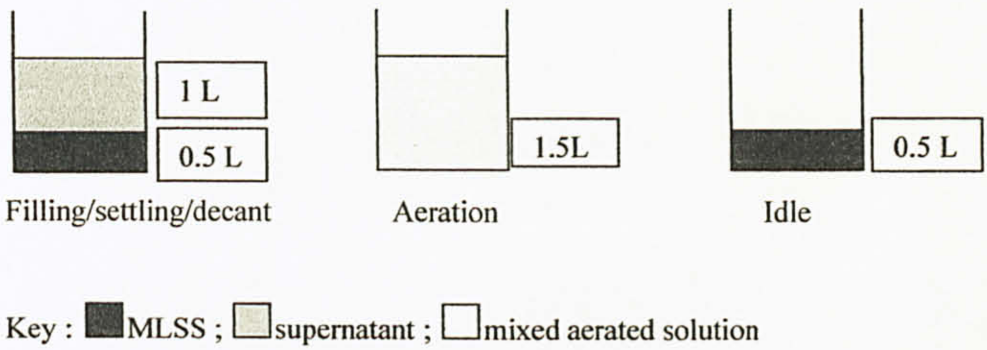

Fig 3.4 Reactor volumes for each stage in SBR cycle

After Acclimation stage the SBR's were fed at following organic loading rates :

Table 3.3 Organic Loading Rates

HRT	Organic Loading Rate
12 hr	2.702 kg/m^3/day
24 hr	1.352 kg/m^3/day
48 hr	0.676 kg/m^3/day

During the experimental work, chemical oxygen demand (COD), ammonia nitrogen (NH_3-N) and nitrate nitrogen (NO_3-N) was tested on a daily basis. Biochemical oxygen demand (BOD), total kjeldahl nitrogen (TKN), mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) was measured on a weekly basis. The flow of this project from January 2009 – May 2010 was carried out as illustrated in Figure 3.5.

The influent wastewater was initially relatively white however turned dark grey over time. The color change was evident after a change in pH. This is assumed to be due to the large amount of unknown componds present in the sample that may be undergoing reaction. The colour change affected the effluent colour and thus the standard procedure for determining nitrates in the effluent was affected. An alternate approach was taken using Ion Chromatography which will be implemented for the rest of the study.

During the study it was found that the reactor with a low biomass concentration developed a frothing problem. This is a result of the detergents and other surfactants in the wastewater. Sludge from the high biomass reactor was recylced into the low biomass reactor so to minimze frothing. An antifoaming chemical additive could have been used in spray water but was not available at the time.

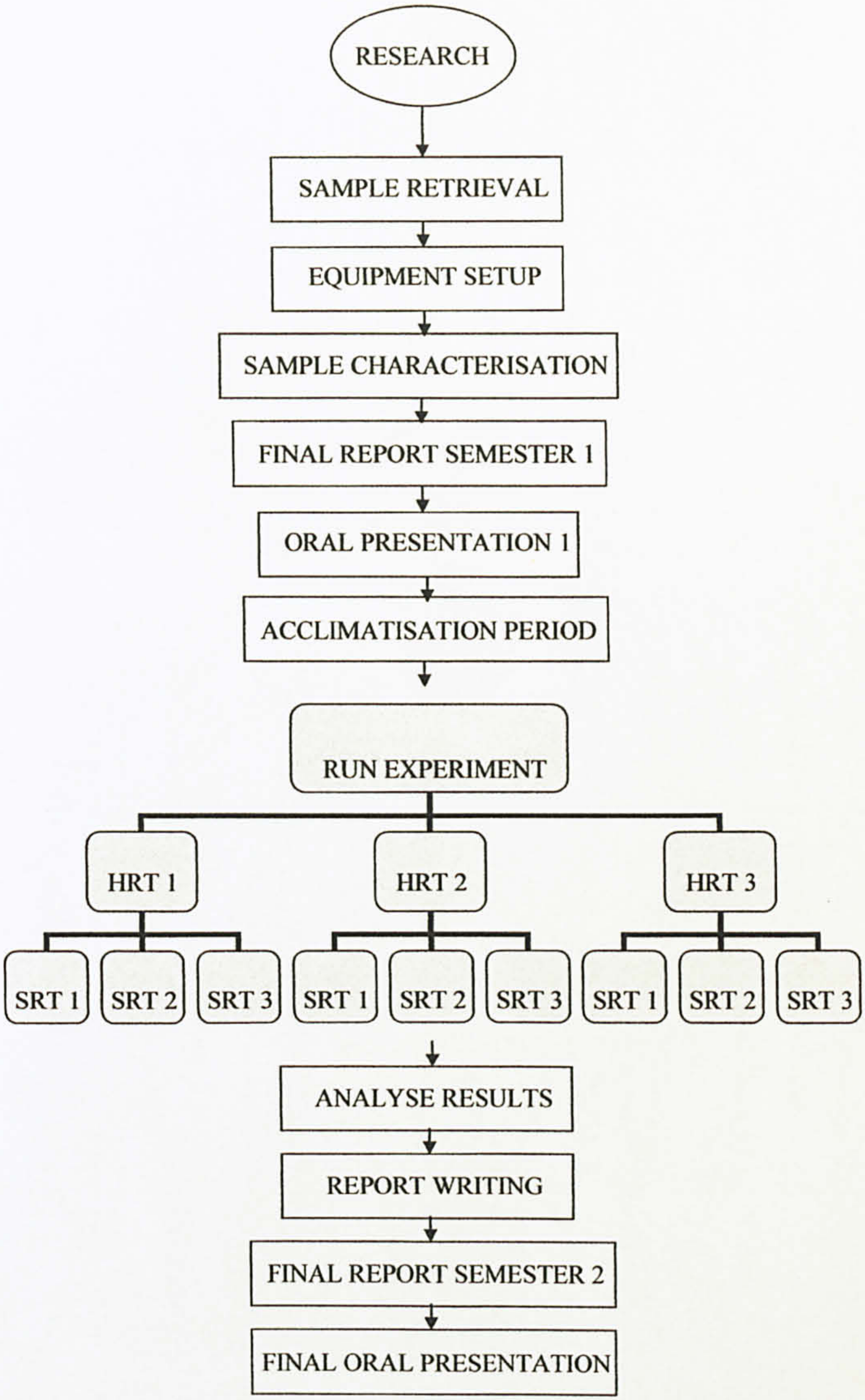

Fig 3.5 Flowchart of FYP tasks

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Effect of Cycle Period

4.1.1 HRT of 12 hr

Table 4.1.1 : Concentrations for HRT = 12 hr

	COD(mg/L)	BOD(mg/L)
Low MLSS	269±14	119±8
High MLSS	254±17	111±8

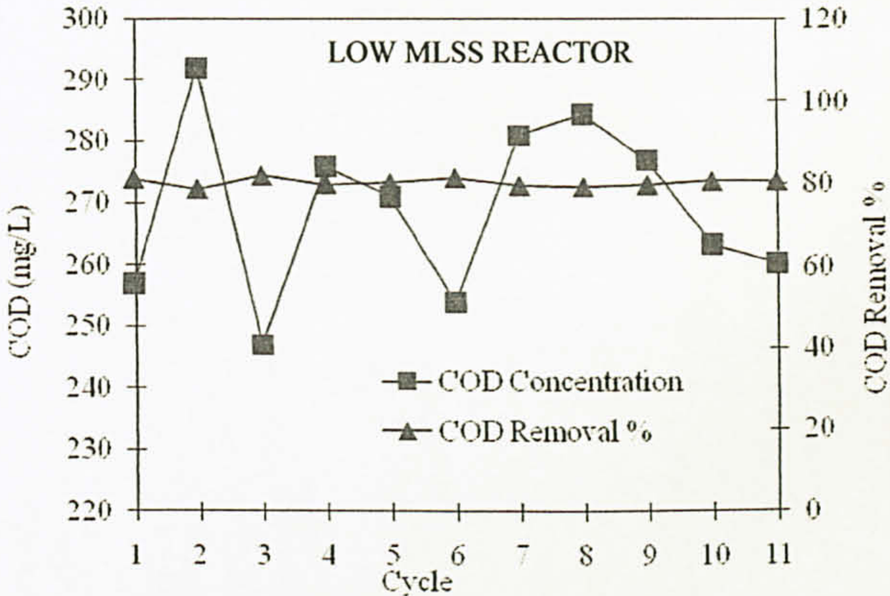

Fig 4.1.1a. Effluent COD for HRT of 12 hr under low MLSS

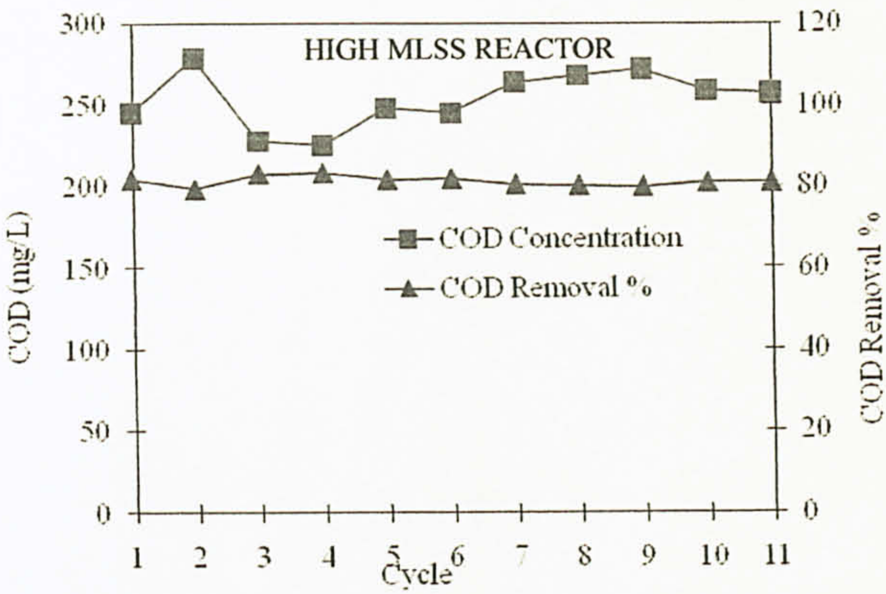

Fig 4.1.1b. Effluent COD for HRT of 12 hr under high MLSS

COD concentrations for the 12 hr cycle are more than twice as expected by effluent standards. Although removal efficiency is approximately 80 % this still does not satisfy the expected effluent concentration of 100mg/L.

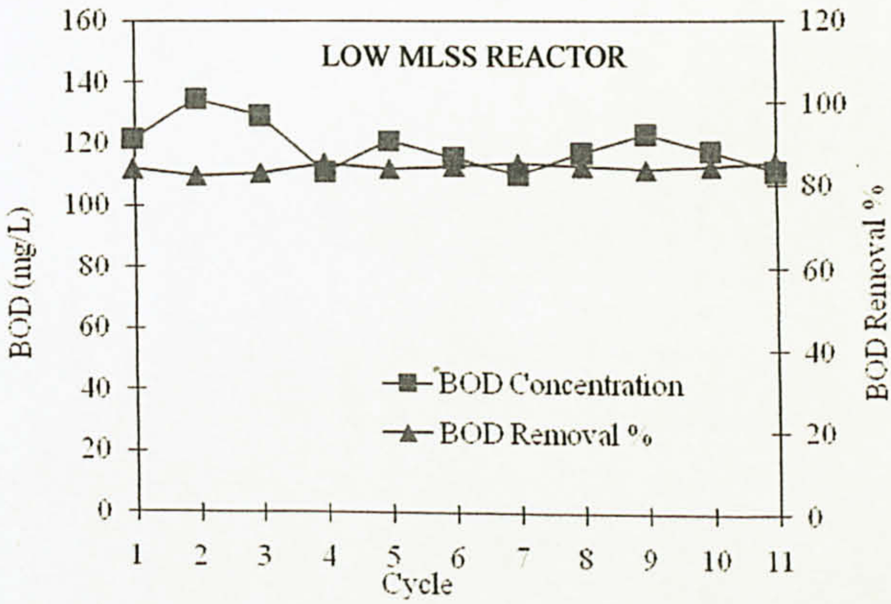

Fig 4.1.1c. BOD performance for HRT of 12 hr under low MLSS

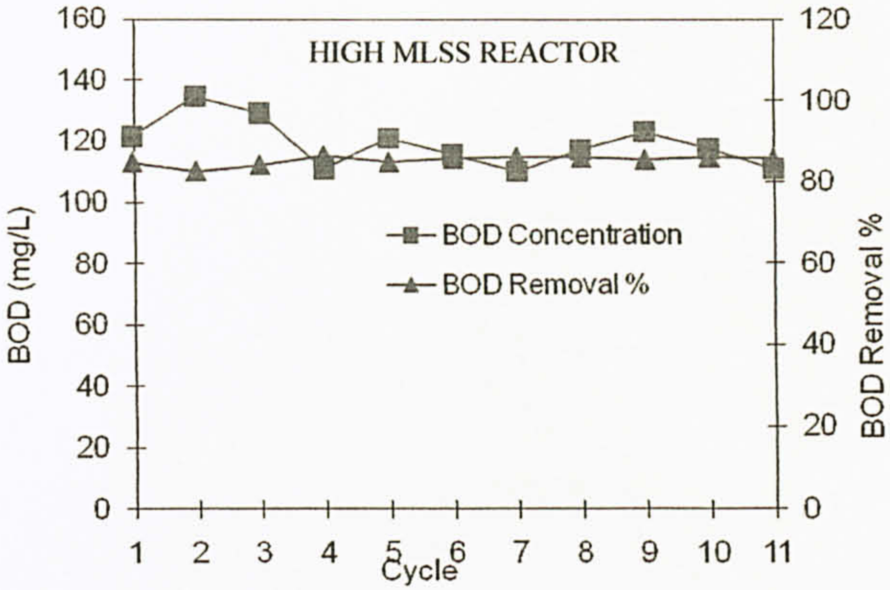

Fig 4.1.1d. Effluent BOD for HRT of 12 hr under high MLSS

Expected effluent BOD concentrations are not met with a 12 hour HRT. There is a significant reduction in BOD by more than 80 % however because of the high BOD in the influent wastewater a 12 hour HRT was not sufficient for effective removal.

Nutrient removal at the 12 hour HRT shows a 45-55% removal for total Kjeldhal nitrogen with the effluent wastewater having an average TKN concentration of approximately 23 mg/L. Effluent ammonia had removal of 80 % at an average concentration of 1.4 mg/L as compared to the influent concentration of 6.8 mg/L.

The effluent pH was with the range of 7.7 – 8.2 which is within required standards with the infulent ranging between 5.9 – 6.5 after pH adjustment using sodium bicarbonate.

4.1.2 HRT of 24 hr

Table 4.1.2 : Concentrations for HRT = 24 hr

	COD	BOD
Low MLSS	217±23.2	46±9.8
High MLSS	222±17.1	48±11.2

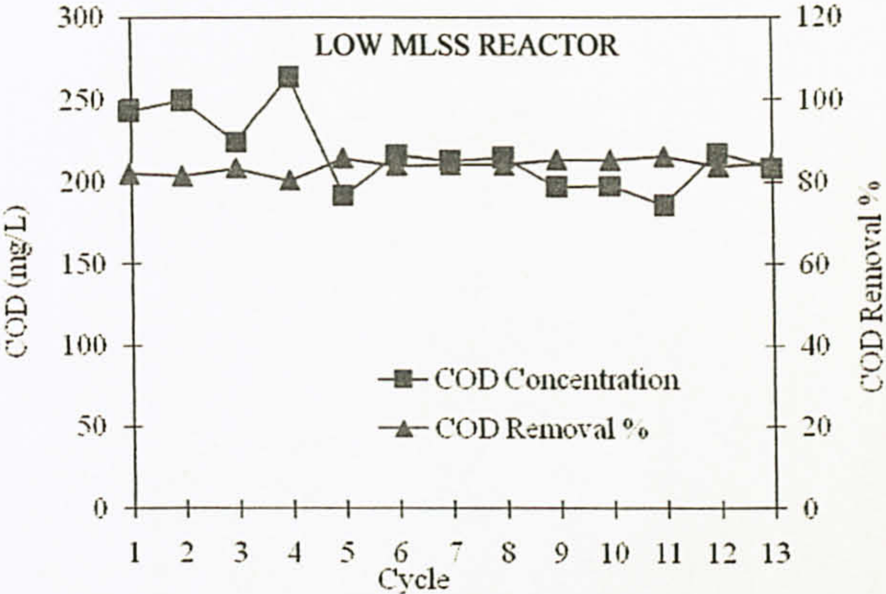

Fig 4.1.2a. Effluent COD for HRT of 24 hr under low MLSS

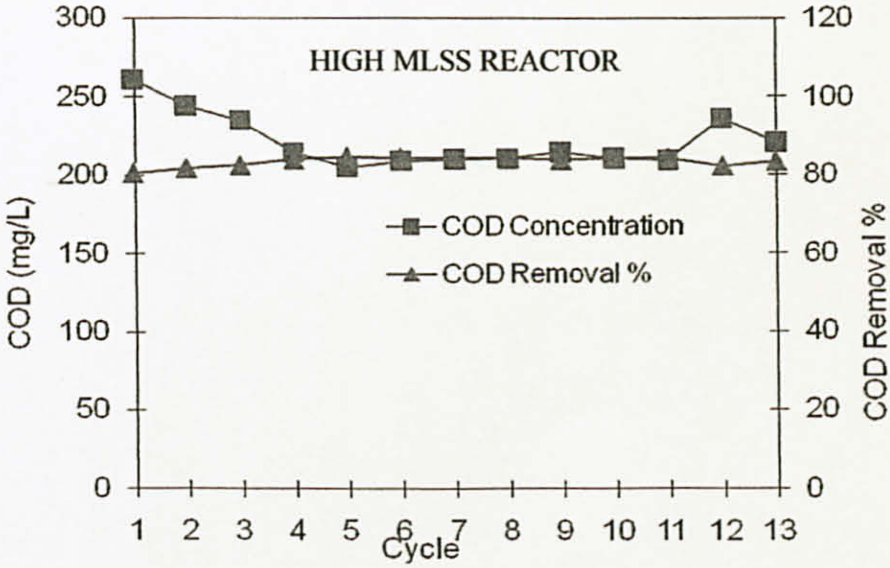

Fig 4.1.2b. Effluent COD for HRT of 24 hr under high MLSS

The 24 hour HRT shows a better COD removal as compared to the 12 hour HRT. The COD concentration for the 24 hour HRT averages at 217 mg/L as compared to the 269 mg/L present in the effluent after a 12 hour HRT. This is clearly due to an increase in reaction time. COD removal at 24 hr HRT is at an average of 84 %. This is still however, lower than that obtained from other treatment methods such as MBR and HUASB (Chang et al, 2008; Welly, 2009)

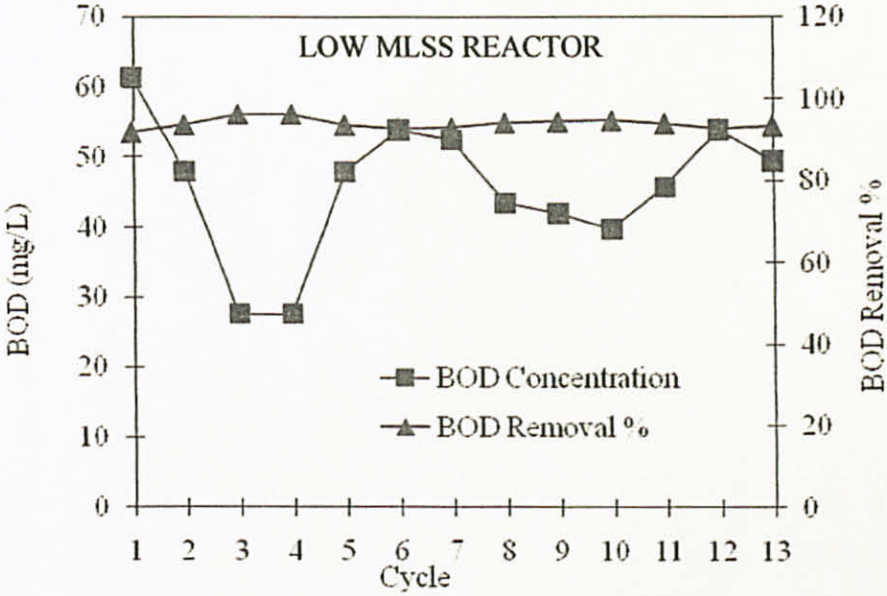

Fig 4.1.2c. Effluent BOD for HRT of 24 hr under low MLSS

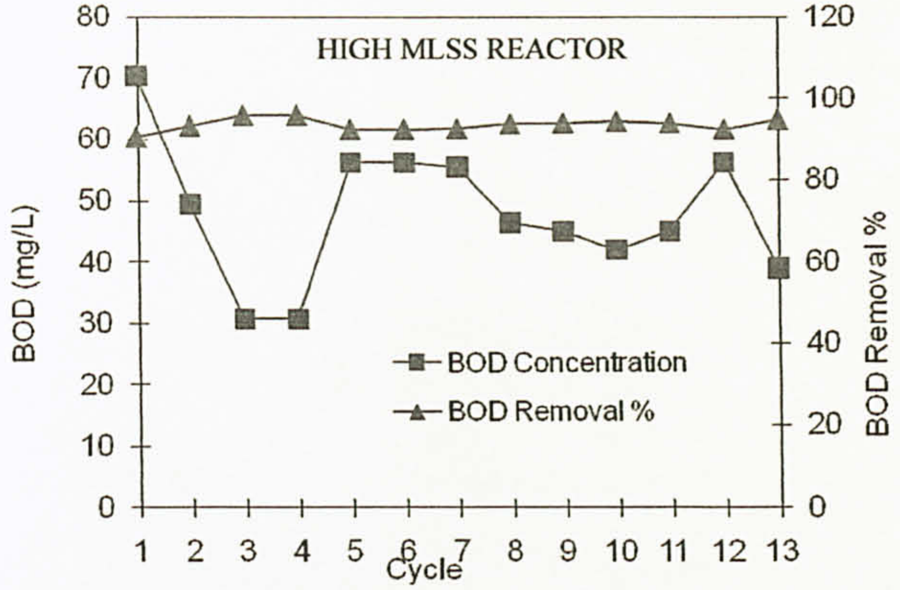

Fig 4.1.2d. Effluent BOD for HRT of 24 hr under high MLSS

BOD removal improved more than COD during the 24 hour HRT. The 24 hour treatment just meets the standard for effluent BOD of 50 mg/L for standard B. BOD removal is now 94 % which is lower but a competitive efficiency to treatment by MBR, HUASB, Fenton-Biological (Chang et al, 2008; Welly, 2009; Bedawy et al, 2009)

Nutrient Removal for the 24 hour HRT is not as effective as ammonia % removal lies between 35-44 %. The initial ammonia concentration was 6.8 mg/L. Effluent had a total Kjeldhal nitrogen removal was 49-59% at an average concentration of 23 mg/L.

Effluent pH was maintained at 7.3–8.1 with the influent ranging 5.5-7.0 after pH adjustment using sodium bicarbonate.

4.1.3 HRT of 48 hr

Table 4.1.3 : Removal Efficiency(%) for HRT = 48 hr

	COD	BOD
Low MLSS	217±22	50±7.2
High MLSS	219±9.0	54±5.4

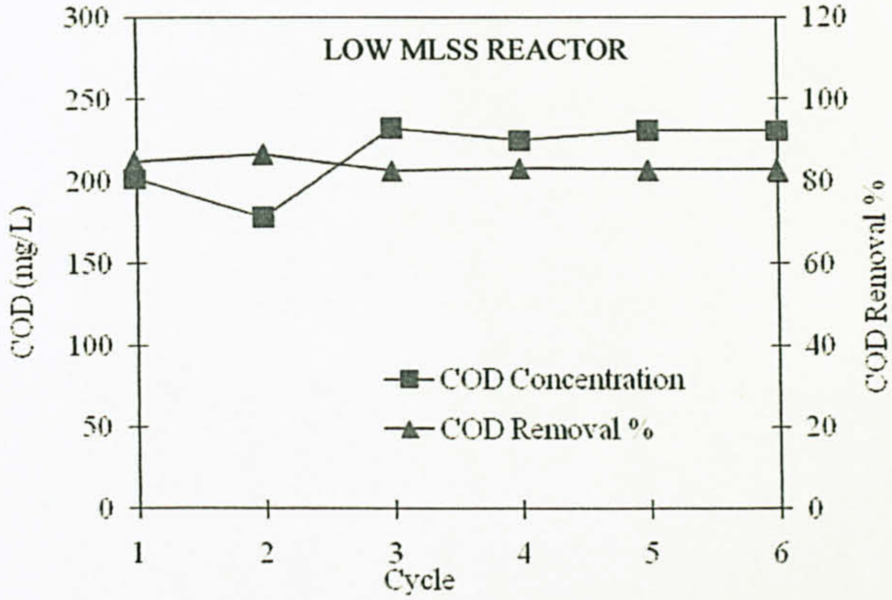

Fig 4.1.3a. COD performance for HRT of 48 hr under low MLSS

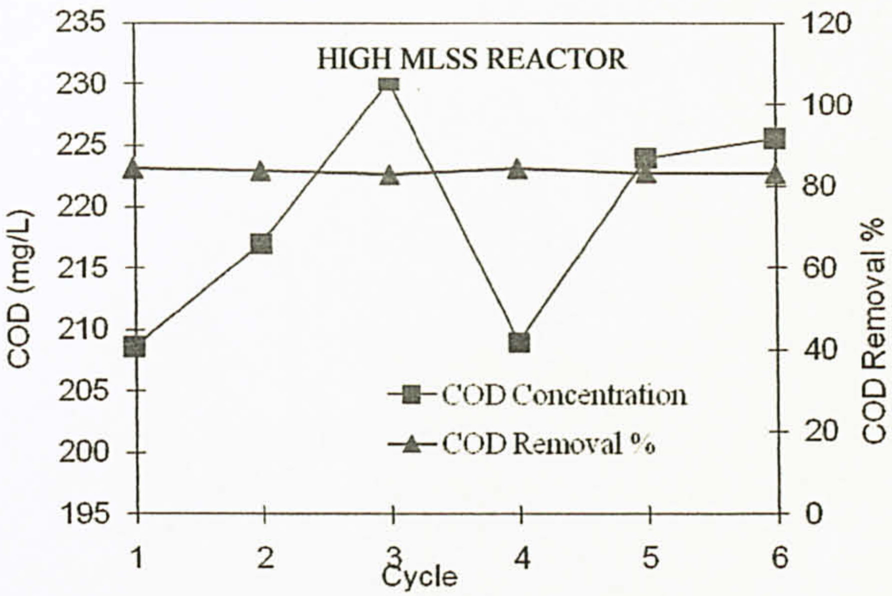

Fig 4.1.3b. Effluent COD for HRT of 48 hr under high MLSS

Treatment at 48 hour HRT and at 24 hour HRT show similar outcomes. A 48 hour HRT of course would have a higher operating cost with the same output which is not feasible.

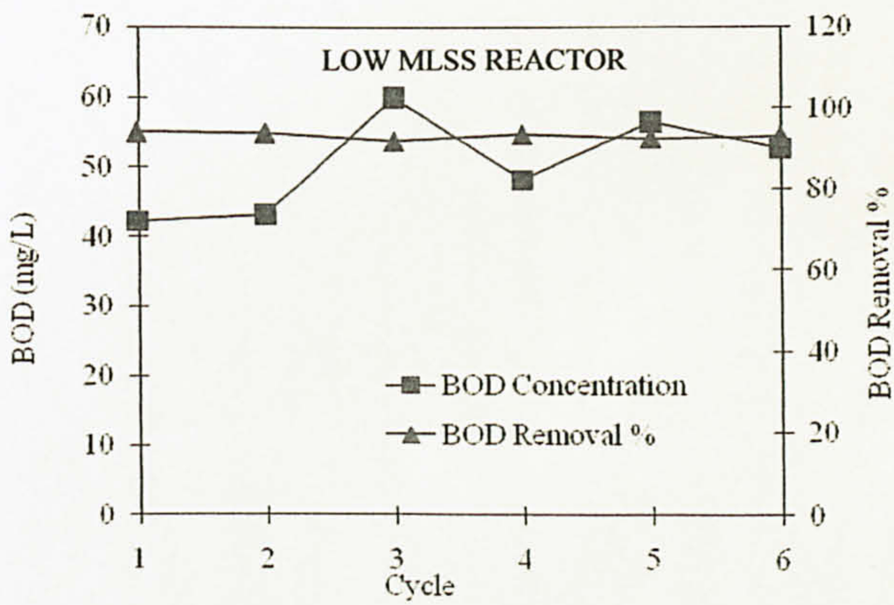

Fig 4.1.3c. Effluent BOD for HRT of 48 hr under low MLSS

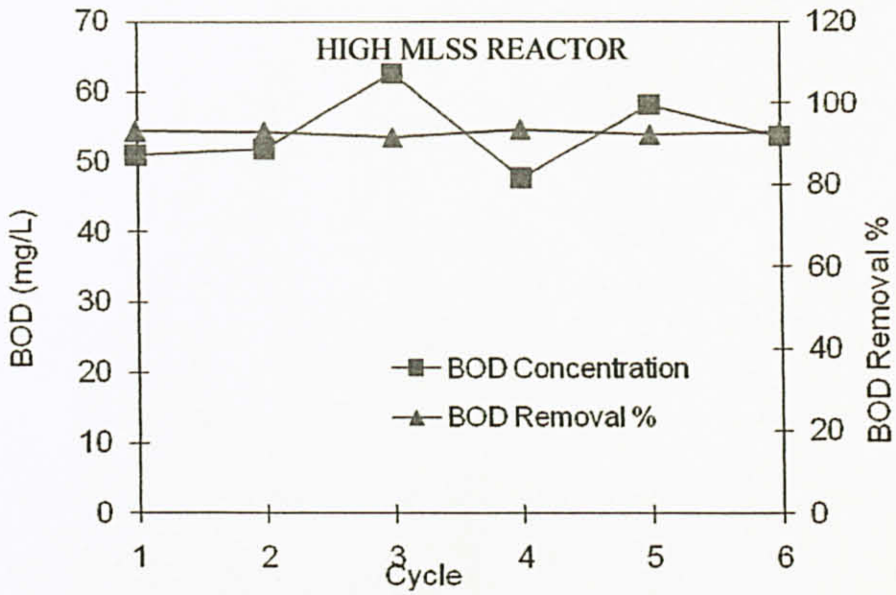

Fig 4.1.3d. Effluent BOD for HRT of 48 hr under high MLSS

As noted for COD removal, the 48 hour HRT results in a similar BOD removal as a 24 hour HRT.

The 48 hour HRT nutrient removal rates were not as stable as those at 12 and 24 hour HRT. Due to logistics matters with the use of the premises during the weekends, the setup was left to run over the weekend and then reset at the beginning of the week. This could have affected the nutrient values however it was noted that TKN was removed at 41 % for the reactor operating at high MLSS. Ammonia concentrations in the effluent was also high as expected due to high TKN values.

Effluent pH was within the range of 7.4–7.9 with the influent ranging from 6.2–6.6 after pH adjustment by sodium bi carbonate.

4.2. Effect of MLSS Concentration

The mixed liquor suspended solids (MLSS) concentration as well as the mixed liquor volatile suspended solids (MLVSS) in both reactors were monitored and are presented in the graph below.

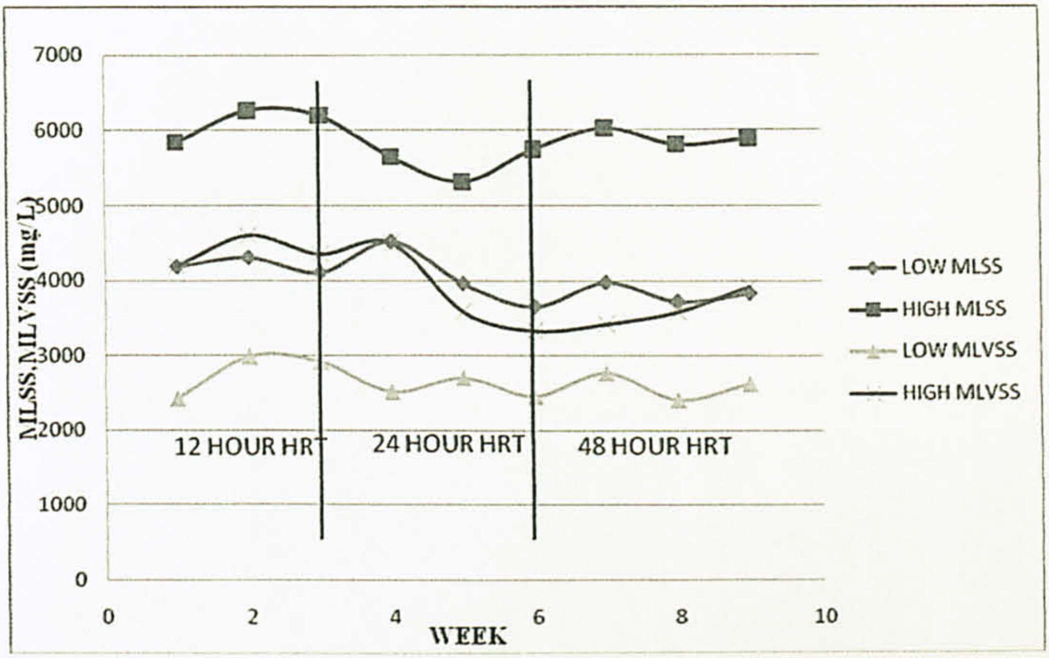

Fig 4.2.1. MLSS and MLVSS concentrations for both reactors under 12, 24 and 48 hr HRT

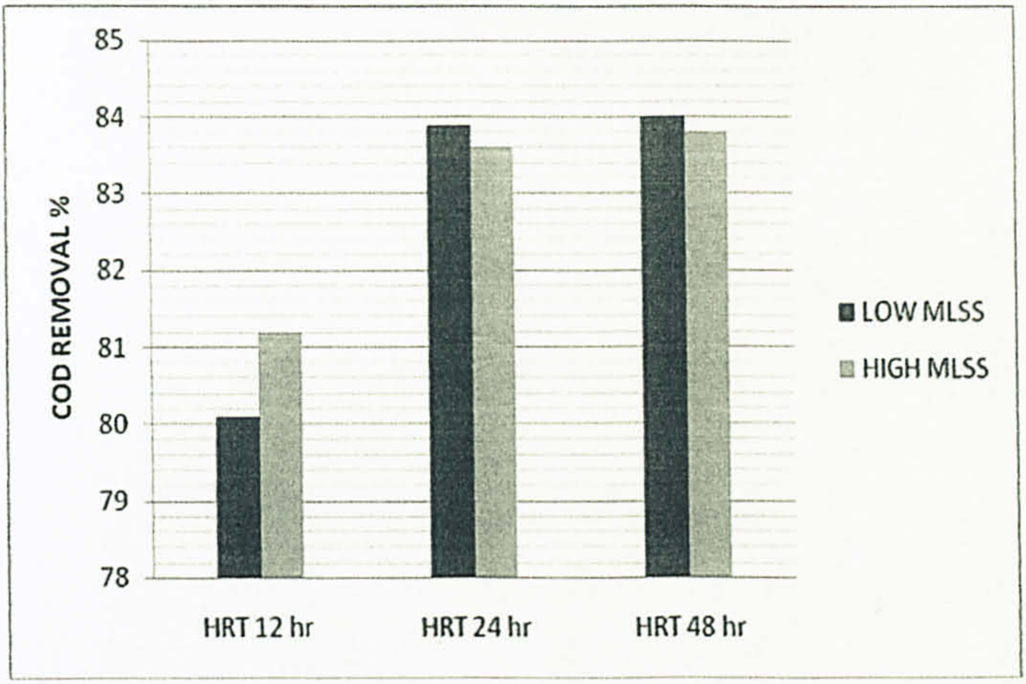

Fig 4.2.2. Effect of MLSS concentration on COD removal for different HRT

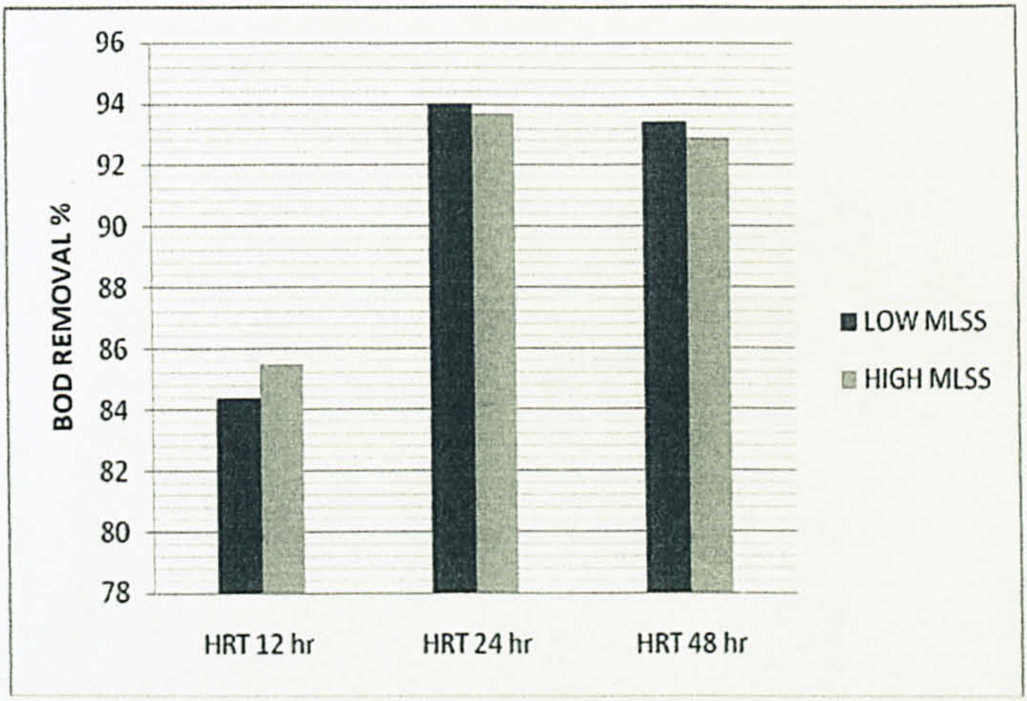

Fig 4.2.3. Effect of MLSS on BOD removal for different HRT

It is evident that the MLSS concentration does not have a significant effect on the performance of the sequencing batch reactor. Low MLSS and High MLSS concentrations result in similar percentage removals for COD and BOD.

At 12 hour HRT the performance is significantly lower than at 24 and 48 hour HRT. However there is no difference in performance between the 24 hour and 48 hour HRT. Both have a sufficient removal of BOD to meet the effluent standards. COD for the 24 and 48 hour HRT however is still much higher than allowed by the effluent standards.

Therefore, it will be more feasible to make favour the 24 hour HRT operating parameters over the 48 hour HRT as operation costs will be much less with the same output.

A pre-treatment may make it possible for this system to accomplish effluent standards by reducing influent concentrations to the sequencing batch reactor.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

The purpose of this study was to determine the optimum operating conditions of a sequencing batch reactor for treatment of the pharmaceutical wastewater. This was done by analysing the effect different cycle periods and different biomass concentrations on the treatment efficiency.

The 24 and 48 hr hydraulic retention time showed similar results. Both these HRTs have a significantly higher treatment efficiency than the 12 hr HRT. However, 24 hr HRT is favored over the 48 hr HRT so as to save on operation costs.

The increase in MLSS did not affect the SBR performance and therefore, the optimum operating conditions of a sequencing batch reactor for treatment of the pharmaceutical wastewater is at a 24 hr hydraulic retention time with cycle period of 15 min idle, 15 min feed, 9.25 hr react, 2 hr settle and 15 min decant.

Under these optimum operating conditions, the final effluent characteristics were COD 217±23.2 mg/L, BOD 46±9.8 mg/L, pH 7.7±0.2, TKN 23.35±17 mg/L, NO_3-N 0.21±0.08 mg/L and NH_3-N 4.4±2.1 mg/L.

Since effluent standards are still not met with these operating conditions it is recommended to use a pre-treatment by chemical or anaerobic process.

CHAPTER 6
ECONOMIC CONSIDERATION

Table 6.1 : Cost of Laboratory Equipment

ITEM	QUANTITY	COST
Reactor vessel (2L Plastic container)	2	Lab equip
Mixing Plate	2	Lab equip
Peristaltic Pump	2	Lab equip
Feed Vessel	1	Lab equip
Effluent Vessel	2	Lab equip
Plastic tubing	2m	Lab equip
Sodium Bicarbonate	1x50g	RM2
Aerator (aquarium pump)	1	RM7
Automatic Timer	3	RM30
Total Cost		RM39

The setup was run over 15 weeks. These costs exclude electricity usage.

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APPENDIX A

EFFLUENT STANDARDS

Table A1 : Effluent standards for WWTP specified by DOE Malaysia

Parameter	Unit	Standards	
		A	B
Temperature	C	40	40
pH Value	-	6.0-9.0	5.5-9.0
BOD5 at 20C	mg/l	20	50
COD	mg/l	50	100
Suspended Solids	mg/l	50	100
Mercury	mg/l	0.005	0.05
Cadmium	mg/l	0.01	0.02
Chromium, Hexavalent	mg/l	0.05	0.05
Arsenic	mg/l	0.05	0.10
Cyanide	mg/l	0.05	0.10
Lead	mg/l	0.10	0.5
Chromium, Trivalent	mg/l	0.20	1.0
Copper	mg/l	0.20	1.0
Manganese	mg/l	0.20	1.0
Nickel	mg/l	0.20	1.0
Tin	mg/l	0.20	1.0
Zinc	mg/l	1.0	1.0
Boron	mg/l	1.0	4.0
Iron (Fe)	mg/l	1.0	5.0
Phenol	mg/l	0.001	1.0
Free Chlorine	mg/l	1.0	2.0
Sulphide	mg/l	0.50	0.5
Oil and Grease	mg/l	Not Detectable	10.0

Environmental Quality (Sewage and Industrial Effluent) Regulations 1979. Engineering Services Division, Ministry of Health, Malaysia.

APPENDIX B

RESULTS

Table B1 : Summary of results for HRT 12 hours

CYCLE	COD		BOD		NH3		NO3		Ph	
	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS
1	257	246	122	116	1.3	1.3	0	0.048	7.9	7.8
2	292	279	135	131	1.2	1.4	0	0	7.9	8.0
3	247	228	129	120	1.5	1.1	0.039	0	7.6	7.6
4	276	226	111	102	1.3	1.2	0	0	8.1	8.0
5	271	248	121	115	1.3	1.4	0	0	7.7	7.6
6	254	245	116	107	1.2	1	0	0.01	7.7	7.6
7	281	264	110	105	1.3	1.5	0	0	8.0	7.7
8	285	268	117	106	1.4	1	0	0	7.9	7.8
9	277	272	123	110	1.4	1.2	0.022	0	7.3	7.4
10	264	259	118	106	1.4	1.5	0	0	7.4	7.6
11	261	257	111	108	1.6	1.9	0	0	7.6	7.5

WEEK	TKN		MLSS		MLVSS	
	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS
1	72.39	35.03	4187	5840	2427	4200
2	18.68	18.68	4307	6267	2987	4600
3	18.68	18.21	4107	6200	2920	4360

Table B2 : Summary of results for HRT 24 hours

Day	COD		BOD		NH3		NO3		Ph	
	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS
1	243	261	62	70	1.3	2.6			7.9	7.8
2	250	245	48	49	1.7	2.3			7.9	8.0
3	224	235	28	31	2.3	2.7			7.6	7.6
4	264	215	28	31	3.8	4.2			8.1	8.0
5	192	205	48	56	4.4	2.9			7.7	7.6
6	216	209	54	56	6	5.5			7.7	7.6
7	213	210	52	56	7.7	6.7			8.0	7.7
8	215	211	43	46	7.1	6.8			7.9	7.8
9	197	215	42	45	5.8	5.8	0.344	0.587	7.3	7.4
10	198	211	40	42	1.8	1.6	0.122	0.294	7.4	7.6
11	186	210	46	45	4.6	2.9	0.205	0.516	7.6	7.5
12	218	237	54	56	5.1	3.2	0.196	0.333	7.6	7.6
13	209	221	49	39	5.2	3.2	0.179	0.361	7.6	7.7

WEEK	TKN		MLSS		MLVSS	
	LOW MLSS	HIGH MLSS	LOW	HIGH	LOW	HIGH
1	77.76	50.20	3907	7480	2427	3907
2	49.04	35.03	4520	5653	2520	4507
3	11.68	7.47	3960	5320	2707	3587
4	35.03	11.68	3653	5747	2460	3340

Table B3 : Summary of results for HRT 48 hours

Day	COD		BOD		NH3		NO3		Ph			WEEK	TKN		MLSS		MLVSS	
	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS			LOW MLSS	HIGH MLSS	LOW MLSS	HIGH MLSS	LOW	HIGH
1	202	209	42	51	11.9	10.1	0.78	1.52	7.8	7.9		1	101.11	77.76	3973	6027	2773	3427
3	179	217	43	52	9	11	1.77	4.72	7.6	7.7		2	96.44	49.74	3720	5813	2413	3587
5	233	230	60	63	1.8	2	1.8	4.35	7.6	7.7		3	96.44	31.06	3827	5893	2627	3920
7	225	209	48	48	1.6	1.6	1.67	3.26	7.5	7.4								
9	231	224	56	58	2.3	1.6	1.9	4.8	7.6	7.7								
11	231	226	53	54	1.4	1.2	2.77	5.75	7.5	7.6								