BOD Reduction of Grey Water by utilizing Sequencing Batch Reactor (SBR)

By

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Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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in partial fulfillment of the requirement for the
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Approved by,

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CERTIFICATION OF ORIGINALITY

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

CHAN PHAI LIN

ABSTRACT

Presently, Universiti Teknologi PETRONAS (UTP) obtains water supply from the treatment plant in Parit, Perak. All the wastewater produced in the student village is sent to the university treatment plant. To save cost on water supply, better quality of wastewater like grey water can be treated and reused for toilet flushing purposes. This project is done to study on the grey water treatment which mainly focuses on the process for BOD removal only. The BOD treatment facility must be incorporated in order to meet the water reuse for toilet flushing standard to ensure safe usage. The standard BOD level taken from NSW Health Department's Publication for toilet flushing is 20 mg/L. Grey water samples are taken from sumps which are located at the ground floor of student village. BOD_5 and COD test analysis was conducted to study the relationship between BOD_5 and COD. COD:BOD_5 ratio is 2.5. Sequencing Batch Reactor (SBR) was set up to study the parameter used for the BOD treatment. SBR cycle consists of 5 phases: FILL, REACT, SETTLE, DECANT and IDLE. The optimum react time for the treatment is obtained in this research project with the reaction time of 3 hours is required to remove 65% of influent COD. Besides, this literature reviews on the alternative ways of BOD reduction of grey water are included: Multistage Rotary Biological Contractor (RBC), Membrane Bioreactor (MBR), and Biologically Aerated Filter (BAF).

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

1.1.1 Grey Water

Grey water, sometimes referred to as 'sullage' consists of all non-toilet wastewater. It includes wastewater from showers, baths, spas, hand basins, washing machines, laundry troughs, dishwashers and kitchen sinks (EPA Publication 812, 2001). Grey water contains lower levels of organic matter and nutrients than ordinary wastewater, as urine, faeces and toilet papers are not included.

There are 3 ways in which wastewater may have become contaminated due to addition of waste material as shown in *Table 1* below:

Table 1: Ways to Contaminate Wastewater

Way	Waste Material
Microbiologically	▪ Disease causing pathogenic
Chemically	▪ Dissolved salts - sodium, nitrogen, phosphates and chlorine ▪ Organic chemicals which may provide food for microorganism and plant growth - oils, fats, milk, soap and detergents
Physically	▪ Dirt particles, food, lint, sand, etc

Source: NSW Health, 2000

In Malaysia, guidelines and standards for water reuse in buildings do not exist. However, other countries like Germany, United States of America, Japan, Australia, Saudi Arabia, Cyprus and Jordan, the reuse of treated grey water has been introduced and highly promoted. The guidelines and standards are being revised and expanded in those countries. Potential of grey water reuse is normally due to severe water scarcity, rainfall fluctuation, the rise in water pollution or extremely high demands of freshwater from the population.

1.1.2 Previous Study

Based on previous study done by Universiti Teknologi Petronas (UTP) student, the characteristics of grey water discharge from village was determined. The parameters studied in the thesis are Biochemical Oxygen Demand (BOD), turbidity, color, iron and manganese contents, coliform and total suspended solids.

It is found out that level of contaminants present is high in kitchen wastewater. The kitchen wastewater is not suitable to be reused back for toilet flushing purposes as a more complicated treatment system will be required to treat the grey water and may not be economically feasible. The kitchen wastewater is heavily polluted physically, microbiologically and chemically. Hence, only water samples from student village and not cafeteria are collected in this project as cafeteria produces more kitchen wastes.

1.1.3 Water Quality Requirements

The performance limits (Toilet Flushing) are based on the New South Wales Health Department's Publication, "Greywater Reuse in Sewered Single Domestic Premises" (April 2000). The quality performance indicators are contained in *Table 2.*

Table 2: The Performance Limits for Toilet Flushing

Performance Indicator	Unit	Maximum
Biochemical Oxygen Demand	mg/L	20
Suspended Solids	mg/L	30
E-coli Bacteria (Organisms)	Organisms/100ml	10
Residual Chlorine	mg/L	#Minimum 0.5

90^{th} percentiles may be used
#Not applicable if Ultra Violet disinfection used

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

Grey water produced in UTP student village can be treated and reused for toilet flushing purposes. Among the parameter of concern of grey water is the BOD level. Based from previous finding, the grey water samples collected has average value of 351.33mg/L which is more than the standard 5-30mg/L (Shakira, 2003). It is required to study the various way of treatment for BOD reduction of Grey Water and determine the optimum parameter of the BOD reduction treatment using Sequencing Batch Reactor (SBR).

1.2.2 Significant of the Project

Qualitative

Drinking water quality as obtain from any tap is not required for toilet flushing. It is possible to reuse of grey water for toilet flushing purposes as the grey water is less polluted than municipal wastewater. Therefore, it would be a good alternative to reuse treated grey water instead.

Quantitative

The reuse of grey water will lower the total costs for wastewater handling by reducing the load of water to the treatment plants. Reuse of grey water for toilet flushing purposes would minimize the intake of fresh water supply from Lembaga Air Perak (LAP). Currently the water cost supply for UTP is about RM1.40/m^3. It has been estimated that 30% of the total household water consumption could be saved by reusing greywater fro flushing toilets (Eriksson E. et al., 2002). If it is assumed that 30,000m^3 is consumed each month and 30% is the grey water that can be treated for toilet flushing purposes, 9000m^3 water is recycled back to the toilet flushing facilities instead of discharging them to the waste water treatment plant at UTP. UTP could save about RM12600/month. One of the solutions suggested to reduce BOD of grey water is by Sequencing Batch Reactor (SBR) system. SBR is a fill-and-draw activated sludge system for wastewater treatment. Therefore, this project is proposed to study the feasibility on the use of equalization, aeration and clarification in removing BOD from grey water.

1.3 OBJECTIVES AND SCOPE OF STUDY

1.3.1 Objectives

- To determine the correlation between COD and BOD_5
- To reduce BOD in grey water to standard 20mg/L based on the BOD results obtained from the experiment
- To set up an experiment to study the optimum reaction time period in Sequencing Batch Reactor (SBR) system to reduce the BOD.

1.3.2 Scope of Study

- **Conduct BOD and COD test**

All the grey water samples collected from village 4 are sent to laboratory for BOD and COD test analysis. The results are analyzed to study the relationship between COD and BOD and to determine the feasibility of BOD reduction treatment to the water.

- **Comparison of various ways of reducing BOD from grey water**

Alternatives treatment for BOD reduction of grey water are suggested based on the BOD results obtained from the experiment and comparison is made to the alternatives.

- **Experiment Set Up**

Aeration unit in Environment Lab is used for Sequencing Batch Reactor (SBR) experiment set up to obtain the optimum time period to reduce BOD of grey water.

1.3.3 Feasibility of the Project within the Scope and Time Frame

This final year research project is one semester project. Half of the semester was spent in studying the correlation between BOD and COD. The SBR experiment set up is mainly to study the parameters applied in SBR system. However, only optimum time period will be obtained in this project. Effects of other parameters such as pH and aeration rate to the treatment system can only be studied if time allows. The comparisons among the suggested processes for BOD removal are based on literature review due to time constrain.

CHAPTER 2
LITERATURE REVIEW/THEORY

2.1 GREY WASTEWATER

2.1.1 Definition

Grey wastewater is defined as wastewater without any input from toilets, which means that it corresponds to wastewater produced in bathtubs, showers, hand basins, laundry machines and kitchen sinks, in households office building, schools, etc. The total grey wastewater fraction has been estimated to account for about 75 vol% of the combined residential sewage (Eriksson et al., 2002).

2.1.2 Characteristics of Grey Wastewater

The characteristic of grey wastewater depend on two factors:

- Quality of the water supply
- Type of distribution net for both drinking water and the grey wastewater (leaching from piping, chemical and biological processes in the biofilm on the piping walls)

The characteristics of greywater produced by any household will vary according to the dynamics of the household and is again influenced by the factors of number of occupants, the age distribution of the occupants, their lifestyle characteristics and water usage patterns. Water is used as medium to dilute and convey waste away from the occupants on the inside of the building and to flush the household plumbing fitting (NSW Health, 2000).

2.1.3 Grey Wastewater Reuse

Water is essential for urban, industrial and agricultural needs. It is estimated that the consumption of fresh water by domestic usage takes up to 70-80% of the total volume of wastewater globally (Lu W. et al., 2003). Water usage and demand are continuously increasing with the increasing population and economic activities.

There are two reasons in the reuse of wastewater:

- Water shortage – too low amounts of rainfall in combination with high evaporation (e.g., Australia) or too large demands of freshwater from the population (e.g., Japan).
- Environmental and economical considerations – the reuse will lower the total costs for wastewater handling by reducing the load of water to the treatment plant.

According to Olsson and Newell (1999), grey water recycling for toilet flushing falls under non-portable urban uses wastewater reuse categories. Public health should take into considerations in recycling greywater. Caution must be exercised with the reuse of greywater to ensure that the potential to transmit disease has been minimized. Care must also be taken to ensure that there is no cross connection with portable water system so that the portable water is not inadvertently contaminated. Besides, greywater reuse must take into account of the effect of water quality on scaling, corrosion, biological growth and fouling which could reduce the effectiveness of the distribution system.

Wastewater reclamation and reuse is one element of water resource development and management. The highest profile in greywater reuse goes to Japan, the United States (US) and Australia. Other countries such as Canada, the United Kingdom (UK), Germany and Sweden are actively involved in greywater research and application (Al-Jayyousi, 2003). In Germany, the reuse of grey wastewater from bathroom has been successfully used and operates without public health risk (Nolde, 1999). Grey wastewater reuse also has been implemented at a number of sites around UK ranging from reuse within a single occupancy to large scale recycling at the Millennium Dome (Jefferson B. et al., 1999).

2.2 GREY WASTEWATER TREATMENT SYSTEM

Treatment of grey wastewater faces difficulty when there is large variation in its composition as mean COD values vary between sites and at individual sites. This has been attributed to changes arising in the quantity and type of detergent products employed during washing. Grey wastewater quality is also subjected to dynamic variation where significant chemical changes may take place over time periods of only a few hours (Al-Jayyousi, 2003).

Some of manufacturers of greywater systems assume a mechanical treatment of the greywater to be satisfactory, whereas others claim a more advanced treatment technology to be necessary. Based on the collected experience on different greywater systems over the past 10 years in Berlin, an extensive biological treatment of the greywater is essential to avoid technical problems and public health risk as well as promotion of public acceptance (Nolde, 1999).

Greywater is contaminated with microorganisms and polluted with chemicals and particulates. Greywater from recycling systems should fulfill four criteria: hygienic safety, aesthetics, environmental tolerance, and technical and economical feasibility. With regard to sustainable water concepts, a lower energy and chemical demand that needed for conventional systems should be achieved in service water systems. Advanced physical methods for water reuse, such as ultrafiltration and reverse osmosis are very high energy demanding (Nolde, 1999).

2.2.1 Activated Sludge Sequencing Batch Reactor (SBR)

All grey water resources need to be collected to a surge/equalization tank and then pumped into wastewater treatment plant for further treatment before discharge. *Figure 1* present the schematic of a SBR plant.

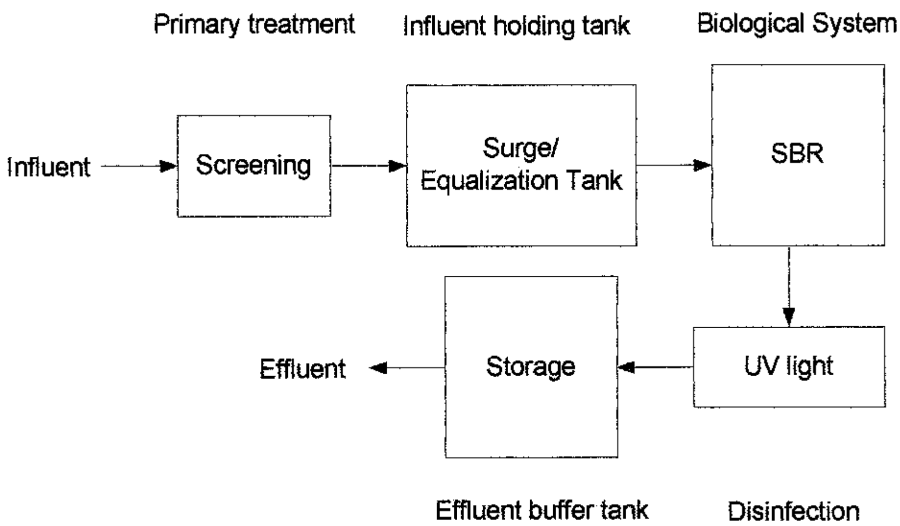


Figure 1: Diagram of an SBR Plant

Surge/Equalization tank

Equalization tank is required to balance the fluctuating of grey water production from village. Greywater contains solids particles such as lint and hair which require a screen to be installed to prevent blockage in the treatment system. The screen need frequent maintenance to ensure that grey water is not reduced significantly.

Besides, residence time in systems dramatically affects the characteristics of greywater. Greywater when stored will turn septic and give rise to extremely offensive odours and provide conditions for microorganisms to multiply. Thermotolerant coliforms have been found multiply by 10 to 100 times during the first 24 to 48 hours of storage before gradually declining. Significant levels of pathogens have been found in stored greywater after 8 days (NSW Health, 2000). Therefore, the greywater must be adequately treated to avoid any disease transmission and attract insect and rodent vectors.

Biological System – Sequencing Batch Reactor (SBR)

Filtration is insufficient to reduce organic contamination to prevent biological regrowth in distribution system. Therefore, removal of biodegradable material requires biological treatment.

The term SBR originally was introduced by R.L. Irvine at the Purdue Industrial Waste Conference in 1971 to describe a specific type of activated sludge periodic process designed to treat wastewater generated during manufacture of specialty carbohydrate polymers. That system was characterized by continuous repetition of periods called FILL, REACT, SETTLE, DRAW and IDLE, each period being defined according to its position and function within the cycle (Wilderer et al., 2001).

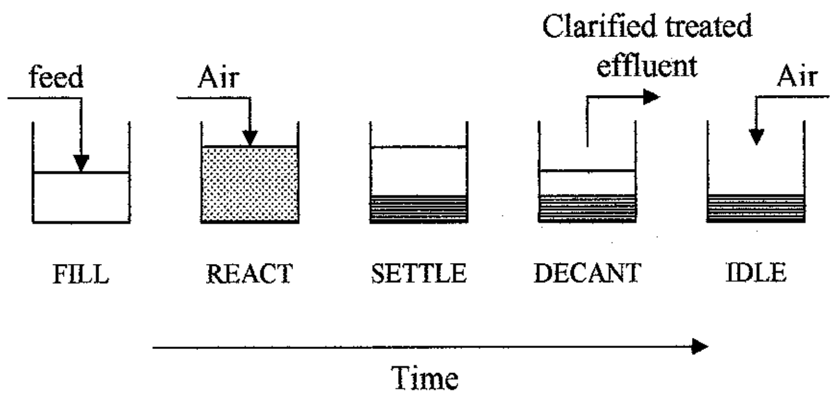


Figure 2: SBR Operating Cycle

A typical sequence is illustrated in *Figure 2*. All steps are accomplished in a single tank in which the reactor goes through as it receives wastewater, treats it and discharges it. Following are the activities for each cycle:

FILL:	Mixing and/or aeration occur as necessary for biological reaction
REACT:	Mixing and/or aeration occur as necessary for biological reaction
SETTLE:	Mixing and aeration terminated. Biomass settles
DRAW:	Treated effluent removed
IDLE:	Reactor ready to be placed in service to receive influent.

Normally sludge wasting takes place near the end of react or during settle. When equalization or holding tank or some other method of handling excess flow is available, the IDLE phase can be taken of.

FILL and REACT can have several sub-phases based on the energy input to the system, which results in various aeration and mixing operation strategy (Wilderer, et al., 2001). The sub-phases are listed below:

Static fill: no energy input to the system; allows accumulation of substrate

Mixed fill: mixing without forced aeration, minimal aerobic activity; typically allows either anoxic or anaerobic reactions

Aerated fill: mixing with forced aeration; typically allows aerobic reactions; often allows simultaneous anoxic and aerobic reactions

Mixed react: mixing without forced aeration, minimal aerobic activity; allows anoxic and possibly anaerobic reactions

Aerated react: mixing with forced aeration; allows aerobic reactions

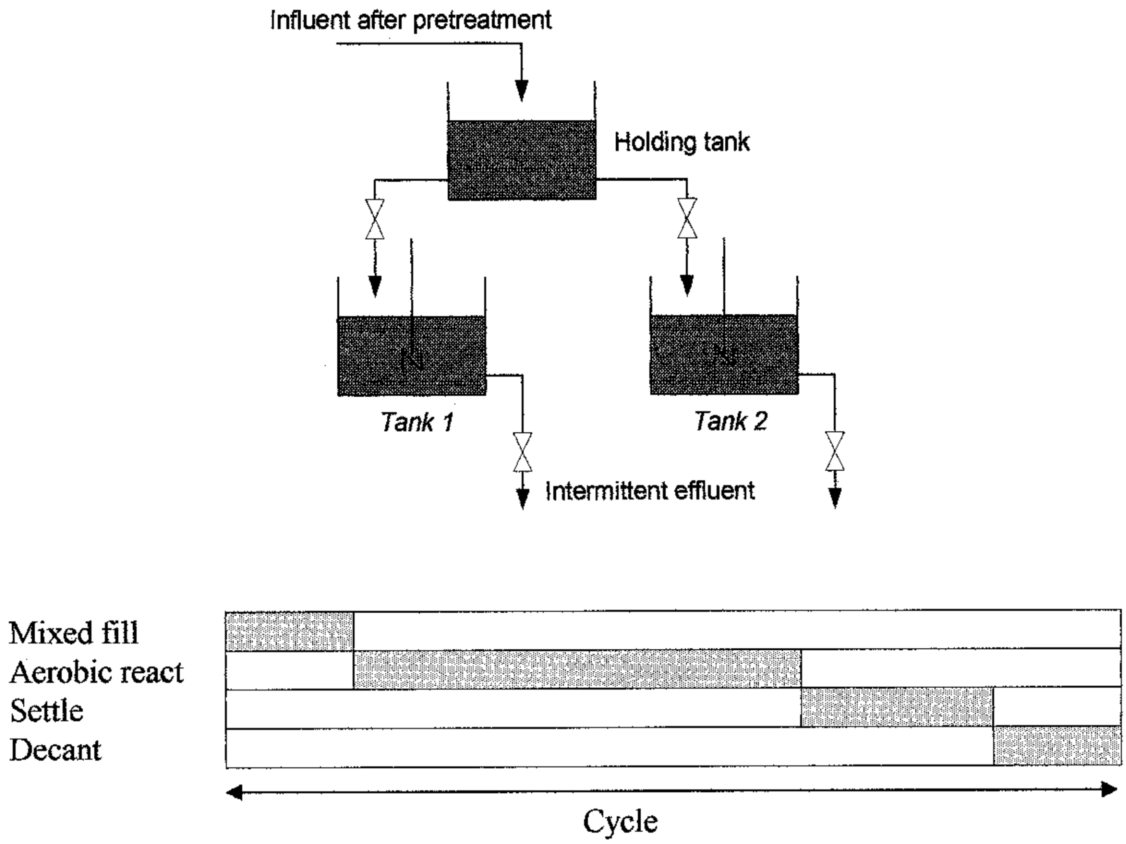


Figure 3: Schematic Representation of an SBR System with a Holding Tank, Periodic Influent, React phase and no Idle phase (Adapted from Wilderer et al., 2001)

Figure 3 illustrates an SBR system which is often used in Germany. The influent enters a holding tank before being distributed into the SBR tanks. Two or more tanks are normally used to allow the system to be operated with a variable fill strategy: dump fill or extended fill. Idle phase is not required as the holding tank provides the same function as the idle phase (Wilderer et al., 2001).

Dump fill is equivalent to a static fill when no energy input to the system and allows the accumulation of substrate. Wastewater constituents accumulate without much biodegradation during static fill. However, static fill is applied as required (Wilderer et al., 2001).

Cycle time should be as short as possible to achieve optimum exploitation of the volumetric capacity of the plant, to keep sludge settleability in a reasonable range, and to stimulate the metabolic activity of the activated sludge micro-organisms. Short fill phases and high exchange rate help to improve the settling characteristics of the sludge. No concentration gradient develop with plant filling which is conducted over a long period of time (t_{fill}/t_{cycle}>0.5). With respect to sludge bulking control short filling times (t_{fill}/t_{cycle}<0.2) are more advantageous but used rather seldomly (Helmreich et al., 2000).

Results of tracer experiments revealed that an optimal axial distribution of water can be achieved by using 2 nozzles per m^2 of cross sectional area. To get an optimal distribution of air in the fixed bed, more than 90 nozzles per m^2 are needed. To achieve optimal nitrification the air velocity should be set as high as $15 m^3m^{-2}h^{-1}$ (Wilderer et al., 2001).

In the activated sludge SBR, pH values lower than 6.8 - 6.9 led to a significant decrease in nitrification activity. pH adjustment is necessary as pH decreases in the nitrification process. To keep the pH and the nitrification rate from decreasing, sodium hydroxide NaOH was used for pH regulation. pH of about 7.0 had to be maintained. Strong pH fluctuations could results in problems with foaming and led to an increasing sludge volume index (SVI) in operating the SBR (Arnold et al., 2000).

Sludge Volume Index (SVI) measurement is used to quantify the settling characteristics of activated sludge. The SVI is the volume of 1 g of sludge after 30 min of settling (MetCalf & Eddy, 2004). A high SVI indicates that the sludge cannot settle well. If sludge cannot settle, the sludge is carried into effluent, resulting in poor effluent quality.

Foam formation and floating sludge accumulation were frequently occurred in the plants investigated and both phenomena seemed to be interrelated. Bubble aerated tanks were more likely subjected to foam problems. Floating sludge accumulated particularly in plants that were operated to achieve denitrification and enhanced biological P removal (Helmreich et al., 2000).

Disinfection

Disinfection is the last treatment process to treat micro-organisms by inactivating pathogenic microorganisms in wastewater. Disinfection of wastewater is ineffective if the wastewater is high in biochemical oxygen demand, suspended solids and organic matter.

The use of chemical disinfections (e.g. chlorine compounds) in greywater systems should be avoided since treated greywater can be satisfactory disinfected with a UV dose ranging between 250 and 400 J/m^2 (Nolde, 1999).

Storage

Storage is required to balance the fluctuation in the dynamic of water demanded by toilet flushing. Detailed examination of the benefits of storage reveal that $1m^3$ tank is suitable for a wide range of occupancy scales (Jefferson B. et al., 1999). Any increment to the storage capacity increases in water savings but increases problem associated with greywater degradation and disinfection reliability. Besides, the tank should be protected against daylight as light has a negative effect on greywater systems.

2.2.2 Other BOD reduction process

Comparison among the processes by its advantages and disadvantages are presented in *Table 3*.

Multistage Rotary Biological Contactor (RBC)

RBC is alternatively known as trickling filter or vertical-flow soil filter. For large greywater systems working with a multistage RBC, the energy demand for greywater treatment, UV disinfection and service water distribution was determined to be less than 1.5 kWh/m^3 (Nolde, 1999)

RBC consists of a series of large discs mounted on a horizontal shaft that rotates slowly (*Figure 4*). The discs are partially submerged and spaced in settled sewage. As the shaft rotates, the disc surfaces are alternatively in contact with air and with the wastewater. This result in biological slime growth on each disc and the slime absorb the organic material in the wastewater. There is no need to recycle sludge but the effluent from RBC requires clarifier to settle out the excess growth of microorganisms that becomes detached from the disc when the slime thickens.

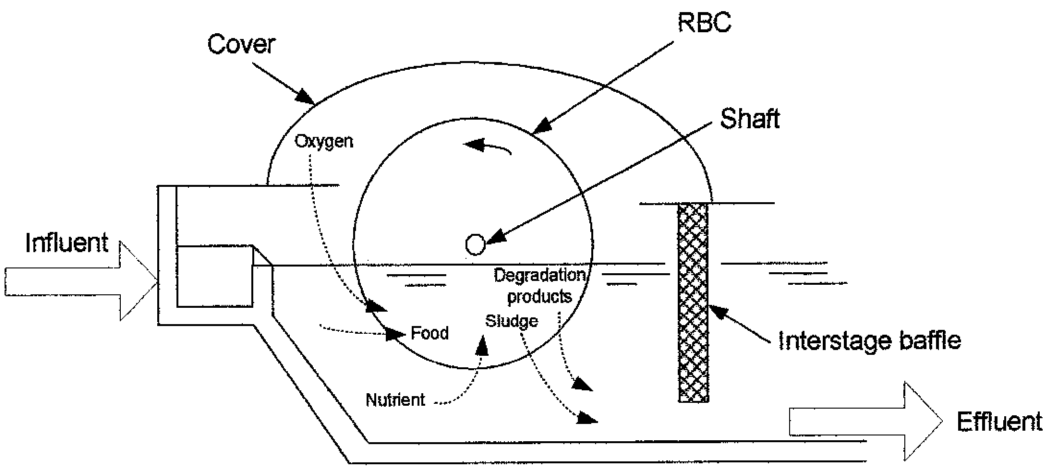


Figure 4: Schematic Diagram of an RBC (Adapted from Leslie Grady et al., 1999)

By varying the speed of rotation and the number of discs, the specific levels of pollutant such as BOD removal can be achieved. Growth of nitrifying bacteria normally predominates in the microbial population on the final disc stages. Besides, the efficiency of the process is adversely affected by low temperature as the rate of metabolism of microbes slows down when the temperature drops (Nathanson, 2000).

Membrane Bioreactor (MBR)

MBR combines an activated sludge reactor with microfiltration membrane and have been successfully employed in Japan for greywater recycling in office blocks and residential buildings (Jefferson B. et al., 1999).

MBR consists of a biological reactor with suspended biomass and solids separation by microfiltration membranes with nominal sizes ranging from 0.1 to 0.4 μm. Membrane biological reactor system may be used with aerobic or anerobic suspended growth bioreactor to separate treated wastewater from the active biomass. This membrane system produces an effluent quality equal to the combination of secondary clarification and effluent micro filtration (MetCalf & Eddy, 2004).

There are two configuration systems which have similar biological performance but differ in membrane permeation:

- Submerged MBR – membrane placed within the reactor in which the internal systems are operated hydraulically, generating lower but stable flow rate.
- Sidestream MBR – membrane placed by externally to reactor in which the external system is run at higher trans-membrane pressures and producing higher flow rates.

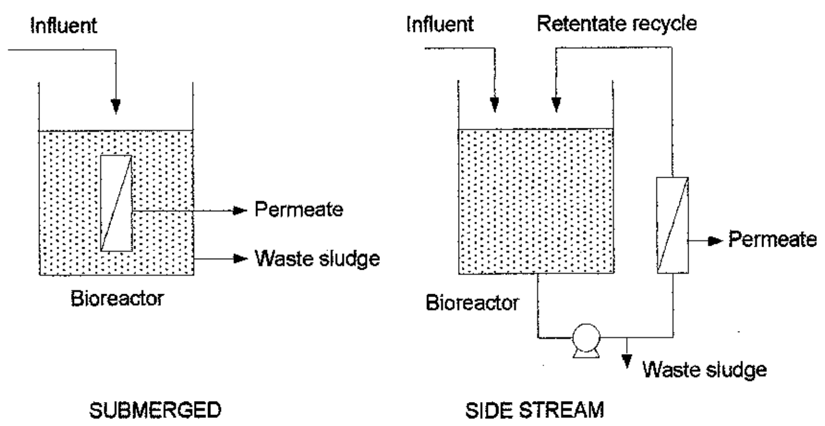


Figure 5: Schematic of a Membrane Bioreactor (Submerged and Sidestream) (Adapted from Jefferson B. et al., 1999)

Biological Aerated Filter (BAF)

BAF also sometimes referred as aerated downflow packed bed (DFPB) bioreactors. It combines depth filtration with a fixed film biological reactor to remove particular matter contained in the wastewater. *Figure 6* provides a schematic diagram of a DFPB bioreactor.

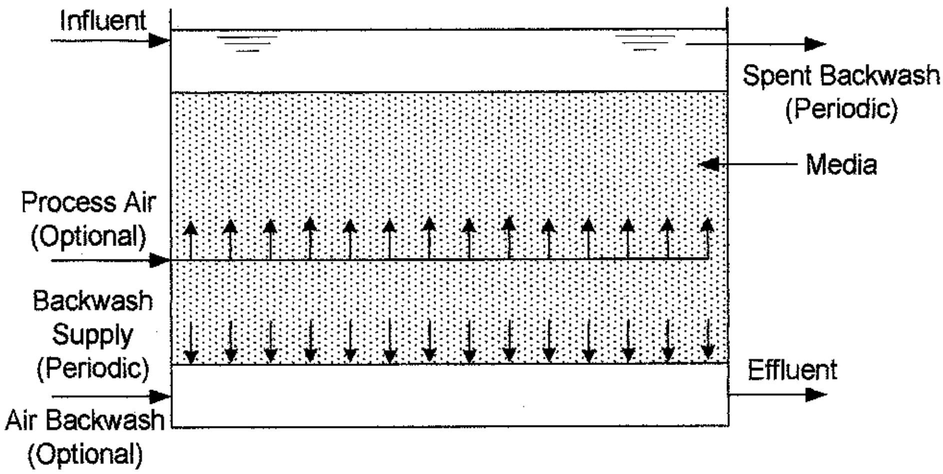


Figure 6: Biological Aerated Reactor (BAF) (Adopted from Leslie Grady, 1999)

BAF provides both biological treatment and filtration. Wastewater is applied to the top and passes downwards through the media to an effluent collection system. Relatively small diameter and modest superficial velocities are used to prevent biomass from being detached and transported through the media bed. BAF must periodically backwash to remove suspended solids that accumulate in the reactor. Backwash also provides a mean to control the biomass inventory by removing microorganisms that grow within the media (Leslie Grady et al., 1999).

Table 3: Biological Systems Comparison Table

Biological Systems	Advantages	Disadvantages
Sequencing batch reactor (SBR)[a,b] - % BOD removal: 95%	- Simple design and operation - High quality effluent - Equalization, primary clarification, biological treatment and secondary clarification can be achieved in a single vessel - Operating flexibility and control - Minimal footprint - Potential capital cost savings by eliminating clarifiers and other equipment	- A higher level of sophistication is required (larger systems of timing units and controls) - Higher level of maintenance (more sophisticated controls, automated switches, and automated valves) - Potential of discharging floating or settled sludge during DRAW phase - Potential plugging of aeration devices during selected operating cycles. - Potential requirement fro equalization after the SBR depending on the downstream processes.
Multistage rotary biological contractor (RBC)[b] - % BOD removal: 90%	- Mechanically simple - Simple process, easy to operate - Low energy requirements - no need to recycle sludge - small quantity of waste sludge	- Performance susceptible to wastewater characteristics - limited process flexibility - limited ability to scale up - Adequate pretreatment required

Membrane bioreactor (MBR)[c] - % BOD removal: 97%	- Combine physical and biological treatment - Reduce membrane cleaning requirement (once in every 6 months) with submerged MBR - Reduce all components of greywater - Meet all applicable water quality standards	- Fouling problems and regular cleaning (monthly, weekly, or daily) with sidestream MBR operating in cross-flow mode. - Costly investment especially submerged MBR - limited tolerance to shock by bactericidal agents such as bleach
Biologically aerated filter (BAF)[b,c] - % BOD removal: 90%	- Combine physical and biological treatment - Efficient biological oxidation - Efficient oxygen transfer - Filtration capability - Denitrification possible - Separate liquid – solids separation not required - More consistent coliform rejection than MBR	- Uses conventional equipment (filtration), but in unconventional mode - No absolute barrier to suspended materials and result in no disinfection to the water. - Do not reliably meet all the water recycling standards comparison to MBR

[a]EPA, 1999
[b]Leslie Grady et al., 1999
[c]Jefferson B. et al., 1999

2.3 BIOCHEMICAL OXYGEN DEMAND (BOD)

Biochemical Oxygen Demand (BOD) refers to the amount of oxygen required by microorganisms to decompose organic waste in water. It is a measure of the amount of organic pollution (Nathanson, 2000). The rate of oxidation is assumed to be proportional to the amount of organic matter remaining.

Bacteria and other microorganisms use organic substances as their food sources to breathe and reproduce. The organics are broken down into simpler compounds, such as CO_2 and H_2O and the energy released for growth and reproduction. The oxygen consumed is the dissolved oxygen (DO) when this process occurs in water. DO level will decrease if oxygen is not continually replaced in the water by artificial or natural means.

$$\text{Organic waste} + O_2\ (\text{D.O.}) \xrightarrow[\text{Microbes}]{\text{Seed}} CO_2 + H_2O$$

BOD is used as an indirect measurement of total amount of biodegradable organics in the water. The higher the BOD exerted by the microbes, the more organic material contains in the water. Besides, BOD is used as a measure of the strength of sewage. A strong sewage has a high concentration of organic material and high BOD. But for a weak sewage with a low BOD, it may not need as much treatment.

The BOD test results are used to calculate the effect of waste discharges on the dissolved oxygen of the receiving water. The BOD is performed by incubating the water sample for the standard 5-day period and then determining the change in dissolved oxygen content in the water sample.

Grey water samples are assumed to contain sufficient bacteria to oxidize the organic matters that may be present. Seeded solution is not required. Care must be taken to the temperature when conducting the experiment. Different results would be obtained at different temperatures as biochemical reaction rates are temperature dependant. In addition to that ensure no air trap inside the BOD bottles.

When dilution water is not seeded, equation below applies:

$$BOD_5, mg/L = \frac{D_1 - D_2}{P}$$

where

D_1 = DO of diluted sample immediately after the preparation, mg/L

D_2 = Do of diluted sample after 5 day incubation at 20°C, mg/L

P = decimal volumetric fraction of sample used

2.4 CHEMICAL OXYGEN DEMAND (COD)

There are nonbiodegradable or slowly biodegradable substances in water that would not be detected by the conventional BOD test. Therefore, the Chemical Oxygen Demand (COD) is another parameter of water quality that measures all organics, including the no biodegradable substances.

In the COD test, the oxygen equivalent of the organic mater that can be oxidized is measured using a strong chemical oxidizing agent in an acidic medium. The strong oxidizing agent, potassium dichromate is contained inside each COD vials. The COD reagent also contains silver sulfate, a catalyst to aid the oxidation of certain classes of organic compounds. COD can be determined in two hours and the test must be performed at an elevated temperature. The principal reaction using dichromate as an oxidizing agent may be represented generally in following unbalanced equation:

$$organic\_matter(C_aH_bO_c) + Cr_2O_7^{2-} + H^+ \xrightarrow{catayst,heat} Cr^{3+} + CO_2 + H_2O$$

2.5 CORRELATIONS BETWEEN COD AND BOD_5

Generally, a wastewater's COD values are always higher than BOD_5 values as more compounds can be oxidized chemically than biologically. For the same sample, there is no consistent correlation between the two tests for different wastewater.

However, it is possible to correlate COD with BOD_5. By conducting COD and BOD_5 tests to the wastewater sample, COD and BOD_5 results from the test are used to determine the ratio COD:BOD_5. Repeatability of tests is required for consistency and accuracy. Once the correlation has been established, BOD_5 results can be calculated from COD measurements. COD measurements can be used as parameter for treatment plant control and operation.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 SAMPLE COLLECTION, PRESERVATION AND STORAGE

3.1.1 Collecting Water Samples

Clean polypropylene or polyethylene containers are used to collect the sample and the containers are rinsed several times with the water to be sampled before taking the sample. For each sample collection, the sample name, the location, time and procedures used for each sample taken are documented.

Grey water samples are collected from sumps which can be found on the ground floor of each block in student village. An aquarium pump (*Figure 7*) is used to aid the sample collection especially when the grey water discharge is low (*Figure 8*) like during mid semester break. Grey water samples are easier to collect when the water level in the sump is high (*Figure 9*).

Figure 7: Aquarium Pump

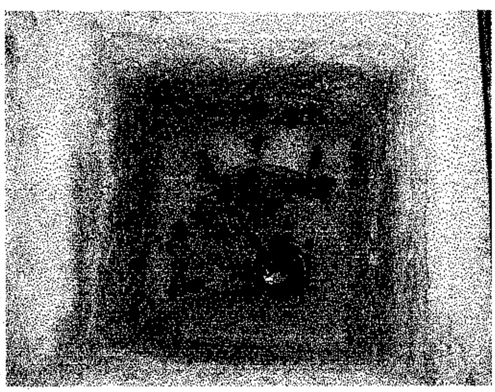


Figure 8: Low Level

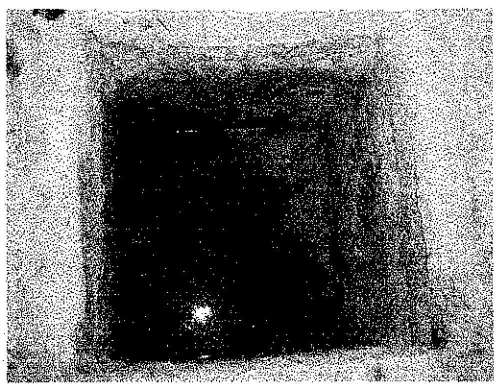


Figure 9: High Level

3.1.2 Storage and Preservation

The water samples are analyzed as soon as possible as chemical and biological processes continue after collection. This is to reduce the chance of error and minimize labor. The samples must be preserved if immediate analysis cannot be done. *Table 4* below presents the preservation methods and holding times for BOD and COD procedures.

Table 4: Required Preservation Techniques and Holding Times for COD and BOD

Parameter name	Preservation	Maximum holding time
Biochemical oxygen demand (BOD)	Cool, 4°C	48 hours
Chemical oxygen demand (COD)	Cool, 4°C, H_2SO_4 to pH<2	28 days

Source: HACH, 1997

3.2 PROCEDURE IDENTIFICATION

3.2.1 Oxygen Demand, Biochemical – Dilution Method

The determination of BOD_5 to the fresh settled sample followed HACH Method 8043 based on dilution method adapted from Standard Methods for the Examination of Water and Wastewater and from Klein, R.L; Gibbs, C. Journal of Water Pollution Control Federation (HACH, 1997).

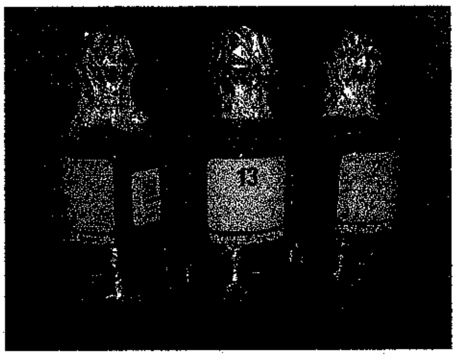


Figure 10: BOD bottles

Seeded solution water is not required as greywater contains sufficient bacteria to oxidize the organic matter that may be present. pH for the BOD test were adjusted to between 6.5 and 7.5 with 1N Sulfuric Acid or IN sodium hydroxide standard solution if the pH is not in this range . The oxygen concentration was measured with a dissolved oxygen probe. BOD measurements were determined following 5 days incubation at 20°C.

3.2.3 Chemical Oxygen Demand (COD) – Reactor Digestion Method

COD was determined in the settled and filtered samples following USEPA approved HACH Method 8000. High range (0-1500ppm) vials were used. Samples were digested for two hours prior to measurement. Measurements of COD were carried out photometrically using a HACH DR/2010 Portable Datalogging Spectrophotometer. Three replicates for each sample were analyzed.

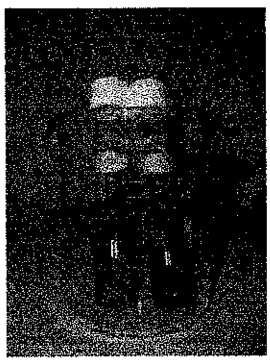


Figure 11: COD vials

3.2.4 Sequencing Batch Reactor (SBR) Experiment Set-up

Description

An aeration unit in wastewater lab comprises an open tank equipped with a paddle stirrer. Air is supplied by an electrically driven pump through a control valve and flow meter to a diffuser which is adjustable within the tank. The equipment consists of a base and backboard standing on four rubber feet. Mounted on the base is the clear acrylic water tank which has a capacity of 24.5 liters. On the front of the tank is a depth scale and at the base is a drainage tap. The lid of the tank is partially removable to allow filling. On the fixed part of the lid are mounted the stirrer motor, stirrer and clamping position for the aerator tube, pH probe and oxygen probe.

Preparation

The reactor was seeded with activated sludge collected from an oxidation pond at the university treatment plant using a Elcman dredge and the bacteria was cultivated for at least a week.

Figure 12: Ekman Dredge

SBR Experiment Set-up

An SBR experiment-set up fed with grey water collected from student village. Dimension of the units were: height of 392 mm and inner diameter of 282 mm. The height to the diameter ratio (H/D) being 1.4. The maximum level of the wastewater inside the tank was 100 mm and the minimum level was 90mm. Oxygen was supplied to the tank by using sparger tube (*Figure 13*) to promote the formation of small air bubbles. The flow was regulated at maximum 12 liters/min by the flow meter. The operation sequence is shown is shown in *Figure 14*. The reactor was operated at room temperature (23-26°C) and at oxygen concentration between 2 and 6 mg O_2/L and with pH control, which varied between 6.8 – 7.0.

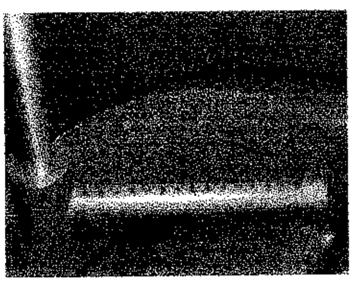


Figure 13: Sparger Tube

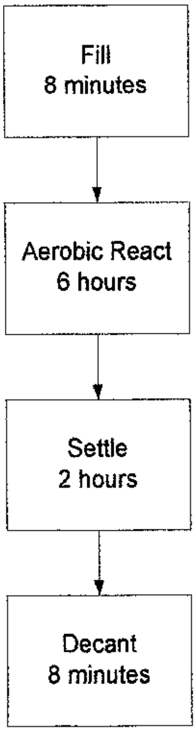
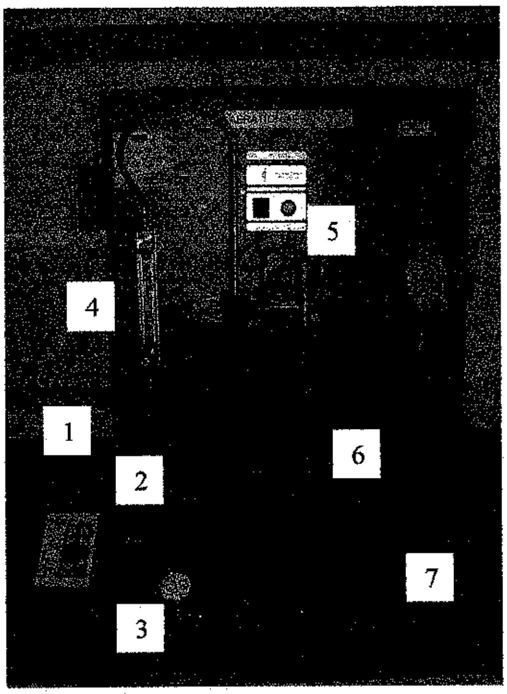


Figure 14: SBR Cycles



Note:
1 – DO meter
2 – pH meter
3 – Clock
4 – Flowmeter
5 – Motor
6 – Aeration tank
7 – Drainage tap

Figure 15: SBR Experiment Set-up

Sampling and Analysis

The influent was introduced in the system using an aquarium pump. The samples were collected during aeration period at certain time interval (15 min, 30 min, 45 min, 60 min, 90 min, 120 min, 150 min, 180 min, 240 min, 300 min, 360 min, 1440 min) at the surface liquid level of the reactor using the aquarium pump. Immediately after collection, all the withdrawing samples were filtered and the samples were immediately stored without preservation at 4°C and processed within 24 hours. COD tests were conducted to the collected water samples. The measurement of initial and final COD made was used to calculate COD removal rate.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 CHARACTERISTICS OF GREYWATER

The compounds present in the water vary from source to source, where the lifestyle, customs, installations and use of chemical household products will be of importance. The composition will vary significantly in terms of both place and time due to the variations in water consumption in relation to the discharged amounts of substances. Furthermore, there could be chemical and biological degradation of the chemical compounds, within the transportation network and during storage (Eriksson et. al, 2002).

Considering situation in student village, the collected grey water quality varies in each sampling point. This might due to the condition of water at the sampling point. Degradation of unknown solids and particles in the sump could increase the BOD and indirectly results in high COD. Generally, BOD is always less than COD. The content of BOD and COD will indicate the risk of oxygen depletion due to organic matter degradation during transport and storing and the risk for sulphide production.

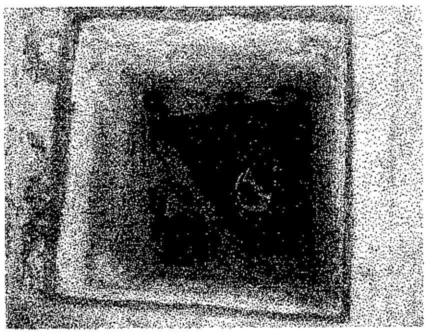


Figure 16: Heavy Contaminated Sump

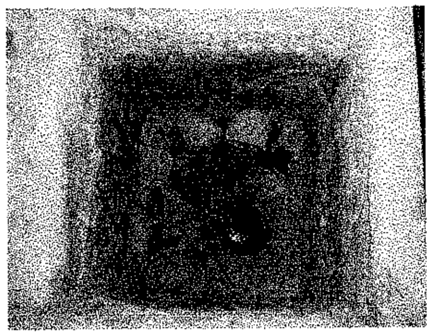


Figure 17: Slightly Contaminated Sump

Samples which have the high detectable COD, range 800-1500 mg/L could be contributed by the unknown biodegradable solids inside the sump and low discharge of water during sampling (*Figure 16*). Amount of dissolved oxygen required in decomposing the oxidizable organic matter is high. However, samples obtained with low COD, range 50-200mg/L obtained during high discharge of wastewater (*Figure 17*). The grey water is diluted with water flowing from bathroom and washing activities in the student block. The range of COD for the grey water is taken when level of water in the sumps is high during sampling as the sump at that time is act as like an equalization tank. The grey water contains 212-870 mg/L COD and 85-350 mg/L BOD.

Different types of greywater have different characteristic. It is believed that bathroom fraction contains the highest in greywater. The most common chemical contaminant found in bathroom greywater is soap and other contaminants are from shampoo, hair dyes, toothpaste and cleaning chemicals. Besides, bathroom water is microbiologically contaminated as people often urinate in showers and baths.

4.2 CORRELATION BETWEEN COD AND BOD

COD and BOD_5 tests were conducted to establish the correlation between these two parameters. By measuring the COD, BOD_5 results can be determined from the established ratio. This is useful as COD results can be gained in 3 hours, while BOD_5 can only be determined after 5 days. COD tests could give better monitoring results especially in studying the reduction of pollutant level in Sequencing Batch Reactor (SBR) experiment. Besides, correlation between COD and BOD_5 is required as only BOD_5 standard limit is set for the performance limits for toilet flushing (*Table 2*).

The COD:BOD_5 ratio obtained for the grey water collected for this research is 2.5 (*Table 5*). The biggest fraction contributing to the grey water collected comes from the bathrooms. According to Eriksson et al. (2001), the bathroom fraction contains 184-633mg/L COD and 76-300mg/L BOD. The COD:BOD_5 ratio is about 2.1-2.4. Hence, the established correlation from the experiment is acceptable as it is near to the ratio established by Eriksson et al. If the ratio of COD to BOD decreases with storage time, this indicates that the grey water is becoming more biodegradable.

Table 5: COD:BOD_5 Correlation Results

Sample	COD (mg/L)	BOD (mg/L)	COD:BOD_5	COD:BOD_5 (Average)
1	111	47.4	2.34	2.5
2	687	236.6	2.90	
3	185	69.55	2.66	

4.3 SEQUENCING BATCH REACTOR (SBR) EXPERIMENT SET UP

4.3.1 SBR Process

The SBR operates as a fill-and-draw activated sludge system for wastewater treatment whereby equalization, aeration and clarification are performed using a timed control sequence in a single tank. The SBR process consists of these following 5 operating modes or periods: FILL, REACT, SETTLE, DECANT, and IDLE. More than one operating strategy is possible during most of these steps.

SBR with equalization tank is suggested for BOD treatment. The tank should be located just before the SBR tank. No distinct idle phase is required but with distinct react and settle phase as equalization tank is used to handle flow variation.

To achieve optimal nitrification, the air velocity should be set as high as 15 $m^3m^{-2}h^{-1}$ (Wilderer et al., 2001). Since the tank base of the aeration unit has an area of $0.0625m^2$, the air velocity should set at $0.9375m^3h^{-1}$ (15.63L/min). However, due to limitation to the experiment set up, the flow was set to maximum, 12 L/min. Optimal nitrification cannot be achieved.

Besides, formation of foam with accumulated sludge can be seen during the experiment as shown in *Figure 18*. Floating sludge accumulated to achieve denitrification and enhanced biological P removal. Problem with floating sludge accumulation can be avoided or minimized by constant and complete removal of scum from the surface of the biological reactor. The removed floating sludge should not be returned or introduced to the biological reactor. Otherwise, the problem is simply transferred from one to the other biological system.

Figure 18: Foam Formation and Floating Sludge Accumulation during Experiment

In the test period, the SBR experiment set up had been operated with a 6 hours cycle to study on the COD reduction process. 3 hours reaction time is sufficient as constant COD values were obtained after 180 minutes. This led up to total of 5.27 hours for complete treatment of one batch. The SBR sequences are presented in *Figure 19*.

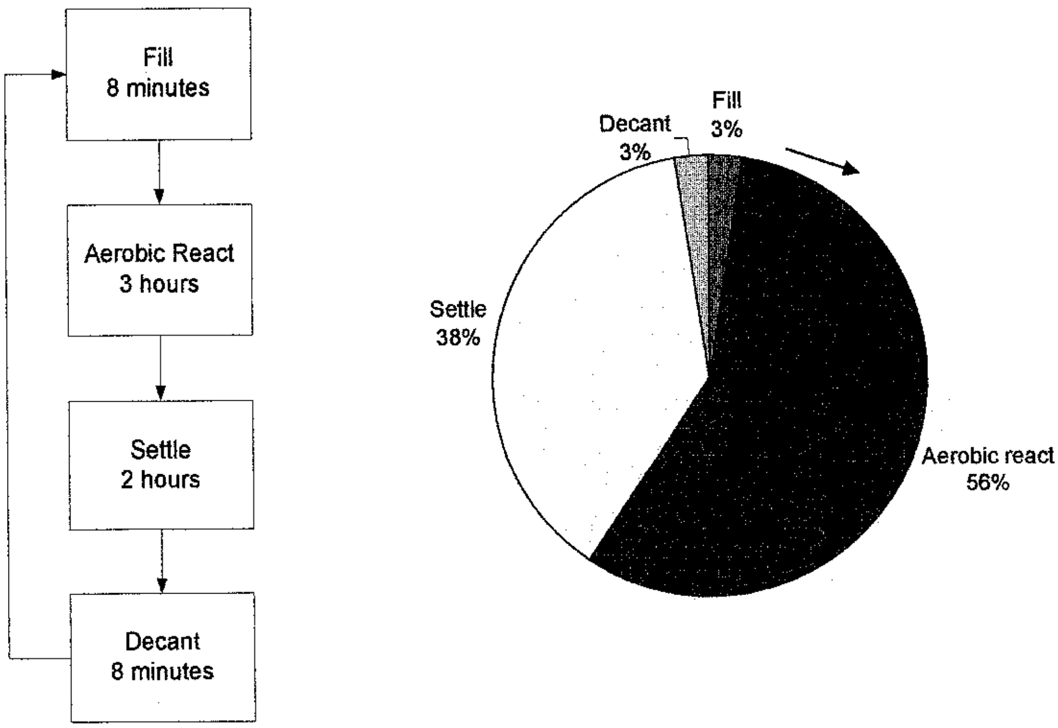


Figure 19: Suggested SBR Treatment Process

4.3.2 Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO) Concentration

Concentration profiles for COD and BOD during aeration phase are shown in *Figure 20*. The DO concentration in the unit was about 3 mg/L during the first few minutes of the aeration phase and increased up to 5 mg/L (*Figure 21*). As the air flow was not regulated, the DO rises with decreasing oxygen requirement of the bacteria.

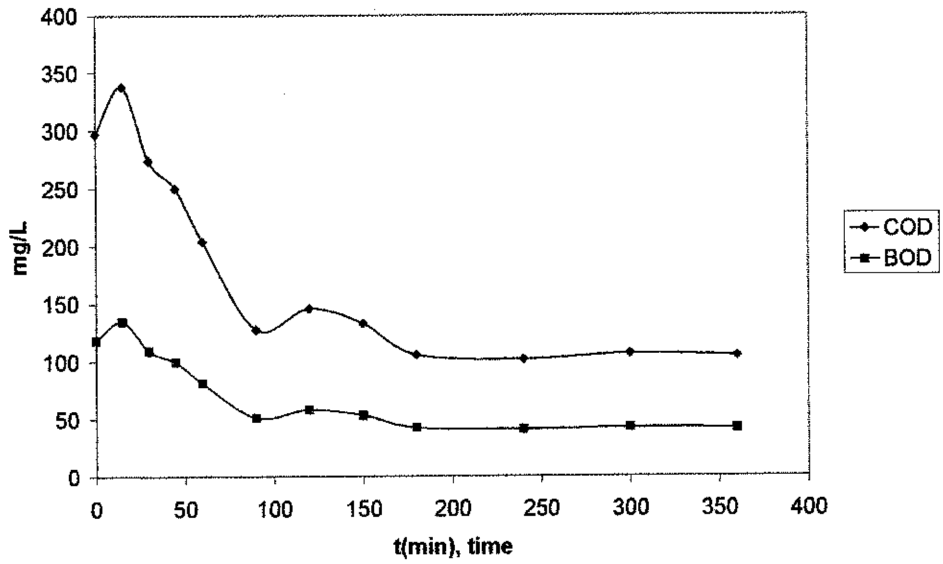


Figure 20: Concentration Profile for COD and BOD during Reaction

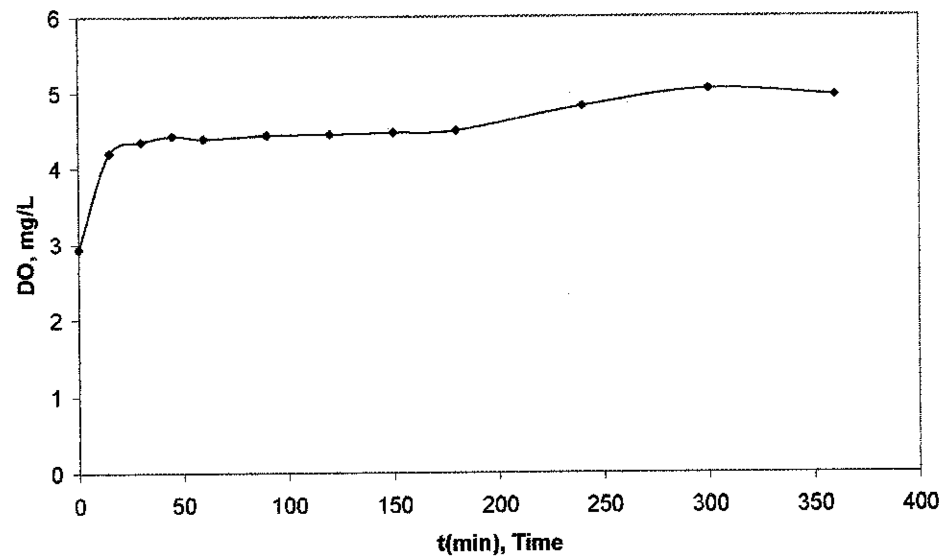


Figure 21: Concentration Profile for DO during Reaction

The BOD in the effluent does not meet the discharge limit which is 20 mg/L. However, almost all the biodegradable COD were completely removed during the first 90 minutes of the cycle (*Figure 20*). At the end of aeration, only fraction of slowly biodegradable substrate contained in the wastewater. Further BOD removal was not achieved which might probably also due to the lack easily degradable organic substrate in the incoming greywater. The measured COD is the total COD in which the total COD is the addition between soluble COD and particulate COD.

Sludge exhibited denitrifying activities under aerobic conditions. During the initial minutes of the cycle, a high amount of COD was dumped fill, which results in drastically elevated its concentration in the reactor. Besides, concentration gradient developed as t_{fill}/t_{cycle} of 0.3 is used for the experiment set-up. Filling times is short. No concentration gradient develop with plant filling which is conducted over a long period of time ($t_{fill}/t_{cycle}<0.2$) (Helmreich et al., 2000).

Greater transport by diffusion of the organic matter fraction occurs inside the sludge than of oxygen during this period. Besides, the 3 mg/L O_2 present during the feeding time were probably being depleted by the outer layers of sludge. The inner layer of sludge which was maintained under anoxic conditions received enough carbon source and nitrate to support the denitrification process. These in accordance with the results of Arrojo B. et al., (2004), who described the similar observation to the total COD trend in a SBR.

Besides, the nitrifying biomass is only growing during the aerobic period. Increment of COD concentration from 90 min to 120 min is might due to the increasing SVI in the reactor when the pH varied too much. A high SVI indicates that the sludge cannot settle well. The sludge settleability deteriorates, result in withdrawal samples collected contained more total suspended solid (TSS) than earlier samples.

4.3.3 COD Removal

Table 6 presents that the organic matter reduction occurs in SBR with the concentration of COD in the influent was 297mg/L and 105 mg/L COD in the effluent. A value of 105 mg/L COD in treated grey water corresponds a BOD value of 42 mg/L using the established COD:BOD_5 ratio of 2.5. Overall COD removal efficiency is about 65%.

Table 6: Influent and Effluent COD and BOD Concentration

Parameter	Influent (mg/L)	Effluent (mg/L)	Limit (mg/L)	Removal
COD	297	105	-	64.65%
BOD	118.8	42	20	

The BOD in the effluent does not meet the standard set by NSW Health which is 20mg/L. Besides, the SBR experiment set up does not achieve the general performance of a SBR. For SBR, the BOD removal efficiency is generally 85 – 95% (EPA, 1999). This could be due to the presence of TSS in the effluent. Presence of TSS concentration in the effluent had resulted in increment in COD concentration. Better effluent quality could be achieved if TSS concentration can be reduced. The presence of TSS in the effluent was a result of the TSS content in the influent and the small biomass wash-out from the reactor. These in accordance with the discussion of Arrojo B. et al. (2004), who explained on the source of the presence of TSS in the effluent.

To reduce the TSS in the effluent, solids present in the feed could be removed by coagulation and flocculation process. The flocs formed during coagulation are settable and can be removed from the water in a sedimentation tank. The coagulation and flocculation process consolidates suspended and colloidal impurities that they demonstrate very poor settling characteristics without treatment. In order to introduce practical settling rates in colloidal particles, it is necessary that they be agglomerated by some coagulating reagent such as alum, sodium aluminate, ferric chloride, ferric sulphate and cationic polymers.

High conversion and good settling properties of biomass is more preferable to be used in SBR. The presence of biomass with very poor settling properties could results in biomass wash-out from the reactor and this increases the COD concentration in the effluent. A suitable post treatment process could be required to remove TSS in order to fulfill the performance limit. Among the post treatments can be used are membrane filtration, depth filters, surface filters and etc.)

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Greywater reuse helps to conserve and optimize the use of water resources. However, greywater treatment and reuse are to be assessed in term of technical feasibility, public health, social acceptability and sustainability (Al-Jayyousi, 2003). Greywater quality varies considerably and appropriate technology is to be evaluated to cater the user's needs before it is applied.

Relationship BOD_5 with COD is established after few trials of tests conducted in this project. The COD:BOD_5 ratio is 2.5. Sequencing Batch Reactor (SBR) offers as one of the alternatives in reducing BOD in greywater. An SBR experiment was set to study the treatment of BOD reduction of greywater. Removal efficiency obtained from the experiment is about 65% with the reaction time period of 3 hours. The effluent does not meet the standard, 20 mg/L. However, the results presented in this paper show the potential of a simple, single tank SBR system for biological nutrient removal from greywater. Other potential processes discussed are multistage Rotary Biological Contractor (RBC), Membrane Bioreactor (MBR), and Biologically Aerated Filter (BAF).

5.2 RECOMMENDATION

Measurement of dissolved components (NH_4-N, NO_2-N, NO_3-N) and sludge parameters (SS, VSS, SVI) should be done to further investigate the performance of Sequencing Batch Reactor in reducing Biochemical Oxygen Demand (BOD). Besides, further research work is required at a larger scale to validate these results and to further optimize the Biological Nutrient Removal (BNR) for the greywater recycling process for toilet flushing.

The biological treatment of greywater can be enhanced by nutrient balancing since nitrogen/phosphorus balancing eliminates the occurrence of macronutrient-limiting conditions that always hindered degradation of the substrate. The biological treatment can be maximized by nitrogen/phosphorus balancing followed by supplements of zinc or copper (Jefferson B. et al., 2001). Zinc or copper can be added to the biological treatment to enhance the BOD removal.

Appropriate technology is to be selected to suit the user's needs as grey water quality varies considerably. Based from the literature review on the potential biological processes to be used for the grey water treatment system, it is recommended to select sequencing batch reactor (SBR) biological system in treating the grey water for the university because of its simple design and operation. Using the assumption stated earlier in problem statement, the influent flowrates is about $300m^3$/day. It is applicable as SBR are typically used at flowrates of 5MGD ($18,927m^3$/day) or less. In addition, cycles within the system can be easily modified for nutrient removal in the future, if it becomes necessary (EPA, 1999). If the regulatory for the greywater recycling for toilet flushing exist in Malaysia in the future, SBR is extremely flexible to adapt to the regulatory changes for effluent parameters. Other process such as rotary biological contractor (RBC) is not applicable as it has limited process flexibility. Membrane bioreactor (MBR) involves costly investment and biologically aerated filter (BAF) does not meet all the water recycling standards as studied by Jefferson B et al, 1999.

Many communities and individuals in other countries already practice greywater reuse. It should be possible that households to have a dual water system with two water qualities in the future for every country. The first is a high quality drinking water from natural water resources and second quality for all other uses. It is essential that greywater reuse practice adequately and wisely to protect public and private health as well as the environment. Regulations and policies should be followed when designing the greywater treatment system to achieve ecological sustainable development and does not decrease the amenity of the local community.

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