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DEPARTMENT OF CIVIL ENGINEERING AND CONSTRUCTION ENGINEERING

SEQUENCING BATCH REACTOR IN TREATMENT OF SLAUGHTERHOUSE EFFLUENT

BY

THEURI AYUB KARIUKI

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Declaration /Approval

Declaration:

This thesis is my original work and has not been presented for a degree in any other university.

Theuri Ayub Kariuki _____ Date: _____

Approval:

This thesis has been submitted for examination with my approval as university supervisor.

Dr. P. K. Ndiba, _____ Date: _____

Senior Lecturer,

Department of Construction & Civil Engineering

Dedication

This thesis is dedicated to my dear wife Priscillah, daughter Grace and son Benny, for their support and goodwill in imparting me the determination to accomplish this research work.

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Abstract

Slaughterhouse wastewaters are difficult to treat because of high concentration of organic matter, nutrients and suspended solids. These materials are readily biodegradable in the environment, resulting in degradation of receiving waters and serious odor problems. Public health authorities have in the past closed four of the slaughterhouses at Dagorretti in Nairobi, Kenya because of inadequate wastewater and solid waste management systems. Conventional treatment methods such as the activated sludge process are unaffordable while waste stabilization ponds require large pieces of land that are unavailable in urban areas where most slaughterhouses are located. Slaughterhouse wastewaters are intermittent, which favor batch treatment methods including the sequencing batch reactor (SBR). The SBR is a fill-and-draw type of activated sludge system that involves a single complete-mix reactor in which all steps of the activated sludge process occur. Because the SBR combines several processes in one unit, it has minimal land requirements, which makes it suitable for urban settings where land is scarce. This study investigated the suitability of SBR in treating wastewater from Dagoretti slaughterhouses.

Three bench scale SBRs were set up with a manual control mechanism for the treatment stages to evaluate the effects volumetric exchange rate on effectiveness of SBR in treating effluent from the slaughterhouses. The average raw slaughterhouse wastewater concentrations for COD, BOD_5, MLSS, NH_4-N, NO_3-N and TP were 11947 ± 2,164; 8233 ± 2025; 1,400 ± 787; 70.3 ± 49.0; 65.2 ± 9.2 and 261 ± 39 mg/L respectively. Volumetric

exchange rate (VER) in the 30 - 50 % range did not show significant difference in the SBR treatment. Therefore, the higher VER of 50% was recommended because it gives higher of volumetric turnover compared to the lower VERs. The SBR treatment process achieved average reductions of 59, 61, 54 and 35% for chemical oxygen demand (COD), biological oxygen demand (BOD_5), ammonia nitrogen (NH_4-N) and total phosphorus (TP) respectively. However, the corresponding average effluent concentrations, 4884 ± 125; 3196 ± 82; 196 ± 82; 32 ± 2 and 171 ± 5 mg/L for COD, BOD_5, NH_4-N and TP, respectively, were above the regulatory standards for discharge to public sewers. Therefore, there is need to improve the SBR treatment through improved aeration and mixing, use of more treatment cycles and inexpensive on-line monitoring and control, or to provide supplementary treatment before discharge.

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Nomenclature

Abbreviations:

BOD_5 = biological oxygen demand after five days of incubation

COD = chemical oxygen demand

DO = dissolved oxygen

HRT = hydraulic retention time

ORP = oxidation- reduction potential

SBR =sequential batch reactor

SRT = solids retention time

TP = total phosphorus

TSS = total suspended solids

Symbols:

dS / dt = rate of change in substrate concentration with time

k = maximum rate of substrate utilization

k_d = endogenous decay coefficient

k_{dn} = endogenous decay coefficient for nitrifying organisms

K_n = half-velocity constant

K_o = oxygen inhibition coefficient

K_s = half-velocity constant

μ_m = maximum specific growth rate

μ_n = specific growth rate for nitrification

μ_{nm} = maximum specific growth rate of nitrifying bacteria

N = nitrogen concentration, mg/L

N_o = NH_4-N concentration at t=0, mg/L

NO_3-N = nitrate-nitrogen

N_t = NH_4-N concentration at time t, mg/L

Q = influent flow rate, m^3/day

r_{su} = soluble substrate utilization rate

S = concentration of growth-limiting substrate in solution, mg/L

S_o= initial substrate concentration at t=0, mg/L

S_t = substrate concentration at time t, mg/L

t = time, days

τ = the hydraulic retention time, days

V = volume of the reactor, m^3

VER = volume exchange rate

X = biomass concentration, mg/L

X_n = nitrifying bacteria concentration, mg/L

Y = biomass yield

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Slaughterhouses wastewaters comprise of diluted blood, guts contents, animal tissue, and faecal material. Treatment of slaughterhouse wastewater is difficult to treat because of high concentration of organic matter, nutrients and suspended solids (Yiu et al., 2001). The effluents comprise streams from stockyard and slaughterhouse floor washings (Yiu et al., 2001). Most of these materials decompose readily in warm weather, releasing odorous gases to the atmosphere. Moreover, such constituents exert high oxygen demand in water bodies and render them incapable of supporting aquatic life. There is therefore need to treat such effluents by using methods that are affordable and can handle strong organic waste water that is released intermittently. Effective and economical treatment methods such as sequencing batch reactors (SBR) are required to improve effluent characteristics for discharge into rivers or public sewers.

Conventional treatment methods such as the activated sludge process have tended to be too expensive for the slaughterhouses while waste stabilization ponds require large pieces of land that are not available in urban areas where most slaughterhouses are located. Sequencing batch reactor is a modified form of activated sludge system (activated or acclimatized microorganisms are returned to the reactor to act on incoming waste), which utilizes a single batch

reactor to treat wastewater. Equalization, aeration, and clarification are achieved sequentially in the batch reactor, thus requiring relatively small area. The SBR treatment process is flexible and economical as the treatment functions are carried out in a time sequence rather than in the conventional space sequence of continuous-flow systems (Zhan et al., 2008). Furthermore, with the SBR there is no need for the return activated sludge and primary sludge pumps associated with the conventional activated sludge systems. The treatment involves a cycle with five stages; fill, react, settle, decant and idle, that can be repeated until the effluent attains discharge requirements. In addition, several process modifications can be made in the duration associated with each step, to achieve nitrification and BOD_5, nitrogen and phosphorus removal (Metcalf & Eddy, 2003). These characteristics indicate potential application of the SBR in situations requiring compliance with environmental standards and the effluent is produced intermittently or has variable characteristics. Despite its many advantages, the SBR technology has not been tried in Kenya.

This study addresses the use of SBR in treatment of slaughterhouse effluent. The thesis presents a review of the literature, methodology, results and discussions, conclusions and recommendations.

1.2 Problem Statement

Slaughterhouses located within urban residential areas in Nairobi are associated with serious odor problems, resulting from poor liquid and solid wastes management. The slaughterhouses are characterized by poorly

designed and maintained wastewater treatment plants, which is attributed to prohibitive costs of conventional treatment plants and scarcity of land for construction of waste stabilization ponds. Consequently, it has been difficult for the slaughterhouses to meet the effluent requirements for discharge into rivers and public sewers.

Four Dagoretti slaughterhouses namely; Thiani Slaughterhouse, Mumu Slaughterhouse, Nyongara Slaughterhouse and Dagoretti Slaughterhouse Company Ltd., supply about 60% of the meat consumed in the city of Nairobi. Inadequate treatment of wastewater from the slaughterhouses led to their closure by the National Environmental Management Authority (NEMA) in May 2008 (UNIC, 2010). Even though the slaughterhouses were subsequently allowed to operate following installations of some anaerobic ponds, the treated effluent is still unacceptable for discharge into the nearby river. Because of limited land for construction of affordable conventional plants such as waste stabilization ponds, there is need to investigate treatment methods with minimal requirements. Moreover, since the slaughterhouse wastewater-streams have intermittent flows, batch-wise treatment using SBR is a possible solution to this problem. Reported success of SBR has been associated with automated controls which may not be affordable by small scale slaughterhouses in developing countries. Additionally, the type of slaughterhouse processes and wastes, and the local climatic conditions may affect performance. Therefore, it is necessary to investigate the viability of using SBR to treat slaughterhouse wastewater for the Kenyan conditions and applicable operating conditions.

1.3 Objectives

The overall objective of the research is to investigate the efficiency of SBR in treating slaughterhouse effluent.

The specific objectives are to:

1. Establish the effects of Volume Exchange Rate (VER) on the performance of SBR.
2. Evaluate reduction of biological oxygen demand (BOD), chemical oxygen demand (COD), nitrogen (N) and phosphorus (P) by SBR treatment.

1.4 Scope of the Study

The study covered treatment of slaughterhouse wastewater using the sequential batch reactor method. Slaughterhouse wastewater used in this study was collected in bulk quantities from the Dagoretti Slaughterhouse Company Ltd and stored in a cold room at 4^{o} C. The wastewater was inoculated with the activated sludge from Kiambu Wastewater Treatment Plant and existing anaerobic pond and the microorganisms acclimatized to the wastewater for 13 days. The SBR wastewater treatment was conducted in three lab-scale reactors to investigate the operating conditions for treating slaughterhouse wastewater. The test measured influent and effluent COD, BOD_5, NO_3-N, NH_4-N and TP. The pH, ORP and DO were monitored to distinguish end of nitrification, carbon oxidation and denitrification during operations of SBRs.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Slaughterhouse Industry and Wastewater Characterization

2.1.1 Slaughtering Processes and Waste Generation

Slaughterhouses are categorized as a food industry. Animal slaughtering processes include receiving of the animal in the stockyard, caging, slaughtering, blood collection, skinning, evisceration, washing of entrails and general cleaning (Nuch, 2007, Figure 2.1).

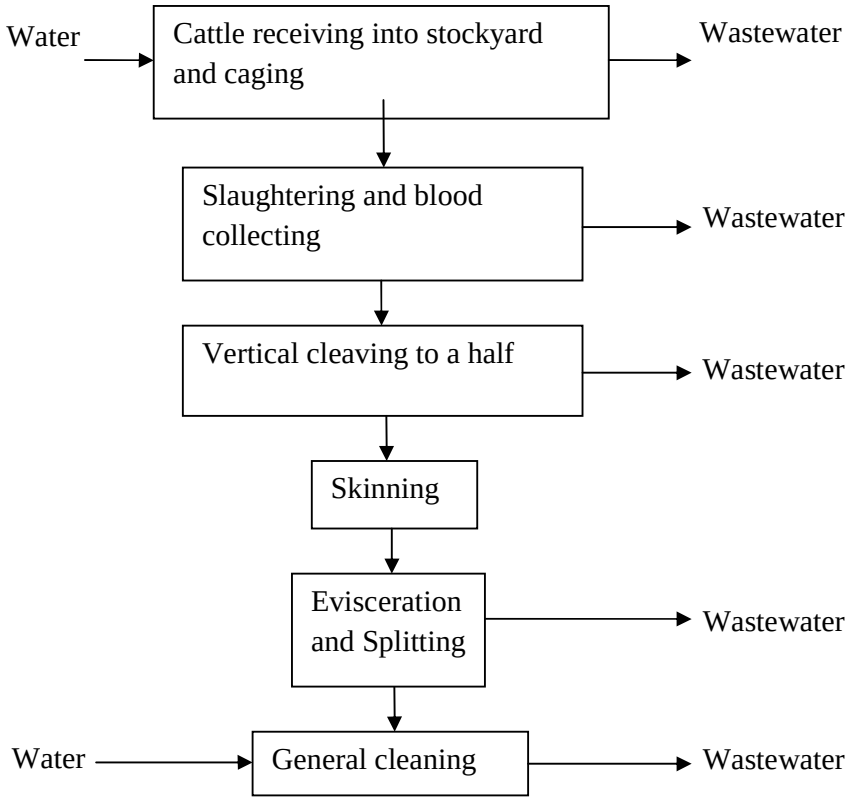


Figure 2.1: Slaughterhouse Processes and Wastewater Streams (Adapted from Nuch, 2007)

Slaughterhouses produce significant volumes of wastewater during the slaughtering process and periodic washing of residual particles. Sources of wastewater include washings from stockyard and slaughtering rooms. The stockyard streams may contain grit, soil, faecal material and urine while those from slaughtering rooms contain diluted blood and gut contents (Nuch, 2007).

To reduce the pollutant loading and wastewater treatment costs, waste minimization and recovery can be applied to blood, waste animal tissues (meat and fat trimmings), gut contents and faecal material. These wastes could be collected in relatively dry forms by dry-dumping paunch contents; dry-collection of stockyard wastes; and dry-cleaning blood stained floors using squeegees then pushing the amassed blood into the blood collection system or scooping the mass into a holding bin for processing with other recovered blood. A low nib wall on the floor around the areas to be dry-cleaned helps to contain the blood and minimize its dilution by wash water used in other operations. Partial recovery of these wastes is also possible during preliminary treatment. Although dry collection can be difficult, and the collected solids pose a significant disposal problem, managing solid waste is more cost effective than treating and disposing of it as a part of wastewater. Because animal tissue increases the potential to generate odor and attract vermin, which can restrict the utilization and disposal of these solids, initial wastewater streams containing animal tissues should be segregated from those containing faecal material and gut contents, for easier recovery (Yiu et al., 2001).

As soon as solids enter a wastewater streams, they begin to break down and release soluble material. This release is increased by turbulence and by high temperatures. Therefore, if the solids cannot be recovered dry, they should be removed from the wastewater stream as quickly and as close to source as possible. Spills of blood should be strictly minimized due to high pollution load in undiluted blood (Table 2.1). Because blood can be a major source of wastewater organic and nitrogen loading, slaughterhouses should monitor their blood collection and processing efficiencies. An increase in blood recovery of 2 liters per beef animal, which equates to about a 15% increase in blood yield, reduces wastewater COD and nitrogen loadings by 600 and 60 g per animal, respectively (Yiu et al., 2001).

Table 2.1: Pollutants of Concern in Undiluted Bovine Blood (Yiu et al. 2001)

Parameter	Typical concentration (mg/L)
Total solids	200,000
COD	300,000
BOD_5	30,000
Total nitrogen	200,000
Total phosphorus	200

2.1.2 Slaughterhouse Wastewater Characterization

Slaughterhouse wastewaters contain high levels of organics, measured biochemical oxygen demand (BOD), nitrogen, phosphorus and suspended solids because of the presence of organic materials such as blood, fat, grease,

and proteins (Sirianuntapiboon and Manoonpong, 2001; Matsumura and Mierzwa, 2008, Nuch, 2007). Therefore, these wastewaters should be treated effectively before discharge into receiving bodies to avoid environmental pollution. The slaughterhouse characteristics vary widely from slaughterhouse to slaughterhouse; and with time: depending on the amount of water used, the kinds of livestock slaughtered, and the processing operations undertaken (Table 2.2).

Table 2.2: Pollutants Concentrations of Screened/Settled Slaughterhouse Wastewater (Yiu et al., 2001)

Pollutant	Concentration range (mg/L)	Pollutant	Concentration range (mg/L)
COD	2,000-6,000	Fat, oil and grease	10-15
Soluble COD	1,200-3,600	Total nitrogen	15-50
BOD_5	1,000-3,000	Total phosphorus	0.5-2
TSS	200-2,000	Faecal coli-forms	10^7-10^{8a}

[a] Measured in counts per 100ml

In comparison with domestic wastewater the pollution load of slaughterhouse effluents is 5 to 10 times greater (Metcalf & Eddy, 2003). Limiting values for the discharge of treated slaughterhouse wastewater into rivers are set based on the discharge volume and the sensitivity of the receiving water bodies (e.g. Zhan et al., 2008, Table 2.3). Moreover, Environmental Management Co-ordination Regulations (EMCR, 2006) outline allowable levels for discharge into public sewers (Table 2.4). Discharge of improperly treated slaughterhouse wastewater, into water- bodies results in oxygen depletion by the BOD_5 and suspended solids. Other effects include, eutrophication,

ammonia toxicity, nitrate contamination of ground water, and turbidity and colour in the receiving waters.

Table 2.3: Treated Effluent Requirements for Discharge to a River (Zhan et al., 2008)

Pollutant	Limiting Concentration range (mg/L)	Pollutant	Limiting Concentration range (mg/L)
COD	50-200	Fat, oil and grease	10-15
BOD_5	10-40	Total nitrogen	15-50
Suspended solids	10-60	Total phosphorus	0.5-2

Table 2.4: Treated Effluent Requirements for Discharge to a Public Sewer (EMCR, 2006)

Pollutant	Limiting Concentration (mg/L)	Pollutant	Limiting Concentration (mg/L)
COD	1,000	Nitrates	20
BOD_5	500	Ammonia - Nitrogen	20
Fat, oil and grease	5	Phosphates	30

2.2 Primary Treatment of Slaughterhouse Wastewater

2.2.1 Preliminary Treatment

Preliminary treatment of effluents aims at removing large objects, suspended solids, grit, fats, oil, grease and animal tissue from wastewater that endanger or obstruct further treatment operations downstream. Available preliminary treatment methods for slaughterhouse wastewater include screens, plain sedimentation and dissolved air flotation. Gravitational separation is more

effective than screens, but it has higher operating costs and a greater potential to generate odor. Consequently, screening or a combination of screening and dissolved air flotation technology is used instead of gravitation separation (Yiu et al., 2001). In the dissolved air flotation process, suspended solids in the wastewater are removed by flotation assisted by micrometer- sized air bubbles. These systems work faster and produce a drier sludge. However, they have higher capital and operational costs than passive gravity separation.

2.2.2 Physicochemical Treatment

Figure 2.2 illustrates unit operations in physicochemical treatment systems as proposed by Yiu et al. (2001).

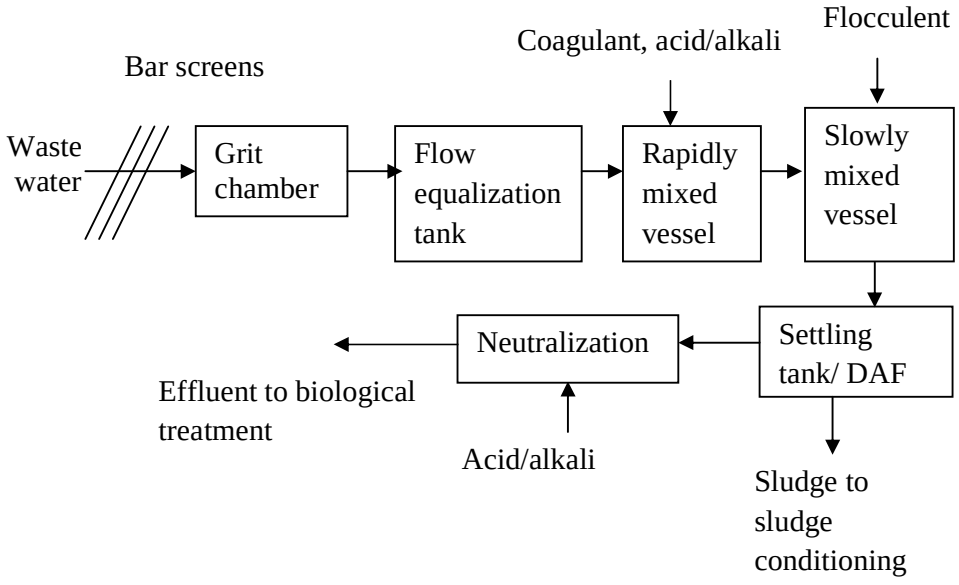


Figure 2.2: Unit Operations in Physicochemical Treatment Systems (Adapted from Yiu et al., 2001)

Physicochemical treatment aims at removing soluble proteins, fat emulsions and colloidal material from wastewater by adjusting pH and dosing the wastewater with specific coagulants and flocculants; dissolved and finely

dispersed organic matter precipitate and agglomerate into larger particles (flocs). The treatment involves chemical coagulation and flocculation that reduce particle surface (negative) charge and overcome repulsive forces between the particles. A physical process such as dissolved air flotation or settling recovers the so formed flocs (Yiu et al., 2001).

2.3 Biological Treatment

Biological treatments involve processes that remove pollutants from wastewaters biologically. They are preferred to the physicochemical processes in terms of environmental effects, economy and operations. These processes are more flexible and are easily modified, for example, through changing the operating procedures to optimize current systems or developing new ones, extending the existing treatment works or purchasing new equipment, and using control systems to optimize treatment-processes (Nuch, 2007). The major groups of biological processes include anaerobic processes, which operate in the absence of oxygen; aerobic processes, which utilize oxygen and a combination of both. The systems are further divided into suspended or attached growth processes for the removal of BOD, nitrification, de-nitrification, phosphorus removal and stabilization (to reduce volume, improve sludge de-water-ability and produce usable methane gas) (Metcalf and Eddy, 2003).

2.3.1 Anaerobic Treatment

Anaerobic wastewater treatments are reliable and have low retention times (Yiu et al., 2001). They have several advantages over aerobic processes

including lower electricity costs, high efficiencies, low construction and operating costs, low rates of sludge production, high organic loading rates, and production of useable biogas. Anaerobic biomass does not have to be fed continuously since anaerobic metabolism is a slow process and the sludge can remain inactive for several months. Moreover, anaerobic processes do not require oxygen and produce low molecular weight end products, carbon dioxide and methane, that can be used for heating. Sludge production is 5 to 20% of that for aerobic processes, thus reducing disposal problems and costs. The degradation times may be longer, because anaerobic metabolism is a slower process but potential increase in detention time is offset by the higher loading rates. Because anaerobic sludge can remain inactive for several months, seasonal wastewaters such as the fish processing, slaughterhouse or sugar refining industries, can be treated an-aerobically (Omil et al., 1996).

In anaerobic treatment systems, organic matter in the wastewater is converted to methane and carbon dioxide in the absence of oxygen. The bacteria involved include fermentative (acidogenic), acetogenic and methanogenic bacteria. Anaerobic treatment depends on complex interactions between bacterial activities. The acetogens produce acetic acid and hydrogen required by the methanogens and consume various fatty acids that are toxic to the methanogens. In return, methanogens remove hydrogen, which is toxic to the acetogens. A balance between microbial populations is essential for the stability and performance of an anaerobic treatment system that performs optimal at pH 7, and where there is a high level of bicarbonate alkalinity to buffer the effects of organic acid production. The rate of anaerobic digestion

at the normal temperature of meat processing wastewater (20^0 to 35^0 C) is usually satisfactory, but digestion is more rapid at higher temperatures. Meat processing wastewater is well suited to biological treatment, as it contains all the nutrients required for microbes to grow. Anaerobic treatment commonly achieves removal rates of 70% to 90% for COD and BOD_5 respectively (Omil et al., 1996).

Anaerobic treatment has low operating cost due to low sludge production and low energy requirements. For every unit of COD removed anaerobically, only about 5% to 15% ends up as sludge, contrasting with about 40% to 60% for aerobic biological treatment and 100% for physical and physicochemical treatment. The biogas produced may be recovered as fuel. Methane yields of up to 0.23kg per COD removed have been reported for the anaerobic treatment of meat processing wastewater (Metzner and Temper, 1990; Borja et al., 1995b), 92% of the theoretical maximum. This yield translates to 12.8 MJ of energy per kg of wastewater COD removed.

Anaerobic treatment does not remove nitrogen or phosphorus. It rapidly reduces organic forms of nitrogen and sulfur to ammonia and hydrogen sulfide, which are toxic to fish and other aquatic organisms. The hydrogen sulfide may cause an odor nuisance and corrosion of equipment. Sulfides are also produced by bacterial reduction of sulfates in the wastewater. As a result, anaerobic treatment of meat processing wastewater is generally applied as a treatment step before discharge to a public sewer, aerobic biological treatment, or land application.

(a) Anaerobic lagoons

Anaerobic lagoons are a popular method of treating meat processing wastewater because of their simplicity, reliability and low cost. They are typically between 3 and 6 m deep, with an operating volume that equates to a loading rate of 0.1 to 0.4 kg BOD_5 /m^3.day (approx. 0.2 to 0.8 kg COD/ m^3.day) or a hydraulic retention time of 5 to 15 days. These systems are shaped to suit their site, however, the greater the length: width ratio- where the influent and effluent are at opposite ends- the better the performance because short-circuiting of flow is minimized. Sometimes several anaerobic lagoons are operated in parallel or in series. They are used mainly for small rural communities where sufficient land is available and discharge requirements may not be as stringent as in urban areas (Metcalf & Eddy, 2003). Increasing concerns about odor from anaerobic lagoon systems has made these systems unpopular in treating slaughterhouse wastewaters in urban setting.

(b) High-rate anaerobic systems

High-rate anaerobic systems are characterized by high densities of anaerobic microorganisms (typically 4000 to 8000 SS g/m^3), allowing BOD and COD loading rates typically 5 to 20 times greater than those of anaerobic lagoons.

Their relatively small size makes them most suitable where land area is limited, and biogas collection and / or strict odor control are objectives. However, compared with lagoons, such systems have higher capital and operating costs, and their performance can be more sensitive to variations in organic loading. These systems include suspended-growth technologies such as anaerobic contact process, upflow anaerobic sludge blanket (UASB)

process and anaerobic SBR and; attached-growth systems such as anaerobic biofilters (Metzner and Temper, 1990) and fluidized bed reactors (Borja et al., 1998). In suspended-growth systems, the biomass in the reactor is maintained in suspension as flocs or granules.

The anaerobic contact process involves stirring digester contents and recovering (by gravity in a clarifier) the biomass washed out with the effluent. Some of the biomass is returned to the digester. The solids-laden effluent from the digester must be degassed (by applying a vacuum) to effect good biomass settling in the clarifier (Yiu et al., 2001). In the UASB process, the wastewater passes upward through the sludge blanket at a rate that prevents washout of the biomass, and thus avoids the need for a separate clarifier tank. Anaerobic SBR is relatively a new process that shows much promise for the treatment of meat processing wastewater (Yiu et al., 2001). In attached- growth systems, the biomass is immobilized on media that have a high surface-to-volume ratio.

Up-flow Anaerobic Sludge Blanket (UASB) Reactor

The sludge blanket process, a variation of the anaerobic contact process, is a biological tank with upflow and a settling tank developed in The Netherlands (Lettinga et al., 1980). Granules are produced during the degradation of the easily degradable organic matter and consist of high concentrations of biomass. The granules are permanently formed and remain in the reactor. The wastewater enters the bottom of the reactor and passes through the granules. The organic matter is converted to methane and carbon dioxide and leads to the formation of gas bubbles which can provide adequate mixing and

wastewater/ biomass contact. The granules rise in the reactor due to the bubbles, however they will settle in the tank since their settling velocities are greater than the upflow velocity (typically 1 m/h). An adequate settling zone is provided (van Haandel and Lettinga, 1994). Since the concentrations of sludge can be up to 5 to 15 kg VSS/m^3, generally twice that of contact processes, recycling is not required. They are the most common type of high rate process in the world today because they can perform at higher efficiencies than anaerobic fixed film and continuous flow aerobic systems (Latkar and Chakrabarti, 1994).

Bacterial sensitivity to pH, temperature and toxic compounds, long start-up and production of odorous compounds has been cited as disadvantages for anaerobic processes. However, although chemical addition may be necessary for industrial effluent treatment, it is not usually the case for domestic wastewater and sewage (van Haandel and Lettinga, 1994). The bacteria adapt well to low temperatures and can tolerate some toxicants such as aliphatic hydrocarbons and chlorinated alcohols even better than aerobic bacteria (Blum and Speece, 1991). UASB reactors applications include sugar-beets, fatty acids, piggery, slaughterhouse, potato starch, pulp and paper, alcohols and milk fat (McCarty, 2001).

Start-up times can be reduced by using adequate inoculum such as digested sludge or biomass from operating anaerobic reactors, particularly if lower operating temperatures are used (Singh et al., 1996). Toxic compounds can lead to biomass that does not settle well and subsequent biomass washout.

UASB reactors are suitable for organic loads of 0.5 to 20 kg COD/m^3.day which is higher than aerobic processes (Kato, 1994). This reduces reactor volume and space requirements. UASB reactors can be used for high strength wastewaters with VSS: COD ratios less than 1 and with COD concentrations between 500 and 20,000 mg/L. The HRT can be less than 24 h.

Anaerobic Sequencing Batch Reactor

The anaerobic sequencing batch reactor is an anaerobic version of the conventional SBR technology. It is applicable for high strength wastewaters and can remove 75 to 94% COD with hydraulic retention times of 8 to 24 hours. The age of the biomass is 60 to 70 days. The four cycles of fill, react, settle and decant operate on three- to twelve-hour cycles. Operation is based on timing. Due to the batch-fed operation, short-circuiting does not occur. The biomass is highly granulated and contains many bacterial species and fungi with mineral deposits. These granules settle rapidly at a rate of a metre per minute. Organic loading rates of 4 kg COD/m^3.day are used (Beun et al., 1999). Dilution of toxic materials does not occur. This type of reactor appears to still be under development due to a lack of full-scale systems. A semi-commercial system has been developed by Agriculture and Agri-Food Canada for swine manure slurries and has been pilot tested at 30°C for the treatment of slaughterhouse wastewater (Masse' and Masse, 2000).

Annamox Process

Strous et al. (1999) discovered anaerobic ammonium oxidation (Annamox) process that converts ammonium in the wastewater to nitrogen gas under

anoxic conditions with nitrite as the electron acceptor and ammonium as the electron donor with sludge production. The ratio of ammonium to nitrite should be 1:1.3. The process can achieve up to 2.6 kg total N/m^3 reactor-day, by using SBR or fluidized bed reactors, compared to 0.1 kg total N/m^3 reactor-day for activated sludge processes (Jetten et al., 1999; STOWA, 1996). Sludge generation in this process is very low. This reaction is very promising but insufficient work has been done to take advantage of this process. The main disadvantage is the slow doubling time of Annamox bacteria (11 days).

Mulligan and Chan (2001) researched on the feasibility of ammonium removal from wastewater at the same time as COD removal by nitrite addition at room temperature. Further experiments were carried out to determine the ratio of nitrite to ammonia required for the Annamox process to take place. The Annamox process was found to work best in continuous rather than batch reactors.

2.3.2 Aerobic Treatment

Aerobic wastewater treatment involves the removal of carbonaceous BOD_5 and suspended solids in the presence of oxygen. Ammonia and hydrogen sulfide are also oxidized to the less harmful nitrates and sulfates. When coupled with specialized anoxic treatment, the process can biologically remove nitrogen and phosphorus. Aerobic processes including activated sludge, trickling filters, aerated lagoons and rotating biological contactors have been used extensively in treatment of wastewater. However, the supply

of air to maintain aerobic conditions is expensive while there are large amounts of sludge for disposal (Metcalf& Eddy, 2003).

Wastewater from meat-processing is most commonly treated aerobically before land application. Aerobic biological treatment systems can be designed for carbonaceous BOD reduction only; however, for meat processing effluent, they are also used for ammonia oxidation (nitrification), and sometimes nitrogen removal by nitrate reduction (de-nitrification) (Yiu et al., 2001). Sulfide will be rapidly oxidized in these systems without need for special design. Heterotrophic bacteria remove organic matter from the wastewater by biological oxidation to carbon dioxide and water and by incorporation into cell biomass, which is subsequently removed as sludge. About 60 to 70% of the COD taken up by the heterotrophic bacteria is incorporated into the biomass, while the balance is respired to provide the energy for cell synthesis (Yiu et al., 2001) (Eq. 2.1)

$$\underset{\text{substrate}}{\text{Organic}} + \text{nutrients} + O_2 \rightarrow CO_2 + \underset{\text{cells}}{\text{bacteria}} + \underset{\text{products}}{\text{other}} \qquad (2.1)$$

Moreover, respiration uses cell biomass as an energy source causing biomass decay (Eq. 2.2)

$$\text{Bacteria cells} + O_2 \rightarrow CO_2 + H_2O + NH_4^+ + \text{energy} \qquad (2.2)$$

The proportion of wastewater COD and BOD_5 converted into cell biomass depends on how long the biomass is retained in the aerobic treatment system. The longer the sludge stays in the system, the less sludge is produced due to cell decay processes. Because cell decay consumes oxygen, a cost of reducing sludge production is the price of supplying more oxygen. Nitro-bactor bacteria

sequentially oxidize ammonium to nitrate through nitrification process. The nitrifying bacteria involved include ammonium and nitrite oxidizers (Eq. 2. 3). These slow-growing bacteria are autotrophs that use the energy derived from the oxidation of inorganic nitrogen compounds to fix inorganic carbon (carbon dioxide).

$$NH_4^+ \xrightarrow[\text{Oxidizers}]{\text{Ammonium}} NO_2^- \xrightarrow[\text{Oxidizers}]{\text{Nitrite}} NO_3^- \qquad (2.3)$$

The stoichiometry for complete nitrification including cell synthesis is given in equation 2.4 (USEPA, 1999);

$$NH_4^+ + 1.89O_2 + 0.081CO_2 \rightarrow 0.016\ C_5H_7O_2N + 0.98NO_3^- + 0.95H_2O + 1.98H^+ \qquad (2.4)$$

where $C_5H_7O_2N$ represents the new bacterial cells.

On a weight basis, each gram of ammonium nitrogen removed requires 4.3 g of oxygen, produces about 0.13 g of nitrifying organisms, and consumes 7.1 g of alkalinity (measured as $CaCO_3$) through the production of hydrogen ions. Biological de-nitrification reduces nitrate or nitrite primarily to nitrogen gas (N_2) but also to nitrous oxide gas (N_2O). Denitrifying bacteria are heterotrophic and therefore obtain their energy and carbon from organic compounds (Metcalf& Eddy, 2003).

One of the most common aerobic treatment methods is the activated sludge process (Metcalf& Eddy, 2003). The method involves production of an activated mass of microorganisms capable of aerobic stabilization of organic material in wastewater. The basic activated sludge treatment process consists of a reactor in which the microorganisms responsible for treatment are kept in

suspension and aerated, liquid-solids separation is carried out in a sedimentation tank and sludge is recycled to the reactor. The treatment processes include primary sedimentation for removal of flocculent settleable solids and biological processes for removal of soluble, colloidal, and particulate (suspended) organic substances; for biological nitrification and de-nitrification; and for biological phosphorus removal.

General types of activated sludge include plug flow, complete–mix and SBR (Metcalf & Eddy, 2003). Plug flow systems are not suitable for toxic discharges from industries because plug flow systems have limited capacity for dilution compared to complete mix systems (Metcalf and Eddy, 2003). Single stage complete-mix activated sludge process do not meet ammonia standards in the effluent discharged. Therefore, two stage systems are used for nitrification, where, each stage consists of an aeration tank and a clarifier; the first stage is used for BOD removal and the second stage for nitrification. The continuous-flow activated sludge processes that incorporate anoxic followed by aerated basins are designed to enhance nitrogen removal by recycling a proportion of the effluent from the aerated basin to the anoxic basin. In the anoxic basin, which is not aerated but gently mixed, the low-BOD, high-nitrate recycle stream mixes with the return sludge and a high-BOD influent. This combination creates ideal conditions for de-nitrification; namely, the presence of nitrate, microorganisms, and a biodegradable carbon source in the absence of oxygen. Various modifications of conventional activated sludge processes that are simpler and less operator-intensive, for example, the sequential batch reactor (SBR) are in use (Metcalf& Eddy, 2003). These

processes may incorporate nitrification, biological nitrogen removal, and/or biological phosphorus removal.

2.4 Tertiary Treatment

Further treatment of effluent from biological processes may be necessary for meeting the effluent requirements for discharging to a river/public sewer or for recycling and reuse purposes. For slaughterhouse effluent, such treatment may include filtration, disinfection and cascade aeration (US-EPA, 1999). These polishing processes attract extra costs in overall treatment process and, therefore, are rarely used. Discharging biologically treated slaughterhouse effluent to a municipal sewer is a feasible option since it requires less treatment than that required for discharging to a river. However, the municipalities may impose surcharges for discharging to the sewers. Land application of biologically treated slaughterhouse effluent may be restricted by regulating bodies because it may degrade the quality of soils, destroy microorganisms within the soils, and increase odor problems. However, controlled application of the effluent may be useful in irrigation farming. Wetland systems may be used to polish the biologically treated effluent before discharging to a river. Constructed wetlands have been designed to include certain plant species for the removal of BOD, TSS, nutrients and heavy metals for optimal performance (Mitsch and Gosselink, 1992).

2.5 Sequencing Batch Reactor (SBR)

Sequencing batch reactor (SBR) is a modified form of activated sludge system (activated or acclimatized microorganisms are returned to the reactor to act on

incoming wastewater) which utilizes a single batch reactor to treat wastewater. Equalization, aeration, and clarification are achieved sequentially in the batch reactor, thus requiring relatively small area. The SBR treatment process is flexible and economical as the treatment functions are carried out in a time sequence rather than in the conventional space sequence of continuous-flow systems. Furthermore, with SBRs, there is no need for the return activated sludge and primary sludge pumps associated with the conventional activated sludge systems. The treatment cycle of SBR has five stages; fill, react, settle, decant and idle. These cycles can be repeated until the effluent attains effluent discharge requirements. In addition, several process modifications have been made in the duration associated with each step, to achieve nitrification and BOD_5, nitrogen and phosphorus removal (Metcalf & Eddy, 2003). These characteristics indicate potential application of the SBR in situations requiring compliance with environmental standards as well as where effluent is produced intermittently or has variable characteristics.

The conventional wastewater treatment methods such as activated sludge, up-flow anaerobic sludge blanket and anaerobic filter require large continuous influent and have high capital and operating costs. These systems cannot completely remove nitrogen and phosphorus that require at least the states of anaerobic, anoxic and aerobic conditions for their effective removal (Nuch, 2007). The more affordable waste stabilization ponds on the other hand have large land requirements. The SBR overcomes most of these shortcomings in these systems because it has less land requirements, can handle intermittent flows and is capable of combining all the operational conditions required for

effective removal of nutrients as well as BOD, COD and TSS, thus providing a better option for treating slaughterhouse wastewaters.

The SBR is particularly suitable for removal of nitrogen and phosphorus (Manning and Irvine, 1985). SBRs are recommended as one of the best available technologies for slaughterhouse wastewater treatment because they are capable of removing organic carbon, nutrients and suspended solids from wastewater, and have low capital and operational costs (Zhan et al., 2008). According to Norcross (1992), SBR systems are more flexible in operations and can be designed to treat a wide range of influent flows whereas the continuous systems are based upon fixed influent flow rates. The availability of artificial intelligence has now made the option of a SBR process more attractive by providing better controls of the treatment. This is coupled by the flexibility of a SBR in the treatment of variable flows, minimum operator interaction required, option for anoxic or anaerobic conditions in the same tank, good oxygen contact with microorganisms and substrate, small floor space, and good removal efficiency (Luis et al., 2005). Such advantages may justify the recent increase in the implementation of the SBR process in industrial and municipal wastewater treatment.

2.5.1 Configurations of SBR and Modes of Operations

A SBR is a variation of the activated sludge biological treatment process. Unlike the conventional treatment system that uses multiple tanks treatment, the SBR uses multiple steps in the same tank. The SBR accomplishes pH correction, aeration, and clarification in a time sequence, in a single reactor

basin. No sludge is lost in react step and none has to be returned to maintain the solids content in the aeration chamber. Each tank has five basic operating modes; fill, react, settle, decant/draw and idle which must occur in each complete cycle in a time sequence (Figure 2.3, Irvine and Busch, 1979; Manning and Irvine, 1985). Several process modifications have been made in the time associated with each step to also achieve nitrogen and phosphorus removal (Metcalf & Eddy, 2003). The modifications include introduction of aerobic, anoxic and anaerobic reactions into the time schedule of batch cycles. The SBR process may involve a number of cycles per day; a typical cycle consisting of 3-hour fill, 2-hour aeration, 0.5-hour settle and 0.5-hour for withdrawal of supernatant (Metcalf & Eddy, 2003). The treatment steps are as described below.

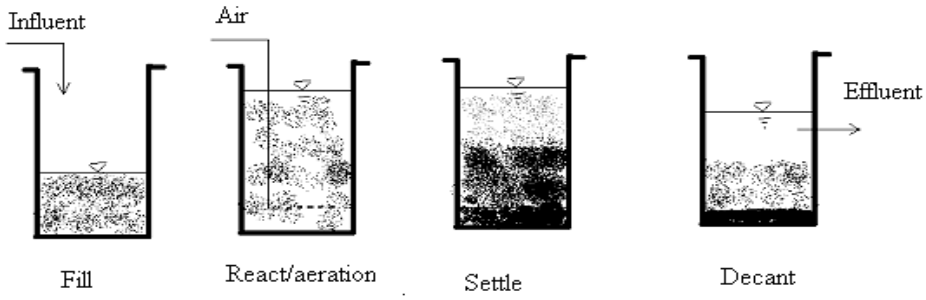


Figure 2.3: Typical SBR Process Cycle for BOD Removal and Nitrification (Metcalf & Eddy, 2003)

(a) Fill

During the fill period, raw wastewater is allowed into the tank, which already contains sludge or biomass retained from the previous cycle. The raw effluent level is allowed to rise from 75% of capacity (at the end of the idle period) to

100 %. Filling takes up about 50% of the full cycle time depending on both the volume of the tank and the wastewater flow rate. Mixing alone or mixing with aeration to promote biological reactions with the influent wastewater is allowed. However, aerating and mixing the system during fill period will result in early treatment of the wastewater, particularly in the cases of longer fill periods, thus affecting nitrification and denitrification process.

Separate mixing system without aerating provides operating flexibility and is useful during the fill period for anoxic operation (Metcalf & Eddy, 2003). The influent wastewater is distributed throughout the settled sludge through the influent distribution manifold to provide good contact between the microorganisms and the substrate (Norcross, 1992). Most of this period occurs without aeration to create an environment that favors the procreation of microorganisms with good settling characteristics. The fill period ends when the tank is either full or when a maximum time for filling is reached and the wastewater flow is directed to another tank to be operated under fill period (Arora et al., 1985; Irvine and Busch, 1979; Dennis and Irvine, 1979).

(b) React Stage

During the react period, the liquid level remains at its maximum and both aeration (during anoxic and aerobic stages) and mixing are provided. The react mode consists of anaerobic, anoxic and aerobic reactions whose length is varied depending on the process need. The biomass consumes the substrate under controlled environmental conditions. Adequate aeration and mixing are required for complete biodegradation of BOD and nitrogen. After the substrate

is consumed famine stage starts. During the react stage some microorganisms undergo endogenous decay which helps reduce the volume of the settling sludge. The length of the aeration period determines the degree of BOD consumption (Norcross, 1992; Chambers, 1993). Sludge wastage is carried out at the end of this period to control the sludge age. The end of react period may be dictated by a time specification or the desired effluent quality (Irvine and Busch, 1979).

(c) Settle Stage

During settle period, solids-liquid separation takes place under quiescent conditions in the same tank. No liquid is allowed to enter or leave the tank to avoid turbulence in the supernatant. Solids separation takes place leaving clear, treated effluent above the sludge blanket. The settling time typically ranges from 0.7 to 1.0 hour to ensure that the sludge blanket settles adequately (Alleman and Irvine, 1980; Irvine et al., 1983).

(d) Decant Stage

During the decant stage treated effluent is withdrawn from approximately 0.6 m below the surface of the mixed liquor to exclude floating solids. This removal should be carried out without disturbing the settled sludge by using floating or adjustable weirs (Metcalf & Eddy, 2003). Decanting is best carried out through a floating decanter, which is maintained about 0.4 m below the scum by a float (Norcross, 1992). The time required for draw is the ratio between the volume of liquid to be drawn and the flow rate during draw period (Arora et al., 1985; Irvine and Busch, 1979).

(e) Idle Stage

The period between decanting and the new cycle is referred to as idle time. The idle stage can be used to waste sludge or perform backwashing of the jet aerator. The frequency of sludge wasting ranges between once each cycle to once every two to three months depending upon system design. No set time period within the cycle is dedicated to wasting (Arora et al., 1985). Metcalf & Eddy (2003) recommends sludge wasting occurs during the reaction phase for discharge of uniform solids including both fine material and large floc particles. The length of the idle mode may be adjusted or eliminated depending on requirements of the treatment problem.

2.5.2 Equipment

Equipment for SBR include a reaction vessel, control system, a feeding system, an agitation device and an oxygen supply as described below (Silva et al. 2001).

2.5.2.1 Aeration/Mixing Equipment

The aeration equipment of the SBR may consist of (i) jet, (ii) fine bubble, and (iii) coarse bubble aeration systems (Norcross, 1992). The jet system combines liquid pumping with air diffusion re-circulates liquid in the aeration basin, ejecting it with compressed air through a nozzle assembly (Metcalf & Eddy, 2003). This operation allows the system to mix the SBR without aerating by agitating the wastewater hydraulically. Therefore, it can provide for aerated and anoxic mix periods as necessary. Accordingly, the jet system

offers several advantages over the other systems such as flexibility, good contact between substrate and microorganisms, and efficient oxygen transfer.

Aspirating aeration consists of a motor-driven aspirator pump. The pump draws air in through a hollow tube and injects it underwater where both high velocity and propeller action create turbulence and diffuse the air bubbles. The header in conjunction with computer controller for flow proportional aeration makes more oxygen available at higher flows than at lower flows by measuring the rate of change in the flow level in reactor. In fine bubble (fine-pore) systems, pore size, surface tension, and air flow-rate interact to produce the bubble size as the air emerges from the surface pores. The air supplied should be clean and free of dust particles that might clog the diffusers (Metcalf & Eddy, 2003). Coarse bubble (non-porous) systems produce larger bubbles than porous diffusers and consequently have lower aeration efficiency. However, lower cost, less maintenance, and the absence of stringent air-purity requirements may offset the lower oxygen transfer efficiency and energy cost (Metcalf & Eddy, 2003).

2.5.2.2 System Control Devices

Traditional SBR operation relies on on-site experience to adjust the duration of each stage to accommodate influent fluctuation, for example, prolong the duration of selective stages such as the mixed-react and react. This approach not only requires more energy input and reduces facility-treating capacity, but it may exert adverse effects on the microbial ecology (Okada and Sudo, 1986). The sequential control of operation is now easy and inexpensive by the use of

recently developed microcomputer and peripheral system technology. The most used control parameters are oxygen-reduction potential (ORP), a measure of the oxidative (biological) state in an aqueous system, DO and pH. SBR system has the possibility of modification during trial phases through on-line control of the treatment strategy. The increasing interest in the on-line control of biological processes allowed the development of techniques and operation strategies able to optimize the treatment plants in terms of both removal efficiencies and costs.

2.6 Process Kinetics

Bio-kinetics is a field, which requires analyses of substrate and biomass concentrations in order to evaluate microbial communities and their metabolic function (Ahmed, 1993). Metcalf & Eddy (2003) describes the process kinetics by relating the change in substrate concentration with time during the react stage starting with the substrate mass balance for a continuous- flow complete-mix reactor as follows:

$$\frac{dS}{dt}V = QS_o - QS + r_{su}V \qquad (2.5)$$

Where dS/dt = rate of change in substrate concentration with time (mg/L.d),

V = volume of the reactor (L),

Q = influent flow rate (L/day),

S = concentration of growth-limiting substrate in solution (mg/L),

S_o = initial substrate concentration in mg/L, and

r_{su} = soluble substrate utilization rate (mg/L.d).

Because Q equals zero for the batch reaction, the rate of substrate consumption is given by,

$$\frac{dS}{dt} = -\frac{\mu_m XS}{Y(K_s + S)} \tag{2.6}$$

where K_s = half-velocity constant,

μ_m = maximum specific growth rate,

X = biomass concentration, mg/L, and

Y = biomass yield

Integrating equation (2.6) with respect to time yields,

$$K_s \ln\frac{S_o}{S_t} + (S_o - S_t) = X\left(\frac{\mu_m}{Y}\right)t \tag{2.7}$$

where S_o = initial substrate concentration in mg/L,

S_t = substrate concentration at time t (mg/L) where

t = time in days.

Other parameters are as defined previously.

The same kinetic expression applies for nitrification where, X= X_n, the nitrifying bacteria concentration, S = N, the NH_4-N concentration, and the Monod model kinetic coefficients are substituted as follows.

$$K_n \ln\frac{N_o}{N_t} + (N_o - N_t) = X_n\left(\frac{\mu_{mn}}{Y_n}\right)t \tag{2.8}$$

The maximum specific growth rate for nitrifying bacteria is affected by the DO concentration as follows:

$$\mu_n = \left(\frac{\mu_{nm} N}{K_n + N}\right)\left(\frac{DO}{K_o + DO}\right) - k_{dn} \tag{2.9}$$

Similarly, the effect of DO is accounted for the kinetic model as follows,

$$K_n \ln\frac{N_o}{N_t} + (N_o - N_t) = X_n\left(\frac{\mu_{mn}}{Y_n}\right)\left(\frac{DO}{K_o + DO}\right)t \tag{2.10}$$

Kinetic relationships are used to determine biomass growth and substrate utilization, to establish if the react period aeration time selected for SBR design is sufficient to provide the desired level of degradation, and to define process performance (Metcalf & Eddy, 2003). The key design conditions selected include the fraction of the tank contents removed during decanting and the settle, decant and aeration times. Because the fill volume equals the decant volume, the fraction of decant volume equals the fraction of the SBR tank volume used for the fill volume per cycle. At the same solids retention time, the SBR may be expected to be more efficient than continuous flow activated sludge processes because of its batch kinetics. However, the biomass may not be under aeration for a significant period of time resulting in a shorter effective solids retention time.

2.7 Effectiveness of SBRs

Several lab-scale SBR studies have shown the effectiveness of the SBR in treating municipal and industrial wastewaters to be acceptable (Irvine et al., 1985; Surampalli et al., 1997, 2000). SBR technology is used for BOD removal, nitrification, de-nitrification and phosphorus removal. The performance of SBR reported in literature is described below.

2.7.1 Removal of Organic Carbon and TSS

Irvine et al. (1985) showed that a full-scale SBR operating at Culver, Indiana for treating municipal wastewater attained effluent limits of 10 mg/l BOD_5, and 10 mg/l TSS , 1 mg/l biological phosphorus and 14 mg/l ammoniacal nitrogen corresponding to 98% BOD_5 removal , 97% TSS removal , 92% TP removal and 70% NH_4-N removal. Surampalli et al. (1997) studied the nitrification, de-nitrification and phosphorus removal in SBR in three full-scale SBR plants treating municipal wastewater. The typical SBR design could meet effluent BOD_5 and TSS concentrations of less than 10 mg/L. With some additional design modifications including combining anaerobic, anoxic and aerobic conditions in treatment process, SBR achieved nitrification of ammonia to the required limits of 1-2 mg/L NH_3-N. The BOD_5 removal varied between 96 and 97% prior to discharge. Approximately, 76% of the phosphorus in the influent was removed during the treatment. Surampalli et al. (2000) found that the average removal efficiency was in the range 88.9 - 98.1% for $BOD_{5;}$ 84.7- 97.2% for TSS; 90.8-96.8% for ammonia; 56% for total nitrogen and 57-83% for phosphorus in 19 municipal and private SBR wastewater treatment plants in USA.

2.7.2 Nutrient (Nitrogen and Phosphorus) Removal

In their studies to remove ammoniacal nitrogen and phenol from refinery wastewater using SBR systems, Silva et al. (2001) observed reductions of 95% for different concentrations of NH_4^+ and phenol, providing an effluent acceptable by Brazilian environmental legislation. An anaerobic/aerobic (or anoxic) sequence was necessary to promote biological phosphorus removal;

phosphorus release occurred in the anaerobic stage followed by an excess of phosphorus uptake in the aerobic stage. When wastewater enters the anaerobic phase, specialized organisms, called poly-phosphate accumulating bacteria, accumulate carbon sources as internal polymer called polyhydroxyalkanoates whose main form is polyhydroxybutyrate. The energy to store this polymer is obtained from breakdown of glycogen and hydrolysis of an energy-rich internal phosphorus chain called poly-phosphate. This chain is broken down to ortho-phosphate and results in increase of phosphate concentration. During the aerobic (or anoxic) phase the stored polyhydroxybutyrate is consumed, generating energy and carbon for replenishment of the glycogen and phosphorus. Phosphorus in wastewater is assimilated by biomass (sludge), and finally removed from the process through the wastage of sludge (Smolder et al., 1994; Baetens, 2001).

Ketchum et al. (1987) found that SBR can provide the proper balance of anoxic, anaerobic and aerobic conditions to allow biological removal of phosphorus by the bio-phosphorus removal organisms. Combined biological and chemical addition for phosphorus removal is sometimes used, especially when the effluent permit limitations are 2.0 mg/L or less (Surampalli et al., 1997). Nitrogen and phosphorus removal in addition to BOD is possible in SBR if operation conditions are modified to introduce anoxic, anaerobic and aerobic reactions into a time schedule of batch cycles, without any addition of separate tank or recycling lines. Simultaneous nitrogen (nitrification and denitrification) and biological phosphorus removal have been achieved by

anaerobic/anoxic process in SBR system (Kuba et al., 1993, 1997; Merzouki et al., 2001).

Vlekke et al. (1988) investigated the feasibility of using nitrate as sole electron acceptor for bio-phosphorus removal from wastewater. Two SBRs, one with supply of nitrate and the other with air (oxygen) to act as terminal electron acceptor, were used to develop two sets of acclimated biomass. The authors showed that it was possible to induce bio-phosphorus removal with nitrate alone, confirming the ability of denitrifying bacteria for this process. Kuba et al. (1997) evaluated the aerobic or anoxic phosphorus uptake tests for sludge characterization in SBR. They found that the use of nitrate rather than oxygen in biological phosphorus removal avoids nitrate inhibition in dephosphatation and utilizes nitrate actively as sole electron acceptor for dephosphatation and the anoxic phosphorus removal occurs simultaneously with denitrification in the same reactor (Kuba et al., 1993, 1997; Merzouki et al., 2001).

2.8 Factors Influencing the Carbon and Nutrients Removal in SBR

External factors including pH, temperature, and sludge age influence carbon, nitrogen and phosphorus removal in SBR treatment. However, factors such as excessive aeration, different carbon sources, nitrates, and sludge total carbohydrate content may be useful only for bio-phosphorus removal (Kuba et al., 1993, 1997; Merzouki et al., 2001). The following factors are considered:

i. pH

ii. Sludge age

iii. Aeration

iv. SBR operation cycles

v. HRT

vi. VER

vii. Temperature

The pH of the culture medium affects the nitrification process and phosphorus removal. Surampalli et al. (2000) observed an optimum pH range of 7.5 - 9.0 while Smolders et al. (1994, 1995) and Kuba et al. (1997) observed that phosphorus release/acetate uptake ratio increased with increasing pH. However, the ratio decreased at pH values above 8.0. Wastewater temperature influences biological process because the rate of biochemical reactions and, therefore, metabolism and growth of activated sludge organisms are affected by temperature changes (Dockhorn et al., 2001; Surampalli et al., 2000; Jones and Stephenson; 1996). The optimum operating wastewater temperature is around 30^{o} C for both anaerobic release and aerobic up take of phosphate.

Sludge age or solids retention time (SRT) determines the biomass concentration and is linked to the growth rate of the microorganisms. The organic compounds in the wastewater, measured as BOD_5, are eliminated at sludge ages higher than 4 days. Uygur and Kargi (2002) found the highest removal efficiencies for COD (94%), NH_4–N (84%) and PO_4–P (70%) were obtained at the sludge age of about 10 days. Excessive growth of protozoa and rotifers occurred under sludge age over 15 days (Tsang et al., 2007). A five-step SBR operation with a total cycle time (HRT) of 10.5 h, and SRT of 10

days, resulted in final COD, NH_4–N, NO_3–N and PO_4–P of 70, 7, 1.3 and 3.6 mg/L, respectively.

Volumetric exchange rate (VER) is expressed as the ratio of the volume of wastewater introduced into the reactor to the working volume of the reactor (Wilderer et al., 2001). It reflects the treatment capacity of a single SBR operation cycle. According to Ant'onio et al. (2003), VER values range between 25-50%. High VER value is usually regarded as advantageous for preventing sludge bulking due to significant gap of the organic substrate produced between before and after feed-filling in the reactor.

2.9 Limitations of SBR

The batch operating nature of the SBR requires influent feed and effluent decanting controls. Intermittent effluent decanting requires larger capacity of downstream facilities than for conventional continuous flow or flow equalization. For small to medium-sized wastewater treatment plants the required control systems are manageable. However, for large plants the number of SBR tanks needed may make the control systems costly and complicated to install and maintain. In addition, there are high head losses through the plants and low reactor volume utilization efficiency due to variable liquid level operations. Furthermore, batch operations have low equipment utilization and high peak oxygen demand (Wu et al., 2001). Consequently, various modified SBR systems have been developed in recent years in an effort to eliminate or minimize the limitations while maintaining the advantages of the SBR (Bernet et al., 2000; Uygur and Kargi, 2002).

However, the operation with aerobic-SBR still has some problems such as the low settle-ability of bio-sludge, high excess sludge production under high organic or hydraulic loading and low removal efficiency due to the limitation of the increasing of bio-sludge (Metcalf & Eddy, 2003).

2.10 Studies on SBR

Many laboratory-scale studies have been used to investigate the effects of temperature, pH, VER, SRT, HRT and number of cycles on the removal of organic carbon and nutrients from domestic and industrial wastewaters by the SBR (Bernet et al., 2000; Tilche et al., 2001). Most of the studies used bench-scale plexiglas reactors with a capacity of 5 to 10 L. In the studies, the SBR is commonly controlled with microprocessor for aeration, agitation, pH and dissolved oxygen (DO). Wastewater in the SBR is aerated using an air pump and diffusers to maintain dissolved oxygen level of above 2 mg/L followed by anaerobic, anoxic, oxic operations in sequence. The cycles in the four-step SBR operation consist of anaerobic/oxic/anoxic and oxic (An/Ox/Ax/Ox) phases with HRTs of 1/3/1/1 h and a settling phase of 45 min. Sludge age (SRT) is held constant at 10 days (Uygur, 2006).

Operations of SBR in treating low strength wastewater require some type of agitation in order to improve transfer of the substrate in the aqueous phase to the microorganisms in the granulated biomass responsible for anaerobic degradation (Hulshoff-Pol et al., 1998). This fact is directly due to the lack of homogeneity in the reaction medium brought about by low biogas production, which is a result of the low substrate concentration since the start-up of

operation. Agitation may be achieved by re-circulating the liquid or gas phases (Brito et al., 1997) or by mechanical stirring (Ratusznei et al., 2000). However, in dealing with a biological system, where the biomass responsible for the whole process has a granular morphology that in turn is directly related to the efficiency of the settling step, implementation of mechanical stirring should be carefully considered. At the same time, mass transfer from the substrate in the fluid phase to the granulated biomass is improved; the shearing forces brought about by mechanical stirring may impair the settle-ability characteristics of the sludge and create biomass drag. Study of the influence of stirring rate on the efficiency and stability of the anaerobic sequencing batch process carried out by Rodrigues et al. (2003) indicated the existence of an optimum stirring rate (50 rpm), below which efficiency drops due to insufficient mixing and above which this reduction occurs due to the disperse growth of biomass brought about by excessive mixing. However, experiments have been conducted with constant stirring during the entire experiment, which was not necessarily an optimal condition, since continuous stirring is not always required to improve mass transfer in sludge. According to Uygur (2006), mixing during anaerobic and anoxic cycles is normally carried out at 25 and 50 rpm, respectively. The reactor is aerated and agitated at 300 rpm during oxic operation.

An important factor in SBR studies is the start-up period during which the anaerobic bacteria are acclimatized to new environmental conditions and substrate. A new equilibrium is slowly established between the various populations of microorganisms, until the biomass can stably and efficiently

degrade the substrate at maximum or target organic loading rate. Kostyshyn et al. (1988) found a 40-day start-up period for a mesophilic (30 to 35^{o}C) anaerobic contact reactor treating slaughterhouse wastewater. Borja et al. (1994a) also reported a 40-day start-up for anaerobic filter reactors treating slaughterhouse wastewater where methanol was added to encourage the proliferation of methanogens. With the anaerobic SBRs, the start-up period is usually less than 11 days (Ahmed, 1993).

ORP, pH and DO are used to monitor the treatment process. The pH profiles are used to determine the end of nitrification and denitrification (Casellas et al., 2006). The pH increases during denitrification (anoxic phase) and decreases during nitrification process (aerobic phase). The end of nitrification is characterized by a minimum pH variation, “ammonia valley’’ during aerobic stage while the end of denitrification is characterized by a maximum pH value, “nitrate apex” during anoxic phase. ORP has a direct correlation with nitrification rates and other biological reactions in SBRs treatment processes. In normal conditions, ORP is positive in aerobic stages and negative in anoxic stages. The normal range of values of ORP is 0-50 mV in aerobic stages and 0-(-300mV) in anoxic stages. The ORP profiles illustrated three inflection points: the beginning of anoxic phase, the end of nitrification during aerobic phase, and the end of denitrification, “nitrate knee” (Casellas et al., 2006).

Monitoring is not a supervision system because it is only focused on the detection of breakpoints in the profiles and it is not possible to assess other

operation situations in the SBRs. Yongzhen et al. (2004) observed that DO concentration rose sharply to a peak level, and then decreased slowly to a plateau during the COD removal phase. Subsequently when the organic substrate was consumed, the DO concentration rose sharply from the previous plateau, which indicated the COD removal phase, and showed an inflection point on the DO profile.

CHAPTER THREE

3.0: MATERIALS AND METHODS

Three SBRs were examined on their capability to treat slaughterhouse wastewater by analyzing treated effluent for COD, BOD_5, TSS and nutrients removal using lab-scale SBR. Throughout the study, the HRT for anaerobic, anoxic and aerobic phases during react stage were set at 2h, 1h and 3h respectively as recommended in literature for effective removal of nutrients from slaughterhouse wastewater. The SRT of 10 days was adopted for the study as suggested by literature for effective removal of organic matter. The aerator used in the study provided 2 mg/L concentration of oxygen. The mixers used in the study provided fixed mixing rates of 50, 61 and 63 rpm respectively for the three SBRs. The volumetric exchange rate (VER) was kept at 30, 40 and 50 % for SBRs 1, 2 and 3 respectively to verify its influence in the performance of SBR in treating slaughterhouse wastewater.

3.1 Slaughterhouse Wastewater Sampling and Characterization

Samples of slaughterhouse wastewater were obtained from Dagoretti Slaughterhouse Company Ltd at Dagoretti in Nairobi. The slaughterhouse activities included slaughtering, rendering, separation of innings, blood collection, washing of innings and floor washing. The washing of the floors began at 11 am after all other activities were completed. Grab samples were taken at the exit of the slaughterhouse, after screening but before anaerobic pond. Therefore, the wastewater included streams from the slaughtering units,

innings washing units and floor washings. However, because the samples were collected in the morning between 9 and 11 am, it did not include water from the afternoon floor washing. Therefore, the raw wastewater collected was likely stronger than a 24 hour-composite sample that would include wash water (e.g. Massé and Masse, 2000). The collected samples were transported in 20 L containers to the cold room of the Department of Biochemistry, Chiromo Campus, University of Nairobi, and stored at 4^{o} C.

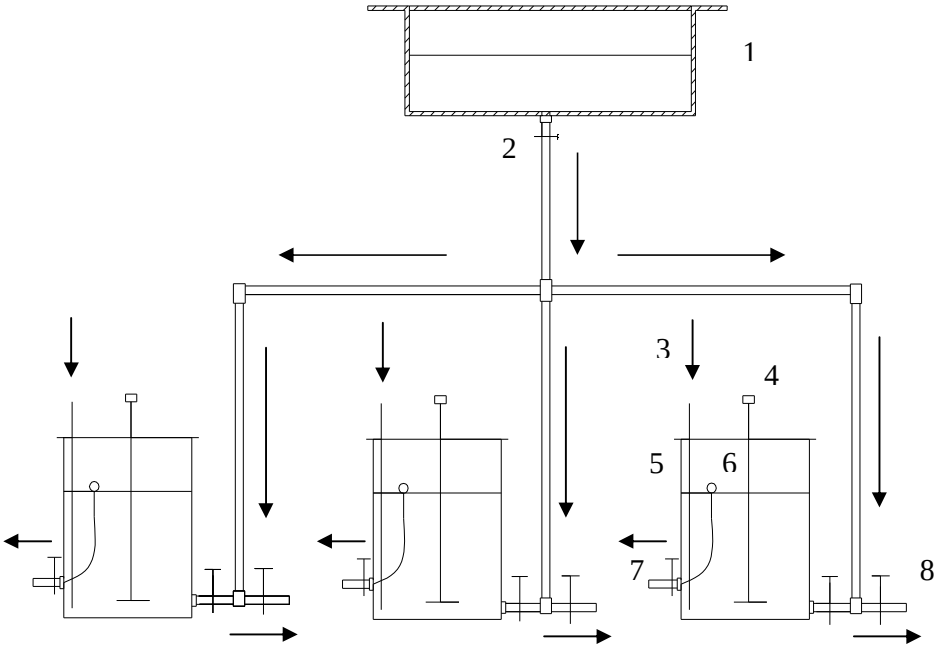
The raw wastewater was characterized by carrying out pH, DO, COD, BOD_5, alkalinity, MLSS, TSS, TP, nitrate-N and ammonium-N tests. All the tests were conducted according to standard methods (Eaton et al., 2005).

3.2 Experimental Set-up

Experiments to test the treatment of slaughterhouse with SBRs were carried out at the University Nairobi Public Health Engineering laboratories. The experimental apparatus consisted of three fabricated 6 mm thick perspex-glass vessels, each 7.5 L capacity (18 x 18 × 23 cm) with a working volume of 5 L (Figure 3.1 and Plate 3.1). Each SBR unit was fitted with a rotary mixer and a blower for mixing and aeration, respectively. The agitation speeds of the available mixers were at 53, 60 and 63 rpm for SBR1, SBR2 and SBR 3 respectively. The resin air pump used for aeration had an air flow rate of 9.0 L/min.

The slaughterhouse wastewater feeding system comprised an overhead tank connected by pipes to the three SBRs. It provided for uniform feed of wastewater flow by gravity (Figure 3.1 and Plate 3.1). Air was spurge into the

reactors via thin tubes connected to a multi-aerator. A float decanting mechanism was provided to decant the supernatant at a fixed depth below the water surface. It consisted of a flexible pipe with its mouth suspended 25 mm below the water surface by a floater (Figures 3.1 and 3.2). Other fittings on SBRs include decanting and sludge wasting mechanisms illustrated in Figures 3.1 and 3.2 as well as Plate 3.1.



1 -Raised feed tank with removable lid, 2 - Influent feed control valve, 3 - Air supply pipe from aerator, 4 - Mixer fitted with a blade, 5 - Removable lid, 6 - Floating mechanism for decanting control, 7 - Decanting valve, 8 - Sludge wasting valve.

Figure 3.1: Schematic Diagram of SBRs Set-up

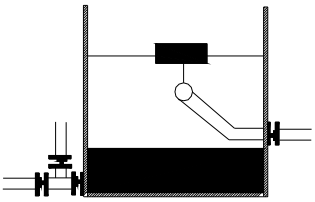


Figure 3.2: Perspex-glass SBR Vessel (adapted from Norcross, 1998)

Plate 3.1: Experimental Set-up of Sequencing Batch Reactors

The pH was monitored using a Hanna pH Meter (HI 98128) with pH resolution of 0.01 and accuracy of ±0.05. The dissolved oxygen (DO) was measured using Hanna DO Meter (HI 9146) with a 0.01 mg/L oxygen resolution and an accuracy of ±1.5% F.S. The oxygen reduction potential (ORP) was measured using Hanna ORP/Temperature Meter (HI 98121) with 1mV and 0.1 ^{o} C resolutions and accuracies of ±2mV and ±0.5 ^{o}C.

3.3 Test Procedure

Schedule of Tests

Tests were carried out for the three SBR set-ups with different volume exchange ratios (VER) (Table 3.1). VER refers to the ratio of volume decanted and sludge wasted to the working volume of the SBR which for this study was 5L. The VER used was 30, 40 and 50% for SBRs 1, 2 and 3 respectively.

Table 3.1: Describing the SBRs in terms of Volume Exchange Ratio

SBR No.	VER %	Daily Exchange Volume (mL)
1	30	1500
2	40	2000
3	50	2500

The VER was achieved by removing or replacing the appropriate volume of contents through a combination of sludge wasting and decanting of the supernatant after settling. Tests were carried out in two stages namely:

(i) Acclimatization stage and

(ii) Treatment stage.

The two stages are described below. Sampling and subsequent analysis for COD, BOD_5, total alkalinity, pH, TSS, VSS, NH_4-N, NO_3-N and TP were also carried out as described below.

3.3.1 Acclimatization of Microorganisms

An activated sludge from a secondary sedimentation pond at Kiambu Wastewater Treatment Plant was used for inoculating slaughterhouse wastewater for startup. The sludge was collected in 5.0 litre plastic containers and preserved in the laboratory at 4^{o} C prior to use. The characteristics of the inoculants sludge were measured. Each of the three SBR vessels was filled with 5,000 mL of activated sludge. The contents were aerated for 9 hours daily during which the laboratory was open, and then left covered without aeration to cultivate a mixed culture of both aerobic and anaerobic micro-organisms for three days (Ahmed, 1993). At the end of the third day, a supernatant of 1.5, 2.0 and 2.5 L was decanted from each reactor to maintain a VER of 30, 40 and 50% for SBRs 1, 2 and 3, respectively. From the fourth day, slaughterhouse wastewater was introduced at a ratio of 1:4 of slaughterhouse wastewater to activated sludge as presented in Table 3.2 below.

Table 3.2: Ratios of Activated Sludge to Slaughterhouse Wastewater for Acclimatization

Treatment Day	Slaughterhouse : Activated Sludge Ratio		
	SBR1	SBR2	SBR3
4	1:4	1:4	1:4
5	1:4	1:4	1:4
6	1:4	1:4	1:4

From the seventh day, larger quantities of slaughterhouse wastewater, in increments of 300 mL, were added. The pH and COD were measured daily. The process was carried out at room temperature of 21 ^{o} C. Sludge wasting was carried out daily by withdrawing 500 mL of reactors contents at the end of react stage while mixing to obtain a homogenous sludge that contained evenly distributed bacteria. During decanting stage, 100 mL-samples of clear supernatants were collected for COD analysis. The activated sludge added daily at the beginning of the cycle together with a gradually increasing amount of slaughterhouse wastewater were to prevent shock loading. The purpose of acclimatization process was to enhance the growth of slaughterhouse wastewater degrading species, and possibly eliminated other microbial species that are not tolerant for higher slaughterhouse wastewater concentration (Ahmed, 1993).

The activated sludge was held for 13 days in the three modeled SBRs. The reactors were operated on the same cycle as the experimental SBRs during treatment phase of slaughterhouse wastewater. After 13 days of acclimatization attested by a stable effluent COD concentration of approximately 5,500 mg/L, slaughterhouse wastewater was fed to the reactors and batch kinetics tests conducted as described in the following sub-section.

3.3.2 Slaughterhouse Wastewater Treatment Tests

The wastewater with acclimatized microorganisms was allowed to settle for 45 minutes according to literature (Uygur, 2006). 4 L of clear supernatant was then decanted to leave 1 L of dense culture. Undiluted slaughterhouse wastewater was fed to the reactor over 45 minutes to obtain a total volume of

5 L. The feed was introduced from the bottom of the reactors to achieve better mixing during reaction phase. In the succeeding tests, the organic loading of slaughterhouse wastewater to be treated was progressively increased by augmenting the volume of wastewater fed to the reactor from 1 to 4 L (Appendix A1). The treatment consisted of four types of operating conditions; namely, feed, reaction, settling, withdrawal and an idle time in 24-h cycles as follows:

1. Feeding time: 20 min,
2. Reacting time: 6 h,
3. Settle time: 45 min,
4. Decanting time: 20 min and
5. Idle time: 16 h 25min.

To enhance the nutrient removal efficiency, anaerobic, anoxic, and aerobic conditions were adjusted during the reaction time by regulating the air blower.

The 6 h-reacting phases consisted of 2h anaerobic, 1h anoxic and 3h aerobic (Appendix A1; Uygur, 2006). During the react phase, 15 min intermittent mixing of the SBRs contents was provided at the start of each of the anaerobic, anoxic and aerobic conditions (e.g. Massé and Masse, 2000). Agitation speed during anaerobic, anoxic and aerobic cycles was kept constant at 53, 60 and 63 rpm for SBRs 1, 2 and 3 respectively. Anoxic conditions were provided by adjusting the aerator to the minimum thus keeping the DO nearly zero. During aerobic condition, the reactors were aerated continuously and agitated during the first 15 minutes and thereafter intermittently. The aeration

was aimed at keeping dissolved oxygen (DO) concentration above 2 mg/L in the oxic phase. Excessive sludge was wasted daily while agitating 15 minutes before the end of aeration stage. 10% of the mixed reactor contents were wasted to maintain a sludge age at 10 days. Samples of 100 mL in volume were collected during sludge wasting, for VSS analysis.

At the end of aerobic operation, the reactors contents were allowed to settle for 45 min and 1.5, 2.0 and 2.5 L of the supernatant wastewater decanted from SBRs 1, 2 and 3 over 15 minutes to maintain the required VERs of 30, 40 and 50 % in the reactors respectively. During decanting stage, 500 mL samples were collected for COD, BOD_5, TP, NO_3-N, NH_4-N, TSS, pH, and alkalinity analysis.

3.3.3 Monitoring Process

The reactors were operated at room temperature (21 ^{o} C) and no temperature control was practiced. The pH, the oxygen reduction potential and the dissolved oxygen concentration (2 – 3 mg/L) of the reactors contents were monitored continuously (Appendix D) in order to verify stability and the presence of oxygen, respectively (Casellas et al., 2006).

3.4 Analytical Methods

The collected supernatant (treated effluent) was analyzed for pH, DO, biomass concentrations (MLSS) in form of TSS, TP, COD, BOD_5, ammonium-nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) and alkalinity. Samples were also collected during sludge wasting for analyzing MLVSS in form of VSS. The analytical procedures for monitoring the above parameters were

employed as outlined in the Standard Methods (Eaton et al., 2005). Samples were analyzed in duplicates and the average value reported (Appendices A, B, C and E).

3.5 Statistical Methods

Three SBRs were used to investigate any variations in treating slaughterhouse effluent. All the data was subjected to linear regression analysis by determining the Pearson product moment correlation coefficient, r, between two variables according to Bluman (1998) (Appendix F2). Moreover, a two-way analysis of variance (ANOVA) using SAS Windows Version 6.12 (SAS Institute, 1996) was used to test any significant difference in the effluent quality and the COD removal efficiencies for the investigated three VERs, at the 95% confidence level. Statistical significance was tested using least significant difference (LSD) at the $p < 0.05$ level (Appendix F2).

Sources of the expected research errors included sample collection, transportation, storing and testing methods. The errors were minimized through stirring the samples while sampling to have homogeneous mixture, transporting the samples within one hour from the sampling site to laboratory for storage, storing the samples in cold room and in refrigerator at $4\ ^{o}C$, doing replicates of the samples for testing and computing the mean values.

CHAPTER FOUR

4.0: RESULTS AND DISCUSSIONS

Sequential batch reactor (SBR) treatment of slaughterhouse wastewater was simulated in laboratory tests carried out at the Public Health Engineering (PHE) Laboratories of the University of Nairobi. Three SBRs were run over a period of 23 days, including 13 days of acclimatization and 10 days of treatment. Performance of the SBRs was evaluated by analysing included COD, BOD_5, NO_3-N, NH_4-N, TP, pH, alkalinity, MLSS and MLVSS. The treatment process was monitored manually by recording pH, ORP, temperature and DO. The following sections present results and discussions.

4.1 Characterization of Raw Slaughterhouse Wastewater

The characteristics of the raw slaughterhouse wastewater collected from Dagoretti Slaughterhouse Company Ltd are presented in Table 4.1.

Table 4.1: Characterization of Raw Slaughterhouse Wastewater from Dagoretti Slaughterhouse Company Limited

Parameter	Range (mg/L)	Mean (mg/L)	SD	n[a]
COD	8,800 - 16,160	11,947	±2,164	6
BOD_5	5,850 - 10,800	8,233	±2,025	3
NH_4-N	34.1 - 139.5	70.3	±49.0	3
NO_3-N	56.5 - 78.0	65.2	±9.2	3
TSS	700 - 2,500	1,400	±787	3
Total phosphorus (TP)	212 - 307	261	±39	3
Total alkalinity as $CaCO_3$	1,320 - 1,680	1,523	±151	3
pH (No units)	6.41 - 6.98	6.7	± 0.24	3

[a] Number of samples analyzed

Compared to slaughterhouse wastewater characteristics reported in literature (e.g. Table 2.2), concentrations of pollutants in Dagoretti slaughterhouse as (Table 4.1) are same order of magnitude but they are higher. The greater concentration may be attributed to raw slaughterhouse wastewater containing the more highly concentrated samples collected in the morning hours. The results are for average pollutants concentrations of morning operations and consist of very concentrated innings washings and spilled blood from slaughtering rooms, and dilute floor washings and do not include the less dilute afternoon washings. Therefore, they are likely more conservative than the 24 hr average value. Additionally, the slaughterhouse effluent had not undergone settling as compared to the effluent reported in Table 2.2.

Results of characterization show that the slaughterhouse wastewater does not meet the Environmental Management and Co-ordination Regulations (EMCR, 2006) requirements for disposal into public sewers (Table 2.4). Therefore, the wastewater requires pretreatment before discharge into the sewers. The existing biological treatment that consists of anaerobic pond, only removes less than 20% COD from slaughterhouse wastewater after three days retention.

4.2 Characteristics of the Activated Sludge for Acclimatization

The characteristics of activated sludge used as inoculants during acclimatization stage are listed in Table 4.2. The sludge was weaker than the slaughterhouse wastewater for all parameters except alkalinity.

Table 4.2: Characterization of Activated Sludge (Inoculants) from Kiambu Wastewater Treatment Plant

Pollutant	Range (mg/L)	Mean (mg/L)	SD	n
COD	320-2,560	1,173	±989	3
BOD_5	210-1,700	778	±658	3
NH_4-N	1.97-2.62	2.36	±0.28	3
NO_3-N	2.02-2.11	2.06	±0.04	3
TSS	200-900	500	±294	3
Total phosphorus (TP)	18-32	25	±3	3
Total alkalinity as $CaCO_3$	1,620-2,000	1,757	±172	3
pH (No units)	7.40- 7.60	7.5	± 0.08	3

4.3 Sludge Acclimatization

Sludge acclimatization stage was carried out for the first 13 days. Slaughterhouse wastewater was introduced gradually into the acclimatized sludge to allow microorganisms in the activated sludge to acclimatize to the stronger and different wastewater.

The microorganisms in the activated sludge were first maintained by aeration for the first three days. Increasing amounts of slaughterhouse wastewater were added gradually to the activated sludge in the SBR starting from day four at daily increments of 100 to 300 mL corresponding to the three volume exchange ratios (VER) of 30, 40 and 50%.

The COD of the settled supernatant remained between 1, 000 and 2, 000 mg/L for the first three days mainly because only the acclimatization sludge was added to the SBRs (Figure 4.1). However, as the slaughterhouse wastewater was added starting from the fourth day, the COD increased gradually to 2,200

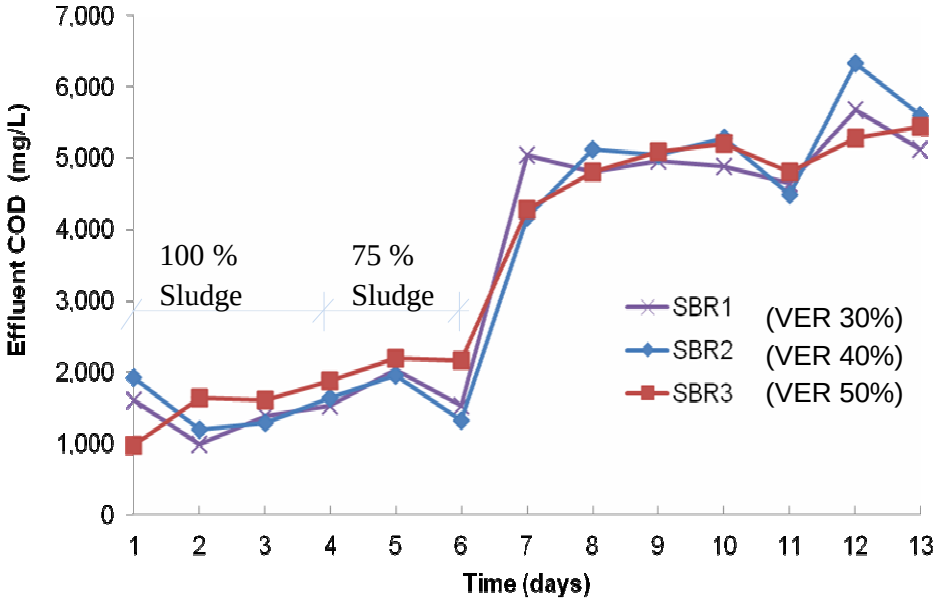


Figure 4.1: Effluent COD for Acclimatization Stage

mg/L. The sharp increase observed in effluent COD on the day seven was as a result of the start of addition of 300 mL of slaughterhouse wastewater.

The acclimatization process in the three SBRs was evaluated by effluent COD concentrations after every cycle. At the end of the acclimatization stage the effluent COD concentrations averaged 5,337 ± 141 mg/L (Figure 4.1) corresponding to average COD removal of 55 ± 1%. Statistical analysis using ANOVA revealed that there was no significant difference between the three sequencing batch reactors ($p < 0.05$, Appendix F2). This important result suggests that at the acclimatization stage the VER was not a major factor in COD removal.

The average MLVSS concentration in the sludge increased from 608 ± 96 to 3,767 ± 324 mg/L at the end of the acclimatization stage. This increment was

possibly because of increased supply of food to the microorganisms as the added slaughterhouse effluent was increased.

4.4 SBR Treatment of Slaughterhouse Wastewater

Treatment of slaughterhouse wastewater was carried out after the acclimatization stage, from day 14 to 23. Performance of SBR was assessed by analyzing pollutants including COD, BOD_5, MLSS, and nutrients such as NH_4-N, NO_3-N and TP. The results are presented and discussed in the following sub-sections.

4.4.1 Removal of COD and BOD_5

The treated effluent BOD_5 concentrations were in the range 2,400 – 4,370 mg/L with an average of 3,196 ± 82 mg/L and the COD in the range 3,760 – 6,560 mg/L with an average of 4,884 ± 125 mg/L (Table 4.3 and Figure 4.2). The removal rate was in the range 45 - 69% for both COD and BOD_5 with an average of 59 ± 1% for COD.

The treated slaughterhouse effluent exceeded the Environmental Management and Co-ordination Regulation (EMCR) of 2006 (Table 2.4) allowable concentrations for discharge to a public sewer of 500 mg/L and, 1,000 mg/L BOD_5 and COD respectively. Therefore, the SBR treatment of the slaughterhouse wastewater did not meet the requirements for disposal of effluent to public sewers. Nevertheless, the SBR treatment achieved a significant BOD_5 and COD reduction of up to 59%, for example from 12,430 to 3,760 mg/L for COD, within a reaction period of 6 hours.

Table 4.3: Quality of SBRs Influent and Effluent

Pollutant	Influent (mg/L)	Effluent Range (mg/L)	Effluent Mean (mg/L)	SE	% Removal
COD	11,947	3,760-6,560	4,884	±125	59±1
BOD_5	8,233	2,400-4,370	3,196	±82	61±1
NH_4-N	70	6-57	32	±2	54±3
NO_3-N	65	25-35	30	±0.4	54±1
TSS	1,400	200-1,200	720	±50	49±4
TP	261	132-211	171	±5	35±2

The results show that the SBR effluents require further treatment of the wastewater before discharge into the sewers. This may include introducing one extra cycle, operating the SBRs system for up 24 hours thus reducing idle time. Additionally, air supply to the SBRs could be improved by acquiring aerators with higher aeration rates to enhance COD removal and nitrification. The mixing could be improved by acquiring mixers that could perform continuously and adjustable up to a rate of 300 rpm during aerobic phase for effective nitrification and COD removal (Uygur, 2006). On-line monitoring could be introduced to predict the end-points of nitrification and denitrification and therefore improve on SBRs performance and reduce cycle time.

Figure 4.2 illustrates a trend of SBR1 that is different from other SBRs between days 17 and 20. The COD removal decreased to below 50 % and then increased to above 60% at day 20. This was attributed to biological changes that could have been taking place in SBR1. The micro-organisms were not effective in reducing the pollutants in the reactor. However, after the day 20,

the SBR1 performed better than others averaging the COD removal above 60%. Moreover, day 23 indicated that the three SBRs had similar performance in treating slaughterhouse wastewater averaging at 59% COD removal. This implied that the use of SBRs 1, 2 or 3 could yield similar results while treating the wastewater.

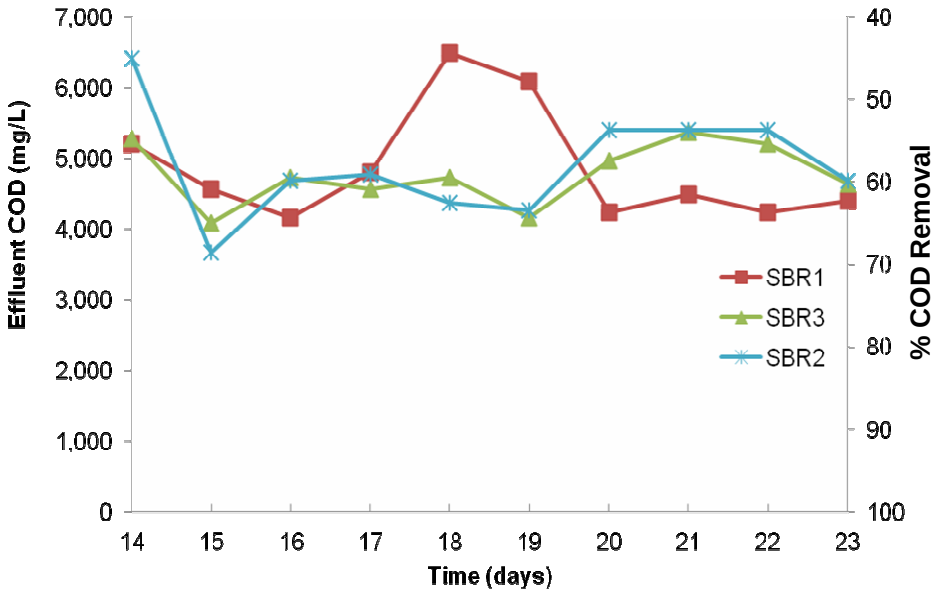


Figure 4.2: Effluent COD and Removal Rate

The statistical analysis using ANOVA revealed that there was no significant difference ($p < 0.05$, Appendix F2) between the SBRs 1, 2 and 3 in treating slaughterhouse wastewater in terms of BOD_5 and COD removal. This suggests that an SBR operating with VER of 30, 40 or 50% with equivalent HRT of 3.3, 2.5 or 2.0 days respectively could produce similar results. Given the finding that VER in the 30 – 50% range is not a significant factor in the operation of the SBR; the higher VER of 50% with a HRT of 2.0 days would

provide a higher volumetric turnover for the slaughterhouse effluent and allow for use of smaller reactors.

4.4.2 Removal of Total Suspended Solids (TSS)

The effluent TSS concentration varied significantly over the 10 days ranging from 200 – 1,200 mg/L with an average of 720 ± 50 mg/L (Table 4.3 and Figure 4.3). The TSS removal rate was in the range 14 - 79% with an average removal rate of 49 ± 4%. The Environmental Management and Co-ordination Regulations (EMCR, 2006) does not set TSS concentrations limits for discharge into public sewers.

Figure 4.3 illustrates SBR1 with a TSS removal rate of 15% at day 15 differing from that of others. This could be as a result of biological changes in the reactor that were not favoring TSS removal. At day 17, the TSS removal rate increased to between 65 and 85% for the three SBRs. This indicated that micro-organisms were able reduce the TSS optimally. However, the performance of the reactors dropped below 50% from days 18 to 21. The reactors performance improved after day 21 indicating the micro-organisms were effectively feeding on TSS. At day 23, the reactors achieved TSS removal rates of between 45 and 75%. Since TSS removal is not a factor for discharge of effluent to a sewer according to EMCR (2006), the performance of the reactors was satisfactory for this study.

There was strong linear correlation (e.g. r = 0.90 for SBR2) between percentage TSS removal and total alkalinity of effluent, which indicated that alkalinity improved settle-ability of the solids. Metcalf & Eddy (2003)

suggests that the improved settle-ability is due to enhancement in floc formation by calcium ions.

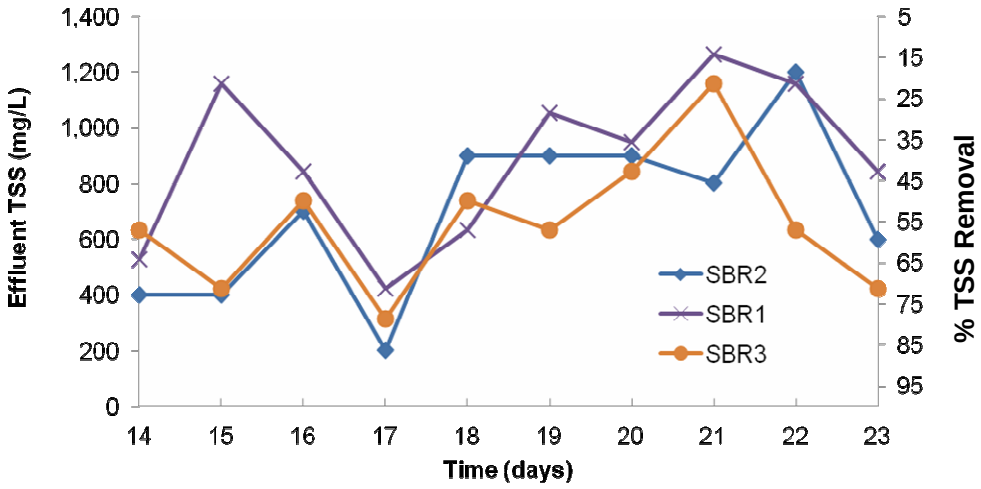


Figure 4.3: Effluent Total Suspended Solids (TSS) and Removal Rate

4.4.3 Removal of nutrients: TP, NO_3-N and NH_4-N

The treated slaughterhouse effluent had total phosphorus concentration of 132 - 211 mg/L with an average of 171 ± 5 mg/L, nitrate-nitrogen concentration of 25 – 35 mg/L with an average of 30 ± 0.4 mg/L and ammonium-nitrogen concentration of 6 – 57 mg/L with an average of 32 ± 2 mg/L (Table 4.3, Figures 4.4 -6). The removal rates by the SBRs were in the range 19 - 50%, average 35 ± 2% for TP; 46 - 62%, average 54 ± 1% for NO_3-N and 19 - 91% average 54 ± 3% for NH_4-N. The allowable concentrations for discharge to a public sewer are 30, 20 and 20 mg/L for total phosphates, ammonium-nitrogen, and nitrates respectively (EMCR, 2006). Therefore, the treated slaughterhouse effluent had higher concentrations than those permissible.

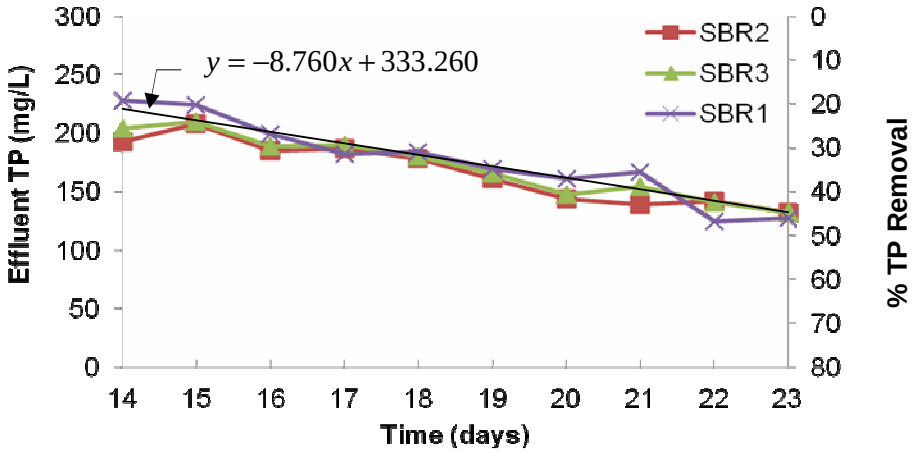


Figure 4.4: Effluent Total Phosphorus and Removal Rate

Figure 4.4 illustrates similar performance of the three reactors in treating slaughterhouse wastewater. This indicated that micro-organisms within the reactors were exposed to similar conditions that made them yield similar results. Moreover, the rate of total phosphorous removal increased with time up to 49% at day 23, implying that micro-organisms improved their performance as the treatment process progressed.

A combined line of best fit for the results of the three reactors (Figure 4.4) gave a slope of -8.760. This helped to predict the total phosphorous concentration beyond day 23 using the following equation:

$$y = -8.760x + 333.260 \qquad (4.1)$$

where y = effluent total phosphorous concentration (mg/L), and

x = time (days).

To meet the EMCR (2006) requirements of 30 mg/L of effluent total phosphorous for discharge to a public sewer (Table 2.4) the reactors require 35 days of treatment process.

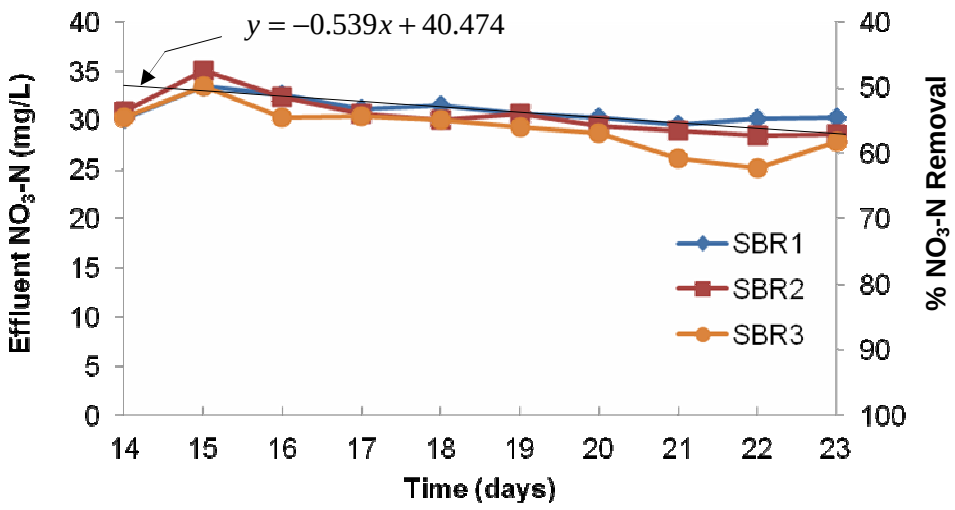


Figure 4.5: Effluent Nitrate-Nitrogen and Removal Rate

The nutrients removal improved with time. For example, on day 23 (Figure 4.5), the average effluent NO_3-N concentration was 29 ± 1 mg/L corresponding to average NO_3-N removals of 56 ± 1%. This concentration was slightly higher than the allowable concentrations for discharge into public sewers (Table 2.4; EMCR, 2006). The one cycle treatment process and limited aeration were found to be inadequate in removing nutrients from slaughterhouse wastewater using the SBRs.

From Figure 4.5, combined line of best fit for the results of three reactors gave a slope of -0.539. As a result, effluent nitrate-nitrogen concentration beyond day 23 could be predicted using the following equation:

$$y = -0.539x + 40.474 \qquad (4.2)$$

where y = effluent total phosphorous concentration (mg/L), and

x = time (days).

To meet the EMCR (2006) requirements of 20 mg/L of effluent total phosphorous for discharge to a public sewer (Table 2.4) the reactors require 38 days of treatment process before the requirements can be met.

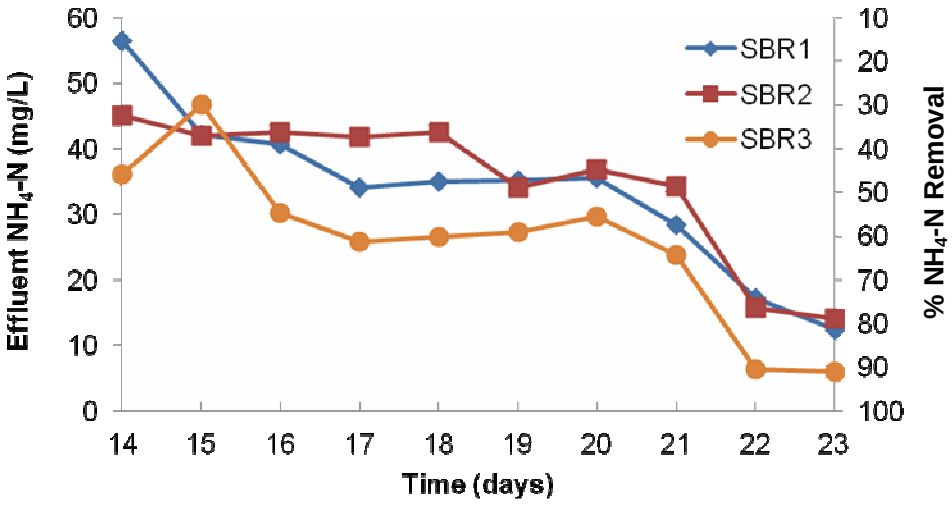


Figure 4.6: Effluent Ammonium-Nitrogen and Removal Rate

Figure 4.6 illustrates progressive improvement in performance of the three reactors in treating slaughterhouse wastewater. For example, between days 16 and 19, SBR3 could remove ammonia-nitrogen at a rate above 60% unlike the other reactors that performed below 50%. However, from days 20 to 23, the three reactors showed improved performance that climaxed on day 23 within a range of 80-90% ammonia-nitrogen removal. This indicated that conditions set within the reactors favored the performance of micro-organisms to feed on ammonia-nitrogen. However, the treatment process could not meet EMCR requirements for effluent discharge to a public sewer.

There was poor linear correlation (e.g. r = -0.60 for SBR3) between NO_3-N and NH_4-N percentage removals and effluent total alkalinity as $CaCO_3$

concentration. Since total alkalinity affects the performance of biological nitrification process and adequate alkalinity is needed to complete nitrification (Metcalf & Eddy, 2003), a stronger correlation between nitrification and total alkalinity would have been expected. The poor correlations may indicate that nitrification was incomplete probably because of too low DO concentrations (less than 2.0 mg/L) in the SBRs (Casellas et al., 2006).

Moreover the sequence of anaerobic-anoxic-aerobic favors the production of nitrates and, therefore, low levels of ammonia in treated effluents (Fabregas, 2004). There was strong linear correlation (for example r = -0.82 for SBR3) between percentage NH_4-N removal and effluent NO_3-N concentration. This strong correlation may imply that low effluent NO_3-N concentration favors removal of ammonium nitrogen in the slaughterhouse effluent. However, since nitrification and denitrification processes require adequate total alkalinity concentration (Metcalf & Eddy, 2003); hourly sampling of total alkalinity should be carried out to ascertain this dependency. This was not carried in this study because such more detailed analysis was beyond the scope of this research work.

There was strong linear correlation (e.g. r= -0.87 for SBR2) between percentage TP removal and effluent NO_3-N and NH_4-N concentrations. This may imply that low effluent NO_3-N and NH_4-N concentrations favored the removal of phosphorus in the slaughterhouse effluent.

Statistical Analysis using ANOVA (Appendix F2) revealed that there was no significant difference ($p < 0.05$) percentage removal of TP, NO_3-N and NH_4-N

from slaughterhouse wastewater between the SBRs 1, 2 and 3. Consequently, it may be concluded that an SBR with VER of 50% could be used in treating slaughterhouse wastewater since it has higher volume content than the other two.

4.4.4 Effluent pH and Total Alkalinity Levels for the Treated Effluent

The average pH values for the treated effluent were in the range 7.3 - 8.0 for all the SBRs throughout the treatment process as illustrated in Figure 4.7 below.

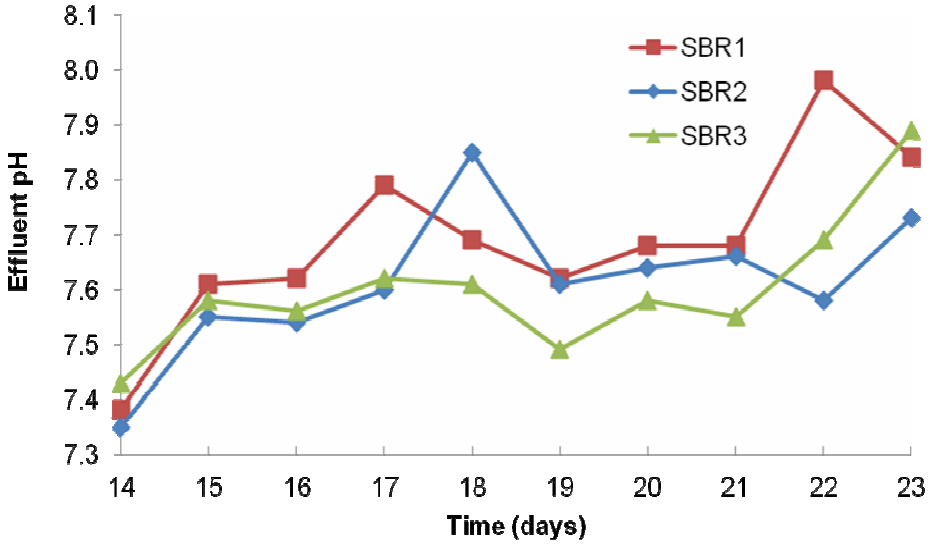


Figure 4.7: Effluent pH for SBR Treatment Stage

The pH values dropped from 7.8 to 7.6 for SBR1 between days 17 and 19. Similarly, for SBR3 the values dropped from 7.6 to 7.45. On the other hand, SBR2 had pH values increase from 7.58 to 7.85 then drop to 7.6 during the same period. On day 22, SBR1 had a pH value of 8.0 that was higher than that for other reactors. However, the pH values for the three reactors were similar on day 23. The monitoring of pH enabled the study to be conducted within

optimum conditions for microbial activities. In particular, the recommended optimal range of pH is 7.0-8.0 when treating slaughterhouse wastewater biologically (Casellas et al., 2006). From the research findings, this range of pH was achieved despite the observed differing pH values for the three reactors.

The treated effluent contained total alkalinity concentration in the narrow range of range 1,400 – 1,780 mg/L as $CaCO_3$ (Figure 4.8). This concentration is slightly higher than the recommended value of 1,000 mg/L as $CaCO_3$ for effective nitrification (Metcalf & Eddy, 2003; Nuch, 2007).

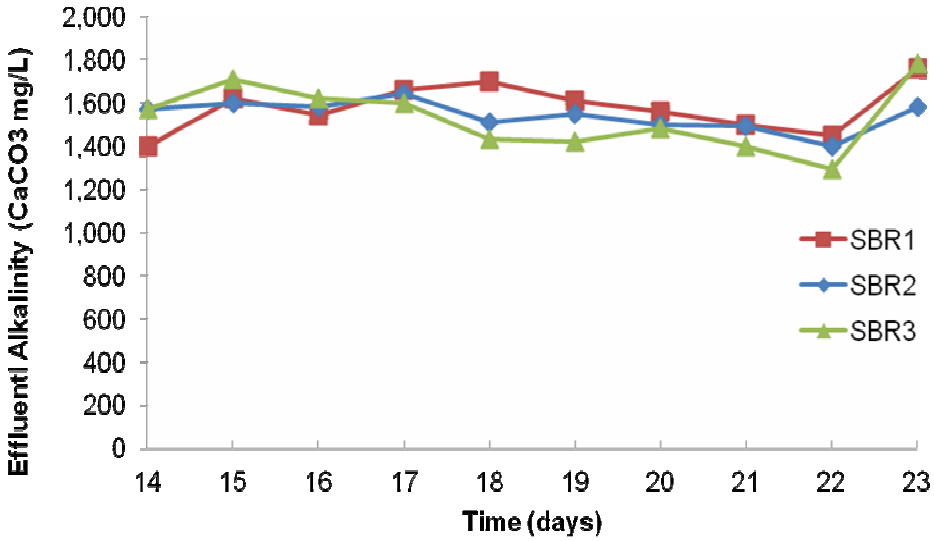


Figure 4.8: Effluent Total Alkalinity for SBR Treatment Stage

Figure 4.8 illustrates a rise in effluent total alkalinity concentration from 1,500 to 1,800 mg/L for SBR1; from 1,500 to 1,600 mg/L for SBR2 and from 1,400 to 1,800 mg/L for SBR3. The general trend of effluent total alkalinity concentration between days 14 and 22 indicated a slight fall in alkalinity levels. Since enough alkalinity is required for effective nitrification (Metcalf

& Eddy, 2003). it is expected that the effluent total alkalinity levels will slightly drop beyond day 24.

4.4.5 Volatile Suspended Solids concentrations for the treated effluent

The treated effluent contained MLVSS concentration in form of VSS ranging between 2,450 – 4,950 mg/L as illustrated in Figure 4.9 below.

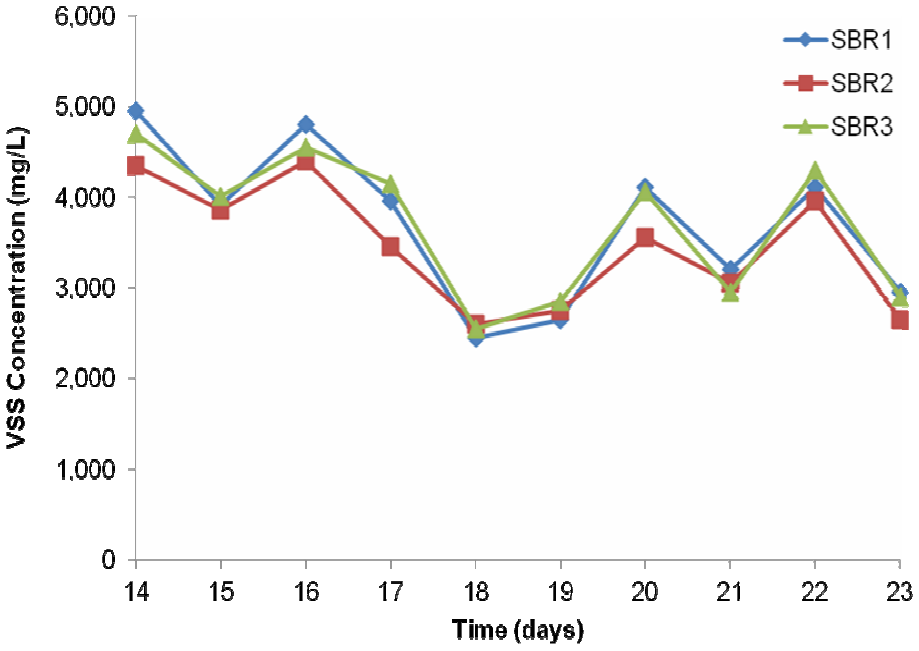


Figure 4.9: Effluent Volatile Suspended Solids for SBR Treatment Stage

The MLVSS was maintained daily through wastage of excess sludge. The excess sludge was observed on days 14, 16, 20 and 22. At alternate days, the sludge wasting was found to stabilize sludge concentration during the treatment stage. There was poor correlation (Appendix F1) between percentage COD removal and both MLVSS and MLSS concentrations, with r values of 0.59 and 0.60, respectively. This result indicates that concentrations of both MLVSS and MLSS and were not the significant factors in COD

removal, which is contrary to findings of other studies (e.g. Metcalf & Eddy, 2003). More research is therefore required to ascertain the dependency between COD removal and the effluent MLVSS and MLSS concentrations for the SBR treatment.

4.5 Monitoring of Treatment Process

Monitoring of the pH, ORP and DO in the operation of the SBR has made it possible to distinguish points with different characteristics, for example, termination times of nitrification, carbon oxidation and denitrification (Casellas et al, 2006). The anaerobic-anoxic-aerobic sequence promotes production of an effluent that has more nitrates and low ammonium concentrations. During anoxic stage denitrifying bacteria convert nitrates to nitrogenous compounds in the presence of organic carbon. The aeration stage that follows anoxic phase oxidizes ammonia to nitrates. However, effective monitoring relies on on-line instrumentations that were not available for this study and that may also not be available to the local slaughterhouses. The manual monitoring of pH, ORP and DO applied in this study was limited to gross improvement in the operation of the SBR performance.

4.5.1 pH and ORP Profiles

The typical pH and ORP profiles for the SBRs are illustrated in Figure 4.10 for one treatment cycle during day 18. The eighteen day represented a more stable performance than other days in regard to pH and ORP monitoring. Generally the pH increased with reaction time during aeration and decreased when no aeration was carried out. This made it difficult to depict a break-point

on the pH profile to indicate an end of nitrification after the suggested three hours of aeration (Casellas et al., 2006).The study findings suggest that the end of nitrification did not occur. Casellas et al. (2006) suggested that on-line pH measurements should be used to minimize the effect of aeration.

The end of denitrification during anoxic stage was not clearly depicted by appearance of a bending- point, a “nitrate knee” in the ORP profile as would have been expected (Casellas et al., 2006) implying incomplete denitrification (Figure 4.10 and Appendix D2). As a result the treated effluent contained more nitrate – nitrogen concentration than it would have had with complete nitrification. The aerobic stage similarly lacked an “ammonia valley’’ appearing in the pH profile (Casellas et al., 2006) that indicates the end of nitrification. This implied incomplete nitrification process which may be attributed to low DO concentration (less than 2.0 mg/L) in the SBRs (Casellas et al., 2006). The mixing rates of 50, 60 and 61 rpm were fixed and could not be adjusted to up to 300 rpm. The recorded dissolved oxygen was below the required 2.0 mg/L concentration (Appendix D) and could not be adjusted to higher values since the aerator provided had fixed supply of oxygen concentration. As a result, the treated effluent may have contained high level of ammonium-nitrogen concentration. Moreover, the end of denitrification was not depicted, as the pH profile lacked a maximum, “nitrate apex” during anoxic phase (Casellas et al., 2006).

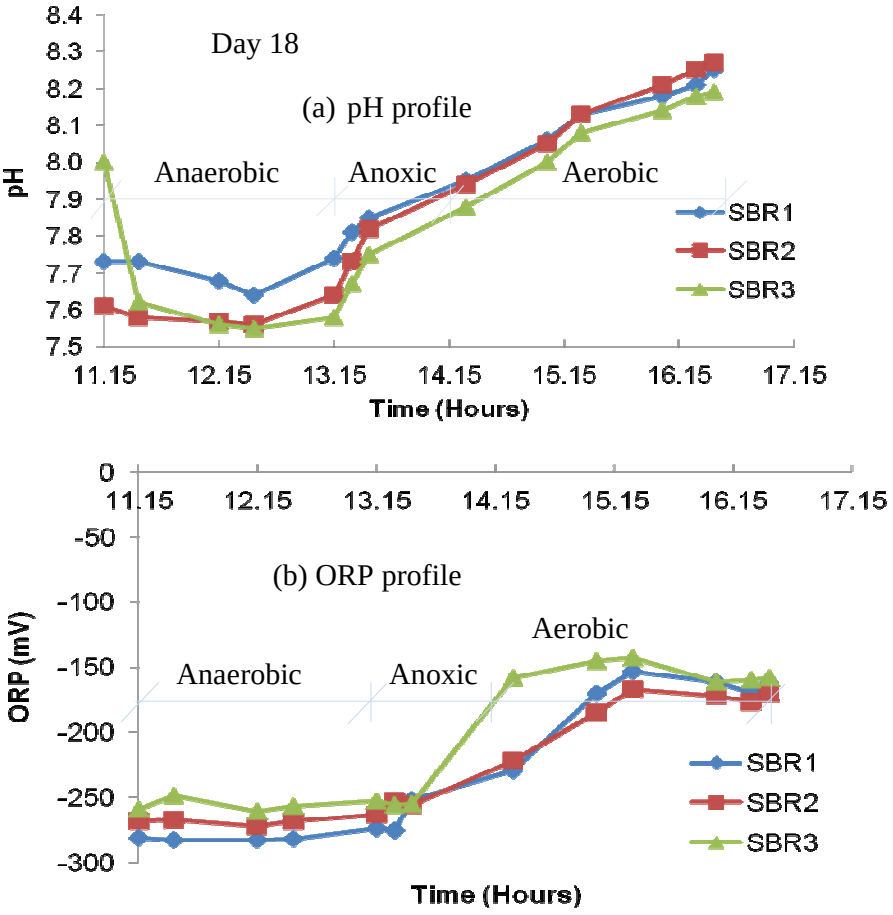


Figure 4.10: Typical pH and ORP Profiles for SBR Treatment Stage

4.5.2 DO profiles

Typical DO profiles (Figure 4.11) for day 18 portrayed an initial increase of DO concentration in all the SBRs. This increase was contrary to what has been observed elsewhere; for example, Yongzhen et al. (2004). This was probably due to availability of some dissolved oxygen within the SBRs 2 and 3 during the anaerobic stage. However, SBR1 results conformed to findings obtained elsewhere (Yongzhen et al., 2004). Dissolved oxygen profile for day 15 (Appendix D2) illustrated a prolonged plateau that lasted longer than other

profiles for all the SBRs. However, day 18 depicted a more stable performance of the reactors than other days in terms of DO monitoring.

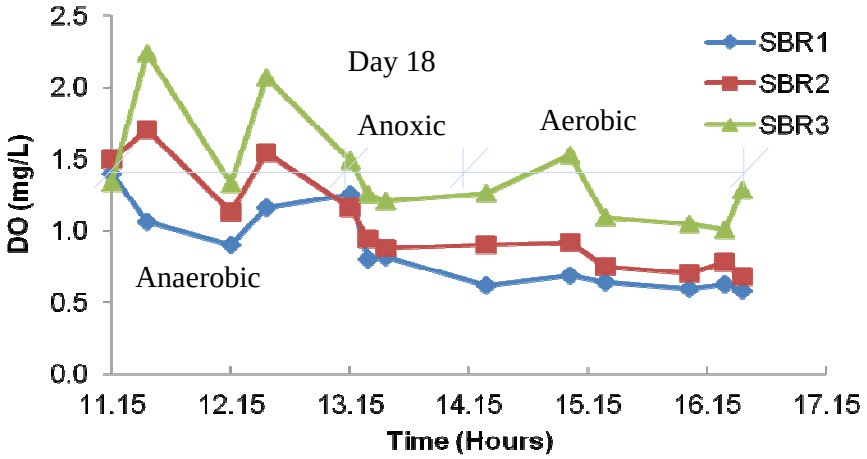


Figure 4.11: Typical DO Profile for SBR Treatment Stage

This observation suggests that COD removal was expected to be more effective during the second day of treatment. However, there lacked prolonged plateau during COD removal due to low supply of DO that was less than 2.0 mg/L in all the SBRs during the aeration stage. The aerator supplied DO concentration of 2.0mg/L that was consumed by organic matter in the SBRs such that the available DO was less than the required 2.0 mg/L. Therefore the performance of the SBRs in COD removal may have been affected by the DO concentration that remained below 2.0mg/L during the aerobic stage (Yongzhen et al, 2004).

4.5.3 Temperature profiles

The typical profiles of hourly temperature for the SBRs are illustrated in Figure 4.12 below, for specifically day 18. The eighteenth day was identified

as the day with a more stable performance than other days and therefore these profiles could depict general behavior of the reactors in terms of temperature.

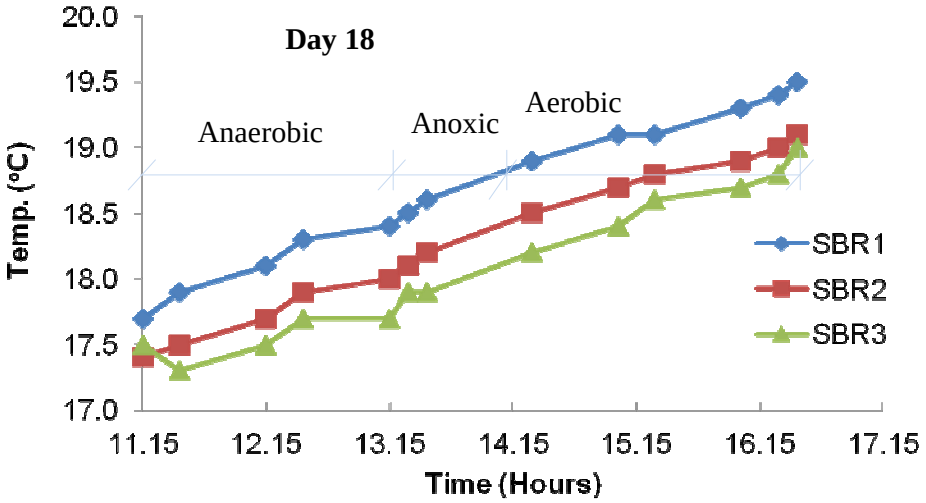


Figure 4.12: Typical Temperature Profile for SBRs

The monitored temperatures ranged from 17.5 to 19.5^{o} C throughout the treatment stage for all the SBRs. The temperature profiles depicted an increasing trend from anaerobic to aerobic stages (Figure 4.12), which may be attributed to increased exothermic microbial activities in the SBRs (e,g. Metcalf & Eddy, 2003).

4.6 General Discussion

Statistical analysis showed that there was no significant difference between SBRs 1, 2 and 3 with VERs of 30, 40 and 50% respectively for both the acclimatization and treatment stages. Consequently, SBR 3, which has the higher volumetric exchange rate of 50%, is preferable because it would result in a higher volumetric turnover and allow use of smaller reactors.

The HRT for anaerobic, anoxic and aerobic phases during react stage were set at 2h, 1h and 3h respectively as recommended in literature for effective removal of nutrients from slaughterhouse wastewater (Casellas et al., 2006). The SRT of 10 days was adopted for the study as suggested by literature for effective removal of organic matter. The aerator used in the study provided 2 mg/L concentration of oxygen that was not adequate for complete nitrification. The mixers used in the study provided fixed mixing rates of 50, 61 and 63 rpm respectively for the three SBRs that could not be regulated up to 300 rpm for effective nitrification.

There were poor correlations between COD and TP removal and effluent MLVSS and MLSS concentrations, which are not consistent with the findings in literature (Casellas et al., 2006). This was probably due to factors such as rates of aeration and mixing that affected the overall performance of the reactors. Therefore, higher aeration rates beyond 2.0 mg/L and mixing rates of upto 300 rpm could improve the correlation between these parameters.

Nitrification was found to be incomplete which is attributed to inadequate oxygen supply from the 2 mg/L aerator used in the study. The oxygen supply from the aerator available in the local market remained fixed and could not be increased. Therefore, it is recommended that nitrification be evaluated for various aeration rates for aerators available in the market to obtain the optimum aeration rate.

The treated effluent had COD and nutrients concentrations were above the limits for discharge to a public sewer. Therefore, the studied SBR treatment

process needs to be modified or improved to achieve the required effluent quality. Such modifications/improvements include obtaining aerators that could supply more than 2.0 mg/L of oxygen, mixers that could be regulated to run up to 300 rpm and introducing an extra cycle to procedure applied in this study.

Although the removal rates were much below those in literature, the study was a step forward towards addressing the challenge of treating slaughterhouse wastewater in Kenya. Therefore, the SBR treatment of slaughterhouse wastewater requires further work in modification and improvement of the mixing, aeration, treatment cycles and on-line monitoring processes.

This study of the SBR treatment process had limitations that affected the performance of the SBR. The key limitations included:

1. The available mixers tended to overheat when used for durations of more than 15 minutes. Mixing was therefore carried out intermittently. Moreover, the available aerators provided a maximum oxygen supply of 2 mg/L that may not have been adequate for effective aeration in the SBRs.

2. On-line monitoring could not be carried out due to lack of equipment. Consequently, parameters such as ORP and DO could not be adjusted in real time.

3. The SBR treatment process was limited to only one treatment cycle per day by limited refrigeration for storage for samples. Therefore, the study did not evaluate other treatment cycles.

CHAPTER FIVE

5.0: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The treatment of slaughterhouse wastewater was carried out using SBR method. The following conclusions were made

1. Volumetric exchange rate (VER) in the 30 - 50% range did not show significant difference in the SBR treatment. Therefore, the higher VER of 50% with a HRT of 2 days is preferable because it has higher volumetric turnover, which allows use of smaller reactors.

2. The SBR treatment process achieved average removals of 59, 61, 49, 54, 54 and 35% of COD, BOD_5, MLSS, NH_4-N, NO_3-N and TP respectively.

3. The average effluent concentrations of COD, BOD_5, MLSS, NH_4-N, NO_3-N and TP of 4, 884 ± 125; 3, 196 ± 82; 720 ± 50; 32 ± 2; 30 ± 0.4 and 171 ± 5 mg/L respectively were all above the regulatory standards for discharge to public sewers. Therefore, improvement of the SBR treatment or supplementary treatment is required before discharge to public sewers.

4. The removal of TP and NH_4-N are dependent on retention time. Low effluent NO_3-N concentration favors the removal of phosphorus and ammonium – nitrogen.

5. The HRT for anaerobic, anoxic and aerobic phases during react stage were set at 2h, 1h and 3h respectively. The SRT of 10 days was adopted

for the study. The aerator used in the study provided 2 mg/L concentration of oxygen that was not adequate for complete nitrification. The mixers used in the study provided fixed mixing rates of 50, 61 and 63 rpm respectively for the three SBRs that could not be regulated up to 300 rpm for effective nitrification.

5.2 RECOMMENDATIONS

The recommendations of the study are:

1. The VER of 50% with a HRT of 2 days to be adopted in treating slaughterhouse wastewater since it has higher volumetric turnover, which allows use of smaller reactors.
2. Two cycles to be carried out per day to avoid excessive idle time and improve effluent quality.
3. The HRT for anaerobic, anoxic and aerobic phases during react stage to be set at 2h, 1h and 3h respectively. The SRT of 10 days to be adopted in treating slaughterhouse wastewater.
4. Further tests to be carried out using higher aeration rates than 2.0 mg/L and mixing rates of up to 300 rpm to improve the results obtained in this study.
5. Because of the importance of effective real time monitoring and control in the operation of the SBR, inexpensive and effective monitoring and on-line controls should be developed.

6.0: REFERENCES

Ahmed A. M. (1993). Modeling of biological wastewater treatment in sequencing batch reactors. Master of Science thesis, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia, pp 100.

Alleman J. E. and Irvine R. L. (1980). Nitrification in the sequencing batch biological reactors, *J. Water Pollution Control Federation*, 52, 11, 2747-2753.

Ant´onio M. P. M., Heijnen J. J. and van Loosdrecht M. C. M. (2003). Effect of feeding pattern and storage on the sludge settleability under aerobic conditions, *J. Water Res.*, 37, 2555–2570.

Arora Madan L., Barth Edwin F. and Umhres Margaret B. (1985). Technological evaluation of sequencing batch reactors, *J. Water Pollution Control Federation*, 57, 8, 867-875.

Baetens D. (2001). Enhanced biological phosphorus removal: modeling and experimental design, *Ph. D. thesis*, Universiteit Gent.

Bernet N., Delgenes N., Akunna J. C., Delgenes J. P. and Moletta R. (2000). Combined anaerobic- aerobic SBR for the treatment of piggery wastewater, *J. Water Res.*, 34, 2, 611-619.

Beun J. J., Hendriks A, van Loosdrecht M.C.M., Morgenroth E., Wilderer P.A. and Heijnen J.J., 1999. Aerobic granulation in a sequencing batch reactor. *J. Water Res.* 33, 10, 2283-2290.

Blum, D. J. W. and Speece, R. E. (1991). A database of chemical toxicity to environmental bacteria and its use in interspecies comparisons and correlations. *J. Water Pollution Control Federation*, 63, 3, 198-207.

Bluman A.G, 1998. *Elementary Statistics: A Step by Step Approach.* WCB McGraw-Hill Companies, Inc., New York, USA.

Borja, R., Banks C.J. and Wang Z. (1994a). Performance and kinetics of an upflow anaerobic sludge blanket (UASB) reactor treating slaughterhouse wastewater. *J. Environ. Sci. Health,* A29, 2063-2085.

Borja, R., Banks C.J. and Wang Z. (1995b). Performance of a hybrid anaerobic reactor combining a sludge blanket and a filter treating slaughterhouse wastewater. *J. Appl. Microbiol. Biotechnol.,* 43, 351-383.

Borja, R., Banks, C.J., Wang, Z. and Mancha, A. (1998). Anaerobic digestion of slaughterhouse wastewater using a combination sludge blanket and filter arrangement in a single reactor. *Bioresource Technol.* 65, 125–133.

Brito, A.G., Rodrigues, A.C. and Melo, F.L. (1997). Feasibility of a pulsed sequencing batch reactor with anaerobic aggregated biomass for the treatment of low strength wastewater. *J. Water Sci. Technol.,* 35, 193.

Casellas M., Dagot C. and Baudu M. (2006). Set up and assessment of a control strategy in a SBR in order to enhance nitrogen and phosphorus removal. *J. Process Biochem.,* 41, 9, 1994 - 2001.

Chambers, B. (1993). Batch operated activated sludge plant for production of high effluent quality at small works, *J. Water Sci. Technol.,* 28, 10.

Dennis Robert W. and Irvine R. L. (1979). Effect of fill: react ratio on sequencing batch biological reactors. *J. WPCF,* 51, 2, 255-263.

Dockhorn T., Dichtl N. and Kayser R. (2001). Comparative investigations on COD- removal in sequencing batch reactors and continuous flow plants. *J. Water Sci. Technol.,* 43, 3, 45-52.

Eaton A.D, Clesceri L.S and Greenberg A.E. (2005). *Standard Methods for the Examination of Water and Wastewater*, 21st Edition, American Public Health Association / American Water Works Association /Water Environment Federation, Washington DC.

Environmental Management and Co-ordination Regulations, (EMCR), (2006) Fifth Schedule: Standards For Effluent Discharge Into Public Sewers https://www.elaw.org/system/files/ke.WaterQualityReg.pdf, 3rd April, 2013.

Fabregas M.T.V, (2004). SBR technology for wastewater treatment: Suitable operational conditions for a nutrient removal. *Ph. D. thesis*, Universitat de Girona.

Hulshoff-Pol, L., Rebac, S., Kato, M.T., Van Lier, J. and Lettinga, G. (1998). Anaerobic treatment of low-strength wastewater. *Proceedings of the 5th Latin-American Workshop-Seminar Wastewater Anaerobic Treatment, Viña del Mar, Chile*, 340-400.

Irvine R. L. and Busch A.W. (1979). Sequencing batch biological reactors-an overview. *J., Water Pollution Control Federation*, 51, 2, 235-243.

Irvine R.L., Ketchum L.H., Breyfogle R and Barth E.F. (1983). Municipal applications of sequencing batch treatment, *J. Water Pollution Control Federation,* 59, 5, pp 9-15.

Irvine R. L., Ketchum Lloyd H. Jr., Arora Madan L. and Barth Edwin F. (1985). An organic loading study of full-scale sequencing batch reactors, *J. Water Pollution Control Federation*, 57, 8, 847-853.

Jetten M.S.M., Strous M., van de Pas-Schoonen K.T., Schalk J., van Dougen L.G.J.M., van de Graaf A.A., Logeman S., Muyzer G., van Loosdrecht M.C.M. and Kuenen J.G. (1999). The anaerobic oxidation of ammonium. *J. FEMS Microbiol. Rev.* 22, 421–437.

Jones M. and Stephenson T. (1996). The effect of temperature on enhanced biological phosphate removal. *J. Environ. Technol.*, 17, 965-976.

Kato M.T. (1994). The anaerobic treatment of low strength soluble wastewaters. PhD Thesis, Agricultural University, Wageningen, The Netherlands.

Ketchum L. H. Jr., Irvine R. L., Breyfogle R. E. and Manning J. F. Jr. (1987). A comparison of biological and chemical phosphorus removal in continuous and sequencing batch reactors, *J. Water Pollution Control Federation*, 59, 1, 13-18.

Kostyshyn, C. R., Bonkoski W. A. and Sointio J. E. (1988). Anaerobic treatment of a beef processing plant wastewater: A case history. In Proceedings of the 42nd Industrial Waste Conference, 673-692. Ann Arbor, MI: Ann Arbor Science.

Kuba T., Smolders G., van Loosdrecht M. C.M. and Heijnen J. J. (1993). Biological phosphorus removal from wastewater by anaerobic-anoxic SBR. *J. Water Sci. Technol.*, 27, 5-6, 241-252.

Kuba T., Wachtmeister A., van Loosdrecht M. C.M. and Heijnen J. J.(1997). A sludge characterization assay fro aerobic and denitrifying phosphorus removing sludge. *J. Water Res.*, 31, 3, 471-478.

Latkar M. and Chakrabarti T. (1994). Performance of upflow anaerobic sludge blanket reactor carrying out biological hydrolysis of urea. *J. Water Environ. Res.*, 66, 1, 12-15.

Lettinga G., van Velsen A.F.M., Hobma S.W., de Zeeuw W. and Klapwijk A. (1980). Use of the upflow sludge blanket (USB) reactor concept for biological wastewater treatment, especially for anaerobic treatment. *J. Biotechnol. Bioeng.* 22, 699 – 734.

Luis H. Abreu and Saribel Estrada, (2005). Sequencing batch reactors: an efficient alternative to wastewater treatment. http://www.rpiscrews.us/dept/chem-eng/Biotech-Environ/Environmental/Steps/EnvSysSBR.html#settle, 20 July 2009.

McCarty, P.L. (2001). The development of anaerobic treatment and its future. *J. Water Sci. Technol.* 44, 8, 149 – 156.

Manning J. F. and Irvine R. L. (1985). The biological removal of phosphorus in a sequencing batch reactor. *J. Water Pollution Control Federation,* 57, 1, 87-94.

Massé D. I. and Masse L. (2000). Treatment of slaughterhouse wastewater in anaerobic sequencing batch reactors. *J. Can. Agric. Eng.*, 42, 131-137.

Matsumura E. M. and Mierzwa J. C. (2008). Water conservation and reuse in poultry processing plant – a case study. *J. Resource Conservation Recycle,* 52, 6, 835–842.

Merzouki M., Bernet N., Delgenés J. P., Moletta R. and Benlemlih M. (2001).Biological denitrifying phosphorus removal in SBR: effect of added nitrate concentration and sludge retention time. *J. Water Sci. Technol*., 43, 3, 191-194.

Metzner G. and Temper U. (1990). Operation and optimization of a full-scale fixed-bed reactor for anaerobic digestion of animal rendering wastewater. *J. Water Sci. Technol*., 22, 373-384.

Metcalf & Eddy Inc. (2003). *Wastewater Engineering Treatment and Reuse*. 4th Ed., Tata McGraw- Hill, New York.

Mitsch W. J. and Gosselink J. G. (1992). *Wetlands*, 2nd Ed. Van Nostrand Reinhold, New York.

Mulligan C. N. and Chan T.Y. (2001). Developments in anaerobic wastewater treatment. Proceedings of the 29th Annual Conference for the Canadian Society for Civil Engineering May 30–June 2, 2001, Victoria, B.C.

Norcross K.L. (1992). Sequencing batch reactors: an overview, *J. Water Sci. Technol.*, 26, 9-11.

Nuch K. (2007). Modification of the existing slaughterhouse wastewater treatment- plant for biological nutrient removal. *Master of Science thesis,* Mahidol University, Bangkok, Thailand.

Okada M. and Sudo R. (1986). Performance of SBR activated sludge processes for simultaneous removal of nitrogen, phosphorus and BOD as applied to small community sewage treatment. *J. Water Sci. Technol*., 18, Tokyo, 363-370.

Omil F., Mendez R.and Lema J. M. (1996). Anaerobic treatment of seafood processing wastewaters in an industrial pilot plant. *J. Water S. A.*, 22, 2, 173-181.

Ratusznei S.M., Rodrigues J.A.D., Camargo E.F.M., Zaiat M. and Borzani W. (2000).Feasibility of a stirred anaerobic sequencing batch reactor containing immobilized biomass for wastewater treatment, *J. Bio-resource Technol*., 75, 127.

Rodrigues J. A.D., Ratusznei S.M., Camargo E.F.M. and Zaiat M. (2003). Influence of agitation rate on the performance of an anaerobic sequencing batch reactor containing granulated biomass treating low-strength wastewater, *J. Advances in Environ .Res.*, 7, 405.

SAS Institute, (1996). *The SAS System for Windows, version 6.12*.SAS Institute, Cary, NC.

Silva M. R., Coelho M. A. Z. and Araújo O. Q. F. (2001). Minimization of phenol and ammoniacal nitrogen in refinery wastewater employing biological treatment. *Rio de Janeiro–Brazil, Engenharia Térmica, Edição Especial*, 33-37.

Singh K. S., Harada H. and Viraraghavan T.(1996). Low strength wastewater treatment by a UASB reactor. *J. Bioresour. Technol*., 55, 3, 187–194.

Sirianuntapiboon S. and Manoonpong K. (2001). Application of granular activated carbon-sequencing batch reactor (GAC-SBR) system for treating wastewater from slaughterhouse. *Thammasat Int. J. Sci., Technol*., 6, 1, 16.

Smolders G. J., van Loosdrecht M. C.M. and Heijnen J. J.(1994). pH: key factor in the biological phosphorus removal process. *J. Water Sci. Technol.*, 29, 71-74.

Smolders G. J., van Loosdrecht M. C.M., Heijnen J. J. and Klop J. M. (1995). A metabolic model of the biological phosphorus removal: Effect of the sludge retention time. *J. Biotechnol. Bioeng.*, 48, 222-233.

Surampalli R. Y., Tyagi R. D. and Scheible K. O. (2000). SBRs-technology and performance evaluation. *J. Environ. Systems*, 28, 1, 25-43.

Surampalli R. Y., Tyagi R. D., Scheible K. O. and Heidman J. A. (1997). Nitrification, denitrification and phosphorus removal in SBRs. *J. Bioresource Tech.*, 61, 151-154.

STOWA. 1996. Removal of ammonium from sludge water with the Annamox process. Feasibility study. Report no. 96–21. STOWA, Utrecht, The Netherlands, ISBN 9– 744476 554.

Strous M., Kuenen J.G. and Jetten M.S.M. (1999). Key physiology of anaerobic ammonium oxidation. *J. Appl. Environ. Microbiol.,* 65, 7, 3248–3250.

Tilche A., Bortone G., Malaspina F., Piccinini S. and Stante L. (2001). Biological nutrient removal in a full-scale SBR treating piggery wastewater: results and modeling. *J. Water Sci. Technol.*, 43, 3, 363-370.

Tsang Y. F., Hua F. L., Chua H., Sin S. N. and Wang Y. J. (2007). Optimization of biological treatment of paper mill effluent in a sequencing batch reactor. *J. Biochem. Eng*., 34, 193–199.

United States Environmental Protection Agency, USEPA,(1999). W*astewater Technology Fact Sheet Sequencing Batch Reactors*, Office of Water Washington, D.C.

UNIC, (2010). UN Newsletter, (April 2010). United Nations Information Centre, Nairobi (Ed.),The United Nations System in Kenya http://www.unicnairobi.org/newsletter/April_UNnewsletter.pdf., 7 January, 2013.

Uygur A. (2006). Specific nutrient removal rates in saline wastewater treatment using sequencing batch reactor. *J. Process Biochem.*, 41, 61–66.

Uygur A. and Kargi F. (2002). Nutrient removal performance of a sequencing batch reactor as a function of the sludge age. *J. Enzyme Microbial Technol.*, 31, 842–847.

van Haandel, A.C. and Lettinga, G. (1994). Anaerobic sewage treatment: A Practical Guide for Regions with a Hot Climate, John Wiley & Sons Ltd., Chichester, UK.

Vlekke G. J. F. M., Comeau Y. and Oldham W. K. (1988). Biological phosphate removal from wastewater with oxygen or nitrate in SBRs. *Environ. Technol. Letters*, 9, 791-796.

Wilderer P. A., Irvine R. L. and Mervyn C. (2001). *Sequencing Batch Reactor Technology*, IWA Publishing, London.

Wu W., Timpany P. and Dawson B. (2001). Simulation and applications of a novel modified SBR system for biological nutrient removal. *J. Water Sci. Technol.,* 43, 3, 215-222.

Yiu H. H., Wai-Kit N. and Robert R. (2001).Meat science and applications, http://books.google.co.ke/books?isbn=0824705483, 20 July 2009.

Yongzhen P., Wei Z. and Shuying W. (2004). DO concentration as a fuzzy control parameter for organic substrate removal in SBR processes, *J. Environ. Eng. Sci.,* 21(5) 606-616.

Zhan X., Healy M. G. & Li J. (2008). Nitrogen removal from slaughterhouse wastewater in a sequencing batch reactor under controlled low DO conditions, *J. Bioprocess and Biosystems Eng.,* 32, 5, 607-614.

7.0: APPENDICES

APPENDIX A1: SCHEDULE OF FILLING, DECANTING AND SLUDGE WASTING IN SBRS

	Treatment Day												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Fill (AS)													
SBR1	5 000	-	-	1125	1050	950	850	550	250	0	0	0	0
SBR2	5 000	-	-	1500	1400	1300	1200	900	600	300	0	0	0
SBR3	5 000	-	-	1875	1800	1700	1600	1300	1000	700	500	200	0
Fill (SW)													
SBR1	-	-	-	375	450	550	650	950	1250	1500	1500	1500	1500
SBR2	-	-	-	500	600	700	800	1100	1400	1700	2000	2000	2000
SBR3	-	-	-	625	700	800	900	1200	1500	1800	2000	2300	2500
Decant													
SBR1	-	-	1500	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
SBR2	-	-	2000	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
SBR3	-	-	2500	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Sludge	-	-	-	500	500	500	500	500	500	500	500	500	500
wasted				500	500	500	500	500	500	500	500	500	500
per SBR				500	500	500	500	500	500	500	500	500	500

SCHEDULE OF ONE CYCLE OPERATIONS IN SBRS

Operations	Fill	Anaerobic	Anoxic	Aerobic	Settle	Decant	Idle
Duration	45 min	2 hrs	1 hr	3 hrs	45 min	20 min	16 h 10 min

APPENDIX A2 : MEAN INFLUENT COD AND BOD_5 CONCENTRATIONS

Day	COD(mg/L)			BOD_5(mg/L)		
	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
1	3867	3867	3867			
2	4405	4405	4190			
3	5123	4944	4621			
4	5842	5483	5052			
5	7997	6345	6345			
6	10151	8715	7637			
7	11947	10331	8930			
8	11947	11947	9792			
9	11947	11947	11085			
10	11947	11947	11947			
11	11947	11947	11947			
12	11947	11947	11947			
13	11947	11947	11947			
14	11947	11947	11947	8233	8233	8233
15	11947	11947	11947	8233	8233	8233
16	11947	11947	11947	8233	8233	8233
17	11947	11947	11947	8233	8233	8233
18	11947	11947	11947	8233	8233	8233
19	11947	11947	11947	8233	8233	8233
20	11947	11947	11947	8233	8233	8233
21	11947	11947	11947	8233	8233	8233
22	11947	11947	11947	8233	8233	8233
23	11947	11947	11947	8233	8233	8233

APPENDIX A3: MEAN INFLUENT TSS AND TP CONCENTRATIONS

Day	TSS(mg/L)			TP(mg/L)		
	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
14	1400	1400	1400	261	261	261
15	1400	1400	1400	261	261	261
16	1400	1400	1400	261	261	261
17	1400	1400	1400	261	261	261
18	1400	1400	1400	261	261	261
19	1400	1400	1400	261	261	261
20	1400	1400	1400	261	261	261
21	1400	1400	1400	261	261	261
22	1400	1400	1400	261	261	261
23	1400	1400	1400	261	261	261

APPENDIX A4: MEAN INFLUENT NO_3-N AND NH_4-N CONCENTRATIONS

Day	NO_3-N(mg/L)			NH_4-N(mg/L)		
	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
14	65	65	65	70	70	70
15	65	65	65	70	70	70
16	65	65	65	70	70	70
17	65	65	65	70	70	70
18	65	65	65	70	70	70
19	65	65	65	70	70	70
20	65	65	65	70	70	70
21	65	65	65	70	70	70
22	65	65	65	70	70	70
23	65	65	65	70	70	70

APPENDIX B: EFFLUENT COD CONCENTRATION (ACCLIMATIZATION) AND PERCENTAGE REMOVAL

		Effluent COD (mg/L) (acclimatization)			Percentage COD Removal (%) (acclimatization)		
Day		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
		1593	1915	953			
1	**Mean**	**1600**	**1920**	**960**	**59**	**50**	**75**
		1607	1927	967			
	STD	±10	±8	±10			
		969	1176	1625			
2	**Mean**	**976**	**1184**	**1632**	**78**	**73**	**61**
		983	1184	1639			
	STD	±10	±11	±10			
		1378	1273	1593			
3	**Mean**	**1386**	**1280**	**1600**	**73**	**74**	**65**
		1394	1287	1607			
	STD	±11	±10	±10			
		1514	1619	1858			
4	**Mean**	**1520**	**1626**	**1866**	**74**	**70**	**63**
		1526	1633	1874			
	STD	±8	±10	±11			
		2019	1940	2180			
5	**Mean**	**2026**	**1946**	**2186**	**75**	**69**	**66**
		2033	1952	2192			
	STD	±10	±8	±8			
		1515	1315	2154			
6	**Mean**	**1520**	**1320**	**2160**	**85**	**85**	**72**
		1525	1325	2166			

		Effluent COD (mg/L) (acclimatization)			Percentage COD Removal (%) (acclimatization)		
Day		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
	STD	±7	±7	±8			
		5033	4154	4274			
7	**Mean**	**5040**	**4160**	**4280**	**58**	**60**	**52**
		5047	4166	4286			
	STD	±10	±8	±8			
		4794	5115	4793			
8	**Mean**	**4800**	**5120**	**4800**	**60**	**57**	**51**
		4806	5125	4807			
	STD	±8	±7	±10			
		4953	5034	5073			
9	**Mean**	**4960**	**5040**	**5080**	**58**	**58**	**54**
		4967	5046	5087			
	STD	±10	±8	±10			
		4873	5274	5193			
10	**Mean**	**4880**	**5280**	**5200**	**59**	**56**	**56**
		4887	5286	5207			
	STD	±10	±8	±10			
		4633	4472	4792			
11	**Mean**	**4640**	**4480**	**4800**	**61**	**63**	**60**
		4647	4488	4808			
	STD	±10	±11	±11			
		5672	6324	5274			
12	**Mean**	**5680**	**6320**	**5280**	**52**	**47**	**56**
		5688	6326	5286			
	STD	±11	±8	±8			
		5113	5593	5434			
13	**Mean**	**5120**	**5600**	**5440**	**57**	**53**	**54**
		5127	5607	5446			
	STD	±10	±10	±8			

APPENDIX C1: EFFLUENT COD CONCENTRATION AND PERCENTAGE REMOVAL

		Effluent COD (mg/L)			Percentage COD Removal (%)		
Day		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
		5194	6553	5273			
14	**Mean**	**5200**	**6560**	**5280**	**56**	**45**	**56**
		5206	6567	5287			
	STD	±8	±10	±10			
		4552	3754	4073			
15	**Mean**	**4560**	**3760**	**4080**	**62**	**69**	**66**

Day		Effluent COD (mg/L) (acclimatization)			Percentage COD Removal (%) (acclimatization)		
		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
		4568	3766	4087			
	STD	±11	±8	±10			
		4153	4792	4713			
16	**Mean**	**4160**	**4800**	**4720**	**65**	**60**	**60**
		4167	4808	4727			
	STD	±10	±11	±10			
		4792	4873	4553			
17	**Mean**	**4800**	**4880**	**4560**	**60**	**59**	**62**
	STD	4808	4887	4567			
		±11	±10	±10			
18	**Mean**	**6480**	**4480**	**4720**	**46**	**63**	**60**
		6487	4488	4727			
	STD	±10	±11	±10			
		6072	4353	4152			
19	**Mean**	**6080**	**4360**	**4160**	**49**	**64**	**65**
		6088	4367	4168			
	STD	±11	±10	±11			
		4233	5512	4952			
20	**Mean**	**4240**	**5520**	**4960**	**65**	**54**	**58**
		4247	5527	5367			
	STD	±11	±10	±10			
		4472	5513	5353			
21	**Mean**	**4480**	**5520**	**5360**	**63**	**54**	**55**
		4488	5527	5367			
	STD	±11	±10	±10			
		4233	5513	5192			
22	**Mean**	**4240**	**5520**	**5200**	**65**	**54**	**56**
		4247	5527	5208			
	STD	±10	±10	±11			
		4392	4793	4633			
23	**Mean**	**4400**	**4800**	**4640**	**63**	**60**	**61**
		4408	4807	4647			
	STD	±11	±10	±10			

SBR1 with VER of30% and HRT of 3.33 days, SBR2 with VER of 40% and HRT of 2.50 days SBR3 with VER of 50% and HRT of 2.00 days.

APPENDIX C2: EFFLUENT BOD_5 CONCENTRATION AND PERCENTAGE REMOVAL

		Effluent BOD_5 (mg/L)			Percentage BOD_5 Removal (%)		
Day		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
		3453	4363	3515			
14	**Mean**	**3460**	**4370**	**3520**	**58**	**47**	**57**
		3467	4377	3525			
	STD	±10	±10	±7			
		3032	2394	2712			
15	**Mean**	**3040**	**2400**	**2720**	**63**	**71**	**67**
		3048	2406	2728			
	STD	±11	±8	±11			
		2592	3143	3093			
16	**Mean**	**2600**	**3150**	**3100**	**68**	**62**	**62**
		2608	3157	3107			
	STD	±11	±10	±10			
		3202	3243	3144			
17	**Mean**	**3210**	**3250**	**3150**	**61**	**61**	**62**
		3218	3257	3156			
	STD	±11	±10	±8			
		4343	2952	2894			
18	**Mean**	**4350**	**2960**	**2900**	**47**	**64**	**65**
		4357	2968	2906			
	STD	±10	±11	±8			
		3201	2882	2744			
19	**Mean**	**3210**	**2890**	**2750**	**61**	**65**	**67**
		3217	2898	2756			
	STD	±10	±11	±8			
		2794	3692	3293			
20	**Mean**	**2800**	**3700**	**3300**	**66**	**55**	**60**
		2806	3708	3307			
	STD	±8	±11	±10			
		2943	3592	3543			
21	**Mean**	**2950**	**3600**	**3550**	**64**	**56**	**57**
		2957	3608	3557			
	STD	±10	±11	±10			
		2782	3593	3394			
22	**Mean**	**2790**	**3600**	**3400**	**66**	**56**	**59**
		2798	3607	3406			
	STD	±11	±10	±8			
		2892	3203	3044			
23	**Mean**	**2900**	**3210**	**3050**	**65**	**61**	**63**
		2908	3217	3056			
	STD	±11	±10	±8			

APPENDIX C3: EFFLUENT TSS CONCENTRATION AND PERCENTAGE REMOVAL

		Effluent TSS (mg/L)			Percentage TSS Removal (%)		
Day		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
		492	393	593			
14	**Mean**	**500**	**400**	**600**	**64**	**71**	**57**
		508	407	607			
	STD	±11	±10	±10			
		1094	392	395			
15	**Mean**	**1100**	**400**	**400**	**21**	**71**	**71**
		1106	408	405			
	STD	±8	±11	±7			
		792	693	692			
16	**Mean**	**800**	**700**	**700**	**43**	**50**	**50**
		808	707	708			
	STD	±11	±10	±11			
		394	195	294			
17	**Mean**	**400**	**200**	**300**	**71**	**86**	**79**
		406	205	306			
	STD	±8	±7	±8			
		592	892	693			
18	**Mean**	**600**	**900**	**700**	**57**	**36**	**50**
		608	908	707			
	STD	±11	±11	±10			
		994	893	592			
19	**Mean**	**1000**	**900**	**600**	**29**	**36**	**57**
		1006	907	608			
	STD	±8	±10	±11			
		892	893	794			
20	**Mean**	**900**	**900**	**800**	**36**	**36**	**43**
		908	907	806			
	STD	±11	±10	±8			
		1192	793	1095			
21	**Mean**	**1200**	**800**	**1100**	**14**	**43**	**21**
		1208	807	1105			
	STD	±11	±10	±7			
		1093	1194	593			
22	**Mean**	**1100**	**1200**	**600**	**21**	**14**	**57**
		1107	1206	607			
	STD	±10	±8	±10			
		794	593	394			
23	**Mean**	**800**	**600**	**400**	**43**	**57**	**71**
		806	607	406			
	STD	±8	±10	±8			

APPENDIX C4: EFFLUENT NH_4-N CONCENTRATION AND PERCENTAGE REMOVAL

		Effluent NH_4-N (mg/L)			Percentage NH_4-N Removal (%)		
Day		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
		53	42	33			
14	**Mean**	**57**	**45**	**38**	**19**	**36**	**46**
		61	48	43			
	STD	±6	±4	±7			
		38	37	44			
15	**Mean**	**42**	**42**	**49**	**40**	**40**	**30**
		46	47	54			
	STD	±6	±7	±7			
		38	37	27			
16	**Mean**	**41**	**42**	**32**	**42**	**39**	**55**
		44	47	37			
	STD	±4	±7	±7			
		29	38	22			
17	**Mean**	**34**	**42**	**27**	**51**	**40**	**61**
		29	46	32			
	STD	±7	±6	±7			
		30	38	23			
18	**Mean**	**35**	**42**	**28**	**50**	**39**	**60**
		40	46	33			
	STD	±7	±6	±7			
		31	29	25			
19	**Mean**	**35**	**34**	**29**	**50**	**51**	**59**
		39	39	33			
	STD	±6	±7	±6			
		30	32	26			
20	**Mean**	**35**	**37**	**31**	**49**	**48**	**55**
		40	42	36			
	STD	±7	±7	±7			
		23	29	20			
21	**Mean**	**28**	**34**	**25**	**60**	**51**	**64**
		33	39	30			
	STD	±7	±7	±7			
		12	12	4			
22	**Mean**	**17**	**16**	**7**	**75**	**78**	**90**
		22	20	10			
	STD	±7	±6	±4			
		7	9	3			
23	**Mean**	**12**	**14**	**6**	**82**	**80**	**91**
		17	19	9			
	STD	±7	±7	±4			

APPENDIX C5: EFFLUENT NO_3-N CONCENTRATION AND PERCENTAGE REMOVAL

		Effluent NO_3-N (mg/L)			Percentage NO_3-N Removal (%)		
Day		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
		27	28	26			
14	**Mean**	**30**	**31**	**29**	**54**	**52**	**55**
		33	34	32			
	STD	±4	±4	±4			
		30	32	29			
15	**Mean**	**33**	**35**	**33**	**48**	**46**	**50**
		36	38	35			
	STD	±4	±4	±4			
		30	28	24			
16	**Mean**	**33**	**32**	**29**	**50**	**50**	**55**
		36	36	34			
	STD	±4	±6	±7			
		26	28	27			
17	**Mean**	**31**	**31**	**30**	**52**	**53**	**54**
		36	34	33			
	STD	±7	±4	±4			
		28	26	24			
18	**Mean**	**32**	**30**	**29**	**51**	**54**	**55**
		36	34	34			
	STD	±6	±6	±7			
		27	26	25			
19	**Mean**	**31**	**31**	**29**	**53**	**53**	**56**
		35	36	33			
	STD	±6	±7	±6			
		25	24	25			
20	**Mean**	**30**	**29**	**28**	**53**	**55**	**57**
		35	34	31			
	STD	±7	±7	±4			
		24	22	20			
21	**Mean**	**29**	**29**	**25**	**55**	**56**	**61**
		34	32	30			
	STD	±7	±7	±7			
		26	24	20			
22	**Mean**	**30**	**28**	**25**	**54**	**56**	**62**
		34	32	30			
	STD	±6	±6	±7			
		26	24	22			
23	**Mean**	**30**	**29**	**27**	**53**	**56**	**58**
		34	34	32			
	STD	±6	±7	±7			

APPENDIX C6: EFFLUENT TP CONCENTRATION AND PERCENTAGE REMOVAL

		Effluent TP (mg/L)			Percentage TP Removal (%)		
Day		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
		203	183	198			
14	**Mean**	**211**	**192**	**204**	**19**	**26**	**22**
		217	197	210			
	STD	±10	±10	±8			
		201	200	203			
15	**Mean**	**208**	**208**	**210**	**20**	**20**	**20**
		215	216	217			
	STD	±10	±11	±10			
		184	177	182			
16	**Mean**	**191**	**185**	**189**	**27**	**29**	**28**
		198	193	196			
	STD	±10	±11	±10			
		172	179	183			
17	**Mean**	**179**	**186**	**190**	**31**	**29**	**27**
		186	193	197			
	STD	±10	±10	±10			
		173	172	174			
18	**Mean**	**180**	**178**	**180**	**31**	**32**	**31**
		187	184	186			
	STD	±10	±8	±8			
		164	152	160			
19	**Mean**	**170**	**160**	**165**	**35**	**39**	**37**
		176	168	170			
	STD	±8	±11	±7			
		156	136	142			
20	**Mean**	**164**	**144**	**148**	**37**	**45**	**43**
		172	152	154			
	STD	±11	±11	±8			
		162	132	148			
21	**Mean**	**168**	**139**	**154**	**36**	**47**	**41**
		174	146	160			
	STD	±8	±10	±8			
		132	136	137			
22	**Mean**	**139**	**142**	**141**	**47**	**46**	**46**
		146	148	145			
	STD	±10	±8	±6			
		137	126	125			
23	**Mean**	**141**	**132**	**132**	**46**	**50**	**49**
		145	138	139			
	STD	±6	±8	±10			

APPENDIX C7: EFFLUENT pH AND TOTAL ALKALINITY

		Effluent pH			Effluent Total Alkalinity as $CaCO_3$ ((mg/L)		
Day		SBR1	SBR2	SBR3	SBR1	SBR2	SBR3
		7.34	7.29	7.38	1392	1563	1564
14	**Mean**	**7.38**	**7.35**	**7.43**	**1400**	**1570**	**1570**
		7.42	7.41	7.48	1408	1577	1576
	STD	±0.06	±0.08	±0.07	±11	±10	±8
		7.53	7.47	7.51	1613	1592	1703
15	**Mean**	**7.61**	**7.55**	**7.58**	**1620**	**1600**	**1710**
		7.69	7.63	7.65	1627	1608	1717
	STD	±0.11	±0.11	±0.10	±10	±11	±10
		7.57	7.48	7.49	1533	1572	1613
16	**Mean**	**7.62**	**7.54**	**7.56**	**1540**	**1580**	**1620**
		7.67	7.60	7.63	1547	1588	1627
	STD	±0.07	±0.08	±0.10	±10	±11	±10
		7.72	7.53	7.57	1652	1633	1592
17	**Mean**	**7.79**	**7.60**	**7.62**	**1660**	**1640**	**1600**
		7.86	7.67	7.67	1668	1647	1608
	STD	±0.10	±0.10	±0.07	±11	±10	±11
		7.62	7.79	7.54	1693	1503	1422
18	**Mean**	**7.69**	**7.85**	**7.61**	**1700**	**1510**	**1430**
		7.76	7.91	7.68	1707	1517	1438
	STD	±0.10	±0.08	±0.10	±10	±10	±11
		7.55	7.56	7.41	1602	1543	1412
19	**Mean**	**7.62**	**7.61**	**7.49**	**1610**	**1550**	**1420**
		7.69	7.66	7.57	1618	1557	1428
	STD	±0.10	±0.07	±0.11	±11	±10	±11
		7.60	7.58	7.51	1553	1492	1473
20	**Mean**	**7.68**	**7.64**	**7.58**	**1560**	**1500**	**1480**
		7.76	7.70	7.65	1567	1508	1487
	STD	±0.11	±0.08	±0.10	±10	±11	±10
		7.62	7.59	7.48	1492	1483	1392
21	**Mean**	**7.68**	**7.66**	**7.55**	**1500**	**1490**	**1400**
		7.74	7.73	7.62	1508	1497	1408
	STD	±0.08	±0.10	±0.10	±11	±10	±11
		7.91	7.51	7.62	1444	1393	1283
22	**Mean**	**7.98**	**7.58**	**7.69**	**1450**	**1400**	**1290**
		8.05	7.65	7.76	1456	1407	1297
	STD	±0.10	±0.10	±0.10	±8	±10	±10
		7.79	7.66	7.82	1752	1573	1772
23	**Mean**	**7.84**	**7.73**	**7.89**	**1760**	**1580**	**1780**
		7.89	7.80	7.96	1768	1587	1788
	STD	±0.07	±0.10	±0.10	±11	±10	±11

APPENDIX D1: MONITORING DATA DURING SBR TREATMENT PROCESS

Time			pH			ORP (mV)			DO (mg/L)			Temp. (^{o} C)			
(Hrs)	(min)	(Hrs)	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	
11.15	0	0.00	7.64	7.59	7.75	-239	-237	-254	1.03	0.80	0.94	15.5	15.6	16.5	
11.45	30	0.50	7.70	7.58	7.75	-245	-233	-233	0.65	0.53	0.69	15.8	15.9	16.7	
12.15	60	1.00	7.61	7.55	7.51	-255	-246	-252	0.63	0.53	0.65	16.4	16.7	16.9	
12.45	90	1.50	7.66	7.58	7.51	-257	-254	-275	0.54	0.56	0.52	16.6	16.6	17.1	
13.15	120	2.00	7.61	7.55	7.49	-252	-246	-268	0.58	0.50	0.55	16.9	16.7	17.2	Day1
13.30	135	2.25	7.67	7.63	7.56	-242	-229	-264	0.46	0.48	0.46	17.1	17.0	17.8	
13.45	150	2.50	7.74	7.73	7.65	-232	-209	-239	0.41	0.37	0.40	17.3	17.2	17.7	
14.30	195	3.25	7.91	7.94	7.91	-169	-175	-178	0.51	0.49	0.67	17.8	17.6	18.1	
15.00	225	3.75	8.01	8.04	8.00	-160	-159	-172	0.46	0.50	0.54	18.0	17.8	18.1	
15.30	255	4.25	8.08	8.09	8.08	-164	-166	-175	0.49	0.47	0.58	18.3	18.0	18.4	
16.00	285	4.75	8.10	8.16	8.10	-173	-171	-177	0.45	0.45	0.51	18.4	18.2	18.4	
16.30	315	5.25	8.12	8.14	8.11	-172	-175	-176	0.47	0.48	0.49	18.2	18.3	18.1	
16.45	330	5.50	8.07	8.10	8.11	-176	-177	-175	0.51	0.45	0.48	18.2	18.3	18.4	
11.15	0	0.00	7.90	7.51	7.61	-292	-270	-263	0.37	0.54	0.46	18.5	18.1	18.8	
11.45	30	0.50	7.45	7.43	7.43	-278	-273	-272	1.29	0.79	0.77	18.4	18.1	18.3	
12.15	60	1.00	7.42	7.39	7.35	-287	-279	-291	1.05	0.60	0.60	18.4	18.1	18.1	
12.45	90	1.50	7.43	7.43	7.35	-288	-289	-304	1.25	0.90	0.59	18.5	18.2	18.2	
13.15	120	2.00	7.45	7.44	7.37	-281	-271	-267	1.02	0.55	0.43	18.8	18.4	18.5	Day2

Time			pH			ORP (mV)			DO (mg/L)			Temp. (^{o} C)			
(Hrs)	(min)	(Hrs)	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	
13.30	135	2.25	7.54	7.55	7.49	-277	-268	-264	0.52	0.46	0.50	18.8	18.4	18.3	Day2
13.45	150	2.50	7.62	7.65	7.60	-263	-261	-247	0.39	0.49	0.37	18.9	18.6	18.5	
14.30	195	3.25	7.82	7.88	7.87	-230	-226	-183	0.39	0.43	0.35	19.2	18.8	18.8	
15.00	225	3.75	7.98	8.03	7.99	-183	-187	-162	0.78	0.56	0.64	18.4	18.5	18.9	
15.30	255	4.25	7.99	8.02	8.04	-182	-186	-171	0.58	0.59	0.62	18.9	19.1	19.2	
16.00	285	4.75	8.09	8.14	8.10	-221	-183	-169	0.81	0.76	0.78	19.2	19.1	19.2	
16.30	315	5.25	8.13	8.19	8.18	-161	-190	-183	0.63	0.63	0.69	19.6	19.4	19.2	
16.45	330	5.50	8.22	8.22	8.22	-152	-192	-175	0.47	0.43	0.47	19.8	19.5	19.5	
11.15	0	0.00	7.67	7.62	7.61	-280	-248	-237	1.11	0.76	0.44	17.7	17.3	17.4	
11.45	30	0.50	7.75	7.62	7.61	-276	-262	-261	1.16	0.95	0.90	17.7	17.3	17.2	
12.15	60	1.00	7.63	7.61	7.55	-274	-257	-236	1.08	1.09	1.27	17.9	17.5	17.2	
12.45	90	1.50	7.63	7.63	7.61	-279	-262	-242	1.16	1.24	0.67	18.0	17.6	17.4	
13.15	120	2.00	7.63	7.62	7.55	-271	-261	-254	0.89	1.03	0.54	18.2	17.8	17.6	Day 3
13.30	135	2.25	7.68	7.68	7.62	-272	-246	-241	0.77	0.68	0.47	18.3	17.9	17.7	
13.45	150	2.50	7.74	7.74	7.68	-262	-258	-235	0.53	0.45	0.46	18.4	18.0	17.8	
14.30	195	3.25	7.84	7.87	7.82	-245	-218	-174	0.48	0.38	0.52	18.6	18.3	18.1	
15.00	225	3.75	7.95	7.96	7.96	-200	-199	-149	0.46	0.43	0.42	18.7	18.4	18.3	
15.30	255	4.25	8.06	8.07	8.05	-174	-186	-156	0.88	0.52	0.48	18.9	18.5	18.5	
16.00	285	4.75	8.08	8.1	8.07	-182	-183	-165	0.43	0.41	0.48	18.9	18.6	18.5	

Time			pH			ORP (mV)			DO (mg/L)			Temp. (^{o} C)			
(Hrs)	(min)	(Hrs)	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	
16.30	315	5.25	8.14	8.16	8.13	-177	-199	-163	0.55	0.49	0.61	19.7	18.7	18.6	Day3
16.45	330	5.50	8.17	8.17	8.13	-171	-192	-170	0.42	0.43	0.45	19.1	18.8	18.7	
11.15	0	0.00	7.60	7.49	7.59	-293	-262	-252	1.08	1.29	0.89	17.9	17.7	18.0	
11.45	30	0.50	7.58	7.48	7.46	-279	-268	-266	0.76	0.60	0.61	18.0	17.6	17.6	
12.15	60	1.00	7.60	7.49	7.45	-272	-262	-264	1.03	0.82	1.09	18.2	17.8	17.6	
12.45	90	1.50	7.60	7.51	7.45	-276	-270	-276	0.93	1.10	1.28	18.3	17.9	17.8	
13.15	120	2.00	7.63	7.56	7.49	-271	-260	-254	0.84	0.94	1.37	18.6	18.2	18.0	
13.30	135	2.25	7.70	7.67	7.58	-266	-258	-251	0.78	0.88	0.96	18.6	18.3	18.1	
13.45	150	2.50	7.77	7.78	7.67	-251	-241	-231	0.62	0.71	0.94	18.6	18.4	18.2	
14.30	195	3.25	7.94	7.95	7.88	-211	-201	-142	0.68	0.80	1.22	19.0	18.6	18.5	Day 4
15.00	225	3.75	8.00	8.02	7.95	-183	-188	-140	0.57	0.58	1.06	19.1	19.0	18.6	
15.30	255	4.25	8.06	8.11	8.03	-171	-162	-148	0.70	0.81	1.00	19.1	18.8	18.8	
16.00	285	4.75	8.12	8.19	8.08	-168	-149	-161	0.73	0.89	1.17	19.2	18.9	18.9	
16.30	315	5.25	8.18	8.26	8.14	-174	-173	-168	0.71	0.85	1.17	19.3	19.0	19.0	
16.45	330	5.50	8.21	8.30	8.17	-169	-173	-167	0.66	0.67	1.00	19.4	19.1	19.1	
17.15	360	6.00	8.27	8.32	8.21	-156	-168	-151	0.63	0.74	0.93	19.3	19.2	19.2	
17.45	390	6.50	8.32	8.35	8.26	-155	-173	-143	0.65	0.68	0.82	19.6	19.3	19.3	
11.15	0	0.00	7.73	7.61	8.00	-281	-268	-259	1.40	1.50	1.34	17.7	17.4	17.5	Day5

Time			pH			ORP (mV)			DO (mg/L)			Temp. (^{o} C)			
(Hrs)	(min)	(Hrs)	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	
11.45	30	0.50	7.73	7.58	7.62	-283	-267	-249	1.06	1.70	2.24	17.9	17.5	17.3	
12.15	60	1.00	7.68	7.57	7.56	-283	-272	-261	0.90	1.13	1.33	18.1	17.7	17.5	
12.45	90	1.50	7.64	7.56	7.55	-282	-268	-257	1.16	1.54	2.07	18.3	17.9	17.7	
13.15	120	2.00	7.74	7.64	7.58	-274	-263	-253	1.25	1.16	1.49	18.4	18.0	17.7	
13.30	135	2.25	7.81	7.73	7.67	-275	-253	-256	0.80	0.94	1.25	18.5	18.1	17.9	Day 5
13.45	150	2.50	7.85	7.82	7.75	-252	-256	-255	0.82	0.88	1.21	18.6	18.2	17.9	
14.30	195	3.25	7.95	7.94	7.88	-229	-222	-158	0.62	0.90	1.26	18.9	18.5	18.2	
15.00	225	3.75	8.06	8.05	8.00	-170	-185	-145	0.69	0.92	1.53	19.1	18.7	18.4	
15.30	255	4.25	8.13	8.13	8.08	-153	-167	-143	0.64	0.75	1.09	19.1	18.8	18.6	
16.00	285	4.75	8.18	8.21	8.14	-161	-172	-161	0.60	0.70	1.05	19.3	18.9	18.7	
16.30	315	5.25	8.21	8.25	8.18	-169	-177	-160	0.63	0.78	1.01	19.4	19.0	18.8	
16.45	330	5.50	8.25	8.27	8.19	-162	-170	-158	0.58	0.68	1.28	19.5	19.1	19.1	
11.15	0	0.00	7.59	7.57	7.6	-272	-253	-247	1.13	1.15	1.35	17.9	17.5	17.6	
11.30	15	0.25	7.60	7.52	7.41	-272	-261	-256	1.19	1.18	1.64	18.0	17.5	17.3	
11.45	30	0.50	7.61	7.50	7.48	-271	-263	-256	0.89	0.99	1.40	18.1	17.6	17.4	
12.15	60	1.00	7.60	7.49	7.41	-278	-268	-259	1.09	1.18	1.71	18.3	17.8	17.7	
12.45	90	1.50	7.62	7.48	7.43	-274	-267	-257	1.28	1.38	1.73	18.4	17.9	17.6	
13.15	120	2.00	7.65	7.56	7.45	-272	-259	-252	0.91	1.07	1.45	18.6	18.1	17.7	
13.30	135	2.25	7.71	7.66	7.53	-261	-258	-248	0.85	0.85	1.19	18.8	18.2	17.9	Day 6

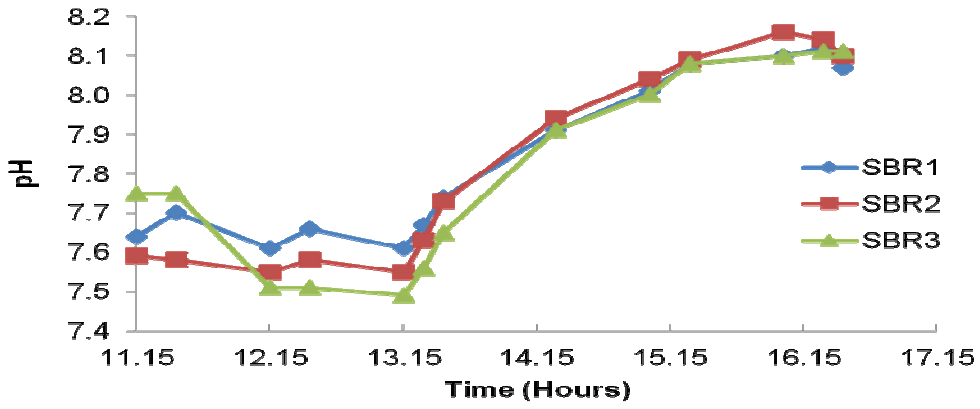
Time			pH			ORP (mV)			DO (mg/L)			Temp. (^{o} C)			
(Hrs)	(min)	(Hrs)	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	
13.45	150	2.50	7.76	7.74	7.60	-260	-251	-236	0.75	0.99	1.59	18.8	18.4	18.1	Day6
14.30	195	3.25	7.90	7.89	7.75	-223	-211	-196	0.75	0.82	1.21	19.0	18.5	18.3	
15.00	225	3.75	8.00	7.99	7.86	-181	-193	-140	0.71	0.84	1.13	19.1	18.7	18.5	
15.30	255	4.25	8.09	8.10	7.98	-161	-168	-145	0.68	0.77	1.19	19.2	18.9	18.7	
16.00	285	4.75	8.16	8.17	8.04	-155	-160	-147	0.55	0.65	0.96	19.3	19.0	18.8	
16.30	315	5.25	8.22	8.23	8.10	-151	-161	-150	0.53	0.62	0.91	19.2	19.0	18.9	
16.45	330	5.50	8.26	8.27	8.12	-154	-167	-156	0.57	0.66	0.95	19.5	19.1	19.0	
11.15	0	0.00	7.81	7.56	7.53	-273	-252	-240	1.07	0.90	1.01	18.2	17.7	18.1	
11.45	30	0.50	7.70	7.55	7.50	-278	-264	-251	0.93	0.98	1.91	18.4	17.8	17.7	
12.15	60	1.00	7.72	7.58	7.54	-276	-261	-247	1.21	1.33	2.23	18.6	18.1	17.9	
12.45	90	1.50	7.71	7.59	7.50	-278	-274	-259	1.18	1.70	2.32	18.7	18.2	18.1	
13.15	120	2.00	7.71	7.58	7.49	-275	-279	-261	0.87	1.11	1.55	19.0	18.3	18.2	Day 7
13.30	135	2.25	7.77	7.70	7.60	-259	-247	-245	0.85	1.09	1.44	19.0	18.5	18.3	
13.45	150	2.50	7.83	7.78	7.67	-265	-261	-255	1.04	1.26	1.98	19.1	18.6	18.5	
14.30	195	3.25	7.97	7.97	7.86	-224	-215	-189	1.03	1.01	1.29	19.2	18.8	18.7	
15.00	225	3.75	8.06	8.07	7.95	-191	-198	-157	0.83	0.98	1.56	19.4	18.9	18.8	
15.30	255	4.25	8.10	8.13	8.02	-156	-171	-146	0.62	0.66	0.94	19.5	19.1	19.0	
16.00	285	4.75	8.17	8.20	8.08	-158	-146	-154	0.57	0.79	1.30	19.7	19.3	19.2	
16.30	315	5.25	8.23	8.25	8.11	-158	-174	-173	0.58	0.69	0.90	19.7	19.3	19.2	

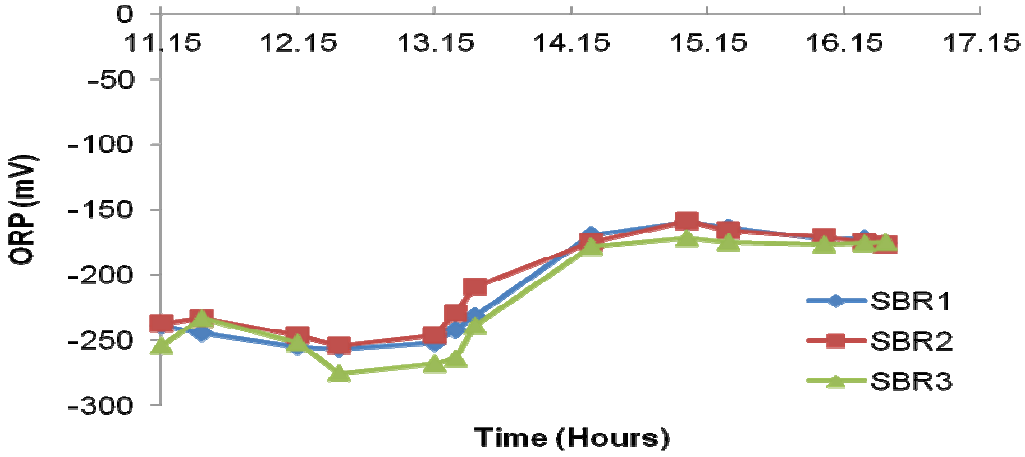
Time			pH			ORP (mV)			DO (mg/L)			Temp. (^{o} C)			
(Hrs)	(min)	(Hrs)	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	
11.15	0	0.00	7.64	7.48	7.54	-280	-260	-267	1.06	1.26	1.87	18.8	18.7	19.1	
11.45	30	0.50	7.60	7.47	7.46	-279	-267	-267	1.09	1.03	2.59	18.9	18.6	18.5	
12.15	60	1.00	7.65	7.52	7.48	-281	-271	-266	1.30	1.43	1.89	19.1	18.7	18.7	
12.45	90	1.50	7.63	7.52	7.46	-283	-275	-273	1.27	1.46	1.74	19.2	18.9	18.8	Day 8
13.15	120	2.00	7.68	7.57	7.50	-273	-264	-253	0.94	1.01	1.30	19.3	19.1	19.1	
13.30	135	2.25	7.73	7.66	7.57	-266	-257	-248	0.93	1.07	1.40	19.4	19.1	19.1	
13.45	150	2.50	7.81	7.78	7.67	-253	-250	-241	0.85	0.95	1.20	19.5	19.2	19.2	
14.30	195	3.25	7.93	7.92	7.80	-234	-233	-210	0.73	0.81	1.01	19.5	19.4	19.3	
15.00	225	3.75	8.02	8.02	7.92	-190	-208	-192	0.8	1.02	1.54	19.7	19.4	19.4	
15.30	255	4.25	8.10	8.10	7.99	-168	-187	-163	0.69	0.80	1.12	19.9	19.6	19.5	
16.00	285	4.75	8.17	8.16	8.07	-158	-174	-153	0.44	0.51	1.04	19.9	19.7	19.6	
16.30	315	5.25	8.29	8.26	8.22	-154	-171	-132	0.68	0.67	1.01	20.0	19.8	19.7	
11.15	0	0.00	7.78	7.65	7.79	-259	-249	-249	1.08	1.06	1.09	18.2	18.1	18.5	
11.45	30	0.50	7.78	7.65	7.65	-268	-257	-249	0.89	1.04	1.36	18.4	18.2	18.2	
12.15	60	1.00	7.66	7.58	7.60	-262	-248	-253	1.02	1.06	1.53	18.6	18.5	18.5	
12.45	90	1.50	7.67	7.59	7.58	-269	-264	-262	1.30	1.23	1.78	18.8	18.5	18.5	
13.15	120	2.00	7.69	7.61	7.57	-264	-259	-245	0.93	0.98	1.40	19.1	18.7	18.7	Day 9
13.30	135	2.25	7.76	7.71	7.65	-263	-258	-251	0.96	1.06	1.20	19.1	18.9	18.8	

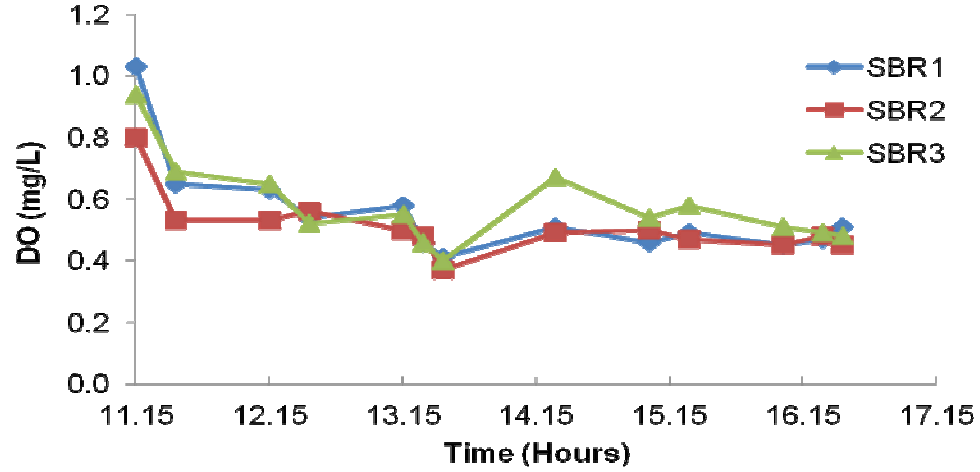
Time			pH			ORP (mV)			DO (mg/L)			Temp. (^{o} C)			
(Hrs)	(min)	(Hrs)	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	SBR1	SBR2	SBR3	
13.45	150	2.50	7.82	7.77	7.71	-252	-247	-241	0.94	1.09	1.53	19.2	19.0	18.9	Day9
14.30	195	3.25	7.92	7.91	7.84	-220	-227	-206	0.75	0.87	1.17	19.4	19.1	19.2	
15.00	225	3.75	8.07	8.08	8.00	-162	-190	-168	0.96	0.91	1.44	19.6	19.3	19.3	
15.30	255	4.25	8.11	8.13	8.04	-166	-173	-177	0.66	0.83	1.31	19.7	19.5	19.5	
16.00	285	4.75	8.16	8.17	8.10	-162	-176	-162	0.72	0.82	1.48	19.8	19.6	19.6	
16.30	315	5.25	8.22	8.23	8.16	-164	-177	-151	0.68	0.78	1.02	20.0	19.8	19.7	
11.15	0	0.00	7.68	7.54	7.58	-263	-251	-240	0.97	0.81	1.15	18.7	18.6	18.8	
11.45	30	0.50	7.61	7.54	7.53	-272	-266	-262	1.01	0.95	1.76	18.9	18.6	18.4	
12.15	60	1.00	7.63	7.54	7.54	-276	-282	-256	1.34	1.58	2.42	19.1	18.9	18.6	
12.45	90	1.50	7.58	7.55	7.48	-273	-256	-246	2.24	2.11	2.37	19.3	19.1	19.1	Day10
13.15	120	2.00	7.64	7.60	7.54	-265	-257	-252	1.45	1.48	1.44	19.5	19.3	19.2	
13.30	135	2.25	7.72	7.72	7.64	-264	-245	-241	0.54	0.54	0.54	19.7	19.5	19.2	
13.45	150	2.50	7.80	7.82	7.73	-246	-240	-251	0.73	0.67	0.61	19.7	19.4	19.4	
14.30	195	3.25	7.91	7.93	7.83	-224	-221	-213	0.87	0.91	1.36	19.6	19.5	19.4	
15.00	225	3.75	8.03	8.08	7.98	-168	-188	-189	0.83	0.85	1.38	20.0	19.7	19.6	
15.30	255	4.25	8.09	8.14	8.03	-167	-192	-187	0.66	0.79	1.05	20.1	19.8	19.6	
16.00	285	4.75	8.18	8.21	8.09	-161	-174	-171	0.86	0.99	1.55	20.2	19.9	19.8	
16.30	315	5.25	8.22	8.24	8.14	-167	-181	-158	0.78	0.84	1.15	20.2	20.0	19.8	

APPENDIX D2: GRAPHICAL REPRESENTATION OF THE MONITORING DATA

DAY 14







GRAPHICAL REPRESENTATION OF THE MONITORING DATA

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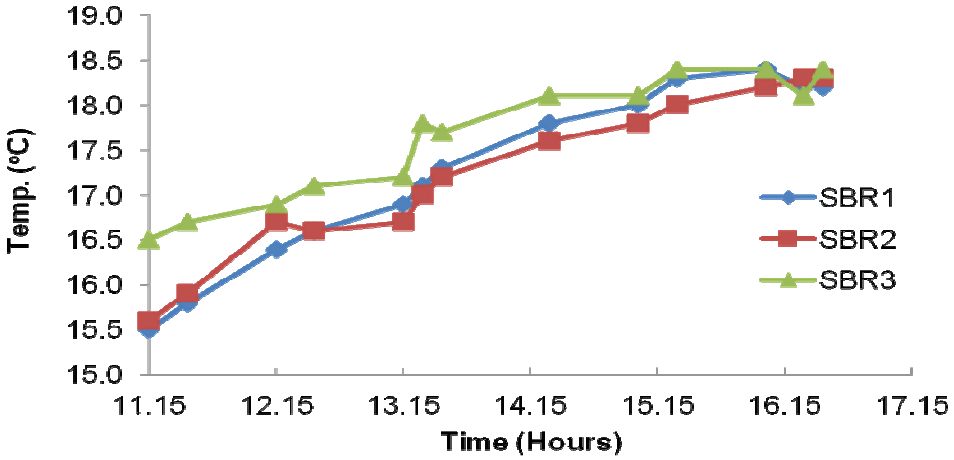

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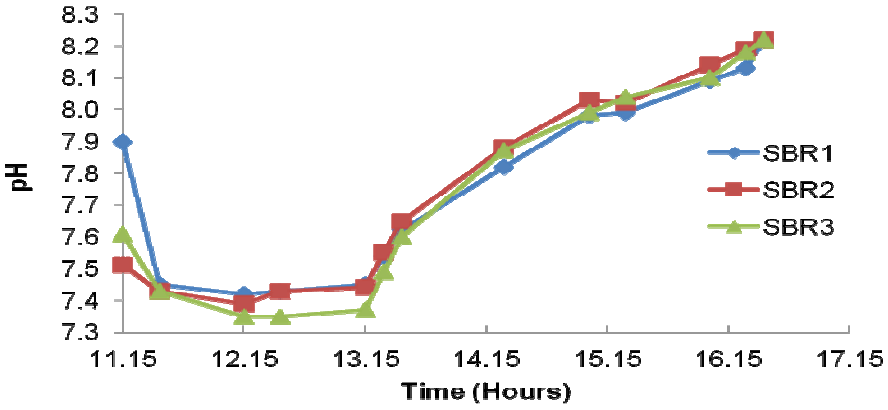

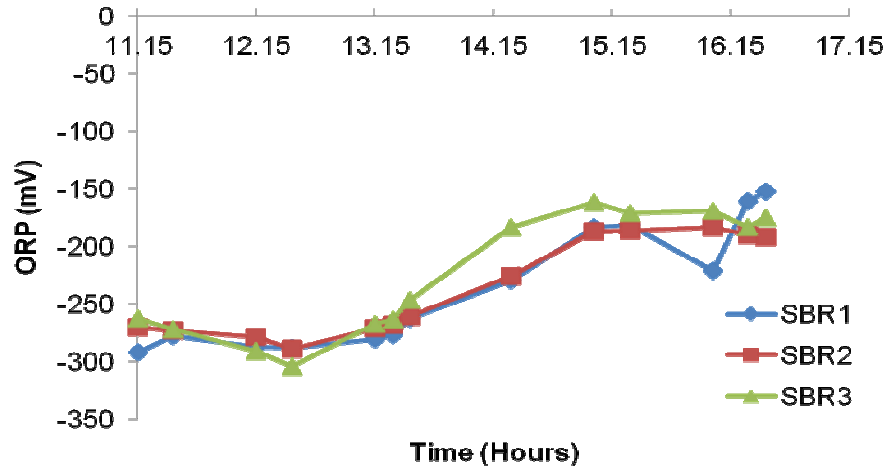

GRAPHICAL REPRESENTATION OF THE MONITORING DATA

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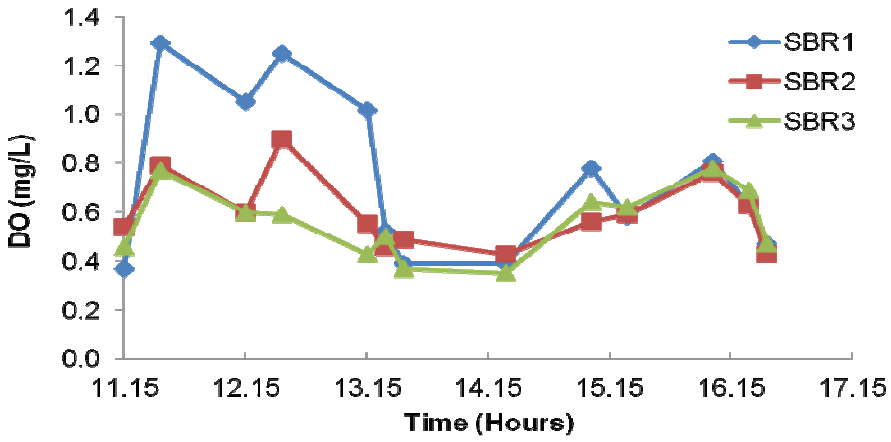

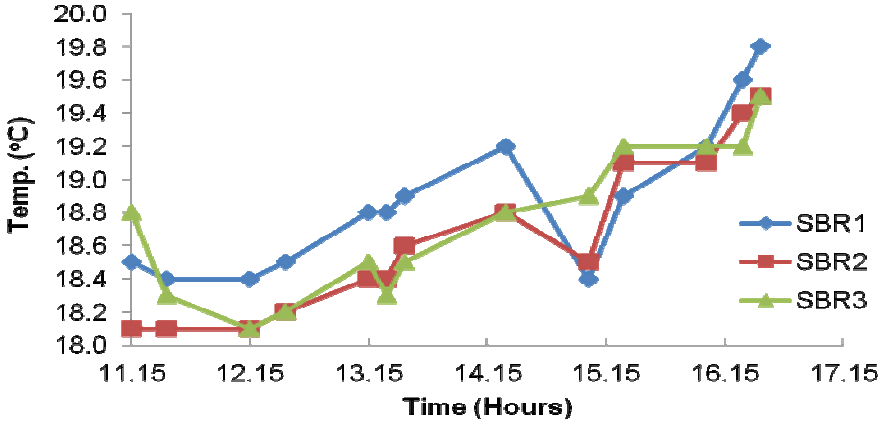

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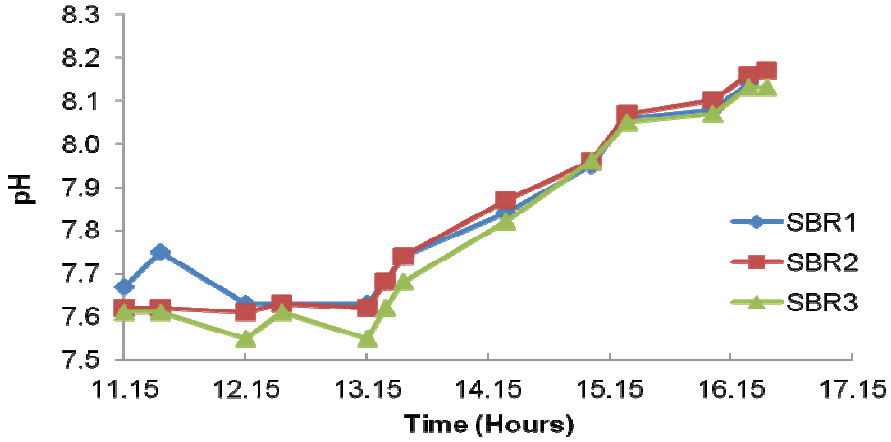

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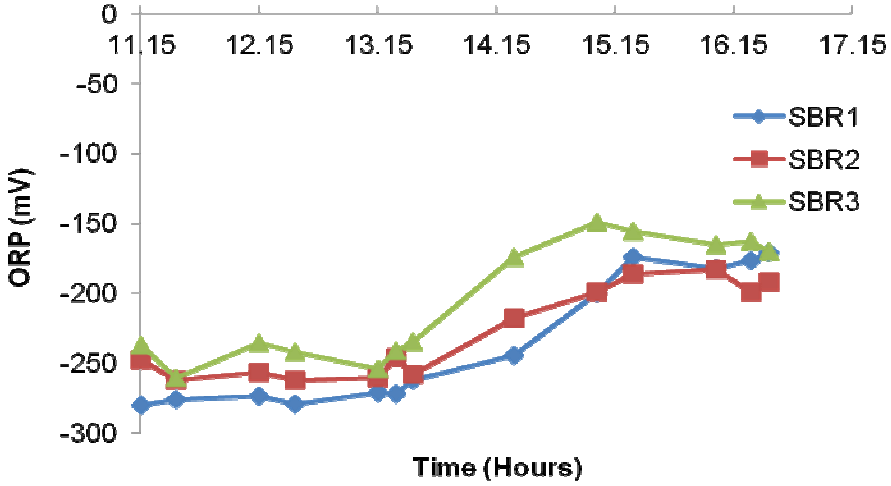

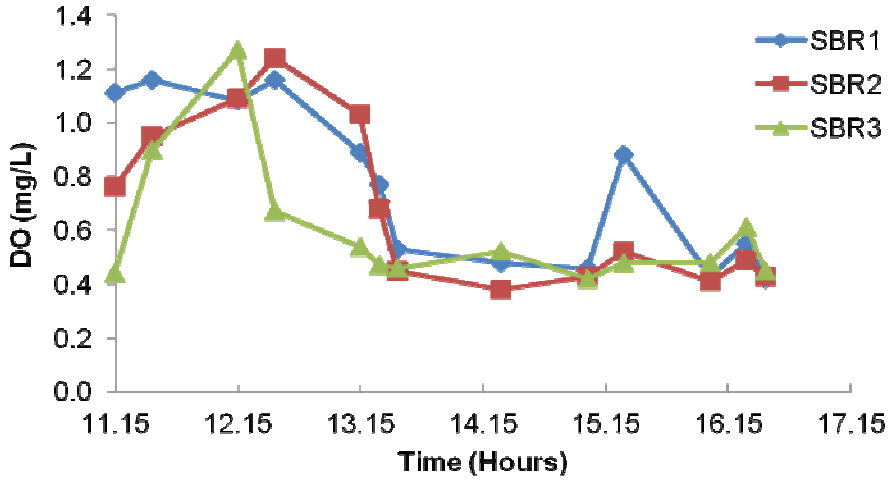

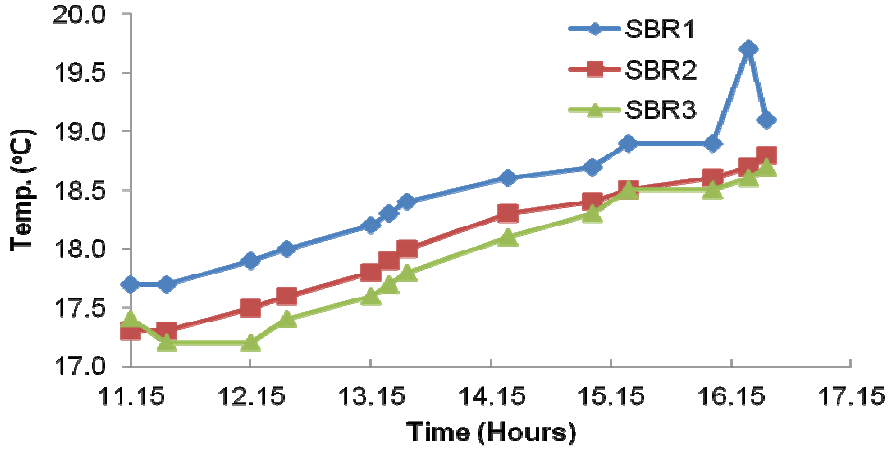

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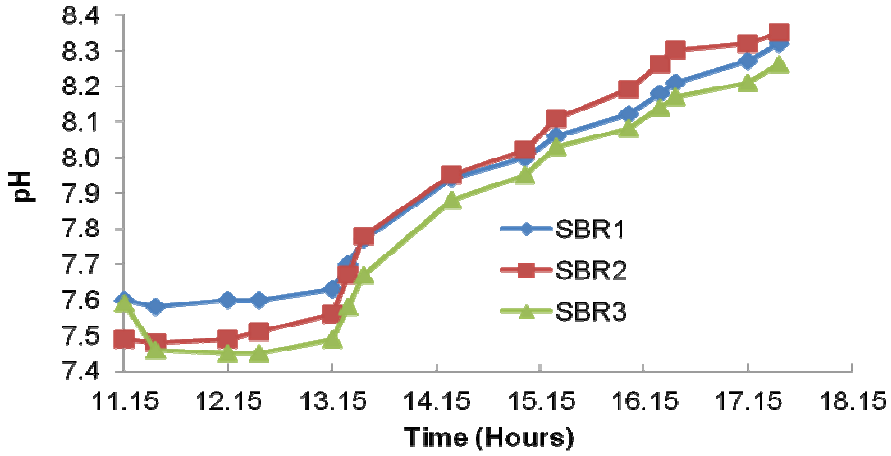

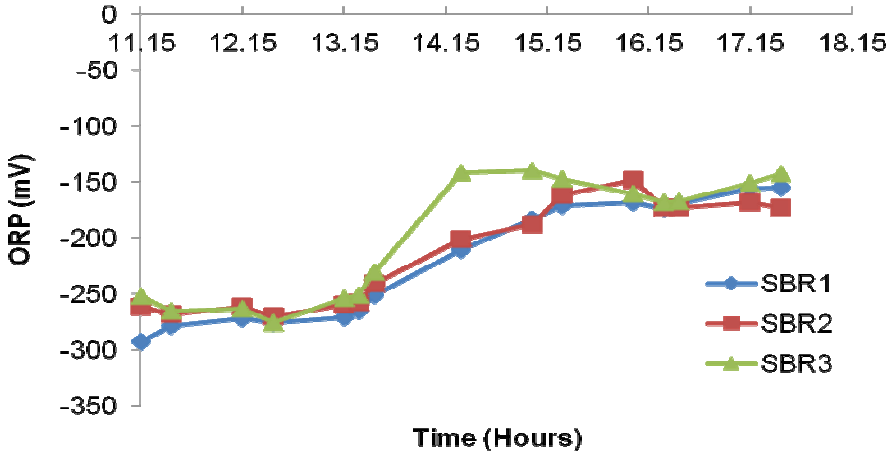

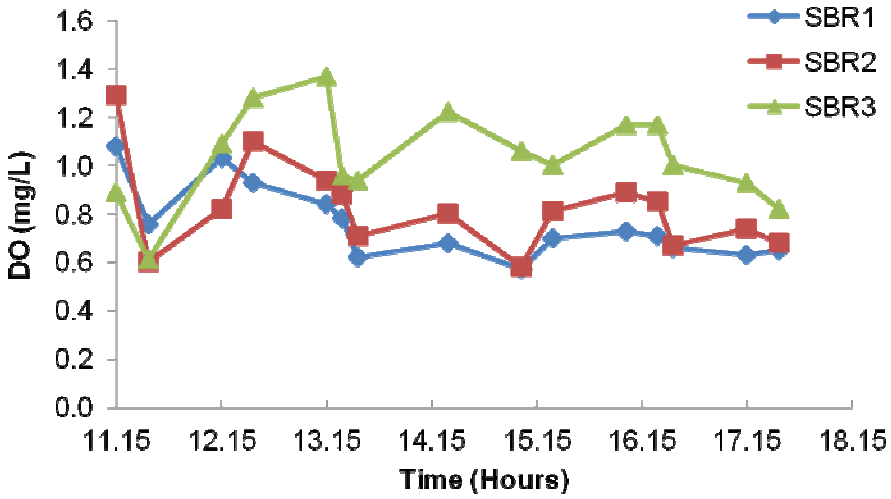

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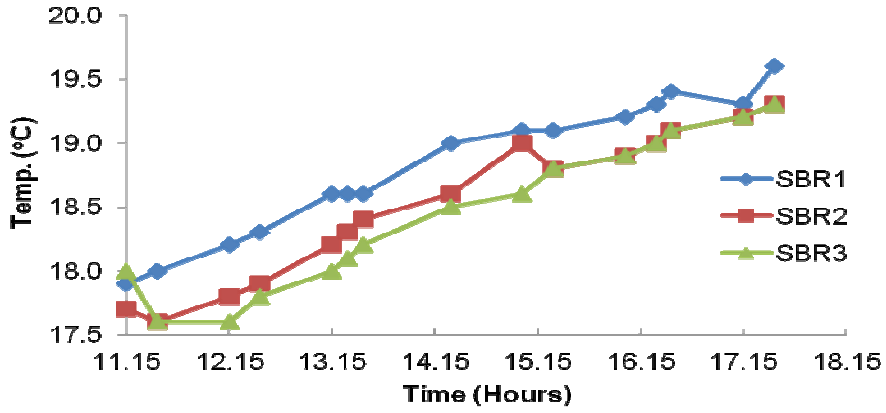
DAY 17



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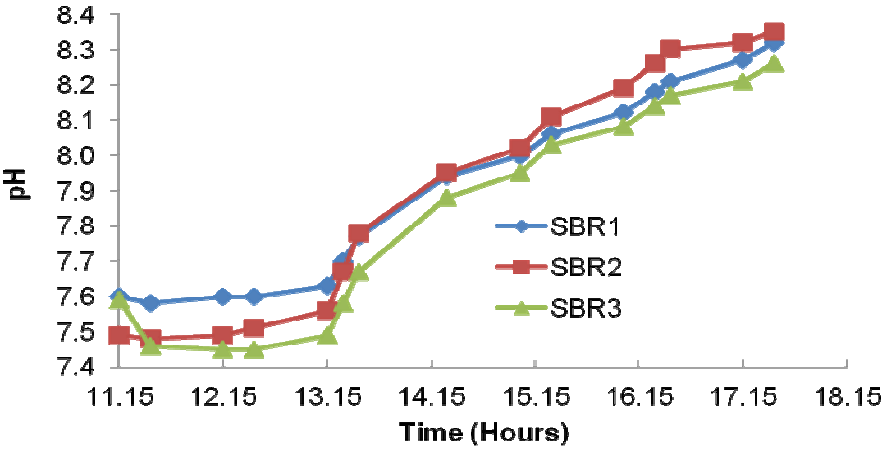

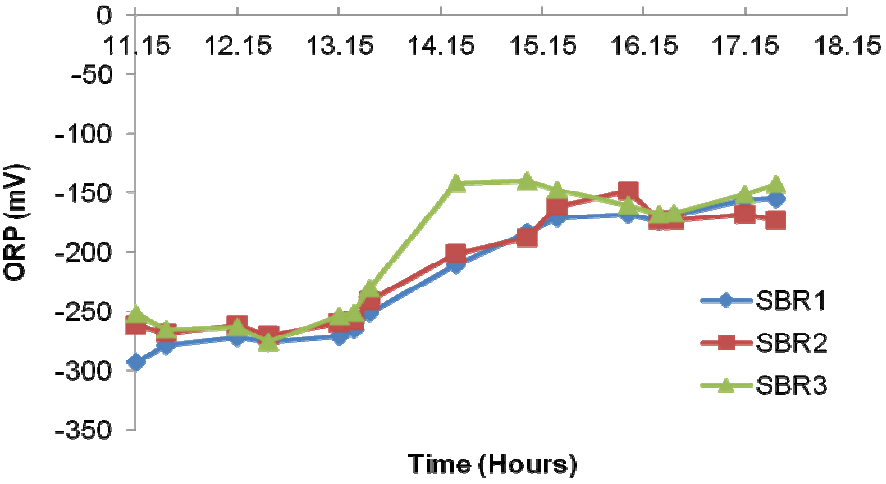

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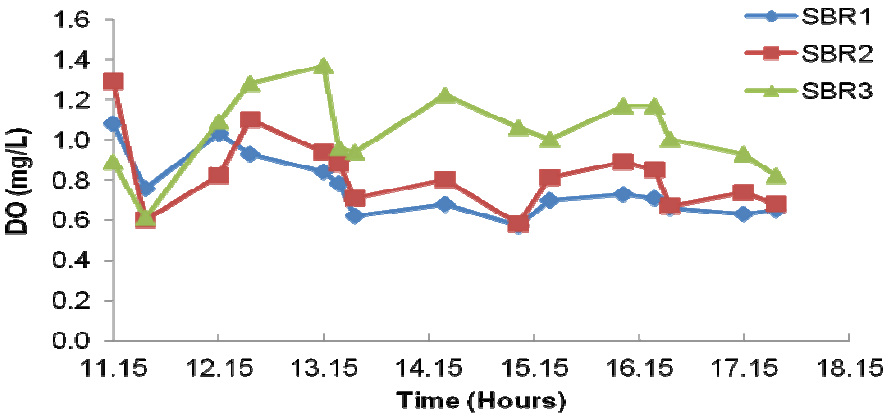

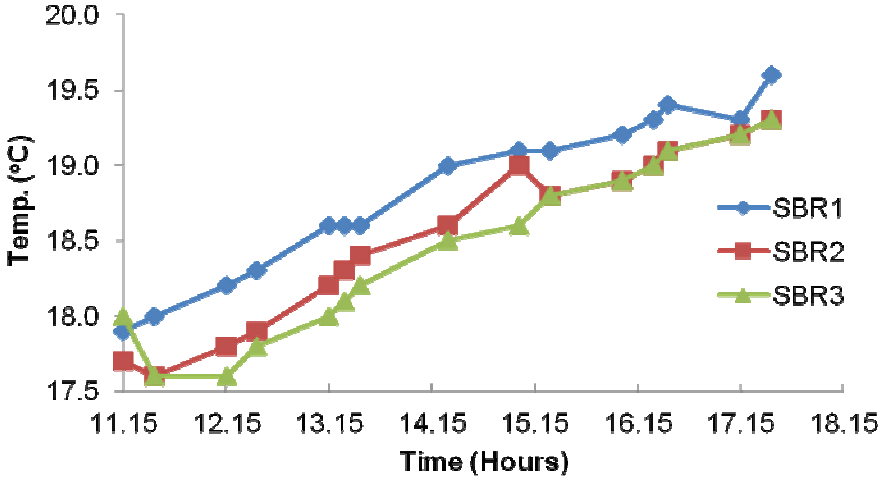

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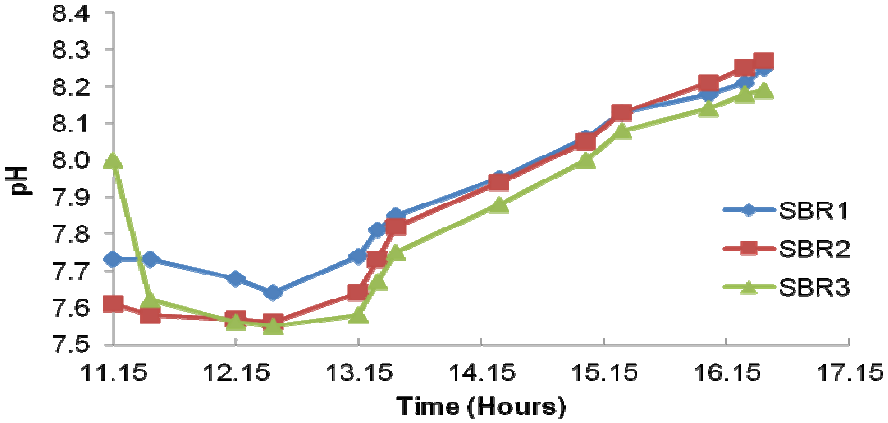

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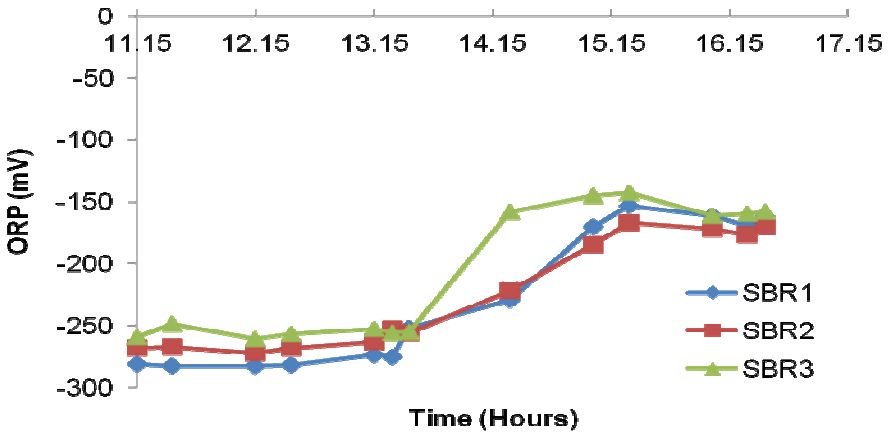

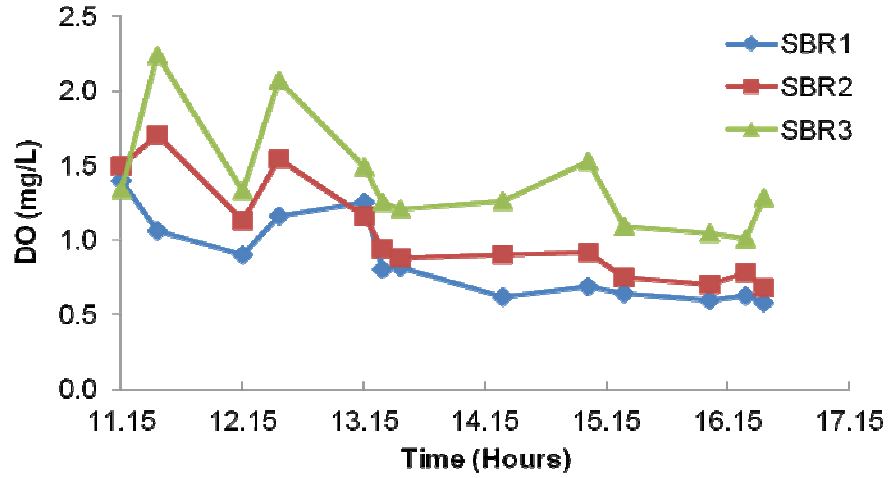

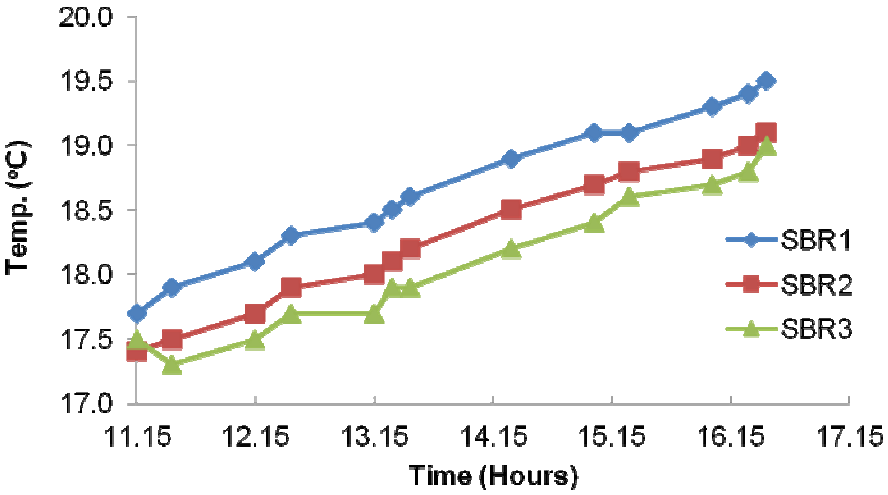

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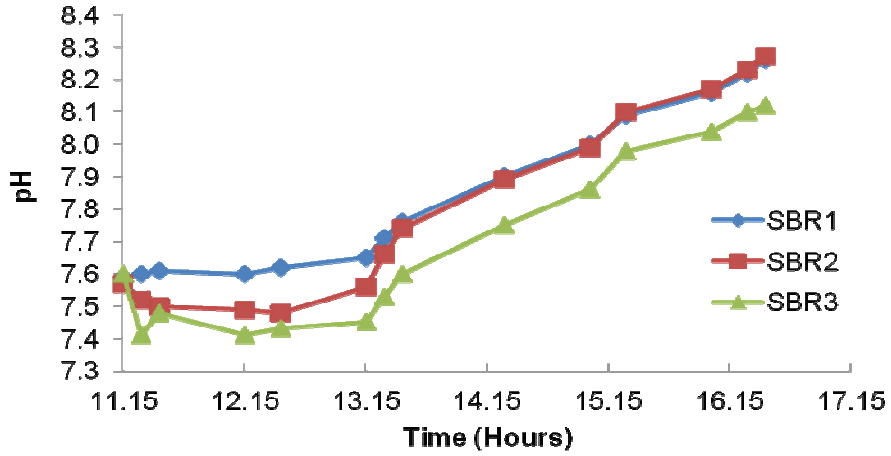
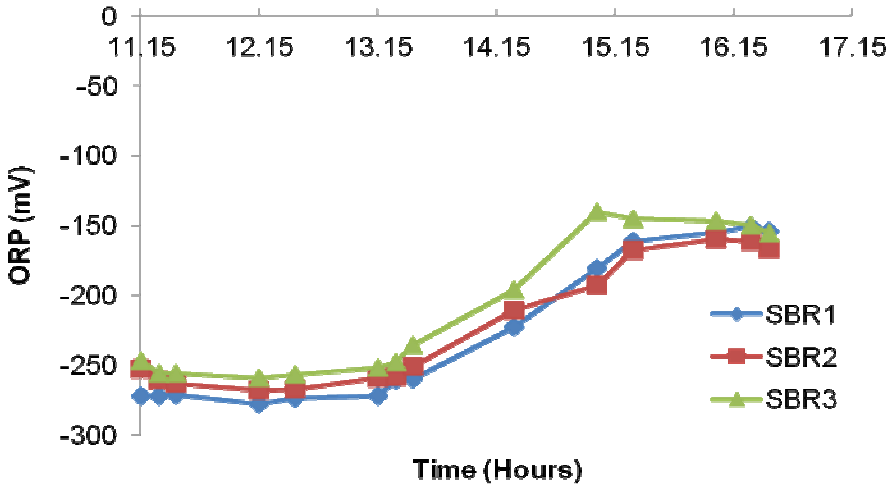
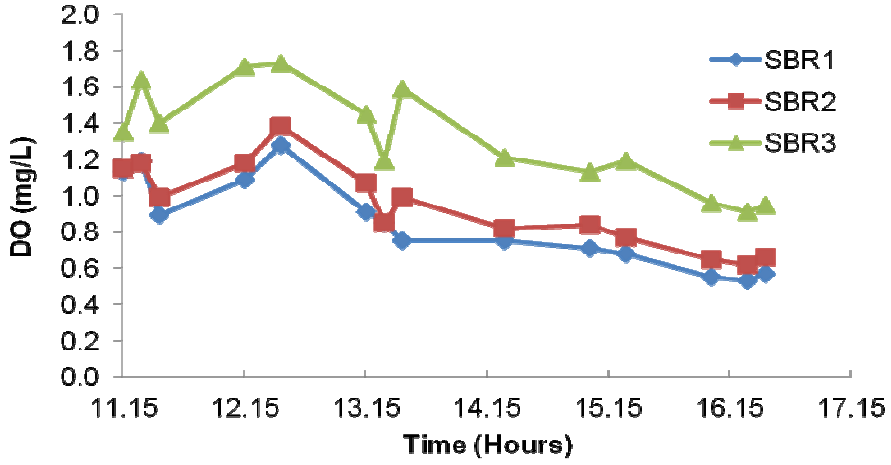
DAY 20







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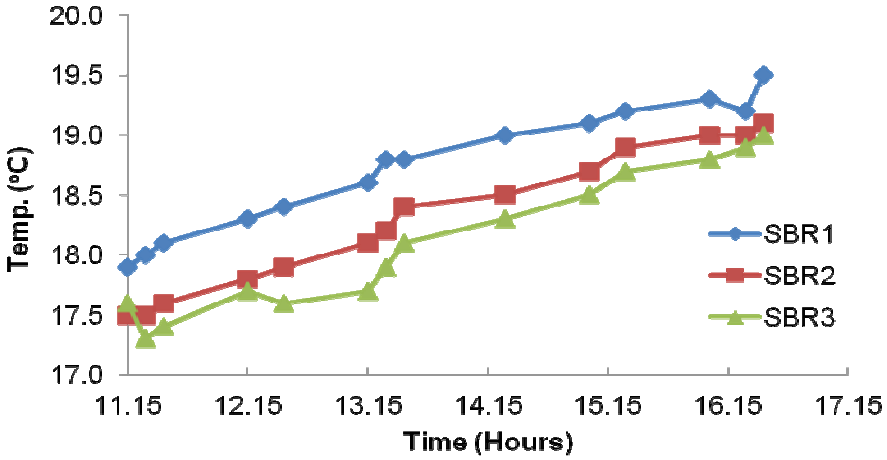

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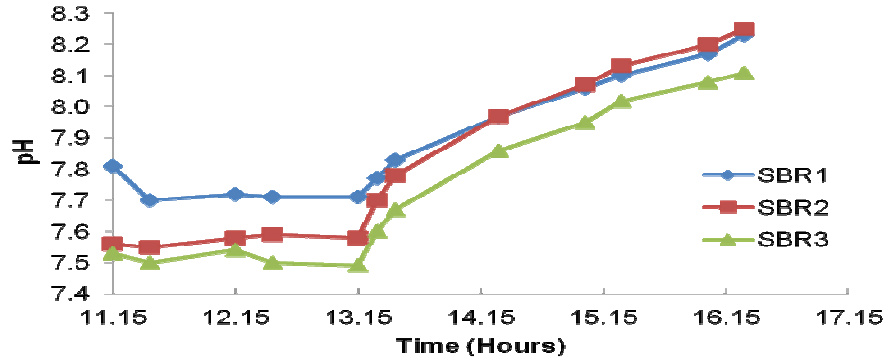

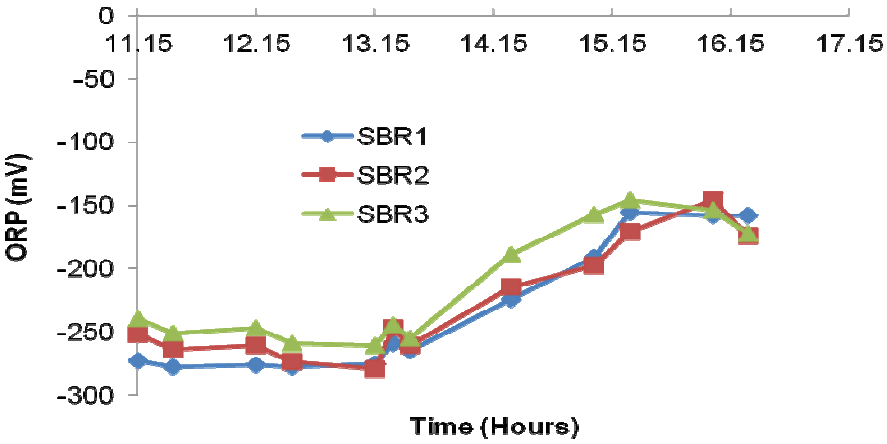

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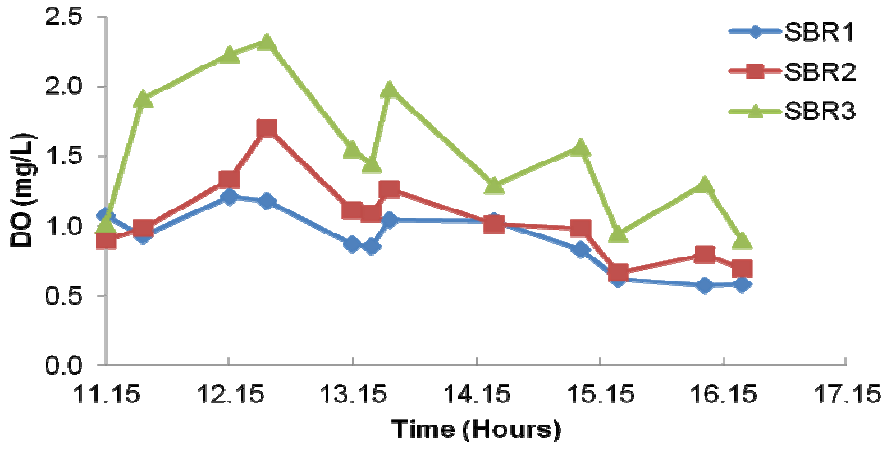

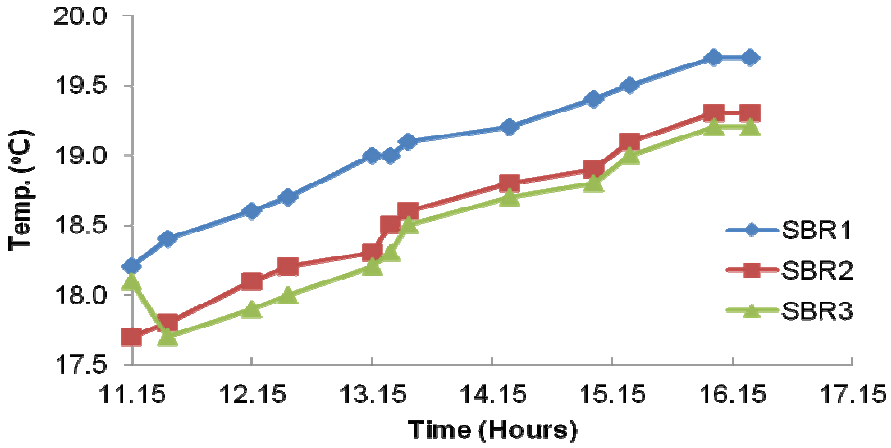

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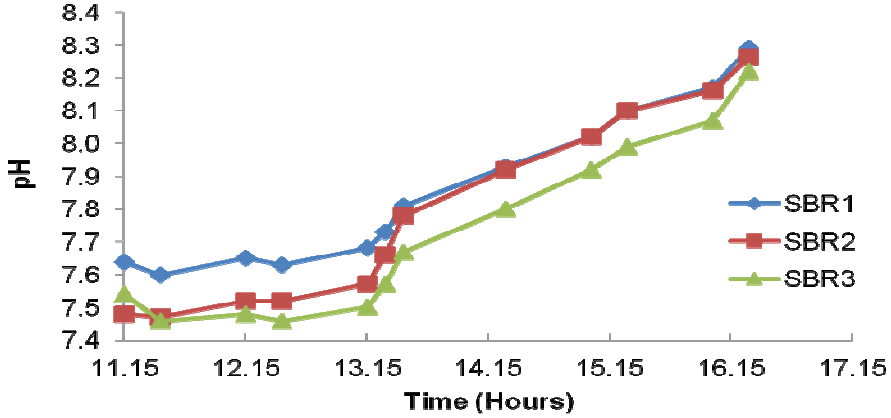

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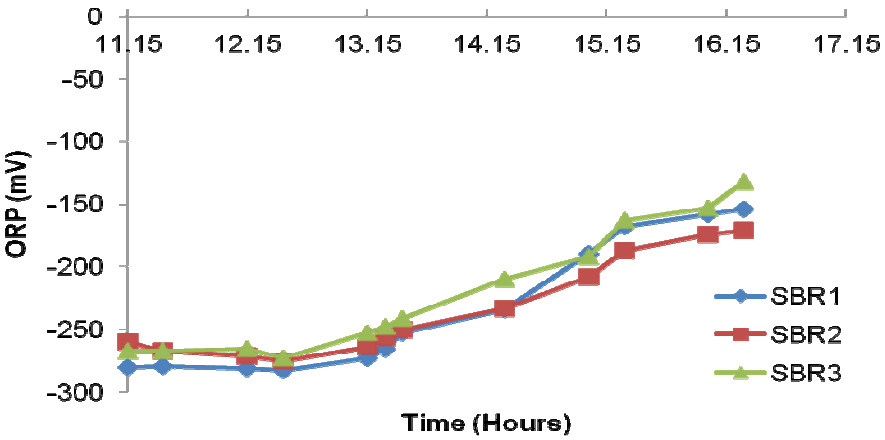

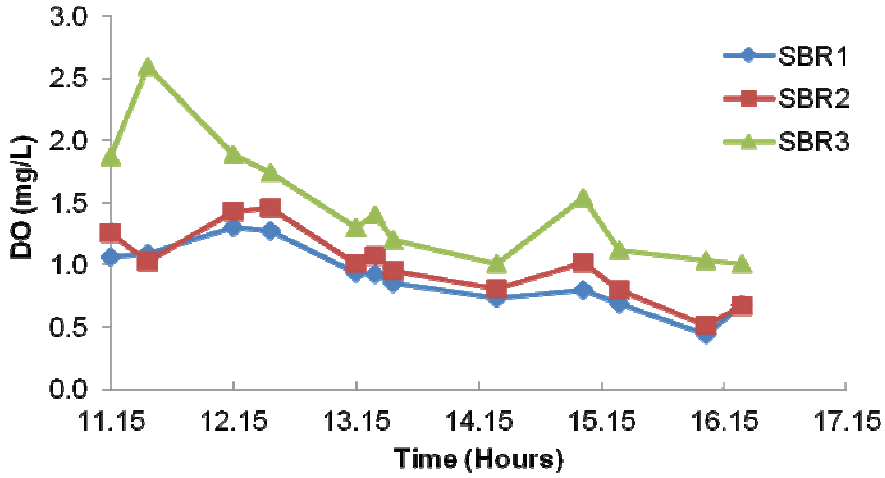

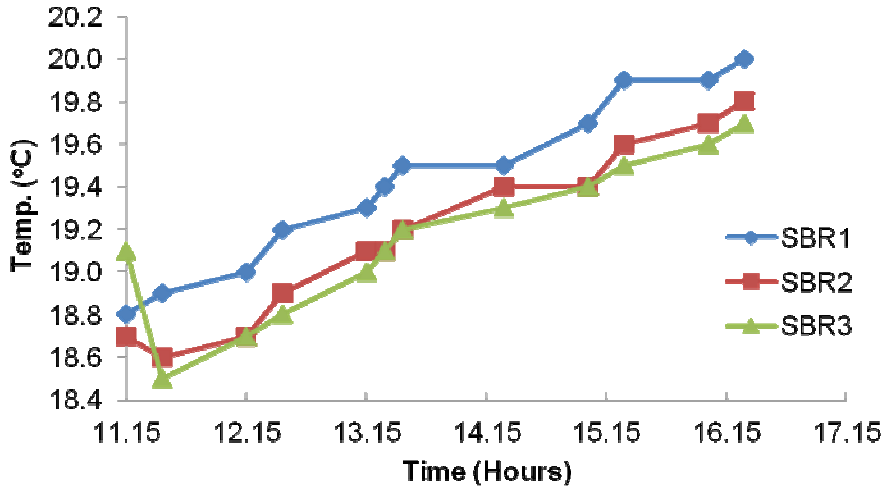

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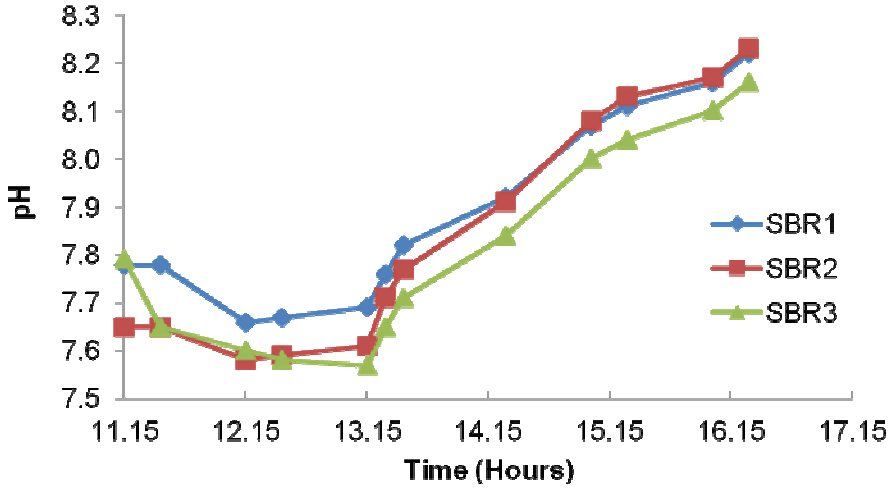

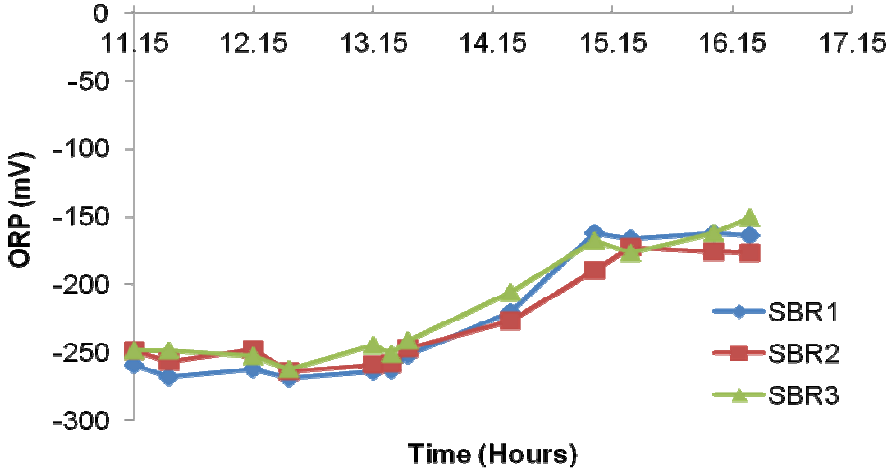

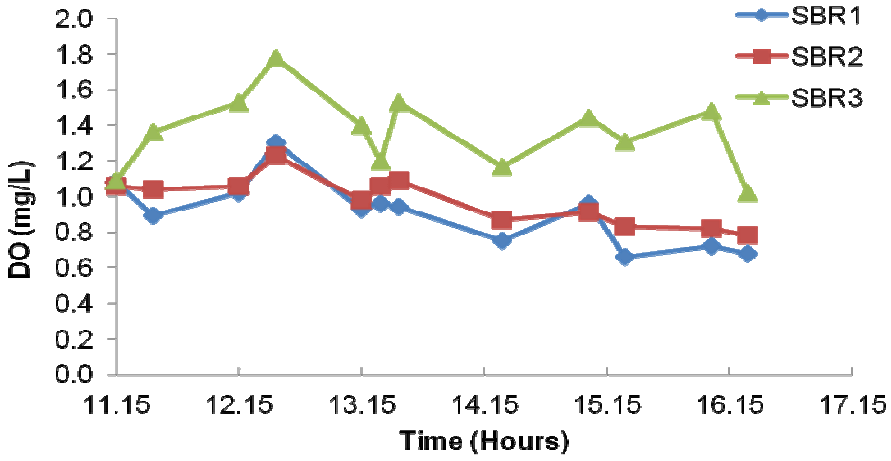

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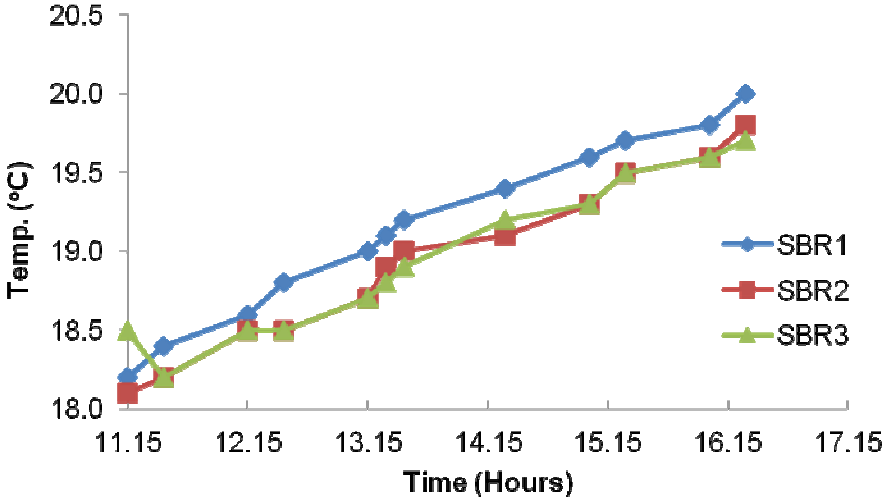

APPENDIX E1: DETERMINATION OF EFFLUENT VOLATILE SUSPENDED SOLIDS (VSS) CONCENTRATIONS

Sample No.	Wt. Empty F. Paper (gm) (a)	Vol. of Sample (mL) (b)	Wt. (a) + TSS (gm) (c)	Wt. Empty Crucible (gm) (d)	Wt. Total after ignition (gm) (e)	Wt. Loss (c + d-e-a)(gm) (f)	VSS $((f)x10^6)/(b)$ (mg/L)
1d1	0.160	4	0.162	25.4148	25.4151	0.002	425
2d1	0.152	2	0.154	19.0258	19.0263	0.002	750
3d1	0.142	4	0.145	24.7022	24.7026	0.003	650
1d2	0.151	4	0.154	20.1389	20.1391	0.003	700
2d2	0.146	4	0.151	21.2542	21.2552	0.004	1000
3d2	0.146	4	0.151	28.0054	28.0065	0.004	975
1d3	0.154	4	0.157	22.7784	22.7787	0.003	675
2d3	0.158	4	0.163	28.2120	28.2131	0.004	975
3d3	0.162	4	0.167	24.1211	24.1227	0.003	850
1d4	0.150	2	0.154	28.2112	28.2126	0.003	1300
2d4	0.156	4	0.162	19.9903	19.9915	0.005	1200
3d4	0.150	4	0.157	22.1985	22.2005	0.005	1250
1d5	0.158	4	0.163	25.2638	25.2654	0.003	850
2d5	0.151	4	0.155	22.2003	22.2007	0.004	900
3d5	0.151	4	0.158	29.6513	29.6542	0.004	1025
1d6	0.146	4	0.155	30.1131	30.1149	0.007	1800
2d6	0.154	4	0.160	26.4054	26.4057	0.006	1425
3d6	0.161	4	0.169	24.2750	24.2762	0.007	1700
1d7	0.148	2	0.153	30.1137	30.1140	0.005	2350

Sample No.	Wt. Empty F.Paper (gm) (a)	Vol. of Sample (mL) (b)	Wt. (a) + TSS (gm) (c)	Wt. Empty Crucible (gm) (d)	Wt. Total after ignition (gm) (e)	Wt. Loss (c + d-e-a)(gm) (f)	VSS $((f)x10^6)/(b)$ (mg/L)
2d7	0.150	4	0.163	24.1204	24.1235	0.010	2475
3d7	0.151	2	0.156	18.6736	18.6741	0.004	2250
1d8	0.146	2	0.151	30.0174	30.0176	0.005	2400
2d8	0.148	4	0.155	31.5221	31.5223	0.007	1700
3d8	0.152	2	0.157	26.4047	26.4056	0.004	2050
1d9	0.157	2	0.162	31.7879	31.7889	0.004	2000
2d9	0.147	2	0.152	29.6520	29.6529	0.004	2050
3d9	0.158	2	0.164	27.6024	27.6036	0.005	2400
1d10	0.147	2	0.155	23.5590	23.5601	0.007	3450
2d10	0.15	2	0.158	23.8101	23.8113	0.007	3400
3d10	0.146	2	0.155	27.6017	27.6043	0.006	3200
1d11	0.153	2	0.162	24.4751	24.4784	0.006	2850
2d11	0.155	2	0.161	23.6508	23.6521	0.005	2350
3d11	0.152	2	0.159	24.3145	24.3152	0.006	3150
1d12	0.154	2	0.164	23.8566	23.8604	0.006	3100
2d12	0.150	2	0.156	23.9191	23.9193	0.006	2900
3d12	0.163	2	0.171	21.5508	21.5522	0.007	3300
1d13	0.148	2	0.155	23.8107	23.8114	0.006	3150
2d13	0.145	2	0.153	31.7885	31.7887	0.008	3900
3d13	0.149	2	0.160	21.5505	21.5530	0.008	4250
1d14	0.147	2	0.159	22.5503	22.5524	0.010	4950

Sample No.	Wt. Empty F.Paper (gm) (a)	Vol. of Sample (mL) (b)	Wt. (a) + TSS (gm) (c)	Wt. Empty Crucible (gm) (d)	Wt. Total after ignition (gm) (e)	Wt. Loss (c + d-e-a)(gm) (f)	VSS $((f)x10^6)/(b)$ (mg/L)
2d14	0.152	2	0.162	25.2003	25.2016	0.009	4350
3d14	0.157	2	0.168	24.4754	24.4770	0.009	4700
1d15	0.152	2	0.161	23.8563	23.8575	0.008	3900
2d15	0.149	2	0.159	24.2737	24.2760	0.008	3850
3d15	0.145	2	0.156	28.0054	28.0084	0.008	4000
1d16	0.152	2	0.164	23.9190	23.9214	0.010	4800
2d16	0.144	2	0.155	23.3310	23.3332	0.009	4400
3d16	0.155	2	0.167	31.5208	31.5237	0.009	4550
1d17	0.144	2	0.154	29.8428	29.8449	0.008	3950
2d17	0.157	2	0.164	22.5522	22.5523	0.007	3450
3d17	0.153	2	0.163	24.7039	24.7056	0.008	4150
1d18	0.147	2	0.154	23.6499	23.6520	0.005	2450
2d18	0.159	2	0.166	43.5399	43.5417	0.005	2600
3d18	0.157	2	0.167	34.4747	34.4796	0.005	2550
1d19	0.161	2	0.169	20.0371	20.0398	0.005	2650
2d19	0.145	2	0.152	29.8165	29.8180	0.006	2750
3d19	0.155	2	0.161	21.4854	21.4857	0.006	2850
1d20	0.158	2	0.168	25.1557	25.1575	0.008	4100
2d20	0.147	2	0.155	23.5585	23.5594	0.007	3550
3d20	0.159	2	0.169	25.2006	25.2025	0.008	4050
1d21	0.157	2	0.166	25.1553	25.1579	0.006	3200

Sample No.	Wt. Empty F.Paper (gm) (a)	Vol. of Sample (mL) (b)	Wt. (a) + TSS (gm) (c)	Wt. Empty Crucible (gm) (d)	Wt. Total after ignition (gm) (e)	Wt. Loss (c + d-e-a)(gm) (f)	VSS $((f)x10^6)/(b)$ (mg/L)
2d21	0.145	2	0.152	18.6724	18.6733	0.006	3050
3d21	0.147	2	0.156	21.5210	21.5241	0.006	2950
1d22	0.150	2	0.159	23.4260	23.4268	0.008	4100
2d22	0.147	2	0.157	30.0168	30.0189	0.008	3950
3d22	0.152	2	0.163	25.4151	25.4175	0.009	4300
1d23	0.147	2	0.155	20.0372	20.0393	0.006	2950
2d23	0.151	2	0.160	29.8434	29.8471	0.005	2650
3d23	0.149	2	0.157	21.7020	21.7042	0.006	2900

APPENDIX E2: EFFLUENT VSS CONCENTRATIONS

Effluent VSS (mg/L)

Day		SBR1	SBR2	SBR3
		418	742	643
1	Mean	425	750	650
		432	758	657
	STD	±10	±11	±10
		694	992	967
2	Mean	700	1000	975
		706	1008	983
	STD	±8	±11	±11
		667	967	843
3	Mean	675	975	850
		683	983	857
	STD	±11	±11	±10
		1293	1194	1243
4	Mean	1300	1200	1250
		1307	1206	1257
	STD	±10	±8	±10
		843	892	1018
5	Mean	850	900	1025
		857	908	1032
	STD	±10	±11	±10
		1793	1418	1693
6	Mean	1800	1425	1700
		1807	1432	1707
	STD	±10	±10	±10
		2343	2469	2243
7	Mean	2350	2475	2250
		2357	2481	2257
	STD	±10	±8	±10
		2393	1694	2043
8	Mean	2400	1700	2050
		2407	1706	2057
	STD	±10	±8	±10
		1992	2043	2393
9	Mean	2000	2050	2400
		2008	2057	2407
	STD	±11	±10	±10
10		3443	3393	3192
	Mean	3450	3400	3200
		3457	3407	3208

Effluent VSS (mg/L)

		SBR1	SBR2	SBR3
	STD	±10	±10	±11
		2842	2343	3144
11	Mean	2850	2350	3150
		2858	2357	3156
	STD	±11	±10	±8
		3092	2894	3293
12	Mean	3100	2900	3300
		3108	2906	3307
	STD	±11	±8	±10
		3144	3893	4243
13	Mean	3150	3900	4250
		3156	3907	4257
	STD	±8	±10	±10
		4943	4342	4694
14	Mean	4950	4350	4700
		4957	4358	4706
	STD	±10	±11	±8
		3893	3843	3994
15	Mean	3900	3850	4000
		3907	3857	4006
	STD	±10	±10	±8
		4796	4394	4543
16	Mean	4800	4400	4550
		4808	4406	4557
	STD	±11	±8	±10
		3942	3444	4143
17	Mean	3950	3450	4150
		3958	3456	4157
	STD	±11	±8	±10
		2444	2593	2543
18	Mean	2450	2600	2550
		2456	2607	2557
	STD	±8	±10	±10
		2642	2742	2844
19	Mean	2650	2750	2850
		2658	2758	2856
	STD	±11	±11	±8
		4094	3543	4044
20	Mean	4100	3550	4050
		4106	3557	4056
	STD	±8	±10	±8
21		3191	3044	2944

		Effluent VSS (mg/L)		
		SBR1	SBR2	SBR3
	Mean	3200	3050	2950
		3209	3056	2956
	STD	±13	±8	±8
		4093	3941	4293
22	Mean	4100	3950	4300
		4107	3959	4307
	STD	±10	±13	±10
		2941	2642	2893
23	Mean	2950	2650	2900
		2959	2658	2907
	STD	±13	±11	±10

APPENDIX F1: REGRESSION ANALYSIS USING PEARSON PRODUCT MOMENT CORRELATION COEFFICIENT, r (Bluman, 1998)

$$r = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{\sqrt{\left[n\left(\sum x^2\right) - \left(\sum x\right)^2\right]\left[n\left(\sum y^2\right) - \left(\sum y\right)^2\right]}}$$

EFFLUENT VSS VERSUS % COD REMOVAL (ACCLIMATIZATION)

r' = -0.60397
r'' = -0.55802
r''' = -0.65182

EFFLUENT VSS VERSUS % COD REMOVAL

r' = 0.5858551
r'' = -0.3898304
r''' = -0.2300344

EFFLUENT TSS VERSUS % COD REMOVAL

r' = 0.3271837
r'' = -0.0787311
r''' = -0.604201

EFFLUENT NH_4-N VERSUS % COD REMOVAL

r' = -0.27827
r'' = 0.048585
r''' = 0.338699

EFFLUENT NO_3-N VERSUS % COD REMOVAL

r' = -0.00679
r'' = 0.514035
r''' = 0.67568

EFFLUENT TP VERSUS % COD REMOVAL

r' = -0.23082
r'' = 0.27505
r''' = 0.319904

EFFLUENT TOTAL ALKALINITY VERSUS % COD REMOVAL

r' = -0.27008
r'' = 0.343099
r''' = 0.45237

EFFLUENT pH VERSUS % COD REMOVAL

r' = 0.31089
r'' = 0.477076
r''' = 0.083001

EFFLUENT NO_3-N VERSUS % TP REMOVAL

r' = -0.57705
r'' = -0.86786
r''' = -0.84427

EFFLUENT NH_4-N VERSUS % TP REMOVAL

r' = -0.93131
r'' = -0.78021
r''' = -0.84166

EFFLUENT TOTAL ALKALINITY VERSUS % NO_3-N

r' = -0.28564
r'' = -0.57858
r''' = -0.59674

EFFLUENT TOTAL ALKALINITY VERSUS % NH_4-N

r' = 0.405016
r'' = -0.47898
r''' = -0.24432

EFFLUENT TOTAL ALKALINITY VERSUS % TSS REMOVAL

r' = 0.207723
r'' = 0.901414
r''' = 0.580752

EFFLUENT pH VERSUS % NH_4-N REMOVAL

r' = 0.906828
r'' = 0.284861
r''' = 0.727954

EFFLUENT pH VERSUS % NO_3-N REMOVAL

r' = 0.200256
r'' = 0.378329
r''' = 0.333925

EFFLUENT TOTAL ALKALINITY VERSUS % TP REMOVAL

r' = 0.225807
r'' = -0.60162
r''' = -0.32248

EFFLUENT NO_3-N VERSUS % NH_4-N REMOVAL

r' = -0.35821
r'' = -0.63321
r''' = -0.81954

APPENDIX F2: ANALYSIS OF VARIANCE (ANOVA)

Effluent VSS Concentration (mg/L)

Day	SBR1		SBR2		SBR3		
14	4950	24502500	4350	18922500	4700	22090000	
15	3900	15210000	3850	14822500	4000	16000000	
16	4800	23040000	4400	19360000	4550	20702500	
17	3950	15602500	3450	11902500	4150	17222500	
18	2450	6002500	2600	6760000	2550	6502500	
19	2650	7022500	2750	7562500	2850	8122500	
20	4100	16810000	3550	12602500	4050	16402500	
21	3200	10240000	3050	9302500	2950	8702500	
22	4100	16810000	3950	15602500	4300	18490000	
23	2950	8702500	2650	7022500	2900	8410000	
		143942500		123860000		142645000	410447500
sum	37050		30250		32300	99600	
n	10		10		10	30	
mean	3705		3025		3230		
sumsqd	1372702500		915062500		1043290000		
sumsqd/n	137270250		91506250		104329000	333105500	

DF=30-1=29
GROUP DF =3-1=2
ERROR DF = 29-2=27

C	330672000
TOTALSS	79775500
GROUPSS	2433500
ERRORSS	77342000

SOURCE OF VAR	SS	DF	MS
TOTAL	79775500	29	
GROUP	2433500	2	1216750
ERROR	77342000	27	2864518.500

F 0.425

F0.05(1),2,27 =3.350

DO NOT REJECT HO(there is no diff. btwn treatments)

the means DO NOT differ

Percentage COD Removal (%) (acclimatization)

DAY	SBR1		SBR2		SBR3	
1	59	3436	50	2535	75	5651
2	78	6060	73	5347	61	3727
3	73	5321	74	5492	65	4274
4	74	5473	70	4948	63	3977
5	75	5575	69	4806	66	4296
6	85	7230	85	7200	72	5143
7	58	3342	60	3568	52	2712
8	60	3579	57	3265	51	2599

9	58	3420	58	3342	54	2935	
10	59	3499	56	3114	56	3189	
11	61	3741	63	3906	60	3579	
12	52	2752	47	2218	56	3114	
13	57	3265	53	2822	54	2966	
		56693		52566		48162	157421
sum	849		815		786	2450	
n	13		13		13	39	
mean	65.317		62.717		60.440		
sumsqd	721000.032		664756.247		617347.064		
sumsqd/n	55461.541		51135.096		47488.236	154085	

DF=30-1=29
GROUP DF =3-1=2
ERROR DF = 29-2=27

C	153930.036
TOTALSS	3491
GROUPSS	155
RRORSS	3336

SOURCE OF VAR	SS	DF	MS
TOTAL	3490.959	29	
GROUP	154.836	2	77.418
ERROR	3336.122	27	123.560

F 0.627

F0.05(1),2,27 =3.350

DO NOT REJECT HO(there is no diff. btwn treatments)

the means DO NOT differ

Percentage COD Removal (%)

DAY	SBR1		SBR2		SBR3		
14	56	3189	45	2033	56	3114	
15	62	3823	69	4696	66	4336	
16	65	4248	60	3579	60	3659	
17	60	3579	59	3499	62	3823	
18	46	2094	63	3906	60	3659	
19	49	2412	64	4033	65	4248	
20	65	4162	54	2894	58	3420	
21	63	3906	54	2894	55	3040	
22	65	4162	54	2894	56	3189	
23	63	3991	60	3579	61	3741	
		35565		34007		36231	105803
sum	593		580		601	1774	
n	10		10		10	30	
mean	59.287		57.981		60.090		
sumsqd	351493.061		336180.600		361085.608		

sumsqd/n	35149.306	33618.060	36108.561	104876

DF=30-1=29
GROUP DF =3-1=2
ERROR DF = 29-2=27

C	104853.261
TOTALSS	950
GROUPSS	23
ERRORSS	927

SOURCE OF VAR	SS	DF	MS
TOTAL	949.782	29	
GROUP	22.666	2	11.333
ERROR	927.116	27	34.338

F 0.330
F0.05(1),2,27 =3.350
DO NOT REJECT HO(there is no diff. btwn treatments)
the means DO NOT differ

Percentage BOD_5 Removal (%)

DAY	SBR1		SBR2		SBR3	
14	58	3361	47	2202	57	3277
15	63	3979	71	5020	67	4484

16	68	4681	62	3812	62	3887	
17	61	3722	61	3663	62	3812	
18	47	2224	64	4102	65	4196	
19	61	3722	65	4212	67	4435	
20	66	4355	55	3031	60	3590	
21	64	4118	56	3167	57	3235	
22	66	4371	56	3167	59	3446	
23	65	4196	61	3722	63	3963	
		38729		36097		38326	113152
sum	620		598		618	1835	
n	10		10		10	30	
mean	61.970		59.760		61.812		
sumsqd	384029.580		357119.837		382075.043		
sumsqd/n	38402.958		35711.984		38207.504	112322	

DF=30-1=29
GROUP DF =3-1=2
ERROR DF = 29-2=27

C	112292.028
TOTALSS	860
GROUPSS	30
ERRORSS	829

SOURCE OF VAR	SS	DF	MS

TOTAL	859.593	29	
GROUP	30.418	2	15.209
ERROR	829.175	27	30.710

F 0.495

F0.05(1),2,27 =3.350

DO NOT REJECT HO(there is no diff. btwn treatments)

the means DO NOT differ

Percentage TSS Removal (%)

DAY	SBR1		SBR2		SBR3		
14	64	4133	71	5102	57	3265	
15	21	459	71	5102	71	5102	
16	43	1837	50	2500	50	2500	
17	71	5102	86	7347	79	6173	
18	57	3265	36	1276	50	2500	
19	29	816	36	1276	57	3265	
20	36	1276	36	1276	43	1837	
21	14	204	43	1837	21	459	
22	21	459	14	204	57	3265	
23	43	1837	57	3265	71	5102	
		19388		29184		33469	82041
sum	400		500		557	1457	

n	10	10	10	30
mean	40.000	50.000	55.714	
sumsqd	160000.000	250000.000	310408.163	
sumsqd/n	16000.000	25000.000	31040.816	72041

DF=30-1=29
GROUP DF =3-1=2
ERROR DF = 29-2=27

C	70775.510
TOTALSS	11265
GROUPSS	1265
ERRORSS	10000

SOURCE OF VAR	SS	DF	MS
TOTAL	11265.310	29	
GROUP	1265.306	2	632.653
ERROR	10000	27	370.370

F 1.708
F0.05(1),2,27 =3.350
DO NOT REJECT HO(there is no diff. btwn treatments)
the means DO NOT differ

Percentage NH_4-N Removal (%)

DAY	SBR1		SBR2		SBR3		
14	19	371	36	1271	46	2106	
15	40	1578	40	1611	30	903	
16	42	1761	39	1555	55	3010	
17	51	2652	40	1623	61	3759	
18	50	2495	39	1544	60	3639	
19	50	2467	51	2637	59	3505	
20	49	2440	48	2263	55	3071	
21	60	3555	51	2609	64	4128	
22	75	5691	78	6039	90	8184	
23	82	6779	80	6393	91	8286	
		29789		27545		40592	97926
sum	519		502		613	1634	
n	10		10		10	30	
mean	51.885		50.248		61.280		
sumsqd	269205.807		252482.769		375528.422		
sumsqd/n	26920.581		25248.277		37552.842	89722	

DF=30-1=29
GROUP DF =3-1=2
ERROR DF = 29-2=27

C	89012.787
TOTALSS	8913
GROUPSS	709
ERRORSS	8204

SOURCE OF VAR	SS	DF	MS
TOTAL	8913.009	29	
GROUP	708.913	2	354.457
ERROR	8204.096	27	303.855

F 1.167

$F_{0.05(1),2,27} = 3.350$

DO NOT REJECT HO(there is no diff. btwn treatments)

the means DO NOT differ

Percentage NO_3-N Removal (%)

DAY	SBR1		SBR2		SBR3	
14	54	2866	52	2751	55	2988
15	48	2352	46	2114	50	2485
16	50	2476	50	2518	55	2984
17	52	2719	53	2797	54	2960
18	51	2652	54	2885	55	3012
19	53	2799	53	2801	56	3132
20	53	2852	55	2988	57	3255

21	55	2984	56	3084	61	3703	
22	54	2875	56	3171	62	3882	
23	53	2848	56	3152	58	3395	
		27423		28262		31796	87480
sum	523		531		563	1617	
n	10		10		10	30	
mean	52.335		53.079		56.286		
sumsqd	273896.703		281739.684		316816.743		
sumsqd/n	27389.670		28173.968		31681.674	87245	

DF=30-1=29
GROUP DF =3-1=2
ERROR DF = 29-2=27

C	87157.135
TOTALSS	323
GROUPSS	88
ERRORSS	235

SOURCE OF VAR	SS	DF	MS
TOTAL	20436.440	29	
GROUP	67.830	2	33.915
ERROR	20368.610	27	754.393

F 0.045

F0.05(1),2,27 =3.350
DO NOT REJECT HO(there is no diff. btwn treatments)
the means DO NOT differ

Percentage TP Removal (%)

DAY	SBR1		SBR2		SBR3		
14	19	374	26	696	22	477	
15	20	413	20	410	20	383	
16	27	721	29	852	28	760	
17	31	990	29	820	27	748	
18	31	960	32	1013	31	973	
19	35	1207	39	1486	37	1342	
20	37	1382	45	2015	43	1889	
21	36	1261	47	2200	41	1690	
22	47	2200	46	2075	46	2118	
23	46	2111	50	2455	49	2430	
		11620		14021		12810	38451
sum	329		362		344	1035	
n	10		10		10	30	
mean	32.925		36.171		34.404		
sumsqd	108407.455		130833.265		118366.316		
sumsqd/n	10840.745		13083.326		11836.632	35761	

DF=30-1=29
GROUP DF =3-1=2
ERROR DF = 29-2=27

C	35707.897
TOTALSS	2743
GROUPSS	53
ERRORSS	2691

SOURCE OF VAR	SS	DF	MS
TOTAL	2743.311	29	
GROUP	52.807	2	26.404
ERROR	2690.504	27	99.648

F 0.265
F0.05(1),2,27 =3.350
DO NOT REJECT HO(there is no diff. btwn treatments)
the means DO NOT differ

Effluent Alkalinity (CaCO3mg/L)

DAY	SBR1		SBR2		SBR3	
14	1400	1960000	1570	2464900	1570	2464900
15	1620	2624400	1600	2560000	1710	2924100
16	1540	2371600	1580	2496400	1620	2624400
17	1660	2755600	1640	2689600	1600	2560000

18	1700	2890000	1510	2280100	1430	2044900	
19	1610	2592100	1550	2402500	1420	2016400	
20	1560	2433600	1500	2250000	1480	2190400	
21	1500	2250000	1490	2220100	1400	1960000	
22	1450	2102500	1400	1960000	1290	1664100	
23	1760	3097600	1580	2496400	1780	3168400	
		25077400		23820000		23617600	72515000
sum	15800		15420		15300	46520	
n	10		10		10	30	
mean	1580.000		1542.000		1530.000		
sumsqd	249640000.000		237776400.000		234090000.000		
sumsqd/n	24964000.000		23777640.000		23409000.000	72150640	

DF=30-1=29
GROUP DF =3-1=2
ERROR DF = 29-2=27

C	72137013.330
TOTALSS	377987
GROUPSS	13627
ERRORSS	364360

SOURCE OF VAR	SS	DF	MS
TOTAL	377986.700	29	
GROUP	13626.670	2	6813.333

ERROR		364360	27	13494.810
F	0.504885278			

F0.05(1),2,27 =3.35

DO NOT REJECT HO(there is no diff. btwn treatments)

the means DO NOT differ

Effluent pH

DAY	SBR1		SBR2		SBR3		
14	7.38	54.46	7.35	54.02	7.43	55.20	
15	7.61	57.91	7.55	57.00	7.58	57.46	
16	7.62	58.06	7.54	56.85	7.56	57.15	
17	7.79	60.68	7.60	57.76	7.62	58.06	
18	7.69	59.14	7.85	61.62	7.61	57.91	
19	7.62	58.06	7.61	57.91	7.49	56.10	
20	7.68	58.98	7.64	58.37	7.58	57.46	
21	7.68	58.98	7.66	58.68	7.55	57.00	
22	7.98	63.68	7.58	57.46	7.69	59.14	
23	7.84	61.47	7.73	59.75	7.89	62.25	
		591.44		579.43		577.74	1748.60
sum	76.89		76.11		76.00	229.00	
n	10		10		10	30	
mean	7.689		7.611		7.600		
sumsqd	5912.072		5792.732		5776.000		

sumsqd/n	591.207	579.273	577.600	1748.080

DF=30-1=29

GROUP DF =3-1=2

ERROR DF = 29-2=27

C	1748.033
TOTALSS	1
GROUPSS	0
ERRORSS	1

SOURCE OF VAR	SS	DF	MS
TOTAL	0.567	29	
GROUP	0.047	2	0.024
ERROR	0.520	27	0.019

F 1.222

F0.05(1),2,27 =3.350

DO NOT REJECT HO(there is no diff. btwn treatments)

the means DO NOT differ