ANAEROBIC TREATMENT OF RUBBER FACTORY WASTEWATER

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JULY 2009

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by

Farhanah binti Abu Samah

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

JULY 2009

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
Bachelor of Engineer (Hons)
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Approved:

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December 2009

CERTIFICATION OF ORIGINALITY

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

Farhanah binti Abu Samah

ABSTRACT

This report discusses the research done on the project topic, Anaerobic Treatment of Rubber Factory Wastewater. The objectives of the project are to study the anaerobic treatability of rubber factory wastewater and determine the effects of process parameters on anaerobic treatment of rubber factory wastewater. Wastewater collected from rubber glove factory was characterized .Wastewater from rubber glove factory that has passed through leaching process and tanks washing is alkaline in nature with pH of 8.3. High Chemical Oxygen Demand (COD) (52 400 mg/L) and Biochemical Oxygen Demand (BOD) (30 133 mg/L) indicate the wastewater has high amount of organic matter which may come from the presence of residual latex. BOD to COD ratio was 0.58 which shows that the wastewater is easily biodegradable. Up-flow Anaerobic Sludge Blanket (UASB) reactor was used to treat the high strength characteristic of rubber wastewater. Experiments were conducted to determine the effects of Hydraulic Retention Time (HRT) on reactor performance. The results obtained shows that increases in the HRT resulted in increases in COD removal efficiency and zinc removal efficiency. The highest efficiency was achieved on day 22 which both of COD and zinc removal efficiency were 91%, corresponding to HRT of 5 days and Organic Loading Rate (OLR) of 0.996 g COD_{in}/L.d and COD_{in} of 4980 mg/L. The lowest efficiency was on day 49 which COD and zinc removal efficiency were 86% and 88%, respectively (corresponding to HRT of 5 days and OLR of 0.998 g COD_{in}/L.d and COD_{in} of 4990 mg/L). The average effluent pH slightly decreased from 7.08 to 7.02 when the HRT was changed from 5 to 4 days. The effluent alkalinity ranged from 1505 to 2390 mg$CaCO_3$/L and 2060 to 2120 mg $CaCO_3$/L for HRT of 5 and 4 days, respectively. Although the COD removal efficiency was high, but COD concentrations in the effluent still exceed EQA limit, which are 400 mg/L. Further treatment is needed before the effluent can be discharged to the surface waters.

Keywords: **anaerobic treatment, rubber glove factory wastewater, UASB**

ACKNOWLEDGEMENT

The greatest thank to Allah Al-Mighty for His blessing for the author to complete this study. The author would like to express her gratitude to her supervisor of this project, AP Dr Mohamed Hasnain Isa and lecturers in Civil Engineering Department for the valuable guidance and advice. Their helpful comments and suggestions throughout the course have tremendously help the author to understand and make the project works.

The author also would like to thank the Civil Engineering and Chemical Engineering laboratory technicians University Technology Petronas (UTP) for their help and support in the study.

Finally, an honourable mention goes to her families and friends for their understanding and moral supports for completing this project.

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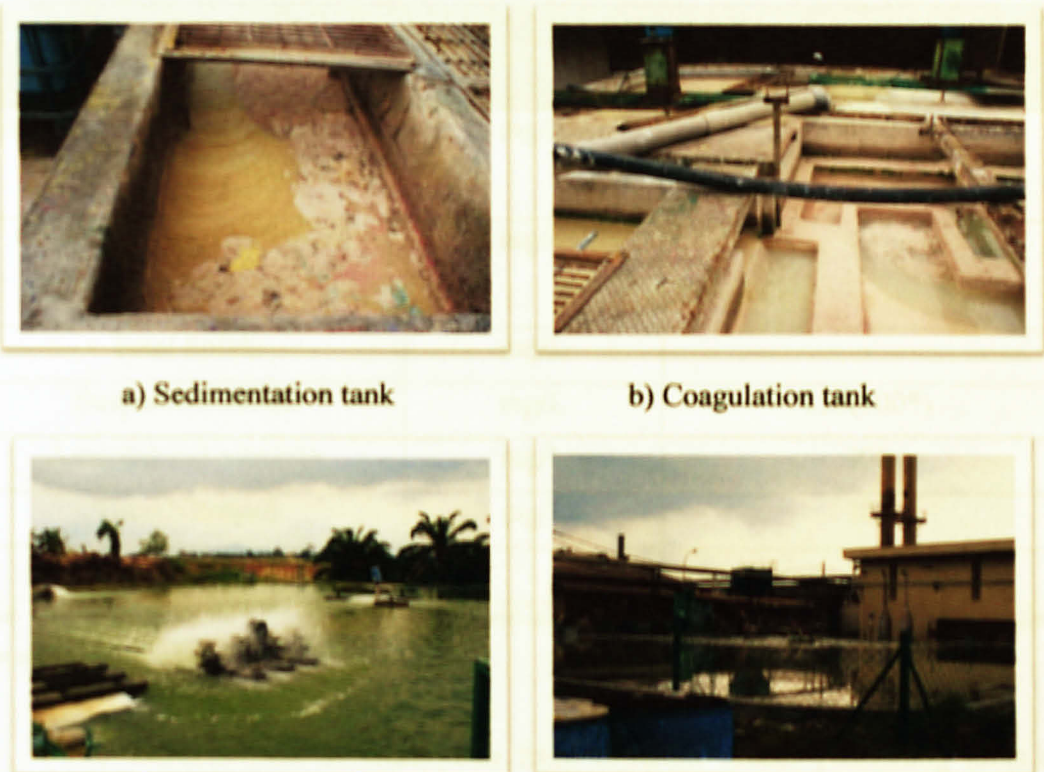
INTRODUCTION

1.1 Background of Study

Natural rubber is an elastic hydrocarbon polymer which is a yellowish and amorphous material obtained from milky sap or latex of various tropical plants especially the rubber tree (*Hevea Brasiliensis*). Rubber industry plays a major role as the contributor to many developing countries' economy. Today, Malaysia is the fourth biggest producer of natural rubber in the world after Thailand, Indonesia and India, the fifth-largest rubber consumer and among the world's largest exporters of rubber products (Vijayaraghavan *et al.*, 2007). The production of natural rubber (dry and latex) in Malaysia was approximately 1.12 million tons in 2007 (Malaysian Rubber Board, 2008). The Malaysian rubber-based products manufacturing industry has established itself as a global supplier, specifically for latex-based products such as gloves, catheters and latex threads. Rubber processing industry produces wastewater as a by-product which contains numerous substances such as rubber hydrocarbon, proteins, minerals, non-rubber hydrocarbons, carbohydrates and any chemicals that might have been added (Asia and Akporhonor, 2007). Wastewater from rubber glove particularly, produces high amount of zinc which can cause pollution if is discharged straight into the surface water (Shyan, 2008). Recent methods applied for rubber wastewater treatment are anaerobic-cum-facultative lagoon system, anaerobic-cum-aerated lagoon system, aerated lagoon and oxidation ditch system (Industrial Processes & The Environment, 1999). However, most glove factories specifically use chemical treatment methods which involve high amount of chemicals, which is costly and need high maintenance operation. Figure 1.1 shows wastewater treatment system at a glove factory in Ipoh, Perak. The treatment system consists of sedimentation tank, coagulation tank, aerobic pond and clarifier. Solids content in the effluent are removed in sedimentation tank then the effluent flows to coagulation tank. Heavy metal such as zinc is removed by using precipitation method where alum is added. After that, the effluent flows to the aeration pond. Mechanical aerators are used to provide oxygen and keep the aerobic organisms suspended and mixed with water to achieve a high rate of organic degradation and nutrient removal. The effluent is finally discharged to Sungai Perak.



a) Sedimentation tank b) Coagulation tank

c) Aeration pond d) Clarifier

Figure 1.1 Wastewater treatment systems at a glove factory in Ipoh, Perak

1.2 Problem Statement

Malaysian Rubber Board (2008) stated that there are about 362 active rubber processing factories in Malaysia in 2007, which of course, produced large quantities of high strength wastewater. The environmental quality regulations for natural rubber industry were described under Environmental Quality Act (EQA) 1974 (Act 127). Environmental Quality (Prescribed Premises) (Raw Natural Rubber) Regulations 1978 describes the parameter limits of effluent discharge from concentrated latex production and its associated products. The effluent discharge limits are presented in Table 1.1.

Table 1.1 Effluent discharge limits for concentrated latex products wastewater (Environmental Quality Act, 1978)

Parameter	Unit	Parameter Limits (Third Schedule)
Biochemical Oxygen Demand (BOD); 3-day, 30°C	mg/L	100(50*)
Chemical Oxygen Demand (COD)	mg/L	400
Total Solids	mg/L	-
Suspended Solids	mg/L	150(100*)
Ammoniacal-nitrogen	mg/L	300
Total Nitrogen	mg/L	300
pH		6-9

*This additional limit is the arithmetic mean value determined on the basis of a minimum of four samples taken at least once a week for four weeks consecutively.

The characteristics of wastewater from different rubber processing units are shown in Table 1.2. Wastewater produced by a glove factory has passed through leaching process and tanks washing. Leaching process is a process of immersing the latex-coated formers into a bath or spray of water, to wash out excess additives which have been added during compounding and dipping stage, resulting in highly concentrated wastewater. Based on the table, the effluent contains really high organic loading (COD and BOD) which would contribute to environmental pollution if discharged directly into surface waters. The effluent also contains high suspended solids which could cause difficulty in disposal. The high concentration of ammonium-nitrogen in the effluent may cause excessive algae growth, thus lead to eutrophication in rivers and streams. Besides, if the water is used for water supply, it will affect the economy and health as nitrate can cause methemoglobinemia in infants. Also, the high ammonia concentration could affect life of aquatic organisms (Asia and Akporhonor, 2007; Rungruang and Babel, 2008). Moreover, zinc is also found widely in glove factory wastewater as it is used as a catalyst during manufacture and as a heat disperser in the final product (Bhowmick, 1994). Consequently, it will affect the environment as zinc-polluted sludge will be deposited on the banks and increases the acidity of water. It will also affect human health as it can cause stomach cramps, skin irritations, vomiting, nausea and anemia. The characteristics of the effluent exceed the limits stated in the EQA standards. Thus, an efficient and practical treatment must be employed to the effluent before being discharged to the environment.

Table 1.2 Characteristics of effluent from different rubber processing units

Parameter	Ribbed Smoked Sheet	Latex Concentrate		Crumb	Crepe	
		Creaming	Centrifuging		Pale Latex	Estate Brown
Flow	5	1.5	5.55	45	45	43
pH	5.05	8.95	5.30	6.8	5.7	6.9
BOD	4080	34900	3645	137	2260	137
COD	8080	58752	5873	464	4667	469
SS	-	14142.5	1962	303	391	386
TDS	4120	28307	13597	804	2303	513
Sulphides	ND	-	-	-	44	-
Ammoniacal Nitrogen	15	35	1751	35	16	16
Toal Nitrogen	18	42	2131	42	22	25

All Parameters are expressed in mg/l, except pH.

BOD to COD ratio of rubber glove factory wastewater is about 0.58 which means it is easily biodegradable. Considering the high strength characteristics of rubber factory wastewater, anaerobic process is a suitable approach for its treatment. Current conventional anaerobic treatment such as stabilization pond needs large space for treatment and has no facilities to capture biogas produced (Chan and Chooi, 1984). Various high rate anaerobic reactors have been studied because of their ability to retain high biomass concentration in the reactor. Up-flow Anaerobic Sludge Blanket (UASB) reactor was chosen in this study because it can treat high organic content wastewater, produces high quality effluent, costs less to operate because no oxygen is required, retains high concentration of biomass in the reactor and produces a high amount of methane (Borja and Banks, 1994).

1.3 Objectives

The objectives of this study are:

i. To study the anaerobic treatability of rubber factory wastewater.

ii. To determine the effect of process parameters on anaerobic treatment of rubber factory wastewater.

1.4 Scope of Study

The scope of the study covered the characterization of rubber factory wastewater such as its pH, COD, BOD, alkalinity, Total Suspended Solid (TSS), turbidity, color, zinc, ammonium-nitrogen, and phosphate. The applicability of anaerobic treatment for rubber factory wastewater was determined after obtaining its characteristics. Type of anaerobic treatment that was used is Up-flow Anaerobic Sludge Blanket (UASB) Reactor in mesophilic temperature (30-38°C). The study also involved determining the effects of the operating parameter which is Hydraulic Retention Time (HRT) on effluent quality which are COD removal, zinc removal pH and alkalinity. The research and investigations included literature review, laboratory experiments and data analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter contains a brief review on the anaerobic treatment process which covers the mechanism of anaerobic digestion, factors affecting anaerobic process, types of anaerobic treatment methods and an overview of some of the treatment methods used for rubber factory wastewater.

2.2 Anaerobic Digestion

Anaerobic digestion is a biological treatment process where complex organic matters are degraded in the absence of oxygen. The process is used primarily for the treatment of waste sludge and high-strength organic wastes. The application of anaerobic digestion has been widely used as an effective alternative for wastewater treatment because of the lower biomass yield and energy production in the form of methane. Other advantages of anaerobic treatment compared to aerobic treatment are; it requires less energy (because of no aeration is needed), lower nutrient requirement and less space for operation. Therefore, this process need lower capital and operation cost compared to other treatment methods because cost for aeration and sludge treatment can be deducted (Metcalf and Eddy, 2003; Poh and Chong, 2008). Disadvantages of anaerobic processes are related to their operation. Anaerobic processes need long retention time and long start-up period because the bacteria have low growth rate and need time to grow and adapt to the new environment before they start to degrade the organic matters. It is also sensitive to possible toxic compounds, operational stability and malodour. However, the problems can be avoided with proper wastewater characterization and process design (Metcalf and Eddy, 2003). In order to overcome long retention time problem, high-rate anaerobic bioreactors can be used. Meanwhile, for long start-up periods, it can be reduced by using granulated seed sludge and suitable pH and temperature in the high rate anaerobic bioreactor for the growth of bacteria (Liu et al., 2002).

2.2.1 Mechanism of Anaerobic Digestion

Three basic steps are involved in the overall anaerobic oxidation of a waste, which are hydrolysis, fermentation (acidogenesis) and methanogenesis. The steps for anaerobic methane fermentation process are shown in Figure 2.1.

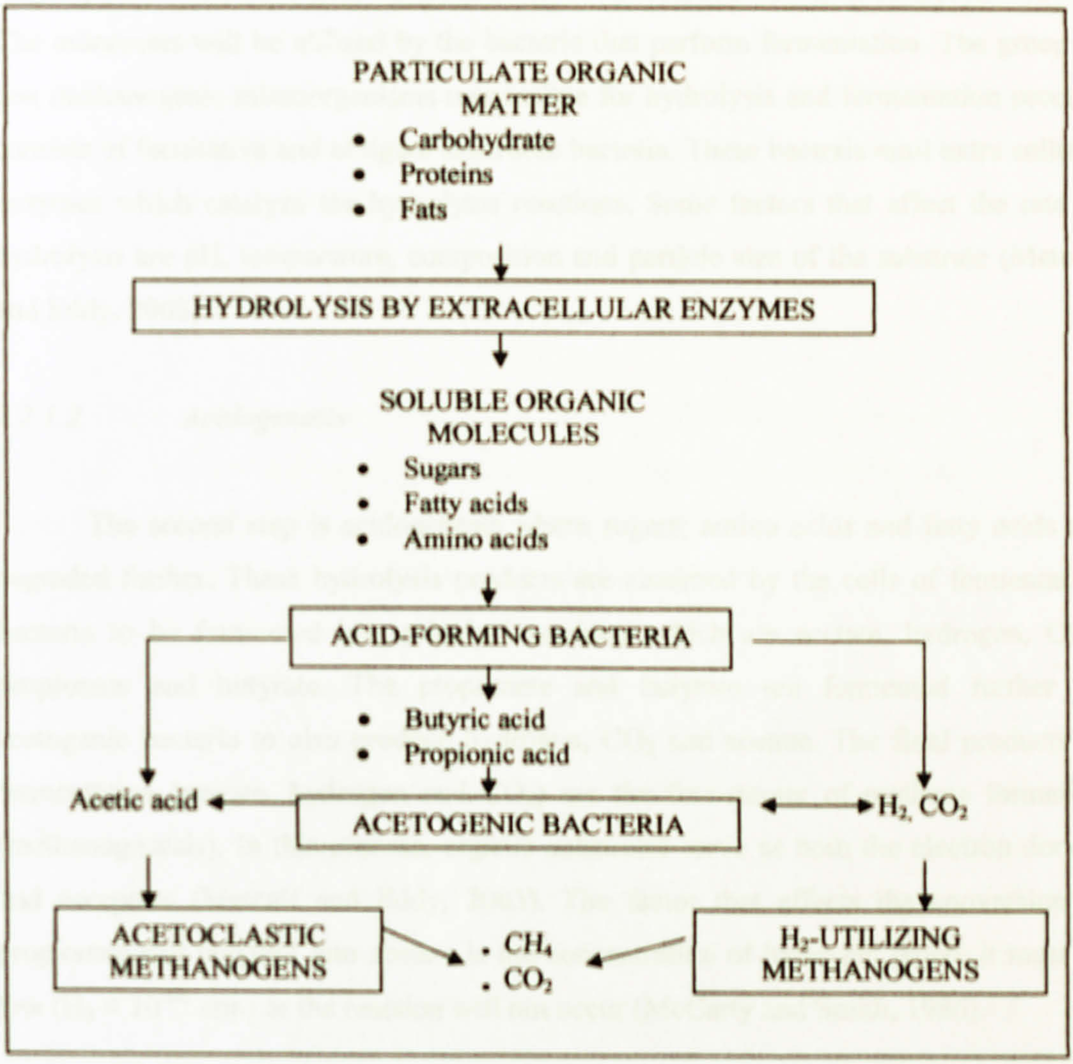


Figure 2.1 Schematic of anaerobic methane fermentation process (Malina and Pohland, 1992)

Based on Figure 2.1, the conversion of insoluble particulate organic material into two final end products – methane and carbon dioxide is accomplished by a consortium of anaerobic bacteria through several steps:-

2.2.1.1 Hydrolysis

Hydrolysis is the first step in most digestion processes in which particulate matters such as carbohydrates, proteins and fats are converted to soluble compounds (sugars, amino acids and fatty acids) that can be hydrolyzed further to simple monomers. The monomers will be utilized by the bacteria that perform fermentation. The group of non methanogenic microorganisms responsible for hydrolysis and fermentation process consists of facultative and obligate anaerobic bacteria. These bacteria emit extra cellular enzymes which catalyze the hydrolysis reactions. Some factors that affect the rate of hydrolysis are pH, temperature, composition and particle size of the substrate (Metcalf and Eddy, 2003).

2.2.1.2 Acidogenesis

The second step is acidogenesis where sugars, amino acids and fatty acids are degraded further. These hydrolysis products are absorbed by the cells of fermentative bacteria to be fermented into principal products which are acetate, hydrogen, CO_2, propionate and butyrate. The propionate and butyrate are fermented further by acetogenic bacteria to also produce hydrogen, CO_2 and acetate. The final products of fermentation (acetate, hydrogen and CO_2) are the fore-runner of methane formation (methanogenesis). In this process, organic substrates serve as both the electron donors and acceptors (Metcalf and Eddy, 2003). The factor that affects the conversion of propionate and butyrate into acetate is the concentration of hydrogen where it must be low ($H_2 < 10^{-4}$ atm) or the reaction will not occur (McCarty and Smith, 1986).

2.2.1.3 *Methanogenesis*

Methanogenesis is the third step where methane is produced by a group of organisms known as methanogens. There are two groups of methanogens involved in methane production. One group, *aceticlastic methanogens*, consists of *Methanosarcina* and *Methanosaeta*, uses acetate to produce methane and carbon dioxide. Meanwhile, the second group, hydrogen-utilizing methanogens such as *Methanobacterium*, *Methanobacillus* and *Methanococcus*, uses hydrogen as electron donor and CO_2 as the electron acceptor to produce methane (Metcalf and Eddy, 2003). Acetate is the major factor in conversion of organic matters to methane and carbon dioxide. About 70% of the total methane produced in anaerobic digestion comes from acetate. Thus, the production of methane from acetate is an important step in the anaerobic digestion process (Rittmann and McCarty, 2001).

2.2.2 *Factors Affecting Anaerobic Process*

There are several variables such as pH, alkalinity, temperature, operating condition, nutrients and nuisance organisms that affect the anaerobic process. These factors affect the growth of methanogenic bacteria which are sensitive to variations in environmental conditions. These factors are discussed below:-

2.2.2.1 *pH and Alkalinity*

The most important parameter affecting the anaerobic process is pH. The optimum pH for methanogenic activity is near neutral which is between 6.8 and 7.2. Methanogenic activity will decrease when the pH deviates from the optimum value; it ceases at pH lower than 4 or higher than 9.5 (Metcalf and Eddy, 2003). pH adjustment can be done by using H_2SO_4 and NaOH to neutralize the wastewater (Anotai *et al.*, 2007). The factors affecting pH in a digester are bicarbonate alkalinity, CO_2 partial pressure, ammonia and concentration of volatile fatty acids.

A high alkalinity (2000 to 4000 mg/L of $CaCO_3$) is needed to ensure pH near neutrality because of high CO_2 content in the gases produced in anaerobic processes (30 to 35 percent CO_2). The alkalinity of importance in anaerobic process is during the treatment not the one that was originally present in the raw waste. The alkalinity requirement varies with the waste, system operation and type of process. Lime and bicarbonate salts can be added to the digester to maintain the alkalinity (Metcalf and Eddy, 2003). Concentration of volatile fatty acids is also an important parameter in maintaining the pH value. Several cases of reactor failure have been reported in studies of wastewater treatment when the volatile fatty acid accumulate and cause the pH to drop which inhibited methanogenesis (Van Lier *et al.*, 1990). Anaerobic digesters can tolerate acetic acid concentrations up to 4000 mg/L without inhibition of methanogenic activity (Stafford, 1982).

2.2.2.2 Temperature

Wastewater temperature greatly affects the economics and feasibility of anaerobic treatment. There are two optimum temperature ranges for anaerobic treatment; mesophilic (30-38°C) and thermophilic (49-57°C). Various parameters are affected by temperature, especially metabolic rate of microorganisms, solubility of substrates/organics, ionization equilibria and the solubility product of salts. Anaerobic process in thermophilic temperature range has treatment rates faster than mesophilic temperature range. High production of methane from the treatment of sugar wastewater in thermophilic condition was also observed (Poh and Chong, 2008). The rates are increased due to the increase in biological reaction rate of methanogenic activity (Van Lier *et al.*, 1990). Thermophilic digesters are able to tolerate higher OLRs and operate at shorter HRT while producing more biogas (Yilmaz *et al.*, 2008). However, failure to control temperature increase can cause a drop in pH and biomass washout due to accumulation of volatile fatty acids because of inhibition of methanogenesis (Van Lier *et al.*, 1990). Methane production can stop at 65 – 70 °C. Many operators prefer to use mesophilic digesters due to better process stability (Poh and Chong, 2008).

2.2.2.3 Operating conditions

Operating conditions such as Organic Loading Rate (OLR) and Hydraulic Retention Time (HRT) are important factors in determining the efficiency of anaerobic treatment. Studies have shown that COD removal efficiency will decrease with higher OLRs. However, gas production will increase with increase in OLR until the methanogens could not work quick enough to convert acetic acid to methane. The factors affecting OLR are substrate concentration and HRT; where low HRT will reduce the time of contact between substrate and biomass (Poh and Chong, 2008).

2.2.2.4 Nutrients

Bacteria in anaerobic process require various nutrients for their optimum growth especially nitrogen (N) and phosphorous (P). Nitrogen represents about 12 percent by weight of the cell, while phosphorous represents about 2 percent. Anaerobic processes also need trace metals for activation of key enzymes for methanogenesis (Droste, 1997). The minimum COD:N:P ratio required for anaerobic digestion process is 100:2.0:0.28 (Speece, 1983).

2.2.2.5 Nuisance organisms

Nuisance organisms in anaerobic operations are the sulphate-reducing bacteria, where they can reduce sulphate to sulphide, which can be toxic to methanogenic bacteria at high concentrations. It will effect methane production as sharing mechanism of methanogenic substrate will occur. Ways to reduce sulphide toxicity are to add iron at controlled amounts to form iron sulphide precipitate, pH adjustment and off-gas scrubbing (Metcalf and Eddy, 2003; Isa and Anderson, 2004).

2.2.3 Anaerobic Treatment Methods

There are various types of anaerobic treatment being used in the industry such as conventional anaerobic digestion (pond and digester), anaerobic filtration, fluidized bed reactor, up-flow anaerobic sludge blanket (UASB) reactor, up-flow anaerobic sludge fixed-film (UASFF) reactor etc.. A brief description of these anaerobic reactors is given below:-

2.2.3.1 Conventional anaerobic digestion

Conventional anaerobic treatment systems that have been used in the industry are pond and digester. Anaerobic ponds need large space for digestion which depends on the quantity of the effluent and have long retention time which is around 20-200 days (Chan and Chooi, 1984). Meanwhile, conventional digester is used when the area is limited (Figure 2.2). It is the simplest anaerobic reactor designs with flow-through tank without biomass recycle. This digester is suitable for wastes with high suspended solids and very high concentrations of soluble organics. However, it requires large reactor volumes to provide necessary Solid Retention Time (SRT) (Marina and Pohland, 1992).

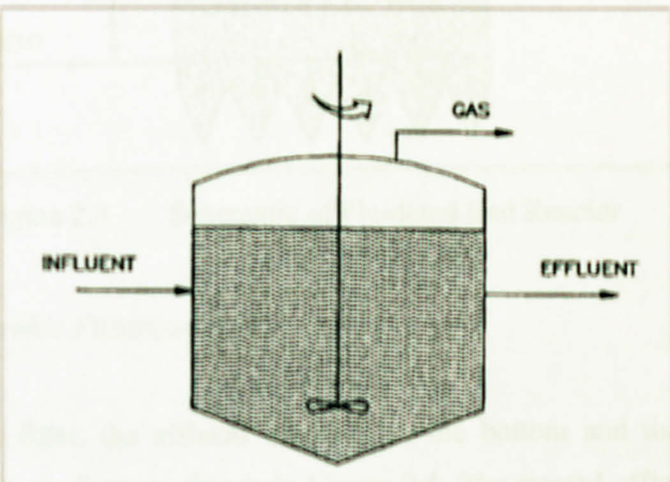


Figure 2.2 Schematic of Conventional Anaerobic Digester

2.2.3.2 Fluidized Bed Reactor

Fluidized Bed Reactor (FBR) is an attached growth process with wastewater introduced at the bottom of the reactor and allowed to overflow from the top. The biomass will attach and grow on the support material as shown in Figure 2.3. The packing size is about 0.3 mm with up-flow velocity of about 20 m/h to provide about 100% bed expansion. This process is more suitable for wastewater containing only soluble contaminants because of the thin biofilms and high turbulence within the reactor prevents the capture and retention of influent suspended solids. The advantages of FBR are it is the most compact of all high rate processes which has very large surface areas for biomass attachment and it allows high OLR with short HRT (Malina and Pohland, 1992).

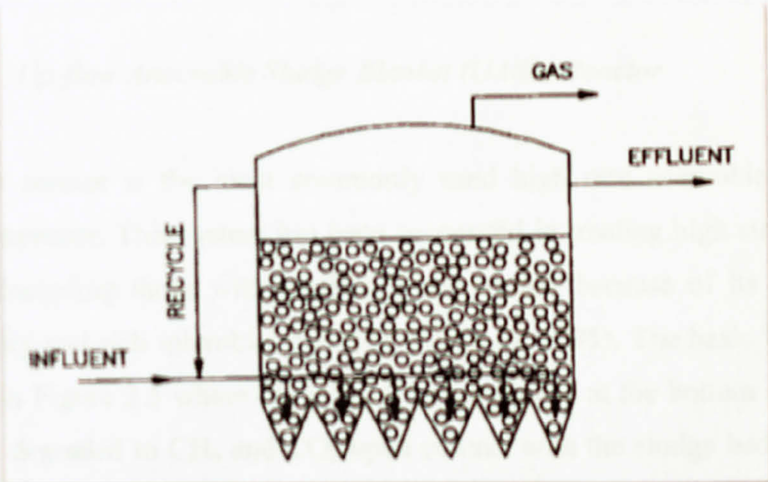


Figure 2.3 Schematic of Fluidized Bed Reactor

2.2.3.2 Anaerobic Filtration (AF)

In anaerobic filter, the effluent enters from the bottom and the biomass will attach to the packing medium as shown in Figure 2.4. The treated effluent and biogas produced will flow out from the top of the bioreactor (Poh and Chong, 2008). The key features of anaerobic filter are high substrate removal efficiency and good effluent quality with at least 70% of COD removal. Besides, it also requires small reactor volume and operates with short HRT. However, filter clogging may occur in the continuous operation of the system (Borja and Banks, 1994).

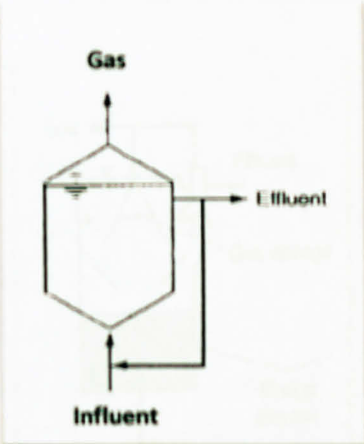


Figure 2.4 Schematic of Anaerobic Filter

2.2.3.4 Up-flow Anaerobic Sludge Blanket (UASB) Reactor

UASB reactor is the most commonly used high rate anaerobic treatment in industrial wastewater. This system has been successful in treating high strength organic wastewaters including those with inhibitory compounds because of its high biomass retention ability and rich microbial diversity (Lettinga, 1995). The basic UASB reactor is illustrated in Figure 2.5 where the influent is introduced at the bottom of the reactor, and then it is degraded to CH_4 and CO_2 upon contact with the sludge bed. The positive features of UASB reactor are it allows high organic loading, short HRT, produces high methane concentration and has a low energy demand (Metcalf and Eddy, 2003). Recommended OLR at mesophilic condition for soluble feed with COD removal of 85-95% is 18-25 g COD/L.d (Lettinga and Hulshoff Pol, 1991). This reactor is also able to treat high suspended solid wastewater that may cause clogging in the reactor (Poh and Chong, 2008). The main difference of UASB reactor with other anaerobic technologies is the granulated sludge formation. The granulated sludge particles have a size range of 1.0 to 3.0 mm and result in excellent sludge-thickening properties (Metcalf and Eddy, 2003). However, long start-up periods are needed if seeded sludge is not granulated (Poh and Chong, 2008). Other drawbacks of this system are high volatile fatty acid concentration inhibits the granulation process, the performance of the reactor is dependent on sludge settleability and foaming may occur at high OLR (Lettinga, 1995).

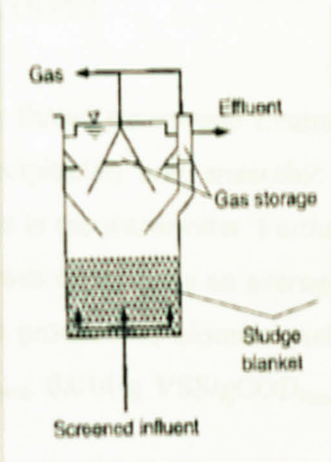


Figure 2.5 Schematic of the UASB reactor (Metcalf and Eddy, 2003)

2.2.3.4 Up-Flow Anaerobic Sludge Fixed-Film (UASFF) Reactor

UASFF reactor is a hybrid bioreactor which combines UASB reactor and anaerobic filter in a single reactor. The lower part of the UASFF bioreactor is UASB portion where granular sludge are formed while the upper part of the reactor serve as a fixed film reactor. This reactor exhibits many advantages such as high biomass retention, reactor stability at shock loadings and can operate at high OLRs. It also can eliminate the problems of clogging and biomass washout (Poh and Chong, 2008).

2.3 Overview of Rubber Wastewater Treatment Methods

Various studies have been conducted to treat wastewater from rubber factory. Agamuthu (1999) proposed a biological treatment method to treat rubber thread manufacturing industry wastewater by using up-flow anaerobic filter reactor. The wastewater was pretreated for zinc removal using sodium sulphide and polyelectrolyte

LT 27 at concentrations of 800 mg/l and 5 mg/l respectively. Based on the study, methane production rate decreased from 69.8% to 63.5% when Organic Loading Rate (OLR) were increased from 2-14g COD/l/d. Meanwhile, the percentage of COD removal by attached biomass compared to total activity ranged from 71.9% to 74.7% for the organic loading rates of 2-14g COD/l/d.

Another study of rubber thread wastewater treatment also done by Anotai *et al.* (2007) by using sulphide precipitation and anaerobic filter. Sulphide precipitation method was used to remove zinc in the wastewater. Further treatment was done by using anaerobic filter. COD removal was found to be an average of 92% at the OLR of 11.8 g COD/L.d. Meanwhile, methane production, biomass yield and apparent methanogenic activity were 0.32 $L/gCOD_{removed}$, 0.014 g $VSS/gCOD_{removed}$ and 0.28 gCOD/g VSS/d, respectively.

Besides, a study on the treatment of natural rubber processing wastewater by combination of ozonation and activated sludge process has also been conducted by Rungruang and Babel (2008). Based on the study, the combined process which uses ozonation as a pretreatment could improve the removal efficiency of BOD_5, COD, NH_3-N, TKN and SS up to 95.79, 91.49, 74.75, 67.95 and 74.68%, respectively. Other advantages of this process are high removal efficiency of pollutants and produced a final effluent low in suspended solid, clear and odourless. However, the individual ozonation processes were not sufficient to treat highly polluted wastewater.

Another study of the treatment is by using electrochemical method where the generated hypochlorous acid served as an oxidizing agent to destroy the organic matter present in the wastewater. This method has greater advantages as they are neither subjected to failures due to variation in wastewater strength nor due to presence of toxic substance and require less HRT. During the electrochemical reduction process the wastewater undergoes in situ disinfection due to generated hypochlorous acid (Vijayaraghavan *et al.*, 2007).

CHAPTER 3

MATERIALS AND METHODS

3.1 Chemicals and Reagents

Chemicals and reagents used in the study are presented in Table 3.1 below:-

Table 3.1 List of chemicals and reagents

Chemical/Reagent	Purpose of Use
• Distilled water	• Solution preparation
• Chromic acid • Mercuric sulfate • Ferroin indicator • Potasium dichromate solution	• COD test
• Sulfuric acid solution	• Alkalinity test • COD test • pH adjustment
• Sodium hydroxide solution	• pH adjustment • Total Phosphorus test
• Sodium bicarbonate solution	• For bicarbonate alkalinity
• ZincoVer 5 Reagent Powder Pillow • Cyclohexanone	• Zinc test
• Mineral stabilizer • Polyvinyl Alcohol Dispersing Agents • Nessler reagent	• Ammonium-nitrogen test
• PhosVer 3 Powder Pillow • Acid Hydrolyzable Test Vial • Potassium Persulfate Powder Pillow	• Total Phosphorus test

3.2 Tools and Equipment

Tools and equipment used in this study are represented in Table 3.2:-

Table 3.2 List of tools and equipment

Tools/Equipment	Purpose of Use
• Heating block • COD Vials	• COD
• BOD bottle, volume 300mL • BOD cap • DO probe equipped with stirring mechanism	• BOD
• pH meter	• pH • Alkalinity
• Turbidimeter	• Turbidity
• Spectrophotometer • Sample cells	• Ammonium-Nitrogen • Phosphorus • COD • Zinc
• Filter paper Whatman GF/C (47mm) • Drying Oven (103°C) • Dessicator unit • Filter holder • Filtering flask • Tweezers	• TSS test • MLVSS • MLSS
• W8 Armfield parallel anaerobic digester unit (UASB) • Single channel Masterflex® Pump	• Anaerobic treatment
• Glassware	• Wastewater characterization • Anaerobic treatment

3.3 Research Methodology

The study of the effects of operating parameter which is HRT on anaerobic treatment of rubber factory wastewater was done by using UASB reactor in the lab. The overall methodology of the study is shown in Figure 3.1.

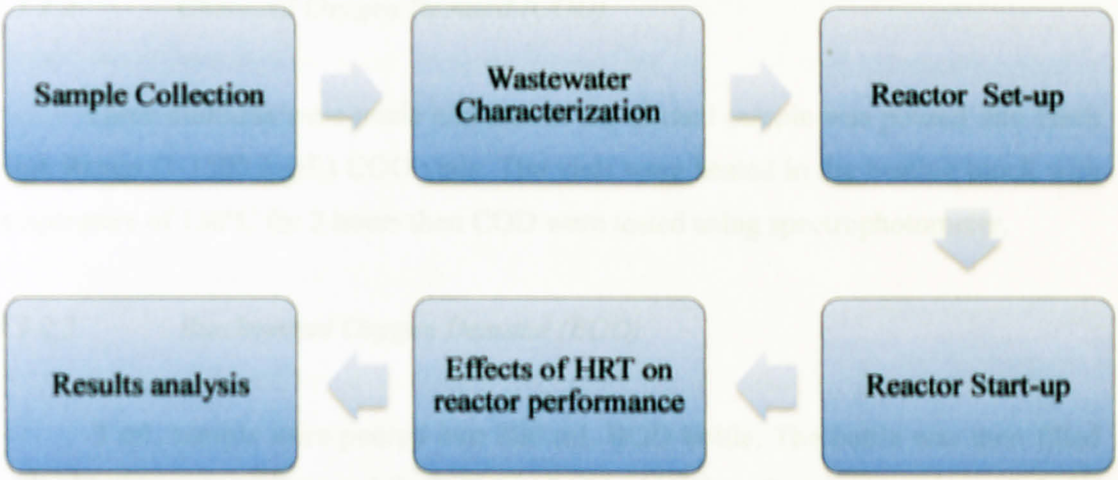


Figure 3.1 Overall Experimental Flow chart

3.3.1 Sample collection

Wastewater sample was obtained from the effluent of rubber glove factory in Ipoh, Perak which had passed through leaching process and tanks washing. The sample taken was preserved at a temperature less than 4°C, but above freezing point in order to prevent the wastewater from undergoing biodegradation due to microbial action.

3.3.2 Wastewater Characterization

Several tests were conducted to determine the characteristics of the sample such as pH, COD, BOD_5, TSS, alkalinity, ammonium-nitrogen, phosphate, zinc, turbidity and color. Analysis was done to determine the applicability of anaerobic treatment to rubber factory wastewater.

3.3.2.1 pH measurement

pH value was measured directly from the pH meter. pH meter must be calibrated first to ensure accuracy of the reading.

3.3.2.2 Chemical Oxygen Demand (COD)

Three dilutions were made and 2ml of the diluted sample was poured into Hach High Range (1-1500 mg/L) COD vials. The vials were heated in the heating block with temperature of 150°C for 2 hours then COD were tested using spectrophotometer.

3.3.2.3 Biochemical Oxygen Demand (BOD)

3 mL sample were poured into 300 mL BOD bottle. The bottle was then filled with dilution water saturated in oxygen and containing the nutrients required for biological growth. Before the bottle was stoppered, the oxygen concentration in the bottle was measured. After the bottle was incubated for 5 days at 20°C, the dissolved oxygen concentration was measured again. The BOD of the sample is the difference in the dissolve oxygen concentration values divided by the decimal fraction of sample used.

3.3.2.4 Total Suspended Solids (TSS)

50 mL samples with different dilutions were filtered using Whatman glass fiber filter. The filter paper was then dried at temperature of 103°C for 1 hour. TSS of the sample is the difference in the weight of the pan and filter paper before and after filtering values divided by the volume of the sample.

3.3.2.5 Alkalinity

50 mL sample was titrated using 0.02N H_2SO_4 until pH≈8.3 which gives phenolphthalein alkalinity. The same sample was further titrated with 0.02N H_2SO_4 to pH≈4.5 which gives the total alkalinity.

3.3.2.6 Zinc

Zinc was measured using USEPA Zincon Method where 20 mL of sample was added with ZincoVer5 Reagent Powder Pillow and 0.5 mL cyclohexanone. After 3 minutes reaction, zinc concentration in the sample was measured using spectrophotometer.

3.3.2.7 Ammonium- nitrogen

Nessler Method was employed to measure Ammonium-nitrogen where 25 mL of sample was added with three drops of Mineral Stabilizer and Polyvinyl Alcohol Dispersing Agent and 1.0 mL of Nessler Reagent. After one minute reaction, Ammonium-nitrogen concentration in the sample was measured using spectrophotometer.

3.3.2.8 Phosphate

Total and Acid Hydrolyzable Test Vial was added with 5.0 mL of sample and Potassium Persulfate Powder Pillow for Phosphonate. After 30 minutes heating period and being cooled to room temperature, the vial was added with 2 mL of 1.54N Sodium Hydroxide Standard Solution and PhosVer 3 Powder Pillow and the concentration of phosphate was then measured using spectrophotometer.

3.3.2.9 Turbidity

10mL of sample with different dilutions were poured into sample cells. The samples were then tested for turbidity using turbidimeter.

3.3.2.10 Color

10 mL of sample with different dilutions were poured into sample cells. The samples were then tested for color using spectrophotometer.

3.3.3 Experimental (Anaerobic Treatment)

3.3.3.1 Up-flow Anaerobic Sludge Blanket (UASB) Reactor Set-up

The bioreactor used in this study was W8 Armfield Parallel Anaerobic Digester. The schematic diagram and the photo of the digester are shown in Figure 3.2 and 3.3, respectively. The digester has two identical upward-flow packed bed reactors and gas collection vessels with nominal capacity of 5-L. The glass column of the reactor has internal diameter of 150 mm and 250 mm high. It also comprises with feed rate and temperature control facilities to allow steady, continuous operation at up to seven litres per day over periods of many days. The temperature of each reactor is controlled by an electric heating mat wrapped around the external wall of the column. A separate insulation mat covers the heating mat to reduce head loss and prevent burns. In this study, the temperature was maintained to 35±2°C. In order to supply a uniform substrate, a magnetic stirrer was used to mix the feed. The sample was continuously fed to the reactors using single channel Masterflex Pump and the effluent was collected from the top of the column. Methane production was monitored by using liquid displacement method. 5% NaOH solution was used as it absorbs CO_2 and allows CH_4 to pass through. Thymol blue was used as an indicator as the blue color will be discharged when the CO_2 absorption capacity of the solution is exhausted (Isa *et al.*, 1993).

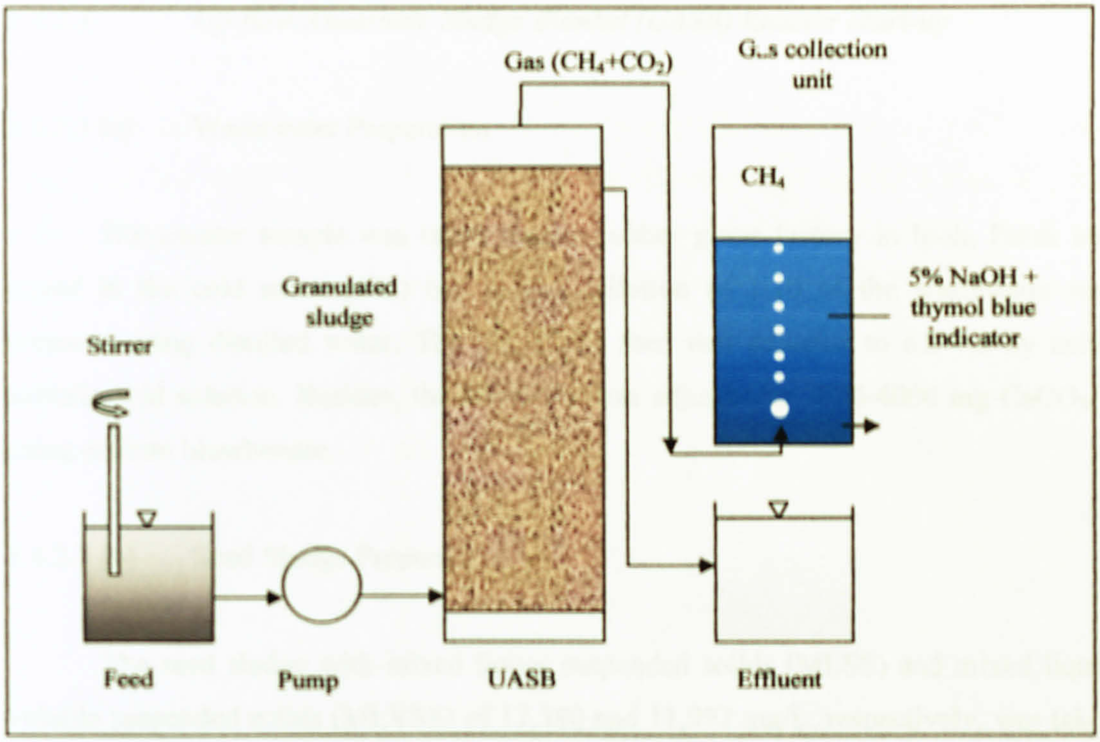


Figure 3.2 Schematic diagram of UASB

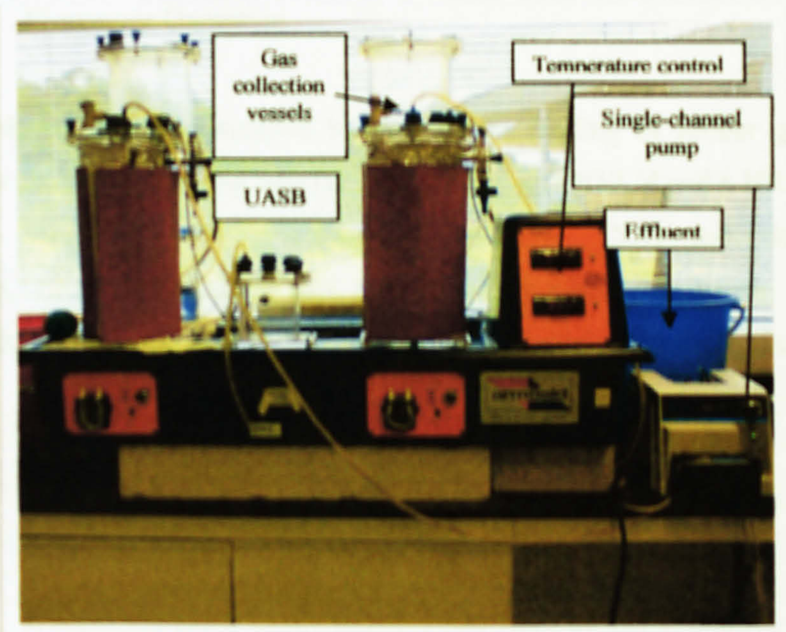


Figure 3.3 W8 Armfield Anaerobic Digester

3.4.2.3 Up-flow Anaerobic Sludge Blanket (UASB) Reactor Start-up

3.4.2.3 (a) Wastewater Preparation

Wastewater sample was taken from a rubber glove factory in Ipoh, Perak and stored in the cold room (4°C) before use. Dilution of 1:10 of the wastewater was prepared using distilled water. The pH of the feed was adjusted to 6.8-7.2 by using sulfuric acid solution. Besides, the alkalinity was adjusted to 2000-4000 mg $CaCO_3$/L using sodium bicarbonate.

3.4.2.3 (b) Seed Sludge Preparation

The seed sludge with mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) of 17,380 and 11,992 mg/L, respectively, was taken from the Sewage Treatment Plant (STP) of Universiti Teknologi Petronas (UTP), Perak.

3.4.2.3 (c) Bioreactor Operation

The sludge was acclimatized by continuous feeding of rubber glove factory wastewater at an organic loading rate (OLR) of 1.048 g COD/L/d and a HRT of 5d for 2 weeks. The temperature is maintained at 35±2°C. COD reduction, biomass concentration, zinc concentration, pH and alkalinity were monitored. Analysis for methane production has not been done due to some errors in gas collection unit.

3.4.2.4 Effects of Hydraulic Retention Time (HRT) on Reactor Performance

The independent factor used in this study was HRT (5 and 4 days). COD_{in} was maintained for about ±5000 mg/L. COD removal, percentage of COD removal, zinc removal and percentage of zinc removal were dependent output responses. After two weeks of sludge acclimatization, bioreactor was fed with the wastewater with initial HRT of 5 days and OLR 1.018 g COD/L.d. After steady state has been achieved, the HRT was changed to 4 days. COD reduction, biomass concentration, zinc concentration, pH and alkalinity were monitored.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Characterization of Rubber Glove Factory Wastewater

The results obtained for rubber glove factory wastewater characterization is presented in Table 4.1:-

Table 4.1 Characteristics of rubber glove factory wastewater

Parameters	Unit	Values
pH		8.3
Turbidity	FTU	45 900
Color	PtCo	460 166
TSS	mg/L	13 266
BOD_5	mg/L	30 133
COD	mg/L	52 400
Zinc	mg/L	35
Phosphate	mg/L	19
Ammonium-Nitrogen	mg/L	127

The details of the results are shown in Appendix A. Wastewater from rubber glove factory that has passed through leaching process and tanks washing is alkaline in nature with average pH value of 8.3. High COD (52 400 mg/L) and BOD (30 133 mg/L) indicates that the wastewater has high amount of organic matter which may come from the presence of residual latex. Based on the result, BOD to COD ratio was 0.58 which shows that the wastewater is easily biodegradable. Zinc amount was found to be high in rubber glove manufacturing wastewater which approximately 35 mg/L because it was used as catalyst in manufacturing process and heat disperser during final product. The results also shows that the wastewater contained high suspended solids (13 266 mg/L) and turbidity (45 900 mg/L) as the wastewater had passed through leaching process which contains high amount of latex residue.

4.2 Up-flow Anaerobic Sludge Blanket (UASB) Reactor Performance

4.2.1 Up-flow Anaerobic Sludge Blanket (UASB) Reactor Start-up

The sludge was acclimatized by continuous feeding of rubber glove factory wastewater at an OLR of 1.048 g COD/L.d and a HRT of 5 days for 2 weeks. The UASB reactor start-up process was analyzed in terms of COD removal, zinc removal, biomass concentration, pH and alkalinity. The results are shown in Appendix B.

4.2.1.1 COD Removal

Influent and effluent COD concentration and COD removal efficiency during start-up period of 2 weeks are shown in Figure 4.1 and Figure 4.2, respectively. The reactor was fed with influent COD of 5240 mg/L and flow rate, Q_F of 1L/d (OLR = 1.048 g COD/L.d).

Based on the figure, COD removal efficiency during start-up period increased from 71% - 85%. The COD removal on day 2 was low as the microorganisms took time to acclimatize with the new environment. After that, the removal efficiency was gradually increasing until it reached the steady state which 85% of COD removal on day 15.

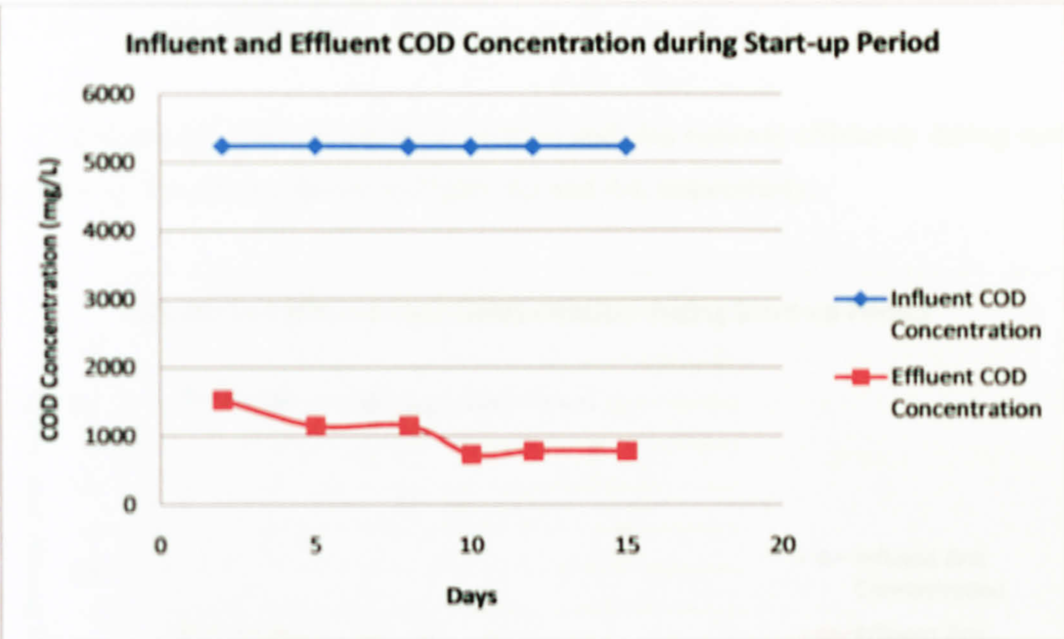


Figure 4.1 Influent and effluent COD concentration during start-up period

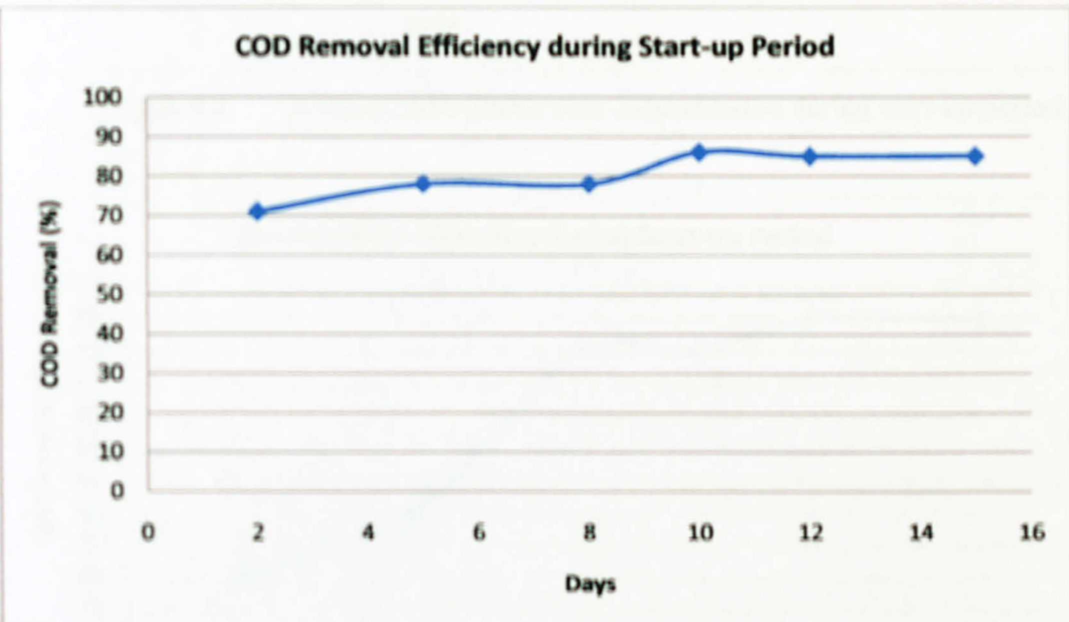


Figure 4.2 COD removal efficiency during start-up period

4.2.1.2 Zinc Removal

Influent and effluent zinc concentration and zinc removal efficiency during start-up period of 2 weeks are shown in Figure 4.3 and 4.4, respectively.

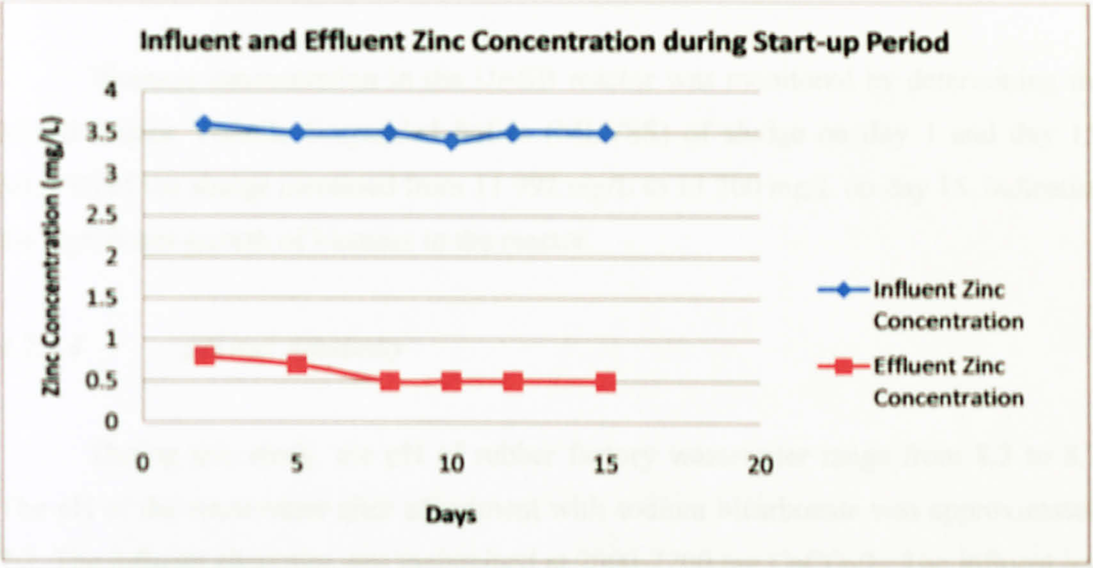


Figure 4.3 Influent and effluent zinc concentration during start-up period

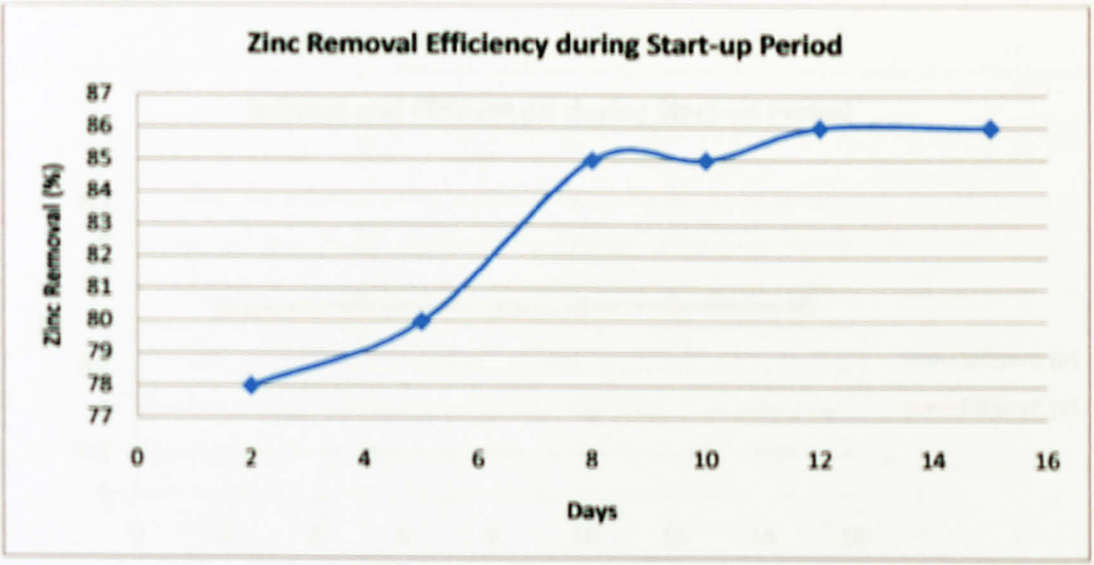


Figure 4.4 Zinc removal efficiency during start-up period

The value of zinc concentration for the influent was in the range of 3.4 – 3.6 mg/L after dilution. This value was not found to be a problem as the zinc removal efficiency increased from 78% to 86%.

4.2.1.3 Biomass Concentration

Biomass concentration in the UASB reactor was monitored by determining the Mixed Liquor Volatile Suspended Solids (MLVSS) of sludge on day 1 and day 15. MLVSS of the sludge increased from 11 992 mg/L to 13 200 mg/L on day 15, indicating the significant growth of biomass in the reactor.

4.2.1.4 pH and Alkalinity

During this study, the pH of rubber factory wastewater range from 8.3 to 8.7. The pH of the wastewater after adjustment with sodium bicarbonate was approximately 7.2. The influent alkalinity was maintained at 2000-2200 mg $CaCO_3$/L. The influent and effluent of pH and alkalinity during start-up period are shown in Figure 4.5 and 4.6, respectively.

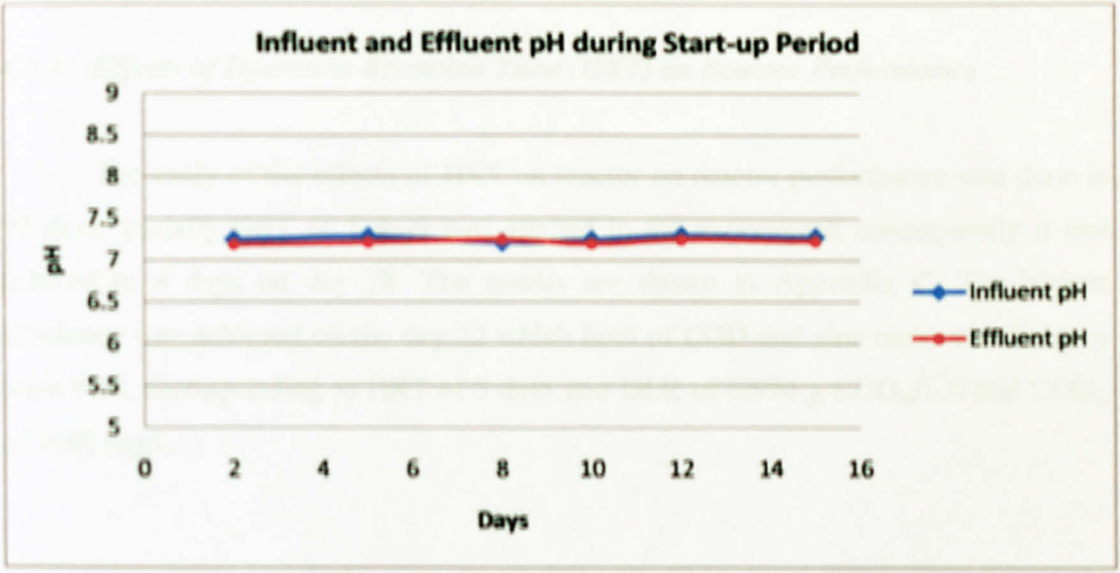


Figure 4.5 Influent and effluent pH during start-up period

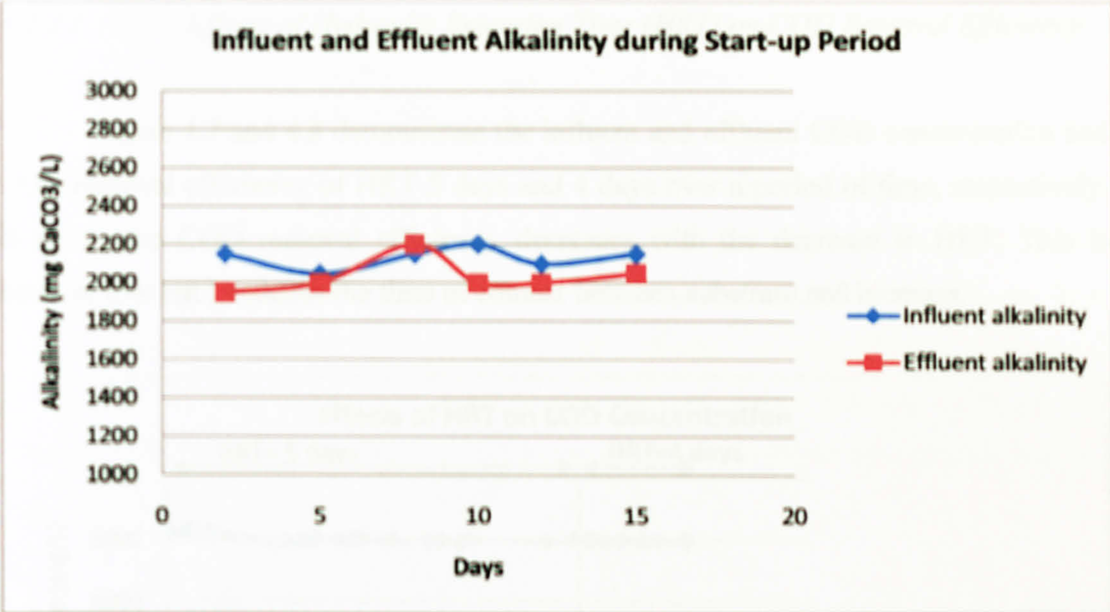


Figure 4.6 Influent and effluent alkalinity during start-up period

The influent pH of the UASB reactors ranged from 7.22-7.30, whereas, the influent alkalinity ranged from 2050 to 2200 mg $CaCO_3$/L for HRT of 5 days. Meanwhile, the effluent pH ranged from 7.19 to 7.25 and the effluent alkalinity ranged from 1950 to 2200 mg $CaCO_3$/L.

4.2.2 Effects of Hydraulic Retention Time (HRT) on Reactor Performance

The study of the effects of HRT on reactor on reactor performance was done in 97 days. Initially HRT of 5 days was applied in the experiment; consequently it was reduced to 4 days on day 78. The results are shown in Appendix C. The highest efficiency was achieved on the day 22 which both of COD and zinc removal efficiency were 91%, corresponding to HRT of 5 days and OLR of 0.996 g COD_{in}/L.d and COD_{in} of 4980 mg/L.

4.2.2.1 *Effects of Hydraulic Retention Time (HRT) on COD Removal Efficiency*

Figure 4.7 and 4.8 demonstrate the influent and effluent COD concentration and COD removal efficiency of HRT 5 days and 4 days over a period of time, respectively. It shows the COD removal efficiency decreases with the decrease in HRT. This is because low HRT reduces the time of contact between substrate and biomass.

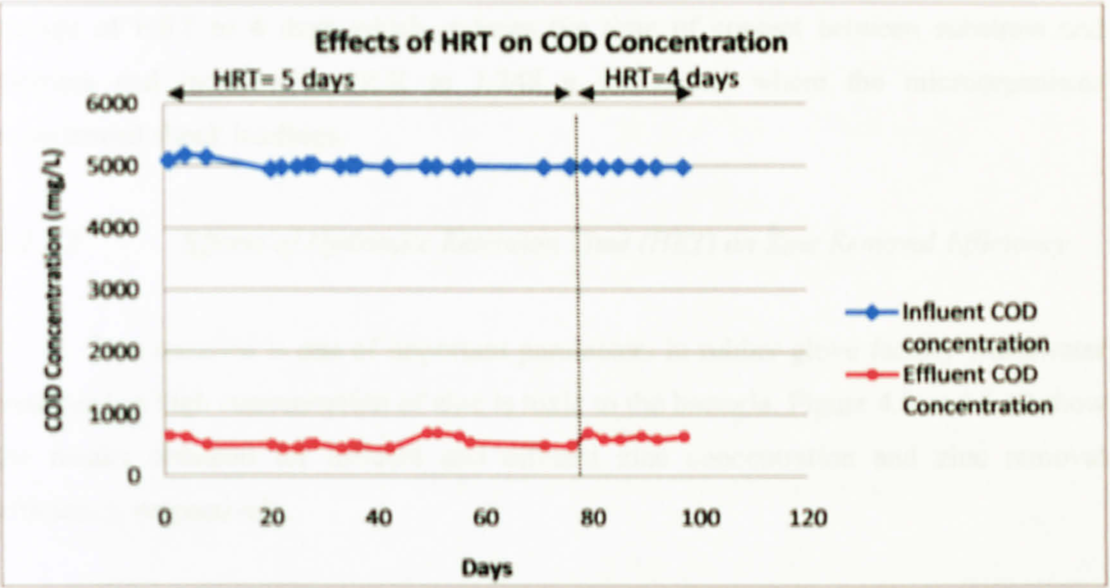


Figure 4.7 Effects of HRT on COD concentration

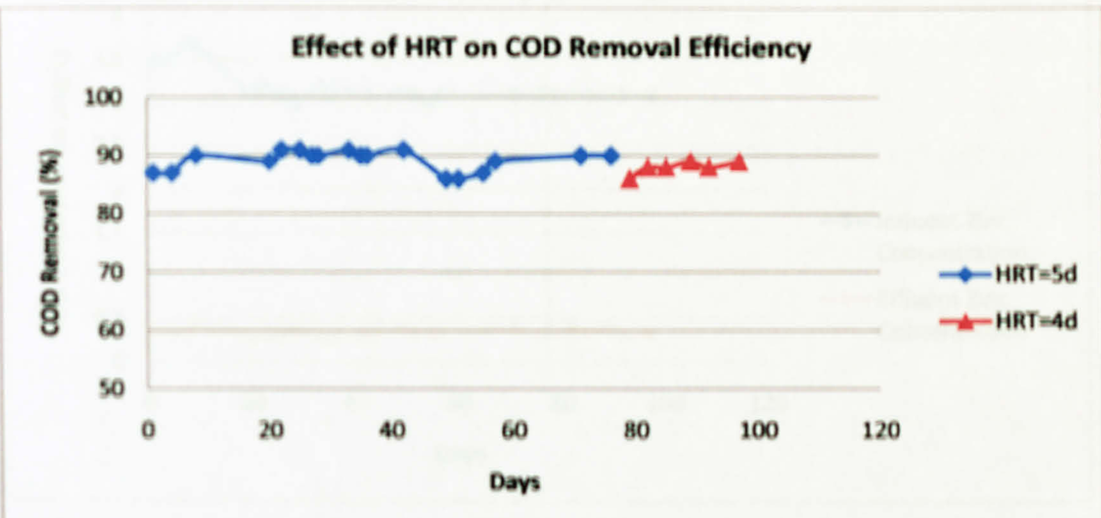


Figure 4.8 Effects of HRT on COD removal efficiency

The highest COD removal was 91% corresponding to HRT of 5 days, OLR of 0.998 g COD_{in}/L.d where the COD was reduced from 4980 mg/L to 453 mg/L. Meanwhile, the lowest efficiency of COD removal was 86% on day 49 and 79. The low efficiency on day 49 was because of reactor instability occurred where there are accumulation of suspended solids in the sludge blanket resulting from suspended solids overload. Consequently, it caused sludge washout and COD removal decreases from 91% to 86%. Besides, the low COD removal efficiency on day 79 was because of change of HRT to 4 days which reduces the time of contact between substrate and biomass and increase in OLR to 1.248 g COD_{in}/L.d where the microorganisms experienced shock loadings.

4.2.2.2 *Effects of Hydraulic Retention Time (HRT) on Zinc Removal Efficiency*

Zinc removal is one of important parameters in rubber glove factory wastewater treatment as high concentration of zinc is toxic to the bacteria. Figure 4.9 and 4.10 show the results obtained for influent and effluent zinc concentration and zinc removal efficiency, respectively.

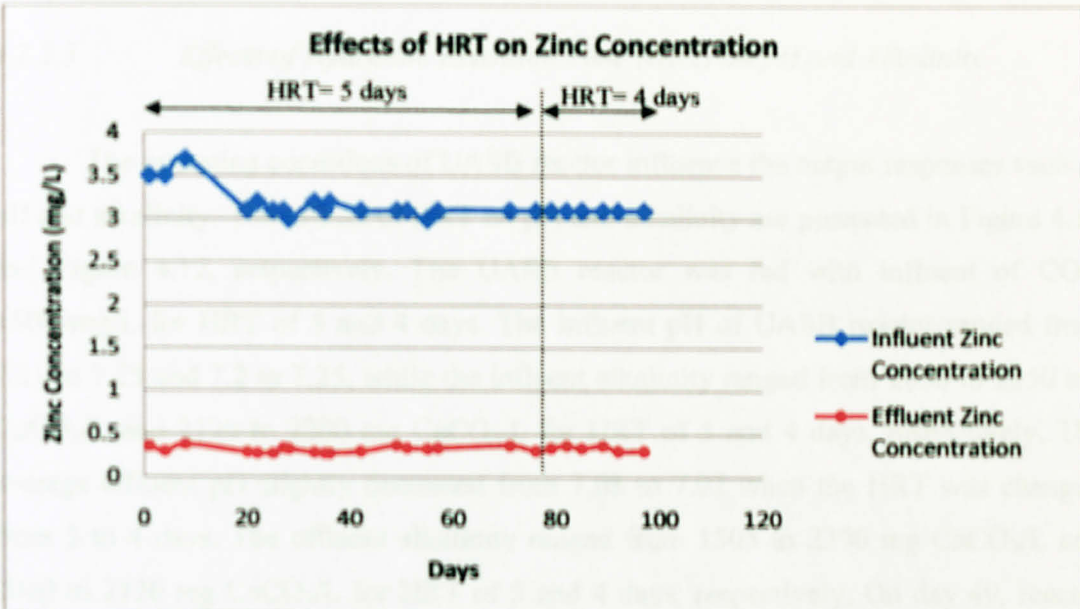


Figure 4.9 Effects of HRT on zinc concentration

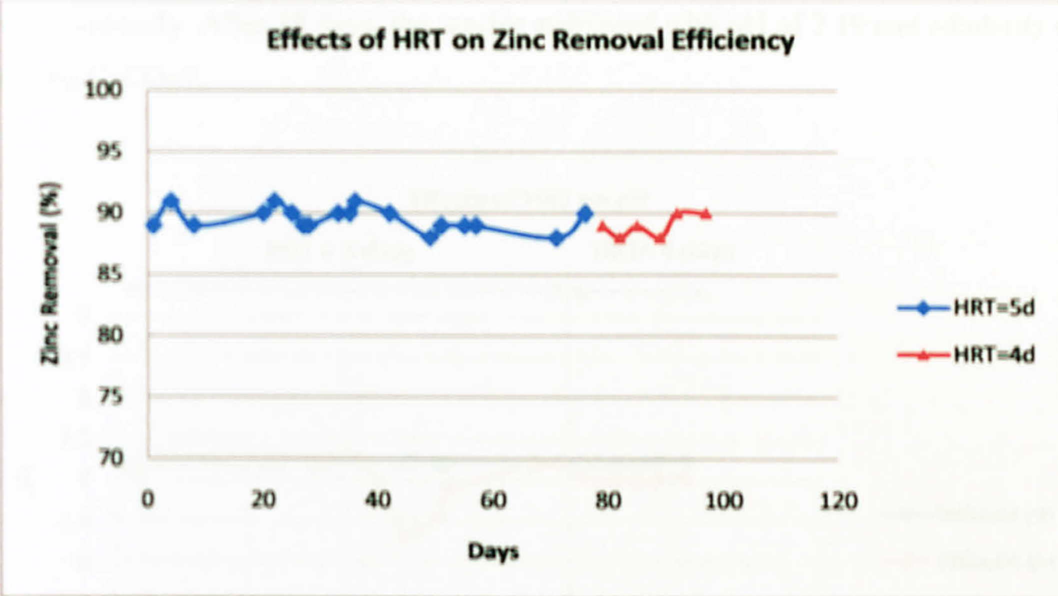


Figure 4.10 Effects of HRT on Zinc Removal Efficiency

The highest removal is 91% (corresponding to HRT of 5 days and OLR of 1.036 g COD_{in}/L.d). From the figure, lower HRT results to lower efficiency of zinc removal. Average amount of zinc concentration in the effluent is 0.33 mg/L which is considerable for effluent value.

4.2.2.3 Effects of Hydraulic Retention Time (HRT) on pH and Alkalinity

The operating conditions of UASB reactor influence the output responses such as pH and alkalinity. The effects of HRT on pH and alkalinity are presented in Figure 4.11 and Figure 4.12, respectively. The UASB reactor was fed with influent of COD ±5000mg/L for HRT of 5 and 4 days. The influent pH of UASB reactor ranged from 7.21 to 7.25 and 7.2 to 7.25, while the influent alkalinity ranged from 2050 to 2250 mg $CaCO_3$/L and 2120 to 2200 mg $CaCO_3$/L for HRT of 5 and 4 days, respectively. The average effluent pH slightly decreased from 7.08 to 7.02 when the HRT was changed from 5 to 4 days. The effluent alkalinity ranged from 1505 to 2390 mg $CaCO_3$/L and 2060 to 2120 mg $CaCO_3$/L for HRT of 5 and 4 days, respectively. On day 49, reactor instability occurred due to biomass washout which caused the effluent pH and alkalinity to drop suddenly. After 38 days, the reactor stabilized with pH of 7.19 and alkalinity of 2060 mg $CaCO_3$/L.

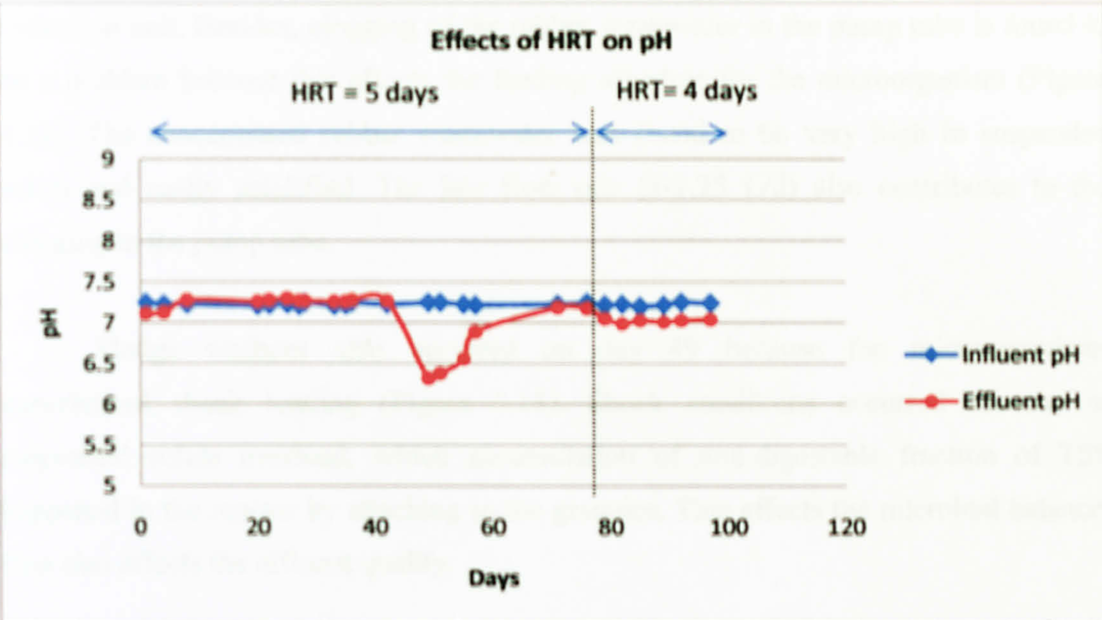


Figure 4.11 Effects of HRT on pH

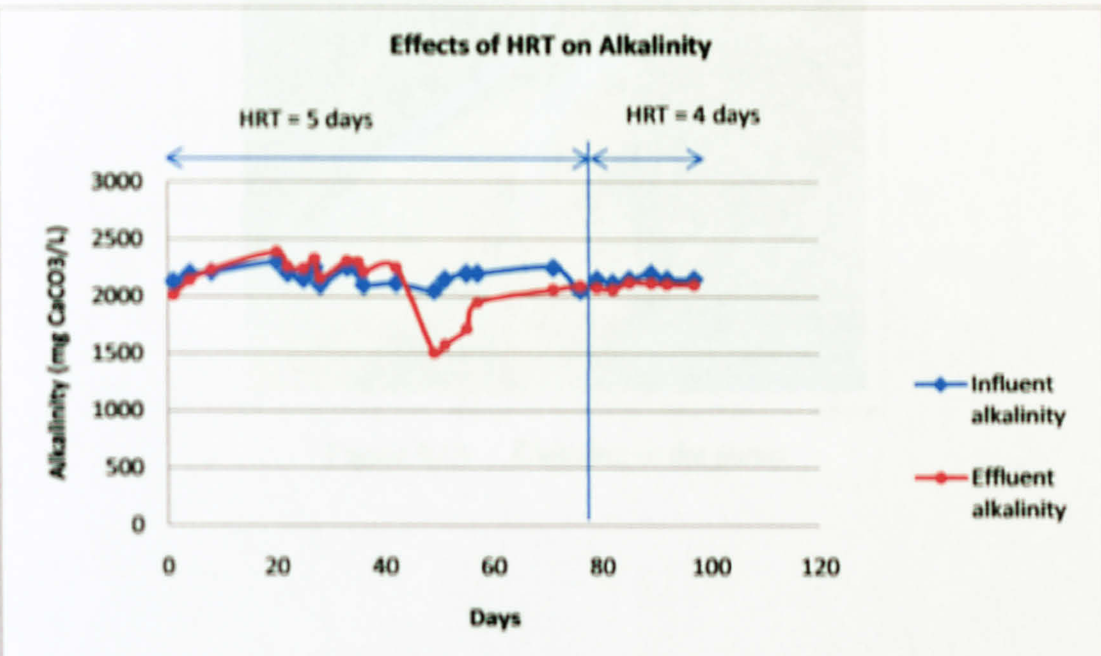


Figure 4.12 Effects of HRT on Alkalinity

4.3 Operational Issues

Analysis for methane production has not been done due to errors in gas collection unit. Besides, clogging of the rubber wastewater in the pump tube is found to be a problem because this affects the feeding schedule for the microorganism (Figure 4.13). The concentrated rubber wastewater was found to be very high in suspended solids and easily solidified. The low flow rate (1-1.25 L/d) also contributes to the clogging in the pump tube.

Sludge washout also occurred on day 49 because the microorganisms experienced shock loading (Figure 4.14). Shock conditions occurred because of suspended solids overload, which accumulation of non-digestable fraction of TSS happened in the reactor by attaching to the granules. This affects the microbial balance, thus also affects the effluent quality.

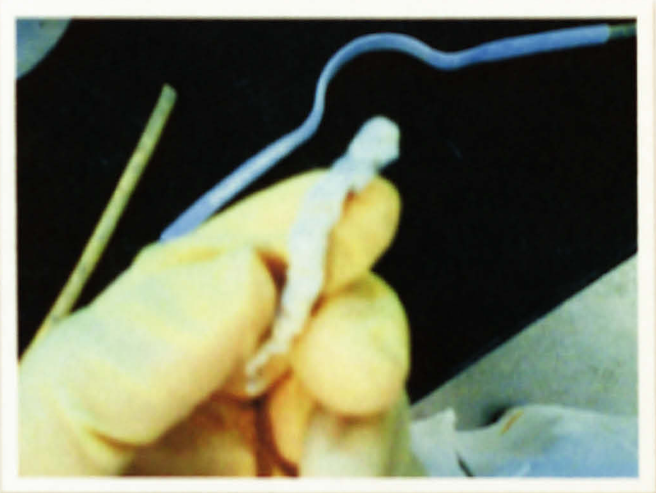


Figure 4.13 Clogging in the pump

Figure 4.14 Biomass washout

CHAPTER 5
CONCLUSION

The anaerobic treatability of rubber glove factory wastewater was successfully studied. The wastewater from rubber glove factories was characterized. Wastewater from rubber glove factory that has passed through leaching process and tanks washing is alkaline in nature with pH of 8.3. High COD (52 400 mg/L) and BOD (30 133 mg/L) indicates that the wastewater has high amount of organic matter which may come from the presence of residual latex. BOD to COD ratio was 0.58 which shows that the wastewater is easily biodegradable. Alternative method for rubber glove factory wastewater treatment has been identified by using high rate anaerobic reactor, Up-flow Anaerobic Sludge Blanket (UASB) reactor.

The results obtained shows that increases in the HRT resulted in increases in COD removal efficiency and zinc removal efficiency. The highest efficiency was achieved on day 22 which both of COD and zinc removal efficiency were 91%, corresponding to HRT of 5 days and Organic Loading Rate (OLR) of 0.996 g COD_{in}/L.d and COD_{in} of 4980 mg/L. The lowest efficiency was on day 49 which COD and zinc removal efficiency were 86% and 88%, respectively (corresponding to HRT of 5 days and OLR of 0.998 g COD_{in}/L.d and COD_{in} of 4990 mg/L). This is due to biomass washout that occurred because of suspended solids overload. The average effluent pH slightly decreased from 7.08 to 7.02 when the HRT was changed from 5 to 4 days. The effluent alkalinity ranged from 1505 to 2390 mg$CaCO_3$/L and 2060 to 2120 mg $CaCO_3$/L for HRT of 5 and 4 days, respectively. Although the COD removal efficiency was high, but COD concentrations in the effluent still exceed EQA limit, which are 400 mg/L. Further treatment is needed before the effluent can be discharged to surface waters.

CHAPTER 6

RECOMMENDATIONS

1. Further studies should be done to investigate the effects of lower HRT on reactor performance. Studies on other parameters of anaerobic treatment such as OLR and temperature should also been done to investigate its effects on treatment of rubber factory wastewater.

2. The treatment of rubber factory wastewater using UASB can be investigated in three parts: treatment by using raw wastewater, treatment by using chemical pretreated wastewater (coagulation and flocculation) and treatment by using physical pretreated wastewater (pre-settling). From this, the best condition for treatment of rubber factory wastewater can be investigated.

3. Studies on methane production cannot be done due to some errors in the gas collection unit. Further studies should be done to investigate the effects of process parameters on methane production.

4. Clogging in the pump and biomass washout was resulted from high suspended solids in the effluent and rubber wastewater is easily solidified. Pretreatment to remove suspended solids must be done first to avoid this.

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APPENDICES

APPENDIX A

RESULTS FOR CHARACTERIZATION OF RUBBER FACTORY WASTEWATER

1. Turbidity

Reading	Dilution	Turbidity (NTU)	x Dilution (NTU)
1	100	458.9	45890
2	150	306.2	45930
3	200	229.4	45880
Average			45900

2. Color

Reading	Dilution	Color (PtCo)	x Dilution (PtCo)
1	100	4601.7	460170
2	150	3067.8	460170
3	200	2300.8	460158
Average			460166

3. Total Suspended Solids (TSS)

Reading	Dilution	Sample Size (mL)	Weight of pan + filter paper before drying (mg)	Weight of pan + filter paper after drying (mg)	TSS (mg/L)	Average TSS (mg/L)
1	100	50	1318.7	1325.4	13400	
2	150	50	1326.3	1330.7	13200	13266
3	200	50	1335.1	1338.4	13200	

where,

$$TSS = \frac{\text{(Weight of pan + filter paper after drying)} - \text{(Weight of pan + filter paper before drying)}}{\text{Sample Size (L)}}$$

4. Biochemical Oxygen Demand (BOD_5)

Sample	Dilution	Volume of Sample (mL)	Initial DO, Do_i (mg/L)	Final DO, Do_f (mg/L)	Do_i- Do_f (mg/L)	Blank Correction	BOD_5 (mg/L)	Average BOD_5 (mg/L)
Blank 1		3	9.21	9.10	0.11			
Blank 2		3	9.16	9.02	0.14			
Blank 3		3	9.18	9.06	0.12			30133
1	100	3	8.93	5.80	3.13	0.12	30100	
2	150	3	8.83	6.69	2.14	0.12	30300	
3	200	3	8.81	7.19	1.62	0.12	30000	

where,

$$BOD_5 = \frac{\text{Initial Dissolved Oxygen } (DO_i) - \text{Final Dissolved Oxygen } (DO_f) - \text{Blank Correction}}{\frac{\text{Volume of Sample (mL)}}{300}}$$

5. Chemical Oxygen Demand (COD)

Reading	Dilution	COD (mg/L)	x Dilution (mg/L)
1	100	523	52300
2	150	350	52500
3	200	262	52400
Average			**52400**

6. Zinc

Reading	Dilution	Zinc (mg/L)	x Dilution (mg/L)
1	100	0.35	35
2	150	0.24	36
3	200	0.17	34
Average			**35**

7. **Phosphate**

Reading	Dilution	Phosphate(mg/L)	x Dilution (mg/L)
1	100	0.19	19
2	150	0.12	18
3	200	0.1	20
Average			**19**

8. **Ammonium-nitrogen**

Reading	Dilution	Ammonium-nitrogen (mg/L)	x Dilution (mg/L)
1	100	1.29	129
2	150	0.84	126
3	200	0.63	126
Average			**127**

APPENDIX B

RESULTS FOR UP-FLOW ANAEROBIC SLUDGE BLANKET (UASB) REACTOR START-UP

Days	Influent				Response						
	CODin (mg/l)	Zincin (mg/L)	pH	Alkalinity (mg CaCO3/L)	CODeff (mg/L)	COD removal (%)	Zinceff (mg/L)	Zinc removal (%)	pH	Alkalinity (mg CaCO3/L)	MLVSS (mg/L)
2	5240	3.6	7.25	2150	1520	71	0.8	78	7.19	1950	11992
5	5240	3.5	7.29	2050	1150	78	0.7	80	7.22	2000	
8	5230	3.5	7.22	2150	1150	78	0.5	85	7.25	2200	
10	5230	3.4	7.25	2200	730	86	0.5	85	7.20	2000	
12	5230	3.5	7.30	2100	780	85	0.5	86	7.25	2000	
15	5230	3.5	7.28	2150	780	85	0.5	86	7.23	2050	13200

APPENDIX C

EFFECTS OF HYDRAULIC RETENTION TIME (HRT) ON REACTOR PERFORMANCE

i) COD and Zinc Removal

Days	HRT (days)	Influent			Effluent		Response	
		COD_{in} (mg/L)	OLR (g COD_{in}/L.d)	$Zinc_{in}$ (mg/L)	COD_{eff} (mg/L)	$Zinc_{eff}$ (mg/L)	COD Removal (%)	Zinc Removal (%)
1	5	5090	1.018	3.5	654	0.36	87	89
4	5	5180	1.036	3.5	635	0.3	87	91
8	5	5150	1.03	3.7	510	0.38	90	89
20	5	4950	0.99	3.1	502	0.29	89	90
22	5	4980	0.996	3.2	453	0.28	91	91
25	5	4990	0.998	3.1	465	0.28	91	90
27	5	5020	1.004	3.1	515	0.34	90	89
28	5	5020	1.004	3	520	0.33	90	89
33	5	4990	0.998	3.2	454	0.29	91	90
35	5	5010	1.002	3.1	498	0.28	90	90
36	5	5010	1.002	3.2	485	0.28	90	91
42	5	4980	0.996	3.1	455	0.3	91	90
49	5	4990	0.998	3.1	698	0.37	86	88
51	5	4990	0.998	3.1	698	0.34	86	89
55	5	4980	0.996	3	647	0.33	87	89
57	5	4990	0.998	3.1	548	0.34	89	89
71	5	4980	0.996	3.1	498	0.37	90	88
76	5	4990	0.998	3.1	499	0.31	90	90
79	4	4990	1.248	3.1	697	0.34	86	89

82	4	4980	1.245	3.1	598	0.37	88	88
85	4	4990	1.245	3.1	599	0.34	88	89
89	4	4980	1.245	3.1	647	0.37	89	88
92	4	4980	1.245	3.1	598	0.31	88	90
97	4	4980	1.245	3.1	646	0.31	89	90

APPENDIX C

EFFECTS OF HYDRAULIC RETENTION TIME (HRT) ON REACTOR PERFORMANCE

ii) pH and Alkalinity

Days	HRT (days)	Influent		Effluent	
		pH	Alkalinity	pH	Alkalinity
1	5	7.25	2130	7.12	2010
4	5	7.23	2200	7.13	2140
8	5	7.23	2210	7.28	2230
20	5	7.21	2300	7.26	2390
22	5	7.22	2200	7.28	2260
25	5	7.23	2150	7.30	2240
27	5	7.21	2250	7.27	2330
28	5	7.25	2100	7.27	2160
33	5	7.21	2250	7.26	2310
35	5	7.22	2225	7.26	2300
36	5	7.25	2100	7.28	2215
42	5	7.23	2115	7.27	2250
49	5	7.25	2050	6.32	1505
51	5	7.25	2150	6.38	1575
55	5	7.23	2200	6.56	1715
57	5	7.22	2200	6.89	1945
71	5	7.23	2250	7.19	2060
76	5	7.25	2050	7.18	2090
79	4	7.22	2150	7.05	2075
82	4	7.23	2120	6.99	2060
85	4	7.2	2150	7.03	2120
89	4	7.22	2200	7.01	2115
92	4	7.25	2150	7.03	2105
97	4	7.24	2150	7.04	2100