PAPAN LANDFILL LEACHATE TREATMENT USING A SEQUENCING BATCH REACTOR AND COAGULATION

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Environmental Engineering

Faculty of Engineering and Green Technology

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

Landfill leachate generation has been increasing dramatically over the past few decades due to the increase of solid waste or municipal solid waste (MSW) as global development continues and people having higher standard of living lead to more material consumption and production of waste. There were many cases in which the treatment of leachate and domestic wastewater involve a two-stage treatment process. Both the sequencing batch reactor (SBR) and coagulation are well-known biological and physiochemical methods which has high efficiency in treating domestic wastewater and landfill leachate for the past few decades. The Papan Landfill in Perak currently has no proper leachate treatment system, therefore SBR will be investigated to treat the Papan landfill leachate. The needs of post treatment after the primary treatment by SBR is a new trend of two-stage treatment technique employed which can greatly improve the treatment effectiveness. The optimum aeration rate, L/min of the SBR, optimal pH and dosage (g/L) of Aluminium Sulphate (ALUM) for coagulation as post-treatment of Papan landfill leachate had been investigated to compare the treatment efficiency of the treated effluent by SBR and after post treatment by ALUM. Firstly, the two-step sequential treatment by SBR followed by coagulation using ALUM had achieved a removal efficiency of 71.03 %, 87.24 %, 91.82 % and 85.59 % for COD, NH_3-N, TSS and colour respectively. Moreover, the two-stage treatment process achieved removal efficiency of heavy metals for Cadmium at 95.00 %, Lead at 95.09 %, Copper at 95.39 %, Selenium at 100.00 % removal and Barium at 87.27 %. Hence, the two-step sequential treatment in this research is an effective treatment method for Papan landfill leachate.

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LIST OF SYMBOLS / ABBREVIATIONS

ALUM	Aluminium Sulphate
Anammox	Anaerobic Ammonium Oxidation
AOP (s)	Advance Oxidation Processes
AS	Activated Sludge
ATP	Adenosine Triphosphate
BOD_5	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOE	Department of Environment
F:M	Food-to-Microorganism Ratio
GDP	Gross Domestic Product
GHGs	Green House Gases
HRT	Hydraulic Retention Time
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
MOH	Ministry of Health
MSW	Municipal Solid Waste
NA	Not Available
ORP	Oxidation Reduction Potential
PAC	Powdered Activated Carbon
PCB	Polychlorinated Biphenyl
PET	Polypropylrene
POME	Palm Oil Mill Effluent
RBC	Rotating Biological Contactor
SBR	Sequencing Batch Reactor
SRT	Sludge Retention Time
SS	Suspended Solids
TDS	Total Dissolve Solids
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UNEP	United Nations Environment Programme
VFA	Volatile Fatty Acids

VS	Volatile Solids
XOCs	Xenobiotic Organic Compounds

Al	Aluminium
$Al(OH)_3$	Aluminium Hydroxide
$C_5H_7NO_2$	Glutarimide or New Organic Cells
CO_2	Carbon Dioxide
Fe	Iron
H^+	Hydrogen ion
H_2O	Water Molecule
N_2	Nitrogen Gas
NH_3	Ammonia
NH_3-N	Ammonical-Nitrogen
NH_4^+	Ammonium
NO_2^-	Nitrite
NO_3^-	Nitrate
O_2	Oxygen Gas
OH^-	Hydroxide ion
P	Phosphorus

ADMI	American Dye Manufactures Institute
g	Grams
g/L	Grams per Liter
hr / h	Hour (s)
kg	Kilogram (s)
kWh	Kilowatt Hour
L	Liter
L/min	Liters per Minutes
m^3	Meter Cube
mg/L	Milligram per Liter
mV	Millivolt
NTU	Nephelometric Turbidity Units
^oC	Degree Celsius
ppT	Parts Per Trillion
PtCo	Platinum Cobalt
RM	Ringgit Malaysia
RPM	Revolutions per Minute
tons	Tonnes
V	Volt
W	Watt
Ω	ohm

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Waste, rubbish, junk or garbage is of the same meaning of unwanted or undesired material or substance by the human concept. The existence of waste or unwanted material is due to the limitations of present technology to turn and treat waste into other useful means like new source of raw material and energy. In nature there is no waste as the waste can be transform back into raw material by natural processes namely bio-degradation, fermentation as well as photosynthesis and can be reused as an energy source. Unfortunately, every product which is produced by the industry during the very end of its life cycle will conceptually turn into waste as current technology cannot afford to transform the waste back to raw material and other useful means. Only a handful of waste can be turned back into new raw material which our current technology can afford is the recycling of paper, plastics, glass and aluminium or metal.

It is inevitable that the increase of the world's population has resulted in the ever increasing generation of solid waste per person. In 2000, 318 million tonnes of waste generated was estimated globally. With an annual increase of 6% of the global solid waste generation (Periathamby et al., 2009). At present, approximately 1.3 billion tonnes per year of Municipal Solid Waste (MSW) is generated and is expected to increase to 2.2 billion tonnes per year by 2025 (Hoornweg and Bhada-Tata, 2012).

Therefore, the generation of solid waste which will be disposed mainly to landfill around the world cause adverse impacts on the population and to the environment. Sustainable landfill is needed to preserve the well-being of the environment (Agamutu et al., 2011). Sanitary landfill is one of the properly designed engineering landfill which makes the landfill sustainable and can be defined as "a method of disposing of refuse into land without creating hazards or nuisance to both the health and well-being of the environment and the people, by means of confining the refuse to a smaller area, to cover it with a layer of earth at the end of each day operation and to reduce it to the smallest practical volume as possible to provide more frequent intervals as may be necessary" (Raghab et al., 2013). To deal with this amount of waste generated globally and to keep urban centres clean, a proper solid waste management is one of the basic essential services needed provided by the municipal authorities in each country (Asnani, 2006).

Malaysia with a gross domestic product (GDP) of $14,400 is made up of the Peninsular of Malaysia and the Borneo island of Sabah and Sarawak states which contributes to an area of 329,750 km^2 with a population of approximately 24.8 million by the year of 2008 (Periathamby et al., 2009). As a country with the aim of to achieve 2020 with the industrialized country status, it is inevitable that Malaysia has to face problems and challenges of solid waste management like other developing countries namely China, India, Indonesia and Taiwan. Landfilling remains the main disposal method of solid waste and there are 290 landfills in Malaysia in which 176 are still in operation and 114 were closed (Noor et al., 2013). In Malaysia, over 80% of the collected MSW is landfilled and others are unsanitary, open dumpsite and over-loaded in capacity (Fazeli et al., 2016). In developing countries, the main challenges for waste management which include waste treatment are the ever increasing per capita waste generation and the complexity of waste composition. In Malaysia alone, 28,500 tonnes of municipal solid waste was daily generated (Agamuthu and Fauziah, 2011). According to Periathamby et al. (2009), the estimated generation of waste in 1996 was 13,000 tonnes and the waste generated escalated to 19,100 tonnes in 2006 was disposed daily into landfill and this is due to Malaysia is a rapid developing country. Over the past 10 years, the generation of municipal solid waste (MSW) has increased more than 91% since the last 10 years due to change in consumption behaviour, increase per capita income, migration of rural to urban and rapid development of urban areas like Kuala Lumpur and Ipoh.

1.2 Problem Statement

The generation and burial of municipal solid waste (MSW) in Malaysia landfills not only cause landfill leachate to be generated when excess precipitation infiltrate through the many layers of the landfill (Kjeldsen, 2002), it also contributed to the generation of greenhouse gas (GHGs) like carbon dioxide and methane gas into the atmosphere.

Landfill leachate which is generated of biochemical processes in the inherent water content of wastes and in the waste's cells through the intrusion or infiltration of groundwater and surface run-off due to precipitation. After the closure of the landfill, the landfill will continue to generate hazardous leachate and the generation of leachate will last for 30-50 years (Ngo et al., 2008). In general, landfill leachate contains mostly of organic matter both biodegradable and refractory to biodegradation (refractory compounds such as humic and fulvic acids) (Peng, 2013), as well as heavy metals, ammonia-nitrogen, and chlorinated organic which if infiltrates and flows into nearby water bodies and into groundwater will poses adverse health effect to the surrounding soil and affecting the entire ecological system including human health (Renou et al., 2008). There are four groups of landfill leachate pollutants that can be categorized into heavy metals, dissolved organic matter, inorganic macro-components and xenobiotic organic compounds. According to Fazeli et al. (2016), the large portion of municipal solid waste are in the form of organic matter which contributes 54.4% of the total municipal solid waste in 1980 and 44.8% in 2005.

In 2005 and 2010, organic wastes contribute 47.5% and 43.5% respectively of material composition of municipal solid waste in Malaysia (Johari et al., 2014). The decrease in the number of organic waste is due to the higher in purchasing power which enables the society to consume various new products (mainly electronic and other plastic or oil based products) which leads to the more complex and highly heterogeneous composition of waste generated in the landfill upon disposal (Agamuthu and Fauziah, 2011).

At present, Papan landfill in Perak does not have a proper leachate treatment system and the landfill is surrounding by streams and rivers. Hence, a proper treatment system is needed to treat the leachate before severely polluting the environment. Biological treatment method is the most worldwide used method for treating landfill leachate. (Liu, 2013) This is because biological treatment (suspended or attached growth) is the most environmentally friendly treatment with a cost-effective, simple and reliable treatment method to remove multiple contaminants in landfill leachate. Moreover, biological treatment is a very effective method in the removal of organic (BOD_5), inorganic and nitrogenous matter from young landfill where the BOD_5/COD ratio has a high value of more than 0.5 (Peng, 2013). The main processes and basic principles for biological removal of nitrogen from landfill leachate are nitrification and denitrification (Liu, 2013). The nitrification process has high treatment efficiency for Total Kjeldahl Nitrogen (TKN) conversion ranging from 85% to 98%. (Baig et al., 1996). There are various kinds of biological treatment methods for aerobic treatment such as aerobic sequencing batch reactors (SBR), activated sludge, nitrification-denitrification, membrane bio-reactors, aerated lagoons and biological aerated filters in which usually having combination with coagulation.

Therefore, the aim of this study is to evaluate the performance and applicability of aerobic sequencing batch reactor (SBR) in treating Papan landfill leachate followed by coagulation using Aluminium Sulphate (ALUM) for post treatment in treating effluent from SBR as at the moment there is no biological or physiochemical treatment for treating leachate at Papan landfill. Biological treatment is chosen as the treatment method for Papan as the leachate from Papan landfill is classified as Young leachate (<5 years in operation) as the Papan landfill only began its operation on March 2012 (Thestar, 2011).

1.3 Objectives

1. To determine the characteristics of leachate generated from fresh waste cell in Papan landfill.
2. To evaluate the treatment efficiency of Papan landfill leachate by sequencing batch reactor (SBR).
3. To evaluate the post treatment efficiency of Papan landfill leachate by coagulation method using Aluminium Sulphate (ALUM).

1.4 Project Outline

This research focuses on the sizing, setting up and to operate the sequencing batch reactor (SBR) and post treatment in further treating the effluent from SBR using ALUM as coagulation in UTAR in the effort to treat leachate generated from Papan Landfill. The efficiency of using Palm Oil Mill sludge from Tian Siang (Air Kuning) Sdn Bhd as activated sludge and ALUM as coagulant for post treatment were studied on the removal on chemical oxygen demand (COD), ammonia-nitrogen (NH_3-N), total suspended solids (TSS) and colour as well as the effect of the two-stage treatment system on heavy metals. Biological treatment method, SBR was chosen as currently there is no treatment for Papan landfill leachate. Moreover, the leachate from Papan landfill is classified to be young leachate as biological treatment is suitable for young leachate. Papan landfill begin its operation since March 2012 which is within 5 years from the current year 2016 and 2017 during this research period. The performance of the SBR and coagulation was determined from the difference quality of the treated effluent compared to the influent (Papan raw leachate). To meet the objectives, this research will be focused on the effect of aeration rate (L / min) of the conventional SBR with specified contact time (hr), sludge retention time (SRT), hydraulic retention time (HRT), pH and constant cycle mixing time, settling time, decanting time and feeding time of the SBR. While for the post treatment using ALUM, the study will focus on the optimal pH and dosage (g/L) of ALUM.

There are five chapters in this report. First chapter reveals the background of study, problem statement and objectives of this research. Chapter two is literature review from solid waste management in Malaysia, landfill leachate properties of Malaysia and Papan landfill and some crucial research on biological treatment using SBR in treating landfill leachate process. Chapter three will be the methodology which includes sample collection, sample analysis, experimental set-up and design, analytical of effluent as well as studies. Chapter four which is the results and discussion include the key findings in this research outcome. Lastly, chapter five provides the conclusion for this research and the recommendation of this project for further study in future.

CHAPTER 2

LITERATURE REVIEW

2.1 Solid Waste

The natural environment is deteriorating rapidly in many developing countries, especially in urban areas. The ever increase in production of solid waste and inadequate municipal solid waste management are the major factors which lead to the degradation of environmental quality (Badgie et al., 2012) and is the main challenges for solid waste management for the local authorities in many countries. Since the industrial evolution, the generation of waste increased. Municipal solid waste (MSW) which usually generated from residential and commercial areas comprise around twenty different categories namely wood waste, food waste, fruit waste, green waste, paper (mixed), paper (high grade and fine grade), plastic (rigid, film and foam), cardboard, textile, metals (ferrous or non-ferrous), diapers, new print, batteries, glass and construction waste. These categories of MSW can be classified into organic and inorganic waste which around 80% of the total MSW will be ended up in landfill (Kalanatarifard and Yang, 2012).

2.1.1 Quantity of Solid Waste

Many Asian countries have experienced urbanization over the past 50 years. Advancement in economic development, faster rate of industrialization and public practices of the region directly influences the level of MSW generation. Currently, 50% of the world's population lives in urban areas and the number will keep on increasing down the century (Fazeli et al., 2016).

The quantity of waste generation is also proportion to the increase of population in Malaysia. In Malaysia, the rural population generates 0.8 kg/cap/day of waste which is twice as less compared to the urban middle-class population which generates 1.9 kg/cap/day of waste (Kalanatarifard and Yang, 2012). The main problem comes from urban areas as people tends to generate more waste as their standard of living is higher hence giving them to have a greater purchasing power. The Ministry of Housing and Local Government (MHLG) reported that for the year 1991 to 1993, the national average rate of MSW production was 0.711 kg/person/day. The number increased to 0.8 kg/person/day for 1994 to 1999 (Sakawi, 2011). The nation MSW generation will keep on increasing and according to Agamuthu et al. (2009) it was reported that in 2003 the nation's MSW generation was 1.3 kg/person/day and in 2007 was at 1.5 kg/person/day. MSW generation reaches at 2.5 kg/person/day in recent past especially in major cities like Kuala Lumpur and Petaling Jaya (Johari et al, 2014). Since 1994, the population in Malaysia has been increasing at a rate of 2.4% or about 600,000 per annum. In 2003, the average generation of municipal solid waste had increased from 0.5-0.8 kg/person/day to 1.7 kg/person/day in many of the major cities especially in Kuala Lumpur and Johor. The quantity of MSW is estimated to increase to 31,000 tons by the year 2020 (Manaf et al, 2009).

Figure 2.1 shows the increase in the amount of waste generated which is correlated to the population respective to each of the states in Malaysia throughout the year from 1996 to 2008 which are summarized by Noor et al. (2013).

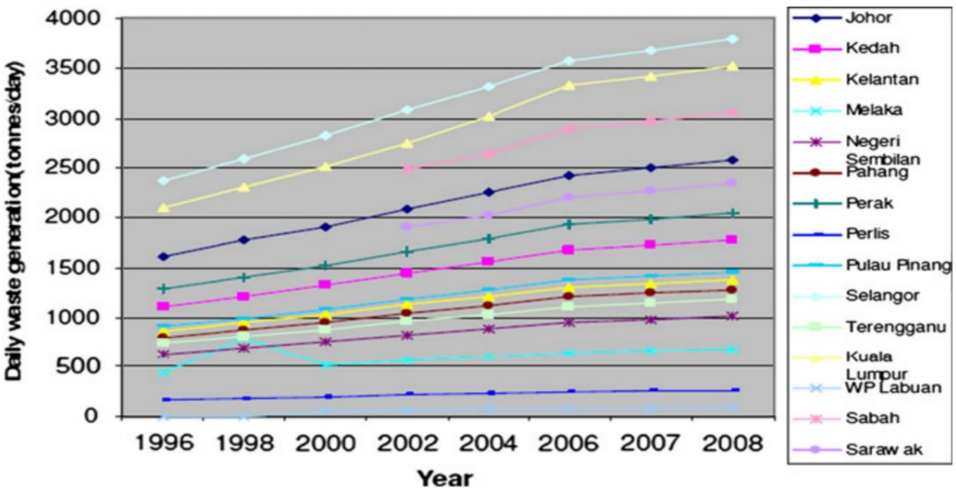

Figure 2.1: Daily Waste Generation in States of Malaysia from 1996 to 2008 (Noor et al., 2013)

2.1.2 Composition of Solid Waste

Waste comes from many different areas in cities from public areas, private institutions, residential population and commercial establishments. The composition of solid waste differs from area to area depending on the type of culture, living style and economical condition in that particular area. Basically, the types of solid waste are generated respectively to the source of generators which is shown in Table 2.1 below.

Table 2.1: Source and Types of Municipal Solid Waste (Shekdar, 2009)

Sources	Typical waste generators	Types of solid waste
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, glass, metals, ashes, special wastes (bulky items, consumer electronics, batteries, oil and tires) and household hazardous wastes

Commercial	Stores, hotels, restaurants, markets, office buildings	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Institutional	Schools, government centre, hospitals, prisons	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Municipal services	Street cleaning, landscaping, parks, beaches, recreational areas	Street sweepings, landscape and tree trimmings, general wastes from parks, beaches and other recreational areas

Table 2.2 shows the composition of municipal waste in percentage generated respective to residential with high income, residential with medium income, residential with low income, commercial and institutional just in Kuala Lumpur which was summarized by Badgie et al. (2012). The outcome of the table shows that the organic waste generated from residential area is obviously more than compared to commercial and institutional sectors. This trend is also similar and agreed with the researched done by Noor et al. (2013) which summaries the average composition of MSW generated in Malaysia where food waste (organic waste) stands the most at 41% of the total generation of municipal solid waste.

Table 2.2: Average Composition (%) Of MSW in KL, Malaysia. (Badgie et al, 2012)

Sources	Residential high income (%)	Residential medium income (%)	Residential low income (%)	Commercial (%)	Institutional (%)
Food/Organic	30.84	38.42	54.04	41.48	22.36
Mixed paper	9.75	7.22	6.37	8.92	11.27
Newsprint	6.05	7.76	3.72	7.13	4.31
High-grade paper	0	1.02	0	0.35	0
Corrugated paper	1.37	1.75	1.53	2.19	1.12
Plastic (rigid)	3.85	3.57	1.90	3.56	3.56
Plastic (film)	21.62	14.75	8.91	12.79	11.82
Plastic (foam)	0.72	1.72	0.85	0.83	4.12
Diapers	6.49	7.58	5.83	3.80	1.69
Textile	1.43	3.55	5.47	1.91	4.65
Rubber/leather	0.48	1.78	1.46	0.80	2.07
Wood	5.83	1.39	0.86	0.96	9.84
Yard waste	6.12	1.12	2.03	5.75	0.87
Glass (clear)	1.58	2.07	1.21	2.90	0.28
Glass (colored)	1.17	2.02	0.09	1.82	0.24
Ferrous	1.93	3.05	2.25	2.47	3.75
Non-ferrous	0.17	0	0.18	0.55	1.55
Aluminium	0.34	0.08	0.39	0.25	0.04
Batteries/hazards	0.22	0.18	0	0.29	0.06
Fine	0	0.71	2.66	0	0.39
Other organic	0.02	0	0	1.26	1.00
Other inorganic	0	0.27	0.25	0	8.05

Other	0	0	0	0	6.97
Total	100.00	100.00	100.00	100.00	100.00

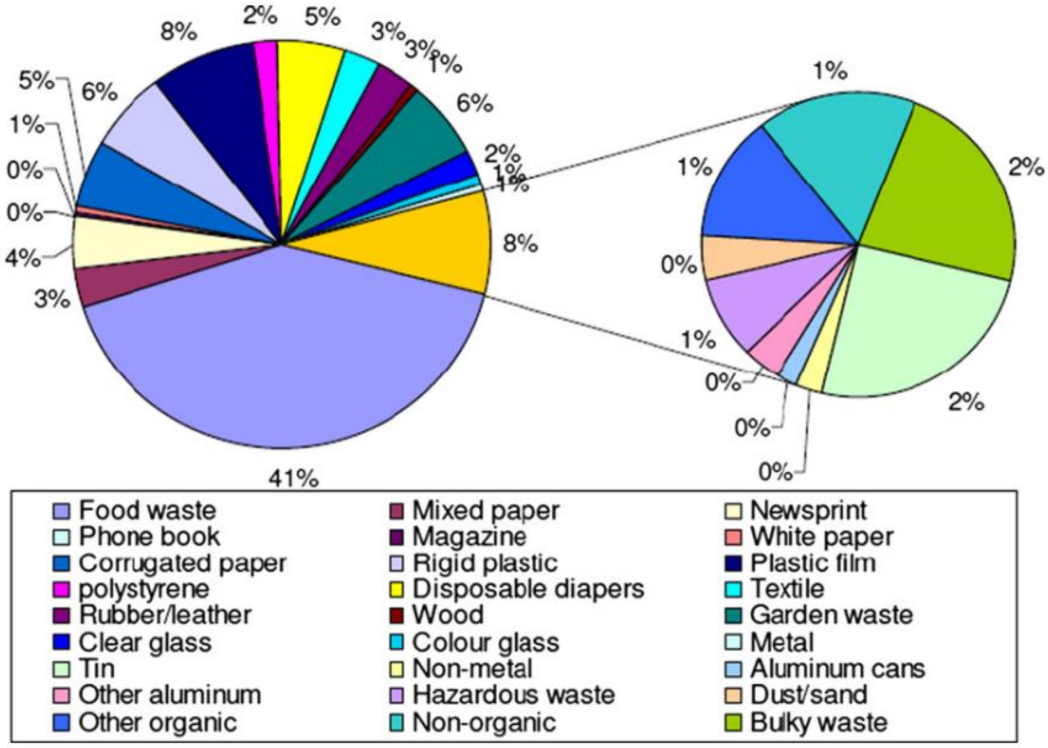

Figure 2.2: Average Composition of MSW Generated in Malaysia (Noor et al., 2013)

The composition of MSW in Malaysia in Figure 2.2 has the same trend with Average Composition of MSW in KL in Table 2.2 with the highest organic waste as food waste at 41 %. The second largest percentage of composition in MSW in Malaysia is plastics and non-metal waste both contributes 8 % follow by garden waste and rigid plastics contribute 6 % to the overall composition of MSW. Other types of waste namely glass, paper, wood, metals and so on contributes to Malaysia MSW. Some of the waste that should not enter into the landfill like hazardous waste materials, electronic wastes and other universal waste unfortunately still being collected and dump into Malaysia's landfill until today. Due to this factor, landfill leachate is naturally very hazardous and toxic to the environment and other living organisms which might contact or interact with landfill leachate.

2.1.3 Solid Waste Management (SWM)

The main purpose of SWM is to ensure the safety of the public and to protect the environment. Solid waste management is directly link to landfill as landfill is a technique to manage solid waste in a more proper way (Masirin et al., 2008). The system of SWM in Asia is reflected based for its climate, topography, economic, food and mixed culture. MSW in Asia has becoming crucial as the concentration of the population in cities is increasing, legal interventions, and rising in public awareness about hygiene and sanitation as well as the availability of newer technology in waste treatment (Shekdar, 2009).

SWM was privatized in Malaysia since 1996 and currently there are three solid waste concessionaries which operate at their own respective zones: southern regions is taken care by Southern Waste management, northern regions is taken care by Idaman Bersih Sdn Bhd and central regions is taken care by Alam Flora Sdn Bhd. (Manaf et al., 2009) The government of Malaysia still has the role in municipal solid waste management as stipulated in Section 72 of the Local Government Act 1976 in under the responsibility of the local authority. Solid waste in Malaysia are generally categorized into three major categories namely:

i. Municipal solid waste
ii. Hazardous waste or schedule waste
iii. Clinical waste

Different government department has their own responsible towards each category of the waste. Ministry of Housing and Local Government is responsible for municipal solid waste, hazardous is under the responsible of Department of Environment (DOE) and clinical waste is under the responsibility of Ministry of Health (MOH) (Manaf et al., 2009). According to Shekdar (2009), the author summarized the typical solid waste management system in Asian countries as shown in Figure 2.3 and Malaysia is having the same SWM system which is similar among Asian countries.

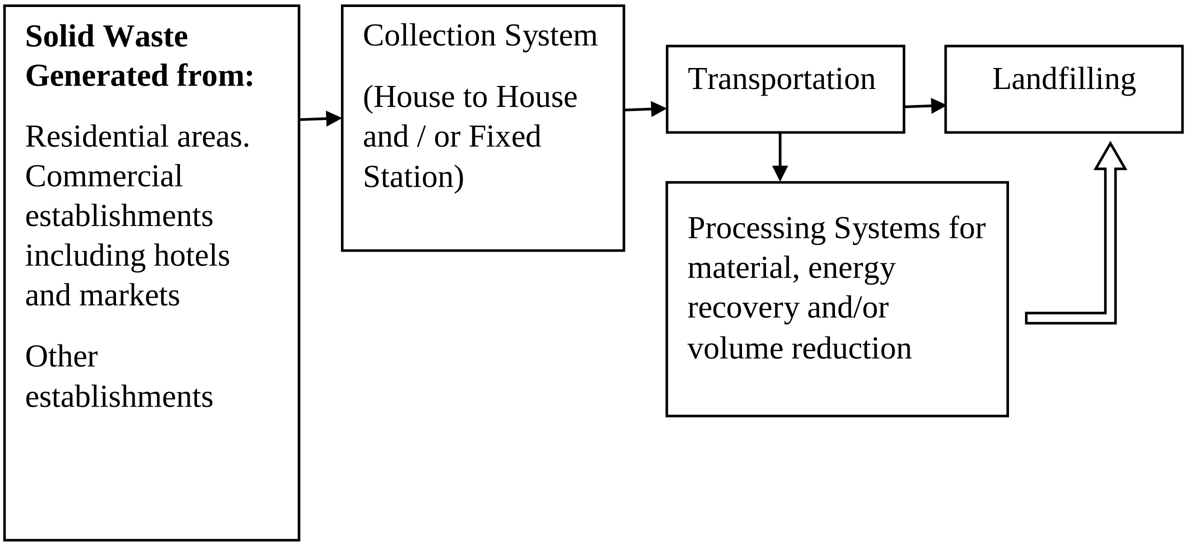

Figure 2.3: Typical Solid Waste Management in Asia Countries (Shekdar, 2009)

2.2 Landfill in Malaysia

Landfill is the last option that can deal with all material in the waste stream and is the physical facility used for the disposal of refuse and other residuals on the earth’s surface (Badgie et al., 2012). Due to this factor, landfill is the main disposal method of solid waste in Malaysia.

The Ministry of Housing and Local Government are in the supervision of Malaysia’s landfill sites. There are 4 levels or stages of improvement of landfill which is listed in the Action Plan 1988 of Malaysia: (Fazeli et al., 2016; Adnan et al., 2013)

- Level 0: Open dumpsite.
- Level 1: Controlled dumping.
- Level 2: Sanitary landfill with daily cover.
- Level 3: Sanitary landfill with leachate circulation.
- Level 4: Sanitary landfill with leachate treatment.

According to Manaf (2009), there are 73 open dumping sites, 71 comtrolled dumping sites and 11 sanitary landfill operating in Malaysia. Table 2.3 summarises the numbers and types of disposal site according to states where the site is operating in Malaysia.

Table 2.3: Types and Number of Disposal Site in Malaysia (Manaf et al., 2009)

State	Open dumping	Controlled dumping	Sanitary landfill	Total
Johor	12	14	1	27
Kedah	9	5	1	15
Kelantan	12	2	0	14
Melaka	2	3	0	5
Negeri Sembilan	8	6	0	14
Pahang	7	5	3	15
Perak	15	11	4	30
Perlis	0	1	0	1
Pulau Pinang	1	1	1	3
Selangor	5	15	0	20
Terengganu	2	8	1	11
Total	73	71	11	155

Level 0: Open Dump Site

Open dumping is the most common method used for the discard of municipal solid waste in Malaysia. As shown in the Table 2.4 above by Manaf et al. (2009) open dumping stands the most in total by 75/155 compared to controlled dumping and sanitary landfill. This is due to the method is the most cost effective for many years compared to other solid waste disposal methods. Open dumping is still in operation in mostly all municipalities until today where the waste is dumped in an uncontrolled manner which can cause severe environmental issues (Tarmudi et al., 2012).

According to UNEP. (2015), open dump sites are unplanned and operating in hazardous conditions where the located areas are not feasible due to the absence of facilities such as biogas collection systems, leachate collection and treatment systems, proper daily soil cover and landfill liner which can help to control and to protect the both environment as well as the wellbeing of humans. Besides that, open dumpsites do not control the quantity and the quality of waste input where toxic, hazardous and medical waste which are not supposed to be landfilled are permitted for site disposal.

Level 1: Controlled Dump Site

Controlled dumpsite is similar to open dumpsite as both of the sites are non-engineered disposal site. Controlled dumping is introduced due to need of the closure of open dumpsites with the addition of some disposal facilities (UNEP, 2015). Controlled dumps is also known as secure landfills which can provide a more effective disposal of solid waste within the environmental protection regulations and standards. This is due to the fact that controlled dumpsite has a planned capacity and the disposal is only allowed at certain designated areas (USAID, 2016). For controlled dumping, there may be gas management systems depending on the project needs and there are only partial leachate management systems. Another main difference of open dump and controlled dump is that open dump does not imply compaction while controlled dump does employ compaction in cases. A controlled dump site has fencing where to control the amount of dump at the end of operation of the site. Moreover, there are basic records for keeping, picking and trading of controlled waste in controlled dumpsite (UNEP, 2015).

Level 2 – 4: Sanitary Landfills

Sanitary landfill is different from open dumpsite and controlled dumpsite in terms of planning and facilities. Sanitary landfill is an engineered disposal facility in which the design, construction and operations manner in a sanitary landfill can minimizes and protects the impacts to the environment and public health. Sanitary landfills go through proper and careful planning from the selection of the disposing site down to the closure of the landfill. Sanitary landfill has all the facilities needed to control the hazards and pollutants from the landfill namely gas monitoring probe, landfill liner system, groundwater monitoring well, leachate collection and treatment systems, biogas management system and daily cover operations with waste (UNEP, 2015).

In Malaysia, there are only 12 sanitary landfills in which 11 of them are still operating and 1 is closed based on Table 2.4. The number of sanitary landfill is small as compared to open dumpsite and controlled dumpsite as the construction of sanitary landfill depends on many factors such as the socio-political constrains, the strength of economics and the physical conditions of the selected site. High initial investment needed for the planning, construction, operation and closure of the sanitary landfill as proper liner system, biogas management system, leachate management system and monitoring systems are all needed for sanitary landfill.

Table 2.4: Sanitary Landfills in Malaysia Respective to Status and Location (Fauziah and Agamuthu, 2012)

Name of landfill	Status of disposal facilities	In operation	Location (state)
Bukit Tagar sanitary landfill	Operating	2006	Selangor
Air Hitam sanitary landfill	Closed	1995	Selangor
Jeram sanitary landfill	Operating	2008	Selangor
Seelong sanitary landfill	Operating	2004	Johor

Pulau Burong sanitary landfill	Operating	2001	Penang
Mambong sanitary landfill	Operating	2000	Sarawak
Bintulu sanitary landfill	Operating	2002	Sarawak
Sibu sanitary landfill	Operating	2002	Sarawak
Kota Kinabalu sanitary landfill	Operating	2001	Sabah
Tanjung Langsat sanitary landfill	Operating	2005	Johor
Tanjung 12 sanitary landfill	Operating	2010	Selangor
Miri sanitary landfill	Operating	2006	Sarawak

2.3 Landfill Leachate

In Malaysia, sanitary landfilling is the most general urban method as to dispose solid waste as the method has such advantages as low initial cost, simplicity, and landscape-restoration of holes from mining work like tin mining and gold mining (Aziz et al., 2011). The formation of leachate from landfill is due to when rainwater water penetrates through the waste in the layers of the landfill and carries pollutants from the landfill (Mojiri et al., 2014). Once the garbage was dumped into the landfill, the garbage will go through the four stages or phases of decay in the landfill which are the initial aerobic phase, the anaerobic acidic phase, the initial methanogenic phase and finally the stabilising methanogenic phase. The different phase of the garbage decay can occur simultaneously in different layers of the landfill (Kuusik et al., 2014).

According to Renou et al. (2008), landfill leachate can be defined as the aqueous effluent as a result of rainwater percolation through waste, the inherent water content of waste and biochemical processes in waste’s cells. Landfill leachate is a toxic waste water which has high values of suspended solids, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), turbidity, color, heavy metals, ammonia nitrogen (NH_3-N), pH and bad odor. If the leachate which contains large amounts of organic and inorganic pollutants generated in municipal landfills are not properly controlled, this will cause servere environmental impact (Raghab et al., 2013). In general, landfill leachate can be represented by the basic parameters BOD, COD, pH, suspended solids (SS), ratio of BOD/COD, ammonium nitrogen, total Kjeldahl nitrogen (TKN) and heavy metals (Renou et al., 2008).

2.4 Factor Affecting Leachate Quality

The pollutant present in the content of the landfill leachate is directly dependent on the intensity of rainfall and the on-going activities near or on the territory of landfill like use of depositing site, garbage sorting and tipping technology. The different decaying phase of the waste in the landfill will affect the composition of the leachate (Kuusik et al., 2014). According to Renou et al. (2008), there are mainly two factors which affects the characteristics of leachate which are the volumetric flow rate and the composition of the solid waste. The composition and the quality of leachate which collected from the transfer station can vary depending on the waste composition of that area, climate condition, moisture content in the waste and the degree of compaction of the waste in the landfill. Not only that, the quality of leachate can be varied by the biodegradable matter present in the leachate and the volume of leachate produced over time (Raghab et al., 2013).

The other factor which affects the quality of the leachate is the age of the landfill which is classified into generally three categories namely young, intermediate and old or stabilized landfill leachate. According to Liu. (2013), as the age of landfill increase, the degrading compounds by microorganisms in landfill converts organic matter into methane and CO_2. Due to this degradation process, the pH will increase as the landfill ages from less than pH 6.5 to more than pH 7.5 in stabilized landfill as due to the reduction of CO_2 with hydrogen. As moving from intermediate to stabilized leachate, the leachate organic compounds are less biodegradable as most of the organic matter had been converted hence the BOD to COD ratio will decrease as the landfill leachate ages over time.

The age of landfill leachate can be identified through several parameters shown in Table 2.5. In common, landfill leachate is classified based on the age (counted from the date start to receive MSW) of the landfill. Basically, leachate is classified to be young, intermediate and stabilized (matured) when the age of the landfill are 5 years, 5-10 years and more than 10 years respectively. The BOD to COD ratio is the significant parameter which determines the age of the leachate. Other parameters such as pH, ammoniacal-nitrogen, organic matter and etc. are relevant for the leachate age determination.

Table 2.5: Landfill Leachate Classification (Baig et al., 1996; Liu, 2013)

Type of leachate	**Young**	**Intermediate**	**Stabilized**
Age of landfill (years)	<5	5 - 10	>10
pH	<6.5	6.5-7.5	>7.5
BOD/COD	>0.3	0.1-0.3	<0.1
COD (g/L)	>15	3-15	<3
NH_4^+-N (mg/L)	<400	NA	>400
TOC/COD	<0.3	0.3-0.5	>0.5
Organic matter (VFA-Volatile Fatty Acids)	70 – 90%	20 – 30%	HWM
Kjeldahl nitrogen (g/L)	0.1-2.0	NA	NA
Heavy metals (mg/L)	>2	<2	<2

2.5 Impacts of Landfill Leachate and Discharge Limit

2.5.1 Environmental Impacts

Initially, landfill was introduced as a need to protect the environment and society from various adverse impacts of other more harmful disposal method of solid waste like open-burning, ocean and river dumping. Landfilling produces hazardous leachate and gas which besides has adverse effect on health, and also possess environmental issues like explosion, fire, unpleasant odours, air pollution and global warming (El-Fadel et al., 1997). Most of the landfill leachate contain xenobiotic organic compounds (XOCs) and various heavy metal which makes leachate hazardous as XOCs and heavy metals may react with themselves and substances in the surrounding environment which can be carcinogenic, mutagenic, eco-toxic, reactive, flammable and may be bio-accumulative or persistent (Slack et al., 2005). Due to the hazardous and toxicity characteristic of the leachate, the infiltration and run-off of leachate has the potential to cause adverse harm to groundwater to near-by surface water and vegetation which surrounds the landfill.

The disposal of containers into sanitary landfill may contains residual of hazardous chemicals like solvents, polychlorinated biphenyl (PCB), insecticides, unused pharmaceuticals and pesticides hence producing highly complex carcinogenic chemicals (Clarke et al., 2015).

Ground water pollution is due to when the leachate breached or seep through the bottom of the landfill or an impermeable layer (liner) of the landfill which the leachate discharge to the ground’s surface and reaching to the water table further contaminate the groundwater (El-Fadel et al., 1997).

2.5.2 Human Health Impacts

Leachate is a potential polluting waste liquid from landfill that poses potential health risk to the surrounding ecosystems and human populations. The biodegradation in landfill yield leachate with high concentration of ammonia-nitrogen and toxic heavy metals such as mercury, cadmium, nickel and others which toxic to many microorganisms in natural environment and contaminant the ground water hence causing hazards to drinking water to people who reply on ground water for their day to day water use. (Salem et al, 2008) Landfill site also poses serious health risk in terms of ground water pollution. (Klinck and Stuart, 1999). Table 2.6 shows the negative impacts of leachate heavy metals on human health by Kannan, (2013).

Table 2.6: Health Effects of Leachate on Humans (Kannan, 2013)

Type of pollutant	**Health effects from exposure**	
	Acute exposure	**Long-term exposure**
Lead	Diarrhoea, vomiting, confusion, abdominal pain, seizures, drowsiness	Hypertension, chronic nephropathy, anorexia, abdominal pain, constipation
Nickel	Gum disease, skin irritation, dermatitis, diarrhoea	NA
Mercury	Dehydration, renal failure, bloody diarrhoea	Memory loss, seizures, coma, decrease in platelets, tremors, irritability, anaemia that follows gastrointestinal bleed
Cadmium compounds	Cough, skin irritation, chest pain, nausea, metallic taste, diarrhoea	Kidney damage, possible prostate and lung problems
Phenols/cresols	Coma, vomiting, nausea, sweating and burning pain in mouth and throat	Renal failure
Toluene	Coma, convulsions, tremors	NA
Benzene	NA	Blood-related disorders

NA – Not Available

2.5.3 Standard Discharge Limit for Landfill Leachate

Raw leachate is a polluted wastewater with highly complex composition in which will threaten the surrounding ecosystems when direct discharge into natural water bodies and mixed with groundwater without any treatment. (Kumar et al., 2013). In order to minimize the hazardous effects and to protect the well-being of the surrounding ecosystems, the treated leachate effluent must comply with the Environmental Quality Act 1974 Regulations 2009 (PU (A) 433) in Appendix K3: Control of Pollution from Solid Waste Transfer Station and Landfill, in which the Table 2.7 shows the discharge limit of parameters of treated effluent leachate in Malaysia. However, the parameters with the discharge limit range and values may varied from country to country.

Table 2.7: Acceptable Conditions for Discharge of Leachate, Second Schedule (Regulation 13) (Department of Environment (DOE) and Ministry of Natural Resources and Environment, 2010)

Parameter	Unit	Standard
Temperature	^{o}C	40
pH Value	-	6.0 – 9.0
BOD_5 at 20 ^{o}C	mg/L	20
COD	mg/L	400
Suspended Solids	mg/L	50
Colour	**ADMI***	100
Ammoniacal-Nitrogen	mg/L	5
Tin	mg/L	0.20
Sulphide	mg/L	0.50
Mercury	mg/L	0.005
Cadmium	mg/L	0.01
Chromium, Hexavalent	mg/L	0.05
Chromium, Trivalent	mg/L	0.20
Arsenic	mg/L	0.05
Lead	mg/L	0.10
Copper	mg/L	0.20

Iron (Fe)	mg/L	5.0
Zinc	mg/L	2.0
Oil and Grease	mg/L	5.0
Boron	mg/L	1.0
Silver	mg/L	0.10
Selenium	mg/L	0.02
Barium	mg/L	1.0
Fluoride	mg/L	2.0
Phenol	mg/L	0.001
Formaldehyde	mg/L	1.0
Cyanide	mg/L	0.05
Manganese	mg/L	0.20
Nickel	mg/L	0.20

ADMI* – American Dye Manufactures Institute

2.6 Leachate Treatment

Leachate treatment is crucial as to control the potential hazardous effect of leachate towards the surrounding environment and to preserve quality of life of human and animal well fare. Conventional leachate treatment is done either by biological or physiochemical treatment or the combination of several treatment techniques. Due to the complex composition of leachate, one single treatment method is not sufficient to treat leachate clean enough to produce ideal result which is safe to return back to the environment and according to standard discharge limit of leachate being set by local authorities.

The choice of treatment also largely influenced by the regulations at national and regional level which gives various treatment methods to be imposed to treat leachate in different countries (Liu, 2013). Besides that, different treatment methods have to be selected based on the age of landfill leachate. Biological processes have more effectiveness in treating young landfill leachate (<5 years) which has more composition of organic matter and physiochemical processes is more suitable in treating older leachate (>5 years) (Baig et al., 1996). In general, conventional leachate treatments are classified into three major categories namely i) leachate transfer within the landfill which includes the recycling of leachate and combined treatment with domestic sewage, ii) chemical and physical treatment which include chemical adsorption, chemical precipitation, coagulation/flocculation, chemical oxidation and air stripping and iii) biodegradation which uses aerobic, anoxic and anaerobic process to treat leachate (Renou et al., 2008).

Nowadays, newer technology has been introduced to leachate treatment in the world like membrane processes, and anaerobic ammonium oxidation (Anammox) process. Moreover, some new methods have also been added in the procedure in treating leachate as to remove both organic and inorganic compounds more effectively. One example is to add powered activated carbon (Liu, 2013). Leachate phytoremediation is a relatively new method which uses plants and wet lands to treat wastewater and leachate. This method is considered to be one of the latest biological treatment for leachate and wastewater (Madera and Valencia-Zuluaga, 2009).

2.6.1 Leachate Transfer

2.6.1.1 Combined Treatment with Domestic Sewage

In some cases, leachate is dispose into the sea through piping into the sewer system or, preferably the leachate collected will be combined with domestic sewage for treatment at conventional municipal sewage plant. This method is being used as the operational cost is relatively low (Renou et al., 2008). This method has been doubt as leachate often contains high amount of heavy metals and organic inhibitory compounds which may affect or reduce the treatment efficiency and increase the effluent concentration from the domestic municipal sewage treatment plant.

However, some research has been done to enhance this method as some authors tried to optimise the volumetric ratio of sewage wastewater to leachate. It is reported that by using sequencing batch reactor (SBR) with ratio 9:1 of sewage to leachate, the removal rate of BOD and nitrogen are 95% and 50% respectively at the end of each cycle daily. (Renou et al, 2008). According to Renou et al. (2008), adding Powdered Activated Carbon (PAC) may improve the effluent quality if the leachate input exceeds 10%.

2.6.1.2 Recycling of Leachate

The landfill itself is an anaerobic biological rector which the leachate can be recirculate back to the landfill hence giving microorganisms to react and treat (Liu, 2013). Recycling or recirculation of leachate back through the tip into the landfill is a widespread technique which has been commonly used for the past decade as is one of the cheapest option available in treating leachate (Renou et al., 2008). This treatment method is also simple to operate, effective in reducing the volume of organic concentration in leachate and just only need pH buffering to recondition the leachate back into the landfill (Liu, 2013). Some research had been done to support this method as it is reported that leachate recirculation increased the moisture content and improve the distribution of nutrients and enzymes between methanogens and solid-liquid in a controlled reactor system. This method had also give significant in lowering the production of methane production and COD. Moreover, the recirculation shortens the time for leachate to reach stabilized leachate from several decades to 2 to 3 years (Renou et al., 2008).

2.6.2 Physical / Chemical treatment

2.6.2.1 Coagulation-Flocculation

In treating intermediate and stabilized leachate, coagulation-flocculation is the best choice. This method is coupled with biological treatments as to improve the degradation of bio-refractory or non-biodegradable materials like humic and fulvic acids. (Wiszniowski et al., 2006) Coagulation-flocculation has been used widely in many wastewater and leachate treatment plant as a pre or post treatment before secondary and final treatment like biological treatment, final polishing treatment and reverse osmosis as to remove non-biodegradable organic matter. Common coagulant like ferric chloride, ferric chloro-sulfate, ferrous sulfate and aluminium sulphate (ALUM) are added during the coagulation process (Renou et al., 2008).

Undesirable compounds in landfill leachate namely heavy metals, AOXs, PCBs and others are effectively being removed using this method. Coagulation-flocculation is more efficient in treating stabilized or matured leachate (COD removal up to 75%) compared to young leachate (COD removal up to 25 – 38%) (Wiszniowski et al., 2006). Since most of the colloidal particles are negatively charged, adding coagulant is the first step in coagulation-flocculation process in order to reduce and neutralize the negative-negative repulsive forces between the particles. Polymers are added to kick start the flocculation process as to form larger flocs after the coagulation process. In some researches, it is reported that COD and heavy metals removal rate are ranged from 30% - 86% and 74% - 98% respectively (Liu, 2013).

The main working mechanism of coagulation is to hydrolyse metal ions from aluminium-based coagulants like aluminium sulphate or aluminium chloride to form aluminium hydroxide floc and other hydrogen, H^+ ions which both are highly positively charged. According to Saukkoriipi, (2010), the coagulation process can be divided into two main mechanisms namely: (1) neutralization of particle charges and (2) sweep coagulation and flocculation. The hydrogen ion will decrease the pH of wastewater slightly as it reacts with the alkalinity of the wastewater during hydrolyse reaction. The equations 2.1 and 2.2 show the general reaction of coagulant with wastewater (Gebbie, 2006).

$$Al_2(SO_4)_3.18H_2O \longrightarrow 2Al^{3+} + 3SO_4^{2-} + 18H_2O \tag{2.1}$$

$$2Al^{3+} + 3SO_4^{2-} + 18H_2O \longrightarrow 2Al(OH)_3 + 6H^+ + 3SO_4^{2-} + 12H_2O \tag{2.2}$$

According to Gebbie, (2006) depending on the type of coagulant used, “sweep-floc coagulation” will occur if hydrolysis reaction take place at pH 5.8 to 7.5. The “sweep-floc coagulation” refers to the removal of both colloidal matter and colour by adsorption either onto or within the formed metal hydroxide hydrolysis products. Duan and Gregory, (2003) also gives the definition of “sweep flocculation” as the action of particles are enmeshed and being “sweep out” or removed by the increase number of amorphous hydroxide precipitate at pH 7.0.

The hydrolysis reaction of ALUM forms multiple species of dissolve Al species and other Al-hydroxide precipitates. The expected ALUM cations are $Al(OH)_4^{1-}$, $Al(OH)^{2+}$, Al^{3+}, $Al(OH)_2^{1+}$ and $Al(OH)_{3(am)}$ which is the amorphous precipitate of ALUM (Pernitsky et al., 2006). Both Al (III) and Fe (III) have limited solubility when pH is close to neutral as amorphous hydroxide precipitate starts to form and dominate at pH 7.0 theoretically. Hossain, (1996) present a graph in figure 2.4 in relating different hydrolyzing ALUM species at different pH and the dominant species of $Al(OH)_3$ amorphous hydroxide formed at pH 7.0 in any types of wastewater including sewage, industrial wastewater and landfill leachate.

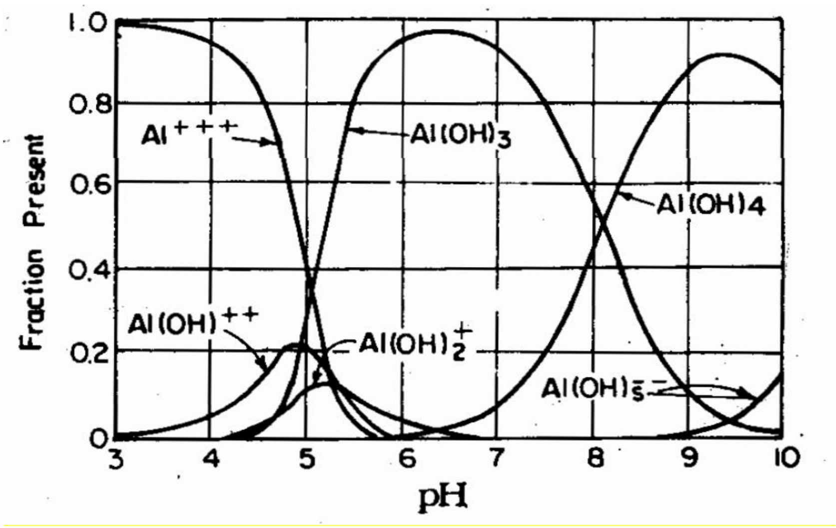

Figure 2.4: Quantity (Fraction) of mono-nucleus aluminium species (monomers) as a function of pH (Hossain, M.D., 1996)

Duan and Gregory, (2003) had presented a schematic diagram showing the interaction of different hydrolyzed aluminum species with negatively charged particles in water including the “Sweep Flocculation” process in the Figure 2.5 below.

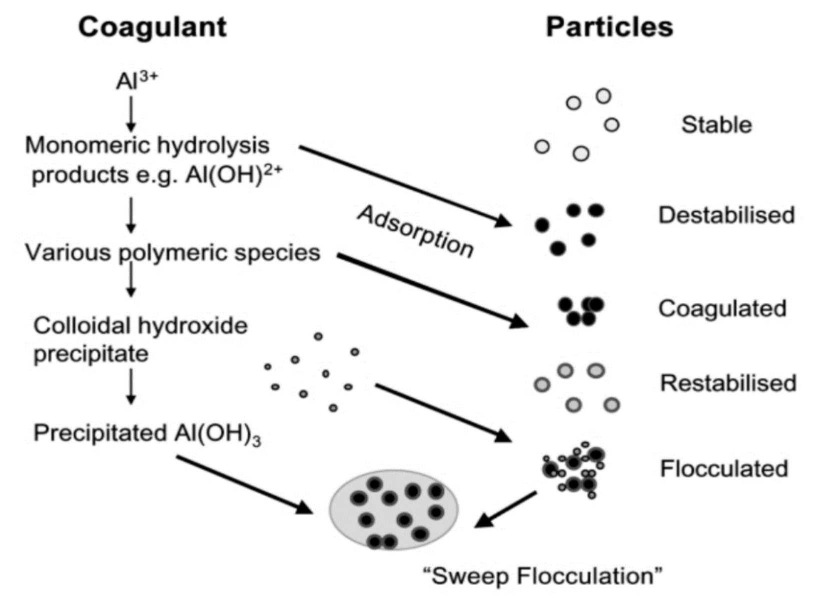

Figure 2.5: A flow diagram describing the process and interaction of initially negatively charged impurities or particles (right-hand side) and the type of hydrolyzed aluminium species including the $Al(OH)_3$ (left-hand side) (Duan and Gregory, 2003)

2.6.2.2 Chemical Precipitation

Chemical precipitation is widely used as pre-treatment in effort to treat leachate as to remove high concentration of ammonium nitrogen (NH_4^+) and to lower COD from 95% to 79%. Chemical precipitation process which place before conventional activated sludge process could prevent high strength of ammonium nitrogen significantly affecting the biological sludge process in treating organic matter in leachate. Some authors reported that this method effectively remove ammonium concentration from 5600 mg/L down to 110 mg/L within 15 minutes by adding $Na_2HPO_4.12H_2O$ and $MgCl_2.6H_2O$ at pH 8.5 to 9.0 with a ratio of 1:1:1 for $Mg/NH_4/PO_4$ (Renou et al., 2008). According to Liu. (2013), by the addition of precipitation reagents, chemical precipitation is effective to precipitate non-biodegradable organic compounds and heavy metals, to further remove the particles from mixture, filtration process can be used after chemical precipitation. Chemical precipitation can remove fluoride, phosphorus and ferro-cynide in leachate and the removal efficiency is largely influenced by the presence of metals, the concentration of reagents and metals. Moreover, lime is used in treating raw medium aged leachate and also for pre-treated biological leachates with a BOD to COD ration of 0.1 – 0.5 which provide the best effectiveness of lime precipitation for removing metals, colour and to reduce COD as well. Lime is used due to its availability and low cost with regard to high dosage needed for lime precipitation (Baig et al., 1996).

2.6.2.3 Adsorption

Adsorption is where dissolved compounds in leachate or in wastewater are adsorbed to the surface of an adsorbing medium. To increase the effectiveness of the adsorption effect, very high specific external and internal surface area of the adsorbing medium is needed therefore Powdered Activated Carbon (PAC) or granular activated carbon (GAC) is the most commonly used adsorbing mediums as the attractive forces of the carbon surface is stronger than the attractive forces of the liquid hence the adsorption process is possible (Liu, 2013). The adsorption of inorganic pollutants onto powder or columns form of activated carbon provides better reduction in COD levels compared to chemicals methods (Renou et al., 2008).

The capacities of activated carbon adsorption increase with the decrease fraction of volatile fatty acid therefore is an alternative treatment method for raw and young biologically pre-treated landfill leachate to chemical precipitation. Chemical adsorption uses PAC can act as polishing treatment for stabilised leachate if combined with coagulation-flocculation (Baig et al., 1996). In many cases, the combine use of powdered activated carbon (PAC) along with biological treatment has been effective in treating landfill leachate as PAC helps to reduce inert COD, non-biodegradable compounds and colour to acceptable levels which can the treated leachate can be returned back into the environment or use for irrigation purposes (Renou et al., 2008).

2.6.2.4 Chemical Oxidation

Chemical oxidation is a method mainly to treat pollutants where biological and physical methods cannot treat effectively such as toxic and hazardous substances, non-biodegradable toxic substance and soluble organic compounds in leachate. Chemical oxidation or advance oxidation process (AOP) uses strong oxidising agent like ozone (O_3-selective), chlorine gas, calcium hydrochloride and potassium permanganate which generates hydroxyl radicals (-OH) to oxidize or to destroy compounds in leachate. By using chemical oxidation, COD can be removed around 20% to 50%. The famous Photo-Fenton process is one of example of chemical oxidation or AOP which uses combination of light and metal ions which has a reduction rate of 64% and 48% in the removal of COD and TOC respectively which are organics in leachate (Liu, 2013). According to Renau et al. (2008), it is confirmed that AOP is adapted to treat well-stabilized or matured landfill where the left over organics substances can be oxidised completely or to reach complete mineralization into carbon dioxide and water. Table 2.8 shows the two main types of AOP system with examples namely homogeneous and heterogeneous systems.

Table 2.8: List of Typical Advance Oxidation Systems (AOP) (Renou et al., 2008)

Type of system		Examples
Homogeneous system	With irradiation	• Ultrasound (US) • O_3/ ultraviolet (UV) • Electron beam • UV/US • H_2O_2/UV or US • H_2O_2/Fe2+/UV (photo-Fenton's)
	Without irradiation	• H_2O_2/Fe2+ (Fenton's) • O_3/OH^- • O_3/ H_2O_2
	With irradiation	• TiO_2/O_2/UV

Heterogeneous system		• TiO_2/ H_2O_2/UV
	Without irradiation	• Electron-Fenton

2.6.2.5 Air stripping

Ammonia stripping or air stripping is a method to remove high concentration of ammonium in wastewater and in leachate. In treating high strength ammonium, pH plays a crucial role as the ammonia will be soluble ammonium if pH is below 7. The dissolved ammonia gas will be present if the pH of the leachate or wastewater is reaching 11. The optimal pH during air stripping shall be adjusted from 11 to 12 by the addition of NaOH (Liu, 2013).

The equilibrium reaction for ammonia stripping:

$$NH_4^+ + OH^- \longrightarrow NH_3 + H_2O \tag{2.3}$$

During treatment, the contaminated ammonia gas will be treated with strong acids like H_2SO_4 or HCl to oxidize the ammonia gas. The author reported that high initial concentration of ammonia striping under condition of 20°C, pH = 11 and retention time of 24 hours, has reduction rate reaches 89% at peak. The ammonia gas striping method has one major environmental concern as the by-product is the release of NH_3 into the atmosphere hence causing adverse impact on air pollution due to some percentage of ammonia couldn't be properly adsorbed with H_2SO_4 or HCl (Renou et. al, 2008).

2.6.3 Biological Treatment

Biological treatment is the most common worldwide practice method in treating leachate (Kumar et al., 2013). In general, biological treatment processes are classified into aerobic (oxygen presence) and anaerobic (oxygen absence) in which depends on whether or not the medium of the biological treatment requires oxygen, O_2 supply from the atmosphere or from oxygen tanks (Renou et al., 2008). Due to the fact that biological treatment method is a reliable, simple and low-cost in operation and maintenance, many of the wastewater plant in domestic areas and on-site landfill leachate treatment facilities uses this method in treating bulk liquid containing high strength of organic matter or BOD. Microorganism and groups of bacteria which are suspended or attached growth in a biological reactor carries out biodegradation to degrade organic compounds in leachate into carbon dioxide, biogas (methane) under anaerobic conditions and biomass (sludge) under aerobic conditions. It is reported that biological processes are very effective in removing nitrogenous pollutants and organic matters from young (<5 years) leachate where the ratio of BOD to COD has a high value of more than 0.5 (Peng, 2013). Biological treatment is suitable to remove ammonia nitrogen and very efficient nitrification process can help to remove high strength TKN, Total Kjeldahl Nitrogen from 85% to 98% (Baig et al., 1996).

There are many examples of aerobic processes namely activated sludge plant (AS), aerated lagoons, rotating biological contactors (RBC), sequencing batch plant and trickling filter. For anaerobic processes, mainly consist of anaerobic filter and anaerobic sludge bed reactor (UASB). As aerobic processes need oxygen supply, therefore one advantages of anaerobic processes are low energy requirement as it does not need artificial supply of oxygen by using pump and irrigation of water surface to increase the dissolve oxygen in water (Kumar et al., 2013).

However, biological treatment has its own limitations as no single treatment method is 100% perfect and efficient in treating all pollutants in leachate. Biological treatment’s efficiency is limited by the presence of major refractory compounds mainly humic and fulvic acids. Moreover, if compared to physical/chemical treatment, biological treatment is considered to be slower in treating specific pollutants in leachate as microorganism and metabolism processes need time to degrade pollutants.

Partial abatement of biodegradable organic compounds and the nitrification of ammonium nitrogen is responsible by aerobic treatment. Conventional activated sludge system, aerated lagoons and sequencing batch reactors (SBR) are based on suspended-growth biomass where microorganisms and groups of bacteria are suspended in the medium of the reactor, lives and degrade (eat) pollutants from the influent (Renou et al., 2008). Attached-growth systems like moving-bed reactor (MBBR) and bio-filters has gained much interest in recent years. Membrane bioreactors is a term which indicates the combination of aerobic bioreactors and membrane separation technology.

Anaerobic process is a biological metabolite which operates without oxygen to transfer organic matters into CO_2 and CH_4 (Liu, 2013). Anaerobic treatment is particularly suitable for dealing with high concentration of organic effluents in which it allows the complete end process of leachate streams from young tips. Anaerobic process has several advantages compared to aerobic process in which anaerobic digestion has low yielding in sludge, lower energy consumption (no aeration is needed) however the biological reaction is slower than aerobic. Therefore, anaerobic treatment are chosen to treat concentrated leachate as this method operates at lower cost and produce usable biogas. The end product from anaerobic process mostly yield methane gas, CH_4 which the gas can be harvest for electric generation (Renou et al., 2008).

2.6.3.1 Activated Sludge Process (AS)

According to Liu. (2013), activated sludge is an active microbial floc where bacteria are supplied with oxygen in the tank. Activated sludge process is a suspended-growth biological treatment which employs aerobic micro-organisms to degrade organic matters in leachate and also in wastewater. Activated sludge process consists of an open tank basin, diffusers or mechanical aerators to provide aeration together with leachate or wastewater as medium. After the aeration stage, the mixture of treated water and microorganisms (mixed liquor) is transferred into the clarifier where gravity play the role of settling microorganisms and a high percentage of these settled solids are recycled back to the aeration basin (Yu, 2007). Activated sludge process has been employed largely in treating domestic wastewater but has been shown to be inadequate in handling leachate although the process is efficient in removing nutrients, ammonia content and organic carbon. The reason of this system to be inadequate for leachate is that the sludge settle ability is bad and longer time for aeration is needed in treating leachate. Moreover, activated sludge produces high amount of sludge and requires a lot of energy in aeration. Due to heavy metals and high concentrations in raw leachate, this may inhibit microorganisms to treat leachate (Renou et al., 2008).

2.6.3.2 Sequencing Batch Reactor (SBR)

Sequencing batch reactor (SBR) has been applied as an efficient technology in treating wastewater in recent years especially in treating domestic wastewater. Several full-scale fill-and draw batch systems has been operating from 1914 to 1920. Until late 1950's and early 1960's, this system gained interest of many researches in the field of wastewater treatment. New technology and equipment are developed to assist the control and aeration which allows SBR to function and to treat wastewater more effectively which can be compared to conventional activated sludge systems (Mahvi, 2008).

Sequencing batch reactor (SBR) is one of many biological treatment methods used to remove several contaminants (Mojiri et al., 2014). This treatment method is ideal for nitrification-denitrification processes as the operation provides pathway for organic carbon nitrification and oxidation. Many authors reported that the SBR system have COD removal of up to 75% and with an excellent ammonia-nitrogen, NH_4-N of 99% where the system has 20-40 days of residence time in treating domestic leachate (Renou et al., 2008). SBR is suitable to remove total suspended solids (TSS), BOD, nitrification, denitrification and biological phosphorus. Never the less, full-scale SBR size can range from 3,000 gpd up to 5 MGD. SBR is chosen rather than using activated sludge system due to SBR's smaller footprint as the essential conventional activated sludge processes of filling, mixing with aeration, settling, extraction and idling happened in just one tank as shown in Figure 2.6. Not only that, the cycles or processes in the SBR can be easily modified to suit different raw influent from different places (Mahvi, 2008).

The five basic processes in a SBR are essential, and is explained according to Yu. (2007),

- Filling is the process where raw influent either domestic leachate or wastewater is fed into the SBR in which contains an acclimated biomass from previous cycle.
- React or mixing with aeration is happened after the filling stage where the medium in the reactor are actively mixed with a mixer and aerated by pumping air into the reactor. This process is crucial as to provide enough oxygen for microorganisms to aerobically degrade organic compounds in the leachate or wastewater.
- Settling is happened after the react stage where mixing and aeration stop completely. This process assists heavy and large solids to settle under quiescent conditions under the influence of gravity.
- Draw or extraction is happened after the settling stage where supernatant near the top of the medium is extracted from the reactor for further treatment or is allowed to be discarded if complied with regulations.
- Idling is the end cycle of the SBR process where the settled solids or sludge are remained in the reactor for the next cycle. In most cases, this stage is not used as is not crucial and there may be a portion of sludge being washed out during this stage.

Figure 2.6: The Five Stages of Operations in a Sequencing Batch Reactor (SBR) (Yu, 2007)

SBR has its own limitations although it has a lot of advantages over the conventional activated sludge system (AS). One of the major downside of using SBR as treatment method is large energy consumption for aeration phase as the aeration systems must be sized properly to provide sufficient air during the react phase and sometimes even for the fill phase. Another drawback of the SBR system is where the system requires an oversize effluent space due to the extraction of daily wastewater is needed. In the past decades, SBR systems faced some major issues in terms of maintenance problems for the decanting mechanism but have been resolved with present day technology and research (Mahvi, 2008).

2.6.3.3 Sequencing Batch Reactor (SBR) Addition with Adsorbent

This method was developed to treat matured leachate with low biodegradability. According to Aziz et al. (2011), low biodegradable leachate collected from Kulim landfill, Malaysia with low BOD_5 to COD ratio of 0.22 which is less than 0.50 shows that sequencing batch reactor added with Powered Activated Carbon (SBR-PAC) is more efficient in treating matured leachate than employing traditional SBR system.

In the paper, the author reported that SBR-PAC has removal rates of 1.3%, 64.1%, 71.2% and 81.4% for Total dissolve solids (TDS), COD, colour and ammonia-nitrogen, NH_4-N while traditional SBR has removal rates of 1.7%, 25.1%, 51.6% and 82.5% for TDS, COD, colour and ammonia-nitrogen, NH_4-N.

2.6.3.4 Rotating Biological Contactor (RBC)

One example of aerobic attached-growth biological treatment is the RBC which consists basically closely spaced plastic disks placed horizontally on a slowly spinning shaft. Around 40% of the disks are submerged and 2 to 4mm thick of slime layer develops and envelopes the disks in which the alternately contact with atmosphere for oxygen adsorption and to contact with organic matters in the wastewater (Mahvi, 2008). According to Kumar. (2013), it is reported that the disks on the RBC has a basis of excellent COD removal of 65% and biological stability. This type of treatment method is more suitable in developing countries like India as the operational cost is low however it requires energy for the disks to rotate by using an electrical motor which is housed to the shaft of the disks.

2.6.3.2 Leachate Phytoremediation

Using plants and constructed wetlands in natural system as to treat leachate is a relatively new method. This method is known as phytoremediation and is being defined as the use of potential from natural or actively managed soil-pant system to degrade, detoxify and inhibit toxic element which could be present in leachate. Constructed wetland basically consist mixture of gravel, soil and sandy beds as a media for plants growth. As leachate or wastewater flows through the constructed wetland, the root of the plants together with the bacteria which attached to the root of the plants and in the soil together purify and adsorb pollutants in leachate as nutrient source for biological growth. The use of phytoremediation is getting more popular in leachate and wastewater treatment as constructed wetlands are low cost in operation and maintenance, good adaptability and very stable in tropical climate.

Some authors have shown phytoremediation can reduce the concentration of several pollutants like heavy metals however the process of plant roots in eliminating pollutants in leachate is yet to be discovered and discussed. Figure 2.7 below shows the set-up of typical phytoremediation system or constructed wetland (Madera and Valencia-Zuluaga, 2009).

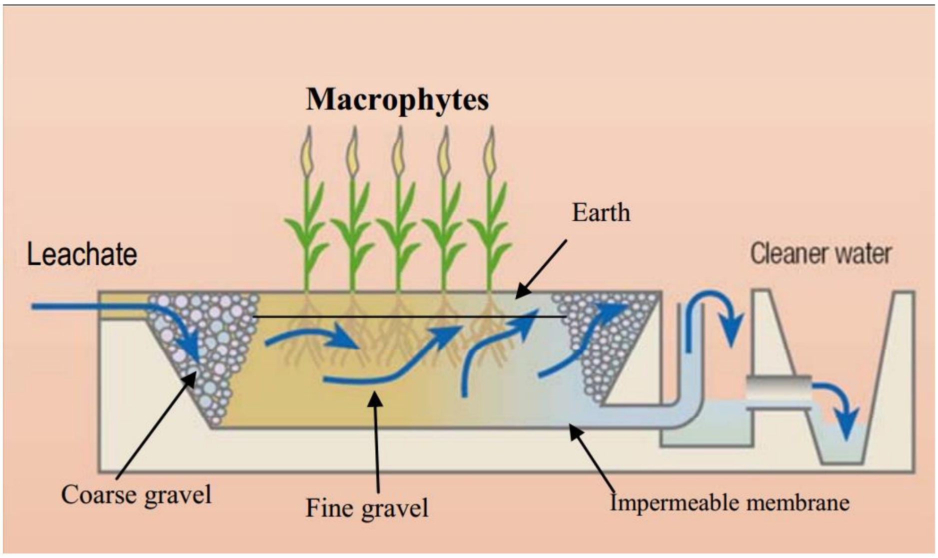

Figure 2.7: The Main Features of a Sub-Surface Constructed Wetland (SSCW) (Madera and Valencia-Zuluaga, 2009)

CHAPTER 3

RESEARCH METHODOLOGY

Figure 3.1 shows the methodology flowchart. Initially, the leachate sample was collected from Papan Landfill (Papan district) and the sludge used to treat Papan leachate was collected at the sedimentation tank No.4, from Tian Siang Oil Mill (Air Kuning) Sdn. Bhd a palm oil mill in Perak. Leachate and POME sludge samples were tested for initial characteristics. For leachate, the measured characteristics include pH, COD, BOD, colour, turbidity, total suspended solids (TSS), Ammoniacal Nitrogen (NH_3-N), volatile solids (VS). The characteristics for POME sludge were pH, COD, BOD, Mixed Liquor Suspended Solids (MLSS) and Mixed Liquor Volatile Suspended Solids (MLVSS). The SBRs was set up and a test run was conducted to ensure the SBRs is working and as an effort to cultivate the activated sludge. Later, post treatment involving coagulation by using ALUM was conducted to further treat the leachate by using the “Jar Test” method to determine the optimal pH and dosage of coagulation.

The flow chart summarized the procedure of experimental as shown in **Figure 3.1**

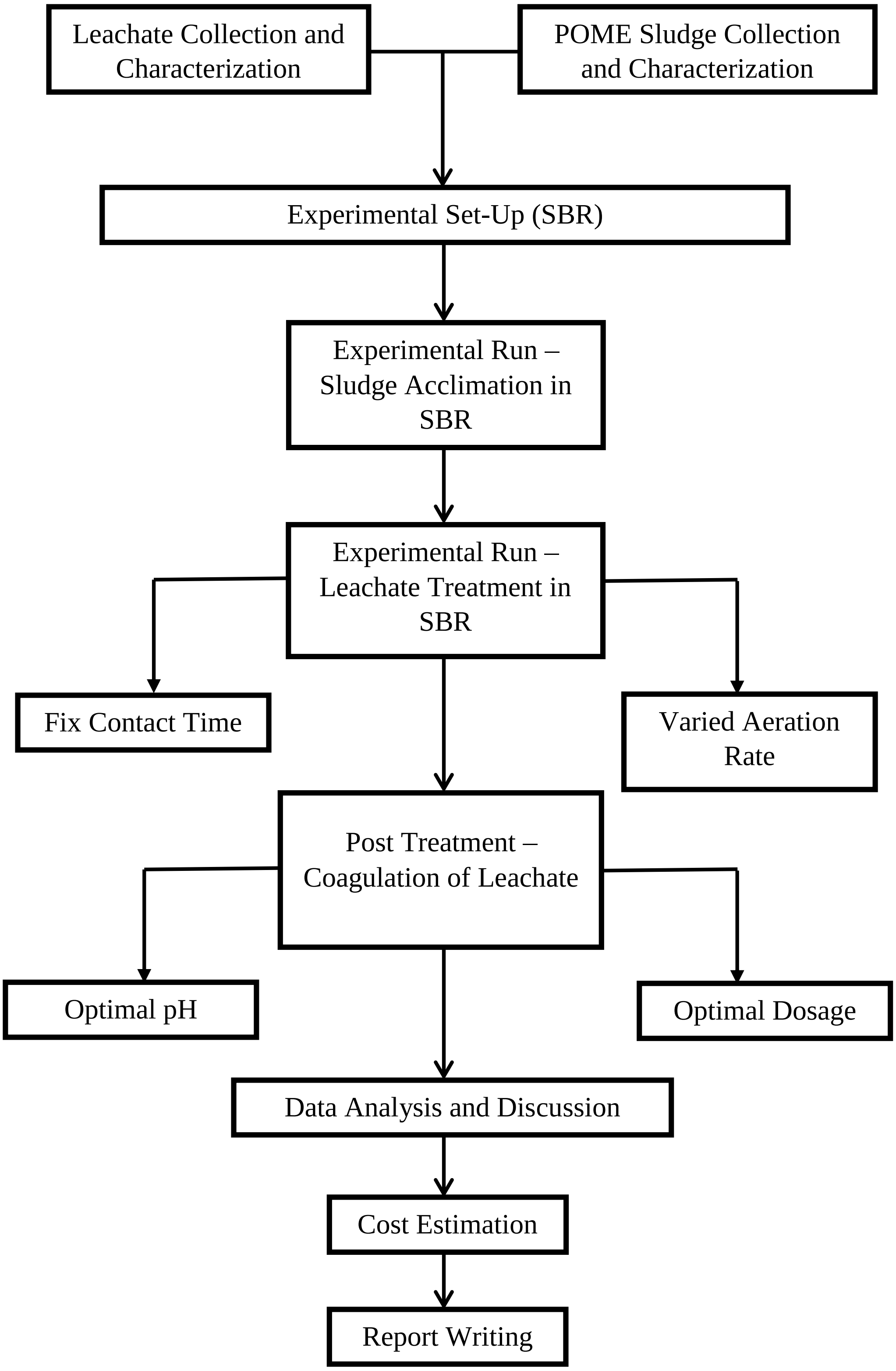

Figure 3.1: Methodology Flowchart

3.1 Leachate Collection and Site Location

The leachate samples were collected from “Tapak Pelupusan Sisa Pepejal, Wilayah Ulu Johan Papan” (Papan Sanitary landfill) at Papan district, Perak, Malaysia. The landfill site location is shown in Figure 3.2.

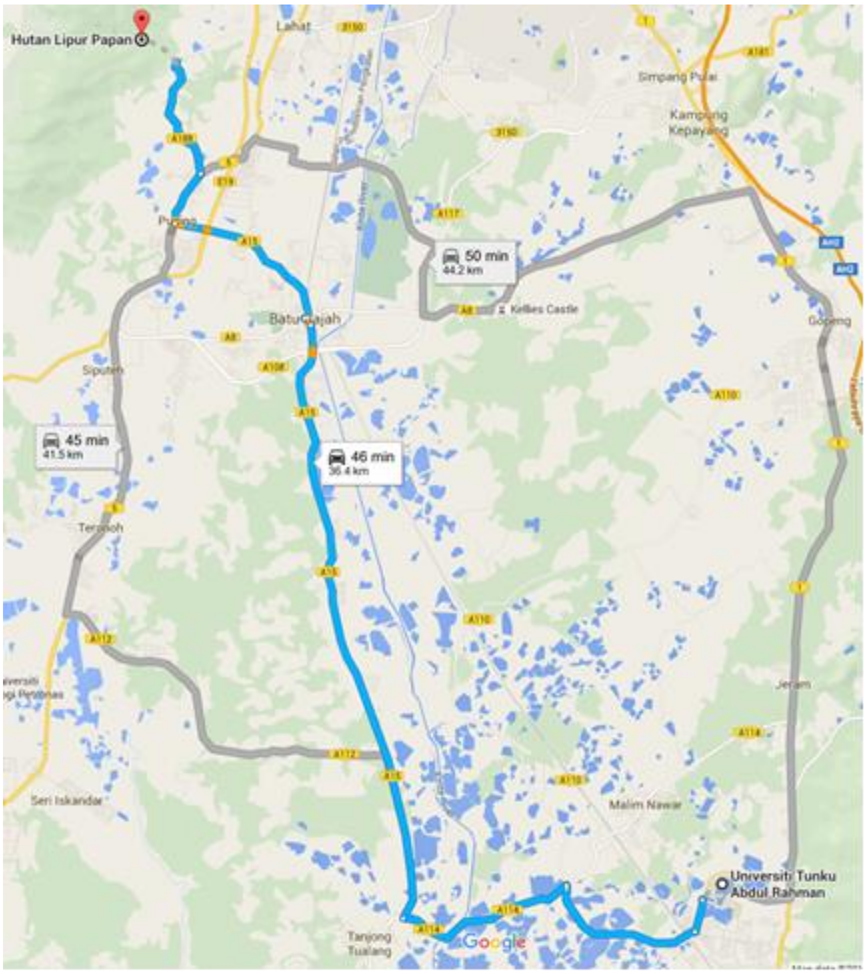

Figure 3.2: Papan Sanitary Landfill Site Location from Universiti Tunku Abdul Rahman, UTAR Perak Kampus (extracted from Google Maps, Accessed on 10th July 2016)

The distance between UTAR Kampar to Papan Sanitary Landfill is 36.4 km following the shortest path provided. Papan Sanitary Landfill is a level 4 sanitary landfill which will be equipped with proper leachate collection and treatment systems, landfill bio-gas collection and electric generation systems and material recovery facility (MRF) upon completion of the project. Since July 2015, Papan landfill has been operating with 10 acres of land and has a larger area of 560.24 acres or 226.73 hectares compared to the older landfill which has only 96 acres in size. Papan landfill serves more capacity to receive dumps at a rate of 800 tonnes a day as the new site has 53,516 residents and 34 housing estates within a 5 km radius which include. Besides that, the lifespan of the landfill is projected to last for 35 years (Negeri Perak, 2013).

The collection of leachate sample based on the weather before one week of the collection date is important as any heavy or persistent precipitation will largely affect the quality of the freshly collected leachate. The week before 1st batch leachate collection on the 11th July 2016 was sunny with minimal precipitation to ensure the best possible quality of undiluted leachate from Papan landfill site. Subsequent landfill leachate samples collection was done on the 11th August and 28th November 2016 respectively. The Figure 3.4 shows leachate sample was collected by using a 6.0 L polypropylrene bottle (PET) from the leachate collection stream beside the covered landfill cell while figure 3.4 shows the on-site parameter analysis of the fresh leachate in Papan landfill using the CyberScan PCD 650 Multi-Parameter, Singapore. After the collection of the sample, the sample was immediately transported back to UTAR Faculty of Engineering and Green Technology Environmental Laboratory (EV-Lab) and stored at a temperature of 4 ^{o}C as to minimize any possible means on any chemical reactions and the biodegradation of the leachate sample (APHA, 2005).

Figure 3.3: Leachate Sample Collection Using A 6.0 L Polypropylrene (PET) Bottle

Figure 3.4: Leachate Sample On-Site Parameter Analysis Using EUTECH CyberScan PCD 650 Multi-Parameter, Singapore

3.2 Sludge Collection at Palm Oil Mill and Site Location

The sludge sample from palm oil mill wastewater treatment facility was collected from Tian Siang Oil Mill (Air Kuning) Sdn. Bhd. on 15th July 2016 which locates in the District of Batang Padang, Perak, Malaysia. The site collection is shown in the Figure 3.5.

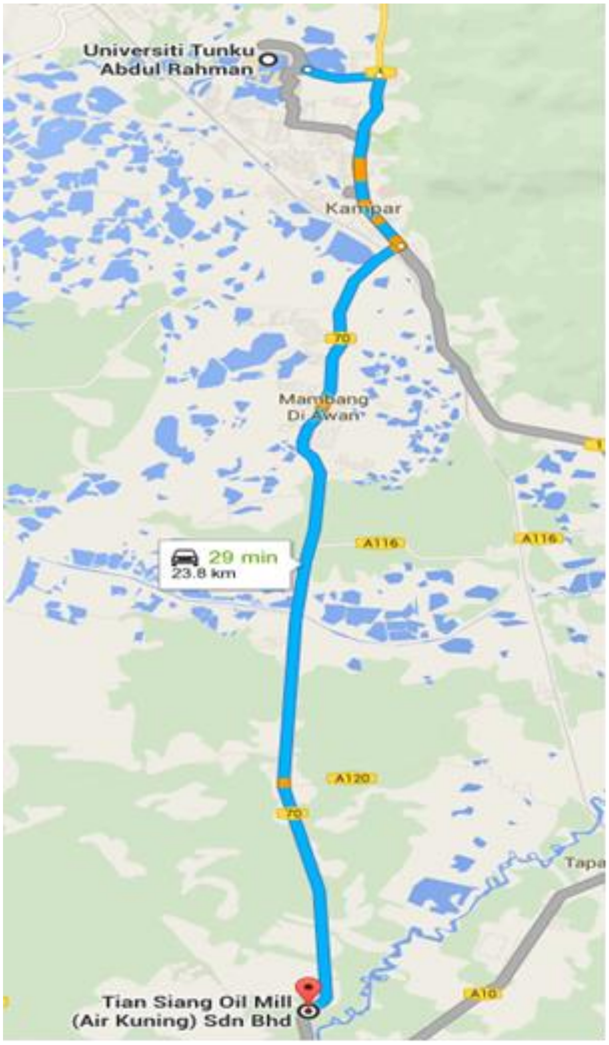

Figure 3.5: Tian Siang Oil Mill (Air Kuning) Sdn Bhd Site Location from Universiti Tunku Abdul Rahman, UTAR Perak Kampus (Extracted from Google Maps, Accessed On 18th July 2016)

Tian Siang Sdn Bhd is a palm oil manufacturer in which the company group owned five palm oil mills in Malaysia namely Tian Siang Oil Mill Sdn Bhd (1995), Tian Siang Oil Mill (Perak) Sdn Bhd (1997), Tiang Sian Oil Mill (Air Kuning) Sdn Bhd (2000), Pujaan Makmur Oil Mill Sdn Bhd (2002) and Tian Siang Oil Mill (Pahang) Sdn Bhd (2005). Tian Siang Oil Mill (Air Kuning) division is located 23.8 km from UTAR Kampar. The mill was commissioned in 2000 with FFB (Fresh Fruit Bunches) with production capacity of 60 tons/hr and up to 120 tons/hr of palm oil upon expansion of the plant. The plant is well equipped with bio-gas anaerobic digester facilities which capture the methane rich biogas from POME and use the gas as energy source for heat and electrical energy production. The POME plant has its own treatment facilities as shown in Figure 3.6 and the (POME) active sludge is freshly collected from sedimentation tank No.4 and Figure 3.7 shows the POME sludge was collected with a 5.5 L polypropylrene (PET) bottle at the POME sludge sedimentation tank sampling-out pipe from sedimentation tank no.4.

Figure 3.6: Sedimentation Tank No.4 at Tian Siang (Air Kuning) Sdn Bhd

Figure 3.7: Collection of POME Sludge with A 5.5 L Polypropylrene (PET) Bottle

3.3 Leachate Characteristics and Palm Oil Mill Effluent (POME) Sludge Analytical Methods

The generation and composition of leachate are largely influenced by local climate condition (rainfall and temperature), site topography (flat land or hill), site hydrology, availability of oxygen, age of landfill and the rate biological and chemical degradation of waste in the landfill (Yu, 2007). In general, there are several representations that can characterise landfill leachate which need to be determined to test the toxicity of the leachate namely pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammoniacal nitrogen (NH_3-N), colour, turbidity and suspended solids (SS) using the standard method (APHA, 2005).

In general, the testing and characterisation for sludge and activated sludge are pH, chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), suspended solid (SS), mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS). Both leachate and POME sludge information are crucial for the types and design of the treatment operations.

3.3.1 pH

The pH in both samples was measured using the pH meter, Hanna HI 2550, Romania as shown in Figure 3.8. 100mL of sample was transferred into a 100 mL beaker. Before each sample was tested, the pH meter was calibrated using the three buffer solutions at pH 4.0, pH 7.0 and pH 10.0 to ensure higher degree of accuracy of the meter. Before the reading was taken, the sample was stirred to ensure homogeneity in sample, then the pH probe was rinsed with distilled water and was inserted into the sample to obtain a stable reading. Each of the pH reading was taken by repeating the stirring of sample and rinsed the pH probe with distilled water.

Figure 3.8: pH Meter (Hanna HI 2550, Romania)

3.3.2 Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand was tested according to the HACH Reactor Digestion Method 8000 in the HACH Water Analysis Handbook (Hach, 2005). The COD heat reactor DRB 200, Germany as shown in Figure 3.8 was switched on and preheated to 250^{o}C before the samples together with the HR COD Digestion Reagent Vial was placed into the reactor. For samples preparation, 2 ml of deionized water was added into the HR COD Digestion Vial using pipette as blank sample. 2 ml of samples with different dilution ratio of 1:1 (Raw), 1: 10, 1: 50 for leachate and 1: 10, 1:50 and 1: 100 for POME sludge was pipetted into different HR COD Digestion Vial and mixed gently before placing into the COD reactor. The Vials were allowed to heat at 250 ^{o}C for 2 hours. After heating, the vials were taken out from the COD reactor and were cooled down to room temperature for 20 minutes. After cooling, the vials were then proceed for COD testing using the spectrophotometer, DR 6000, Germany as shown in Figure 3.9. The removal efficiency in percentage, % can be calculated by the following below equation 3.1:

$$\text{Percentage of COD removal efficiency, \%} = \frac{Initial\ COD - Final\ COD}{Initial\ COD} \times 100\% \qquad (3.1)$$

Figure 3.9: COD Heat Reactor (DRB 200, Germany)

Figure 3.10: Spectrophotometer (DR 6000, USA)

3.3.3 Biochemical Oxygen Demand (BOD_5)

The Biochemical Oxygen Demand, BOD_5 measurement of leachate sample is crucial to identify the age of the landfill leachate. Young landfill leachate in general results in higher value of BOD_5 level compared to old landfill leachate which gives lower value of BOD_5. The BOD_5 level. The BOD_5 for leachate samples were diluted and tested with different dilution ratio of 1: 100, 1:500 and 1:1000 with duplicate samples using dilution method (APHA, 2005). The diluted samples were transferred and allowed to over flow into 300 ml BOD bottles. The initial dissolved oxygen (DO_0) of each sample was measured by DO 6+ Dissolved Oxygen Meter, EUTECH, Singapore as shown in Figure 3.11. The bottles were then immediately sealed tightly with parafilm to prevent air disturbance and aluminium foil to prevent growth of photoautotrophs. The bottles were then placed into the BOD incubator FOC 225E, Europe as shown in Figure 3.12 for 5 days at 20 ^oC. The final dissolved oxygen, DO_5 was measured after the 5 days incubation period. The BOD_5 was calculated based on the below Equation 3.2:

$$BOD_5 = \frac{DO0-DO5}{Dilution\ Fraction} \tag{3.2}$$

Figure 3.11: DO 6+ Dissolved Oxygen Meter (EUTECH, Singapore)

Figure 3.12: BOD Incubator (FOC 225E, VELP SCIENTIFICA, ITALY)

3.3.4 Ammoniacal Nitrogen (NH_3-N)

The ammoniacal-nitrogen as nutrient indicator in leachate and POME sludge samples were measured by Nessler Method (APHA, 2005). The samples were then shaken several times after each time adding the reagents to ensure homogeneous mixing before measured. The blank sample and other samples were filled in an empty cuvette. The cuvette containing the blank sample was placed to set as zero in the UV spectrophotometer DR 6000, Germany, subsequently press read on the screen to take measurements of each samples in the cuvette of NH_3-N in mg/L.

3.3.5 Colour

The colour of both leachate and POME sludge samples were measured according to the standard method of Platinum-Cobalt (PtCo) provided by Hach Company. Cleaned empty glass COD HR vials were filled with the diluted samples and one blank vial which contains distilled water only was prepared as blank for the test. The blank sample was first placed in position as zero in the spectrophotometer, DR 6000, Germany by selecting the program “Colour 465nm” at 465nm wavelength. The colour value of each samples tested was obtained in Platinum-Cobalt scale, PtCo.

3.3.6 Turbidity

The turbidity measurement of leachate and POME sludge samples was done by using the turbidity meter, Hanna HI 98703, Romania as shown in Figure 3.13. Before each sample was tested, the meter was calibrated to ensure higher degree of accuracy of the test results. After the calibration, the diluted samples were filled until the marked line in the 10 ml sample cells provided together with the meter. Before the cells were placed into the meter, the cells were wiped clean with a towel. The turbidity measurement value was in Nephelometric Turbidity Units, NTU.

Figure 3.13: Turbidity Meter (Hanna HI 98703, Romania)

3.3.7 Suspended Solid

The suspended solids measurement was done using The Photometric Method, method 8006 according provided by Hach Company. The equipment used was the spectrophotometer, DR 6000, Germany. 5 ml of distilled water as blank and the diluted samples were transferred into clean empty glass vials. The program “Suspended Solids 750mg/L” was chosen and the blank glass vials first was placed into the spectrophotometer, DR 6000, Germany to set as zero. The results were measured in mg/L.

3.3.8 Heavy Metals

The Papan landfill leachate sample containing heavy metals are analysed by the Inductively Coupled Plasma Mass Spectrometry (ICP-MS PERKIN ELMER NEXION^{TM} 300Q, USA) as shown in Figure 3.14. Heavy metals like Manganese (Mn), Iron (Fe), Nickel (Ni), Copper (Cu), Silver (Ag), Lead (Pb), Zinc (Zn), Arsenic (As), Selenium (Se), Cadnium (Cd) and Barium (Ba) were tested using the ICP-MS. Before analysis, standard stock solutions of 10 ppb, 500 ppb and 1000 ppb together with a blank solution (Ultrapure water) were prepared for calibration of the ICP-MS. The leachate sample was filtered by 0.45μm filter syringe paper and diluted with a dilution factor of 100 and 1000 to ensure all readings fall within the ICP-MS's measurable range and lastly by adding 1% of nitric acid (HNO_3). After labelling and preparing all standard stock solutions and diluted leachate samples, the samples was keyed into the computer which connects to the ICP-MS. The samples were tested and all data were saved in the computer database.

Figure 3.14: Inductively Coupled Plasma Mass Spectrometry (ICP-MS PERKIN ELMER NEXION^{TM} 300Q, USA)

3.3.9 Mixed Liquor Suspended Solids, MLSS and Mixed Liquor Volatile Suspended Solids, MLVSS

The MLSS and MLVSS were measured by Standard Methods (APHA, 2005). This test is solely for POME sludge sample as to determine the amount of food and the amount of microorganism present in the sample. The MLSS is the weight of the total suspended solids in the mixed liquor which consist of organic matter (microorganisms mass) and non-organic, non-biodegradable matter. In general, the MLVSS value composed of 70 – 80% of the MLSS and both parameters can have used to figure out the Food to Mass, F:M ratio to ensure sufficient supply of substrate to the microorganisms in the reactor.

A small 25 ml crucible together with 21mm, 1.2µm pore size 261 Glass Microfibre Filter, France (The filter was placed into the crucible) as shown in Figure 3.15 were placed into the furnace at 550 ^{o}C as shown in Figure 3.17 for 15 minutes. After furnace, the crucible with filter paper were allowed to cool down in the oven as shown in Figure 3.18 for 15 minutes at 105 ^{o}C and then is transferred into a desiccator for 20 minutes to cool down to room temperature and subsequently the initial mass (a) of crucible with the filter were weighted using the analytical balance, Sartorius, Germany and recorded in grams, g shown in Figure 3.16.

After weighing, the filter paper is filtered with distilled water by using a filter funnel together with a suction pump and 1 ml of sludge sample was transferred to the filter paper for filtering. After filtering, both the crucible and the filter was placed into the Heating and Drying Universal Oven, Germany for 2 hours. Then, the crucible with the filter was allowed to cool down to room temperature in the desiccator for 15 minutes and the mass (b) was obtained by weighing the crucible with the filter. The crucible with the filter is then furnace at 550 ^{o}C in the Electric Muffle Furnace, LabTech, India for 15 minutes and were allowed to cool down to room temperature in the desiccator for 20 minutes. The last weight (c) was weighted and recorded.

The value in mg / L of MLSS and MLVSS are calculated based on the below equation 3.3 and 3.4:

Weight (a) = weight of crucible + filter paper

Weight (b) = Weight of crucible + filter paper + 1 mL of sludge, after heated at 105 ^{o}C

Weight (c) = Weight of crucible + filter paper + 1 mL of sludge, after heated at 550 ^{o}C

MLSS, amount of microorganisms = (b) – (a) in grams, g/mL $\times \frac{1{,}000\ mg}{1\ g} \times \frac{1{,}000\ ml}{1\ l}$

$$\text{MLSS} = \text{mg / L} \tag{3.3}$$

MLVSS, amount of food = (c) – (b) in grams, g/mL $\times \frac{1{,}000\ mg}{1\ g} \times \frac{1{,}000\ ml}{1\ l}$

$$\text{MLVSS} = \text{mg / L} \tag{3.4}$$

Figure 3.15: 21mm, 1.2µm pore size 261 Glass Micro-fibre Filter (Filtres Fioroni, France)

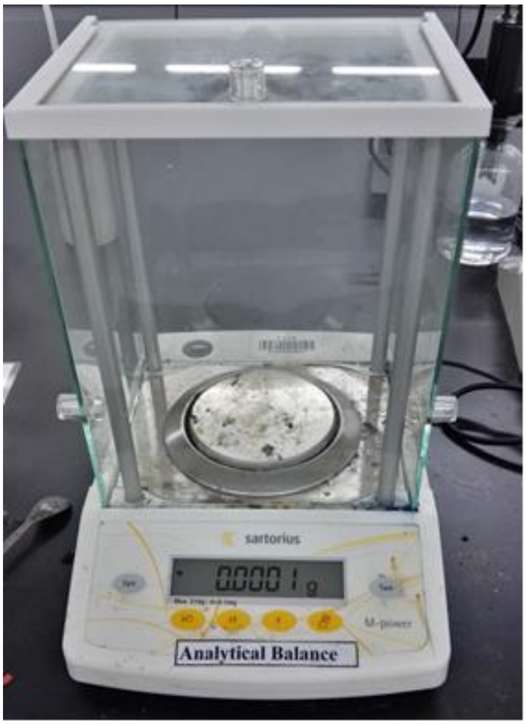

Figure 3.16: Entris 124-1S Analytical Balance (Sartorius, Germany)

Figure 3.17: Electric Muffle Furnace (LEF-P type, LabTech, India)

Figure 3.18: Heating and Drying Universal Oven (Memmert, Germany)

3.3.10 Temperature

The temperature of the reactor was measured using the Infrared Thermometer by Intell Instruments Plus, Houston, Texas as shown in the Figure 3.19 below. The temperature of the feed (leachate) and other solutions or samples in this research were measured using the integrated temperature probe in the pH meter by Hanna HI 2550, Romania in figure 3.8.

Figure 3.19: AR300+ Infrared Thermometer (SMART SENSOR, Intell Instruments^{TM} Plus, Houston, Texas)

3.3.11 On-Site Parameter Analysis

The CyberScan PCD 650 Multi-Parameter, EUTECH Singapore as shown in Figure 3.20 was brought together with other necessary equipment to Papan landfill to conduct the On-Site Parameter test for the fresh leachate sample. This test in important as to measure the basic changes of the fresh leachate collected on the landfill site compared to the stored leachate samples in the lab refrigerator. The Multi-Parameter was well calibrated using standard stock solutions which were present in the box as well as other standard stock solutions present in the laboratory. After calibration, 4 double A size (AA) batteries were installed into the Multi-Parameter before the day going to the landfill to conduct On-Site testing while collecting fresh leachate samples. Leachate parameter namely pH, temperature, conductivity, resistivity, dissolved oxygen (DO), oxidation reduction potential (ORP), total dissolved solids (TDS), salinity and ion were tested both On-Site and Off-Site using the Multi-Parameter. The Multi-Parameter was calibrated each time before each test to ensure a more accurate reading acquired.

Figure 3.21: CyberScan PCD 650 Multi-Parameter (EUTECH Instruments, SINGAPORE)

3.4 Experimental Set-Up

In this research, there were six 1.5 L mineral plastic bottle bio-reactors made from Polypropylrene (PET) in which being held firmly by clamp attached to a retort stand. There were 3 sets of plastic tubes with different purpose which were inserted into the reactor at different lengths for aeration, feeding / withdrawing and sludge collection respectively. The plastic tubes were secure and held tightly by a modified plastic cap which was placed on top of the opening of the reactor and there were valves attached to the tubes. To provide proper mixing and sufficient DO in the reactor, each SBR employed a set of pump with a flow meter connected between the pump and the reactor to control the air-flow rate as well as to provide constant aeration and mixing during the reacting period. The reactors were divided into 3 groups comprising each 2 SBR with flow-rate of 1 L/min, 3 L/min and 5 L/min respectively.

Figure 3.21 shows the set-up of equipment and apparatus for a complete set of a SBR. There were 6 sets of SBR in this experiment; each of the one pair operating for a specific air flowrate of 1 L/min, 3 L/min and 5 L/min respectively.

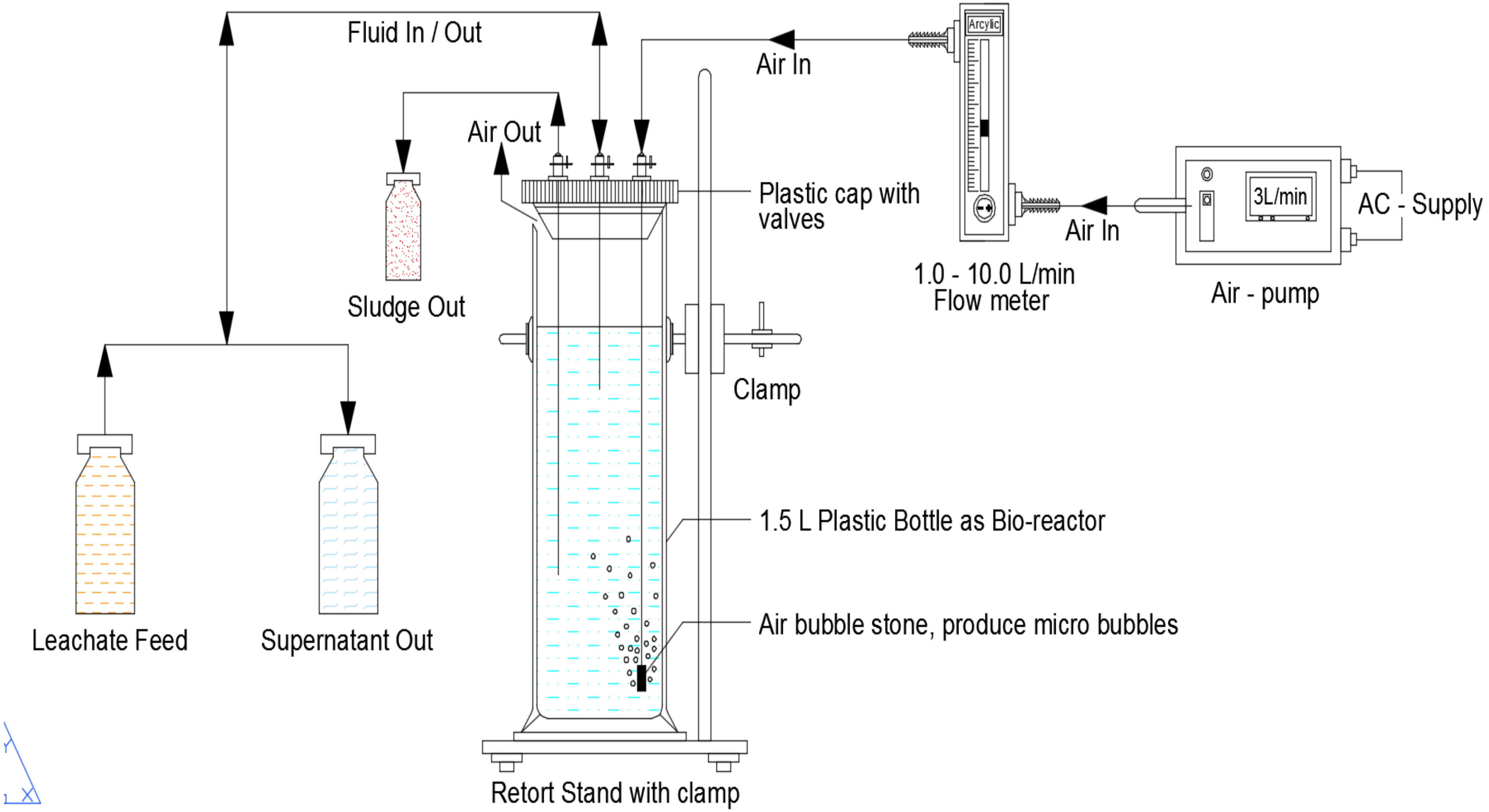

Figure 3.21: Sequencing Batch Reactor (SBR) Experimental Setup

3.5 Experimental Run

The experiment run was conducted as an effort to study the cultivation process of bacteria in the SBR. The cultivation was done by a 10-15 days period as to allow the sludge to adapt to the environment. Each of the 1.5 L plastic bottle was filled with 720 ml of POME sludge and 80 ml of Papan landfill leachate which gives a mixing ration of 1:10 of landfill leachate to palm oil mill sludge and has a working volume of 800 mL. During the sludge cultivation period, the sequential operation of the reactor comprises filling and mixing (20 minutes), react and aeration (22 hours), settling (90 minutes) and drawing (10 minutes) which the complete cycle of the SBR was a 24 hours cycle. Figure 3.22 illustrates the sequential stage of a complete 24 hours cycle of SBR in this research.

Figure 3.22: A Complete Cycle of SBR

During the cultivation period, 480 mL of leachate was allowed to warm up to room temperature and the pH of leachate was adjusted to 7.50 as the initial pH of the leachate was at 8.44 which is not suitable for bacteria acclimation. The contact time was set to be 22 hours and the aeration rate was set to be at 1.0 L/min, 3.0 L/min and 5.0 L/min for the respective groups of the SBR. An aquarium bubble stone was attached to each end of the aeration tube in the SBR to produce micro bubbles to enhance the dissolve oxygen (DO) and to improve the even mixing of sludge with the medium in the reactor. The SBR was operating at room temperature condition (23 ^{o}C – 26 ^{o}C). The 1 L/min air was supplied by an air pump. The air flow rate was manually controlled by an air flow meter (SHLLJ ACRYLC Flow meter, Model: LZM-6, Range: 0 – 10 L/min).

3 mL of sludge sample was extracted from each SBR using a pipette right after the aeration was stopped. The sludge samples were collected into cleaned empty COD vial once every two days during the 10 days cultivation period and were immediately stored in the fridge at 4 ^{0}C for future analysis. The top effluent was taken from each

SBR after 90 minutes of settling through a thin plastic tube into a sampling bottle (180 mL) once per day and was immediately stored in the fridge at 4 ^{0}C for further analysis.

Daily desludging of 25 mL of fresh sludge right after the aeration for each SBR was conducted and fresh sludge sample was continued to be collected once every two or three days after the 10 days' cultivation period.

3.5.1 Food-To-Microorganism Ratio (F/M Ratio)

F/M ratio or Food-to-Microorganism ratio affects the growth of microbes in SBRs. In this terminology, Food (the "F" in F/M) is the availability of readily biodegradable organic matters or BOD_5 or partially COD concentrations in the wastewater per day per quantity of Microorganisms (the "M" in F/M) (Gerardi, M.H., 2002). The amount of bacteria in an activated sludge system is very dependent to the amount of food in the infeed of the system. If the amount of food increases per day, the amount of bacterial within the system will increase. The general formula for calculating amount of Food, Microorganisms and F/M ratio are presented in equations 3.5, 3.6 and 3.7 respectively:

$$\text{Food} = \text{Infeed concentration of COD or } BOD_5 \text{ (mg/L)} \times \text{Influent Volume per day (L)} \quad (3.5)$$

$$\text{Microorganisms} = \text{MVLSS concentration (mg/L)} \times \text{Reactor Working Volume (L)} \quad (3.6)$$

$$\text{F/M} = \frac{BOD5\left(\frac{mg}{L}\right) \times \text{Influent Volume per day (L)}}{MVLSS\left(\frac{mg}{L}\right) \times \text{Reactor Working Volume (L)}} \quad (3.7)$$

3.5.2 Sludge Retention Time (SRT)

SRT, Sludge retention time or solid retention time is the exchange ratio of solids mass in a reactor divided by the solids exiting the activated sludge system per day. Adequate SRT is crucial for SBR as is one of the design factor for nutrient-removal process and the SRT should be based on the aeration time during a complete cycle of the SBR (Poltak, R.F., 2005) (Davies, P.S., 2005) The SRT formula:

$$\mathrm{SRT} = \frac{Reactor\ Working\ Volume\ (L)}{\text{Desuldge or Volume of sludge leaving per day (L/day)}} \tag{3.8}$$

3.5.3 Hydraulic Retention Time (HRT)

HRT also known as hydraulic residence time is the exchange ratio of liquid volume in a reactor divided by the liquid (effluent) exiting the activated sludge system per day. (NPTEL.ac.in., 2013) The HRT formula is as below (Davies., 2005):

$$\mathrm{HRT} = \frac{Reactor\ Working\ Volume\ (L)}{\text{Decant or Volume of effluent leaving per day (L/day)}} \tag{3.9}$$

3.6 Post Treatment – Coagulation of Leachate

The purpose of post treatment is to further treat the effluent from the SBR as to increase the treatment efficiency of the sequencing batch reactor. Aluminium Sulphate, ALUM with chemical formula: $Al_2\ (SO_4)_3.16H_2O$ and molecular weight of 630.39 g/mole was used as coagulant for post treatment of the effluent by SBR. Effluent samples from SBR were transferred into 50 mL beakers and were placed in the KS 4000 I control orbital shaker as shown in Figure 3.23 to run the post treatment. Jar test method was used to determine the optimum pH and dosage of the leachate sample and ALUM respectively. During the jar test, each of the sample in a 50 mL beakers were placed into the orbital shaker with rapid mixing: 120 RPM for 3 minutes, slow mixing: 20 RPM for 20 minutes and settling time of 60 minutes.

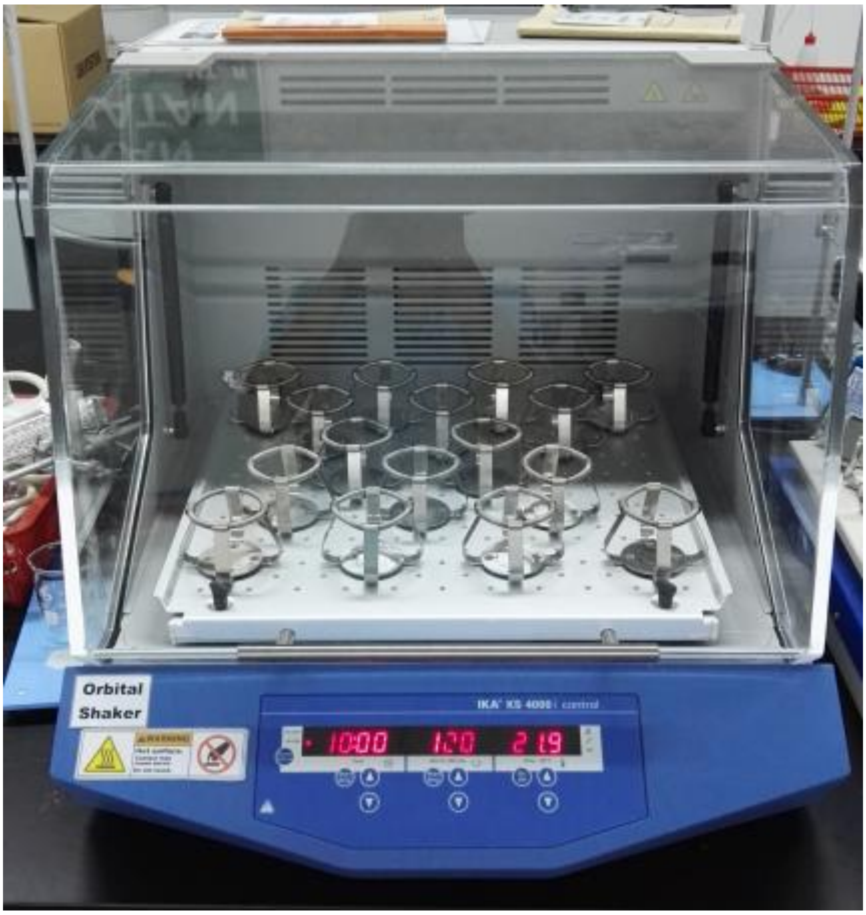

Figure 3.23: KS 4000 I control Orbital Shaker (IKA$^{@}$ Werke Staufen, Germany)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Leachate Characteristics

The raw leachate samples were collected three times from Papan landfill site on 11th July, 11th August and 28th November of 2016. Before characterization, the leachate sample was taken out from the laboratory refrigerator and placed into a water bath at 26.0 °C for 20 minutes to ensure the sample was heated to room temperature in order to get the most relevant results. Table 4.1 summarizes the characteristics of the raw leachate.

Based on Table 4.1, the raw leachate sample collected from Papan landfill were significantly high in COD, BOD_5, NH_3-N, Colour, Turbidity, Suspended Solids and other heavy metals like Lead, Copper, Zinc, Iron, Silver, and Selenium. Based on the main parameter of BOD_5/COD, the raw leachate sample is classified to be intermediate leachate. The values range indicates the minimum and maximum concentration of each parameter for the three samples collected at different period.

Table 4.1 Raw Leachate Samples Characterization

Parameter	Unit	Value Range	Malaysia Discharge Standards
pH	-	8.34 - 8.44	6.0 – 9.0
Temperature	°C	25.3 -26.1	40
COD	mg/L	3,530 – 6,420	400

BOD_5	mg/L	830 – 1,100	20
BOD_5/COD	-	0.17 - 0.24	-
Ammoniacal Nitrogen, NH_3-N	mg/L	958 – 1,403	5
Oxidation Reduction Potential, ORP	mV	-73.7 to -75.6	-
Electrical Conductivity	mS	20.0 – 24.9	-
Total Suspended Solis, TSS	mg/L	115 - 220	50
Colour	PtCo	3,800 – 4,510	100
Turbidity	NTU	163 - 213	-
Salinity	ppt	16.93 – 17.25	-
Cadmium	mg/L	0.54	
Arsenic	mg/L	0.43	0.05
Lead	mg/L	3.46	0.10
Copper	mg/L	13.01	0.20
Manganese	mg/L	0.83	0.20
Nickel	mg/L	0.46	0.20
Zinc	mg/L	7.51	2.00
Iron	mg/L	23.18	5.00
Silver	mg/L	0.94	0.10
Selenium	mg/L	0.65	0.02
Barium	mg/L	1.10	1.00

4.2 Field and Laboratory Characterization of Leachate

The main purpose of this test is to evaluate the change in quality and characteristics of the leachate collected from Papan landfill. This study is important as to know the changes in the stored sampled as this will greatly affect the research outcome and the results obtained in this research may not be reliable if the quality of the stored leachate in the laboratory fridge changes too much. Therefore, the leachate characterization is required in this research as an effort to monitor the quality of the leachate.

Table 4.2: Field and Laboratory Leachate Sample Characteristics Test Comparison

Parameter	Unit	Value		Changes, %
		On-Site	Off-Site	
pH	-	8.05	8.29	2.98
Temperature	^oC	35.3	25.3	28.33
Electrical Conductivity	mS	23.88	23.50	1.59
Resistivity	Ω	22.66	22.98	1.41
Dissolved Oxygen, DO	mg/L	2.69	1.00	62.83
Oxidation Reduction Potential, ORP	mV	-66.5	-76.2	14.59
Total Dissolved Solis, TDS	ppT	22.11	21.77	1.54
Salinity	ppT	17.34	16.98	2.08
Ion	-	0	0	0

Table 4.2 shows that the quality of the leachate slightly changes after 2 week of storage in a 4 ^oC laboratory fridge. The changes are shown in the leachate characteristics value for on-site and off-site parameters in the table. However, there are four parameters with significant changes which are taken into consideration namely pH, temperature, DO and ORP which changes at 2.98 %, 28.33 %, 62.83 % and 14.59 % after two weeks of storage. Bakar et al. (2012) stated that the nitrification and denitrification are able to take place at very low temperature even at 4 ^oC which is near to the cease of nitrification process however the author reported that nitrification can occurred up to 40 ^oC. Nitrification process at 4 ^oC will be extremely low. According to Gerardi (2002), the effect of temperature related to nitrification as shown in the below Table 4.3. No growth of Nitrosomonas or Nitrobacter occurs below 4 ^oC (Gerardi, 2002)**;** which is the reason that very small percentage of nitrifying bacteria are still active in the leachate which is stored in the laboratory fridge at 4 ^oC.

Table 4.3: Nitrification Process Related to Temperature (Gerardi, 2002)

Temperature	**Effect upon Nitrification**
< 5 ^{o}C	Nitrification ceases
10 ^{o}C	Significant reduction in rate, approx. 20% of rate at 30 ^{o}C
16 ^{o}C	Approx. 50% of nitrification rate at 30 ^{o}C
28 - 32 ^{o}C	Range of optimal temperature
> 45 ^{o}C	Nitrification ceases

The pH of the stored leachate increases from 8.05 to 8.29 after 2 weeks of storage is mainly due to the denitrification process which produces OH^- base during the reduction of nitrate, NO_3^- as shown in the general equation below:

$$NO_3^- + bCOD \xrightarrow{\text{Denitrifiers}} N_2 + CO_2 + H_2O + OH^- + \text{New Cells} \qquad (4.1)$$

Wiszniowski et al. (2006) reported that 3.57 g of alkalinity and 0.45 g of new cell were produce upon the reduction of per gram of $NO_3 - N$ in wastewater under anoxic or anaerobic condition. Therefore, the overall pH of the leachate sample will increase with time in the 4 ^{o}C storage.

The DO in the stored leachate sample greatly reduced from 2.69 mg/L to 1.00 mg/L as this is due to the consumption of dissolved O_2 during the activity of bio-degradation of organic waste in the stored leachate over time. In general, they are many natural occurring aerobic microorganisms in the leachate to degrade organic waste and in other sources of wastewater. The below equation shows the general equation of the degradation of organic matters in water:

$$\text{Organic matter} + O_2 + \text{Nutrients} \longrightarrow CO_2 + H_2O + C_5H_7NO_2 + \text{other products} \qquad (4.2)$$

Where $C_5H_7NO_2$ represents the newly produced cells (Strande et al, 2014).

The ORP, oxidation-reduction potential value indicates the amount of readily oxidized or reduced compounds in wastewater. The negative value of the ORP indicates the water medium has more compound to be reduced and vice versa for the positive value in the ORP readings. Denitrification process promotes more negative ORP as the process reduces nitrate, NO_3^- into nitrogen gas (Mark Prein, 2012). The increase in the negativity of the ORP value after 2 weeks in the leachate indicates the denitrification process is active.

4.3 Palm Oil Mill Sludge Characteristics

The palm oil mill sludge was collected twice from Tian Siang (Air Kuning) Sdn Bhd Oil Mill at sedimentation tank No.4 after the anaerobic digester tank on the 15th July and 31st October of 2016 respectively. The first collection was used for the characterization of the POME sludge and testing the SBR bio-reactor while the second collection was used to cultivate and undergo acclimation process of the sludge to treat leachate. The Table 4.3 below summarized the measured characteristics of the POME sludge from Tian Siang Oil Mill. The value range indicates the minimum and maximum concentration of each parameter for the two samples collected at different period.

Table 4.4: Palm Oil Mill Sludge Sample Characterization

Parameter	Unit	Value
pH	-	7.40 - 7.44
Temperature	°C	26.1
COD	mg/L	10,870 - 13,600
Mixed Liquor Suspended Solids, MLSS	mg/L	9,500 - 12,500
Mixed Liquor Volatile Suspended Solids, MLVSS	mg/L	8,350 - 9,700
MLVSS/MLSS	-	0.78 - 0.88
Ammoniacal Nitrogen, NH_3-N	mg/L	161-190

Oxidation Reduction Potential, ORP	mV	-30.5
Electrical Conductivity	mS	6.91
Total Suspended Solis, TSS	mg/L	2,767 - 3,800
Colour	PtCo	973
Turbidity	NTU	5,783 - 6,606

Based on table 4.4, the POME sludge was high in organic matters in terms of COD, suspended solids, turbidity, Mixed Liquor Suspended Solids (MLSS: 9,500 – 12,500) and Mixed Liquor Volatile Suspended Solids (MLVSS: 8,350 – 9,700). The high amount of COD concentration is due to the high amount of organic matters in the sludge. According to Aziz, (2013) in which the activated sludge from a sewage treatment plant was used having the same trend in terms of pH, temperature, suspended solids, MLSS/MLVSS ratio. It was reported that the sewage activated sludge has pH of 6.75, temperature of 26.95 ^{o}C and MLVSS/MLSS ratio of 0.84 hence the POME sludge is a suitable sludge for the cultivation of nitrifying and denitrifying microorganisms for the treatment of Papan landfill leachate (Aziz et al., 2013).

4.4 Microorganisms growth-curve based on MLSS and MLVSS

In this study, POME sludge is allowed to be cultivated in the SBR as an effort to cultivate specific nitrification and denitrification microorganisms in the SBRs. This process is done by allowing the POME sludge to slowly adapt to the Papan landfill leachate and the reactor environment at room temperature with extended 22 hours of aeration.

MLSS and MLVSS are both notations which is a standard parameter to indicate the concentration of microorganisms in a liquid medium such as in a bio-reactor of an activated sludge system. According to DEP (2014), MLSS is the total concentration of inorganic and organic solids in a liquid medium while MLVSS indicates the concentration of microorganisms or organic solids in a liquid medium in which MLVSS is about 70% or 80% of MLSS. The MLSS concentration in a typical conventional activated sludge system ranges between 2,000 mg/L to 4,000 mg/L. The fresh POME sludge have initial MLSS and MLVSS concentrations at 9,500 - 12,500 mg/L and 8,350 - 9,700 mg/L respectively in which these abnormally high values of biomass and solids will drop to a suitable range over time.

Activated sludge process can be found in domestic wastewater treatment plant, leachate treatment plant and even in sedimentation tank of POME wastewater treatment facility. The process employs microscopic organisms in aeration tank and clarifier to remove or biodegradable wastes (Gerardi, 2005). Activated sludge comprises of different kinds of complex active biological lifeforms which they interact with one another upon receiving incoming waste (food). These active biological microorganisms mainly are yeast, fungi, bacteria, protozoa and possible higher organism like rotifers (Wiszniowski et al., 2006). According to Davies (2005), the composition of activated sludge varies from source to source; the bacteria remains the most dominant organisms of which may comprises 300 species or more with each bacteria having the size between 0.5 – 2.0 µm. Under aerobic conditions, these microorganisms use readily available dissolved oxygen, DO in the wastewater to oxidize soluble, suspended or colloidal organic matters which are present in wastewater like leachate (Wiszniowski et al., 2006).

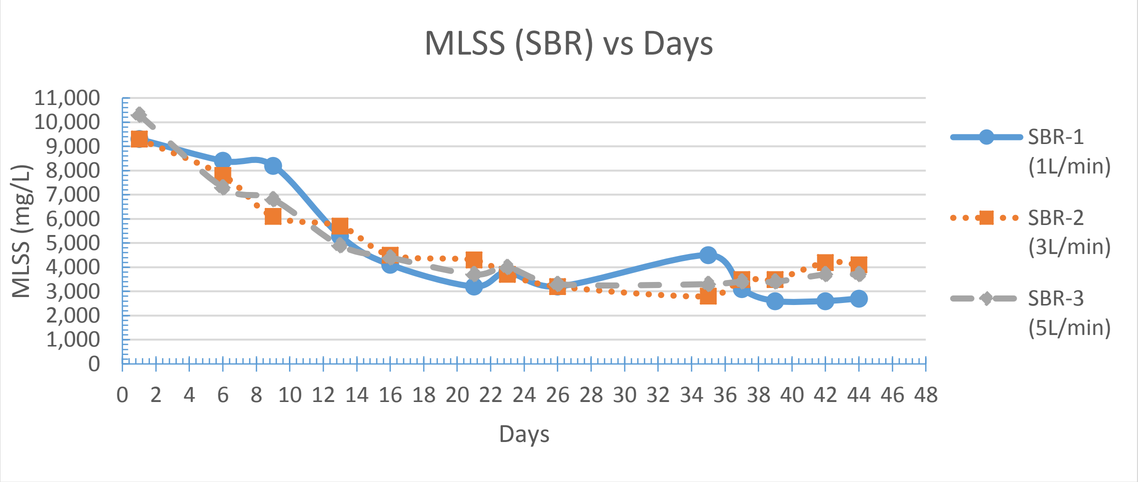

Figure 4.1: Concentration of MLSS (mg/L) inside SBRs

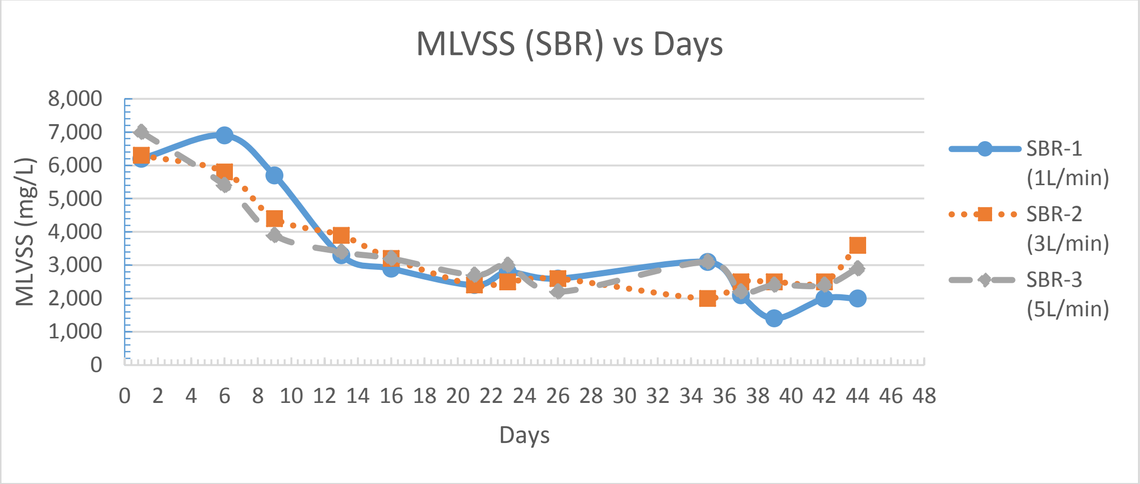

Figure 4.2: Concentration of MLVSS (mg/L) inside SBRs

Figures 4.1 and 4.2 show the trend for MLSS and MLVSS concentrations in the SBRs during the research period respectively. As shown in Figure 4.2, the overall microbial concentration of MLVSS value in the 3 reactors dropped to the second lowest at day 21 and to the lowest at day 37 with values of 2,400 mg/L, 2,400 mg/L, 2,700 mg/L for SBR-1, SBR-2 and SBR-3 and 2,100 mg/L, 2,500 mg/L and 2,200 mg/L for SBR-1, SBR-2 and SBR-3 respectively. The main reason for the continual dropped of MLVSS is due to most of the suspended solids from the sludge were carried up and adhered to the surrounding cylindrical wall and the plastic cap of the reactor by micro bubbles produced from aeration as shown in Figure 4.3; this is also the reason for the fluctuation in SBR 1 in MLVSS at day 39 which had a sudden decrease in value to 1,400 mg/L. Furthermore, the POME sludge in the SBRs may experience a “Lag” phase in a bacteria growth curve in a batch system as shown in Figure 4.4.

Figure 4.3: The Suspended POME Sludge and Other Solids Adhere On the Wall and The Cap of the Reactor.

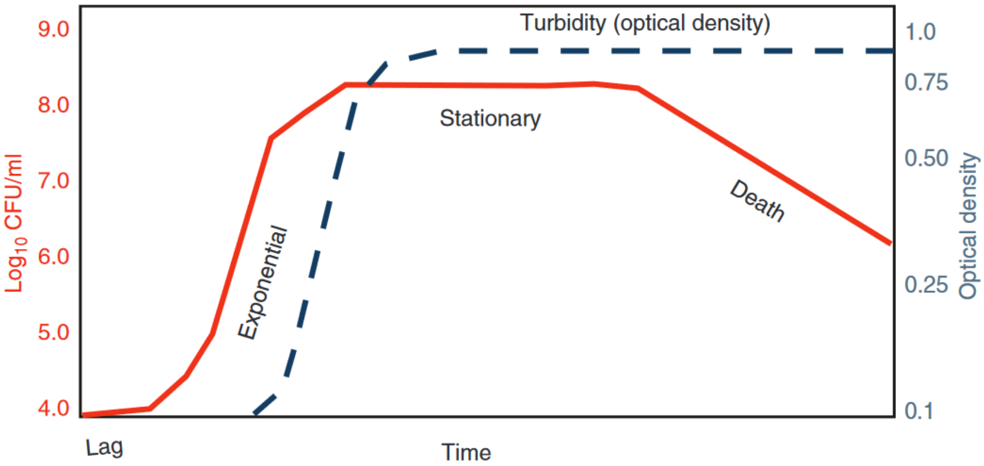

Figure 4.4: A Typical Growth Curve for A Bacterial Population in A Batch Reactor (Maier, 2000)

According to Maier (2000), when a fresh inoculum or sludge was placed into a fresh medium or to a new environment, the growth rate of these bacteria will be zero. The “Lag” phase is due to the physiological adaptation of the cells to the new environment and may involve more time to adapt to the new environment. A portion of the bacterial population may die off and another portion will survive in this process hence decrease in bacterial population or concentration. The continual drop of microbial concentration in the reactors resulted in an acceptable MLVSS concentration range from 2,000 mg/L to 4,000 mg/L as mentioned by DEP. (2014).

There was an increase of MLVSS concentration after day 39 of the suspended activated sludge in the reactor and at day 44 the MLVSS concentrations in SBR-1, SBR-2 and SBR-3 are 2,000 mg/L, 3,600 mg/L and 2,900 mg/L respectively. This may due to the fact that the bacterial population inside the SBRs has adapted to the environment and start to enter to the second phase which is the "Exponential" phase based on figure 4.4. In this phase, the bacterial population start to double at a rate of increase of cells which is proportional to the number of cells present in a given time (Maier, 2000).

New cells or microbial biomass are synthesized together with other end products like H_2O, CO_2 and other minerals during the biodegradation of the organic matters present in wastewater. These organic matters can be represented parameters like COD, BOD_5, TOC and with other nutrients like Ammoniacal nitrogen, NH_3^+-N and TKN which are present in wastewater in a concentrated amount. In this research, organic matters are in terms of BOD_5 and COD while nutrient is in term of NH_3-N. The below general equation 4.3 shows the mineralization of organic matters (CHONS) through biodegradation (oxidation) and cell synthesis by microbes in wastewater (Wiszniowski et al., 2006).

$$\underset{\text{(Organic matter)}}{\text{CHONS}} + O_2 + \text{Nutrients} \longrightarrow CO_2 + NH_3 + \underset{\text{(New bacterial cells)}}{C_5H_7NO_2} \tag{4.3}$$

EPA. (1997) and Strande et al. (2014) present a more specific equation for the conversion of fats, protein and carbohydrates organic materials by heterotrophic bacteria in wastewater are presented in the equations 4.4 and 4.5:

i) $$\text{Organic matter} + O_2 \xrightarrow{\text{Bacteria + enzymes}} CO_2 + H_2O + \text{Energy (ATP)} \tag{4.4}$$

ii) $\text{Organic matter} + P + NH_3 + O_2 + \text{Energy (ATP)} \xrightarrow{\text{Bacteria + enzymes}}$ New cell material (4.5)

Where P represents phosphorus and ATP represents Adenosine Triphosphate is an energy rich molecule which were synthesize within the microbes (bacteria) and will be used for regeneration of new cells.

According to the above equations 4.4 and 4.5, this is the main reason that both MLSS and MLVSS concentration start to increase after day 39 for the three SBRs as the starts to double up after fully adapting to the environment in the SBRs. Bakar et al. (2012) mentioned that in the aerobic pathway of biological oxidation of organic matters, a portion of the organic wastes is used by microorganisms to synthesize and to grow new organisms. Figure 4.5 below shows the schematic path way of the biological oxidation of organic wastes.

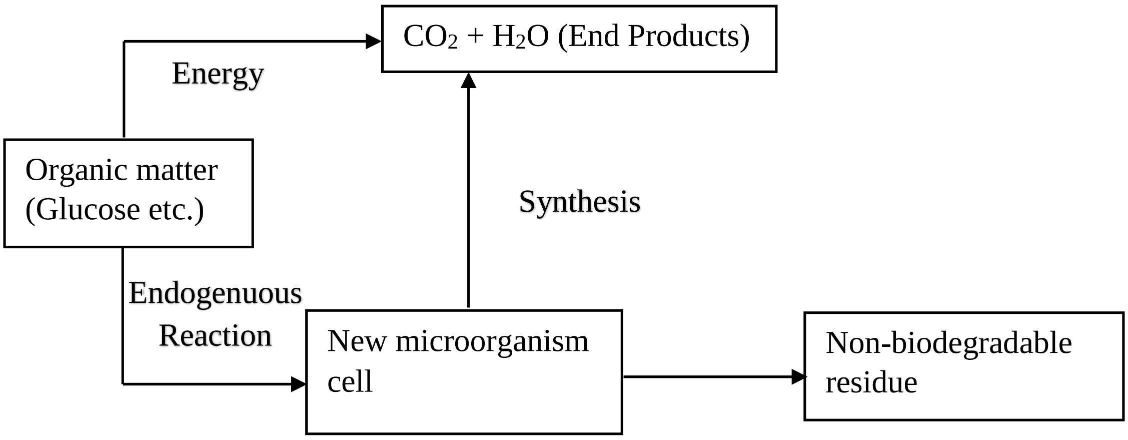

Figure 4.5: Oxidation of Organic Matters Ion Wastewater Under Aerobic Condition by Activated Sludge System (Bakar Et Al., 2012)

There are many factors affecting the performance of activated sludge in a SBR system. These factors are crucial in controlling the performance of SBR for short-term and long-term results. Factors such as F/M ratio, HRT (Hydraulic retention time), SRT (Sludge retention time or sludge age), temperature, pH, and DO. F/M ratio or Food-to-Microorganism ratio affects the growth of microbes in SBRs.

In this research, the concentration and volume of the influent of the raw leachate as feed is 6,420 mg/L and 80 mL + 30 mL= 110 mL = 0.11 L daily; at day 42, the average MLSS is at 3,500 mg/L. Hence the F/M ratio for each SBR is calculated as shown below using equation 3.7 in methodology.

$$\text{F/M} = \frac{6{,}420\ (\text{mg/L}) \times 0.11\ \ (\text{L})}{3{,}500\ \left(\frac{mg}{L}\right) \times 0.8\ (\text{L})}$$

$$\text{F/M} = \frac{706.20\ \text{mg}}{2{,}800\ mg}$$

$$\text{F/M} = 0.25$$

According to Davies, 2005, many of the conventional wastewater treatment plants operating an F/M ratio between 0.2 – 0.5. Hence in this research the F/M = 0.25 is considered to be normal for a suspended activated sludge system in SBR. The reason for lower values of F/M instead of theoretical F/M ratio which usually ranges from 0.5 to 1.0 is due to the fact that which will cause poor settlability of the sludge and may need a longer duration during the settling time for SBR.

The volume of sludge exiting the SBR is 30 mL on a daily basis and the calculation for SRT as shown below is according to the equation 3.8 in methodology.

$$\text{SRT} = \frac{0.8\ (\text{L})}{0.03\ (L/day)} = 26.67\ \text{days} \sim 27\ \text{days}$$

The SRT in this research is 27 days and it was mentioned by Davies, P.S., (2005) that the SRT may vary from system to system. The SRT for a very high-rate system may be less than ½ a day and a very slow-growing-rate system like an extended aeration system in SBR may up to 75 days. Hence, SRT of 27 days is a suitable SRT for the extended 22 hours aeration in the SBRs. The volume of effluent with the desludge volume exiting the SBR is 80 mL + 30 mL = 110 mL = 0.11 L on a daily basis. By using equation 3.9 in methodology, the HRT of SBR is about 7 days as shown in the calculation below.

$$\text{HRT} = \frac{0.8\ (L)}{0.11\ (\text{L/day})}$$

$$\text{HRT} = 7.27 \text{ days} \sim 7 \text{ days}$$

The HRT in this research is longer compare to other research which treats domestic wastewater as Papan landfill leachate containing high amount of COD at 6,420 mg/L (highest record) and BOD at 1,100 mg/L (highest record) hence the suspended activated sludge or bacteria need more time to oxidize the high concentration yet complex of the organic matters in the reactor. The growth condition in terms of temperature, pH and DO of both nitrification and denitrification bacteria are shown below (Wiszniowski et al., 2006) (Bakar et al., 2012). The requirements for the growth of nitrifiers (AOB and NOD) in nitrification are summarized as follow:

- Temperature range between 5 ^{o}C to 40 ^{o}C (mesophilic microorganisms), optimal temperature = 30 ^{o}C to 37 ^{o}C
- Acceptable pH range between 5.5 – 9.0 and optimal pH = 7.5
- DO more than 1.0 mg/L, optimal DO > 2.0 mg/L

According to Peng and Zhu. (2006), the optimal temperature for nitrification process is at 35 ^{o}C to 38 ^{o}C which gives the maximum activity for nitrification as temperature raise can expand and promote the specific growth rate of the nitrifying bacterial groups. The requirements for growth of denitrifiers in denitrification are summarized as follow:

- Temperature range between 5 ^{o}C to 60 ^{o}C (mesophilic microorganisms), optimal temperature = 30 ^{o}C to 37 ^{o}C
- Acceptable pH range between 6.0 – 8.0 and optimal pH = 7.0 – 7.5
- DO to be close to 0 mg/L or DO < 0.5 mg/L

In this research, the temperature, pH and DO of the reactor fulfill the requirements for both nitrification and denitrification processes. The temperature and pH of the SBRs were monitored daily using the Intell Instruments Plus infrared thermometer and submerging the pH probe of the Hanna HI 2550 pH meter. DO is to be monitored once a week by taking out 50 mL of sample right after aeration and right after 1.5 hours of settling time. The DO was taken once a week as to reduce the disturbance to the reactor. The Table 4.5 below shows the operating condition of the reactor on daily basis.

Table 4.5: The daily operational conditions in SBRs

Operational Parameters	**Units**	**Aerobic Phase (During Aeration)**	**Anaerobic Phase (During Settling)**
Temperature	^{o}C	22.8	23.2
pH	-	7.50	8.44
DO	mg / L	5.65	0.00

4.5 Sequencing Batch Reactor, SBRs Treatment Efficiency

Figure 4.6 show the best treatment efficiency for COD, NH_3-N, TSS and colour from Papan landfill leachate by aerobic SBRs at different aeration rates at 1.0 L/min, 3.0 L/min and 5.0 L/min. The SBRs has a complete cycle of 24 hours which has a sequential operation of 0.5 hour for feeding and mixing, followed by 22 hours of extended aeration, 1.5 hours of settling and lastly 0.5 hour of decanting and sample extraction and collection.

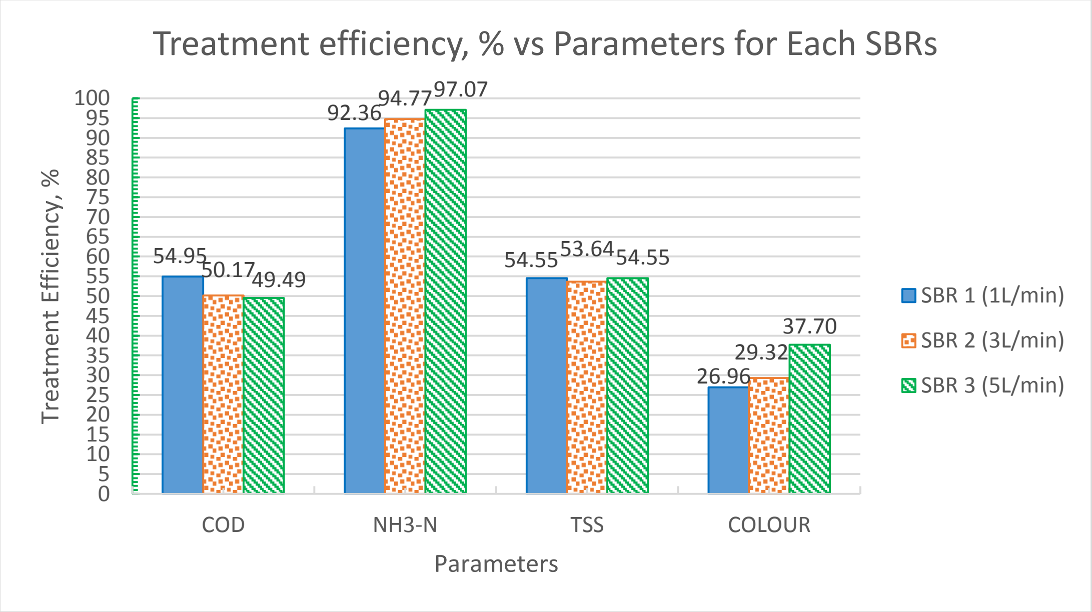

Figure 4.6: Treatment Efficiency of the Four Parameters (COD, NH_3-N, TSS and Colour)

Overall, the aerobic SBRs in treating raw Papan landfill leachate has the greatest removal efficiency for NH_3-N of more than 90 %, medium removal strength for COD and TSS at around 50 % and about 30 % for removing colour.

4.5.1 Ammonical Nitrogen (NH_3-N) Removal Efficiency

The above graph shows that NH_3-N having the highest removal efficiency at 92.36 %, 94.77 % and 97.07 % for SBR having aeration rates of 1 L/min, 3 L/min and 5 L/min respectively compared to other parameters.

In biological nitrogen removal, the process mainly can be categorized into two separate steps namely nitrification involves the conversion of ammonium to nitrate under aerobic condition and denitrification involves the conversion of nitrate to nitrogen gas, N_2 using readily biodegradable organics as electron acceptor under anoxic or anaerobic condition (Wei et al., 2012). According to Wiszniowski et al. (2006), aerobic autotrophic bacteria is responsible for the complete nitrification process in which two sequential processes take place which the AOB (Ammonia – Oxidizing Bacteria) oxidize ammonia into nitrite and the nitrite is further oxidized by NOB (Nitrite – Oxidizing Bacteria). The equations below are the chemical oxidation of ammonia to nitrite and nitrite to nitrate (Wiszniowski et al., 2006).

Stoichiometry of Biological Nitrification:

$$NH_4^+ + 1.5\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + H_2O + 2H^+ + \text{Energy} \qquad (4.11)$$

$$[\ \Delta G'_0 = -\ 275\ \text{KJ/mol}\ ]$$

After the AOB oxidize ammonia into nitrite, the nitrite is further oxidized by NOB (Nitrite – oxidizing bacteria) hence producing nitrate in the following equation 4.12:

$$NO_2^- + 0.5\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- + \text{Energy} \qquad (4.12)$$

$$[\ \Delta G'_0 = -\ 75\ \text{KJ/mol}\ ]$$

The two energy-yielding processes leads to the below overall reaction for a complete nitrification,

$$NH_4^+ + 2O_2 \xrightarrow{\text{Nitrifying bacteria}} NO_3^- + 2H^+ + H_2O \qquad (4.13)$$

$$[\ \Delta G'_0 = -\ 305\ \text{KJ/mol}\ ]$$

Where $\Delta G'_0$ is Gibbs Free Energy

The below diagram prepared by Gerardi, M.H. (2002) illustrate the interaction and the complete process of nitrification in wastewater by nitrosomonas and nitrobacter.

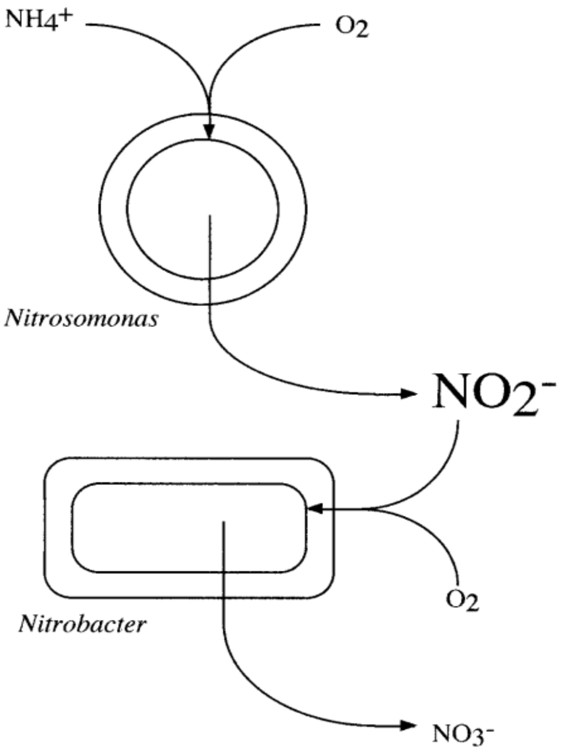

Figure 4.7: Nitrite Ions Are Waste Product from Nitrosomonas Upon Oxidation of Ammonium Ions. The NO_2^- Waste Is the Food for Nitrobacter to Oxidize into Nitrite Ions in Which NO_3^- Will Be Later Used by Denitrifying Bacteria (Gerardi, 2002)

Denitrification is the second step to complete the nitrogen cycle. In nitrification, the process does not remove nitrogen from wastewater as it simply converts ammonium ions into nitrate ions. Denitrification removes nitrogen from wastewater by converting nitrate into soluble N_2 gas which can be released back to the environment safely by heterotrophic bacteria (Metcalf & Eddy., 2014) In this process, nitrate, NO_3^- function as an electron acceptor and the organic matters, BOD_5 or COD function as electron donor to complete the denitrification under anoxic or anaerobic condition with DO less than 0.5 mg/L (Wiszniowski et al., 2006). Denitrification is also known as “dissimilatory” or “Anoxic respiration” as both nitrite and nitrate ions are reduced to form molecular nitrogen, N_2 (Gerardi, 2002). The below equations show the denitrification path performed by denitrifiers.

Stoichiometry of Biological Denitrification:

$$5\ C_6H_{12}O_6 + 24\ NO_3^- + H^+ \longrightarrow 12\ N_2 + 30\ CO_2 + 42\ H_2O \qquad (4.14)$$
$$[\ \Delta G'_0 = -\ 13.5\ \text{MJ/mol}\ ]$$

Where $C_6H_{12}O_6$ is a six-carbon sugar example glucose in wastewater that are available for denitrifiers to consume.

$$NO_3^- + bCOD \longrightarrow N_2 + CO_2 + H_2O + OH^- + \text{New Cells} \qquad (4.15)$$

There are several groups of facultative denitrifying microorganisms as they are facultative because they can survive in aerobic condition hence not strict anaerobic microbes. Denitrifiers consists mostly out of facultative anaerobic bacteria. They can be named into organotrophs, heterotrops and dentrifiers. It is reported that the genera of denitrifying bacteria Pseudomonas, Alcaligenes and Basillus are the largest wastewater activated sludge (Gerardi, M.H., 2002).

The $\Delta G'_0$ representing Gibbs Free Energy which is the amount of energy capable of doing work during a process at constant pressure and temperature. $\Delta G'_0$ values are obtained under standard condition of T = 25 °C and pH = 7.0 (Metcalf & Eddy, Aecom., 2014). This terminology applies to all biological activity and the conversion from one form of chemical into another by microbes. The negative value of $\Delta G'_0$ means the process is spontaneous and is an exergonic process which releases energy to its surrounding (heat); while the positive value of $\Delta G'_0$ means the process is non-spontaneous and is an endergonic process which consumes energy from its surrounding (Miles, 2013) Therefore, the nitrogen removal process in SBRs is very spontaneous and this is the reason for the high removal efficiency of NH_3-N in which SBR-3 achieved 97.07 %.

4.5.2 Chemical Oxygen Demand (COD) Removal Efficiency

Both the COD and TSS removal efficiencies are sharing the same removal efficiency at around 50.00 %. As shown in the Figure 4.6, the removal of COD for SBR 1 is 54.95 %, SBR 2 is 50.17 %, SBR 3 is 49.49 %. The overall removal for the three SBRs is around 50 % in this research and is considered to be not very efficient. The main reason for this is the design of the SBRs cycle in which extended aeration which involve high concentration of DO in the reactor maybe the factor that inhibit the denitrification activity. Besides, only 2 hours of non-aeration time is allowed in this research for each cycle of the SBRs during the settling phase and the decand with sampling phase which causes the duration for anoxic or anaerobic phase in the SBRs to be short if compared to other researches. According to Breisha and Winter. (2010), high DO plays an important role in nitrification but has a negative effect on denitrification. This is due to the fact that denitrification bacterial are facultative in which the denitrifiers energetically prefer dissolved oxygen over nitrate, NO_3^- as electron acceptor if the DO is more than 0.5 mg/L. Hence, the inhibition of denitrification process at high concentration of DO and short non-aeration duration will lead to the inhibition of degradation of organic matter in terms of COD or BOD_5.

In Figure 4.6, the removal efficiency of COD dropped with increase in aeration from 1.0 L/min to 5.0 L/min from 54.95 % in SBR 1 down to 49.49 % in SBR 3. This is due to the inhibition of denitrification process at higher DO concentration as denitrification is the main process in removing organic matters in leachate according to the stoichiometry of biological denitrification in Equation 4.14.

The presence of high concentrations of refractory organic compounds like FA (Fulvic acids), HS (Humic substances) which is very hard to degrade by bacterial is one of the factor that inhibit the degradation of COD (Gotvain et al., 2015). Not only that, the presence of xenobiotic compounds (XOCs) which are not natural occurring in nature but man-made substances are very hard to degrade by biological method (Slack et al., 2005). As COD is defined as the sum of inorganic and organic carbon, hence the available of readily biodegradable organic matters may not be high as the BOD_5 is 1/6 of that of COD hence the removal efficiency of COD in this research is limited by using biological treatment methods.

4.5.3 Total Suspended Solids (TSS) Removal Efficiency

The removal of TSS for SBR 1 is 54.55 %, SBR 2 is 53.64 %, SBR 3 is 54.55 %. The removal of TSS is mainly dependant to the settling time of the SBR after the aeration and mixing is switch off. According to Aslam, (2013) the removal of colloidal and suspended solids from wastewater is greatly influence by gravity separation. The terms "settling" means the action of separation of suspended solids which are heavier than water by the force of gravity (Metcalf & Eddy, 2014). The total suspended solids in raw leachate ranges from 115 – 220 mg/L and can be gravitational settled in the SBR. In general, suspended solids in wastewater can be categories into four groups namely settleable, supra-colloidal, colloidal and dissolved with each category having the particle size of 100 µm – 1000 µm, 1 µm – 100 µm, 0.001 µm – 1 µm and less than 0.001 µm respectively (Ebeling and Vinci, 2012). Only the first two categories namely settleable and supra-colloidal of waste solids can be separated by using gravitational settling.

The removal of suspended solids can be performed by microorganisms in the SBR as some form of suspended solids are organic matters hence the microorganisms can break-down and dissolve the organic solids into cell masses. Poor bacteria floc formation in the reactor may lead to a non-settleable and dispersed solids which has a negative influence on the removal of suspended solids (Richard, 2003).

4.5.4 Colour Removal Efficiency

The SBR system in this research does not perform well in treating colour from Papan landfill leachate as the yellow, brown and black colour in the leachate indicates high concentration of humic acids. As mentioned by Bakar et al. (2012), the decomposition of humic acids and other organic matters will results in such colours in wastewater especially in leachate as it is usual for high concentration of humic and fulvic acids in landfill leachate. As observed in the table 4.6 above, the highest colour removal efficiency was achieved by SBR 3 while the colour removal efficiency decreases with decreasing aeration rate at 29.32 % for SBR 2 and 26.96 % for SBR 1. As, mentioned by the Bakar et al. (2012), the main cause of the brownish in leachate is mainly due to the presence of organic matters. The higher aeration rate promotes more DO or free molecular oxygen in the reactor hence promoting a more vigorous bio-degradation of the organic matters during the extended aeration period. However, the removal of colour in this research is considered to be not effective by biological treatment hence a second treatment using coagulation to further treat the leachate is required.

4.6 Optimal Aeration Rate of SBR

In this research, the optimal aeration for the treatment of Papan landfill leachate in SBR is 3.0 L/min. The 5.0 L/min aeration will be considered over aerated although the treatment efficiencies for the parameters (except for COD) are slightly better compared to SBR 2 having aeration rate at 3.0 L/min. Hence, aeration rate at 5.0 L/min is not considered to be the optimal aeration for SBR as the operational cost may be very high if compared to the 3.0 L/min aeration.

4.7 Post Treatment of Leachate by Coagulation Process (ALUM)

The coagulation process is chosen to be post treatment after the biological treatment by SBR is due to the fact that high levels of aluminium may inhibit and has a toxic effect to bacteria especially for nitrifiers and denitrifiers in an activated sludge system (Maranon et al., 2008). Furthermore, the pH of the treated medium by ALUM during coagulation will become more acidic in nature and therefore have to recondition the treated medium by adding base or alkalinity to reach about neutral pH as biological treatment in SBRs are sensitive to pH if coagulation process is chosen as pre-treatment for Papan landfill leachate before SBRs.

The main reason for ALUM chosen to be the coagulant in coagulation as post treatment in this research is to mainly promote better treatment efficiency for COD, TSS and Colour as a compensation for the ineffective treatment in SBR for the parameters respectively. Furthermore, ALUM is a well-known commercial coagulant in treating domestic wastewater and leachate, therefore is easily available if coagulation employ using ALUM as coagulant in treating Papan landfill leachate. In the research reported by Samadi et al. (2010), by using 1.0 g/L of ALUM at pH 12, the removal efficiency for COD is 62.33 %; 1.5 g/L of ALUM at pH 2, the removal efficiency for TSS is 58.73 %. In another research done by Ghafari et la. (2010), the COD, turbidity, colour and TSS removal efficiency in leachate from Pulau Burung Landfill Site by using 9.4 g/L of ALUM at pH 7.0 is 56.76 %, 94.82 %, 92.23 % and 95.92 % respectively. Hence, ALUM is a promising coagulant which can increase the treatment effectiveness of the SBR in treating COD, TSS and colour. In this research, Aluminum Sulphate (ALUM) with chemical formula $Al_2(SO_4)_3.16H_2O$ and Molar concentration of 630.39 g/mol was used as coagulant for post treatment in this section. The effect of different pH of the coagulation medium and different dosage in terms of g/L of Alum were the two major parameters which taken into account for this post treatment study.

4.7.1 pH Optimization

In this section, constant ALUM dosage of 1.0 g/L was used to study the effect of different pH with constant mixing speed (RPM) and settling time (minutes) after mixing on COD, Ammonical Nitrogen NH_3-N, Total Suspended Solids TSS and Colour removal efficiency. The treated leachate samples were allocated into six 50 mL beaker and the pH value of 4.0, 5.0, 6.0, 7.0, 8.0 and 9.0 of the samples were adjusted with 1 M sulphuric acid (H_2SO_4) and 1 M sodium hydroxide (NaOH).

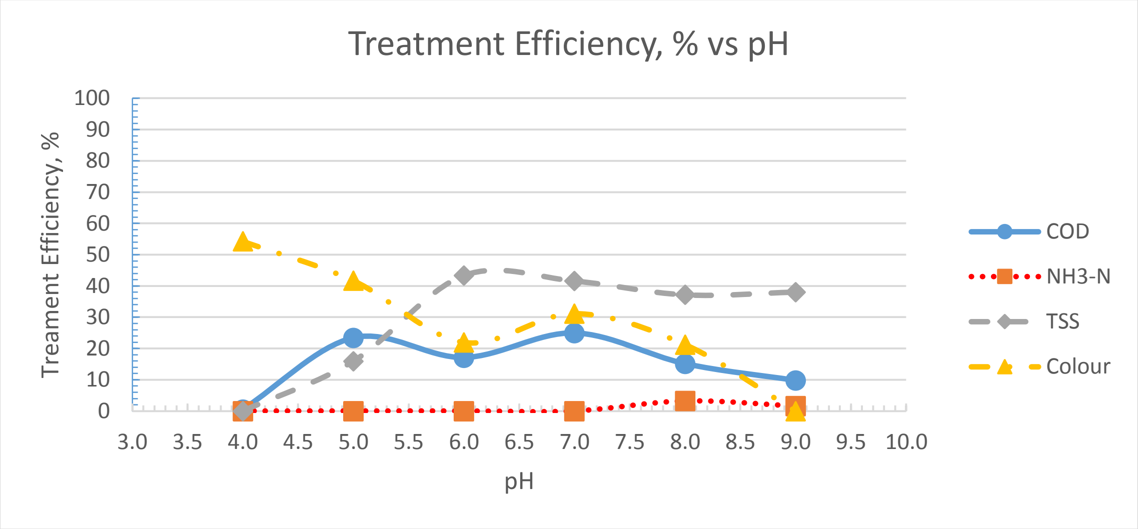

Figure 4.8: The Effects of Different pH onto COD, NH_3-N, TSS and Colour Removal Efficiency (Rapid Mixing: 120 Rpm, 3 Minutes; Slow Mixing: 20 Rpm, 20 Minutes; Settling Time: 60 Minutes)

Figure 4.8, pH 7.0 was chosen to be the optimal pH for coagulation using ALUM in this study as it achieved an overall most efficient removal in terms of COD, TSS and colour compared to other pH ranges. At pH 7.0, 24.91 % of COD, 41.59 % of TSS and 31.16 % of colour removal efficiencies had been achieved. The surface of the particles in common wastewater are nearly always negatively charged therefore they repel one another (Saukkoriipi, 2010) The main mechanism for coagulation is the hydrolyzing of metal salts into highly charged cations Al $^{3+}$ and Fe $^{3+}$ which will be very effective in destabilizing the negatively charged particles in leachate. It was mentioned that pH is the most influencing factor for the coagulation process in wastewater (Samadi et al., 2010; Saukkoriipi, 2010).

As ALUM was added into the treated leachate by SBR, hydrolysis of the ALUM rapidly (< 1 second) take place to form highly positively charged cations. At pH 7.0, the formation of ALUM in the leachate medium is mostly hydroxide precipitates of the Al species according to Figure 4.9 which was being discussed in chapter 2. The positively charged amorphous hydroxide plays a crucial role in coagulation as it deposits on the negatively charged impurities and other NOM (natural organic matter) hence destabilization and neutralization of these stable impurities (Duan and Gregory.,2003).

According to Saukkoriipi, (2010), sweep coagulation involve in the formation of amorphous metal hydroxide precipitate where the aluminum hydroxide flocs trap the impurities by a ‘swept down” action or by sinking flocs as the adsorption of polyaluminum ion or the adsorption of aluminum triggers on the surface of the impurities. This may be the main reason for ALUM to perform most optimally at pH 7 in this research rather than in other pH in treating the leachate. According to Duan and Gregory, (2003) that charged neutralization with aluminum salts at neutral pH (pH 7.0) occurs at a very low metal concentration typically a few µM.

4.7.2 Dosage Optimization

In this section, different ALUM dosage of 0.2 g/L, 0.5 g/L, 1.0 g/L, 1.5 g/L, 2.0 g/L, 3.0 g/L, 4.0 g/L ,5.0 g/L and 6.0 g/L at constant pH 7.0 were used to study the effect of different ALUM dosage on the removal efficiencies of COD, Ammoniacal Nitrogen NH_3-N, Total Suspended Solids TSS and Colour. The test was carried out with constant mixing speed (RPM) and settling time (minutes). The treated leachate samples were allocated into six 50 mL beaker and the pH value of the samples were adjusted to pH 7.0 with 1 M sulphuric acid (H_2SO_4) as the pH value of the post treated leachate is 7.56.

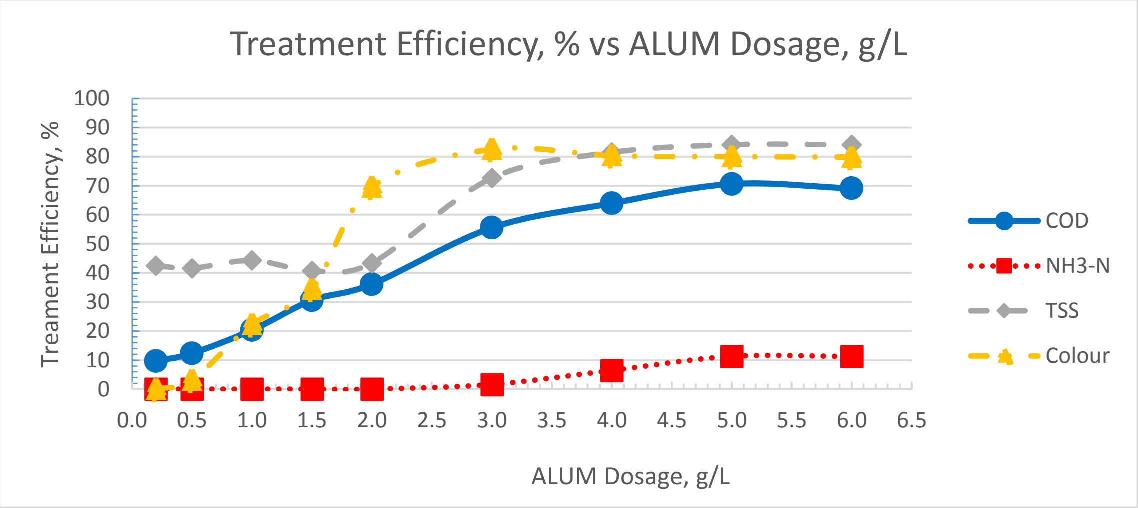

Figure 4.9: The Effects of Different ALUM Dosage at pH 7.0 Onto COD, NH_3-N, TSS and Colour Removal Efficiency (rapid mixing: 120 rpm, 3 minutes; slow mixing: 20 rpm, 20 minutes; settling time: 60 minutes)

Based on Figure 4.9, the optimal dosage of ALUM was chosen at 5.0 g/L as it achieved the overall highest removal efficiency for COD at 70.61 %, 84.07 % for TSS and 80.00% for colour. As shown in the figure above, higher dosage of ALUM at pH 7.0 gives a better treatment results for the post-treated leachate by SBR.

In this research, the optimal dosage of ALUM at 5.0 g/L was consider to be in the medium strength dosage of ALUM as it was reported that 9.4 g/L of ALUM at pH 7.0 by Ghafari et al. (2010) and 9.5 g/l at pH 7.0 by Ghafari et al. (2009) were the optimal dosage in treating landfill leachate from Pulau Burung Landfill Site which the COD in the raw leachate was reported to be at 1,794 mg/L – 2,094 mg/L while the treated leachate COD of this research is at 4,100 mg/L which is higher. According to Duan and Gregory, (2003), in general the optimal ALUM dosage will increase with increasing pH value due to the decrease of positively charged absorbed species and the proportional relationship between the particles concentration with coagulant concentration. Therefore, in this research at higher ALUM dosage of 2.5 g/L and above in treating treated leachate at pH 7.0 was observed to be more efficient.

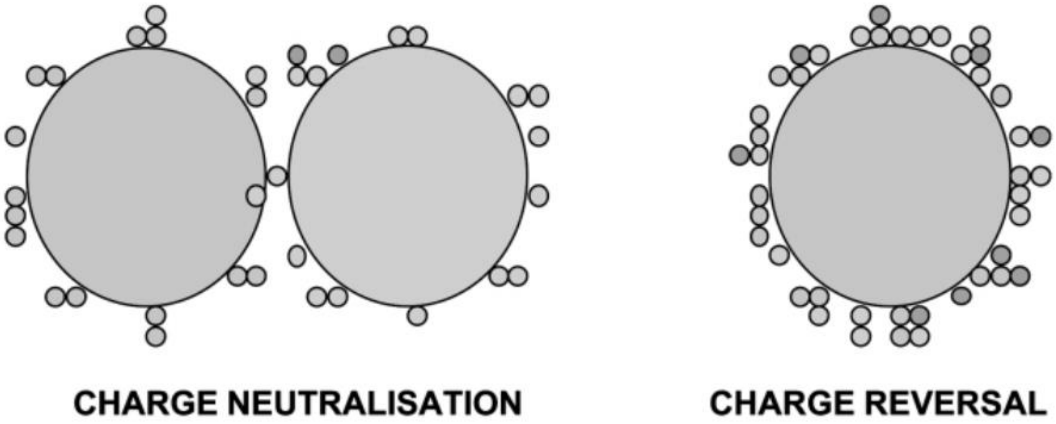

Figure 4.10: Showing Charge Neutralization (Left-Hand Side) and Charge Reversal (Right-Hand Side) if Overdose of Coagulant of the Deposition of Metal Hydroxide Species, $Al(OH)_{3(Am)}$ at Around Neutral pH (Duan and Gregory., 2003)

In coagulation, there are four different zones at different coagulant dosage starting from the lower to the higher coagulant dosage. The Table 4.6 below shows the different zones with different effects on negatively charged particles:

Table 4.6: Effects of Dosage On Particles in Wastewater Respective to The Different Zones

Zone	**Effects of dosage with particle charge**
Zone 1	Insufficient dosage; particles still stable due to no charged neutralisation hence particles are still negatively charged.

Zone 2	Sufficient dosage; particles are being charge neutralised by coagulant hence coagulation.
Zone 3	Higher dosage; particles are first being charge neutralise and further re-stabilisation of particles occurred.
Zone 4	Overdose; formation of hydroxide precipitation and sweep flocculation starts to occur.

Due to the above reason, overdose of coagulant will not further improve the removal efficiency of particles in the leachate and the performance will slightly drop as observed in the above Figure 4.10 in this research. This can be observed at 6.0 g/L of ALUM where the COD removal is lower than in 5.0 g/L of ALUM at 69.06 % with the same removal for TSS.

4.8 Overall Treatment Efficiency of Leachate by SBR and Coagulation Process

Papan landfill leachate requires a two-step treatment system to effectively treat the leachate as to return back safely to the environment with minimal impact. The research done in this period shows a promising treatment results for Papan landfill leachate treatment by combining biological and physiochemical treatment techniques in the treating the leachate. The biological treatment by employing SBR bio-reactor method treats ammonical nitrogen, NH_3-N very effectively and a moderate treatment efficiency for COD and TSS. While the following treatment performed by coagulation using ALUM as coagulant enhance the treatment for COD, TSS and colour by further treating the leachate.

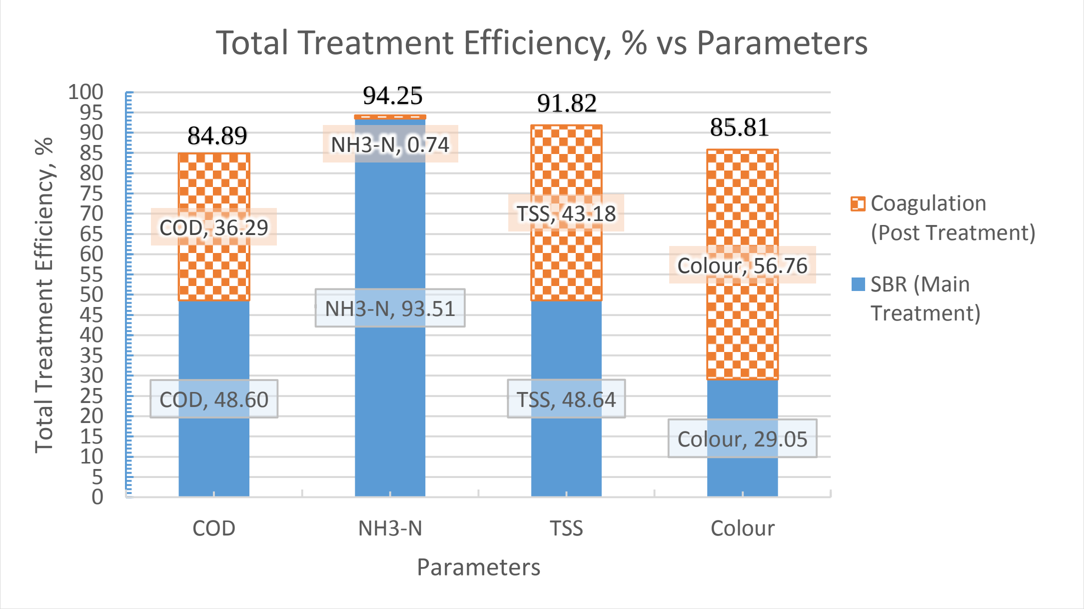

Figure 4.11: The Overall Treatment Efficiency, % by SBR and Coagulation Vs Parameters (COD, NH_3-N, TSS and Colour)

The above Figure 4.11 shows the overall combined treatment results by SBRs and Coagulation using ALUM to treat Papan landfill leachate. The two-step biological first and physiochemical leachate treatment system achieved a total removal efficiency of 84.89 %, 94.25 %, 91.82 % and 85.81 % for COD, NH_3-N, TSS and colour respectively.

4.9 Heavy Metal Removal

There are 11 types of heavy metals namely Cadmium, Arsenic, Lead, Copper, Manganese, Nickel, Zinc, Iron, Silver, Selenium and Barium which are present in the leachate according to Table 4.1 above. The relative abundance and concentration, mg/L of the 11 types of heavy metals in fresh Papan landfill leachate sample followed the order: Iron > Copper > Zinc > Lead > Barium > Silver > Manganese > Selenium > Cadmium > Nickel > Arsenic. All of the heavy metals concentration in the raw leachate sample exceeded the leachate discard standard in Malaysia. Figure 4.12 below shows the removal efficiency, % of the heavy metals after the two-stage treatment by SBR and coagulation.

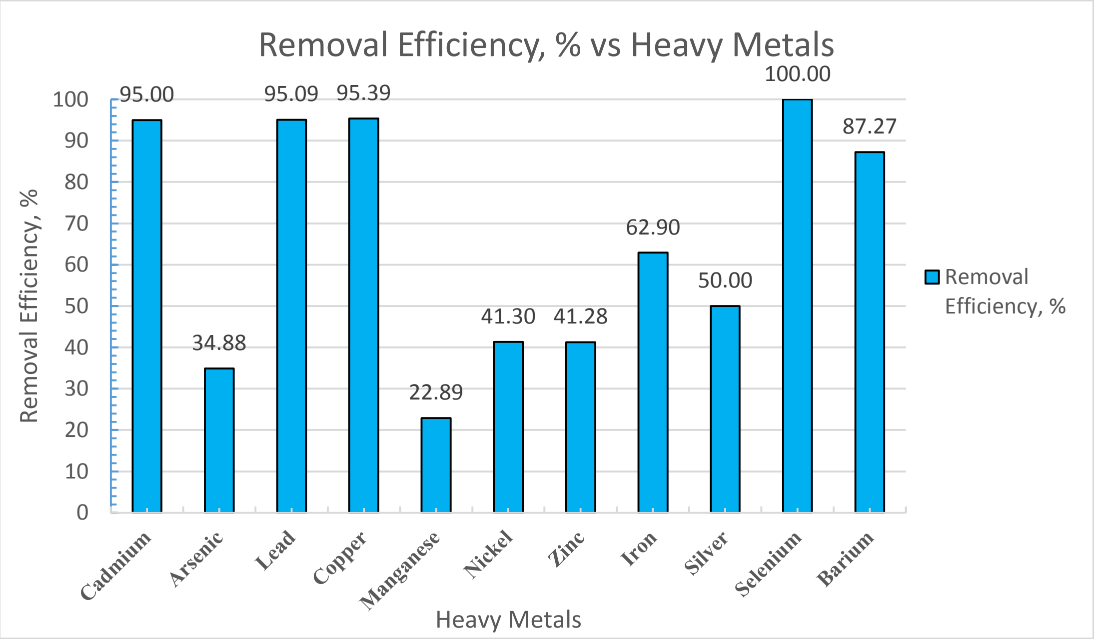

Figure 4.12: Removal Efficiency, % vs Types of Heavy Metals

The two-stage treatment system by SBR followed by Coagulation to treat Papan landfill leachate is very effective in treating Cadmium, Lead, Copper, Selenium and Barium which had the removal efficiency of 95.00 %, 95.09 %, 95.39 %, 100.00 % and 87.27 % respectively.

According to Abd-Rahman et al. (2013), the main mechanism in removing heavy metals in SBR is biosorption and bio-accumulation where-by the removal of heavy metals in leachate is through a series of complex interaction of microorganisms in the reactor. Effective heavy metals removal is performed by various groups of microorganisms through biosorption and bio-accumulation namely bacterial, algal or fungal biomass and cyanobacterial under a range of conditions. Microorganisms are able to concentrate metals in their cells higher than in the surrounding environment through either active metal uptake which needs energy from the cells to move metals into the cells or passive metal uptake which the surrounding metals are in higher concentration hence diffuse into the cells which follows the concentration gradient. Biosorption and bio-accumulation include actions like ion exchange, entrapment, chelation and adsorption of heavy metals which take place during the metabolism of the microbial in the reactor (Kosolapov et al., 2004). Certain microorganisms have strong biosorbent behaviour towards metallic ions such as copper which make-up the cells of the microbial (Ahalya et al., 2003).

According to Pang et al. (2009), coagulation using Aluminium Sulphate, ALUM is a common method used to remove heavy metals through the formation of hydroxide precipitate in which during the post treatment in this research the dominant species at pH 7.0 is the amorphous hydroxide precipitate, $Al(OH)_3$ as shown in Figure 2.4 in Chapter 2. Effective removal of particulates and impurities during coagulation by enmeshment of impurities on the formed amorphous metal hydroxide precipitates and by neutralisation of particle charges (Fu and Wang, 2011). Koc-Jurczyk and Jurczyk, (2007) mentioned that sorption and precipitation are the main mechanisms in removing heavy metals in leachate. The amorphous hydroxide precipitate enmeshes or traps the heavy metals ions together with other dissolved colloidal organics to form a larger flocs and settle down or precipitate by gravitational force. Hence, the “sweep-floc coagulation” as discussed in Chapter 2 is the mechanism in removing heavy metals during the post treatment of this research.

4.10 Operational Cost Estimation

4.10.1 SBR Operational Cost

This cost estimation is to evaluate the operational cost and to compare the cost difference mainly between SBR 3 and SBR 5 having 3 L/min and 5 L/min of aeration. The AC electric air pumps used in this research were powered at 5.6 W for 3.0 L/min and 8.0 W for 5.0 L/min. It was noted that these aquarium pumps can support a larger volume of a 10.0 L aquarium with effective DO circulating the liquid instead of a 1.0 L SBR. Hence, the operational cost comparison between 3.0 L/min and 5.0 L/min aeration rate was to be determined. The cost of electrical energy consumption was determined.

According to Pondsolutions.com (2017), the general formula for calculating the operating cost for an electric pumps and aerators is show below:

a) Electricity consumption (kWh) = watts, W (power of the pump) × running time in hours per day of pump, h ÷ 1000 (4.16)

b) Operational cost = Electricity consumption (kWh) × cost per kilowatt hour (4.17)

Where kWh = kilowatt hour, W = Watts and h = hours.

Table 4.7 shows three categories of voltage level and according to The United Nation (2014), a typical wastewater treatment plant with all equipment and facilities requires voltage supply of up to 11,000 V. Hence, wastewater treatment plants are considered to be in the medium voltage category. Table 4.8 indicates the commercial tariff respective to the price of the electricity. The operational cost of wastewater treatment plant will be categories under Tariff C 1 and Tariff C 2 in which both Tariffs having the same rate at 23.40 sens / kWh.

Table 4.7: TNB’s Supply Voltage Respective to Voltage Level Category (Tenaga National Berhad, TNB., 2017)

Voltage Level	Supply Voltage
Low Voltage – Single Phase	240 V
Low Voltage – Three Phase	415 V
Medium Voltage	6,600 V – 66,000 V
High Voltage	132,000 V – 275,000 V

Table 4.8: The Electrical Pricing and Tariff Rates for Commercial Users (Tenaga National Berhad, TNB., 2017)

Tariff Category	Tariff Description	Unit	Current Rate
Tariff B	Low Voltage Commercial Tariff	sen / kWh	32.30
Tariff C 1	Medium Voltage General Commercial Tariff	sen / kWh	23.40
Tariff C 2	Medium Voltage Peak Commercial Tariff	sen / kWh	23.40
	Medium Voltage Off-Peak Commercial Tariff	sen / kWh	14.40

i) For SBR 2 having operation of aeration at 3 L/min for 22 hours per day,

Electricity consumption per L of leachate = 5.6 W × 22 hours ÷ 1000

Electricity consumption = 0.1232 kWh / L of leachate

Operational cost = 0.1232 kWh / L of leachate × 23.40 sen / kWh

Operational cost = 2.88 sens or RM 0.028 per L of leachate

ii) For SBR 3 having operation of aeration at 5 L/min for 22 hours per day, Electricity consumption per L of leachate = 8.0 W × 22 hours ÷ 1000

Electricity consumption = 0.176 kWh / L of leachate

Operational cost = 0.176 kWh / L of leachate × 23.40 sen / kWh

Operational cost = 4.12 sens or RM 0.041 / L of leachate

Comparison in percentage difference between aeration cost for SBR 2 and SBR 3 at 3 L/min and 5 L/min aeration rates.

Cost saving = (RM 0.041 - RM 0.028) / L of leachate

Cost saving = RM 0.013 / L of leachate

Percentage of cost saving if employ 3 L/min aeration as optimal aeration rate for the treatment of leachate by SBR.

$$\text{Cost saving} = \frac{RM\ 0.041 - RM\ 0.028}{RM\ 0.028} \times 100\ \%$$

Cost saving = 46.43 %

The operational cost can be saved up to 46.43 % theoretically if 3.0 L/min of aeration is employed in treating the Papan leachate in SBR. Hence, the operational cost in treating per m^3 of leachate at 3.0 L/min of aeration is calculated as below:

$$\text{Aeration Operational Cost} = \text{RM 0.028 / L of leachate} \times \frac{1{,}000\ L}{1\ m3}$$

Aeration Operational Cost = RM 28.00 / m^3 of leachate

4.10.2 Coagulation Operational Cost

The optimal quantity of ALUM used in treating Papan leachate is evaluated as an operational cost in this session. Optimal dosage of 5.0 g/L of ALUM was determined in treating Papan landfill leachate as post treatment after SBR.

The average price of ALUM according to Made-in-China.com (2017) is RM 770 per ton of ALUM. Hence, the cost for ALUM in terms of 5.0 g/L is calculated as below:

$$\text{Cost of ALUM treating per m}^3 \text{ of leachate} = 5.0\ \text{g/L} \times \frac{RM\ 770}{1{,}000\ kg} \times \frac{1\ kg}{1{,}000\ g} \times \frac{1{,}000\ L}{1\ m3}$$

$$= \text{RM } 3.85 / \text{m}^3 \text{ Leachate}$$

The operational cost for coagulation as post treatment requires RM 3.85 of ALUM to treat per m^3 of leachate.

4.10.3 Total Operational Cost Estimation

The total operational cost for sequential treatment of Papan landfill leachate by SBR follow by coagulation using ALUM is calculated as below:

$$\text{Total Operational Cost} = \text{Aeration Cost} + \text{Coagulation Cost}$$

$$\text{Total Operational Cost} = \text{RM } 28.00 / \text{m}^3 \text{ of leachate} + \text{RM } 3.85 / \text{m}^3 \text{ of leachate}$$

$$\text{Total Operational Cost} = \text{RM } 31.85 / \text{m}^3 \text{ of leachate}$$

Thus, the total operational cost combining first SBR at aeration rate 3.0 L/min followed by coagulation using optimal dosage at 5.0 g/L of ALUM in this research is RM 31.85 to treat per m^3 of Papan landfill leachate. The higher operational cost for SBR 2 at 3.0 L/min in treating leachate is mainly due to the long running time of aeration which had been earlier design to be 22 hours of aeration per day.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The Papan leachate is considered to reached intermediate stage as the BOD_5/COD in this research is found to be 0.17 to 0.24 in which is in the range of 0.10 to 0.30 to be classified as intermediate leachate (Baig et al., 1996; Liu, S., 2013; Yu, D., 2007). The selection of treatment methods varies according to the leachate characteristics. Hence, biological treatment combined with physiochemical treatment is a more suitable as a two-step treatment process for the Papan landfill leachate. Biological treatment employs aerobic SBR and was found that SBR 2 with aeration rate at 3.0 L/min with fixed contact time and SBR cycle is the optimal biological treatment which achieved an effective maximum removal rate at 94.77 % of NH_3-N, 50.17 % of COD, 50.00 % of TSS and 29.32 % of colour. It was found that 5.0 L/min of aeration was over aerated as the DO concentration is same as in 3.0 L/min hence it the optimal aeration rate in SBR is 3.0 L/min. The high removal rate of NH_3-N is due to the active metabolisms of nitrification and denitrification bacterial which consume NH_3-N as their nutrient together with COD as their carbon source. The effluent from the SBR 2 was collected daily from day 12 to day 35 and the collected effluent was characterized. The effluent was then allowed for coagulation process as post-treatment as to improve the COD, TSS and colour removal efficiencies. Optimal pH at 7.0 and dosage at 5.0 g/L of ALUM, aluminum sulphate were determined by the jar test for coagulation. The coagulation using ALUM, aluminum sulphate as coagulant showed a great improvement for removing COD, TSS and colour up to 71.03 %, 91.82 % and 85.59 % respectively at the end of the coagulation process. Coagulation is known to treat various kinds of impurities in wastewater as the process hydrolyzed aluminum metals into highly positively charged cations which can interact vigorously with the negative colloids in wastewater (Duan and Gregory, 2002). Operational cost saving of up to 46.43 % can be achieved if aeration of 3.0 L/min for the SBR is selected instead of 5.0 L/min.

5.2 Recommendations for Future Research

The aerobic SBR has a great potential in treating leachate hence a more comprehensive study need to be performed on the contact time as well as the aeration rate at a smaller scale to determine the optimal contact time and aeration rate. The decrease in the contact time after successful cultivation of activated sludge in the reactor can greatly improve the removal of COD as well as reducing operational cost for aeration in SBR. Furthermore, the SBR can be enhance by placing plastic media into the reactor as to increase the specific surface area of the reactor by allowing bacterial to attach on the surface of the plastic media. As reported by Koupaie et al. (2011), the moving bed SBR is more effective in bacterial accumulation hence improving the MLSS and MLVSS in the reactor hence the system can remove waste from the wastewater more effectively as increase in the amount of bacterial population.

Anaerobic SBR is the future trend of wastewater treatment as the anaerobic system is a more sustainable approach in treating wastewater. This is due to the fact that the end product of anaerobic biological treatment in wastewater is methane gas, CH_4 which can be captured and used as a source of alternative energy to generic electricity.

REFERENCES

Abd-Rahman, R., Hasani, H., Wasmi, B.A., Al-amiery, A.A. and Mohamad, A.B., 2013. Heavy metal biosorption efficiencies of expanded bed biofilm reactor and sequencing batch biofilm reactor. *Asian Journal of Chemistry, 25*(13), p.7193.

Adnan, S.N.S.M., Yusoff, S. and Chua, Y.P., 2013. Soil chemistry and pollution study of a closed landfill site at Ampar Tenang, Selangor, Malaysia. *Waste Management & Research,* 31, 6, pp.599-612.

Agamuthu, P. and Fauziah, S.H., 2011. Challenges and issues in moving towards sustainable landfilling in a transitory country-Malaysia. *Waste Management & Research*, *29*(1), 13-19.

Ahalya, N., Ramachandra, T.V. and Kanamadi, R.D., 2003. Biosorption of heavy metals. *Res. J. Chem. Environ*, *7*(4), pp.71-79.

Al-Rekabi, W.S., Qiang, H. and Qiang, W.W., 2007. Review on sequencing batch reactors. *Pakistan Journal of nutrition*, *6*(1), pp.11-19.

American Public Health Association (APHA), 2005. Standard Methods for the Examination of Water and Wastewater, 21st sd. Washington, DC: APHA.

Aslam, M, T., 2013. Settling of Solids in Raw Wastewater – Primary Settling Tanks and Storm Water Tanks. Technische Universität Graz. pp. 67 – 149.

Asnani, P.U., 2006. Solid waste management. *India infrastructure report,* pp.*570*.

Aziz, S.Q., Aziz, H.A., Mojiri, A., Bashir, M.J. and Amr, S.S.A., 2013. Landfill Leachate Treatment Using Sequencing Batch Reactor (SBR) Process: Limitation of Operational Parameters and Performance. *Int. J. Sci. Res. Knowl*, *1*, pp.34-43.

Aziz, S.Q., Aziz, H.A., Yusoff, M.S. and Bashir, M.J., 2011. Landfill leachate treatment using powdered activated carbon augmented sequencing batch reactor (SBR) process: Optimization by response surface methodology. *Journal of Hazardous Materials*, *189*(1), pp.404-413.

Badgie, D., Samah, M.A., Manaf, L.A. and Muda, A.B., 2012. Assessment of municipal solid waste composition in Malaysia: Management, practice and challenges. *Polish Journal of Environmental Studies*, *21*(3), pp.539-547.

Baig, S., Thiéblin, E., Zuliani, F., Jenny, R., Coste, C., DEGREMONT, S. and Bern, O.Z.O.N.I.A., 1996. Landfill Leachate Treatment: Case Studies. *Water Research*, *30*(1), pp.21.

Bakar, A.A., Daud, Z., Ahmad, Z. and Othman, M.A.R., 2012. Treatment of Leachate Using Sequencing Batch Reactor (SBR). In: The International Conference on Civil and Environmental Engineering Sustainability (IConCEES 2011), Johor Bahru, Malaysia.

Breisha, G.Z. and Winter, J., 2010. Bio-removal of nitrogen from wastewaters-A review. *Journal of American Science*, *6*(12), pp.508-528.

Budhiarta, I., Siwar, C. and Basri, H., 2012. Current status of municipal solid waste generation in Malaysia. *International Journal on Advanced Science, Engineering and Information Technology*, *2*(2), pp.129-134.

Clarke, B.O., Anumol, T., Barlaz, M. and Snyder, S.A., 2015. Investigating landfill leachate as a source of trace organic pollutants. *Chemosphere*, *127*, pp.269-275.

Davies, P.S., 2005. The biological basis of wastewater treatment. *Strathkelvin Instruments Ltd*, *3*.

Department of Environment (DOE) and Ministry of Natural Resources and Environment, October 2010. Environmental Requirements: A Guide for Investors. (Eleventh Edition) [Online].Available at: http://www.doe.gov.my/eia/wp-content/uploads/2012/03/A-Guide-For-Investors1.pdf [Accessed on 28th Jun 2016]

Duan, J. and Gregory, J., 2003. Coagulation by hydrolyzing metal salts. *Advances in colloid and interface science*, *100*, pp.475-502.

Ebeling, J, M., and Vinci, B., 2012. Recirculating Aquaculture System Short Course - Solids Capture. [online] Available at: https://cals.arizona.edu/azaqua/ista/ISTA7/RecircWorkshop/Workshop%20PP%20%20&%20Misc%20Papers%20Adobe%202006/5%20Solids%20Capture/Solids%20Control.pdf [Accessed on 29th March 2017].

El-Fadel, M., Findikakis, A.N. and Leckie, J.O., 1997. Environmental impacts of solid waste landfilling. *Journal of environmental management*, *50*(1), pp.1-25.

EPA., 1997. WASTE WATER TREATMENT MANUALS PRIMARY, SECONDARY and TERTIARY TREATMENT. 1st ed Manual. Ardcavan, Wexford: Environmental Protection Agency, Ireland., 1997. Print.

EPA, U., 1999. *Wastewater technology fact sheet—sequencing batch reactors*. EPA 832-F-99-073.

Fauziah, S.H. and Agamuthu, P., 2010. Landfills in Malaysia: Past, present and future.

Fauziah, S.H. and Agamuthu, P., 2012. Trends in sustainable landfilling in Malaysia, a developing country. *Waste Management & Research*, pp.656-663.

Fazeli, A., Bakhtvar, F., Jahanshaloo, L., Sidik, N.A.C. and Bayat, A.E., 2016. Malaysia′ s stand on municipal solid waste conversion to energy: A review. *Renewable and Sustainable Energy Reviews*, *58*, pp.1007-1016.

Fu, F. and Wang, Q., 2011. Removal of heavy metal ions from wastewaters: a review. *Journal of environmental management*, *92*(3), pp.407-418.

Gebbie, Peter., 2006. AN OPERATOR’S GUIDE TO WATER TREATMENT COAGULANTS. 31st Annaul Water Industry Workshop – Operations Skills. pp. 14 – 20.

Gerardi, M.H., 2002. *Nitrification and Denitrification in the activated sludge process*. John Wiley & Sons, Inc.

Ghafari, S., Aziz, H.A. and Bashir, M.J., 2010. The use of poly-aluminum chloride and alum for the treatment of partially stabilized leachate: A comparative study. *Desalination*, *257*(1), pp.110-116.

Gotvajn, A.Z., and Pavko, A., 2015. Perspectives on Biological Treatment of Sanitaty Landfill Leachate. Book of Wastewater Treatment Engineering, Chapter 5, pp. 115-151.

Hach, 2005. Water Analysis Handbook, 5th ed. US: Hach Company.

Hassan, M.N., Chong, T.L., Rahman, M., Salleh, M.N., Zakaria, Z. and Awang, M., 2001, October. Solid waste management in Southeast Asian countries with special attention to Malaysia. In *Proceedings Sardinia, 8th International Waste Management and Landfill Symposium, Italy* pp. 1-5.

Hoornweg, D. and Bhada-Tata, P., 2012, March. WHAT A WASTE: A Global Review of Solid Waste Management. *The World Bank*: *Urban Development Series Knowledge Papers, No.15* pp. 1-95.

Hossain, M.D., 1996. Mechanism of coagulation of coloured water with aluminium sulphate. *J. Civil Eng.-Inst. Eng. Bangladesh*, *24*(2), pp.213-220.

Ibrahim, T.N.T., Mahmood, N.Z. and Othman, F., 2017. Estimation of Leachate Generation from MSW Landfills in Selangor. Environmental Science, Vol 19, No. (1) 43-48.

Idris, A., Inanc, B. and Hassan, M.N., 2004. Overview of waste disposal and landfills/dumps in Asian countries. *Journal of material cycles and waste management*, *6*(2), pp.104-110.

Johari, A., Alkali, H., Hashim, H., Ahmed, S.I. and Mat, R., 2014. Municipal solid waste management and potential revenue from recycling in Malaysia. *Modern Applied Science*, *8*(4), pp. 37-49.

Kalanatarifard, A. and Yang, G.S., 2012. Identification of the municipal solid waste characteristics and potential of plastic recovery at Bakri Landfill, Muar, Malaysia. *Journal of Sustainable Development*, *5*(7), pp.11.

Kannan, R., 2013. What contaminated ground water can do to your health? [Online] *The Hindu*. Available at: http://www.thehindu.com/news/cities/chennai/what-contaminated-ground-water-can-do-to-your-health/article5019514.ece [Accessed on 11 Jul 2016]

Kjeldsen, P., Barlaz, M.A., Rooker, A.P., Baun, A., Ledin, A. and Christensen, T.H., 2002. Present and long-term composition of MSW landfill leachate: a review. *Critical reviews in environmental science and technology*, *32*(4), pp.297-336.

Klinck, B.A. and Stuart, M.E., 1999. Human health risk in relation to landfill leachate quality. *British Geological Survey, Technical report WC/99/17*.

Koc-Jurczyk, J. and Jurczyk, L., 2007. Efficiency of removal of heavy metals from municipal landfill leachate. *Journal of Elementology*, *12*(4), pp.327-334.

Kosolapov, D.B., Kuschk, P., Vainshtein, M.B., Vatsourina, A.V., Wiessner, A., Kästner, M. and Müller, R.A., 2004. Microbial processes of heavy metal removal from carbon-deficient effluents in constructed wetlands. *Engineering in Life Sciences*, *4*(5), pp.403-411.

Koupaie, E.H., Moghaddam, M.A. and Hashemi, H., 2011. Comparison of overall performance between moving-bed and conventional sequencing batch reactor. *Iranian Journal of Environmental Health Science & Engineering*, *8*(3), p.235.

Kumar, S., Katoria, D. and Singh, G., 2013. Leachate Treatment Technologies. *International Journal of Environmental Engineering and Management*, *4*, Number, 439-444.

Kuusik, A., Pachel, K., Kuusik, A. and Loigu, E., 2014, January. Landfill runoff water and landfill leachate discharge and treatment. In *Environmental Engineering. Proceedings of the International Conference on Environmental Engineering. ICEE* (Vol. 9, p. 1). Vilnius Gediminas Technical University, Department of Construction Economics & Property.

Lim, P.E., Lim, S.P., Seng, C.E. and Noor, A.M., 2010. Treatment of landfill leachate in sequencing batch reactor supplemented with activated rice husk as adsorbent. *Chemical Engineering Journal*, *159*(1), pp.123-128.

Liu, S., 2013. Landfill leachate treatment methods and evolution of Hedeskoga and Masalycke landfills (Doctoral dissertation, Thesis, Sweden: Luden University)

[Online]. Available at: http://www.vateknik.lth.se/exjobbR/E709.pdf [Accessed on 4th Jun 2016]

Liu, X., Chen, Y., Zhang, X., Jiang, X., Wu, S., Shen, J., Sun, X., Li, J., Lu, L. and Wang, L., 2015. Aerobic granulation strategy for bioaugmentation of a sequencing batch reactor (SBR) treating high strength pyridine wastewater, *Journal of Hazardous Materials*, 295, pp.153-160.

Made-in-China.com, 2017. *[Hot Item] Aluminum Sulphate for Water Treatment*. [online] Available at: http: //yuyinchem.en.made-in-china.com/product/tBkJUoGuajWz/China-Aluminum-Sulphate-for-Water-Treatment.html [Accessed 25th March 2017].

Madera, C. and Valencia-Zuluaga, V., 2009, October. Landfill leachate treatment: one of the bigger and underestimated problems of the urban water management in developing countries. In *9th World Wide Workshop for Young Environmental Scientists WWW-YES-Brazil-2009: Urban waters: resource or risks?* (No. 12).

Mahvi, A.H., 2008. Sequencing batch reactor: a promising technology in wastewater treatment. *Journal of Environmental Health Science & Engineering*, *5*(2), pp.79-90.

Maier, R.M., 2000. Bacterial growth. In: Maier, R.M., Pepper, I.L., Gebra, C.P. (Eds.), Environmental Microbiology. Academic Press, UK, pp. 43–59.

Manaf, L.A., Samah, M.A.A. and Zukki, N.I.M., 2009. Municipal solid waste management in Malaysia: Practices and challenges. *Waste management*, *29*(11), pp.2902-2906.

Mark Prein, P.E., 2012. ORP Improves Operational Efficiency. MWEA Annual Conference. Prein & Newhof.

Masirin, M., Idrus, M., Ridzuan, M.B. and Mustapha, S., 2008. An overview of landfill management and technologies: A Malaysian case study at Ampar Tenang. pp.157-165.

Metcalf & Eddy, Aecom. (2014) WASTEWATER ENGINEERING: Treatment and Resource Recovery. 5th ed. (International), Vol 1 & Vol 2, Mc Graw-Hill Book Company.

Miles, B., 2013. Bioenergetics [online] Available at: http://files.dep.state.pa.us/Water/BSDW/OperatorCertification/TrainingModules/ww16_sludge_2_wb.pdf [Accessed on 26th February 2017].

Mojiri, A., Aziz, H.A., Zaman, N.Q., Aziz, S.Q. and Zahed, M.A., 2014. Powdered ZELIAC augmented sequencing batch reactors (SBR) process for co-treatment of landfill leachate and domestic wastewater, *Journal of Environmental Management*, 139, pp.1-14.

Mor, S., Ravindra, K., Dahiya, R.P. and Chandra, A., 2006. Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environmental monitoring and assessment*, *118*(1-3), pp.435-456.

Negeri Perak, 2013. Maklumat Asas: Pihak Berkuasa Tempatan. (NEGERI PERAK DARUL RIDZUAN) [Online]. Available at: https://www.perak.gov.my/images/menu_utama/ms/rakyat/dataasaspbt2013.pdf [Accessed on 10th July 2016]

Ngo, H.H., Guo, W. and Xing, W., 2008. Applied technologies in municipal solid waste landfill leachate treatment. *Encyclopedia of life support systems (EOLSS)*, pp.*17*.

Noor, Z.Z., Yusuf, R.O., Abba, A.H., Hassan, M.A.A. and Din, M.F.M., 2013. An overview for energy recovery from municipal solid wastes (MSW) in Malaysia scenario. *Renewable and Sustainable Energy Reviews*, *20*, pp.378-384.

NPTEL.ac.in., 2013. Lecture 5 Sequening batch Reactor [online] Available at: http://nptel.ac.in/courses/103107084/module4/lecture5/lecture5.pdf [Accessed on 26th February 2017].

Pa. DEP., 2014. Module 16: The Activated Sludge Process Part II (Wastewater Treatment Plant Operator Certification Training). [online] Available at: http://files.dep.state.pa.us/Water/BSDW/OperatorCertification/TrainingModules/ww16_sludge_2_wb.pdf [Accessed on 22nd February 2017].

Peng, Y., 2013. Perspectives on technology for landfill leachate treatment. *Arabian Journal of Chemistry*.

Periathamby, A., Hamid, F. and Khidzir, K., 2009. Evolution of solid waste management in Malaysia: impacts and implications of the solid waste bill, 2007. *Journal of Material Cycles and Waste Management*, *2*(11), pp.96-103.

Pernitsky, D.J. and Edzwald, J.K., 2006. Selection of alum and polyaluminum coagulants: principles and applications. *Journal of Water Supply: Research and Technology-AQUA*, *55*(2), pp.121-141.

Poltak, R, F., 2005. SEQUENCING BATCH REACTOR DESIGN AND OPERATIONAL CONSIDERATIONS. *New england interstate water pollution control commission.*

Pondsolutions.com., 2017. "How to Determine Electric Cost, Operating Electricity Cost" [online] Available at: https://www.pondsolutions.com/determine-electric-cost/ [Accessed on 26th February 2017].

Raghab, S.M., Meguid, A.M.A.EI., Hegazi, H.A., 2013. Treatment of leachate from municipal solid waste landfill, HBRC Journal, 9, 2, 187-192.

Renou, S., Givaudan, J.G., Poulain, S., Dirassouyan, F. and Moulin, P., 2008. Landfill leachate treatment: review and opportunity. *Journal of hazardous materials*, *150*(3), pp.468-493.

Richard, M., 2003. ACTIVATED SLUDGE MICROBIOLOGY PROBLEMS AND THEIR CONTROL. 20th Annual USEPA National Operator Trainers Conference Buffalo. pp 1- 21.

Rittman, B.E. and McCarty, P.L., 2001. Environmental Biotechnology: Principles and Applications. International edition, Mc Graw-Hill Book Company.

Sakawi, Z., 2011. Municipal solid waste management in Malaysia: solution for sustainable waste management. *Journal of Applied Sciences in Environmental Sanitation*, *6*(1), 29-38.

Salem, Z., Hamouri, K., Djemaa, R. and Allia, K., 2008. Evaluation of landfill leachate pollution and treatment. *Desalination*, *220*(1), 108-114.

Samadi, M.T., Saghi, M.H., Rahmani, A., Hasanvand, J., Rahimi, S. and Syboney, M.S., 2010. Hamadan landfill leachate treatment by coagulation-flocculation process. *Iranian Journal of Environmental Health Science & Engineering*, *7*(3), p.253.

Saukkoriipi, J., 2010. THEORETICAL STUDY OF THE HYDROLYSIS OF ALUMINIUM COMPLEXES. ACTA University of Oulu, A scientiae Rerum Naturalium. A 554.

Shekdar, A.V., 2009. Sustainable solid waste management: an integrated approach for Asian countries. *Waste management*, *29*(4), pp.1438-1448.

Singh, M. and Srivastava, R.K., 2011. Sequencing batch reactor technology for biological wastewater treatment: a review. *Asia‐Pacific Journal of Chemical Engineering*, *6*(1), pp.3-13.

Slack, R.J., Gronow, J.R. and Voulvoulis, N., 2005. Household hazardous waste in municipal landfills: contaminants in leachate. *Science of the total environment*, *337*(1), pp.119-137.

Strande, L., Ronteltap, M. and Brdjanovic, D., 2014. Faecal Sludge Management: System Approach for Implementation and Operation. IWA Publishing

Tarmudi, Z., Abdullah, M.L. and Tap, A.O.M., 2012. A Review of Municipal Solid Waste Management in Malaysia. *Jurnal Teknologi*, *57*(1), pp.41-56.

Tenaga Nasional Berhad, TNB., 2017. Electricity Pricing And Tariffs Rates [online] Available at: https://www.tnb.com.my/residential/pricing-tariffs [Accessed on 26th February 2017].

Thestar.com.my., 2011. *New RM19mil centralised sanitary landfill in Papan on a 224ha area by March – Community: The Star Online*. [online] Available at:

http://www.thestar.com.my/news/community/2011/12/01/new-rm19mil-centralised-sanitary-landfill-in-papan-on-a-224ha-area-by-march/ [Accessed on 7 Aug. 2016].

The United Nations, 2014. SECTION 1: REQUIREMENTS FOR WATER TREATMENT PLANT AND WATER NETWORK [online] Available at: http://www.un.org/Depts/oip/dp/dp10/03-01.pdf [Accessed on 25th February 2017].

Tiansiang.com., 2016. Overview: Tian Siang Group. [online] Available at: http://www.tiansiang.com/?page_id=177 [Accessed on 23rd July 2016].

UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP), 2005. Training Module: *Closing of an Open Dumpsite and Shifting from Open Dumping to Controlled Dumping and to Sanitary Land Filling.* Department of Environment and Natural Resources. Republic of the Philippines.

USAID, 2016. *Chapter 6: Landfilling and Open Dump Closure*. (Solid Waste Management Privatization Procedure Manual, Egyptian Environmental Policy Program) Available at: http://pdf.usaid.gov/pdf_docs/Pnacy344.pdf [Accessed on 10th July 2016]

Wei, Y., Ji, M., Li, R. and Qin, F., 2012. Organic and nitrogen removal from landfill leachate in aerobic granular sludge sequencing batch reactors. *Waste Management, 32*(3), pp.448-455.

Wisonsin Department of Natural Resources., 2012. Advance Activated Sludge Study Guide [online] Available at: http://dnr.wi.gov/regulations/opcert/documents/wwsgactsludgeadv.pdf [Accessed on 19th February 2017].

Wiszniowski, J., Robert, D., Surmacz-Gorska, J., Miksch, K. and Weber, J.V., 2006. Landfill leachate treatment methods: A review. *Environmental Chemistry Letters, 4*(1), pp.51-61.

Yabroudi, S.C., Morita, D.M. and Alem, P., 2013. Landfill leachate treatment over nitritation/denitritation in an activated sludge sequencing batch reactor. *APCBEE Procedia*, *5*, pp.163-168.

Yu, D., 2007. Landfill Leachate Treatment Case Study, SRV Atervinning, Sweden.

APPENDICES

APPENDIX A TABLES OF EXPERIMENTAL RESULTS

Table A1: Results for MLSS in The SBRs Respective to Days

Days (Date)	Mixed Liquor Suspended Solids, MLSS (mg/L)		
	SBR (Aeration Rate)		
	SBR 1 (1 L/min)	SBR 2 (3 L/min)	SBR 3 (5 L/min)
1 (9/11/2016)	9,300	9,300	10,300
6 (14/11/2016)	8,400	7,800	7,300
9 (17/11/2016)	8,200	6,100	6,800
13(21/11/2016)	5,300	5,700	4,900
16 (24/11/2016)	4,100	4,500	4,400
21(29/11/2016)	3,200	4,300	3,700
23(1/12/2016)	3,800	3,700	4,000
26(4/12/2016)	3,200	3,200	3,300
35(13/12/2016)	4,500	2,800	3,300
37(15/12/2016)	3,100	3,500	3,400
39(17/12/2016)	2,600	3,500	3,400
42(20/12/2016)	2,600	4,200	3,700
44(22/12/2016)	2,700	4,100	3,700

Table A2: Results for MLVSS in The SBRs Respective to Days

Days (Date)	Mixed Liquor Volatile Suspended Solids, MLVSS (mg/L)		
	SBR (Aeration Rate)		
	SBR 1 (1 L/min)	SBR 2 (3 L/min)	SBR 3 (5 L/min)
1 (9/11/2016)	6,200	6,300	7,000
6 (14/11/2016)	6,900	5,800	5,400
9 (17/11/2016)	5,700	4,400	3,900
13(21/11/2016)	3,300	3,900	3,400
16 (24/11/2016)	2,900	3,200	3,200
21(29/11/2016)	2,400	2,400	2,700
23(1/12/2016)	2,800	2,500	3,000
26(4/12/2016)	2,600	2,600	2,200
35(13/12/2016)	3,100	2,000	3,100
37(15/12/2016)	2,100	2,500	2,200
39(17/12/2016)	1,400	2,500	2,400

42(20/12/2016)	2,000	2,500	2,400
44(22/12/2016)	2,000	3,600	2,900

Table A3: Results for SBR Treatment for COD, NH_3-N, TSS and Colour

Parameter	**SBR 1 (1 L/min)**		**SBR 2 (3 L/min)**		**SBR 3 (5 L/min)**		**Raw Leachate**
	mg/L	%	mg/L	%	mg/L	%	mg/L
COD	2,640	54.95	2,920	50.17	2,960	49.49	6,420
NH_3-N	73	92.36	50	94.77	28	97.07	956
TSS	100	54.55	102	53.64	100	54.55	220
Colour (PtCo)	3,294	26.96	3,188	29.32	2,810	37.70	4,510

Table A4: Results for pH Optimisation of Coagulation Process by ALUM Respective to COD, NH_3-N, TSS and Colour

pH	**COD**		**NH_3-N**		**TSS**		**Colour**	
	mg/L	%	mg/L	%	mg/L	%	PtCo	%
4.0	3,284	0.48	64	-3.23	122	-7.96	1,463	54.28
5.0	2,528	23.39	65	-4.84	95	15.93	1,866	41.69
6.0	2,736	17.09	68	-9.68	64	43.36	2,498	21.94
7.0	2,478	24.91	66	-6.45	66	41.59	2,203	31.16
8.0	2,801	15.12	60	3.23	71	37.17	2,520	21.25
9.0	2,978	9.76	61	1.61	70	38.05	3,445	-7.66

Table A5: Results for Dosage Optimisation of Coagulation Process by ALUM Respective to COD, NH_3-N, TSS and Colour

Dosage (mg/L)	**COD**		**NH_3-N**		**TSS**		**Colour**	
	mg/L	%	mg/L	%	mg/L	%	PtCo	%
0.2	2,980	9.70	81	-30.65	65	42.48	3,342	-4.44
0.5	2,892	12.36	82	-32.26	66	41.59	3,102	3.06
1.0	2,628	20.36	80	-29.03	63	44.25	2,490	22.19
1.5	2,290	30.61	78	-25.81	67	40.71	2,100	34.38
2.0	2,107	36.15	70	-12.90	64	43.36	978	69.44
3.0	1,467	55.55	61	1.61	31	72.57	560	82.50
4.0	1,189	63.97	58	6.45	21	81.42	630	80.31
5.0	970	70.61	55	11.29	18	84.07	640	80.00
6.0	1,020	69.09	55	11.29	18	84.07	645	79.84

Table A6: Results for Total Treatment Combining SBR and Coagulation Process Respective to COD, NH_3-N, TSS and Colour

Parameter	**Raw Leachate**		**After SBR (3 L/min)**		**After Coagulation**	
	mg/L	%	mg/L	%	mg/L	%
COD	6,420	0	3,300	48.60	970	84.89
NH_3-N	956	0	62	93.51	55	94.25
TSS	220	0	113	48.64	18	91.82
Colour	4,510	0	3,200	29.05	640	85.81

Table A7: Results for Heavy Metal Concentrations in Raw Leachate and in Final Treated Leachate Respective to The Removal Efficiency, %

Heavy Metal	**Concentration, mg/L**		**Removal, %**
	Raw Leachate	**Treated Leachate**	
Cadmium	0.54	0.027	95.00
Arsenic	0.43	0.28	34.88
Lead	3.46	0.17	95.09
Copper	13.01	0.60	95.39
Manganese	0.83	0.64	22.89
Nickel	0.46	0.27	41.30
Zinc	7.51	4.41	41.28
Iron	23.18	8.60	62.90
Silver	0.94	0.47	50.00
Selenium	0.65	0.00	100.00
Barium	1.10	0.14	87.27