UP-FLOW ANAEROBIC SLUDGE BLANKET (UASB) REACTOR TO TREAT LANDFILL LEACHATE UNDER TROPICAL CONDITION

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Degree of Master of Science

Department of Civil Engineering

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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ABSTRACT

With the growth of population and changing the lifestyle, solid waste generation and management has become the major problem all over the world. Open dumping of solid waste has created problems related in health and the living standards of the people. Leachate generated from open dumping has created problems such as, surface and ground water pollution and soil contamination with toxic compounds.

This study was conducted to investigate the applicability of Up-flow Anaerobic Sludge Blanket (UASB) reactor to leachate treatment under the ambient temperature condition. Treatment efficiencies were measured in terms of COD reduction percentage of leachate that fed to the UASB reactor. The reactor was operated 94 days at different Hydraulic Retention Times (HRT) with the objective of finding the optimum HRT value. Maximum COD removal efficiency of (64 ± 1) % was achieved when HRT was at 6 hours. Reactor inside pH was controlled within the range of 6.2 – 7.5. Gas production rate, composition and Oxygen Reduction Potential (ORP) were measured for all the HRT values to maintain the reactor in proper anaerobic condition. Methane composition in biogas produced was high for all HRT values and at 6 hours HRT it was (86.11±1.1) %. Maximum TSS removal efficiency of 66% was also achieved at 6 hours of HRT. But maximum VSS removal efficiency of 29% was achieved at 7 hours of HRT. When comparing the heavy metal removal, the highest removal efficiencies were achieved for Pb and Cr which are (55 ± 1)% and (47 ± 1) % respectively.

Key Words: Leachate, Up Flow Anaerobic Sludge Blanket (UASB) reactor,
Hydraulic Retention Time (HRT), Anaerobic Process

DEDICATION

I dedicate this thesis to my parents who have devoted their lives to make me an educated and a successful person. I would like to express my love and appreciation for the encouragement and the sacrifices made by them.

I also dedicate this thesis to my husband who gave great support and encouragement to successfully complete this research work.

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LIST OF ABBREVIATIONS

Abbreviation	Description
MSW	Municipal Solid Waste
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
SS	Suspended Solids
TSS	Total Suspended Solids
VSS	Volatile Suspended Solids
T-N	Total Nitrogen
T-P	Total Phosphorous
UASB	Up-flow Anaerobic Sludge Blanket
HUASB	Hybrid Up-flow Anaerobic Sludge Blanket
EGSB	Expanded Granular Sludge Bed
HRT	Hydraulic Retention Time
SRT	Solid Retention Time
ORP	Oxygen Reduction Potential
RBC	Rotating Biological Contactors
OLR	Organic Loading Rate
VFA	Volatile Fatty Acid
SBR	Sequential Batch Reactor

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

With the development of the world and population increase, the amount of solid waste production increased. Solid waste is solid or semisolid materials that are produced by the human or animal activities and dispose because they are useless. There are several methods to treat the solid wastes such as land filling, composting, anaerobic digestion, recycling, incineration, etc. But still up to 95% of solid waste generated worldwide is currently disposed in landfills (Kwarciak*et al*, 2008).

Disposal of a solid waste in open dumps is a major problem all over the world. It causes to become the urban areas, unhealthy, dirty, and unsightly and it also causes damage the terrestrial organisms and reduces the uses of the land. In Sri Lanka solid wastes is collected by local municipalities and dispose into open dumpsites that are not managed technically. Disposal of Municipal Solid Waste (MSW) into dump sites continues to grow day by day with the growth of population and development of industries.

Currently, most of the countries dispose the solid waste into landfills. Landfill is the most economical and environmentally acceptable method for the disposal of solid waste. Most satisfactory method of the landfill is a sanitary landfill. One of the critical environmental problems of the landfill is a production of leachate that contaminated with ground water and nearby surface water sources. Leachate is wastewater that contains organic materials, heavy metals, Nitrogen-Ammonia and other material that result from degradation of MSW. It percolates through a soil and contaminates with the underground water sources that creates serious environmental impact. Studies of Sewwandi *et al.*, (2011) showed that there is a risk of soil and water pollution by heavy metals in nearby areas of the dumpsites in the Sri Lanka.

Characteristics of leachate can be represented by the basic parameters like Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), pH, Suspended Solids

(SS), Total Nitrogen (TN) and Total Phosphorus (TP). But the chemical composition of leachate change with the factors such as age of the landfill, climate/seasonal weather variation on the deposited site and the kind of waste deposited (Ifeanyichukwu, 2008). Variation of composition greatly depends on the age of the landfill (Baig *et al.*, 1999).

Due to high pollution effect of landfill leachate, treatment has become a major environmental concern as it cannot be directly disposed to the land or any surface water body. Treatment of landfill leachate makes very difficult due to the presence of high amount of organic, inorganic wastes and inhibitory substances like ammonia. According to the (Yuzer, et al., 2012), Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) removal efficiencies decreased gradually from 95% to 15%, while ammonia concentration was increased. Now many countries have implemented regulation for Municipal Solid Waste (MSW) disposal and according to these regulations, landfills should be built with engineered liners and leachate collection system. Then proper treatment should be done for this collected leachate before discharging to the environment as leachate is classified as an industrial waste under federal pre – treatment guidelines. (Qasim, 1994).

Aerobic treatment and anaerobic treatment processes are the most common types of treatment systems used. Since leachate is high strength wastewater stream, anaerobic processes are more effective and recommended than the aerobic processes due to lower operating cost, low sludge production nearly 5 – 10% (Karthikeyan and Kandasamy, 2009) and the emission of bio gas that can be used as an energy source. In recent years, attempts have been made to apply anaerobic technology and design high rate anaerobic reactors to overcome drawbacks of low rate anaerobic reactors.

Up-flow Anaerobic Sludge Blanket (UASB) reactor is also a high rate reactor that is mostly used for treatment of high strength wastewater. It uses a blanket of granular sludge which is suspended in the liquid.

1.2 SIGNIFICANCE OF THE STUDY

Many studies have been performed for the leachate treatment either aerobic or anaerobic or with a combination of aerobic and anaerobic. It has been shown that anaerobic processes are more effective and the UASB reactor has high treatment efficiency. But this treatment efficiency changes with some factors like climate of the country, age and composition of the landfill, etc.

When considering the tropical conditions, temperature is a significant factor that affects on the efficiency of the anaerobic treatment processes. As anaerobic reactor operated in closed system surrounding moisture or humidity levels are not affected to the processes of inside reactor. High treatment efficiency can be achieved within the thermophilic temperature (45°C - 60°C) range (Bandara *et al.*, 2011). Sri Lanka belongs to the tropical zone and average temperature in this zone remains in (20^0C - 30^0C) temperature range. If the reactor is operated within thermophilic range, wastewater need to be heated and additional cost involves.

Department of Civil Engineering, University of Ruhuna has developed the lab scale Up-flow Anaerobic Sludge Blanket (UASB) reactor and Fonseka and Senewirathna (2016) conducted the research to examine the applicability of UASB reactor to treat the synthetic leachate under the ambient temperature. Based on their research study COD removal efficiency of 80% has been reported. This research is a continuation of previous study with the objective of applying the UASB reactor to treat the leachate that generated naturally in the Wakunugoda landfill (Figure 1-1), which is being operated under the supervision of the Galle Municipal Council. This solid waste site is 20 years old and it is located near the Mahamodara Alla.

This research was conducted under the ambient temperature and at short Hydraulic Retention Times (HRT). Composition of leachate was analyzed and treatment efficiency of UASB is compared with the lab scale experiment.

Figure 1-1: Location of Wakunugoda Solid Waste Dump

1.3 OBJECTIVES

The main aim of this research is to study the performance of UASB reactor to treat leachate naturally generated in the landfill and to determine the treatment efficiency under short hydraulic retention times at ambient temperature of Sri Lanka.

The objectives of this study are;

- Find the optimum HRT value and performance of UASB reactor in leachate treatment.
- Find the removal efficiency of heavy metals for an UASB reactor at the selected optimum HRT.

1.4 OULTINE OF THE THESIS

The first chapter of the thesis gives an introduction to the topic and states the objectives of this research project. Chapter two is the literature review. Anaerobic treatment process, wastewater treatment in Up-flow Anaerobic Sludge Blanket reactor and leachate characteristics are discussed under this chapter. Chapter three focuses on the methodology of carrying out the research. UASB reactor design and testing methods of parameters of wastewater are discussed under this chapter. Chapter four focuses on result and discussion. This chapter includes a results and description about the study. Finally, the chapter five gives the conclusion of the research and suggestions for future directions.

CHAPTER 2

LITERATURE REVIEW

2.1 STABILIZATION PROCESSES IN LANDFILLS

According to the study of (Kjeldsen *et al.*, 2002), with the burial of refuse in a landfill, complex series of chemical and biological reactions initiate and form the several compounds.

At the time of waste deposition in a landfill, the oxygen present in the void spaces of fresh solid waste is rapidly consumed by the aerobic decomposition of biodegradable organic materials and form carbon dioxide, water, and other by-products. The aerobic decomposition lasts only for a few days because oxygen is not replenished once the waste is covered. Most leachate produced during this phase results from the release of moisture during compaction as well as short-circuiting of precipitation through the buried refuse (Kjeldsen *et al.*, 2002).With the depletion of oxygen most dominant phase of anaerobic decomposition starts and supports for the fermentation reaction and bio gas formation.

2.2 ANAEROBIC DIGESTION

There are several major conversion steps to describe the anaerobic decomposition phase during which organic materials are converted to methane and carbon dioxide. These steps are shown in Figure 2-1. They are highly interdependent and included hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Alexnder, 1971).

Generally, the breakdown of organic matters in anaerobic ecosystems proceed sequentially from the complex to the simple starting with the hydrolysis of complex particulate matters to simpler monomers like amino acids, sugars, and high molecular fatty acids. Amino acids and sugars are converted into either intermediate by-products (e.g. Propionic, butyric and other volatile acids) or directly fermented into acetic acid. High molecular fatty acids are oxidized to intermediate by-products and hydrogen. Methane and carbon dioxide generation occurs primarily through cleavage of acetate.

Due to the fermentation of organic compounds by acid-forming bacteria (acetagenic bacteria) and methane forming bacteria, growth of new bacterial cells or sludge occurs. In anaerobic respiration, energy obtained by the bacteria is relatively small (compared with aerobic respiration) and this small quantity of energy results in production of a relatively small quantity of cells or sludge.

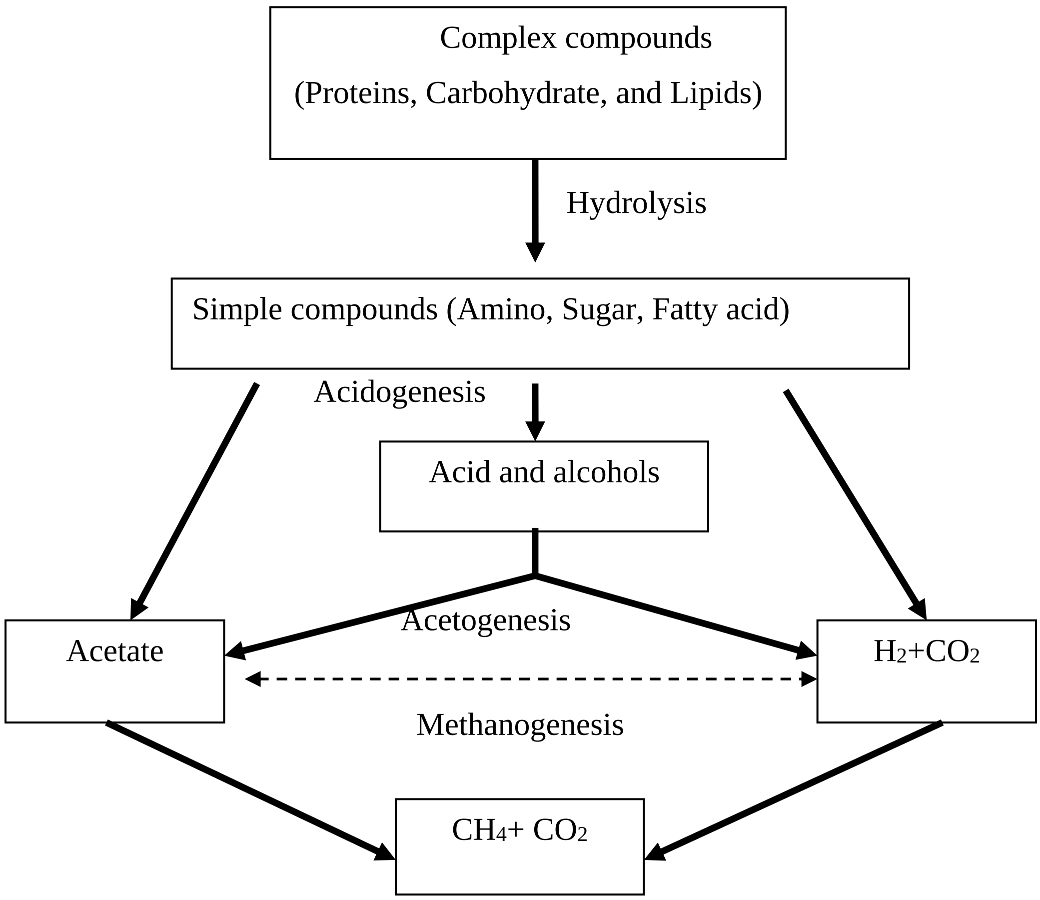

Figure 2-1: Conversion steps of Anaerobic Process

2.2.1 Volatile Fatty Acids

Organic, short- chain acids are known as volatile acids or volatile fatty acids. Volatile acids can vaporize or evaporate at atmospheric pressure. These acids occur as substrates and products in the anaerobic digester. Many serve as substrate for methane-forming bacteria, and they are the products of the fermentative activities of facultative anaerobes. The volatile acids that commonly found in an anaerobic digester are shown in Table 2-1 and predominant volatile acid is the acetate (nearly 85%). All volatile acids are soluble in water.

Table 2-1: Volatile acid commonly found in an anaerobic digester

(Adapted from Gerardi, 2003)

Volatile acid	Number of Carbon units	Formula
Formate	1	$HCOOH$
Acetate	2	CH_3COOH
Propionate	3	CH_3CH_2COOH
Butyrate	4	$CH_3(CH_2)_2COOH$
Valeric acid	5	$CH_3(CH_2)_3COOH$
Isovaleric acid	5	$(CH_3)_2CHCH_2COOH$
Caproic acid	6	$CH_3(CH_2)_4COOH$

2.2.2 BioGas

As a result of anaerobic digestion, the mixtures of gases that are referred to as digester gas or biogas are produced. Different gasses presence in the biogas has shown in the Table 2-2. The two major components of biogas are methane (CH_4) and carbon dioxide (CO_2) and these two gases contribute more than 90% of the composition of the biogas. Only methane has the economic value among these gases. Nitrogen and oxygen are normally present in small quantities primarily as a result of air entrapment during waste deposition, atmospheric air diffusion through the landfill cover, especially in the near surface layers.

The heat value of biogas is approximately 18.63 – 22.35 MJ/m^3, much lower than that of methane because of the dilution of methane by carbon dioxide. With increasing quantities of carbon dioxide in biogas, decreasing heat values of biogas occur. If the carbon dioxide content of biogas becomes too large, it will not allow for a self-sustained burn and supplemental fuel will be required. If the carbon dioxide fraction in the biogas increases above 30%, the acid concentration in the sludge increases and the pH drops below 7.0. Significant acid fermentation occurs at the pH values below 7.0 (Gerardi, 2003).

Table 2-2: Composition of bio gas

(Adapted from Bandara, 2013)

Matter	Percentage by volume (%)
Methane (CH_4)	50-70
Carbon dioxide (CO_2)	30-40
Hydrogen (H_2)	1-10
Nitrogen (N_2)	1-3
Hydrogen sulfide (H_2S)	0-3

2.2.3 Oxygen Reduction Potential (ORP)

Table 2-3: Microbial process classification according to the ORP value

(Adapted from Gerardi, 2003)

ORP value	Process Type
Greater than +50 mV	Aerobic Respiration
+50 to -50 mV	Anoxic Respiration (De-nitrification)
Less than -50 mV	Sulfate Reduction (SO_4^{2-}) – Fermentation
Less than -100 mV	Anaerobic Respiration Mixed acids and alcohol fermentation
Less than -200 mV	Methane fermentation

ORP is an indicator of the capacity of the molecules in the wastewater or sludge to release or gain electrons (oxidation or reduction, respectively). This measurement also is an indicator of the form of respiration that may occur. Table 2-3 shows the type of the microbial process occurs within the reactor according to the ORP value.

However, in a mixed culture of fermenting organisms would exist in an anaerobic digester. Methane fermentation or the growth of methane-forming bacteria does not occur until the ORP is less than –300mV. This is due to the inability of the methane-forming bacteria to successfully compete with other fermenting organisms at values greater than –300mV (Gerardi, 2003).

2.2.4 Operational Parameters

Operational parameters within the digester should be periodically monitored and maintained because Methane – forming bacteria are extremely sensitive to the changes occur within the reactor. As shown in table 2-4, alkalinity, pH, temperature, gas composition, hydraulic retention time (HRT), oxidation-reduction potential (ORP), and volatile acid concentration are the parameters that should be maintained at optimum ranges.

The anaerobic process is susceptible to the toxic and shock loadings and also the presence of different bacterial groups that have different optimum values or ranges of values for operational conditions can interfere with the operational process. For example, there are two optimal temperatures for anaerobic digestion of solids. The acid-forming bacteria have an optimum temperature at 30°C, and the mesophilic, methane-forming bacteria have an optimum temperature at 35°C (Gerardi, 2003).

Ammonia toxicity is the other problem that causes of the poor operation in an anaerobic digester. By maintaining pH within the optimum range of 6.8 to 7.2 this problem can be avoided. The increase in ammonia-nitrogen or alkalinity causes production of foam and scum within the digester.

Table 2-4: Operational conditions for Acceptable activity of Methane - forming bacteria and methane production

(Adapted from Gerardi, 2003)

Condition	Optimum	Marginal
Alkalinity, mg/l as $CaCO_3$	1500-3000	1000-1500 3000-5000
Gas composition Methane, % volume Carbon dioxide, % volume	 65-70 30-35	 60-65 & 70-75 25-30 & 35-40
Hydraulic retention time, days	10-15	7-10 & 15-30
pH	6.8-7.2	6.6-6.8 & 7.2-7.6
Temperature, mesophilic	30-35 ºC	20-30º& 35-40 ºC
Temperature, thermophilic	50-56 ºC	45-50º& 57-60 ºC
Volatile acids, mg/l as acetic acid	50-500	500-2000

2.2.5 Retention Times

Solids retention time (SRT) and hydraulic retention time (HRT) are the two main retention times in an anaerobic reactor. The SRT is the average time that bacteria (solids) are in the anaerobic digester and HRT is the time that the wastewater or sludge is in the anaerobic digester. The SRT and the HRT are the same for a suspended-growth anaerobic digester that has no recycle. SRT and HRT may vary if recycle of solids is incorporated into the operation of the digester.

2.3 GENERATION OF LANDFILL LEACHATE

Figure 2-2 shows a number of factors that affect for the leachate generation, such as:

- Infiltration of ground water
- Rainfall (precipitation)
- Water from the deposited waste, mainly due to the static pressure
- Evaporation from the site.

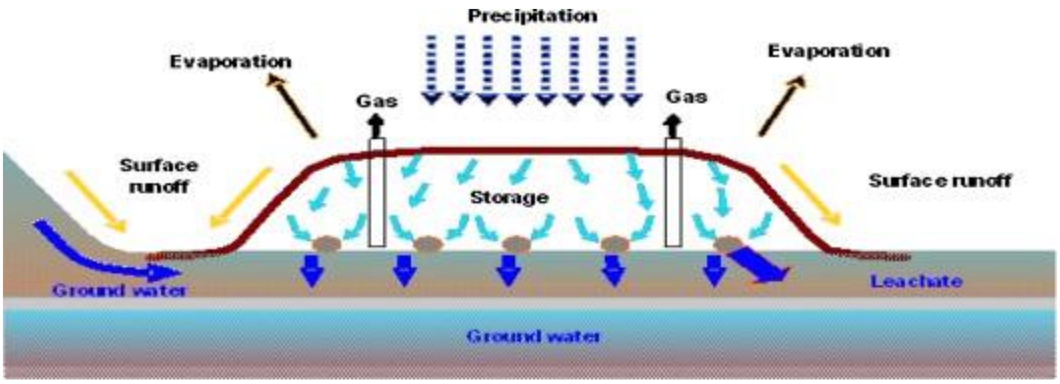

Figure 2-2: Methods of Landfill Leachate Generation

Source: Article on www.journals.elsevierhealth.com

Leachate flow rate is closely linked to precipitation (*P*), surface runoff and infiltration (*I*) or intrusion of groundwater percolating through the landfill. The climate has also a great influence on leachate production because it affects the input of precipitation (*P*) and losses through evaporation (EV). Finally, the production of leachate depends on the nature of the waste itself, water content and its degree of compaction into the tip. The production is generally greater whenever the waste is less compacted, since compaction reduces the filtration rate (Renou *et al.*, 2008).

2.4 COMPOSITION OF LEACHATE

Leachate composition can be characterized as primary importance and secondary importance compounds. The major concern on treatment should be focused on the primary compounds, as secondary compounds are found in very low concentrations.

According to the (Kjeldsen *et al.*, 2002) primary pollutants can be divided into mainly four groups such as;

1. Dissolved organic matter (volatile fatty acids and more refractory compounds such as fulvic-like and humic-like compounds).
2. Inorganic components (calcium ($Ca2^+$), magnesium ($Mg2^+$), sodium (Na^+), potassium (K^+), ammonium ($NH4^+$), iron ($Fe2^+$), manganese ($Mn2^+$), chloride ($Cl^–$), sulfate ($SO_4{}^{2–}$) and hydrogen carbonate ($HCO_3{}^–$)).
3. Heavy metals (cadmium (Cd^{2+}), chromium (Cr^{3+}), copper (Cu^{2+}), lead (Pb^{2+}),nickel (Ni^{2+}) and zinc (Zn^{2+})).
4. Xenobiotic organic compounds (XOCs) originating from household or industrial chemicals and present in relatively low (These compounds mainly include, among a variety of aromatic hydrocarbons, phenols, chlorinated aliphatics, pesticides, and plastizers).

When considering the nutrient content in leachate most leachates are rich in nitrogen and also normally phosphorus contains in very low concentration. The nitrogen – ammonium part of the total nitrogen increases with the time due to anaerobic hydrolysis of organic nitrogen into ammonia. During the acidic phase in the landfill the ammonia content represents the major part of the total nitrogen. At methane phase the ammonia nitrogen represents 85 to 95 %of the total nitrogen content in the leachate (Morling, 2007).

There are many factors affecting the quality of leachates. Such as;

- Age
- Precipitation
- Seasonal weather variation
- Waste type and composition that depend on the standard of living of the surrounding population.

In particular, the composition of landfill leachates varies greatly depending on the age of the landfill. With the age landfill passes four phases by changing the composition of leachate. Table 2 -5 shows the leachate composition variation according to the three phases.

Table 2-5: Simplified characterization of the biological performance in a landfill related to disposal time

(Adapted from Morling, 2007)

First Phase: Aerobic Phase	
Duration	Some weeks
Characterization of landfill leachate	pH~ 8 High levels of heavy metals
Second phase: Acidic (anaerobic) phase	
Duration	Some weeks
Characterization of landfill leachate	pH~ 5 High concentration of VFA High levels of BOD Ratio COD/BOD is low: 1.3:1 – 2.0:1 High levels of NH_3-N, organic N and PO_4-p
Third phase: Methane phase (anaerobic)	
Duration	> 100 years
Characterization of landfill leachate	pH ~ 7 Low concentration of VFA Low levels of BOD Ratio COD/BOD is high 20:1 – 10:1 High levels of NH_4-N, Moderate to low levels of organic N Very low levels of PO_4-P Low to very low levels of heavy metals, apart from Fe and Mn

In the second phase, the hydrolytic, fermentative, and acetogenic bacteria dominate, resulting in an accumulation of carboxylic acids and a pH decrease. The highest BOD and COD concentrations in the leachate will be measured during this phase (Barlaz, 1993). According to the study of Sewwandi (2014), pH of landfill leachate increases with the age of the landfill due to the biological decomposition of organic N into ammonium N. As stated in (Morling, 2007) the fourth phase is named as the "humic phase" and the knowledge about this phase is limited.

2.5 LEACHATE TREATMENT TECHNOLOGIES

Table 2-6: Tolerance Limits for the Discharge of Industrial Waste in to Inland Surface Waters

(Adapted from Gazette Extraordinary of the Democratic Socialist Republic of Sri Lanka - 01.02.2008)

Parameter	Limiting concentration mg/l	Parameter	Limiting concentration mg/l
COD	250	Chromium	0.5
BOD5	30	Chromium (VI)	0.1
Total Kjeldahl nitrogen (as N)	150	Nickel	3.0
Dissolved Phosphate (As P)	5	Lead	0.1
Total suspended solids	50	Copper	3.0
Ammoniacal nitrogen (as N)	50	Arsenic	0.2
Phenolic compounds (as C_6H_5OH)	1	Cyanide#	0.2
Mercury	0.0005	Sulfide	2.0
Cadmium	0.1		

By analyzing the leachate samples collected from different locations in Sri Lanka, Sewwandi (2014) showed that most of the pollutants (F^-, Cl^-, PO_4^{3-}, NH_4^+, Fe, Se, Pb, BOD_5, and COD) in leachate exceeded the maximum tolerance limits in Sri Lankan Standards. Maximum permissible levels of heavy metals differ according to the impact caused by them. Even though, the concentrations of those metals are low, the impact of them may be higher. Due to the toxicity and harmful effect of the leachate, it should be pumped out of the landfill and the proper treatment must be done before discharge. There are different types of treatment methods and these are classified into biological, physical / chemical as well as combined biological and membrane technological methods.

2.5.1 Biological Treatment Methods

Biological treatment methods are the most commonly used methods due to the reliability, simplicity and high cost-effectiveness of the treatment. Biological processes have been shown to be very effective in removing organic and nitrogenous matter when the BOD/COD ratio has a high value (>0.5).

Biological treatment methods can be divided mainly into aerobic and anaerobic processes. Following are the type of aerobic and anaerobic processes that commonly used;

Aerobic Process

- Activated sludge reactors
- Aerated lagoons
- Rotating Biological Contactors (RBC)
- Trickling filter

Anaerobic Process

- Lagoons
- Anaerobic filters
- Anaerobic Digesters
- Up-flow anaerobic sludge blanket reactor (UASB)

Even aerobic processes have shown more effective in removing organic carbon, nutrients and ammonia. Disadvantages of these processes tend to be focused on the anaerobic processes. These disadvantages are as follows;

- Inadequate sludge settles ability and the need for longer aeration times
- High energy demand and excess sludge production
- Microbial inhibition due to high ammonium-nitrogen strength

2.5.2 Physical / Chemical Treatment

Physical and chemical processes are used in addition to the biological treatment as a pre-treatment or post – treatment for removing the suspended solids, colloidal particles, floating material, color, and toxic compounds.

These methods include;

- Flotation
- Coagulation/flocculation,
- Adsorption
- Chemical oxidation
- Air stripping.
- Chemical Precipitation

2.5.3 Membrane Technologies

Membrane materials are used in membrane technology in the treatment process. The principle of the membrane process is the separation of two solutions with different concentrations by a semi permeable membrane. Pressure is induced on the more concentrated solution to force the water into the one of lower concentration side while most of the concentrated compounds are well retained. However, the degree of retention of compounds varies depending on the membrane type.

Different types of membrane treatment methods are;

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse osmosis (RO)

Membrane technologies are not used more commonly due to its high cost and it cannot be used individually as most of the compounds cannot be removed using one membrane type.

2.5.4 Comparison between different types of leachate treatment methods

Table 2-7 shows the COD removal efficiencies for different type of reactors according to the literatures. Table 2-8 and 2-9 show the comparison of different treatment methods according to the several factors.

Table 2-7: The summary of research papers related to treatment of leachate using various methods

Used reactor	COD removal efficiency	Reference
HUASB reactor	73.7%	(Ridzuan et al 2013)
SBR	83.1% to 76.7%	(Dorota K. et al 2006)
EGSB	Around 90%	(Reilly et al 2009)
SBR	75%	(Uygur &kargi 2004)
Activated sludge process	63%	(Ahn, Chung &chang 2007)
Anaerobic submerged membrane bioreactor	90%	(Bohdziewicz, Neczaj&Kwarciak 2008)

Table 2-8: Comparison based on age of leachate, space and skill of personnel

(Adapted from Ifeanyichukwu, 2008)

Treatment process	Treatment of young leachate	Treatment of medium leachate	Treatment of old leachate	Economy of space	Requiring less skilled personnel
Biological					
Activated sludge	Good	Fair	Poor	Poor	No
RBC	Good	Fair	Poor	Good	Yes
SBR	Good	Fair	Poor	Good	No
Reed beds	Fair	Fair	Good	Poor	Yes
BAF	Good	Fair	Fair	Good	Yes
Lagoons	Good	Fair	Poor	Poor	Yes
USAD	Good	Fair	Fair	Good	Yes
AF	Good	Fair	Fair	Good	Yes
MBBR	Good	Fair	Poor	Poor	No
MBR	Good	Fair	Fair	Poor	No
Physicochemical					
Coagulation& flocculation	Poor	Fair	Fair	Fair	No
Precipitation	Poor	Fair	Poor	Fair	No
Adsorption	Poor	Fair	Good	Good	No
Flotation	Poor	Fair	Fair	Poor	Yes
Chem. Oxidation	Poor	Fair	Fair	Good	No
Ammonia stripping	Poor	Fair	Fair	Poor	No
Membrane process					
Microfiltration	Poor	Poor	Poor	Good	Yes
Ultrafiltration	Fair	Fair	Fair	Good	Yes
Nanofiltration	Good	Good	Good	Good	Yes
Reverse Osmosis	Good	Good	Good	Good	Yes

Table 2-9: Comparison based on effect of secondary clarifier, pre-treatment and cost

(Adapted from Ifeanyichukwu, 2008)

Treatment process	Effective without secondary clarifier	Effective without pre-treatment	Installation and operational cost
Biological			
Activated sludge	No	No	Expensive
RBC	Yes	Yes	Expensive
SBR	Yes	No	Less expensive
Reed beds	Yes	No	Less expensive
BAF	Yes	Yes	Expensive
Lagoons	Yes	Yes	Expensive
USAD	Yes	No	Less expensive
AF	Yes	Yes	Expensive
MBBR	No	No	Expensive
MBR	No	No	Expensive
Physicochemical			
Coagulation& flocculation	No	Yes	Less expensive
Precipitation	No	Yes	Less expensive
Adsorption	Yes	Yes	Less expensive
Flotation	No	No	Expensive
Chem. Oxidation	No	Yes	Expensive
Ammonia stripping	Yes	Yes	Expensive
Membrane process			
Microfiltration	No	No	Expensive
Ultrafiltration	No	No	Expensive
Nanofiltration	Yes	No	Expensive
Reverse Osmosis	Yes	No	Expensive

When treating young leachate, biological techniques can yield a reasonable treatment performance with respect to COD, NH_3-N and heavy metals. When treating stabilized (less bio-degradable) leachate, physico-chemical treatments have been found to be suitable as a refining step for biological treatment, in order to remove organic refractory substances. Integrated chemical–physical–biological processes can overcome the drawbacks of individual processes contributing to a higher efficacy of the overall treatment (Renou *et al.*, 2008). Sewwandi (2014) showed that the electrical Conductivity for all the leachate samples collected within the Sri Lanka were high and varied, ranging from 4.5 to 38.3 mS/cm and biological treatment system alone would not be effective in reducing the pollutants especially for heavy metals.

2.6 UPFLOW ANAEROBIC SLUDGE BLANKET (UASB) REACTOR

UASB process is a modern anaerobic treatment that can have high treatment efficiency and a short hydraulic retention time. UASB reactor operates as a suspended growth system where microorganisms attached to granules to form an active sludge blanket at the bottom of the reactor. The wastewater introduced at the bottom of the tank passes upward through this sludge blanket. When wastewater passes through the sludge, microorganisms in the granules degrade organic matter in it and produce biogas (methane and carbon dioxide) as a result of anaerobic processes. On UASB system the sludge retention is based on the settling characteristics of sludge aggregates and thickening and expansion characteristics of the established flocculent sludge bed with its inherent structures.

As the gas moves upwards to escape, internal circulation takes place in the reactor prompting mixing, which results to more degradation due to more contact of microorganisms with substrate. At the top of the reactor the gas is collected from the gas collection dome. Liquid is sent to the settling chamber and settled solids are sent to the top of the sludge blanket through the baffle system. Figure 2 -3 shows a schematic diagram of UASB reactor.

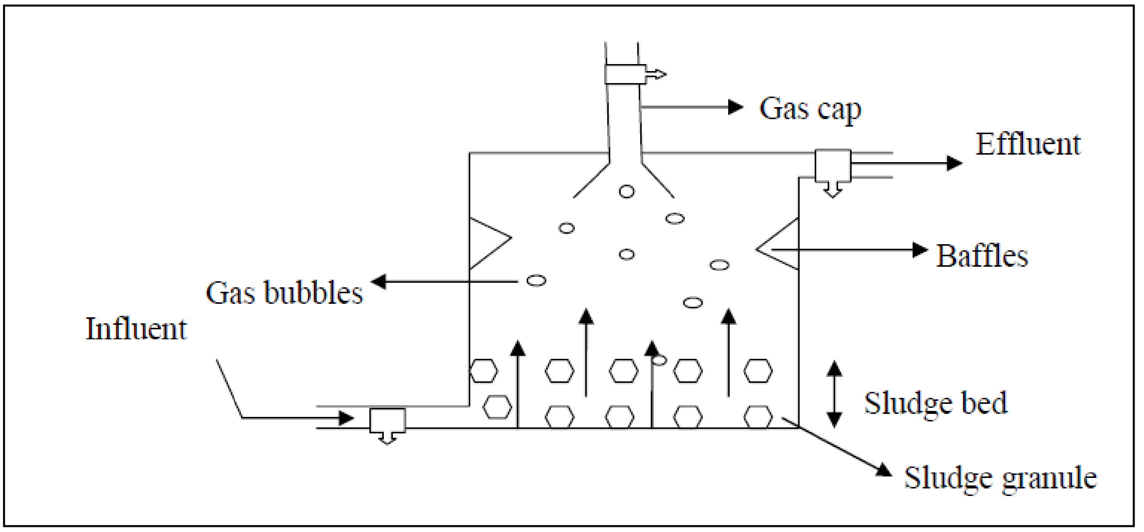

Figure 2-3: Up Flow Anaerobic Sludge Blanket Reactor

The particulate organics are removed by settling, adsorption and entrapment in the sludge bed of the UASB. Then start the hydrolysis of retained particles and it is considered as the rate-limiting step in the overall digestion process. Time taken for this step mainly depends on the applied process temperature. According to the (Lettinga.,et al., 1999) study single or multi-compartment (staged) granular sludge reactors is better high rate reactor for psychrophilic anaerobic wastewater treatment. (Lettinga, et al., 2001) states that SRT of 15 days is sufficient for process temperature of 25^{0}C and SRT of 75 days is required at a process temperature of 15^{0}C. If longer SRT is maintained within the reactor, it can be applied the shorter HRT. Also, Lettinga (2001) study recommended the staged reactor for sewage treatment at low temperatures between 15^{0}C – 20^{0}C and single UASB reactor for higher temperatures.

The temperature is strongly affected on microbial methogenic activities of anaerobic process. Master thesis of (Bandara, 2010) showed that mesophilic (30°C-35°C), and thermophilic (50°C-60°C) temperature ranges have optimum CH_4 production in the UASB reactor. To elevate the wastewater temperature up to these ranges results in additional cost in wastewater treatment. If UASB can operate within an ambient temperature without any heat, it would be saved the money and energy.

When UASB reactors are subjected to high volumetric organic loading rate at process temperature between 20–35 ^{0}C, it exhibits higher performances compared to other kinds of anaerobic reactors (Renou *et al.*, 2008). Table 2-10 shows the advantages of UASB in wastewater treatment.

The reactor attained maximum COD removal efficiency of 91%, for the treatment of fresh leachate, whereas, efficiency declined sharply from 90 to 35% while treating the old leachate (Singh and Mittal, 1997).

A lab-scale UASB reactor was used to study the synthetic leachate sample by Fonseka and Senewirathna at University of Ruhuna in 2015 and results showed that the maximum COD removal efficiency of 80% was obtained at the 7 hours of Hydraulic Retention Time (HRT).

Table 2-10: Advantages and disadvantages of UASB reactor

Advantages	Disadvantages
✓ Less reactor volume and space ✓ Lower sludge generation ✓ Simple to construct and operate ✓ Emit Biogas as end product ✓ Tolerate high organic and hydraulic loading rates ✓ High removal efficiencies even at low temperatures ✓ Low nutrient and chemical requirement	✓ Reaction rate depends on temperature ✓ Potential bad odor ✓ CH_4 dissolved in the effluent.

CHAPTER 3

METHODOLOGY

3.1 REACTOR DESIGN

The experiment was carried out in a lab-scale UASB reactor that made from Perspex material with 60 cm height and 10 cm diameter. Working volume of the reactor is 5 L. PVC conical shaped funnel with a valve was connected to the bottom of the reactor to make the uniform flow throughout the reactor. Bottom valve was used to introduce the influent leachate. Top part of the reactor was designed with two valves to collect the head space gases during the treatment and to collect the treated leachate (effluent). One valve was connected to the body of the reactor to take out the samples from the inside of the reactor.

Figure 3-1 shows the picture of a lab scale reactor and figure 3-2 shows the schematic diagram of an experiment set up.

Figure 3-1: Lab Scale UASB Reactor

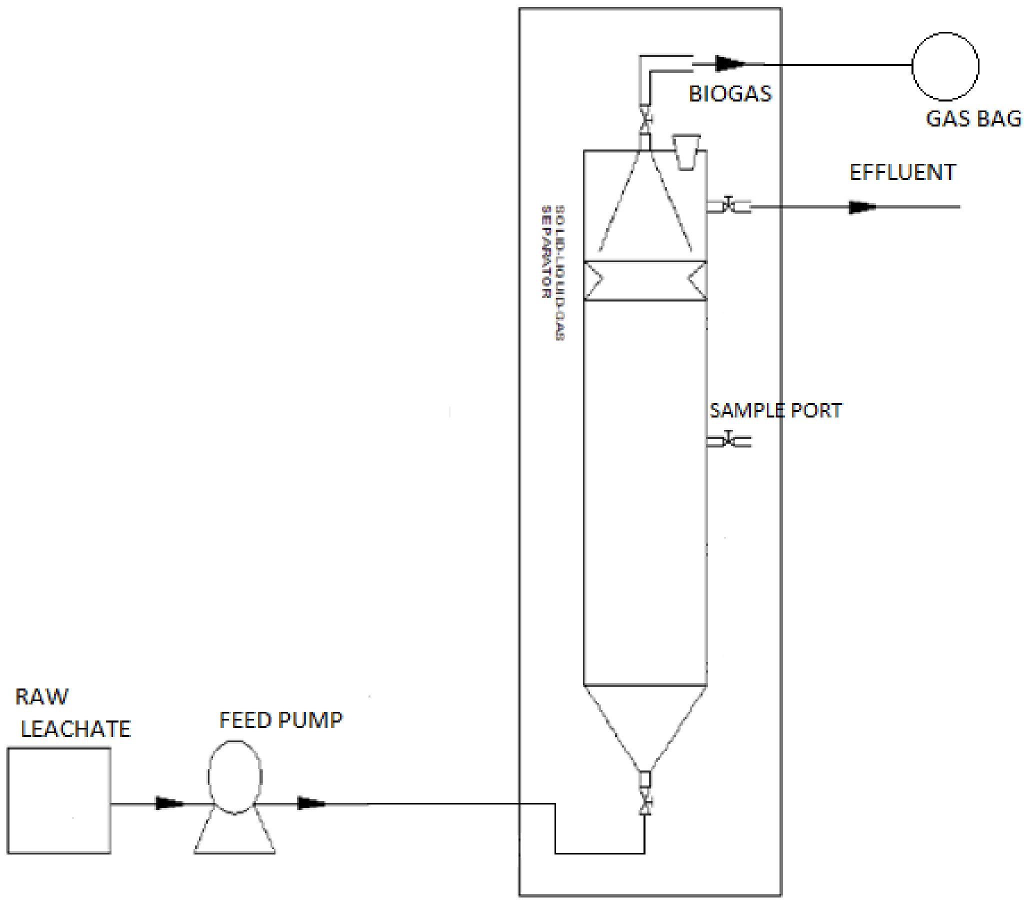

Figure 3-2: UASB Reactor Configuration

3.2 REACTOR START UP AND OPERATION

Since the leachates contained low numbers of anaerobic bacteria, the reactor was inoculated with 1L anaerobic granular sludge, which contains total solids and volatile solids concentration of 29 g/L and 23 g/L respectively. Leachate was introduced from the bottom of the reactor. Variable Displacement Pump was set into the required flow rate to achieve the desired HRT value.

This experiment was carried out over 94 days due to the introducing of inoculated sludge granules into the reactor. Reaction rate of the anaerobic process can be increased by inoculated sludge granules. Leachate was collected from Wakunugoda Landfill once a week and stored in the plastic drum that was connected to the feed pump inlet. Composition of the collected leachate is shown in the Table 3-1.

Continuous mixing of influent leachate was performed by the agitator that was installed within the feeding drum. (By performing agitation, it was expected to avoid the stagnant areas within the leachate feeding drum).The reactor was operated at different HRT values to find the optimum HRT value.

Figure 3-3: Granular Sludge

Table 3-1: Composition of leachate collected from Wakunugoda site

Parameter	Value (mg/l)
COD	23,625
pH	8.15
SS	13,161
VSS	4495
T-N	2200
T-P	22.38
Heavy Metals	
Cr	0.109
Cd	0.005
As	0.036
Fe	18.083
Hg	0.05

The reactor was monitored daily for temperature, pH and ORP by collecting the sample from liquid column inside the reactor. Figure 3.3 shows the variation of pH in influent and inside of UASB. pH of Influent leachate varied in the range of 7.5 - 8.5 and inside of the UASB varied within the 7 – 7.5. The pH value of the leachates was directly related to the ammonium ion content and volatile acidity. According to the (Gerardi, 2003), most anaerobic bacteria, including methane-forming bacteria, perform well within a pH range of 6.8 to 7.2. Proper operation of anaerobic process can be expected as the reactor was continuously operated within this pH range without any pH correction. Since reactor was always operated at pH higher than 7, it gave favourable environment to both methane forming bacteria and acetate forming bacteria.

Figure 3.4 shows the temperature and ORP variation during the reactor operation period. The temperature was not controlled. It varied from 28^0C to 32^0C during this period, which was ambient temperature condition. The reactor operated at an average temperature of 30 ^{0}.

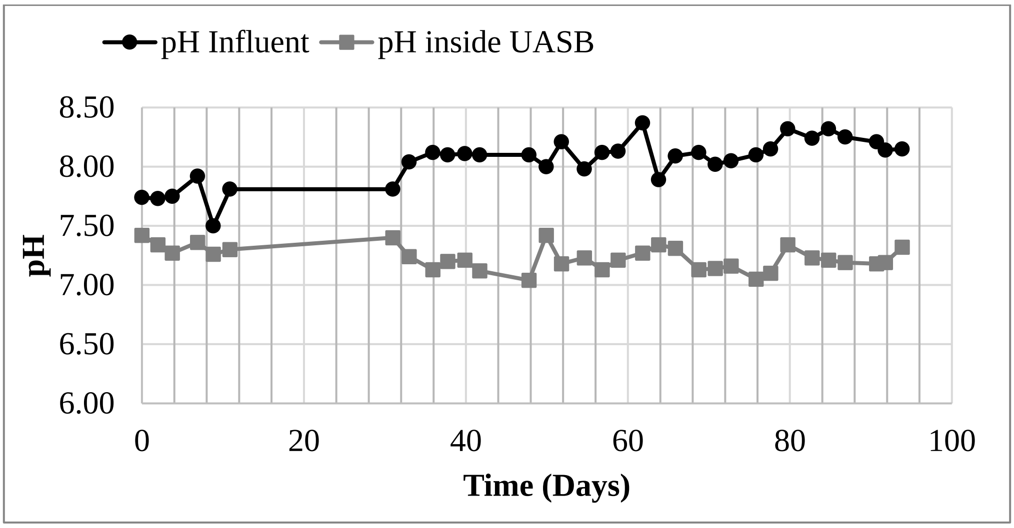

Figure 3-4: pH variation in influent (leachate) and inside of the UASB

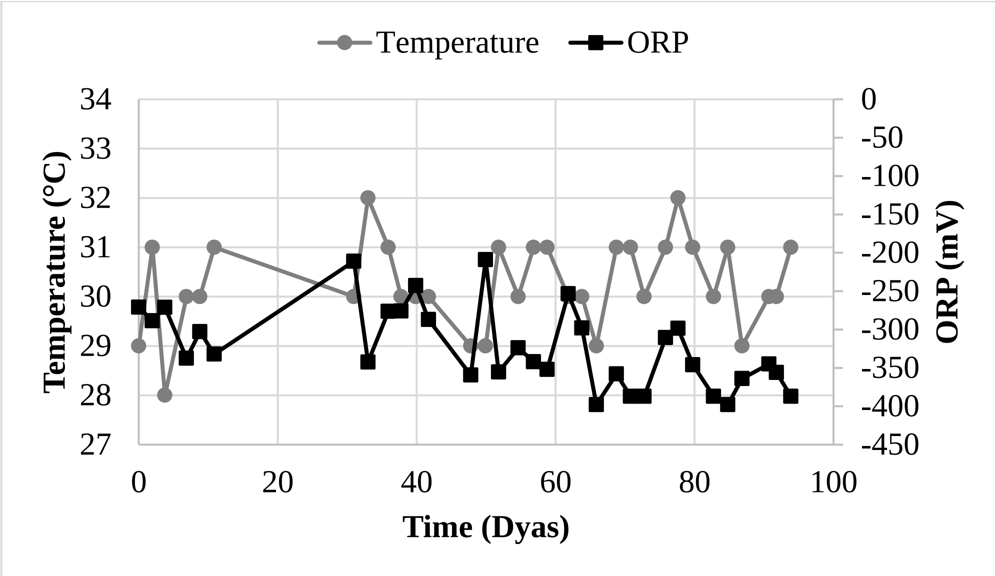

Figure 3-5: Temperature and ORP variation inside the UASB reactor

ORP is an indicator of the form of respiration that may occur in the bacterial environment. Anaerobic respiration may occur at the ORP values less than -100 mV. Reactor was operated in between -253mV to -387mV ORP. Proper anaerobic respiration and methane fermentation may occur as ORP values were always less than -200 mV though out the experiment.

3.3 SAMPLING PROCESS AND TESTING

Test samples were collected 3 times per week and the parameters were checked for the samples collected from the inlet, inside and outlet of the reactor. They are shown in the Table3-3. The collected samples were carried out and stored at 4°C until samples are analysed.

Table 3-2: Parameters tested during the experiment and sample collection points

Parameters	Influent	Effluent	Inside reactor	Sludge& granular	Headspace gas
COD	✓	✓			
pH	✓		✓		
Temperature			✓		
Gas production rate					✓
Gas composition					✓
SS	✓	✓			
VSS	✓	✓			
Oxygen Reduction Potential (ORP)			✓		
Heavy metals	✓	✓		✓	

3.3.1 Testing Methods

The testing was conducted according to the standard methods by considering the availability of the instrument and facilities. Table 3-4 shows the parameters with their corresponding analytical methods.

Table 3-3: Analysis method of each parameter tested

Parameters	Analysis method
COD	COD analyzer – DR 1900 – 01, Hach company, USA
pH	pH meter – PHC301, Hach Company, USA
Gas production rate	Water displacement method
Gas composition	Bio Gas Analyzer, Gasboard 3200L, Hubei – Ruiyi Instrument Co. Ltd., Japan
Oxygen Reduction Potential (ORP)	MTC101, Hach Company, USA
Temperature	Thermometer
SS	According to Standard method (APHA)
VSS	According to Standard method (APHA)
Heavy Metals	Inductively Coupled Plasma Optical Emission Spectroscopy

Figure 3-6: COD Analyzer (left) and Gas Composition Analyzer (right)

3.3.1.1 Gas Production Rate

For analysis of one sample, daily cumulative gas volume was collected into the gas bag. Then this gas volume was measured using the water displacement method as shown in figure 3-7 and gas production rate was calculated. For each HRT value six samples of gas volumes were collected (one sample was collected over 24 hours) and calculated the average gas production rate. Same water column was used throughout the experiment to minimize the error which could be occurred due to the dissolving of gas in the water.

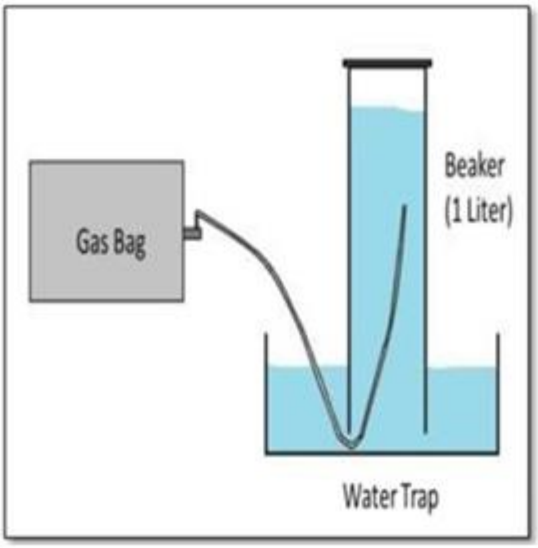

Figure 3-7: Water Displacement Method

CHAPTER 4

RESULT AND DISCUSSION

4.1 COD REMOVAL EFFICIENCY

Organic loading rate depends on both influent Total COD (T-COD) concentration and flow rate. Figure 4-1 shows the variation of organic loading rate for all HRT values. A gradual increase in Organic Loading Rate (OLR) is mainly due to the increase in flow rate (Flow rate increased with the decreasing of HRT). In this study OLR was varied from 51.06 g-CODL^{-1}d^{-1} to 144.19 g-CODL^{-1}d^{-1}. Following strategy adapted by Satoh *et al.*, (2017). According to them COD removal efficiency varied with the T-COD loading rate when OLR changes from4.8 gL^{-1} d^{-1}to 148.7 gL^{-1} d^{-1}. In this study, mean OLR in influent leachate is 42.334 (g-COD/L/day).

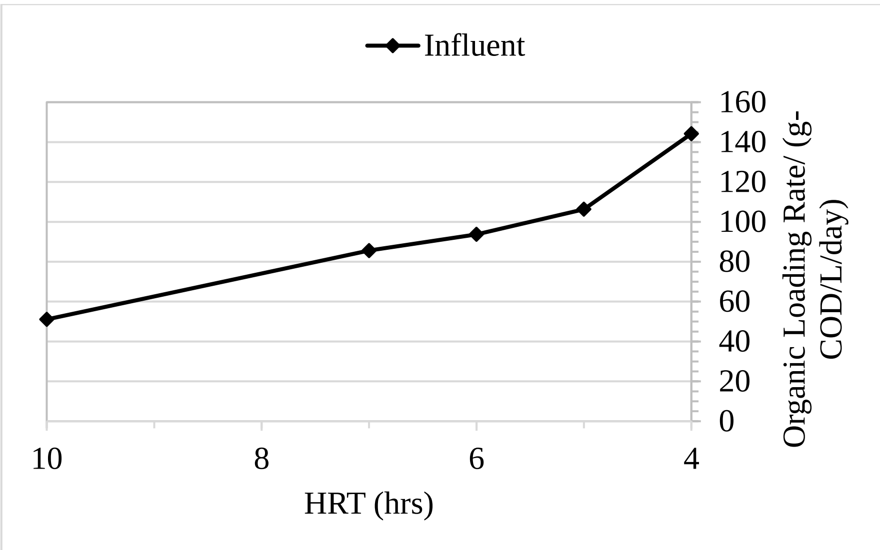

Figure 4-1: Organic Loading Rate Variation with HRT

The removal of organic matter in leachate was determined by measuring the concentration of influent COD and effluent COD of the UASB reactor. Variation of

COD in influent and effluent of UASB is shown in the Figure 4-2. The average influent COD concentration was about 23,625 mg/l during the operation period of the reactor. It can be concluded that leachate as a high strength wastewater stream. Organic matter removal of UASB can be expected up to11, 620 mg/l. According to this result natural leachate can be degraded in the UASB reactor.

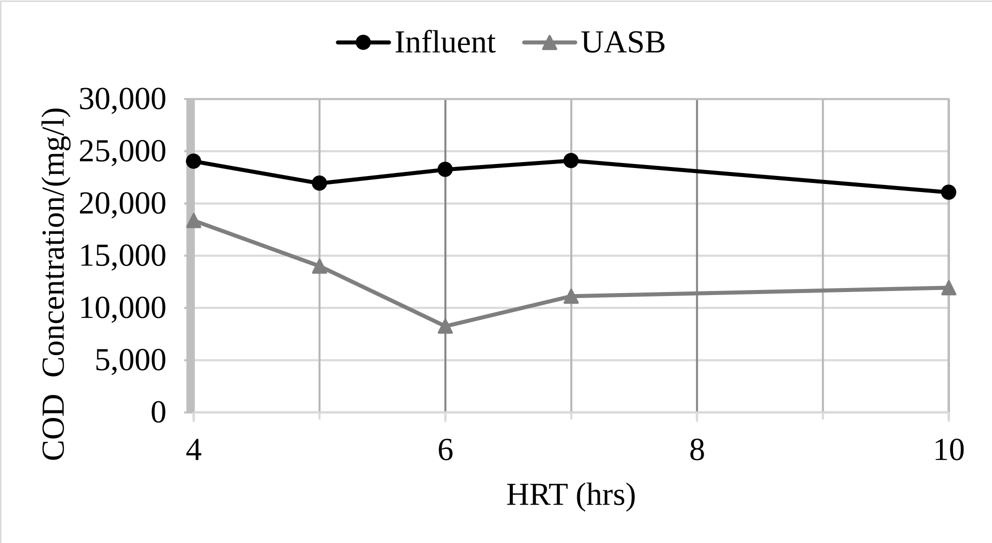

Figure 4-2: COD variation in influent leachate and UASB effluent

The variation of COD removal efficiency by changing of HRT is shown in Figure 4-3. According to this figure, the highest COD removal efficiency of 64 ± 1 is achieved at 6 hours of HRT. Experiment was started with 10 hours HRT and gradually decreased. At 10 hours HRT, COD removal efficiency was lower and it increased when HRT was decreased up to 6 hours. Then the COD removal efficiency started to decrease when HRT was less than 6 hours. Therefore the optimum HRT for the treatment of landfill leachate is observed as 6 hours. Average COD removal efficiency was (44 ± 2) %. According to the Satoh *et al.*, (2017) study T-COD removal efficiency became lower with increase in T-COD loading rate. This may be due to the sudden shock load applied to the reactor. In this study also at low HRT values (4 and 5 hours HRT) it shows lowest COD removal efficiencies compared to other HRT values.

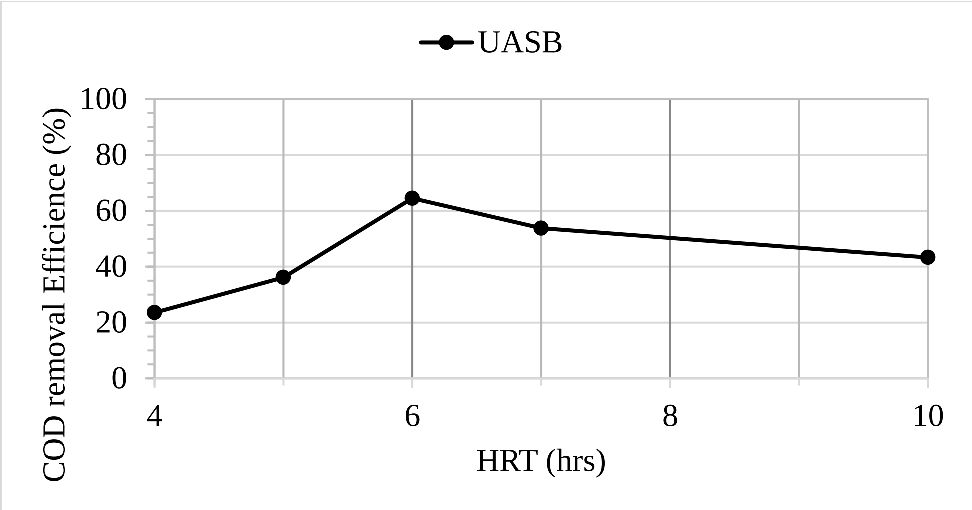

Figure 4-3: COD removal efficiencies variation with HRT

4.2 BIOGAS PRODUCTION

In an anaerobic biodegradation process, biogas is the main useful gas produced. The biogas was collected in the gas bag and measured the gas production rate and the composition for every HRT. Figure 4-4 shows the variation of the average biogas production rate with the time. The highest gas production rate was shown at the 6 hours HRT which is the optimum HRT of the reactor. The highest gas production rate at this optimum HRT is (23.35±0.42) ml/h/L. The average biogas production rate is (16.76±0.85) ml/h/L. When decreasing the HRT values below 6 hours it showed high decrease in biogas production. Biogas generation also comply with the overall COD removal profile.

According to the Table 4-1 it can be seen that the formation of H_2 gas and also there is an increase of N_2 and CO_2 percentage and a decrease in methane percentage. In the anaerobic process hydrogen must be presented at a very low concentration to ensure the proper operation of the process. As stated by (Satoh *et al.*, 2017), in order to decompose the propionate and n-butyrate into acetate H_2 partial pressure should be very low. They showed that H_2 partial pressure can be exceeded usual level due to the stress conditions applied to the reactor such as high organic loading rates, short hydraulic retention times (HRTs) or inflow of inhibitors. This condition may lead to process failure, such as low organic matter removal, reduced biogas production, and poor effluent quality. In this experiment at 4 and 5 hours HRT, has shown the formation of H_2 gas and it may be due to the reactor was subjected to the shock loading at short HRT values.

Study of Pauss *et al.*, (1990) showed that the level of dissolved hydrogen as the one of the growth-limiting factor in fermentation process in anaerobic digestion. Also, it states that negative thermodynamic effect can be happened due to the presence of an inhibitory gas, such as H_2. If pH drop happened in the biological process, acidic gases such as CO_2 or H_2S can be formed in high concentrations.

According to Table 4-1 low concentration of N_2 also formed within the mixture of biogas. This gas may be generating from dissolved nitrogen in the influent according to the Cakir et al., (2005) or may be from the decomposing of nitrogen compounds by microorganisms other than the methanogenesis bacteria.

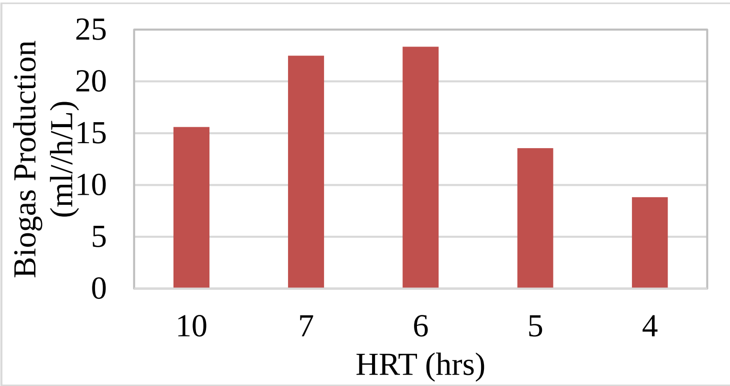

Figure 4-4: Bio Gas production rate variation with HRT

Table 4-1: Bio gas composition variation with HRT

HRT	Gas Concentration (%)			
	H2 (ppm)	N2	CH4	CO2
10		11.52	82.99	5.49
7		10.31	84.63	5.06
6		8.03	86.11	5.85
5	137	19.31	68.32	12.38
4	252	18.70	73.16	8.14

According to Figure 4-5, CH_4 shows the highest composition compared in other gasses for all HRT values. Furthermore, CH_4 varies with HRT value and at 6 hours HRT, methane formation is higher than the other HRT values. The maximum methane percentage is (86.11± 1.10) %. It can be concluded that the biogas produced at this HRT has high calorific value.

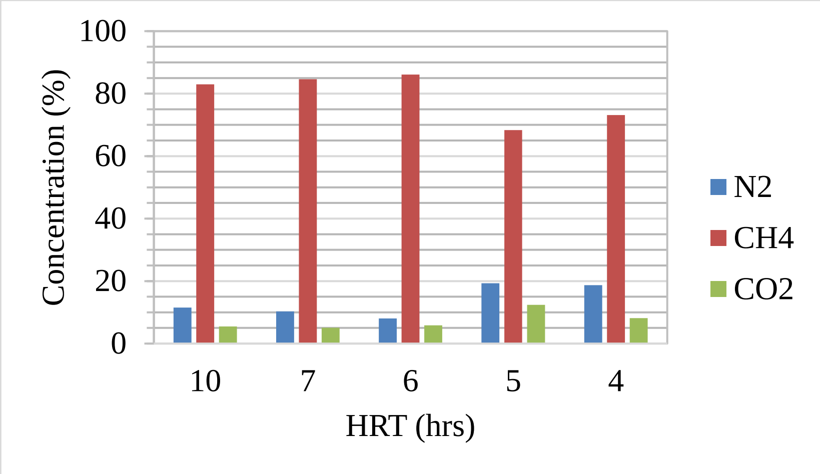

Figure 4-5: Head Space Biogas variation with HRT

Figure 4-6 shows the average composition of bio gas produced when changing HRT. The main components of bio gas are CH_4, CO_2 and N_2. Other gases like H_2S, H_2 were negligible.

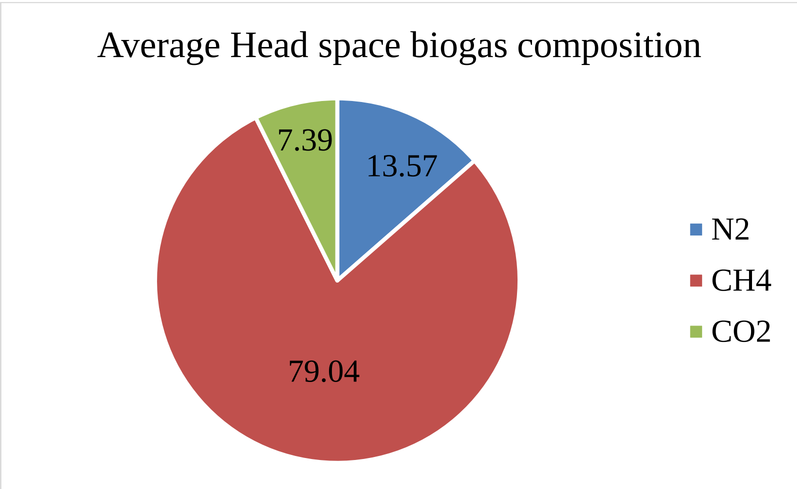

Figure 4-6: Average Biogas Composition

4.3 REMOVAL OF HEAVY METALS

A trace level of many heavy metals is required for the activation and functioning of many enzymes and co-enzymes of microorganisms. But Kumar (2013) showed that heavy metals may be stimulatory, inhibitory, or even toxic to anaerobic reactions depend on the metal species and its concentration.

Heavy metal removal was tested only for 6 hours HRT which is the optimum HRT. Table 4-2 illustrates the heavy metal composition of influent leachate. In this study heavy metals were not found in high concentrations except iron (Fe). As stated by Berrueta and Castrill (1992), in anaerobic processes, the content of metals in the waste decreases due to precipitation as sulfides. Kjeldsen *et al.*, (2002) study stated that showing of low concentration of heavy metals in leachate not implies the lack of heavy metals present in the solid waste or leachate. Heavy metals are bound as sulphides, phosphates and hydroxides and form the precipitates at or above neutral pH values.

UASB reactor inoculated Granules also contain small concentrations of heavy metals and it can be seen an increase of heavy metals in (Granule+ Sludge) in UASB reactor.

Table 4-2: Heavy metal content variation with treatment

Heavy Metals	Influent (mg/l)	Effluent UASB (mg/l)	Initial Granule (mg/l)	Granule + Sludge inside UASB (mg/kg)
Pb	0.030	0.014	0.011	18.897
Hg	0.050	0.047	0.000	4.025
Cr	0.109	0.057	0.032	59.150
Cd	0.005	0.004	0.002	1.146
As	0.036	0.025	0.002	13.054
Fe	18.083	13.979	0.732	4746.481

According to the figure 4-7, the highest removal efficiencies were shown for Pb and Cr which are (55 ± 1) % and (47 ± 1) % respectively. For the Cd, As and Fe can't achieve high removal using UASB and Hg removal is in very lowest level which is (7 ± 1)%.

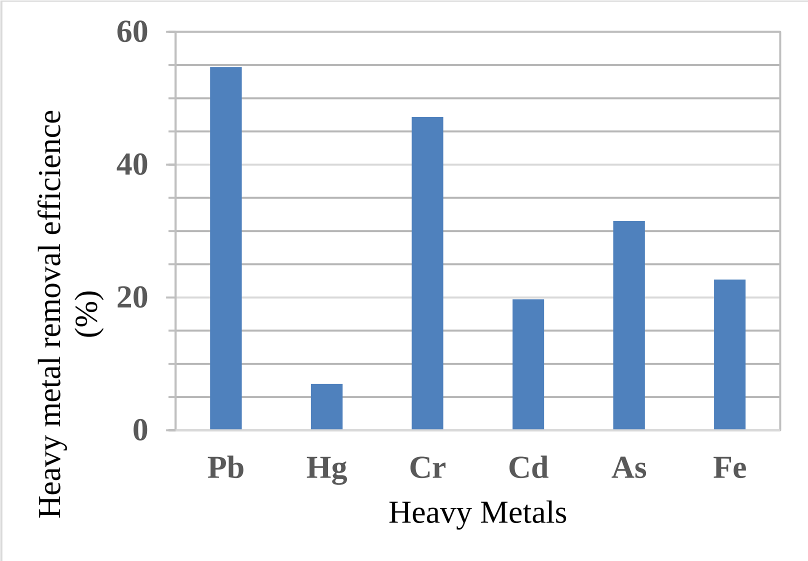

Figure 4-7: Heavy Metal removal efficiency at 6 hours HRT

4.4 TOTAL SUSPENDED SOLID (TSS) AND VOLATILE SUSPENDED SOLID (VSS) REMOVAL EFFICIENCIES

Total Suspended Solid (TSS) and Volatile Suspended Solid (VSS) are water quality measurements. Influent TSS and VSS values are (13161.2± 1864) mg/l and (4495.47 ±711) mg/l respectively. Figure 4-8 shows removal efficiencies of TSS and VSS for different HRT values. At the optimum HRT of 6 hours it shows the maximum removal efficiency of TSS which is 66% and at 7 hours HRT it has shown maximum removal efficiency of VSS which is 29%. Average removal of TSS and VSS are 48% and 23% respectively. The result shows low removal of TSS and VSS from the UASB reactor.

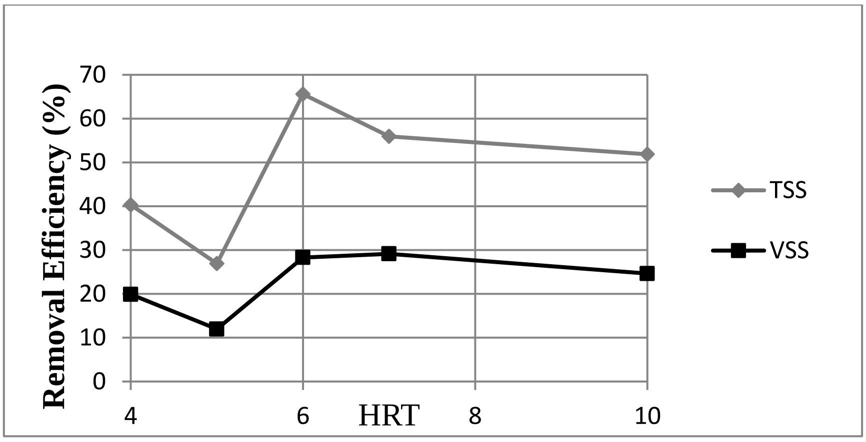

Figure 4-8: TSS and VSS removal efficiencies variation with HRT

Table 4-3 shows a significant increase of TSS and VSS of the granular in UASB reactor. This is due to the adsorption of solids to the granules and biomass formed within the reactor.

Table 4-3: TSS and VSS variation of granules after the treatment

	TSS (mg/L)	VSS (mg/L)
Inoculated Granules	28832	22737
Granular in UASB	34654	27381

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

The results and study show the following conclusions:

- Leachate is a high strength wastewater stream that has an average COD of 23,625 mg/l in Wakunugoda landfill.
- With the aim of finding the optimum HRT value in this treatment, UASB reactor was operated at 10, 7, 6, 5 and 4 hours of HRT values respectively.
- By treating leachate only in UASB reactor at ambient temperature, it could be achieved (64 ± 1) % of COD removal efficiency at the selected optimum HRT which was 6 hours.
- At 4 and 5 hours HRT values, it has showed high decline of COD removal efficiencies. This may be due to the reactor subjected to the shock load at these HRT values.
- Highest biogas production rate was recorded at the optimum HRT of 6 hours and it was (23.35 ± 0.42) ml/h/L. Biogas production rate was also compiled with the COD removal profile.
- Methane (CH_4) gas was formed in high concentration than the other gases. Maximum percentage of (86.11± 1.10) % of methane formation was achieved at the optimum HRT.
- At short HRT values such as 4 and 5 hours, it was shown the formation of H_2 gas. This may be due to the stress conditions applied to the reactor such as high organic loading rates, short hydraulic retention times (HRTs) or inflow of inhibitors.
- When considering the heavy metal removal using UASB, the highest removal efficiencies were shown for Pb and Cr which were (55 ± 1) % and (47 ± 1)% respectively. For the Cd, As and Fe high removal efficiencies cannot be achieved using UASB reactor and Hg removal was in very lowest level, which was (7 ± 1) %.

- Influent TSS and VSS values are (13161.2± 1864) mg/l and (4495.47 ±711) mg/l respectively. At the optimum HRT of 6 hours it shows the maximum removal efficiency of TSS which was 66% and at 7 hours HRT it shows the maximum removal efficiency of VSS which was 29%.

5.2 RECOMMENDATIONS

The design, construction and operation of leachate treatment facilities have not been standardized due to the variation in leachate production and characteristics according to the different factors like climate, age, etc., of the landfill.

The future research strategies for landfill leachate treatment can focus mainly on the modifications of up-flow anaerobic sludge blanket (UASB) reactor. Following treatment methods could be promising in terms of innovative and effective leachate treatment.

1. Combine the UASB with natural treatment processes that use different substrates like peat, coal, sawdust, clinker, soil etc.
2. Modify UASB reactor with a post treatment system to increase the removal efficiencies of COD, TSS, VSS and heavy metals.
3. Develop the natural leachate treatment system using wetland and different species of grass and test the removal of different pollutants in leachate.

REFERENCES

Ahn, D. H., Chung, Y. C., & Chang, W. S., 2002, 'Use of coagulant and zeolite to enhance the biological treatment efficiency of high ammonia leachate' *Journal of Environmental Science and Health, Part A*, *37*(2), 163-173.

Alexnder, M., (1971). Microbial ecology, New York: John Wiley & Sons, Inc.

Baig, S., Coulomb, I., Courant, P., Liechti, P., 1993, 'Treatment of landfill leachates' Lapeyrouse and Satrod case studies, Ozone Sci. Eng. 21 (1999) 1–22.

Bandara, W. M. K. R. T. W. *et al.* (2011) 'Removal of residual dissolved methane gas in an upflow anaerobic sludge blanket reactor treating low-strength wastewater at low temperature with degassing membrane', *Water Research*. Elsevier Ltd, 45(11), pp. 3533–3540. doi: 10.1016/j.watres.2011.04.030.

Bandara, W. M. K. R. T. W., Ikeda, M., Satoh, H., Sasakawa, M., Nakahara, Y., Takahashi, M., & Okabe, S., 2013b, 'Introduction of a degassing membrane technology into anaerobic wastewater treatment'*Water Environment Research*, *85*(5), 387-390.

Bandara, W.M. K. R. T. W., 2013a, 'Anaerobic treatment of low-strength wastewaters at ambient temperature in up flow anaerobic sludge blanket reactors' PhD thesis, Division of Environmental Engineering Graduate School of Engineering, Hokkaido University

Berrueta, J. and Castrill??n, L. (1992) 'Anaerobic treatment of leachates in UASB reactors', *Journal of Chemical Technology & Biotechnology*, 54(1), pp. 33–37. doi: 10.1002/jctb.280540107.

Gerardi, M. H. (2003) *The Microbiology of Anaerobic Digesters*, *Vasa*. doi: 10.1002/0471468967.

Heyer, K. and Stegmann, R. (1998) ‘Leachate management : leachate generation , collection , treatment and costs’, pp. 1–23.

Ifeanyichukwu, M. J. (2008) ‘Water and Environmental Engineering’, *Lund University*, (April), pp. 1–77.

Karthikeyan, K. and Kandasamy, J. (2009) ‘Upflow Anaerobic Sludge Blanket (Uasb) Reactor in Wastewater Treatment’, *WATER AND WASTEWATER TREATMENT TECHNOLOGIES - Volume II*, pp. 180–198.

Kjeldsen, P. *et al.* (2002) ‘Present and Long-Term Composition of MSW Landfill Leachate: A Review’, *Critical Reviews in Environmental Science and Technology*, 32(4), pp. 297–336. doi: 10.1080/10643380290813462.

Kumar, A. M. S. (2013) ‘Effects of heavy metals as stress factors on anaerobic digestion processes and biogas production from biomass’, pp. 1383–1398. doi: 10.1007/s13762-012-0167-y.

Lettinga, G.; Rebac, S.; Parshina, S. . and Nozhevnikova, A.; van Lier, J. B.; Stams, A. J. M. (1999) ‘High-Rate Anaerobic Treatment of Wastewater at Low Temperatures’, *Applied and Environmental Microbiology*, 65(4), pp. 1696–1702.

Lettinga, G., Rebac, S. and Zeeman, G. (2001) ‘Challenge of psychrophilic anaerobic wastewater treatment’, *Trends in Biotechnology*, 19(9), pp. 363–370. doi: 10.1016/S0167-7799(01)01701-2.

Morling, B. S. (2007) ‘Composition , and Some Findings From Leachate Treatment At’, *Vann-2*, pp. 174–184.

Pauss, A. *et al.* (1990) ‘Liquid-to-Gas mass transfer in anaerobic processes: Inevitable transfer limitations of methane and hydrogen in the biomethanation process', *Applied and Environmental Microbiology*, 56(6), pp. 1636–1644.

Renou, S. *et al.* (2008) 'Landfill leachate treatment: Review and opportunity', *Journal of Hazardous Materials*, 150(3), pp. 468–493. doi: 10.1016/j.jhazmat.2007.09.077.

Selvam, S. B. *et al.* (no date) 'Performance of an Up-Flow Anaerobic Sludge Bed (UASB) Reactor Treating Landfill Leachate Containing Heavy Metals and Formaldehyde', pp. 0–6.

Sewwandi, B. G. N., S. S. R. M. D. H. R. Wijesekara, A. Rajapaksha, M. I. M. Mowjood and M. Vithanage. 2011. Risk of Soil and Water Pollution by Heavy Metals in Landfill Leachate. *In Proc. International Conference on Agricultural Engineering "Novelty, Clean and Sustainable".* Thailand, 31st March-1st April 2011: pp 43.

Sewwandi, B. G. N., (2014) 'Development of a Permeable Reactive Barrier to Treat Leachate from Municipal Solid waste Dumpsites in Sri Lanka' PhD thesis, Graduate School of Science and Engineering, Saitama University.

Singh, V. and Mittal, A. K. (1997) 'Applicabilit Y of Uasb Reactor for Leachate Treatment : a Case Study for Okhla Landfill'.

Yuzer, B., Akgul, D. and Mertoglu, B. (2012) 'Effect of High Ammonia Concentration on UASB Reactor Treating Sanitary Landfill Leachate', *Fen Bilimleri Dergisi*, 24(2), pp. 59–67.