A STUDY ON LEACHATE COD FRACTIONS FROM SEMI-AEROBIC LANDFILL

By

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LIST OF ABBREVIATIONS

Ag	=	Mercury
Al_2SO_3	=	Aluminium sulphate
$Al_2(SO_4)_3.18H_2O$	=	Aluminium sulphate 18-hydrate
ANOVA	=	Analysis on variance
Arg	=	Arginine
As	=	Arsenic
Asp	=	Aspartic acid
BOD_5	=	Biochemical oxygen demand
Ca	=	Calcium
Cd	=	Cadmium
CH_4	=	Methane
Co	=	Cobalt
COO^-	=	Carboxyl groups
CO_2	=	Carbon dioxide
COD	=	Chemical oxygen demand
Cr	=	Chromium
Cu	=	Copper
Da	=	Size unit
DAF	=	Dissolved air floatation
DO	=	Dissolved oxygen concentration
DOM	=	Dissolved organic matter
FA	=	Fulvic acid
Fe	=	Ferum
$FeCl_3.6H_2O$	=	Ferum chloride

Glu	=	Glutamic acid
H^+	=	Hydrogen ion
HA	=	Humic acid
Hg	=	Silver
H_2SO_4	=	Sulphuric acid
IBSB	=	Idaman Bersih Sdn. Bhd.
$LaCl_3$	=	Lanthanum chloride
Lys	=	Lysine
$MgCl_2$	=	Magnesium chloride
Mn	=	Manganese
MPSP	=	Majlis Perbandaran Seberang Perai
MSW	=	Municipal solid wastes
NaOH	=	Sodium hydroxide
NH_2	=	Amino
NH_3-N	=	Ammoniacal Nitrogen
Ni	=	Nickel
NTU	=	Nephelometric turbidity units
NUR	=	Nitrate ultilization rate
OUR	=	Oxygen utilization rate
PAC	=	Poly aluminium chloride
PAC	=	Powder activated carbon
Pb	=	Lead
PBSL	=	Pulau Burung sanitary landfill
PCOD	=	Particulate COD
S_{bi}	=	Biodegradable COD

S_{bpi}	=	Slowly biodegradable COD
S_{bsi}	=	Readily biodegradable COD
S_{fi}	=	Final total COD
S_{ui}	=	Unbiodegradable COD
S_{upi}	=	Unbiodegradable particulate COD
S_{usi}	=	Unbiodegradable soluble COD
S_{ti}	=	Total COD/Inial total COD
SCOD	=	Soluble COD
SS	=	Suspended solid
SV	=	Settled volume
SVI	=	Sludge volume index
TDS	=	Total dissolved solid
TKN	=	Total Kjeldahl nitrogen
TOC	=	Total organic carbon
T_bOD	=	Total biological demand
TS	=	Total solid
VSS	=	Volatile suspended solid
V_{tot}	=	Total volume of the reactor
V_{ww}	=	Volume of the wastewater
Y_h	=	Heterotrophic yield
Zn	=	Zinc
$Zn(OH)_2$	=	Zinc hydroxide
$ZnSO_4$	=	Zinc sulphate

KAJIAN TENTANG PECAHAN COD PADA LARUT LESAPAN DARI TAPAK PELUPUSAN SEMI-AEROBIK

ABSTRAK

Kajian yang dijalankan bertujuan untuk mengkaji sifat larut resapan dari tapak pelupusan sisa pepejal Pulau Burung (PBSL). PBSL adalah tapak pelupusan jenis semi-aerobik yang mengaplikasikan Kaedah Fukuoka dalam mengurangkan kuantiti metana dan meningkatkan kestabilan berbanding tapak pelupusan anaerobik. Kajian membandingkan dua jenis larut resapan iaitu jenis tua dan muda. Selain itu, kajian ini bertujuan untuk mendapatkan nilai dan kaedah yang sesuai dalam menganalisis nilai pecahan COD berikutan nilai COD yang signifikan sebagai parameter bahan pencemar. Pecahan COD mengandungi COD biodegradasi perlahan (S_{bpi}), COD biodegradasi segera (S_{bsi}), COD terlarut tak terbiodegradasi (S_{usi}) dan COD terampai tak terbiodegradasi (S_{upi}). Proses-proses yang terlibat dalam penentuan kaedah adalah penggumpalan, pengenapan, penapisan, kelompok dan pengudaraan. Data dianalisis menggunakan ANOVA satu hala. Hasil kajian mendapati, nilai COD terlarut adalah lebih tinggi berbanding COD terampai (larut resapan tua = 72.44% - 73%; larut resapan muda = 75.52% - 76%). Tiga kaedah fisiokimia digunakan dalam mendapatkan nilai pecahan COD iaitu Kaedah 1, Kaedah 2 dan Kaedah 3 berdasarkan kajian lepas. Kajian mendapati kaedah yang digunakan adalah berbeza secara signifikan dan Kaedah 1 merupakan kaedah yang sesuai dalam menentukan pecahan COD di PBSL. Larut resapan tua mengandungi, S_{bsi} = 0.51%, S_{usi} = 72.49%, S_{bpi} = 14.64% dan S_{upi} = 12.36%. Manakala, larut resapan muda menunjukkan, S_{bsi} = 1.83%, S_{usi} = 74.17%, S_{bpi} = 23.33% dan S_{upi} = 0.67%. Nilai pecahan COD mungkin dipengaruhi oleh faktor usia dan jenis tapak pelupusan.

A STUDY ON LEACHATE COD FRACTIONS FROM

SEMI-AEROBIC LANDFILL

ABSTRACT

The purpose of this research is to characterize leachate from Pulau Burung sanitary landfill (PBSL). PBSL is a semi-aerobic landfill which applies Fukuoka Method to reduce the amount of methane and enhance the stability of landfill compared to anaerobic types. This study compares two types of leachate, namely young and old. The study was carried out to determine the suitable method to determine the fractions of COD which has significant value as a contaminant parameter. The COD fractions include slowly biodegradable COD (S_{bsi}), readily biodegradable COD (S_{bsi}), soluble unbiodegradable COD (S_{usi}) and particulate unbiodegradable COD (S_{upi}). Few methods are applied in this research, such as coagulation, flocculation, filtration, batch method and aeration. The data obtained is evaluated using one-way ANOVA. The result from the COD fractionation shows that the soluble COD (old leachate = 72.44% - 73%; young leachate = 75.52% - 76%) has higher percentage compared to particulate COD. Three physicochemical methods namely Method 1, Method 2 and Method 3, which are adopted from the literature, are applied in the current study, to find the COD fractions. Comparison of these methods shows that they are significantly different, and Method 1 found to be the appropriate method to determine the COD fractions in PBSL. Results for COD fractions in old leachate show that, S_{bsi} = 0.51%, S_{usi} = 72.49%, S_{bpi} = 14.64% and S_{upi} = 12.36%. COD fractions in young leachate are obtained as, S_{bsi} = 1.83%, S_{usi} = 74.17%, S_{bpi} = 23.33% and S_{upi} = 0.67%. This research concludes that the factors may affecting the COD fractions are age and type of landfill.

CHAPTER I

INTRODUCTION

1.1 Background of Study

Generation of solid wastes in many countries is increasing every year. Ineffective management practices create a negative impact on the environment, human health and eventually on foreign investors and tourists and the health of the economy. In order to solve the problem of solid waste, the landfill technology was introduced. Besides, researchers tried to gain many ideas and innovations to improve solid waste management at landfill (Tatsi and Zouboulis, 2002).

Sanitary landfills are sites where waste is isolated from the environment until it is safe. It is considered when it has completely degraded biologically, chemically and physically. The difference between open dumping and sanitary landfill is that, in the latter, the wastes are adequately covered by soil everyday thereby reducing odours and adding excess vermin to the waste. The sanitary landfill method is widely used and accepted due to its economic advantages. Generally, this method offers lower cost of operation and maintenance (Chong et al., 2005).

There are many problems to maintain a landfill. One of the problems in the landfill is the generation of leachate which is generated when water passes through the waste (Kylefors et al., 2003). The discharge leachate from sanitary landfill could be a potential source of surface and groundwater pollutions (Aziz et al., 2004). Historically, most landfills were built without engineered liners and leachate collection system, which consequently could pose high risk to the groundwater. The major possible effects of leachate discharge to surface water are, reduction of oxygen in part of the surface water body, changes in the river bottom water living creature and ammonia toxicity (Kjeldsen et al., 2002); these issues can lead to serious environmental problems. Leachate from municipal solid waste site are often defined as hazardous and heavily polluted wastewaters although some of these pollutants can be degraded by microorganisms (Wang et al., 2002).

There are many methods for treating leachate, such as biological, physical and chemical treatments. These treatments are commonly applied as a single or in combinations. One of the most important factors is the feasibility study and the availability of these materials in the market price. Combinations of biological, physical and chemical treatments are usually used for an effective treatment (Kargi and Pamukoglu, 2003).

1.2 Pulau Burung Sanitary Landfill (PBSL)

The present research focuses on the leachate generated at the Pulau Burung Sanitary Landfill (PBSL) which is located at Nibong Tebal about 15 km from Universiti Sains Malaysia (USM) Engineering Campus. PBSL started operation as a dumping site (Level 2) which has been in existence before 1994 by establishing a controlled tipping technique in 1991. Then, the development for sanitary landfill (Level 3) began in 2001, which proposed infrastructure, and further upgraded by employing controlled tipping with leachate recirculation (Aziz et al., 2004).

It was developed in 2 phases. The first phase was 10 years old which represented a middle age landfill and produced ‘old leachate’ while the second (fresh) phase represented a new landfill which produced 'young leachate'. PBSL covers an area approximately 62.4 hactares and has been identified as a site for development of a sanitary landfill. This site is responsible in catering for the disposal of solid waste for the whole Penang covering areas in Majlis Perbandaran Seberang Perai (MPSP) as well as Majlis Perbandaran Pulau Pinang (MPPP) (IBSB, 2001).

PBSL is one of the semi-aerobic landfills in Malaysia, which uses semi-aerobic system managed by Idaman Bersih Sdn. Bhd (IBSB, 2001). Leachate from Pulau Burung is collected using collection pipes feed into the detention pond (Aghamohammadi et al., 2007). The leachate from PBSL is classified as standard B which refers to discharges outside catchment area by Environmental Quality (Sewage and Industrial Effluents) Regulations 2009, under the Environmental Quality Act 1974.

The previous studies on PBSL focused more on leachate treatment. For instance, Aziz et al. (2004) concluded that limestone had a potential as an alternative filter to remove iron (Fe) by physico-chemical treatment. Limestone could be used as replacement for activated carbon, based on economic value. The treatment using dissolved air floatation (DAF) was also investigated in this landfill by Palaniandy et al. (2010). Further, Halim et al. (2010) determined the ammoniacal nitrogen and COD removal from semi-aerobic landfill leachate using a composite adsorbent; the treatment employed fixed bed column adsorption.

1.3 Problem Statement

There are about 177 landfill sites in Peninsular Malaysia and 50% of the landfill is still practicing open dumping (Waste Not Asia, 2001). According to the Ministry of Housing and Local Government, Malaysia (MHLG, 1999), there were 77 open dumps, 49 controlled tipping landfills (level 1), and only 35 landfill sites including levels 2, 3, and 4. The results also show that the largest numbers of open dumps are in Sarawak, followed by Johor, Sabah and Kelantan.

In the late 1960s, Japanese scholar presented the concept of semi-aerobic landfill (Matsufuji, 2004). Pulau Burung is one of the three landfills in Malaysia, which uses semi-aerobic system applied from Fukuoka Method (Aghamohammadi et al., 2007). The semi-aerobic system enhances the quality of leachate by leachate collection and gas venting systems (Tang et al., 2008). The Pulau Burung landfill can receive 1600 tons of solid waste that can produce about 500 cm^3 volume of leachate everyday (Aziz et al., 2004).

The characteristics of landfill can usually be represented by the basic parameters COD, BOD_5, pH, ammoniacal nitrogen (NH_3-N), colour, suspended solids (SS) and heavy metals (Aziz et al., 2010). The different ages of landfill types also influence the characteristics of leachate (Calace et al., 2001). Generally, the treatment on landfill including PBSL tries to remove organic matters to make it suitable for reuse or discharging into natural water (Shon et al., 2007). COD is usually used as the main indicator of organic pollutants (Rodriguez et al., 2004). The knowledge on organic matter fractions (COD fractions) is important in identifying the suitable wastewater treatment process (Sophonsiri and Morgenroth, 2004; Eremektar et al., 2007; Dulekgurgen et al., 2006).

COD fractions consist of soluble COD (SCOD), particulate COD (PCOD), biodegradable COD (S_{bi}), unbiodegradable COD (S_{ui}), particulate slowly biodegradable COD (S_{bpi}), soluble readily biodegradable COD (S_{bsi}), soluble unbiodegradable COD (S_{usi}), and particulate unbiodegradable COD (S_{upi}) (Bilgili et al., 2008).

Therefore, the determination of COD fractions gains more information and important data that can be used for identifying the appropriate treatment. Characterization of leachate at these sites is very important as it may represent future landfill design and operations in Malaysia.

1.4 Objectives

This research focuses on characteristics of semi-aerobic leachate from Pulau Burung Sanitary Landfill, with the following objectives:

i. To determine the difference between young and old leachate characteristics from Pulau Burung Sanitary Landfill (PBSL).

ii. To determine composition of COD and its fractions in semi-aerobic leachate.

iii. To determine the suitable methods for fractionation of COD in semi-aerobic leachate.

1.5 Importance of Study

The literature data on Malaysia's leachate characteristics is limited and not focused on semi-aerobic leachate. This study may be useful in defining the suitable treatment based on leachate characteristics. The proper landfill management will enhance the quality of leachate. Hence, it is important to determine the characteristics of semi-aerobic leachate from Pulau Burung Sanitary Landfill (PBSL) for 'old' and 'young leachate' before choosing the significant treatments.

The characteristics that are analyzed for PBSL include, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), ratio of BOD_5/COD, iron (Fe), ammoniacal nitrogen (NH_3-N), suspended solid (SS), colour, turbidity and pH. However, the value of COD shows the highest value compared to other parameters. The fractionation of COD is important in identifying the potential treatments based on solubility and biodegradability of leachate (Huang et al., 2010).

1.6 Scope and Limitation of Study

This research was done by taking the leachate samples from PBSL that produced 'old leachate' and 'young leachate'. Both samples were analyzed to determine the characteristics of the leachate, such as Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), ratio of BOD_5/COD, iron (Fe), ammoniacal nitrogen (NH_3-N), suspended solid (SS), colour, turbidity and pH. Then, the samples were analyzed to find the COD fractions.

Determination of COD fractions is performed by physicochemical methods. The soluble COD (SCOD) in leachate from PBSL samples are determined by three methods, namely Method 1, Method 2 and Method 3. In Method 1, one ml of coagulant (0.6 M $ZnSO_4$) is mixed with the sample, and after coagulation and flocculation, filtration is performed using 0.45 µm membrane filter. In Method 2, the procedure is repeated with the optimum dosage (6 ml for old leachate and 5 ml for young leachate) of the coagulant. Method 3 involves only filtration process using 0.45 µm membrane filter, to separate the soluble and particulate fractions. Besides that, the aeration process is conducted to determine the biodegradable COD fraction. COD value is measured every hour until the constant value is achieved. Then, the value of biodegradable COD is applied on three different methods from literature reviews, to compare the significant data for this research in finding COD fractions.

1.7 Thesis Organization

Chapter I includes the background of study, information of Pulau Burung Sanitary Landfill (PBSL), problem statement, objectives, importance of study, and scope and limitations.

Chapter II will be discussing about background of solid waste management, landfill types, decomposition process in landfill, leachate, leachate characteristics and generations, treatment of leachate and relationship between leachate characterizations and treatments. Besides, the fractionation of COD will be introduced in this chapter.

Chapter III will discuss the methodology of this study in determining the COD fractions including soluble COD (SCOD), particulate COD (PCOD), biodegradable COD (S_{bi}), unbiodegradable COD (S_{ui}), particulate slowly biodegradable COD (S_{bpi}), soluble readily biodegradable COD (S_{bsi}), soluble unbiodegradable COD (S_{usi}), and particulate unbiodegradable COD (S_{upi}).

Chapter IV will show the results and discussions for this study. In this chapter, the characteristics of semi-aerobic leachate, which include Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), BOD_5/COD, iron (Fe), ammoniacal nitrogen (NH_3-N), suspended solid (SS), colour, turbidity and pH will be discussed. Besides that, the COD fractions also discussing based on the results.

The last chapter for this study is Chapter V which includes conclusions, and recommendations for future study.

CHAPTER II

LITERATURE REVIEW

2.1 Background of Solid Waste Management

Solid wastes became a serious issue for developed and developing countries owing to the increasing volume of municipal solid wastes (MSW) year by year (Castrillón et al., 2010). The total MSW collected and disposed is up to 95% worldwide. The generation of wastes increased rapidly in response to population and influence from urbanization and industrialization. However, waste density is higher in developing countries than in industrialized countries (Kurniawan et al., 2005).

MSW can be defined as materials such as garbage, old newspapers, packaging materials, yard wastes and others. Household wastes and any waste produced from a domestic source represent over two-third of the MSW. Household wastes include paint, garden pesticides, pharmaceuticals, photographic chemicals, certain detergents, personal care products, waste oil, heavy metals inside batteries, wood treated with dangerous substances, and waste electronic and electrical equipments (Slack et al., 2005).

Asian countries with greater rural populations produce more organic wastes such as kitchen wastes and fewer recyclable items such as paper, metals, and plastics. However, many cities in developing Asian countries face serious problems in managing solid wastes. The increasing of population and urbanization has become a challenge for the ultimate disposal of these solid wastes. Asian countries also reported problems with the existing landfill sites (Saeed et al., 2009).

Idris et al. (2004) concluded that, Asian countries showed a lack of proper waste characterization, waste stream analysis, landfill and dump site data. Most of the disposal sites are still open dumps and are managed poorly either by the local authorities or by other landfill operators. These problems will have negative short and long term impacts on the environment and the safety of the general public. It is likely that proper waste disposal will remain one of the most important environmental and health issues in the Asian developing countries.

The uncontrolled operating and design conditions and unsuitable location of deposit points reflect the high values for probability of contamination in landfill (Mendez et al., 2008). Improper waste management in typical landfill may pose environmental health risks that less than optimal. The chemicals concerned generate the exposure of hazardous agents such as methylene chloride, trichloroethylene, 1,2-dichloroethane, 1,1,2-trichloroethane, chloroethane, benzene, methyl mercaptan, ethyl mercaptan, hydrogen sulfide, iron, zinc and lead. The chemicals pollution on the landfill will increase the number of cancer effect (Moy et al., 2008).

Table 2.1 shows the waste composition from various countries in Asia including China, India, Indonesia, South Korea, Philippines, Turkey and Japan. This table concludes that organic matter contributes the highest percentage in all countries compared with other solid waste components. However, metals show the smallest percentage for solid waste contribution (Terazano et al., 2003).

Table 2.1: Waste composition from various countries in Asia

Component (%) / Country	Organic matter	Paper and cardboard	Plastics	Glass	Metals	Textile and others
China (Shanghai)	67.3	8.8	13.5	5.2	0.7	4.5
India	41.8	5.7	3.9	2.1	1.9	44.6 (textile 4.3)
Indonesia	70.2	10.9	8.7	1.7	1.8	6.2
South Korea	32.8	23.8	-	2.8[a]	-	40.6[b]
Philippines	49	19	17	-	6	9
Turkey (Istanbul)	43	7.8	14.2	6.2	5.8	23.1
Japan	34	33	13	5	3	12

(Source: Terazano et al. 2003)

[a]Including metals and ceramics
[b]Including ash

Zamali et al. (2009) discussed that the increasing population and urbanization growth became the main factor contributing the generation of MSW in Malaysia. Idris et al. (2004) showed that the value of MSW generation percapita varied between 0.88 and 1.44 kg/day, and generally assumed to be 1.0 kg/day. In year 2012, Kuala Lumpur was estimated to produce more than 4810.49 tons/day solid wastes (Saeed et al., 2009). The whole country produces around six million tons annually (Idris et al., 2004).

Table 2.2 (Saeed et al., 2009; Othman, 2006) shows that, organic waste has the highest percentage (56.80%) while plastics contribute 15.30% from the total composition of solid waste in Kuala Lumpur. Organic wastes usually include household materials. Institutional and industrial wastes can also contain significant proportions of organic waste. Organic waste is biodegradable and can be processed in the presence of oxygen by composting or in the absence of oxygen using anaerobic digestion (Huang et al., 2010).

Table 2.2: Comparison of solid wastes composition in the year of 2006 and 2009

Waste type	**Solid waste (% by weight)**	
	Kuala Lumpur (2009)	**PBSL (2006)**
Food waste/organic waste	56.80	49.26
Textile	1.30	5.96
Aluminium	0.10	0.72
Paper	16.50	8.16
Garden Trimming	-	8.94
Metal	2.40	0.82
Plastic	15.30	20.80
Wood	0.40	2.54
Glass	1.20	2.80
Rubber	0.60	-
Others	5.40	-
Total (%)	**100.00**	**100.00**

(Source: Saeed et al., 2009; Othman, 2006)

On the other hand, research was also done on Pulau Burung Sanitary Landfill (PBSL) in the year 2006 to characterize the solid waste in this landfill. Table 2.2 shows that food waste contributes 49.26% which is the highest composition while plastics contribute 20.80%, the second highest percentage (Othman, 2006). Generally, the amount of organic or food waste in landfill is increasing from year to year. In particular, the landfill in Malaysia still produces a large amount of organic waste or food waste which is more than 50% (Kathirvale et al., 2003).

2.2 Landfill

Landfilling is the most common waste disposal strategy for today and is expected to increase in developing countries due to the movement from open dumping to landfilling. It is also one of the waste management options for disposal of solid urban wastes. This method still is expected to be applied in the disposal of non-recyclable solid wastes and incineration residues (Lou and Nair, 2009).

The landfilling is the simplest, cheapest and most cost effective method in disposing wastes. These factors influence the choosing of landfill as solid waste management strategy in most countries. Landfill method will be accepted for a long period although other waste treatment options were developed, and recycling programmes were introduced in minimizing the volume of wastes for future (Bashir et al., 2010).

The impact of landfill process is that it generates hazardous materials such as leachate and methane gas which contribute to greenhouse gas emission (Themelis and Ulloa, 2007). Leachate is considered as contaminated liquid, highly variable and heterogeneous. The leachate contains organic hazardous substances. Moreover, according to Kargi and Pamukoglu (2003) and Kurniawan et al. (2005), high concentrations of ammonia were found in the leachate. Methane had a potential for global warming 23 times greater than same volume of carbon dioxide (Themelis and Ulloa, 2007).

Sanitary landfill is also defined as a land disposal site employing an engineered method to minimize the environment hazards. Besides, sanitary landfills have ability to minimize environmental insults and other inconveniences and allow most solid wastes to be decomposed under more or less controlled conditions until become stabilized materials (Tatsi and Zoubolis, 2002).

Malaysia has two classification systems for landfill sites. The first landfill classification system is based on the decomposition processes that occur in a landfill. These systems include anaerobic landfill, anaerobic sanitary landfill with daily cover, improved anaerobic sanitary landfill with buried leachate collection pipes, semi-aerobic landfill with natural ventilation and leachate collection facilities and aerobic landfill with forced aeration (Idris et al., 2004). In the second classification system, all the landfill sites in Malaysia are assessed and classified into four types: (1) dumping into water bodies; (2) open dumps; (3) controlled tipping (levels 1, 2, and 3 landfills); (4) sanitary landfill (level 4 landfills). According to the study of Latifah et al. (2009) 25% of landfill sites in municipal area and 59% in district area are open dumps.

2.3 Types of Landfill

Generally, landfill sites are categorized into three including anaerobic landfill, aerobic landfill and semi-aerobic landfill. All these landfill methods are used widely based on suitability and economic factors (Chong et al., 2005). Table 2.3 shows the differences between types of landfill decomposition process. The processes that occur in the landfill influence the characteristics of leachate in the landfill. Table 2.4 shows the comparison based on typical characteristics of anaerobic, aerobic and semi-aerobic landfills.

Table 2.3: The differences between types of landfill decomposition process

Types	Anaerobic	Aerobic	Semi-aerobic
Process	Five stages: aerobic, fermentation, acetogenesis, methanogenesis, oxidation	Aerobic conditions achieved by forcing air into waste mass	Passive drawing of air into waste mass due to temperature gradient
Temperature range	30–65 °C	Ideally 54–66°C (Read et al., 2001)	40–50 °C (Yoshida, 2005)
pH range	5–9 (7–8 during methanogenesis stage; ideally 6.8-7.5)	7.5–8.5:fewer acids are produced than in anaerobic landfill, as fermentaion reactions are limited	Ideally above ~8 (Aziz et al., 2010)
Timescale	Estimates vary from decades to millennia	2–3 years 4–5 years ; other attempts at estimates less successful	30 years (Chong et al., 2005)
Emissions	CO_2, CH_4, H_2O, trace pollutants	CO_2, H_2O, trace pollutants	CO_2, H_2O, trace pollutants

(Source: Rich et al., 2008)

Table 2.4: The typical characteristics of anaerobic, aerobic and semi-aerobic landfill leachate

Parameter	Anaerobic landfill[a]		Aerobic landfill[b]		Semi-aerobic landfill[c]	
	Range	Mean	Range	Mean	Range	Mean
pH	7.20-7.90	7.50	4.5-7.5	-	8.30-8.80	8.50
COD (mg/L)	7830-28120	14950	3000-60000	-	2533–2880	2860
BOD_5 (mg/L)	7720	4894	2000-30000	-	252–760	377
Conductivity (ms/cm)	32.20-67.20	43.47	-	-	-	-
Suspended solid (mg/L)	-	-	200-2000	-	78–80	79
Colour (PtCo)	-	-	-	-	4000–4560	4200
Zinc (mg/L)	0.34-0.60	0.44	-	-	2.06	2.06
Iron (mg/L)	2.72-12.62	7.40	50-1200	-	6.1–19	6.6
Ammoniacal nitrogen (mg/L)	1728-4998	2570	10-800	-	1188–1812	1400

(Source: [a]Imen et al., 2009; [b]Tchobanoglous et al., 1993; [c]Aghamohammadi et al., 2007)

2.3.1 Anaerobic Landfill

Anaerobic landfill is used to decompose the solid wastes as a conventional municipal method (Inanc et al., 2000). It consists of five stages such as aerobic, fermentation, acetogenesis, methanogenesis and oxidation processes, as configured in Table 2.3 (Rich et al., 2008). However, this landfill poses major environmental and health concerns because of the production of toxic leachate and methane. Methane produced from the methanogenesis process becomes the main landfill gas composition (Huang et al., 2008).

The anaerobic landfill shows the highest levels of all pollution parameters with high concentrations of COD, TOC, BOD_5, ammonia, phosphorus and alkaline metals in the leachate (Erses et al., 2008). Table 2.4 summarizes the similar characteristics of anaerobic leachate based on previous studies (Imen et al., 2009). Oxidation process in anaerobic landfill is lower compared with aerobic landfill. The decomposition process in anaerobic landfill is within 462 days while it is 70 days in the aerobic landfill (Erses et al., 2008). In addition, slow degradation of the waste mass preserves long-term risks to the landfill (Moletta, 2005).

2.3.2 Aerobic Landfill

Aerobic landfill technology has been evaluated over the last few years to rapidly stabilize and detoxify the waste, reduce methane gas, volatile organic compounds and odour emissions as well as eliminate off site leachate treatment needs (Cassu et al., 2003). Aerobic landfill method injects air into waste layers by using air blower in order to keep waste layers in aerobic conditions as shown in Table 2.3. This process enhances the biodegradation of waste and speeds up stabilisation of landfill. The recirculation of leachate combined with the injection of air not only promotes a higher rate of waste decomposition and settlement compared with leachate recirculation alone, but also decreases the production of methane gas (Matsufuji, 2004).

Erses et al. (2008) concluded that aerobic landfills were expected to reduce the cost for monitoring and leachate treatment due to rapid waste decomposition and low organic carbon. Aerobic landfill can be stabilized in a significantly shorter time frame compared with anaerobic conditions by providing the organic waste fractions the proper proportions of air and moisture. In an aerobic environment, respiring bacteria converts the biodegradable mass of the waste and other organic compounds to mostly carbon dioxide and water (Read et al., 2001).

Bilgili et al. (2007) and Huo et al. (2008) identified that aerobic reactor was more effective in removing ammonia content compared to anaerobic and semi-aerobic reactors. Table 2.4 shows that ammoniacal nitrogen range is 800-1000 mg/L which is the smallest range for ammonia content in landfill.

2.3.3 Semi-Aerobic Landfill

Japanese researchers have proposed a ‘‘semi-aerobic landfill’’ process. The semi-aerobic landfill type was developed through an aerobic landfill type experiment. Semi-aerobic landfill also known as Fukuoka Method and was developed as a joint project of Fukuoka City and Fukuoka University in the year 1966. Fukuoka method was first tested in the construction of Shin-Kamata Landfill in 1975. Pilot study of recirculatory semi-aerobic landfill system to Malaysia was started in 1990 (Matsufuji, 2004).

This system removes the leachate and gas continuously from the waste mass using leachate collection and gas venting system. The ambient air flows into the waste body naturally through the leachate collection pipes and subsequently improves the waste stabilization process. Since leachate is removed as quickly as it is formed, the internal waste layers have lower water content, increases the leachate quality and reduces the cost of final treatment of leachate (Aziz et al., 2010).

Semi-aerobic landfill has many advantages compared with other landfill types. The quality of leachate improves significantly and more rapidly than in anaerobic condition. Besides, the generation of methane is reduced thus contributing to the prevention of global warming which concluded that the production of CH_4 is about 23 times more than CO_2 in effect global warming (Themis and Uloa, 2007). Table 2.3 shows the similar results by Rich et al. (2008).

Research done by Huang et al. (2008) concluded that semi-aerobic landfill yielded carbon dioxide, oxygen and methane in the ranges 19-28%, 1-8%, and 5-13% respectively. The relations in variation of leachate quality, landfill gas and temperature showed that the semi-aerobic landfilling structure could speed up the landfill stabilization process. Sun et al. (2011) concluded that the semi-aerobic landfill could reduce the COD value rapidly compared to anaerobic landfill. Similar results also configured in Table 2.4.

Aziz et al., (2010) reported that the amount of methane gas (CH_4) in semi-aerobic landfill was less than conventional landfill types (anaerobic landfill). However, the amount of carbon dioxide (CO_2) from semi-aerobic landfill type was more than anaerobic landfill. It indicated that the amount of greenhouse effect gases might depend on landfill type. The maintenance cost of semi-aerobic is lower than aerobic type of landfill and it is cost effective as initial investment (Pang et al., 2008).

Figure 2.1 shows the differences between anaerobic and semi-aerobic landfill cross sectional areas (JICA, 2005). Anaerobic type only filled solid waste on the landfill and then covered by soil while semi-aerobic landfill had a leachate collection pipe to remove the leachate immediately and air injection to increase the stability of leachate (Huang et al., 2008).

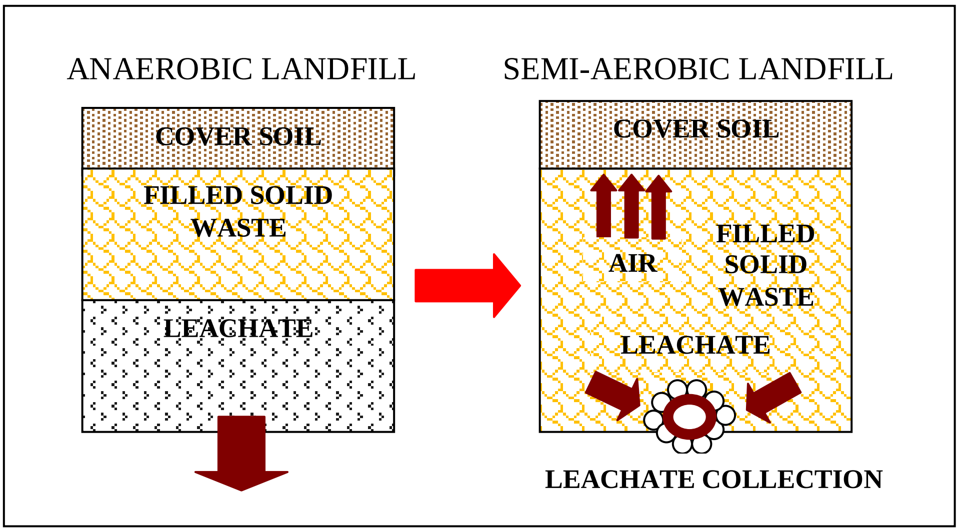

Figure 2.1: Different of an aerobic and semi-aerobic landfill cross sectional areas.
(Source: JICA, 2005)

2.4 The Decomposition Process in Landfill

The complex series of chemical and biological reactions occur at the landfill when wastes are buried into the landfill. Landfill at least undergoes with five phases of decomposition, such as initial adjustment phase (Phase I), transition phase (Phase II), acidogenic phase (Phase III), methane fermentation phase (Phase IV) and finally maturation phase (Phase V). Figure 2.2 shows the decomposition process in landfill (Tchobanoglous et al., 1993).

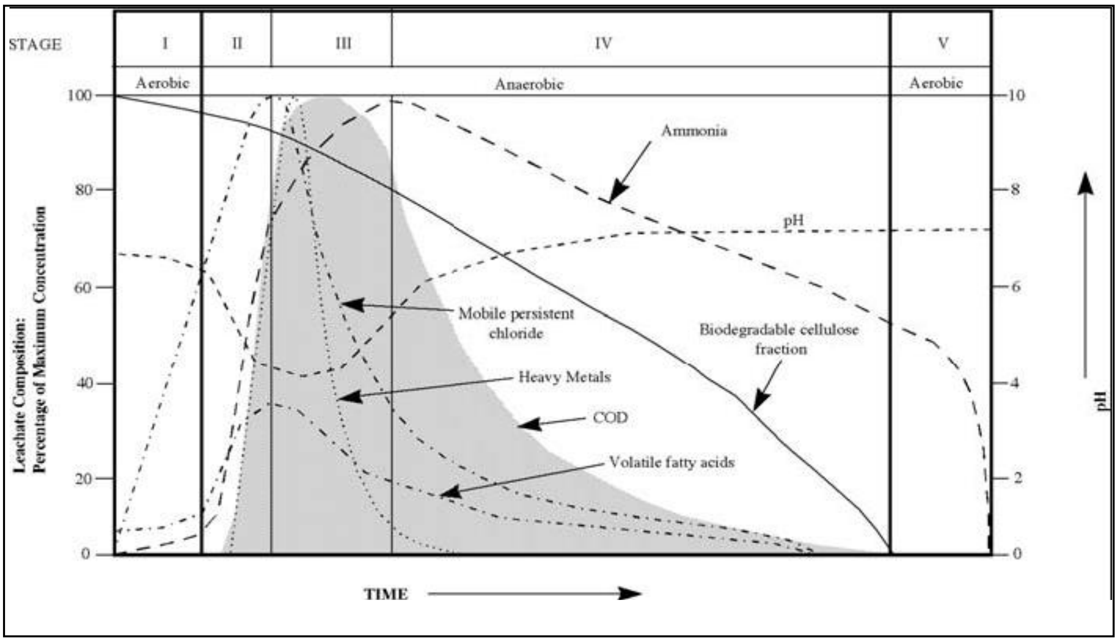

Figure 2.2: Leachate characteristics during decomposition process.
(Source: Tchobanoglous et al., 1993)

2.4.1 Initial Adjustment Phase

The initial adjustment phase occurs in aerobic condition where the organic biodegradable materials undergo microbial decomposition by using the amount of air trapped within landfill. In this phase, the amount of leachate generated is generally not substantial (William, 2005).

2.4.2 Transition Phase

Typically the leachate generated under aerobic conditions produces a complex solution in the early stage of decomposition of wastes in landfill. Microbial decomposition occurs in organic biodegradable components. The pH value is near to neutral pH. This stage can last for few days or few months depending on the oxygen present when the waste is disposed of in the landfill because oxygen is not replenished once the waste is covered (Salem et al., 2008).

The aerobic degradation produces heat, and the leachate temperatures can rise as high as 80-90°C. It can enhance the later stages of leachate production if the heat is retained. The leachate produced during this stage results from the release of moisture during compaction as well as short-circuiting of precipitation through the buried refuse (Kjelsen et al., 2002).

2.4.3 Acidogenic Phase

After the oxygen in landfill is used up, the landfill is turned to anaerobic stage. The early stage of anaerobic decomposition is known as acidogenic or acitogenic phase which develops high concentrations of soluble degradable organic compounds, and a slightly to strongly acidic pH. The strongly acidic pH in this phase is due to the development of CO_2 (Salem et al., 2008).

The pH of the leachate drops to 5 or below as the acidic leachate and organic acids are produced. Therefore, the heavy metals become soluble and the essential nutrients are removed from the leachate because of the decrease of pH of the leachate. Ammonium and metal concentrations also rise, and the complex molecules are degraded during this stage. It takes three to four months to become established, and the rate of landfill gas production will stabilize within one to two years (Rich et al., 2008).

2.4.4 Methane Fermentation Phase

Methanogenic conditions are established after several months or years and leachate becomes neutral or slightly alkaline. Methanogens are used to produce methane and carbon dioxide. Under a stabilized methanogenic condition, landfill gas is composed of approximately 55-60% methane and 40-45% carbon dioxide with trace amounts of other gases (He et al., 2005).

There are two types of bacteria, mesophilic and thermophilic, which consume carbon dioxide and acetate. Mesophilic bacteria lives in the temperature of between 30 and 35˚C while thermophilic bacteria lives in the temperature of between 45 and 65˚C. The reaction is very slow and takes long time. The advantage during the process is that the pH of leachate is estabilized of between 7 and 8. Therefore, the heavy metals in leachate decrease due to the changes in the pH of leachate. The longest stage of waste degradation depends on the level of water content and water circulation (Williams, 2005).

2.4.5 Maturation Phase

The aerobic conditions may return after the biodegradable waste is converted to carbon dioxide and methane gas. New aerobic microorganisms slowly replace the anaerobic forms, and aerobic conditions are re-established (William, 2005). Figure 2.2 illustrates the leachate characteristics during decomposition process in landfill.

2.5 Leachate

Landfill process generates a great amount of leachate. Leachate is defined as any liquid which seeps through the landfill or comes in contact with waste. Leachate is also a liquid formed from the percolation of water or other liquid through landfill waste (Wang et al., 2006). Leachate is considered to be a contaminated liquid, since it contains many dissolved, suspended materials, inorganic substances and high concentration of organic substances (Renou et al., 2008). Leachate may also carry insoluble liquids (such as oils) and small particles in the form of suspended solids (Salem et al., 2008)

Wang et al. (2002) concluded that, leachate contained many types of high quantities of pollutants like organic matters (biodegradable and non-biodegradable carbon), ammonia and nitrogen, heavy metals and non-organic salts. However, it could be noted that the principal pollutants in leachate were organics and ammonia nitrogen (Kulikowska and Klimiuk, 2008). The leachate had a strong odour, probably due to a high content of volatile fatty acids (Inanc et al., 2000). Siddique et al. (2010) reported that the smell of leachate was acidic and offensive and might be very pervasive because of hydrogen, nitrogen, and sulphur rich organic species such as mercaptans.

The decomposition of organic matter such as humic acid may cause the water to be yellow, brown or black. Humic matter contains probably at least 40 organic compounds with a complex chemical structure like a condensation product containing aromatic nuclei linked together with many functional groups (Zoubolis et al., 2004; Aziz et al., 2004). The humic substances contain humic acids and fulvic acids that are mainly produced by living organisms (Wang et al., 2010). Figure 2.3 shows the composition of organic matter (Berthe et al., 2008).

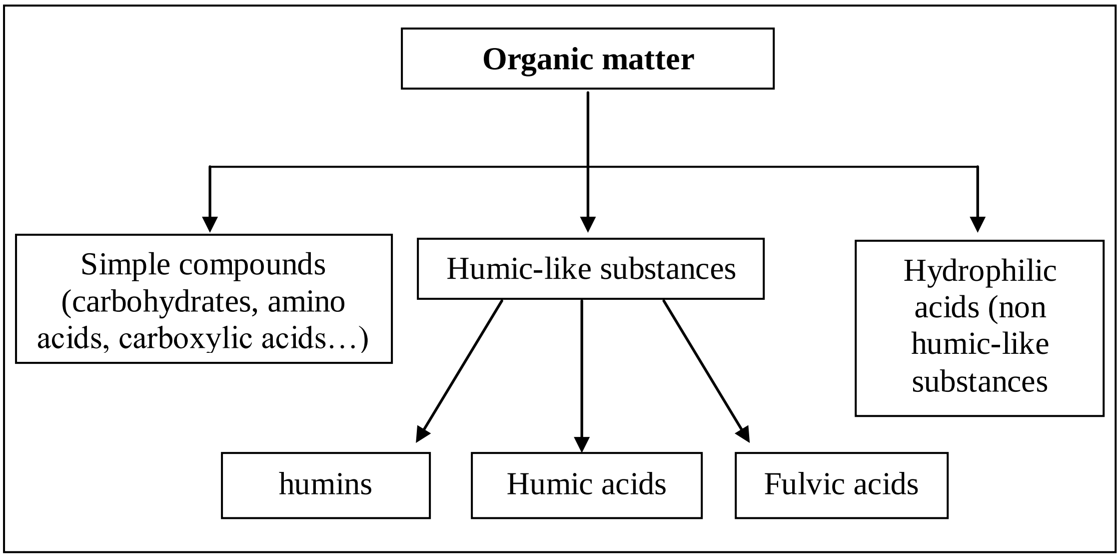

Figure 2.3: Composition of organic matter.
(Source: Berthe et al., 2008)

The fulvic acids have a lower molecular weight and a higher percentage of carboxylic groups than humic acids. It increases the hydrophilic characteristics. Humic acids are hydrophobic and have a high molecular weight. It shows a high metal complexing capacity and forms ‘micelle’-structure like a bonding of hydrophilic at the water side while hydrophobic is able to bind with pollutants (Worms et al., 2010). It could be concluded that fulvic acid could have a more important role in the mobility of pollutants in the environment based on molecular weight (Cabaniss et al., 2000).

The presence of humic substances in leachate might enhance the transportation of heavy metals (Wang et al., 2010). Wang et al. (2009) concluded that the presence of soil humic acids enhanced the adsorption of Pb (II) at low pH values but fulvic acids was shown to decrease the adsorption of Pb (II). Furthermore, the