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Penang Experience in Solid Waste Disposal by Semi-Aerobic Sanitary Landfill: Towards Achieving A Sustainable Development

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ABSTRACT

Municipal solid waste (MSW) disposal has become an ever-increasing problem in many part of the world, especially in the developing countries. Its management involves all aspects of storage, collection, transportation, processing, disposal of waste and the related management. This paper highlights the basic rule in solid waste management in particular discussions on the importance of adhering the waste management hierarchy in the overall management systems. Waste minimization strategies and technologies will be elaborated. Effective and current technology of collection systems will be shared. More focus will be given on the aspect of waste disposal as this is one of the main and common issues faced by many developing countries. For this, a concept of sustainable waste disposal by means of a semi-aerobic landfilling technology which is more environmental friendly, will be put forward as implemented in Malaysia. Local experience in effectively handling and treating the leachate up to the standard discharge limit will be discussed. The recovery of landfill gases for use as an energy resource has become the center of interest in recent years. In view of this, gas emissions data sampled at selected semi-aerobic landfill in Malaysia will be shared. The Clean Development Mechanism (CDM) approach in reducing greenhouse gas emissions for a developing country will also be highlighted. Some of the options for an integrated solid waste management system will be discussed. Selected model in developed countries will be elaborated and some of the key elements in achieving sustainable development in waste management will be discussed.

Keywords: integrated solid waste management, landfill, leachate, greenhouse gases

1.0 INTRODUCTION

Advances in environmental measurement techniques have been shown that the current demand on the earth's resources is not sustainable and needs addressing immediately. Solid waste is becoming a critical issue, not only in terms of the impacts being created but also in terms of resources being consumed [1]. Generally, only small portion of raw materials consumed will end up as product, the rest is waste in one form or another. The last 20 years, for example, has seen a substantial increase in the use of plastic packaging. Before this time many products such as foodstuffs were purchased loose or in reusable containers [2].

In general, solid waste may be defined as any material, solid, liquid or gas, that is unwanted and/or unvalued, and discarded or discharged by its owner [3]. Municipal solid waste (MSW) consists mainly of household waste and a range of other wastes such as trade waste and street sweepings. Household waste makes up about 85–90% of the total MSW content for the majority of local authorities in the UK [2]. The biodegradable organic matter contained in municipal solid waste (MSW) probably is one of the most problematic fractions to deal

with it is difficult to sort if mixed with the other fractions, it affects the performance of incinerators in terms of energy recovery and it is the cause of the long lasting emissions from sanitary landfills [4].

Solid waste management involves all aspects of storage, collection, transportation, processing, disposal of waste and the related management. It normally involves an integrated approach covering all of the above activities. It does not stop after collection only, but what needs to be done with the wastes is one of the important aspects in the whole management protocol .

Presently, Malaysia generated nearly 18,000 metric tonnes of solid waste daily. The per capita waste generation rate is between 0.7 and 1.2 kg/day, of which, only 76 percent is collected and disposed. The remaining is either disposed of illegally or is recycled. However, it is estimated at only 3-5 percent of the waste is actually recycled. Generation rate of solid waste is estimated to increase about 2 percent a year due to increase in population and economic growth of the country. An efficient and systematic disposal method is needed to avoid problems associated with this issue [5-7].

2.0 COMPOSITION OF SOLID WASTE

Composition is the term used to describe the components of waste that make up a solid waste stream and their relative distribution, usually based on percent by weight. The waste component have been strongly affected by social and economic factors, including population increases, consumption growth, changes in consumption patterns and the technological development of the waste treatment systems [8] . It also varies from one country to the other. The composition of solid wastes generated in Asian cities is shown in Table 1. The composition of solid wastes generated in Malaysia in 1995, 2001 and 2004 is shown in Table 2.

Kathirvale et al. (2003) determined the composition of solid waste which was collected from different sources (high, medium, and low-income residential households, institutional and commercial) of the area of Kuala Lumpur; the results are shown in Table 3 [9]. The result indicated that there is an obvious difference between the amount of organic wastes generated by the residential premises as compared with generation by the institutional and commercial sectors. The results also show that more than 85% of the wastes are organic wastes.

Table 1: Comparison of solid waste composition in different Asian cities

City	Waste composition (average percentage of wet weight)						
	organic	paper	Plastic	Glass	Metal	Textiles	others
Kuala Lumpur	68.4	6.4	11.4	1.4	2.7	1.5	7.8
Indonesia	74	10	8	2	2	2	2
Dhaka	70	4.3	4.7	0.3	0.1	4.6	16
Katmandu	68	8.8	11.4	1.6	0.9	3.9	5.3
Bangkok	53	9	19	3	1	7	8
Hanoi	50	4.2	5.5	-	2.5	-	37.7
Manila	49	19	17	-	6	-	9
India	42	6	4	2	2	4	40
Karachi	39	10	7	2	1	9	32

Source: [10, 11]

Table 2: Malaysian Solid Waste Composition

Waste composition	Percentage (% by weight)		
	1995	2001	2004
Organic/food waste	32.0	29.5	35.72
Paper	29.5	26.8	16.61
Textile/leather	3.4	3.9	5.1
Waste Yard and wood	7.0	13.6	13.85
Plastics	16.0	12.5	22.19
Rubber	2.0	1.9	0.89
Glass	4.5	2.7	3.2
Metals	4.3	1.9	2.44
Others	1.3	5.3	0.0
Total	100	100	100
Total compostable waste	71.9	73.8	71.28

Sources:[5-7]

Table 3: Average composition weight percentage of components in MSW generated by various sources in Kuala Lumpur.

Waste composition	Residential high income (%)	Residential medium income (%)	Residential low income (%)	Commercial (%)	Institutional (%)
Food	30.84	38.42	54.04	41.48	22.36
Mix paper	9.75	7.22	6.37	8.92	11.27
News print	6.05	7.76	3.72	7.13	4.31
High grade paper	0.0	1.02	0.0	0.35	0.0
Corrugated paper	1.37	1.75	1.53	2.19	1.12
Plastic (rigid)	3.85	3.57	1.90	3.56	3.56
Plastic (film)	21.62	14.75	8.91	12.79	11.82
Plastic (foam)	0.74	1.72	0.85	0.83	4.12
Pampers	6.49	7.58	5.83	3.80	1.69
Textile	1.43	3.55	5.47	1.91	4.65
Rubber	0.48	1.78	1.46	0.80	2.07
Wood	5.83	1.39	0.86	0.96	9.84
Yard	6.12	1.12	2.03	5.75	0.87
Clear glass	1.58	2.07	1.21	2.90	0.28
Colour glass	1.17	2.02	0.09	1.82	0.24
Ferrous	1.93	3.05	2.25	2.47	3.75
Non-ferrous	0.17	0.0	0.18	0.55	1.55
Aluminum	0.34	0.08	0.39	0.25	0.04
Batteries	0.22	0.18	0.0	0.29	0.06
Fine	0.0	0.71	2.66	0.0	0.39
Other organic	0.02	0.0	0.0	1.26	1.0
Other inorganic.	0.0	0.27	0.25	0.0	8.05
Others	0.0	0.0	0.0	0.0	6.97
Total	100	100	100	100	100

Source: [9]

3.0 INTEGRATED SOLID WASTE MANAGEMENT

Integrated solid waste management (ISWM) can be defined as the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals [12]. It can be used to develop a sustainable solid waste management system that is environmentally effective, economically affordable and socially acceptable for a particular region and its individual circumstances [1]. It also incorporates the waste management hierarchy by considering direct impacts (transportation, collection, treatment and disposal of waste) and indirect impacts (use of waste materials and energy outside the waste management system).

An ISWM approach is currently the most appropriate system for solid waste management. The management consists of the total waste management system whereby waste is managed from source to source (a cradle to grave approach). Apart from the waste treatment either by traditional methods or by innovative methods, ISWM also emphasizes waste minimization through waste recovery, reuse and recycle by improving the efficiency of the overall management system for all type of wastes, composting, incineration and landfilling.

4.0 WASTE MANAGEMENT HIERARCHY

A hierarchy (arrangement in order of rank) in waste management can be used to rank actions to implement programs within the community. The ISWM hierarchy is usually composed of source reduction, recycling, waste transformation/processing, and landfilling. Greater portion should be emphasized on source reduction and the least is for final disposal, as shown in Figure 1 [1].

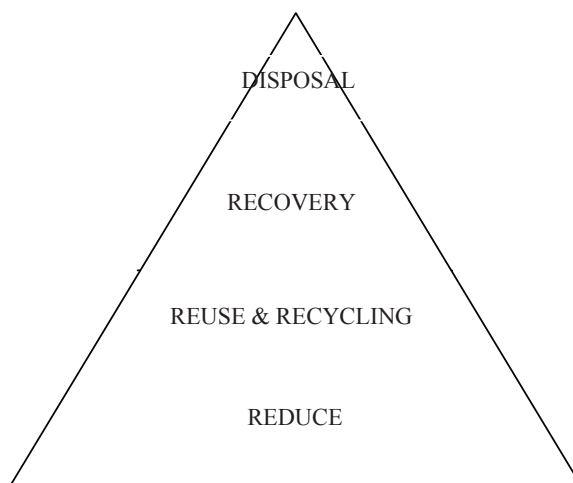


Figure 1: Waste management hierarchy

Source Reduction (Reduce): The highest rank of the ISWM hierarchy, source reduction (reduce), involves reducing the amount and/or toxicity of the wastes that are now generated. Waste reduction may occur through the design, manufacture, and packaging of products with minimum toxic content, minimum volume of material, or a longer useful life. Waste reduction may also occur at the household, commercial, or industrial facility through selective buying patterns and the reuse of products and materials.

Reuse and Recycling: The second highest rank in the hierarchy is reuse and recycling which involves (1) the separation and collection of waste materials; (2) the preparation of these materials for reuse, reprocessing, and remanufacture; and (3) the reuse, reprocessing, and remanufacture of these materials. Recycling is an important factor in helping to reduce the demand on resources and the amount of waste requiring disposal by landfilling.

Good recovery of recyclable items can be obtained by installing a Materials Recovery Facilities (MRF). This plant will separate all recyclable items in a systematic manner which then can be recovered and processed for new products. This will also extend the lifespan of the landfill.

A proper system with waste segregation is expected to improve the overall recycling process and increase the lifespan of the landfill. At the same time, campaign on 3R's (recover, reuse, recycle) should also be given a priority. The importance for residents to sort their waste at source should be emphasized. A proper recycling program needs to be worked out as soon as possible. Education is of paramount importance in the long run. Campaign on 3R's is very important and it is indeed a challenging task and can only be effective through education. This may take several years, but it should start as soon as possible. Residents will need to sort their waste at source. Facilities need to be provided. Measurement of success/failure will be necessary. With these 2 approaches (recycling at end-point through MRF and recycling through awareness), it is hoped that the recycling rate would be increased significantly in the near future.

Waste Processing/Transformation: The third rank in the ISWM hierarchy, waste transformation, involves the physical, chemical, or biological alteration of wastes. Typically, the physical, chemical, and biological transformations that can be applied to MSW are used (1) to improve the efficiency of solid waste management operations and systems, (2) to recover reusable and recyclable materials, and (3) to recover conversion products (e.g., compost) and energy in the form of heat and combustible biogas. The transformation of waste materials usually results in the reduced use of landfill capacity. The reduction in waste volume through combustion is a well-known example.

Disposal by landfilling: Ultimately, something must be done with (1) the solid wastes that cannot be recycled and are of no further use; (2) the residual matter remaining after solid wastes have been separated at a materials recovery facility; and (3) the residual matter remaining after the recovery of conversion products or energy. Landfilling, the fourth rank of the ISWM hierarchy, involves the controlled disposal of wastes on or in the earth's mantle, and it is by far the most common method of ultimate disposal for waste residuals.

5.0 LEGISLATION

As much as possible, the amount of waste to be disposed at landfill (especially the biodegradable components) should be minimized. Some countries have enacted various legislations for this. In Europe, European legislation requires a drastic reduction of the amount of biodegradable organic residues to be landfilled [4].

Landfill Directive was introduced in 1999, which set ambitious targets for the reduction of biodegradable municipal waste sent to landfill (European Parliament and Council Directive, 1999). Subsequently, waste targets for England and Wales were introduced in 2000 and 2002, respectively, which concentrated on recycling, composting and energy from waste (EFW) technologies for the recovery of municipal solid waste (MSW) [2]. The Landfill Directive (European Commission, 1999), the Directive 2000/76/EC on waste incineration (European Commission, 2000), the packaging and waste packaging Directive (European Commission, 2004) are the basis of the current European policy on waste [8]. Under the EU Landfill Directive, was adopted on 26 April 1999 and came into force on the 16 July 1999, the obligatory targets will mean that by 2010 the UK and other countries in the EU will have to reduce the biodegradable fraction of municipal waste sent to landfill to 75% of the 1995 level. Similarly, this will have to be further reduced to 50% by 2013 and to 35% by 2020. The Welsh Assembly Government published a National Waste Strategy for Wales 'Wise About Waste' in 2002, which seeks to ensure compliance with the European Directives on waste management. The targets state that by 2003/2004 a minimum 15% of MSW must be recycled/composted with a minimum objective for each category of 5%. The target then increases to 25% by 2006/2007 with a minimum objective for each category of 10%. The final target is set at 40% by 2009/2010 with a minimum objective for each category of 15%. [2].

In Malaysia, solid waste management is currently implemented through the use of four subsidiary laws which are the Local Government Act, 1976, Environmental Quality Act, 1974, Town and Country Planning Act, 1976 and the Streets, Drainage and Building Act, 1976. The most prominent institution involved currently in solid waste management is the Local Authorities. Consequently, in 1988 the Technical Section of the Local Government Department in the Ministry of Housing and Local Government in Malaysia initiated a proposal for a National Solid Waste Management Action Plan or also known as Action Plan for a Beautiful and Clean Malaysia (ABC). This year, the government has gazette 2 new legislation, namely The Solid Waste and Public Cleansing Management Act 672, 2008 and the Solid Waste and Public Cleansing Management Corporation Act 673, 2008.

6.0 DISPOSAL

Solid waste disposal is defined as the final placement of refuse that is not salvaged or recycled. Treatment and disposal of solid waste vary from one country to another and depend on various factors such as the type of waste, composition, infrastructure, land availability, labour, economic aspects, recycling strategy, public awareness and environmental impact. The aim of waste disposal is to remove the solid waste from the community as soon as possible, reduce its quantity, stabilised it and maintain the cleanliness.

The techniques used for waste management should have minimal impact on the environment. Ideally the disposal methods should be environmental friendly, cause no health hazard to the workers or public, economically, maximum recycling options and non-labour intensive. Waste management technology has evolved over time, varying with the type and complexity of waste generated. Waste disposal was practiced starting with the simple open dumps to the current sanitary and secure landfills with specialized liners, leachate collection and treatment systems, and fuel gas collection and utilization in place.

The main purpose of landfill disposal is to dispose and stabilise the solid waste. Besides that, it is also used to make it hygienic through proper storage of waste by which waste is decomposed and stabilised through natural processes. In old days landfills were nothing more than a place where one stored wastes. However, it has been realised that a landfill also performs purification function in the sense that it is the place where waste decomposes and achieves a level of stability. This process is enhanced by the environment. When it occurs in the presence of oxygen (aerobic), the process is faster.

6.1 TYPE OF LANDFILL

Even with implementation of waste reduction, recycling, and transformation technologies, disposal of solid waste in landfills still remains an important component of an integrated solid waste management strategy. Sanitary landfill or control tipping is one of the methods of waste disposal without treatment or direct disposal that is practiced in Malaysia. Landfilling is the primary means of disposal of municipal solid waste will continue to be so for at least 10-15 years to come.

Most of the existing solid waste landfill sites in developing countries are practicing either open dumping or controlled dumping. Proper sanitary landfill concepts are not fully implemented due to technological and financial constraints. Implementation of a fully engineered sanitary landfill is necessary and a more economically feasible landfill design is crucial, particularly for developing countries. The amount of waste continues to increase in response to rapid population increase and accelerated urbanization and industrialization. Like most developing countries, solid waste landfill sites in Malaysia are mostly practicing either open dumping or controlled dumping because proper sanitary landfill concepts are not fully implemented due to technological and financial constraints

Types of landfill can be broadly classified as detailed in Table 4.

Table 4: Classification of Landfill

Classification	Explanation
Anaerobic landfill	Solid wastes are filled in digged area of plain field or valley. Wastes are filled with water and in anaerobic condition
Anaerobic sanitary landfill	Anaerobic landfill with layers of solid wastes and cover material like sandwich shape. Condition of solid waste is the same as anaerobic landfill.
Improved anaerobic sanitary landfill (Improved sanitary landfill)	This has leachate collection system at the bottom of the landfill site. Others are the same as anaerobic sanitary landfill. The conditions are still anaerobic and moisture content is much less than anaerobic sanitary landfill.
Semi-aerobic landfill	Leachate collection duct is bigger than the one of improved sanitary landfill. The opening of the duct is surrounded by air and the duct is covered with small crushed stones. Moisture content in solid waste is small. Oxygen is supplied to solid waste from leachate collection duct.
Aerobic landfill	In addition to the leachate collection pipes, air supply pipes are attached and air is forced to enter the solid waste by which condition becomes more aerobic than semi-aerobic landfill.

Source: [13]

6.1.1 ANAEROBIC LANDFILL

Anaerobic landfill system is the common system to degrade and decompose solid waste [14]. However, the system may give potential bad impacts to the environment and health problem because it produces toxic pathogens and also the production in significant quantities of methane and carbon dioxide which contribute to the global warming phenomenon.

Figure 2 to 4 show the cross-sections of an aerobic landfill, anaerobic sanitary landfill and an improved anaerobic sanitary landfill respectively [15].

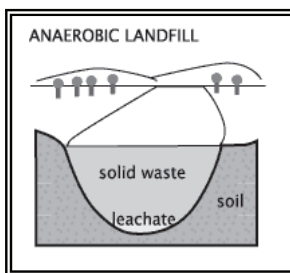


Figure 2: Anaerobic Landfill

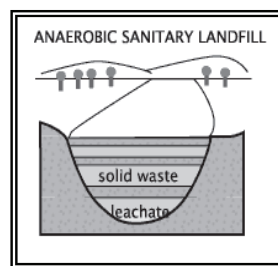


Figure 3: Anaerobic Sanitary Landfill

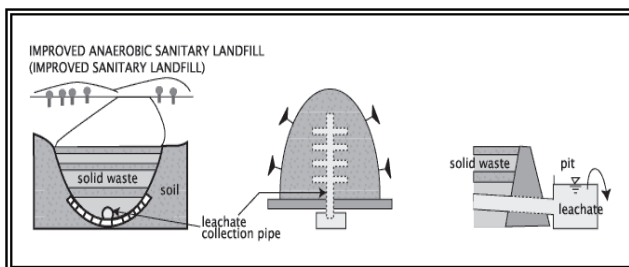


Figure 4: Improved Anaerobic Sanitary Landfill

The main problems of an anaerobic landfill include high concentration of leachate which is difficult to be treated and to comply with standard discharge limits, emissions of green house gases (mainly CH₄ and CO₂) and problem of fires.

6.1.2 SEMI-AEROBIC LANDFILL

The Fukuoka method semi-aerobic system was developed more than 20 years ago at the Fukuoka University but it is not widely known to many countries around the world. It is a proven technology practically tested in many places in Japan, and in a few developing countries such as Malaysia, Iran and China.

Generally, semi-aerobic landfill is designed with piping system underneath the landfill. The function of leachate collection pipe is to allow the air to flow in and out from the solid waste. Leachate collection pipes are provided to allow access of air from the atmosphere to the waste mass in the landfill. The pipes are designed to permit the passive movement of air through the headspace of the pipes which are open to the atmosphere. The collection pipes are capable of drawing large amounts of air by natural convection to supply oxygen to the decomposition microorganisms for decomposition of waste. The semi-aerobic landfill allows inflow of air through leachate collection pipes laid at the bottom of the landfill, which helps to enlarge aerobic parts, to make aerobic bacteria active, and increase the rate of waste decomposition. Then these actions make the leachate quality better by lowering the level of leachate concentration, and reducing the generation of hazardous gases, all of which lead to faster stabilization of the landfill site. A semi-aerobic system can be achieved through a convection process [16].

Following this method, a leachate recirculation system sometimes is incorporated when applicable, where the leachate collected is recirculated by using a pump from the top into the waste layers. The waste mass plays a role as a natural filter medium for the leachate and subsequently improves the leachate quality after each round of recirculation. The mechanisms and concepts used in the semi-aerobic system are illustrated in Figures 5 to 7.

In Malaysia, the implementation of semi-aerobic landfilling began in 1988, and the results have shown significant improvements in the leachate quality. The Fukuoka method semi-aerobic landfill concept can be implemented in developing countries under many circumstances for different purposes; these include developing a new landfill site, upgrading an existing landfill site or proper closure of a completed landfill site .

There are two disposal sites in Seberang Perai Municipal namely Ampang Jajar Landfill Site (AJLS) and Pulau Burong Landfill Site (PBLs). Both used to be an open dumping/controlled tipping sites since 1989. They cause various environmental problems such as fires and bad odours in their vicinities. The site was constantly burning and emitting smoke for more than six months every year. From 1989 to 1991, MPSP has upgraded the AJLS to a semiaerobic site (Level III) with the assistance from JICA. The concept was developed in Japan and it has been claimed that it is more efficient than anaerobic landfill in terms of leachate, BOD and COD reductions. Leachate from the AJLS was collected in integrated collection systems connected to a retention ditch. The leachate in the retention ditch is aerated and then recirculated to the landfill through gas-venting facilities and collection pipes. Vent pipes were packed with stones through which the recirculated leachate trickles. The packed stones serve as an anaerobic system and as a medium for microorganisms.

Pulau Burong landfill site (PBLs) is also a waste disposal site adopting a semi-aerobic landfill system. The landfill operation at the site began in August 2001, and completed for two-sections at the end of 2007. The semi-aerobic landfill system, which has been adopted in

many sites in Japan, is an effective system for early stabilization of landfill sites and improvement of their environments. It was found that the leachate from a semi-aerobic system has slightly lower organic contaminants compared with an anaerobic landfill in terms of BOD and COD [17, 18]. The green house emissions will finish faster than the anaerobic landfill, hence reducing the risk of fire. The other advantage is that the settlement will be faster (1 m in 2 years), hence extra volume of landfill can be attained over time.

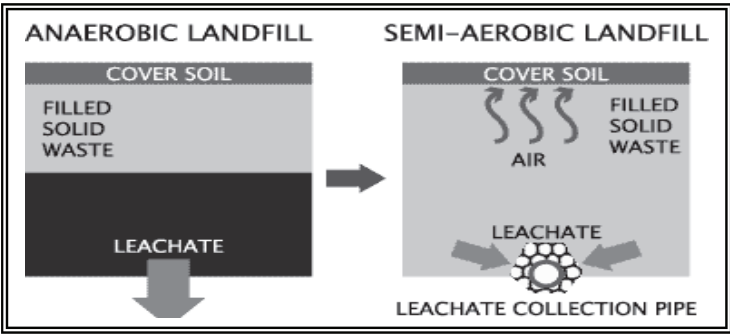


Figure 5: Difference between cross sectional areas of anaerobic and semi-aerobic landfills.



Figure 6 : Design of semi-aerobic landfill [14]

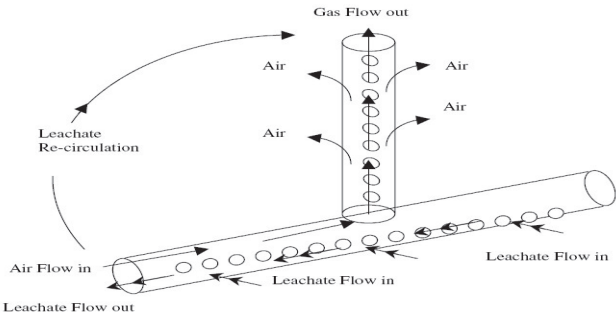


Figure 7: Cross section of semi-aerobic landfill [16]

6.2 LEACHATE

Leachate is a contaminated liquid that contains a number of suspended solids and with a high organic and inorganic content. The infiltration of rainfall, and surface water into a landfill coupled with biochemical and physical breakdown of wastes produces a liquor or 'leachate'. The discharge of landfill leachate can lead to serious environmental problems, since the leachate contains a large amount of organic matter (both biodegradable and non-biodegradable carbon), ammonia-nitrogen, heavy metals, chlorinated organic and inorganic salts.

The composition of landfill leachates can vary depending on the nature of the landfilled solid wastes, the active microbial flora, characteristics of the soil, the rainfall patterns and the age of the landfill. Young landfill leachates are usually treated more easily than old ones.

6.2.1 LEACHATE COMPOSITION

Landfill leachates are difficult to characterize because their compositions and concentrations depend on a variety of factors, such as soil type, waste composition, degree of compaction, rainfall, evapotranspiration, and landfill type and age [19-22]. In general, leachate production depends on the reactions and microbial activities in the waste [23]. Concentration of eluted matter will be the highest within 3-5 years when biological decomposition is the most active. It is generally recognized that mature leachates contain relatively low concentrations of degradable organic material but high levels of N-NH₃, up to 5000 mg/l. Such high N-NH₃ levels, together with enormous quantities of leachates, have posed a serious pollution threat to the water environment, and the removal of N-NH₃ has become a critical issue of leachate treatment.

Leachate contains various organic materials (biodegradable and non-biodegradable carbon, humic acids and fulvic acids) and the inorganic material such as colloidal, heavy metals and non-organic salts for example, sodium, calcium, sulphate, ammonia and high concentration toxics [12, 21, 24, 25]. The pollutant produced from the solid waste depends on the physical, chemical and biological processes [26].

Amokrane *et al.* (1997) presented different characteristics of landfill leachate correlated to the age of landfill which is listed in Table 5 and 6. Moreover, they classified the landfills as young (<5 years old), medium (5-10 years old), and old landfills (>10 years old) [27]. According to this classification, generated leachate falls into three categories: biodegradable, intermediate, and stabilized leachate, respectively. Landfill leachates from old sites are usually highly contaminated with ammonia resulting from the hydrolysis and fermentation of nitrogen containing fractions of biodegradable refuse substrates. Leachate from young landfills contains high dissolved solids content as well as high concentration of organic matter compared to domestic wastewater [27].

The characteristics of leachate from various countries are given in Table 7. The characteristics of leachate from Pulau Burung semi-aerobic landfills in Penang and other landfill sites in Malaysia are given in Table 8 and 9. This table shows decreasing in COD, COD/TOC ratio, BOD₅/COD ratio, and TOC percentage, but increasing in pH, as a result of an increase in the age of landfill.

The biodegradation of leachate is different with age of landfill. Biodegradation can also be determined by ratio of BOD₅: COD [12]. Usually, the ratio of BOD₅: COD is 0.5 or more. If the ratio is between 0.4 and 0.6, it shows that organic matter in leachate has been

biodegraded. For old landfill, the ratio of BOD₅: COD is between normally 0.05 to/and 0.2. The stabilized leachates from sanitary landfills are characterized by high concentrations of recalcitrant organic matter (BOD₅/COD < 0.1). A significant proportion of recalcitrant material (>60% of TOC) comprises humic substances, mainly humic acids [28]. A further proportion is made up of synthetic compounds: aliphatic, aromatic, phenolic and alicyclic compounds (acids, alkyls, with the substitution of nitrogen and halogen), and phosphate ester are among the organic pollutants frequently detected [29]. Humic substances are natural organic matter made up of complex structures of polymerized organic acids, carboxylic acids, and carbohydrates [30].

In general, the beginning of rain increases the concentration of pollutants in leachate because of the wash-out effect of organic material in waste. The pollutants concentration of leachate start to decrease during rainy season because leachate is diluted by rain water and the addition of humidity will increase the activities of microorganisms and waste decomposing bacteria [21].

Table 5: Characteristics of landfill leachate correlated to age of landfill [27]

Landfill age Leachate type	<5 years (young) Biodegradable	5-10 years (Medium) Intermediate	>10 years (old) Stabilized
pH	<6.5	6.5-7.5	>7.5
COD (g/L)	>10	<10	<5
COD/TOC	<2.7	2.0-2.7	>2.0
BOD ₅ /COD	<0.5	0.1-0.5	<0.1
% TOC	>70	5-30	<5

Table 6: Typical data on the composition of leachate from new and mature landfill

Constituents (*mg/L)	New Landfill (less than two years)		Mature landfill (greater than ten years)
	Range	Typical	
BOD ₅	2 000 – 30 000	10 000	100 – 200
TOC	1 500 – 20 000	6 000	80 – 160
COD	3 000 – 60 000	18 000	100 – 500
Total Suspended Solids	200 – 2 000	500	100 – 400
Organic Nitrogen	10 – 800	200	80 – 120
Ammonia Nitrogen	10 – 800	200	20 – 40
Nitrate	5 – 40	25	5 – 10
Total Phosphorus	5 – 100	30	5 – 10
Ortho Phosphorus	4 – 80	20	4 – 8
Alkalinity as CaCO ₃	1 000 – 10 000	3 000	200 – 1 000
pH	4.5 – 7.5	6	6.6 – 7.5
Total Hardness as CaCO ₃	300 – 10 000	3 500	200 – 500
Calcium	200 – 3 000	1 000	100 – 400
Magnesium	50 – 1 500	250	50 – 200
Potassium	50 – 1 000	300	50 – 400
Sodium	200 – 2 500	500	100 – 200
Chloride	200 – 3 000	500	100 – 400
Sulphate	50 – 1 000	300	20 – 50
Total Iron	50 – 1 200	60	20 – 200

Source: [12]

* Unit in mg/L except for pH

6.2.2 Leachate treatment

Leachate should be treated properly before discharging into the environment. Discharging of untreated leachate can cause adverse impact on aquatic life and water quality. Treatment of such leachate with a conventional water treatment system i.e. a combination of sedimentation, biological treatment, filtration and carbon adsorption cannot remove salts nor can it remove certain organics such as recalcitrant harmful compounds [42].

The variation of leachate properties has become main difficulty in designing leachate treatment system [12, 43]. For example, leachate with high concentration of dissolved solids (> 50000 mg/L) is difficult to treat with biological method. Leachate with high value of COD cannot be treated with aerobic method because it will involve high cost [44]. Therefore, it is important to design solid waste landfills systematically and provide facility such as leachate detention pond. Leachate from solid waste degradation process will be collected in detention pond.

The specific composition of leachates determines its relative treatability. Combinations of physical, chemical and biological methods are usually used for effective treatment of landfill leachate since it is difficult to obtain satisfactory effluent water quality by using any one of these methods alone [45]. Furthermore, [46] emphasized that because of the variety in leachate quality from site to site which depends on age of landfill, neither biological treatment nor physical-chemical treatment processes separately are able to achieve high treatment efficiency. A combination of both types of treatment is one of the more effective process trains for the treatment of leachate. They are designed as modular, multi-stage units capable of coping with the changing leachate characteristics over the years [35]. Several processes drawn from wastewater and drinking water technology have been applied for the treatment of landfill leachates, such as anaerobic and/or aerobic biological degradation, chemical oxidation, coagulation-precipitation, activated carbon adsorption, photo-oxidation and membrane processes [19, 25, 47]. Physical-chemical processes are needed for the pretreatment of young leachate to make it amenable to biological treatment, and to hydrolyze some refractory organic compounds found in leachate from older landfills. Biological treatment is primarily used to stabilize degradable organic matter found in young and middle aged leachates.

Table 7 : Compositions of landfill leachate in various countries. Units in mg/L, except, age and BOD/COD ratio

Parameter	Kanada ^a	Uruguay ^b	Turki ^c	Korea ^d	Greece ^e	Malaysia ^f	Turki ^g	China ^h	Thailand ⁱ	India ^j	Hong Kong ^k
	Montreal	Morvideo	Kamuruoda	Kyungjoo	Thessaloniki	Taman Beringin	Istanbul	Shenzhen Xiaping	Nonthaburi	Chennai	Pillar Point
Age(year)	N.D.	N.D.	N.D.	N.D.	N.D.	16	6	2	20	16	6
pH	5.7	8.0	7.5	7.3	6.2	7.8 – 8.7	6.2-8.4	7.8	8.1-8.5	7.3-9.3	8.1-8.6
Alkali	3463	9280	9720	6700	12880	3750-9375	3800-13040	N.D.	1140-5800	N.D.	10700-11700
COD	12760	18550	21500	24400	70900	1960-5500	5850-47800	13040	8800-17600	71-5100	2460-2830
BOD ₅	5000	10500	13150	10800	26800	562-1990	3500-28500	3220	800-1800	3-207	N.D.
BOD ₅ /COD	0.39	0.57	0.61	0.44	0.38	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SS	1440	N.D.	1720	N.D.	950	420-1150	670-2720	250	150-746	N.D.	40-53
VSS	364	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Total P	<0.05	17	2.7	31.2	167	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
TKN	218	1640	2410	1766	3400	104-1014	1550-3590	N.D.	154-2540	N.D.	2219-2860
NH ₃ -N	179	1470	2160	1682	3100	2-47	N.D.	2090	N.D.	N.D.	1190-2700
Sulphate	N.D.	91	N.D.	162	1600	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Chloride	N.D.	3280	3320	3160	3260	875-2875	725-8500	N.D.	3600-4200	119-5856	2320-2740
Fe	N.D.	41	61	76	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Ni	N.D.	N.D.	N.D.	N.D.	N.D.	0-0.6	0.16-4.6	0.39	0.2-0.66	1.05	N.D.
Cd	N.D.	N.D.	N.D.	N.D.	N.D.	0-0.15	1.0	0.01	0.001	0.001-	N.D.
Pb	N.D.	N.D.	N.D.	N.D.	N.D.	0.345	0.78	0.08	0.06	0.009-	N.D.
										0.645	

Source: ^a [31], ^b [32], ^c [33], ^d [34], ^e [35], ^f [36], ^g [37], ^h [38], ⁱ [39], ^j [40], ^k [41]
 N.D. – No Data

Table 8 : Characteristics of of Pulau Burung Sanitary landfill (June 2005-June 2007)

Parameter	Minimum	Maximum	Average	Standard B*
BOD ₅ (mg/L)	70	100	85	50.0
COD (mg/L)	1950	2480	2120	100
BOD/COD	0.02	0.35	0.13	0.5
pH	8.15	8.5	8.25	5.5-9.0
SS (mg/L)	165	225	185	100
Ammonia (mg/L)	1150	1280	1189	-
Colour (Pt.Co)	3200	3420	3310	-
Turbidity (NTU)	100	160	125	-
Oil & Grease (mg/L)	3	41	10.7	10.0
Zinc (mg/L)	0.05	0.15	0.1	2.0
Manganese (mg/L)	0.1	0.5	0.3	1.0
Ferum (mg/L)	2.8	8.6	5.3	5.0
Chromium (mg/L)	0.02	0.04	0.03	0.05
Nickel (mg/L)	0.35	0.68	0.42	1.0
Copper (mg/L)	0.1	0.3	0.2	1.0
Cadmium (mg/L)	0.08	0.3	0.18	0.02
Lead (mg/L)	0.01	0.02	0.02	0.1

* Standard B, Environmental Quality Act 1974, Sewage and Industrial Effluent, Regulations, 1979

Table 9: Characteristics of leachate from MSW landfills of different age [36]

Component	First 1.3 L/ft ³	6-9 months	Air Hitam landfill 1½ yrs (March 98)	Beringin landfill 15 yrs (March 98)
COD		20000-40000	5370-7040	2050-5230
BOD	21700-30300	10000-20000	1560-1800	560-1520
TSS			1090-1250	670-1050
pH	6.0-6.5	5.6-5.7	7.6-7.9	8.07-8.50
Total organic C		5000-10000	1614-1694	1380-2070
NH ₄ -N	0.22-480	400-700	2-8	2-23
NO ₃ -N	-	<0.1-0.1	-	-
Conductivity (mS/cm)	-	-	7.6-7.9	8.07-8.50
Hardness as CaCO ₃	890-7600	-	315-317	430-720
Alkalinity as CaCO ₃	730-9500	-	8800-9000	4380-7580
Ca ²⁺	240-2330	-	48-48	63-166
Mg ²⁺	64-410	-	47-48	34-81
Na ⁺	85-1700	600-900	3040-5660	4200-5640
K ⁺	28-1700	600-900	720-1820	1660-1940
Fe, total	6.5-220	60-200	9-10	7-9
Ferrous ion	8.7-8.7	-	-	-
Cl ⁻	96-2350	900-1100	2000-2200	1450-2250
Sulphate	84-730	1700-1900	19-20	66-70
Phosphate	0.3-29	-	21-22	9-24
Total-N	-	-	131-140	104-630
Organic-N	2.4-465	-	-	-

Concentration range in mg/L except pH and conductivity (mS/cm)

The contents of pollutants also depend on the type of landfill [20]. The pollutant content is higher at anaerobic landfill. This is because, slow reaction of waste degradation happens at anaerobic landfill. Young leachate has high content of volatile fatty acids and their salts such as acetate (Ac⁻), propionate (Pr⁻) and butyrate (Bu⁻), compared to old leachate [48]. According to Tatsi *et al.*, (2003), young leachate has low pH value and high pollutant, especially organic matters compared to old leachate [35]. The concentrations of COD and BOD in young leachate are in the range of 44000 – 115000 mg/L and 9500 – 80800 mg/L, respectively. On the other hand, the concentration of COD and BOD in old leachate is between 700 – 1500

mg/L and 50 – 4200 mg/L. Leachate from mature landfills is less contaminated since the pH moves slightly from acid to neutral over time and the ratio of BOD/COD is also decreased [49]. An example of the BOD levels over years is shown in Figure 8.

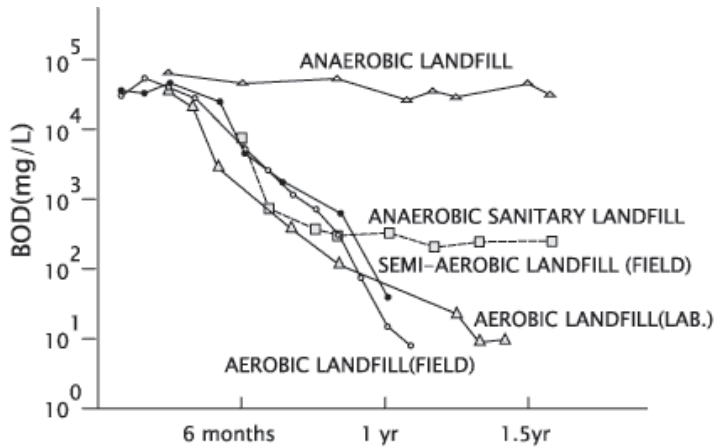


Figure 8: Change in the BOD concentration of Leachate by Landfill Type[14]

A summary of leachate treatment options is given in Table 10-12.

Table 10: Treatment efficiency of some leachate treatment processes with landfill age for removal leachate organic content [27]

Processes	Treatment Efficiency		
	Biodegradable leachate	Intermediate leachate	Stabilized leachate
Biodegradation	Good	Fair	Poor
Chemical oxidation	Fair-poor	Fair	Fair
Chemical precipitation	Fair-poor	Fair	Poor
Activated carbon	Fair-poor	Good-fair	Good
Coagulation-Flocculation	Fair-poor	Good-fair	Good
Reverse osmosis	Fair	Good	Good

Table 11: Summary of Leachate Treatment Method [14]

Treatment Method	BOD	COD	Leachate component			
			SS	T-N	Colour	Heavy Metals
Activated Sludge Process	B	M	S	S	S	S
Contact Aeration Process	B	M	S	S	S	S
Rotary Bio-disk Conductor Process	B	M	S	S	S	S

Biological Trickling Process	B	M	B	S	S	S
Biological Nitrogen Freeing Process	B	M	S	B	S	S
Flocculation/Sedimentation	M	B	B	S	B	M
Sand Filtration	S	S	B	N.A.	S	N.A.
Activated Carbon	B	B	M	N.A.	B	M
Ozone Oxidation	N.A.	M	N.A.	N.A.	B	N.A.
Chelates	N.A.	N.A.	N.A.	N.A.	N.A.	B
N.A.: Not Applicable	B: Big effect	M: Medium effect	S: Small effect			

Table 12: Leachate treatment options [12]

Treatment process	Application	Comments
Biological processes		
Activated sludge	Removal of organics	Defoaming additives may be necessary; separate clarifier needed
Sequencing batch reactors	Removal of organics	Similar to activated sludge, but no separate clarifier needed; only applicable to relatively low flow rates
Aerated stabilization basins	Removal of organics	Requires large land area
Fixed film processes (trickling filters, rotating biological contactors)	Removal of organics	Commonly used on industrial effluents similar to leachates, but untested on actual landfill leachates
Anaerobic lagoons and contactors	Removal of organics	Lower power requirements and sludge production than aerobic systems; requires heating; greater potential for process instability; slower than aerobic systems
Nitrification/denitrification	Removal of nitrogen	Nitrification/denitrification can be accomplished simultaneously with the removal of organics
Chemical processes		
Neutralization	pH control	Of limited applicability to most leachates
Precipitation	Removal of metals and some anions	Produces a sludge, possibly requiring disposal as a hazardous waste
Oxidation	Removal of organics; detoxification of some inorganic species	Works best on dilute waste streams; use of chlorine can result in formation of chlorinated hydrocarbons
Wet air oxidation	Removal of organics	Costly; works well on refractory organics
Physical operations		
Sedimentation/flotation	Removal of suspended matter	Of limited applicability alone; may be used in conjunction with other treatment processes
Filtration	Removal of suspended matter	Useful only as a polishing step
Air stripping	Removal of ammonia or volatile organics	May require air pollution control equipment
Steam stripping	Removal of volatile organics	High energy costs; condensate steam requires further treatment
Adsorption	Removal of organics	Proven technology; variable costs depending on leachate
Ion exchange	Removal of dissolved inorganics	Useful only as a polishing step
Ultrafiltration	Removal of bacteria and high molecular weight organics	Subject to fouling; of limited applicability to leachate
Reverse osmosis	Dilute solutions of inorganics	Costly; extensive pretreatment necessary
Evaporation	Where leachate discharge is not permissible	Resulting sludge may be hazardous; can be costly except in arid regions

*Adapted from Ref. 43.

6.2.3 PENANG EXPERIENCED

Currently, domestic and municipal solid waste in Malaysia and many parts of the developing countries is disposed at designated dumping ground, either as controlled

tipping or by open dumping. Very limited number of properly designed landfill is available to date. Most of the landfills do not have leachate treatment facilities. Leachate from this improperly designed landfill may pollute our environment, especially the surface and groundwater. Ammoniacal nitrogen, metals, colour and COD in leachate are among the parameters of concern at landfill sites. USM team has also focused in research on the removal of metals, COD and colour from leachate which was not well documented and to date there have been no studies being carried out in Malaysia. In case of ammoniacal nitrogen, slow leaching of wastes producing nitrogen and no significant mechanism for transformation of N-NH₃ in the landfills resulted in high concentration of N-NH₃ in leachate over a long period of times. Currently, the removal of ammoniacal nitrogen from leachate was not well documented and to date, there were limited studies on this aspect especially in adsorption treatment. The USM key researchers have investigated the suitability of activated carbon, limestone and a mixture of both materials as a filtering medium, in combination with other treatments capable of attenuating ammoniacal nitrogen which is present in significant quantity (between 429 and 1,909 mg/L) in one of the landfill sites in Malaysia. The results of the study show that about 40% of ammoniacal nitrogen with concentration more than 1,000 mg/L could be removed either by activated carbon or its mixture with limestone at mixture rate 5:35 [50, 51] (Figure 9). This result shows that limestone is potential to be used as a cost-effective medium to replace activated carbon for ammoniacal nitrogen removal at considerably low cost. Experimental data shown in this chapter are on the treatability study conducted on leachate obtained from Pulau Burung Landfill Site (PLBS) and Ampang Jajar Landfill Site (AJLS) in Penang, Malaysia.

In terms of metals, iron (Fe) for example, was found in significant quantities at the landfill site. USM key researcher has established the Fe isotherm and breakthrough time of the limestone filter for post-treatment of Fe to the migrating landfill leachate before its release to the environment. Results indicated that 90% of Fe can be removed from the leachate based on retention time of 57.8 minutes and surface loading of 12.2 m³/m².day [51]

Colour in leachate is also one of the problems normally faced by landfill operators. USM researchers have conducted research on the suitability of activated carbon, limestone and a mixture of both materials as a filtering medium, capable of attenuation colour which is present in significant quantity (between 3,000 and 4,000 Pto) in one of the landfill sites in Malaysia. The adsorption isotherms were established and the breakthrough time was calculated. Results of the study show that more than 80% colour with an intensity up to 4,000 Pto could be removed using limestone with a quantity above 20 mL (equivalent to 56 g). The adsorption phenomenon has contributed to the removal process. For a filter bed of 2.25 m² and 2 m depth, as much as 3156 m³ of leachate can be treated for about 32 days with a leachate flow rate of 100 m³/day. The media usage rate is about 33 kg/day or 3.3 kg/m³ [6, 18, 51, 52]

USM team has also developed the treatment system consists of a combination of biological and physical-chemical treatment of leachate in which the latter plays a very significant role in removing organic matter and heavy metals. The treatment system has been examined in the laboratory and in the field and proven capable of removing all constituents in the leachate up to the standard level as compared to the conventional treatment system. The design was based on comprehensive laboratory studies with supporting field model conducted at various landfill sites in Malaysia, namely Ampang Jajar and Pulau Burung in Penang, Jabi in Kedah, Puchong in Selangor, Kamunting in Perak, etc. [6, 52]. Ampang Jajar Sanitary Landfill and Pulau Burung Sanitary Landfill in Seberang Perai being the first landfill with leachate

collection facilities in Malaysia has resulted in various researches related to landfill such as leachate characterization and its treatment.

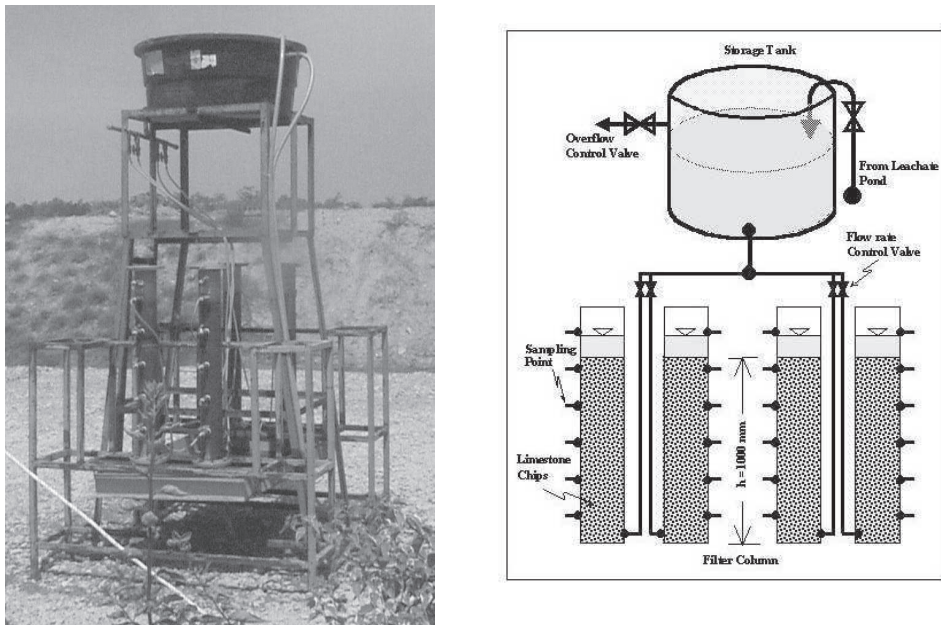


Figure 9: Filtration study in the field

Basically, the plant consists of the several operational units (Table 13). The result shows that limestone can be used as a cost-effective medium to replace activated carbon for the removal of metals, colour, ammonia and COD at considerably low cost. The basic design parameter such as the loading rate, isotherm, retention and breakthrough times for design purpose was developed. The first treatment plant in this region using this media is now in operation in one of the landfill sites in Malaysia, and capable to comply to Standard B of the Environmental Quality Act.

Table 13: Treatment stages for leachate

Treatment stage	Objective
Primary sedimentation tank	to settle flocs formed from aeration basin ahead of the sedimentation tank and able to remove BOD and COD
Filtration using limestone	To remove metals and turbidity/suspended solids
Filtration using activated carbon	To remove colour, BOD and COD and remaining metals
Filtration using zeolite	To remove colour, BOD and COD and remaining metals
Filtration using USM Media (ZELIAC)	To remove colour, BOD and COD and remaining metals
Water gallery	For balancing the flow
Rapid mixer/coagulation	Chemical treatment to further remove remaining BOD, COD and suspended solids. Neutralization of pH.
Single stage of flocculation	
Sedimentation tank	To settle flocs from coagulation and flocculation stage for further remove remaining BOD, COD and suspended solids

Coagulation flocculation process has been studied and applied to semi-aerobic landfill leachate at Pulau Burung Landfill Site (PBLs) in Penang, Malaysia for removing colloidal particles. Suspended solids and turbidity are the main parameters of concern at this landfill. Three types of coagulants were examined, i.e., ferric chloride, ferric sulfate and aluminum

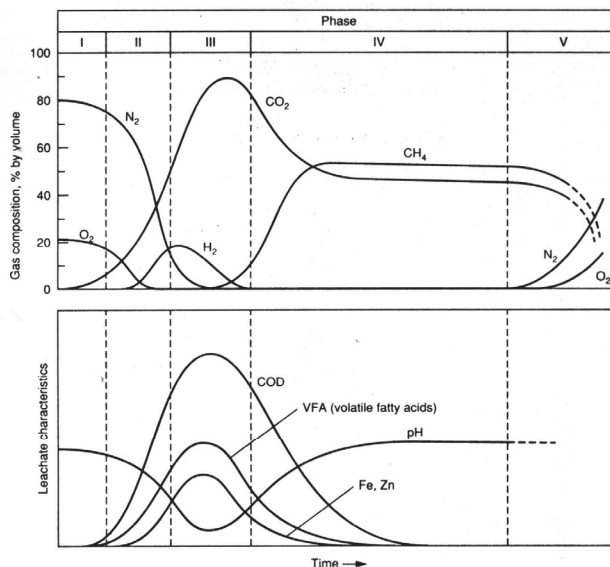
sulfate. Ferric chloride has exhibited good performance in removing suspended solids, COD and colour from leachate as compared to the other coagulants, namely alum and ferric sulphate. At an optimum pH of 4 and 12, ferric chloride removed over 90% of suspended solids and colour at 500-600 mg/L dosage of coagulant, and between 30-50% COD at 1000 mg/L dosage of coagulant. The amount of coagulant can be reduced to 500 mg/L for COD removal with addition of 250 mg/L of tapioca starch as coagulant aid (Alias, et.al., 2004). The effluent from the treatment process complied with Standard A of the Malaysian Environmental Quality Act 1974. The removal performance is shown in Table 14 and 15.

6.3 LANDFILL GAS

Many people assume that once solid wastes are in the ground, they just stay there in their original state. After solid wastes are deposited in a landfill, physical, chemical, and biological processes modify the waste. Almost all materials (other than metals and some synthetic materials such as plastic), undergo some form of break-down. This break-down is due primarily to biological activity within the waste, although chemical and physical processes do assist in breaking down the waste. Biological reactions in landfills involve the organic material of municipal solid waste that produce landfill gases and liquids (leachate). Initially the reactions are aerobic and gradually turn to anaerobic as the available oxygen is depleted. The principal gas produced in aerobic decomposition is CO₂. In anaerobic decomposition, CO₂, CH₄ and trace amounts of NH₃ and H₂S are produced.

6.3.1 GAS PRODUCTION

There are five phases of biological process in landfill area. The processes are Phase I: initial adjustment phase, Phase II: transition phase, Phase III: acid phase, Phase IV: methane fermentation phase and Phase V: maturation phase, as shown in Figure 10. Flow rate and characteristics of leachate changes from time to time because of these processes. Aerobic and anaerobic degradation occur along these processes [12, 22]. Typical constituents found in MSW landfill gas is given in Table 16 and 17.



Generalized phases in the generation of landfill gases (I = initial adjustment, II = transition phase, III = acid phase, IV = methane fermentation, and V = maturation phase). (Adapted from Refs. 13, 34, 37, and 38.)

Figure 10: Biodegradation phases in landfill [12]

Table 14: Removal performance of leachate treatment plant at Pulau Burung Landfill Site, Penang

Main Parameters	Inf. (mg/L)	After aeration		After lime stone filter		After Zeolite filter		After activated carbon		After Coagulation and Flocculation (PAC)		Compliance Status *
		Removal, %	Eff., mg/L	Removal, %	Eff., mg/L	Removal, %	EFF. (mg/L)	Removal, %	EFF. (mg/L)	Removal, %	EFF. (mg/L)	
Colour (PtCo)	3500	25	2625	25	1969	56	866	95	43	85	7	Complying Std. (100 ADMI)
NH ₄ -N	1500	43	855	30	600	96	24	45	13	60	5	Complying Std. (5 mg/L)
COD	2500	40	1500	25	1125	45	619	75	155	85	23	Complying Std. (400 mg/L)
Fe	15	20	12	95	0.6	87	<0.1	85	<0.1	70	<0.1	Complying Std. (5 mg/L)

Table 15: Removal performance of leachate treatment plant at Pulau Burung Landfill Site, Penang using new USM Media (ZELLIAC)

Main Parameters	Inf. (mg/L)	After aeration		After new Media filter 1		After new Media filter 2		New Media filter 2 (Not required)		Coagulation and Flocculation (Not required)		NOTE
		Removal, %	Eff., mg/L	Removal, %	Eff., mg/L	Removal, %	Eff., mg/L	Removal, %	Eff., mg/L	Removal, %	Eff., mg/L	
Colour (PtCo)	3500	25	2625	94	158	94	9	-	-	-	-	No Standard
NH ₄ -N	1500	40	900	88	108	88	13	-	-	-	-	No Standard
COD	2500	40	1500	92	120	92	10	-	-	-	-	Complying Std. A (50 mg/L)
Fe	15	20	12	99	0.12	99	<0.01	-	-	-	-	Complying Std. A (1 mg/L)

Table 16: Typical constituents found in MSW landfill gas [12]

Component	Percent (dry volume basis)
Methane	45-60
Carbon dioxide	40-60
Nitrogen	2-5
Oxygen	0.1-1.0
Sulfides, disulfides, mercaptans, ect.	0-1.0
Ammonia	0.1-1.0
Hydrogen	0-0.2
Carbon monoxide	0-0.2
Trace constituents	0.01-0.6

Table 17: Percentage distribution of landfill gases observed during the first 48 hours after the closure of a landfill cell [12]

Time interval since cell completion, months	Average, percent by volume		
	Nitrogen, N ₂	Carbon dioxide, CO ₂	Methane, CH ₄
0-3	5.2	88	5
3-6	3.8	76	21
6-12	0.4	65	29
12-18	1.1	52	40
18-24	0.4	53	47
24-30	0.2	52	48
30-36	1.3	46	51
36-42	0.9	50	47
42-48	0.4	51	48

Monitoring done at PBLs (semi-aerobic landfill operated since 2001) and AJLS (semi-aerobic landfill operated since 1989) indicated that the PBLs is still not fully operated as a semi-aerobic landfill as compared to the AJLS. The results are given in Table 18. This is probably due to the fact that stacking the waste on soft ground has caused subsidence of the ground. Drainage and vent pipes may have also affected by this subsidence.

Table 18: Gas monitoring data at PBLs and AJLS, monitored between November 2007 and March 2008.

LANDFILL	GASSES						
	CH ₄ (%)	CO ₂ (%)	CH ₄ /CO ₂	O ₂	CO (ppm)	H ₂ S (ppm)	Temperature (°C)
PBLs	56.7	41.4	1.37	0.2	0.5	140	44.3
AJLS	5.4	6.7	0.81	9.0	0	7.7	48.7

6.3.2 CLEAN DEVELOPMENT MECHANISM (CDM)

The threat of global climate change is also a serious issue and a driving force for changes in MSW management systems in many countries to reduce greenhouse gas emissions. Many opportunities exist for greenhouse gas (GHG) emissions reduction in MSW management systems [30]

The Clean Development Mechanism (CDM) is one of two so-called project-based flexible mechanisms under the Kyoto Protocol (Article 12), which permits projects that reduce greenhouse gas emissions to allocate the carbon reductions to companies in developed countries. CH₄ and CO₂ are among the GHGs regulated by the Kyoto Protocol. While CH₄ has a shorter lifetime in the atmosphere than CO₂ it is a much more powerful absorbent of heat radiation. The global warming potential (GWP), a measure of the contribution to global warming over a certain time period by a given mass of a GHG, uses a relative scale, which compares the gas in question to CO₂ (whose GWP is one) (Intergovernmental Panel on Climate Change, 2001). The GWP100 of CH₄ is 21, which thus represents that CH₄ is a 21 times more powerful GHG than CO₂ per mass unit over a 100 year period. GHG emissions are commonly reported in terms of CO₂e which is determined by multiplying the amount (in mass units) of emissions of a particular gas by the GWP of the gas.

If CH₄, that would otherwise have been released to the atmosphere, is recovered and oxidised, CO₂ is emitted instead of CH₄. Considering the stoichiometry of the reaction, the GWP100s and the molar masses of CH₄ and CO₂, respectively, oxidisation of this CH₄ reduces the climate impact by approximately 87%. A few options of GHGs gas conversion include:

- (i) The recovered CH₄ is oxidised and thus not emitted,
- (ii) CO₂ formed through CH₄ oxidisation is emitted, and
- (iii) Heat recovered from CH₄ oxidation may be used to generate useful heat and/or electricity, which in turn might displace heat and/or electricity from another source, whereby an indirect result could be some degree of avoided fossil fuel combustion.

For the case of Malaysia, there are three factors concerning indicators of sustainable development, which are environment, economy and sociality. Application of CDM in involves conversions of existing anaerobic landfills to a semi-aerobic landfill. The process will benefit in terms of:

- (i) Generations of gasses such as CH₄, CO₂ and H₂S from the landfill site will be reduced and the burden on the environment will be lightened.
- (ii) Risks of explosion and toxic gas generation at the landfill will be eliminated.
- (iii) Since the drainage of leachate will be improved, the aerobic area will be expanded, degradation of wastes will be promoted and the impact of the leachate on the surrounding environment will be lessened.
- (iv) Safe closure of the landfill site can be achieved at an early stage.
- (v) The post-closure landfill site can be utilized for forests, park development, etc. at an early stage.

Item (i) is the most significant as it is intended to suppress greenhouse effect through reduction of the ratio of CH₄ generated from the landfill site to curb its emission itself by improving the landfill site in an anaerobic condition to a semi-aerobic condition. The CHG emission from the present landfill site can be estimated using the equation presented in UNFCCC/CCNUCC Annex 14.

Based on the waste disposal rate of 1200 ton/day, and the present waste composition, conversion of anaerobic landfill to semi-aerobic condition, the GHG emission is

expected to be reduced from nearly 100,000 t-CO_{2e} to about 70,000 t-CO_{2e} the first year, and reduced from nearly 20,000 t-CO_{2e} to about 13,000 t-CO_{2e} after 10 years in the tenth year.

However, just as the Kyoto targets have led to measures that can support waste management in developed countries, developing countries can benefit through the clean development mechanism (Article 12 of the Kyoto Protocol). The Kyoto credit scheme developed by the UNFCCC and the more mature EU ETS provides the mechanisms for exchange and, in principle, provides a more economically efficient way to reduce GHGs gas.

6.3.2 GAS CONTROL

There are a few options of gas control in landfill.

Perimeter Gas Extraction Trenches. Perimeter extraction trenches are usually installed in native soil adjacent to the landfill perimeter. They are typically used for shallow landfill disposal sites with depths of 25 feet or less. The trenches are gravel-filled and contain perforated plastic pipes that are connected through laterals to a collection header and centrifugal suction blower. Extraction trenches can extend vertically down from the landfill surface to the depth of the solid waste or to groundwater and can be further sealed on the surface with a membrane liner. The suction blower creates a zone of negative pressure in each trench, which extends toward the solid waste. Landfill gas migrating into this zone is drawn into the perforated pipe and collection header, and subsequently vented or flared at the blower station. Flow adjustments can be made via control valves at each trench.

Perimeter Air Injection Wells (Air Curtain System). Perimeter air injection wells consist of a series of vertical wells installed in natural soils between the limits of the solid waste landfill and the facilities to be protected against the intrusion of landfill gas. Air injection wells are typically installed near landfills with solid waste depths of 20 ft or more in areas of undisturbed soil between the landfill and the potentially affected properties.

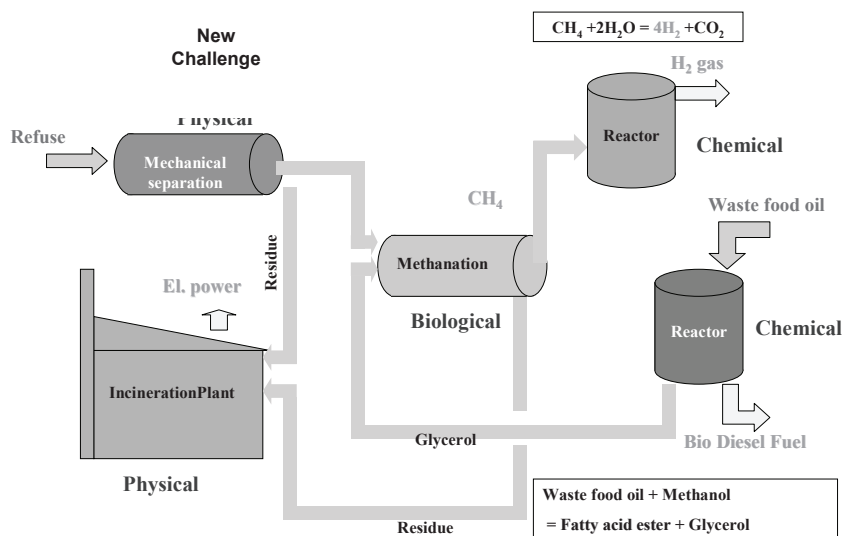
Active Control of Landfill Gas with Vertical and Horizontal Gas Extraction Wells

Both vertical and horizontal gas wells have been used for the extraction of landfill gas from within landfills. In some installations both types of wells have been used. The management of the condensate that forms when landfill gas is extracted is also an important element in the design of gas recovery systems.

Vertical Gas Extraction Wells. A typical gas recovery system using vertical gas extraction wells is illustrated in Fig. 11-21. The wells are spaced so that their radii of influence overlap. For completed landfills without gas recovery facilities, the radius of influence for gas wells is sometimes determined by conducting gas drawdown tests in the field. Typically, an extraction well is installed along with gas probes at regular distances from the well, and the vacuum within the landfill is measured as a vacuum is applied to the extraction well. Both

7.0 SUSTAINABLE WASTE MANAGEMENT IN OTHER COUNTRIES

There are a few options of sustainable waste management in developed countries. One of the best model is in Japan where a combination between physical, chemical and biological system is incorporated in the overall management system, as shown in Figure 11.



Physical– Chemical– Biological Treatment System

Figure 11: Future integrated waste management approach in Japan

Source: Prof. Nobuo Takeda, Kyoto University (Personal Communication, 2006)

8.0 CONCLUSIONS

Sustainable waste management system requires full compliance to the waste management hierarchy in the overall management systems, either in developed or developing countries. Education is one of the key factors that influence the success/failure of any waste minimization programme. This should begin from early age. Appropriate syllabus can be incorporated in the primary school curriculum. Campaign on 3R's is very important and it is indeed a challenging task and can only be effective through education. This may take several years, but it should start as soon as possible. Good recovery of recycleable items can be obtained by installing Materials Recovery Facilities (MRF). This plant will separate all recycleable items in a systematic manner which then can be recovered and processed for new products. This will also extend the lifespan of the landfill. However, this facility may be expensive for developing countries.

Implementation of a fully engineered semi-aerobic sanitary landfill is suggested in developing countries towards achieving the goal for sustainable development. The semi-aerobic landfill system which is more environmental friendly is an effective system for early stabilization of landfill sites and improvement of their environments. It was found that the leachate from a semi-aerobic system has slightly lower organic contaminants compared with an anaerobic landfill in terms of BOD and COD, and easier to manage. The green house emissions will finish faster than the anaerobic landfill, hence reducing the risk of fire. The other advantage is that the settlement will be faster (1 m in 2 years), hence extra volume of landfill can be attained over time. The average BOD and COD values in leachate for semi-aerobic landfill is less 100 mg/L and 2,000 mg/L, respectively, as compared to over 1,500 mg/L and 5,000 mg/L, respectively for anaerobic landfill. In Penang, based on the waste disposal rate of 1200 ton/day, and the present waste composition, conversion of anaerobic landfill to semi-aerobic condition, the Green House Gasses emission is expected to be reduced from nearly 100,000 t-CO_{2e} to about 70,000 t-CO_{2e} the first year, and reduced from nearly 20,000 t-CO_{2e} to about 13,000 t-CO_{2e} after 10

years in the tenth year. This is one of the main advantages of application of The Clean Development Mechanism (CDM) approach in reducing greenhouse gas emissions for a developing country.

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