ASSESSMENT OF AERATION AND LEACHATE RECIRCULATION IN OPEN CELL LANDFILL OPERATION WITH LEACHATE MANAGEMENT STRATEGIES

by

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Abstract

The main purpose of this study is to improve the open dumping site practices and environmental pollution control for sustainable landfilling in correlation with the Asian tropical climate. Four landfill lysimeters located at AIT research station were operated in different operating conditions (open cell landfill, open cell landfill combine with leachate recirculation, open cell landfill combine with aeration and leachate recirculation and conventional landfill). The leachate generation, leachate characteristics and settlement variation of MSW were monitored. Aeration and leachate recirculation operation was introduced to enhance biodegradable and faster settlement in Open Cell no 3 and only leachate recirculation was done in Open cell no 2.

After five months of operation period, the specific cumulative load of COD, BOD, DOC, TKN, NH_3 – N, Org – N and TN from Open Cell No.1, 2, 3 and Conventional Landfill were COD :1,294; 7,535; 7,369 and 1,461 mg/kg , BOD : 930; 5,211; 4,387 and 926 mg/kg, DOC : 410; 1,361; 1,187 and 391 mg/kg, TKN : 195; 795; 652 and 167 mg/kg, NH_3 – N : 135; 633; 547 and 124 mg/kg, Org – N : 58; 163; 109 and 48 mg/kg, TN :191; 698, 399 and 163 mg/kg solid waste, respectively. The faster settlement was observed in Open Cell No.3 (Leachate recirculation with aeration) than Open Cell No.2, No. 1 and Conventional Landfill. The Open Cell No.2 (213 L) and Open Cell no.3 (201L) had lower leachate remaining compared with Open Cell No.1(300L) and Conventional Landfill (250L).Similarly, concentration of pollutants in leachate in Open cell no. 3 (with aeration and leachate recirculation) showed the lower values compared to the others lysimeters without aeration and leachate recirculation.

The operation of open cell landfill by combining aeration and leachate recirculation showed increased quantity of leachate generation and faster the level of solid waste settlement. Water management in open cell landfill lysimeters by storage, evaporation and leachate recycling is a good option.

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List of Abbreviations

ADB	Asian Development Bank
AIT	Asian Institute of Technology
BOD	Biological Oxygen Demand
$CaCO_3$	Calcium carbonate
CH_4	Methane
CLF	Conventional Landfill
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
DOC	Dissolved Organic Carbon
DTN	Dissolved Total Nitrogen
FC	Field Capacity
H_2S	Hydrogen sulfide
IC	Inorganic Carbon
LFG	Landfill Gas
MC	Moisture Content
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
N_2	Nitrogen
NH_3 -N	Ammonia nitrogen
NH_3	Ammonia
O_2	Oxygen
OC 1	Open Cell Landfill Lysimeter No. 1
OC 2	Open Cell Landfill Lysimeter No. 2
OC 3	Open Cell Landfill Lysimeter No .3
ROC2	Leachate Recirculation from Open Cell No.2
ROCC3	Leachate Recirculation from Open Cell No.3
TC	Total Carbon
TDS	Total Dissolved Solid
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TS	Total Solid
TSS	Total Suspended Solid
TVSS	Total Volatile Suspended Solid
UMP	Urban Management Programme
UNEP	United Nation Environmental Program
USEPA	United State Environmental Protection Agency
VOA	Volatile Organic Acid
VS	Volatile Solid
WB	World Bank

Chapter 1

Introduction

1.1 Background

The amount of Municipal Solid Waste (MSW) is increasing with time influenced by socio-economic activities and population growth. There is no positive sign that the waste generation tends to decrease. Management of the vast quantities of solid waste generated by urban communities is a very complicated process. Solid Waste Management (SWM) requires the knowledge of available waste management, technologies a long with economics and environmental consideration. Indirect activities that also play an important role in SWM include: financing, operation, equipment, personnel, cost accounting, and budgeting, contract administration, ordinances and guidelines and public communications.

In addition, poor and developing cities in Asia lack the management capacity to deal with the increasing volume of waste and its changing characteristics as a city becomes richer, its waste composition changes due to increased consumption of paper, plastics, packaging and multi-material items. Moreover, poverty still leads to urban problems such as irregular settlements and scavenging. Even in economically developed Asian countries, waste management is overwhelmed by overpopulation and economic affluence (Mandes and Imura, 2002)

Municipal Solid Waste (MSW) consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. Asian cities are home to more than one billion people today. But by 2025, Asia will be inhabited by more than four billion people - half of them in cities - and will produce more than 180 million tons of MSW per day (World Bank, 1999). The waste managed by municipalities usually includes household waste and waste from small business, offices, restaurants, etc. But in some countries (particularly those with limited waste legislation), it may also include waste from small industrial plants.

Common problems for Municipal Solid Waste Management (MSWM) in developing countries in Asia include institutional deficiencies, inadequate legislation and resource constraints. Long- and short-term plans are lacking due to capital and human resource limitations. There is a need for financing instruments for MSWM, training and capacity building. National policies are now being formulated in several countries, but the lack of effective enforcement of environmental regulations is a major problem. Recycling laws, even if they exist, are not enforced. Although there are recycling activities promoted by communities, non-governmental organizations (NGOs) and the private sectors, these are informal and are not supported by the municipal authorities.

Final disposal methods of MSW by open dumping and land filling are commonly used in developing countries. It usually consists of MSW collection and transportation to disposal site. As reported by Visvanathan et al. (2004), it can not be denied that many Asian countries practiced more open dumping than sanitary land filling for MSW disposal.

In an open dump, waste is dumped in an uncontrolled manner which creates several problems. Aside from being unsightly and foul smelling, dumps attract insects, gulls, rats, and other rodents. These animal "vectors" are harmful to the health of the people living nearby because they can carry diseases. Uncontrolled fires, either set or spontaneously combusting, plague open dumps. The most serious problem results from rain percolating through the garbage and carrying harmful bacteria and hazardous chemicals from dumps into groundwater and nearby lakes or streams. This polluted runoff is called leachate. As a result of these problems, open dumps are banned in many developed countries but in developing countries they still used. However, efforts have been made for improving and upgrading open dumps.

In sanitary landfill, waste is disposed in controlled manner through the procedure entails alternating layers of compacted MSW with cover material. This can be soil, compost, or any other approved material. MSW is dumped and then compacted by special bulldozers aptly called compactors. At the end of each operation day when all the MSW has been dumped and flattened, bulldozers cover the fresh layer of MSW with cover material. This process slows decay, prevents exposure to health hazards, and reduces odor problems. All sanitary landfill operation be "lined" and equipped with leachate collection systems. A typical liner is composed of layers of clay, gravel, plastic and synthetic material to prevent leachate from escaping. Lined landfills are also fitted with pipes to collect and drain the leachate. Collected leachate is treated and discharged, or can be recirculated through the landfill (RIRRC, 2006).

Leachate that can be produced from the open dump MSW may be defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials. In most landfill, leachate is composed of the liquid that can enter the landfill from external sources, such as surface drainage, rainfall, ground water and liquid produced from the decomposition of solid waste within landfill. Leachate can pose problem to the environment. However, utilizing leachate within the landfill through leachate recirculation is beneficial to transform the landfill into a bioreactor which could help waste degradation.

One of the main purposes of leachate recirculation is to optimize the water content in order to accelerate waste degradation. In the same way, the liquid flow enables to dilute the eventual presence of inhibitors and provides nutrients for biological degradation enhancement. The beneficial effects on waste degradation are biogas production, organic load reduction in leachate and settlements of MSW. Because, leachate recirculation provides a means of optimizing environmental conditions in within the landfill, provides enhanced stabilization of landfill contents as well as treatment of leachate moving through the landfill (Reinhart and AL-Yousfi 1996; Barina, 2005).

Leachate is generated as rain falls on an uncapped landfill and percolates through the wastes. The water dissolves and rinses down certain constituents within the waste and settles down to the bottom of the landfill. Mobilization of the landfill constituents is a function of their chemical solubility and the rate of water movement through the waste. The composition and quantity of leachate is subject to seasonal, and even daily, fluctuations which significantly impacts the design of leachate treatment plants. Leachate recirculation system is one option of landfills which is well known as bioreactor landfill. Moreover**,** Leachate recirculation is one of the many techniques used to manage leachate from landfills. Because of the characteristics of landfill leachate, the main goal of leachate control is to prevent uncontrolled dispersion. Leachate should always be collected and treated before it is released into the environment. During leachate recirculation, the leachate is returned to a lined landfill for reinfiltration into the MSW. This is considered as a method of leachate control because as the leachate continues to flow through the landfill it is treated through biological processes, precipitation, and sorption. This process also benefits the landfill by increasing the moisture content which in turn increases the rate of biological degradation in the landfill, and the rate of methane, nitrogen and carbon recovery from the landfill (Fellin, et.al., 1996).

The purpose of this study is to evaluate and compare the influence of the application of aeration and flushing in open cell landfilling loaded with fresh and unsorted MSW. In addition, carbon and nitrogen balances and some heavy metals analysis are also be considered with leachate management

1.2 Objectives of Study

The objectives of this study are summarized as follows:

a) To simulate the open cell landfill technique under aeration and leachate circulation to determine the degree of waste stabilization in lysimeters.

b) To determine the Carbon and Nitrogen balances in open cell landfill under different operation strategies (influence of aeration, aeration and flushing compared with control open cell and conventional landfill).

c) To recommend an appropriate operation for open cell landfill and leachate management option for sustainable landfilling in correlation with the Asian tropical climate.

1.3 Scope of Study

This study is based on the pilot scale experimental research on open cell landfill lysimeters. The effect of the application of aeration and flushing in waste stabilization under open cell landfill was studied. The existing four landfill lysimeters at the research station as used before by Wisiterakul (2006) were utilized to study the different operation strategies. The scope of this study is given as follows:

1.) Four landfill lysimeters at Environmental Research Station of AIT were used to study the influence of aeration and flushing (leachate recirculation) on waste degradation as well as to study the Carbon and Nitrogen balances within the open cells:

- Open cell landfill lysimeter No. 1 (OC1) is used as a control open cell wherein no aeration or leachate recirculation was applied.
- Open cell landfill No. 2 (OC2) is operated with leachate recirculation no aeration.
- Open cell landfill No. 3 (OC3) operated with leachate recirculation and aeration.
- Control landfill (CLF) was used to simulate the actual behavior of landfill. All four landfill lysimeters were loaded with a total 1,800 kg of fresh and unsorted MSW

2.) Monitoring the open cell landfill lysimeters in terms of leachate generation, leachate characteristics and settlement variation of MSW.

3.) Determining leachate management by leachate recirculation, leachate storage under the influence of evaporation and precipitation (rainfall) under the actual climatic condition. Determining the amount and quality of leachate left at the end of the study period.

Chapter 2

Literature Review

2.1 Municipal Solid Waste Management (MSWM) and Disposal in Asia

Municipal solid waste (MSW) includes all community wastes with the exception of industrial process wastes and agricultural wastes. Nowadays, the quantity of MSW has increased significantly. It caused by the increasing population, urbanization and industrialization. In 1999, World Bank reported that the cities in Asia generated approximately 0.76 million tons/day of MSW. In most developing countries, local organizations or municipalities are responsible for the collection, transportation and the disposal of MSW. Daily collection is a common practice in big cities. In Asia, on an average about 70% of the solid waste is collected (Eisa and Visvanathan, 2002). Inadequate staff, funds and equipment are the main reasons of solid waste uncollected. These lead to solid waste littering, dumping or burning in backyard and open spaces.

Asian cities are home to more than one billion people today. But by 2025, Asia will be inhabited by more than four billion people - half of them in cities - and will produce more than 180 million tons / day of MSW. The waste managed by municipalities usually includes household waste and waste from small business, offices, restaurants, etc. But in some countries (particularly those with limited waste legislation), it may also include waste from small industrial plants. Asia's diverse nature (e.g. economic development, institutional framework, climate and culture) means that waste management characteristics and issues vary across the region. Accurate information on waste generation and composition is necessary to monitor existing management systems and make regulatory, financial and institutional decisions. MSW management in Asian cities, which are classified into less developed (or poor), developing (or rapidly industrializing) and developed (or mature) cities (Mades and Imura, 2002).

However, the amount of waste collected by municipalities is generally much less than that generated. Due to inconsistencies in definitions and methodologies, comparing MSW data between countries and cities in Asia is difficult and should be performed with caution. Waste characterization also tends to be carried out at the final disposal site rather than at the source of waste before any scavenging or recycling activity occurs.Table 2.1 shows that about 70% or more (by weight) of the waste is combustible (i.e. organics, paper and plastics). However, the composition differs depending on the economic level of cities as well as other factors such as geographic location, energy sources, climate, living standards and cultural habits, and the sources of waste that are considered as MSW or are collected by the municipality (Mades and Imura, 2002).

The ratio of paper and plastics including voluminous materials such as food containers and wrapping materials is higher in mature cities, while organic waste accounts for most of the waste in developing cities. Moreover, the calorific value of waste in mature cities is high. On the other hand, waste in developing cities has a high organic content and a low calorific value; biological treatment such as composting and biogasification (i.e. anaerobic digestion) are thus more suitable. Since suitable treatment methods are different for different waste compositions, they thus differ among cities with different levels of economic development. However, other factors have to be taken into account when choosing the most appropriate waste treatment method such as markets for the by-products, costs, energy sources, environmental impact, public acceptance, etc (Mades and Imura, 2002). Table 2.2 shows the typical waste composition in low-, medium- and high-income Asian cities

Table 2.1 Compositions of urban solid waste in selected Asian countries (%)

Country	Organic waste (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Others (%)
China	35.7	3.7	3.8	2.0	0.3	54.5
Hong Kong	37.3	21.6	15.7	3.9	3.9	17.6
India	45	52.6	28.5	18.4	6.5	35.4
Indonesia	70.2	10.9	8.7	1.7	1.8	6.2
Japan	17.0	40.0	20.0	10.0	6.0	7.0
Laos	54.3	3.3	7.8	8.5	3.8	22.5
Malaysia	43.2	23.7	11.2	3.2	4.2	14.5
Myanmar (Burma)	80.0	4.0	2.0	0.0	0.0	14.0
Philippines	41.6	19.5	13.8	2.5	4.8	17.9
Singapore	44.4	28.3	11.8	4.1	4.8	6.6
South Korea	31.0	27.0	6.0	5.0	7.0	23.0
Sri lanka	68.51	5.99	6.69	1.64	1.85	11.63
Thailand	48.6	14.6	13.9	5.1	3.6	14.2

Sources: Mades and Imura. (2002)

Table 2.2 Typical waste composition of low- medium- and high-income Asian cities

Waste fractions	Low – income cities	Medium - income cities	High - income cities
Paper (%)	3-10	10-25	20-50
Plastics (%)	2-8	8-14	9-22
Ash, fines, others (%)	2-62	6-18	3-10
Organics (%)	35-80	40-50	15-40
Moisture (%)	30-60	20-50	10-30
Bulk density or density (kg/m^3)	300-550	200-350	150-300

Source: Mades and Imura.(2002)

2.1.1 Open dump approach

Most Asian countries are facing problems regarding final disposal. In Thailand and India, for example, 70 % – 90 % of the final disposal sites are open dump. As cities grow, the few existing landfills are filled up quickly and the lengths of time it take to develop a new landfill frequently result to open dumping. Insufficient allocation of financial resources in the waste management sector, acceptance of the status quo and a lack of awareness among both the public and politician of environmental and health concerns are the root cause of the low quality of waste services (William et al., 2005).

Another reason for sustaining the current disposal practices are insufficient guidelines for determining location, design and operation of new landfills, or for upgrading of old dumps. Often the only guidelines and training materials available are those from high-income countries. These are based on technological standards and practices suited to the conditions and regulations of high-income countries and do not take into account the different technical, economical, social and institutional aspects of developing countries. The responsible authorities, seeing no other solution for their disposal situation, then start searching for waste treatment methods like composting or incineration to alleviate their problems. Such treatment methods however do not eliminate the need of a disposal site.

Most of the MSW in low-income Asian countries which is collected is dumped on land in a more or less uncontrolled manner. Such inadequate waste disposal creates serious environmental problems that affect health of humans and animals and cause serious economic and other welfare losses. The environmental degradation caused by inadequate disposal of waste can be expressed by the contamination of surface and ground water through leachate, soil contamination through direct waste contact or leachate, air pollution by burning of wastes, spreading of diseases by different vectors like birds, insects and rodents, or uncontrolled release of methane by anaerobic decomposition of solid waste. Open dumps, where the waste is dumped in an uncontrolled manner, can be detrimental to the urban environment. Many governments now acknowledge the dangers to the environment and to public health derived from uncontrolled waste dumping. However often officials think that uncontrolled waste disposal is the best that is possible. Financial and institutional constraints are one of the main reasons for inadequate disposal of waste, especially where local governments are weak or underfinanced and rapid population growth (Zurbrϋgg, 2003). Table 2.3 illustrates the disposal methods in some selected countries of the Asia.

2.1.2 Sanitary landfill

The implementation and practice of sanitary land filling are severely constrained in developing countries by the lack of reliable information specific to these countries, as well as by a shortage of capital and properly trained human resources. Sanitary landfill call for the isolation of the land filled wastes from the environment until the wastes are rendered innocuous through the biological, chemical, and physical processes of nature. In industrialized nations, the degree of isolation required usually is much more complete than would be practical in developing nations.

Sanitary land filling, which is the controlled disposal of waste on the land, is well suited to developing countries as a means of managing the disposal of wastes because of the flexibility and relative simplicity of the technology. Sanitary land filling controls the exposure of the environment and humans to the detrimental effects of solid wastes placed on the land. Through sanitary land filling, disposal is accomplished in a way such that contact between wastes and the environment is significantly reduced, and wastes are concentrated in a well defined area. The result is good control of landfill gas and leachate, and limited access of vectors (e.g., rodents, flies, etc.). The practice of sanitary land filling, however, should be adopted in accordance with other modern waste management strategies that emphasize waste reduction, recycling, and sustainable development. To design a sanitary landfill, a disposal site must meet the following three general basic conditions: 1) compaction of the wastes, 2) daily covering of the wastes (with soil or other material) to remove them from the influence of the outside environment, and 3) control and prevention of negative impacts on the public health and on the environment (e.g., odours, contaminated water supplies, etc.). Figure 2.1 shows the section views of sanitary landfill.

The most important condition is the prevention of negative impacts on public health and the environment (UNEP, 2005).

Table 2.3 Disposal methods of MSW selected in Asian countries

Country/ Territory	Disposal Method (%)			
	Land disposal	Incineration	Composting	Others
Bangladesh	95	-	-	5
Brunei Darussalam	90	-	-	10
Hong Kong	92	8	-	-
India	70	-	20	10
Indonesia	80	5	10	5
Japan	22	74	0.1	3.9
Rep of Korea	90	-	-	10
Malaysia	70	5	10	15
Philippines	85	-	10	5
Singapore	35	65	-	-
Sri Lanka	90	-	-	10
Thailand	80	5	10	5

Source: ADB, (1995)

2.1.3 Landfill processes

There are three types of reaction that occurred in landfill processes they are: 1) Physical, 2) chemical, and 3) Biological processes. Of the three processes, the biological processes probably are the most significant. However, the biological processes are strongly influenced by the physical and chemical processes.

A. Physical process

In general, significant physical reactions in the fill are in one of three very broad forms:
Compaction, dissolution, and sorption, settlement is an invariable accompaniment of compression. Similarly, dissolution and transport are closely associated phenomena, although not to the same degree as compression and settlement. The continuing compression is due to the weight of the wastes and that of the soil cover (burden). Shifting of soil and other fines is responsible for some consolidation. Settling of the completed fill is an end result of compression. This settling is in addition to the settlement brought about by other reactions (e.g., loss of mass due to chemical and biological decomposition).

The amount of water that enters the fill has an important bearing on physical reactions. Water acts as a medium for the dissolution of soluble substances and for the transport of un-reacted materials. In a typical fill, the broad variety of components and particle sizes of the wastes provides conditions that lead to an extensive amount of adsorption, which is the adhesion of molecules to a surface. Of the physical phenomena, adsorption is one of the more important because it brings about the immobilization of living and non-living substances that could pose a problem if allowed to reach the external environment.

B. Chemical process

Oxidation is one of the two major forms of chemical reaction in landfill. Obviously, the extent of the oxidation reactions is rather limited, in as much as the reactions depend upon the presence of oxygen trapped in the fill when the fill was made. Ferrous metals are the components likely to be most affected.

The second major form of chemical reaction includes the reactions that are due to the presence of organic acids and carbon dioxide (CO_2) synthesized in the biological processes and dissolved in water (H_2O). Reactions involving organic acids and dissolved CO_2 are typical acid-metal reactions. Products of these reactions are largely the metallic ions and salts in the liquid contents in landfill. The acids lead to the volatilization and, hence, mobilization of materials that otherwise would not be the source of pollution. The dissolution of CO_2 in water deteriorates the quality of the water, especially in the presence of calcium and magnesium.

C. Biological process

The importance of biological reactions in a fill is due to the following two results of the reactions: First, the organic fraction is rendered biologically stable and, as such, no longer constitutes a potential source of nuisances. Second, the conversion of a sizeable portion of the carbonaceous and pertinacious materials into gas substantially reduces the mass and volume of the organic fraction.

The wide varieties of fill components that can be broken down biologically constitute the biodegradable organic fraction of MSW. This fraction includes the garbage fraction, paper and paper products, and "natural fibers" (fibrous material of plant or animal origin). Biological decomposition may take place either aerobically or an anaerobically. Both modes come into play sequentially in a typical fill, in that the aerobic mode precedes the anaerobic mode. Although both modes are important, anaerobic decomposition exerts the greater and longer lasting influence in terms of associated fill characteristics.

Aerobic decomposition

The greater part of decomposition that occurs directly after the wastes are buried is aerobic. It continues to be aerobic until all of the oxygen (O_2) in the interstitial air has been removed. The duration of the aerobic phase is quite brief and depends upon the degree of compaction of the wastes, as well as the moisture content since the moisture displaces air from the interstices. Microbes active during this phase include obligate as well as some facultative aerobes.

Because the ultimate end products of biological aerobic decomposition are "ash", CO_2, and H_2O, adverse environmental impact during the aerobic phase is minimal. Although intermediate breakdown products may be released, their amounts and contribution to pollution usually are small.

$$\text{Organic matter} + O_2 + \text{nutrients} \xrightarrow{\text{Microbes}} \text{new cells} + \text{resistant organic matter} + CO_2 + H_2O + NH_3 + SO_2 + \text{heat}$$

(*Aerobic decomposition*)

Because the oxygen supply in a landfill soon is depleted, most of the biodegradable Organic matter eventually is subjected to anaerobic breakdown. This anaerobic decomposition is biologically much the same as that in the anaerobic digestion of sewage sludge. Microbial organisms responsible for anaerobic decomposition include both facultative and obligate anaerobes. The products can be classified into two main groups: volatile organic acids and gases. Most of the acids are malodorous and of the short-chain fatty-acid type.

In addition to chemical reactions with other components, the acids serve as substrates for methane-producing microbes. The two principal gases formed are methane (CH_4) and CO_2. Gases in trace amounts are hydrogen sulphide (H_2S), hydrogen (H_2), and nitrogen (N_2). Landfill gas production, management, and recovery are discussed in another section (UNEP, 2005).

$$\text{Organic matter} + H_2O + \text{nutrients} \xrightarrow{\text{Microbes}} \text{new cells} + \text{resistant organic matter} + CO_2 + CH_4 + NH_3 + H_2S + \text{heat}$$

(*Anaerobic decomposition*)

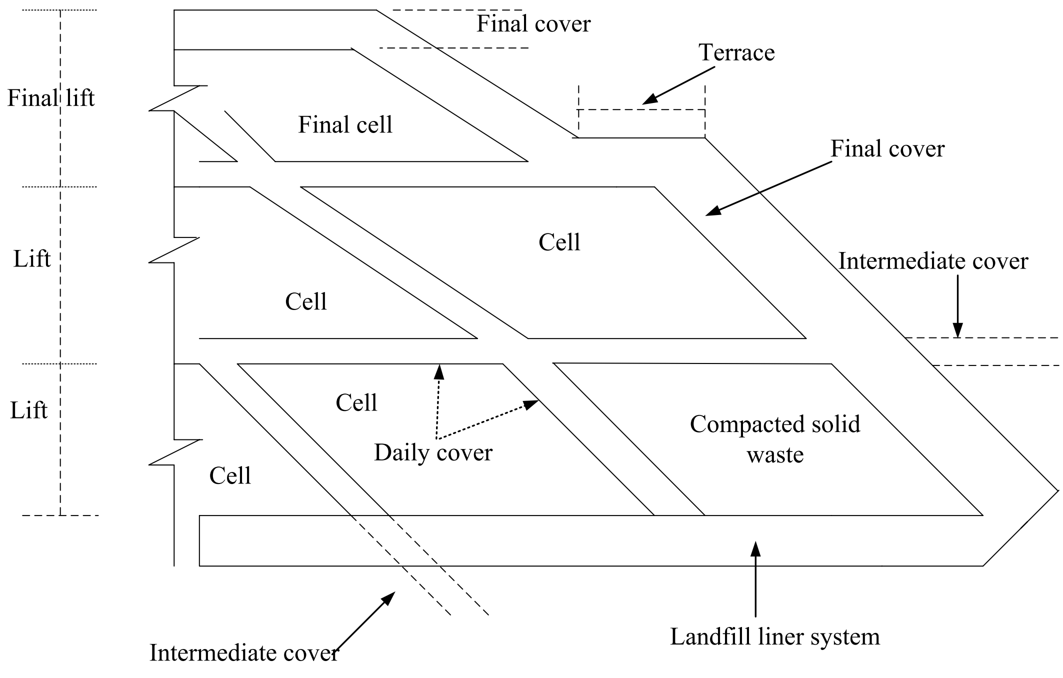


Figure 2.1 Sectional views of a sanitary landfill

2.2 Bioreactor Landfill

Bioreactor landfill is a sanitary landfill that uses enhanced microbiological processes to transform and stabilize the readily and moderately decomposable organic waste constituents within 5 to 10 years of bioreactor process implementation. The bioreactor landfill significantly increases the extent of organic waste decomposition, conversion rates and process effectiveness over what would otherwise occur within the landfill. Stabilization means that the environmental performance measurement parameters (landfill gas composition and generation rate and leachate constituent concentrations) remain at steady levels, and should not increase in the event of any partial containment system failures beyond 5 to 10 years of bioreactor process implementation. The bioreactor landfill requires certain specific management activities and operational modifications to enhance microbial decomposition processes. The single most important and cost-effective method is liquid addition and management. Other strategies, including waste shredding, pH adjustment, nutrient addition, waste pre-disposal and post-disposal conditioning, and temperature management, may also serve to optimize the bioreactor process. In effect, the bioreactor landfill is merely an extension of the accepted recirculation landfill option. However, the bioreactor process requires significant liquid addition to reach and maintain optimal conditions. Leachate alone is usually not available in sufficient quantity to sustain the bioreactor process. Water or other non-toxic or non-hazardous liquids and semi-liquids are suitable amendments to supplement leachate (depending on climatic conditions and regulatory approval).

The bioreactor landfill differs from the leachate recirculating landfill for it can obtain rapid and complete stabilization by use the water and other amendments. For the bioreactor landfill, water is clearly not a waste but an amendment. Other potential bioreactor additions such as sludge and nutrients could also be categorized as amendments (Pacey et al., 1998).

Numerous benefits can be derived from the bioreactor landfill as follows:

a) Rapid organic waste conversion and Stabilization

- Rapid settlement - volume reduced and stabilized within bioreactor process implementation
- Increased gas unit yield, total yield and flow rate almost all of the rapid and moderately decomposable organic constituents will be degraded
- Improved leachate quality - stabilizes within 3 to 10 years after closure.
- Early land use possible following closure.

b) Maximizing of landfill gas capture for energy recovery projects

- Significant increase in total gas available for energy use, which provides entrepreneurial opportunities
- Potential increase in total landfill gas extraction efficiency (enabled over a shorter generation period)
- Increased greenhouse gas reduction from lessened emissions
- Increase in fossil fuel offsets due to increased gas energy sales
- Assistance in defraying landfill gas non-funded environmental costs
- Significant economy of scale advantage due to high generation rate over relatively Short time.

c) Increased landfill space capacity reuse due to rapid settlement during operational time period

- Increase in the amount of waste that can be placed into the permitted landfill airspace (Effective density increase.)
- Extension of landfill life through additional waste placement
- Deferred capital and financing costs needed to locate, permit and construct

- Replacement landfill results in capital and interest savings
- Significant increase in realized waste disposal revenues

d) Improved leachate treatment and Storage

- Low cost partial or complete treatment; significant biological and chemical transformation of both organic and inorganic constituents, although mostly relevant to the organic constituents
- Reintroduction of all leachate over most of the operational and post-closure care Period significantly reduces leachate disposal costs
- Absorption of leachate within landfill available up to field capacity

e) Reduction in post-closure care, maintenance and Risk

- Rapid waste stabilization (within 5 to 10 years) minimizes environmental risk and liability due to settlement, leachate and gas
- Landfill operation and maintenance activities are considerably reduced
- Landfill monitoring activities can be reduced
- Reduction of financial package requirement
- In the event of partial liner failure, there should be no risk of increased gas generation, worsening leachate quality, increased settlement rate or magnitude

Another major benefit of bioreactors may come from greenhouse gas abatement. Bioreactors can generally rapidly complete methane generation while attaining maximum yield. This can be combined with nearly complete capture of generated gas using the bioreactor landfill in combination with a landfill gas energy project (Pacey et al., 1998). With this approach, the high generation level and gas capture efficiency maximizes landfill greenhouse gas offset potential. Additional goals and benefits may also include: 1) transformation of certain resistant organics (dehalogenation, etc.) and sequestration of certain inorganics (precipitation, etc.); and 2) pollutant removal processes of filtration, capture, sorption, etc. that are promoted by leachate recirculation (Pacey et al., 2000).

Generally, the pattern of construction and operation of conventional landfills has deep pits, liners (bottom layers) and caps (top cover layers). These designs and operations lead to anaerobic condition and limit moisture content that are necessary for biodegradation in landfill. Referred to as the "dry-tomb method", this conventional landfill can create environmental problems and health risks in long-term period. The efficiency of protection liners and caps is decreased or failed for long time operations or completed landfills. If moisture is permitted into landfills, the biological activity would happen again then the leachate and landfill gas are produced. Conventional landfill can't be considered as sites for final storage quality or sustainable landfill (Komilis et al., 1999).

Upgrading existing landfill technology from storage/containment (conventional landfill) to a process-based approach is called as bioreactor landfill (Chiemchaisri et al., 2002). In contrary to conventional landfill, bioreactor landfill is designed to maximize the infiltration of water into the waste. The bioreactor landfill is managed by controlling moisture content of the waste, recycling of nutrients and seeding of microorganisms by leachate recirculation system. It provides the moisture content into landfill for accelerating biodegradation process until stabilization. Stabilization means that the environment performance measurement parameters remain at steady level along the process implementation (USEPA, 2000).

Bioreactor technology is selected by considering four reasons: 1) to increase potential for waste to energy conversion, 2) to store and/or treat leachate, 3) to recover air space and 4) to ensure sustainability. The sustainability is most important in terms of economic benefit because bioreactor technology reduce the cost of long-term monitoring and delayed siting of a new landfill (Reinhart et al., 2002).

Results comparison of leachate characteristics between bioreactor landfill and conventional landfill had been studied by Reinhart and Al-Yousfi (1996) is shows in Table 2.4 and studied by Reinhart and Towsend (1998) is shows in Table 2.5. By starting from phase II (Transition phase). Results are compares all data from full-scale recirculating landfills (Conventional & Bioreactor landfills). In conclusion from this study, the concentration of leachate constituents in both types of landfills is same pattern in sequential phases. Acid formation phase produced high strength of leachate more than other phase (Table 2.4). Table 2.5 shows the strength of leachate of bioreactor is less than conventional landfill as a result of moisture content in landfill.

Repeating recirculation of leachate reduces its concentration until stabilization. Furthermore, leachate recirculation provides appropriate condition for reducing the metal contamination by sulphide and hydroxide precipitation process. Other advantages of leachate recirculation are supporting gas production by providing organic material for conversion to methane gas under anaerobic condition, waste volume reduction by enhancing the settlement in depth of waste more than conventional landfill. For example, at the Sonoma County, California, pilot scale landfill, leachate recirculated cell settled around 20% of its waste depth, for dry cells settled less than 8%. Long-term liability, bioreactor landfill operation provided cost saving of aftercare. Thus, the difference between conventional and bioreactor landfill is that the bioreactor landfill operates with the leachate recirculation technique while the conventional landfill treats leachate offsite for disposal (Chiemchaisri et al., 2004).

In Asian countries, in comparison to many developed countries, the concept of bioreactor landfill is still relatively new. In South and Southeast Asia more than 90% of all landfills are non-engineered (Tränkler et al., 2005). Therefore, in developing countries, changing from normal disposal practice or open dumping to sanitary landfill or bioreactor landfill needs funds, knowledge and long time. However, improving dumpsite to suitable landfill design and operation should be done for environmental protection.

Chemical reactions within the landfill includes, dissolution and suspension of waste materials and many compounds in the liquid percolating through the waste, evaporation of water and chemical compounds, oxidation-reduction reactions, etc. For the physical reactions in landfill are, for instance, lateral diffusion of gases and emission of landfill gases to atmosphere, movement of leachate and settlement caused by consolidation and decomposition of landfilled material, etc. (Tchobanoglous et al., 1993).

Environmental conditions which significantly impact on biodegradation include pH, temperature, nutrients, absence of toxic material, moisture content, particle size and oxidation reduction potential (Reinhart and Al-Yousfi, 1996).

Stabilization of MSW proceeds in five sequential phases is described in the following sections. The rate and characteristics of leachate production and landfill gas generation from landfill are varying in different phases. These variations can be used for monitoring stabilization of MSW landfill. Five phases of MSW decomposition and stabilization are described as follow:

Phase I: Initial adjustment phase

This phase relates with initial placement of MSW and accumulation of moisture within the landfill. In this phase, biological decomposition occurs under aerobic conditions which oxygen present in the void spaces of MSW. Microorganisms are provided from soil material or other sources such as leachate recirculation, sludge, etc. Moisture content is entered with incoming MSW to landfill, soil material covers and rainfall. Most leachate produced during this phase results from the releasing of moisture during compaction and short-circuiting of precipitation through the MSW landfill. During this phase oxygen is rapidly consumed then produced carbon dioxide.

Phase II: Transition phase

This phase triggers the transformation from aerobic to anaerobic condition because of the depletion of oxygen within landfill. When landfill condition is anaerobic, nitrate and sulfate will be the electron acceptors in biological conversion reactions and reduced to nitrogen gas and hydrogen sulfide gas, and displacement of oxygen by carbon dioxide. In this phase, pH of the leachate starts dropping due to the presence of organic acids and the effect of the elevated carbon dioxide. By the end of this phase, chemical oxygen demand (COD) and volatile organic acids (VOA) or volatile fatty acids (VFA) can be detected in the leachate.

Phase III: Acid formation phase

The continuous hydrolysis (solubilization) of solid waste and biological activities of microorganisms which converse biodegradable organic content to intermediate volatile fatty acids at high concentrations. Decreasing pH values is often observed, accompanied by metal species mobilization. Rapid consumption of substrate and nutrients occurred in this phase.

Phase IV: Methane fermentation phase

Intermediate acids from phase III are consumed by methanogenic bacteria and converted to methane and carbon dioxide. Sulfate and nitrate are reduced to sulphides and ammonia, respectively. The pH values increase by the bicarbonate buffering system, this condition will support the growth of methanogenic bacteria. Heavy metals are removed by compellation and precipitation.

Phase V: Maturation phase

In this phase, nutrients and available substrate become limiting, and slowly biological activities. Gas production drops dramatically and leachate strength stays steady at lower concentrations. Reappearance of oxygen and oxidized species may be observed slowly. However, the slow degradation of resistant organic fractions may continue with the production of humic substances. During maturation phase, the leachate will often contain humic acid and fulvic acid, which are difficult to process further biologically (Tchobanoglous et al., 1993; Reinhart and Al-Yousfi, 1996; Kjeldsen et al., 2002).

Table 2.4 Landfill constituent concentration ranges a function of the degree of landfill stabilization

Parameter	Phase II. Transition		Phase III. Acid formation		Phase IV. Methane fermentation		Phase V. Final maturation	
	Conventional	Recirculation	Conventional	Recirculation	Conventional	Recirculation	Conventional	Recirculation
BOD (mg/L)	100 - 1,000	0 – 6,893	1,000 - 57,700	0 – 28,000	600 -3,400	100 - 10,000	4 - 120	100
COD (mg/L)	480 - 18,000	20 – 20,000	1,500- 71,000	11,600- 34,550	580 - 9,760	1,800 - 17,000	31 - 900	770 - 1,000
TVA (mg/L as acetic acid)	100 - 3,000	200 – 2,700	3,000- 18,800	0-30,730	250 - 4,000	0 - 39,000	0	-
BOD/COD	0.23 - 0.87	0.1 – 0.98	0.4 - 0.8	0.45 - 0.95	0.17 - 0.64	0.05 - 0.8	0.02-0.13	0.05 - 0.08
NH_4 (mg/L-N)	120 - 125	76 - 125	2- 1,030	0-1,800	6 - 340	32 - 1,850	6 - 430	420 - 580
pH	6.7	5.4 – 8.1	4.7 - 7.7	5.7-7.4	6.3 - 8.8	5.9 - 8.6	7.1 - 8.8	7.4 - 8.3
Conductivity (mS /cm)	2,450 - 3,310	2,200 – 8,000	10,000- 17,100	10,000- 18,000	2,900 - 7,700	4,200 - 16,000	1,400 - 4,500	-

Source : Reinhart and Al- Y ousfi (1996); Reinhart and Towsend (1998).

Table 2.5 Leachate constituents of conventional and recirculating landfills (summarizing all phases)

Parameters	Unit	Conventional landfill	Bioreactor landfill
BOD	mg/L	20 – 40,000	12 – 28,000
COD	mg/L	500 – 60,000	20 – 34,500
Iron	mg/L	20 – 2,100	4 – 1,095
Ammonia	mg/L	30 – 3,000	6 – 1,850
Chloride	mg/L	100 – 5,000	9 – 1,884
Zine	mg/L	6 - 370	0.1 - 66

Source: Reinhart and Al- Yousfi (1996); Reinhart and Towsend (1998).

2.3 Landfill gas

Methane (CH_4) and carbon dioxide (CO_2) are predominate Landfill Gas (LFG). CH_4 generated in landfills typically excess of 45% of the total landfill gases and over 20 times more harmful than CO_2. Landfill gas controlling system is employed to prevent emission of LFG into the atmosphere or the lateral and vertical movement through the surrounding soil. Furthermore, collection LFG can be used to produce energy. However, in many cases, collection LFG for energy recovery is not economical and LFG management still contains inherent risks (Tatsi and Zouboulis, 2002). As open dumpsite is a predominant MSW disposal method in Asia, the methane emissions from the MSW shallow dumpsites and without cover layer is less due to their more or less anoxic status (Hogland et al., 2005). However, improvement existing landfills should be designed to reduce methane emission. The biological oxidation of methane gas would be an inexpensive gas treatment system to reduce greenhouse gas emitted from landfill (Visvanathan et al., 2003).

A bioreactor landfill will generate more landfill gas in a much shorter time than a conventional landfill. To efficiently control gas and avoid odor problems, the bioreactor landfill gas extraction system may require installation of larger pipes, blowers and related equipment early in its operational life. Horizontal trenches, vertical wells, near surface collectors, or hybrid systems may be used for gas extraction. Greater gas flows are readily accommodated by increased pipe diameter, as capacity increases as the square of pipe diameter. Liquid addition systems should be separate from gas extraction systems to avoid flow impedance. The porous leachate removal system underlying the refuse should be considered for integration with the gas extraction system.

Enhanced gas production can negatively impact side slopes and cover if an efficient collection system is not installed during active landfill phases. Uplift pressure on geo-membrane covers during installation may cause ballooning of the membrane and may lead to some local instability and soil loss. Temporary venting or aggressive extraction of gas during cover installation may facilitate cover placement. Once the final cover is in place, venting should be adequate to resist the uplift force created by landfill gas pressure buildup. The designer should consider the pressure buildup condition on slope stability when the collection system is shut down for any significant time (Pacey et al., 1998).

2.3.1 Carbon and nitrogen in landfill

Emissions from landfills via leachate and the gas phase are influenced by state and stability of the organic matter in the solid waste and by environmental conditions within the landfill. Aeration is one of the methods to reduce these emissions by establishing aerobic conditions to accelerate biological processes in the landfill. Carbon and Nitrogen in landfill site can account by the volume of carbon and nitrogen in leachte in form of dissoluble, in form of gasses emission and in solid form that remaining in solid waste in landfill. Carbon and Nitrogen balances can be done by calculating the amount of carbon and nitrogen in the leachate, in the gas and remaining in the solid waste in the landfill.

The lab scale experiments with open cell landfill has been carried out and the main goal of the present work is to characterize the changes of the carbon and nitrogen compounds in the aerated solid waste, in the leachate and in the gas under varying conditions. Even when open cell will be operated under anaerobic conditions after a long running period of aeration, the emissions remain low (Pratl et al., 2005).

2.4 Landfill Leachate

Leachate is composed of liquid that can enters the landfill from external sources, such as surface drainage, rainfall, ground water and liquid produced from the decomposition of solid waste within the landfill. The liquids migrating through the waste dissolve salt, pick up organic constituents and leach heavy metals. The organic strength of landfill leachate can be 20 to 100 times greater than the strength of raw sewage, making this “landfill liquor” a potentially potent polluter of soil and water. In open dumps, the material that leached would be absorbed into the ground and percolated move into ground water, surface water, or aquifer system. In sanitary landfill, it is required that leachate collection systems be designed to pump and collect the leachate for treatment (Hheimlich, 2000).

2.4.1 Leachate formation and Water Balance

Leachate is the percolation of precipitation, surface drainage and irrigation water into the landfill including the biological and chemical reaction of waste being disposed at the landfill. Leachate formation is an indicative of increased moisture content, which is associated with enhancing biodegradation in landfills (El-Fadel et al., 2002). Leachate generation can be determined directly by collecting leachate production from landfill site that has leachate collection system.

Generally, water balance of landfill is used to estimate leachate formation. The water balance components include water inflow, water outflow and water store within the landfill. Water input such as water entering from the top of landfill is called precipitation, water entering in solid waste and cover materials from which moisture is inherent in materials. Water output such as water leaving from the bottom is called leachate, water consumed in the formation of landfill gas and water lost as water vapor. The water balance components are presented in Figures 2.2. In addition, water lost as evaporation from landfill is determined or not that depend on local conditions (Techobanoglous et al., 1993; Manandhar and Tränkler, 2000).

Water balance concept is a simple approach for estimating the quantity of leachate and deciding the design and requirement of landfill needs leachate collection system and bottom liner (Manandhar, 2000). The climatic water balance can be repressed in equation 2.1:

$$W = P - ET \qquad \text{(Eq. 2.1)}$$

Where, W = the quantity of moisture either lost or retained in the waste (mm)
P = the precipitation (mm)
ET = the evapotranspiration from the landfill (mm)

Furthermore, leachate formation can be estimated by means of conventional hydrological water balance equation which is shown in equation 2.2;

$$L = P - R - ET - \Delta S \qquad \text{(Eq. 2.2)}$$

Where, L = quantity of percolate through the cover per unit area of soil cover (mm)
P = quantity of net precipitation per unit area (mm)
R = quantity of runoff per unit area (mm)

ET = quantity of moisture lost through evapotranspiration per unit area (mm)

ΔS = change in the amount of moisture stored in a unit volume of landfill (mm)

Evaporation and surface runoff in the case of bare soil cover are dominant factors in water loss from the landfill surface and resulting reduced infiltration (Shrestha, 2001). In developing countries, where the refuse is rarely covered, the major portion of the precipitation would enter the fill. Flow in a vertical percolation layer is either downward (due to gravity drainage) or removed via evapotranspiration. The rainfall pattern is also different in the region. The water balance component in landfill might be different especially on evaporation due to variation in temperature as well as solar radiation. The runoff also varies with the type of soil used in the region. Landfill design and operation also affect leachate formation (El-Fadel et al., 2002). Less compacted MSW will accelerate leachate production because the compaction will reduce the filtration rate of water (Tatsi and Zouboulis, 2002).

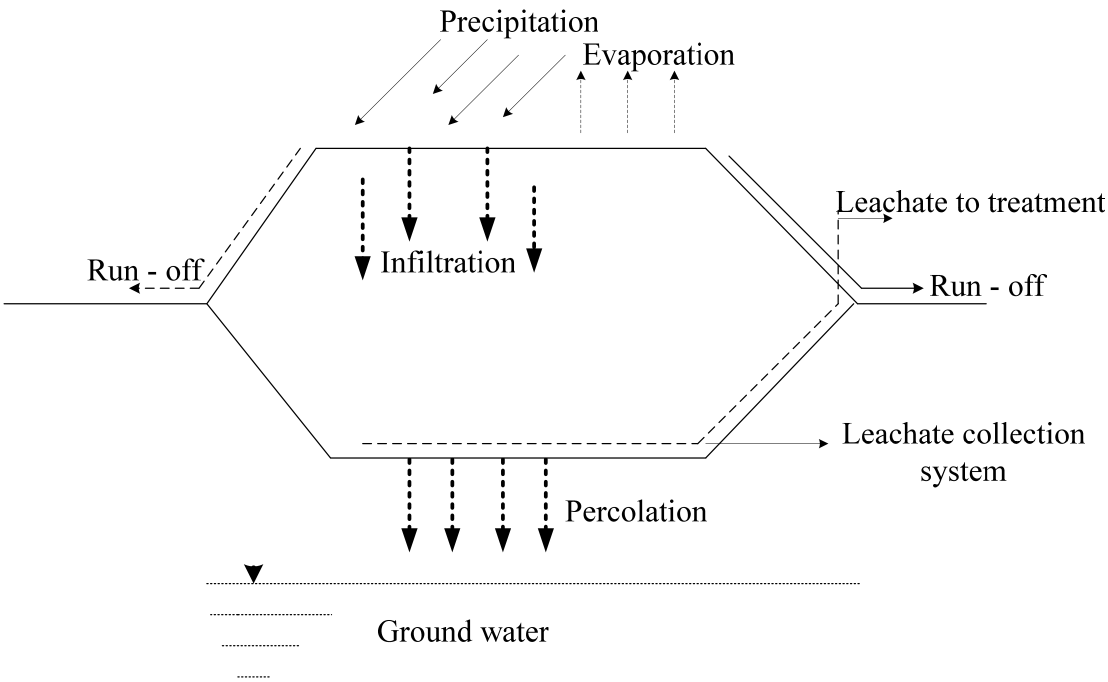


Figure 2.2 Water balance components in landfill

2.4.2 Leachate characteristics

Composition of leachate varies depending upon the age of landfill and stabilization phase of waste degradation. Representative data on the characteristics of leachate are reported in Table 2.6. Factors influence to leachate quality are processed refuse, depth of landfill, age of landfill, climate, landfill operation, co-disposal with sewage sludge, co-disposal with hazardous wastes and co-disposal with sorbitive waste (e.g. incinerator ash, fly ash, kilns dust, limestone etc.) (Nakwan, 2002).

Table 2.6 Typical data on the composition of leachate from new and mature landfills

Constituent	Values, mg/L[a]		
	New landfill (less than 2 years)		Mature landfill (> 10 years)
	Range [b]	Typical[c]	
BOD_5	2,000 - 30,000	10,000	100 - 200
COD	3,000 – 60,000	18,000	100 - 500
TOC	1,500 – 20,000	6,000	80 - 160
TSS	200 – 2,000	500	100 - 400
pH	4.5 – 7.5	6	6.6 – 7.5
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
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	200 – 1,000	300	50 - 400
Sodium	200 – 2,500	500	100 - 200
Chloride	200 – 3,000	500	100 - 400
Sulfate	50 – 1,000	300	20 - 50
Total iron	50 – 1,200	60	20 - 200

(a) .Except pH, which has no unit
(b).Representative range of values. Higher maximum values have been reported in the literature for some of the constituents.
(c) .Typical values for new landfills will vary with the metabolic state of the landfill.
Source: Tchobanoglous et al. (1993).

2.5 Leachate Recirculation

Leachate recirculation is one of many techniques used to manage leachate from landfills. The main goal of leachate control is to prevent uncontrolled dispersion. Leachate should always be collected, treated or contained before it is released into the environment. During leachate recirculation, the leachate is returned to a lined landfill for reinfiltration into the MSW. This is considered a method of leachate control because as the leachate continues to flow through the landfill it is treated through biological processes, precipitation, and sorption. This process also benefits the landfill by increasing the moisture content which in turn increases the rate of biological degradation in the landfill, the biological stability of the landfill, and the rate of methane recovery from the landfill (Fellin et al.,1996). Leachate recirculation can be applied to all types of landfills from the current “EU Waste Regulations Compliant” MSW landfills to the most basic (with little engineering and management) seen in the developing nations (Enviros, 2006).

2.5.1 Recirculation in landfills

Recycling leachate in MSW landfills can provide: a) means of disposal (not only short-term as it percolates through the waste but also by allowing the waste to absorb (soak-up) the leachate); b) enhancement of the rate of landfill stabilisation (encouraging both the onset of fermentation leading to gas) and reduced long term settlement; and c) increased gas yields). Leachate recycling would also seem to be a positive measure when the alternative (that is absence of moisture within a landfill) is considered. Modern lined and capped containment landfill practice is often referred to as "dry-tomb landfilling", which will postpone the onset of emissions, rather than prevent them. If the waste is too dry it will never decompose. If decomposition does not take place or a geological (or other) event disrupts the lining, groundwater pollution will take place from landfill leachate. In reality groundwater pollution will still occur unless decomposition and "flushing" has taken place when the containment ruptures, but at least encouraging decomposition is a start.

Although leachate recycling has been gaining recognition worldwide, the merits of recycling MSW leachate are controversial. Leachate recycling should in any event not be allowed to continue to the point when excessive leachate retention periods in contact with the waste then raise the non-organic pollutant loads which are usually diffusion rate limited. Leachate recycling in composite-lined landfills where adequate leachate drainage is present to ensure that permitted maximum leachate levels are not exceeded, and a high level of monitoring is undertaken to demonstrate leachate recirculation (Enviros, 2006).

2.5.2 Recirculation in open dumps

Recirculation of leachate in open dumps can also be proposed as the following:

a) Leachate recirculation can provide balance moisture during dry weather when leachate which would otherwise escape can be soaked back into the waste

b) By improving the wetting of the waste, stabilization will be improved and if landfill gas can be collected the amount of gas and the early payback potential to recoup the investment will be maximized. Utilization of gas is an other benefit to the local community as it generates bio-fuel energy that can be connected to the local power grid; and

c) After initial fermentation/ acetogenesis the recirculated leachate will be easer to treate aerobically.

Other severe risks from recirculation arise if the level of leachate in the landfill is not carefully monitored and controlled. If leachate levels rise in the waste, breakouts may rapidly develop uncontrollable and cause surface water pollution, however, worse can occur. A number of landfills have suffered collapse of sloping faces and the presence of high leachate levels has been a major if not the primary contributor (Enviros, 2006).

One of the main purposes of leachate recirculation is to optimize the water content in order to accelerate waste degradation. In the same way, the liquid flow enables to dilute the even - tual presence of inhibitors and provides nutrients for biological degradation enhancement.

Beneficial effects on waste degradation (and, in consequence, on biogas production, leachate organic load reduction and waste settlements).However, at large scale, optimization of water distribution and quantification of effects represent still an important
optimization of water distribution and quantification of effects represent still an important
challenge. A good typical monitoring (hydraulic balance of liquids, quality of leachate reci rculated and collected, biogas flow rate, quality of biogas collected and settlements) can give overall vision of leachate recirculation performance that can be sufficient for bioreactor operators (Barina, 2005)

2.5.3 Benefits of leachate recirculation

Leachate recirculation in MSW landfills offers these key benefits: (1) reduction in leachate treatment and disposal costs; (2) accelerated decomposition and settlement of waste resulting in gain in airspace; (3) acceleration in gas production; and (4) potential reduction in post-closure care period and associated costs. Most common methods for long-term leachate recirculation in MSW landfills include vertical injection wells and horizontal trenches. Both of these methods result in non-uniform distribution of leachate. In addition, the amount of leachate that can be recirculated by these methods is not sufficient to get rid off all leachate typically produced by landfills located in humid regions. Non-uniform distribution of leachate leads to uneven landfill settlement and hence higher maintenance costs (Khire, 2006).

There are several methods of leachate recirculation to be applied into landfill such as:

a) Direct application to the waste during disposal-During this process the leachate is added to the incoming solid waste while it is being unloaded, deposited, and compacted. The problems with this method include odor problems, health risks due to exposure, exposure to landfill equipment and machinery, and off-site migration due to drift. This method also requires a leachate storage facility for periods such as high winds, rainfall, and landfill shutdowns when the leachate cannot be applied.

b) Spray Irrigation of landfill surface-Here leachate is applied to the landfill surface in the same method that irrigation water is applied to crops. This method is beneficial because it allows the leachate to be applied to a larger portion of the landfill, and because the leachate volume is reduced due to evaporation. However, the disadvantages associated with direct application are associated with this method as well.

c) Surface application-This is achieved through ponding or spreading the leachate. The ponds are generally formed in landfill areas that have been isolated with soil berms or within excavated sites in the solid waste. The disadvantages of these methods include an increase in the amount of required land area, and monitoring of the ponds to detect seepage, leaks, and breaks that would make it possible for leachate to escape directly or with storm water runoff.

d) Subsurface application-This is achieved through placing either vertical recharge wells or horizontal drain fields within the solid waste. There is a large amount of excavation and construction required with this method, but the risk of atmospheric exposure is drastically reduced (Fellin et al., 1996)

2.6 Landfill Field Capacity

The amount of moisture by weigh or volumetric basis, expressed as percentage of MSW, (wet or dry) is the moisture content of waste. Moisture added to waste beyond its holding capacity constitutes the amount of leachate produced from the waste .The quantity of water that can be held within body of landfill is referred as field capacity. The amount of water that excess of the landfill field capacity is defined as leachate. It has been reported by Yuen et al (2000) that the field capacity of MSW range from 14 to 44 (v/v) depending on the waste compaction.

The settlement of landfills is caused by waste decomposition and compression. The settlement invokes problems associated for leachate and gas collection systems and the structural integrity of a landfill. Common problems due to vertical strain are rupture of conduits and fixtures used for leachate recirculation and gas collection, ground water pollution from washout and direct ingress. Secondary problems may arise from the rupture of cover soil/layer and expose the MSW to atmosphere and thereby create vector nuisance. Field scale experiments with leachate recirculation prove rapid biodegradation and settlement in MSW landfills (Vaidya, 2002).

MSW settlement is observed in three distinct stages, these are initial compression, primary compression and secondary compression. Initial compression occurs on application of a direct load or overburden in a landfill. This results in an immediate compaction of void space and causes particle deformation to some extent. Primary settlement is significant after load application for about a month, after which secondary compression effects become significant and approach that of primary settlement in magnitude. Secondary compression is a result of creep and biological decay but independent of the stress on the waste and can result settlement of 25 % of waste thickness of which biological decomposition is reported to account for 18-24 % of waste thickness (Vaidya, 2002). The field capacity is expected to change with time as a result of the change with waste density, composition and age of waste including affected by overburdening pressure and settlement (Yuen et al., 2000).

2.7 Leachate Management Options

Leachate management options are summarized by Tchobanoglous et al. (1993) including leachate evaporation, treatment followed by disposal and discharge to municipal wastewater collection system.

2.7.1 Leachate evaporation

Leachate was storage in leachate evaporation ponds that had liner. It is evaporated by natural sunlight. However, lined leachate evaporation ponds may have covering or uncovering depending on the climatic condition of each location and operation decides.

2.7.2 Leachate treatment

Treatment of leachate by biological processes or physical/chemical processes and options are selected regarding to the concentration of pollutant in leachate that need to be removed.

2.7.3 Discharge to wastewater treatment plant

In case of landfill is located near a wastewater collection system or available to connect that system. Leachate can be discharged to system and treated at wastewater treatment plant. However, pre-treatment of leachate is necessary for reducing organic content before discharge to sewer.

2.8 Influence of Tropical Seasonal Variation on Landfill Leachate

Most landfill sites in Asia are located in a monsoon climate. Climatic condition in tropical countries such as Thailand, Malaysia, etc. can be characterized by rainy season and dry season. There is high intensity rainfall (up to 80 mm/day and above) in rainy season while dry season does not have rainfall. It has been observed that 220-250 days per year shows no rain at all and there exists distinct arid period of about 4 months. With a medium temperature of 28˚C and an average sunshine duration of 6.8 hours the solar radiation is computed to be 18.8 $MJ/m^2/day$. This results in high evaporation rates around 50% (Manandhar and Tränkler, 2000). Climatic variation can significantly affect the leachate quantity and quality (Visvanathan et al., 2003). During dry season leachate and gas production nearly stop and restarts immediately with the merge of the rainy season (Ranaweera and Tränkler, 2001).

Landfill lysimeters were simulated at Environmental Research Station of AIT, Thailand at least 3-4 years. Effects of tropical climatic correlation with leachate characteristics were studied by Tränkler et al., (2005) and Tubtimthai (2003). Mainly operation modes of study included: 1) Simulation of sanitary landfill with triple layer covers system, 2) Pretreatment and pre-sorting effects on leachate generation and quality, 3) Effect of top cover design on leachate generation and 4) Effect of climatic influence on open dump simulation. Fives lysimeters were operated: sanitary landfill with standard top cover layer (reference), sanitary landfill with top cover layer (no barrier layer), sanitary landfill with top cover layer (one layer mixed with compost waste, no barrier layer), pre-treated waste landfill and open cell. Normally, Thailand has three seasons, which are rainy season (from May until mid- November), winter season (from mid-November until mid-February) and summer season (from mid-February until mid-May). However, reality conditions of seasonal variation were observed in this study for determining relationship of weather condition and leachate generation, leachate characteristics etc.

Comparison and interpretation of all results were concluded that leachate generation and its quality are affected from;

- Climatic condition (rainy season and dry season): rainfall pattern effects leachate generation. During dry season means less or no precipitation due to small amount of leachate generation, less cumulative of leachate or stagnant discharge. During rainy season which normally had intensive rainfall, more leachate generation and highly cumulative than dry season. Furthermore, in term of leachate characteristics were found that fluctuation with phase of decomposition and rainfall pattern.

- Top cover layer design (standard cover, alternatives cover or no cover): open dump had only thin sand cover due to high water infiltration caused high leachate generation.

- Properties of MSW input (pre-treated waste, MSW compaction, moisture content of incoming MSW, etc.): pre-treated waste by composting result in lowest COD and TKN concentration and loading. On the other hand, open cell lysimeter produced highest COD and TKN loading (20% and 180%, respectively, more than sanitary landfill lysimeter).

In addition, settlement of landfill lysimeters was observed. Primary settlement of MSW in lysimeter determined during initially of MSW placement. After one year operation are defined as secondary settlement. Operation MSW with high compaction caused less settlement such as pre-treated waste lysimeter. In contrast, low compaction caused high settlement such as open cell lysimeter. In case of open cell landfill lysimeter relate with tropical climatic condition, the study recommended that open cell should combine with leachate recirculation, because open cell practice which no top cover allows water infiltration. Thus, it provides moisture content for biodegrading of MSW. And as a result of highest leachate generation during rainy season (leachate formation more than 60% of the precipitation) in this operation, lechate should be stored and recirculated during dry season. This concept was supported by Hogland et al., (2005), Asian countries need to be improvements to the concept of leacahte recirculation with a secure liner system.

Chapter 3

Methodology

3.1 Introduction

This research focuses on the municipal solid waste disposal in open dump method. Four lysimeters were used to study the operation of open cell lysimeters under different strategies. The influence of the application of aeration into the waste bed and its combination with flushing (leachate recirculation) in open cell landfill operation was studied. Moreover, leachate management was also conducted. The nitrogen and carbon balances in open cell lysimeters were also studied. The main methodology can be divided into two tasks as follows:

1) Leachate management for open cell landfill lysimeters: Leachate generated from Open Cell No.2 and Open Cell No.3 was used for flushing operation through leachate recirculation. The long term effect of leachate recirculation in wetting the waste up to its field capacity in relation to climatic variations was performed. The amount and quality of leachate were monitored under the influence of actual climate. The application operation started in dry season (November, 2006) thus the amount of leachate were produced from both Open Cell No.2 and No. 3 is not enough in recirculation of 30 L/day simulated to average rainfall . In order to produce leachate the water were used for leachate recirculation into both lysimeters until leachate were produce around 500 liters.

2) Application of aeration and its combination with flushing was conducted and studied in Open Cell No.3. The operation, monitoring, and comparison of four landfill lysimeters (OC1, OC2, OC3, and CLF) were performed. Carbon and nitrogen balances were studied. The fate and profile of heavy metals (Cd, Cr, Cu, Mn, Pb and Zn) in the open cell were studied.

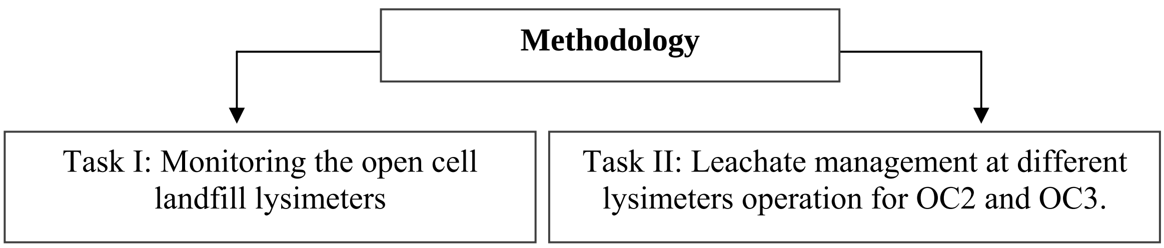


Figure 3.1 Flowchart of methodology

3.2 Task I: Monitoring Open Cell Landfill Lysimeters

The four landfill lysimeters constructed at Environmental Research Station of AIT was used in this study. The details of landfill lysimeter construction are shown in Figure 3.2

In this study, four lysimeters were used simulating open dump approach (OC1, OC2, and OC3) and Conventional landfill (CLF). The operation mode of lysimeter is shown in Table 3.1 and the details of Task I were presented in Figure 3.3.

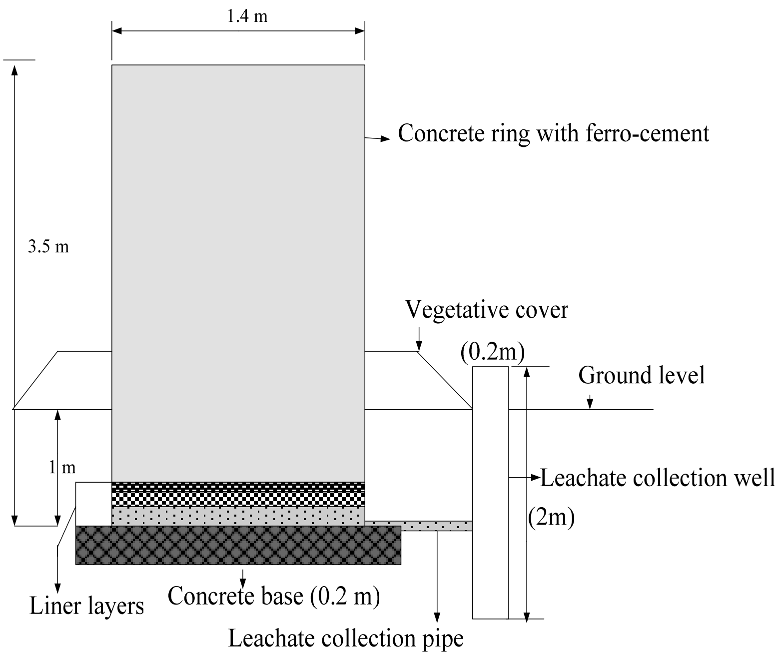


Figure 3.2 Details of landfill lysimeter

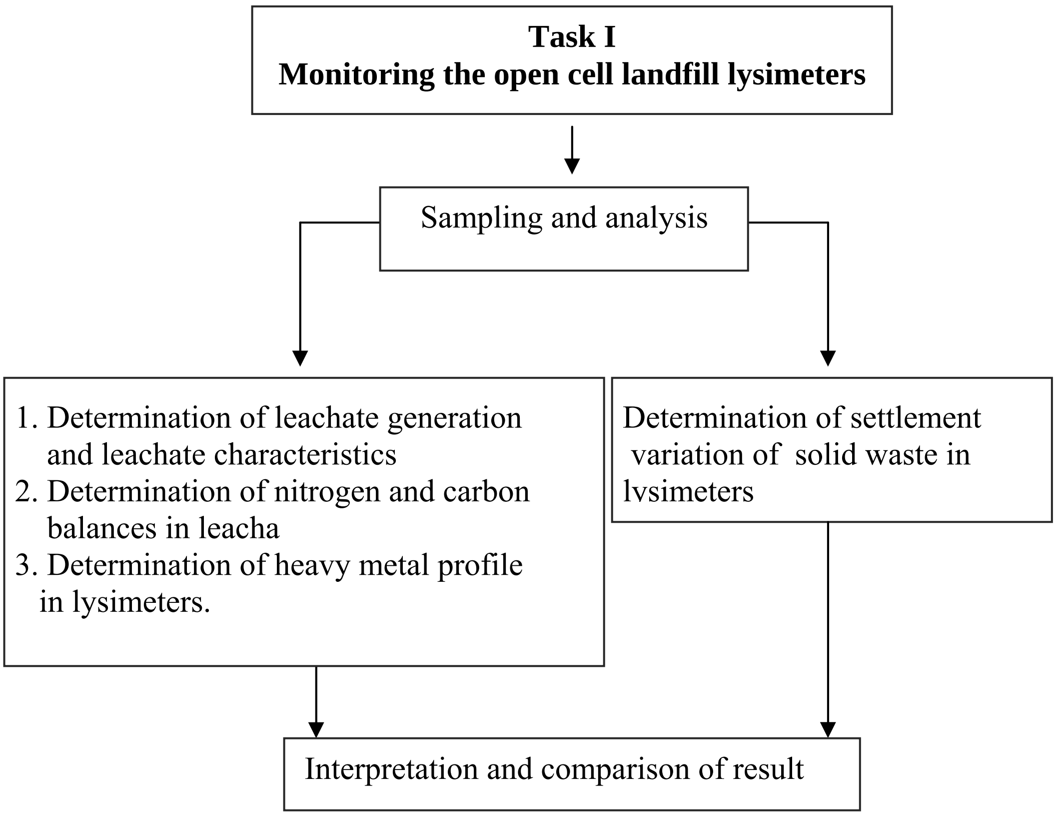


Figure 3.3 Flow chart of methodology of Task I

Table 3.1 Details of landfill lysimeters operation

Lysimeters	Operations				
	Input material	**Compaction density**	**Cover layer**	**flushing**	**Aeration**
OC 1	Fresh and unsorted MSW	490 kg/m^3	No top cover layer, but was covered with 5 cm sand layer just to avoid direct contact of waste with external environment. Waste loading was conducted in 6 intervals; approximately 300 kg of waste will be loaded per time until it reaches to a height 2.4 m and after 6 weeks the lysimeter was covered with sand.	No	No
OC 2	Fresh and unsorted MSW	490 kg/m^3	No top cover layer, but is covered with 5 cm sand layer just to avoid direct contact of waste with external environment. Waste loading was conducted in 6 intervals; approximately 300 kg of waste was loaded per time until it reaches to a height 2.4 m and after 6 weeks the lysimeter was covered with sand.	Yes	No
OC 3	Fresh and unsorted MSW	490 kg/m^3	No top cover layer, but it covered with 5 cm sand layer just to avoid direct contact of waste with external environment. Waste loading was conducted in 6 intervals; approximately 300 kg of waste will be loaded per time until it reaches to a height 2.4 m and after 6 weeks the lysimeter was covered with sand.	Yes	Yes
C LF	Fresh and unsorted MSW	500 kg/m^3	Intermediate cover (15 cm soil layer) and top cover (40 cm drainage layer; sand, silt and clay mixture in the ratio 70:15:15, 20 cm barrier layer and 10 cm gravel foundation layer). Waste loading only one time placement until the height of 2.4 m	No	No

3.2.1 Lysimeters preparation

The solid waste was collected from Taklong municipality was loaded directly into each lysimeter. There were six times in loading of MSW into lysimeter Open Cell No. 1, No. 2 and No. 3 was filled with fresh and unsorted municipal solid waste in 6 layers, one layer approximately 40 cm equivalent to around 300 kg of waste to be loaded every week and covered by 5 cm of sand layer in compaction density of around 490 kg/m^3 until it reached about 2.4 m height of waste in lysimeters. The open cell landfill lysimeters have a 5 cm of thick sand cover was used to avoid contact with the external environment.

But for Conventional landfill (CLF) was loaded of fresh and unsorted MSW amount 1, 800kg in compaction density 500 kg/m^3 had loaded only one time until it reached about 2.4 m height of waste. The Conventional Landfill had an intermediate cover (15 cm soil layer) and top cover (40 cm drainage layer; sand, silt and clay mixture in the ratio 70:15:15, 20 cm barrier layer and 10 cm gravel foundation layer, respectively from top to down). Figure 3.4 represents the manner of waste loading into each lysimeters.

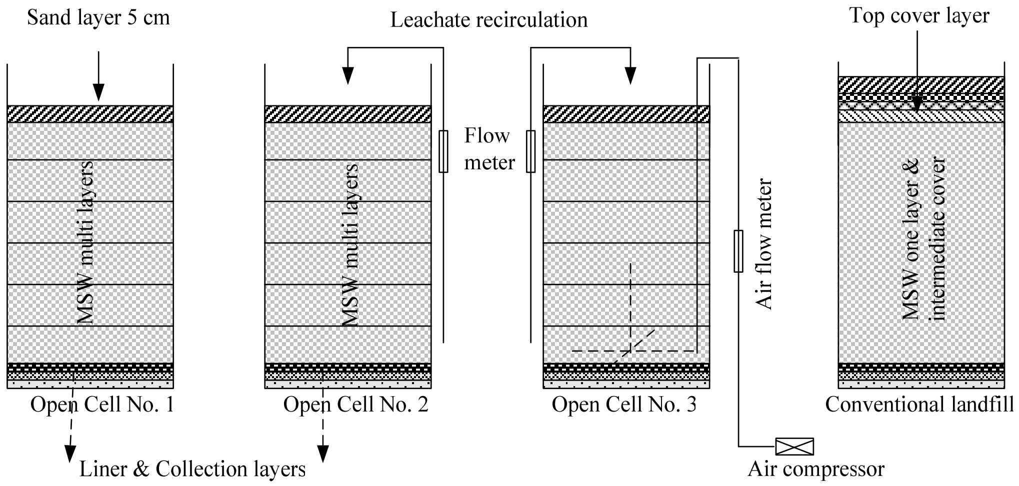


Figure 3.4 Flow chart of lysimeters preparation

3.2.2 Sampling and analysis

a) Determination of physical and chemical properties of MSW

The collected MSW was sampled by a quartering method at every loading of MSW at lysimeters. Physical characteristics in terms of bulk density (kg/m^3) and compositions of MSW (% by weight) were determined. Determination of moisture content (% MC), total solid (% TS), volatile solid (% VS), ash content and total organic carbon (% TOC) were considered.

b) Determination of leachate generation and leachate characteristics

Leachate was pumped by using submersible pump for determining leachate generation and leachate was kept in sampling bottles and preserved for leachate characteristics analysis. The determination of parameters includes pH, conductivity, alkalinity, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3 -N), organic nitrogen (organic-N),Total Organic Carbon (TOC), Total Nitrogen (TN), Nitrate, Nitrite, Total Solid (TS), Volatile Solid (VS), Total Suspended Solid (TSS), Total Dissolve Solid (TDS), Total Volatile Suspended Solid (TVSS) and selected heavy metals (Cd, Cr, Cu, Mn, Pb and Zn). The frequency of sampling and analysis was four times per month for Open Cell No.1 (OC 1) and Conventional landfill (CLF) and for the Open Cell No. 2, No. 3, Leachate recirculation No.2, & No. 3 (ROC2, ROC 3) twelve times per month.

Table 3.2 Determination physical and chemical properties of MSW

Parameters	Analytical method	Instruments
MSW compositions	Quartering method, hand sorting and weighting	Weight Balance
Bulk density	Quartering method and weighting	Weight Balance
Moisture content	Gravimetric method (drying at temperature < 100˚ C)	Oven and Analytical balance
Total solid	Gravimetric method (105˚ C - moisture content)	Oven and Analytical balance
Volatile solid	Gravimetric method (ignition at temperature 550˚ C)	Furnace and Analytical balance
Ash content	Gravimetric method (total solid - volatile solid)	Furnace and Analytical balance
Percentage of Carbon & Nitrogen	Gravimetric method (Volatile solid)	Oven, Analytical balance

Note: - Sampling and analysis of MSW properties were followed ASTM Standard (American Society for Testing and Materials) (1992) which modified by EEM laboratory.
- All units except bulk density (kg/m^3) are in % by weight.

c) Determination of settlement variation of MSW

Settlement of MSW from each lysimeter was measured in terms of total settlement variation. The frequency of settlement measurement was measured every two days during first month of operation every week at the second and third month and then once a month for the succeeding months. In this study therefore, waste settlement was measured every day.

3.2.3 Data collection

Primary data was the results of sampling and analysis of MSW properties, leachate quantity and leachate quality, nitrogen and carbon balances in leachate, some heavy metals and settlement variation of MSW. Secondary data was the previous experimental data and literature review.

3.2.4 Interpretation and comparison of the results

Comparison of the results of different open cell landfill operation in terms of the leachate quantity, leachate quality, stabilization, biodegradability and settlement of MSW, all of these were determined and the results were interpreted.

3.3 Task II: Determining Leachate Management for Open Cell Landfill Lysimeters

Leachate management of open cell landfill lysimeters, Open Cell: OC1, OC2, OC3, CLF is carry out by considering on experimental analysis, leachate management, and leachate recirculation. Figure 3.5 illustrates the details of Task II.

Table 3.3 Leachate analyses for running experiment for 5 months from December 2006 – April 2007

Parameters	Methods	Equipments	Interference
pH		pH meter	-
COD	Closed reflux method	Closed reflux apparatus	Chloride iron and other reagent that activates the silver ion etc.
BOD_5	Dilution method	Incubator, titration apparatuses, etc.	Chloride iron and other reagent that activates the silver ion etc.
TOC	Dilution method	TOC machine	pH adjustion range from 2-3
NO_3 & NO_2	Dilution method	Spectrophotometer machine	Color reagent , Nitrate powder reagent
TSS	Filtration and evaporation at temperature 103 - 105˚C	Oven and analytical balance	Large, floating particles or submerged agglomerates of non homogenous materials, visible floating oil and grease etc.
TDS	Filtration and evaporation at temperature 180˚C	Oven and analytical balance, filtration apparatuses, glass fiber, filter, dish, suction flask, etc.	Large, floating particles or submerged agglomerates of non homogenous materials, visible floating oil and grease etc
TKN	Kejeldahl	Digestion and distillation apparatuses	Nitrate, inorganic salts and solid and organic matter
NH_3 -N	Distillation and titration method	Distillation and titration apparatuses	Volatile alkaline compounds and residual chlorine
TS	Evaporation and dry at temperature re 103 -105˚C	Oven and analytical balance	Large, floating particles or submerged agglomerates of non homogenous materials, visible floating oil and grease etc.
VS	Ignition at temp erature 550˚C	Oven and analytical balance	Loss of ammonium carbon ate and volatile organic matter during drying
TVSS	Ignition at temp erature 550˚C	Oven and analytical balance	Loss of ammonium carbon ate and volatile organic matter during drying
Alkalinity	Titration	Titration apparatuses	Soaps oily matter, suspend-ed solid, precipitation
Conductivity	Conductivity	Conductivity meter	
Heavy metals (Mn,Cr,Cd,Pb, Ni,Zn & Cu)		Inductively coupled, plasma- optical, emission spectrometry	Metrix effect, significant dissolved solid, ionization interference

Note: - Sampling and analysis of leachate was based on Standard Methods for the examination of Water and Wastewater. (20th Ed.), APHA et al.,(2000).
All units are in mg/L except pH (no unit) and conductivity (mS /cm).

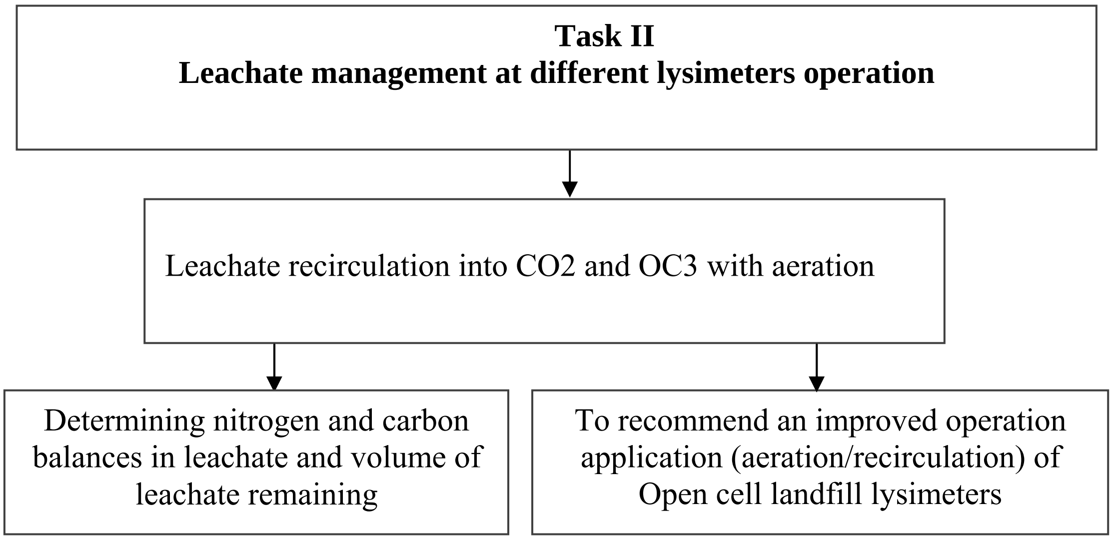


Figure 3.5 Flowchart of methodology of Task II

3.3.1 Experiments on leachate recirculation

Leachate generation from Open Cell No.2 (OC2) and No. 3 (OC3) was pumped and collected into separate storage tanks for use to recirculation on both lysimeters but the amount of leachate were generated from lysimeters is not enough for leachate recirculation 30 L/day because of the period of application is dry season was started from November 2006 in this case tap water amount 500 liters was used simulated to rainfall in order to produce leachate form both lysimeters.

a) Determining leachate balance of Open Cell No.2 and No. 3

The main water inflow into lysimeters was had only recirculated leachate. Water outflow was leachate production and evaporation. Initial moisture content of MSW, leachate stored in the body of lysimeter, in storage tanks and evapotranspiration were other factors to influence leachate balance.

b) Determining the volume of leachate remaining

Leachate recirculation was provided by directly pumping it from the storage tanks into selected lysimeters. The storage tanks were the close tank, which not allowed high evaporation. Therefore, the amount of leachate in these tanks is leachate used for recirculation and leachate remaining in storage tanks and subtracting leachate loss as evaporation. Sampling and analysis of leachate recirculated were analysis the same parameter like as OC1, OC2, OC3 and CLF. The results of analysis will be continuously investigated for balancing system and protection of clogging of leachate collection and recirculation system. The necessity of pre-treated leachate before recirculation was considered too. The flow chart of leachate recirculation and leachate recirculation with aeration are shows in Figure 3.6 and Figure 3.7.

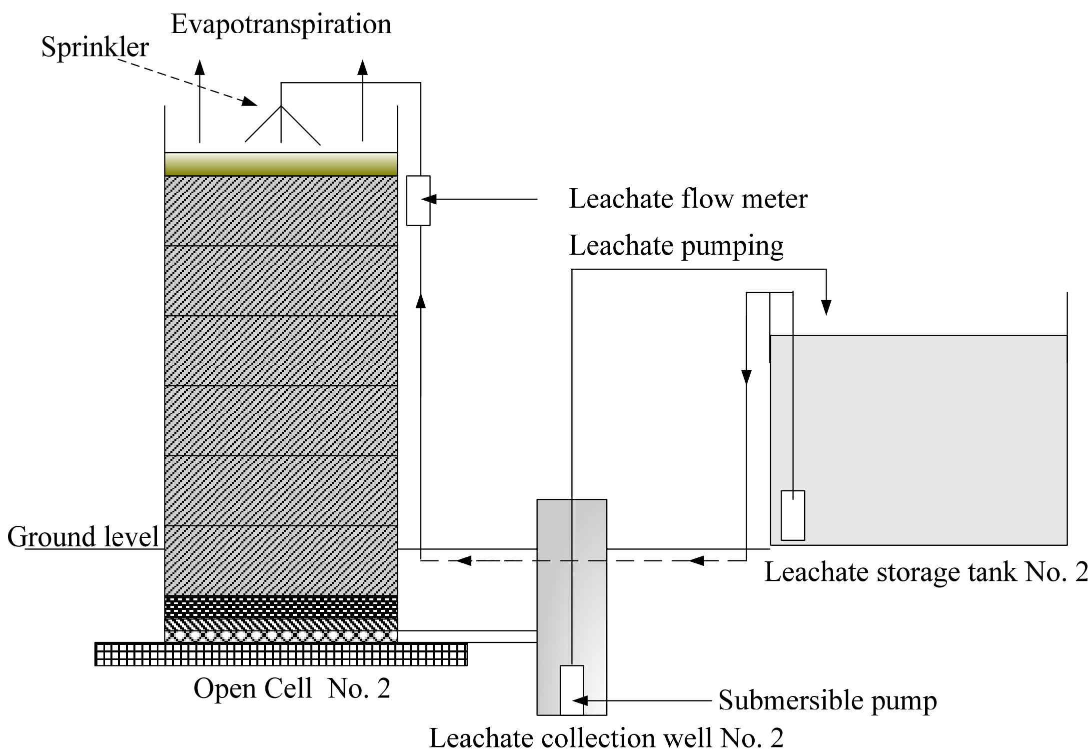


Figure 3.6 Leachate recirculation System in OC 2

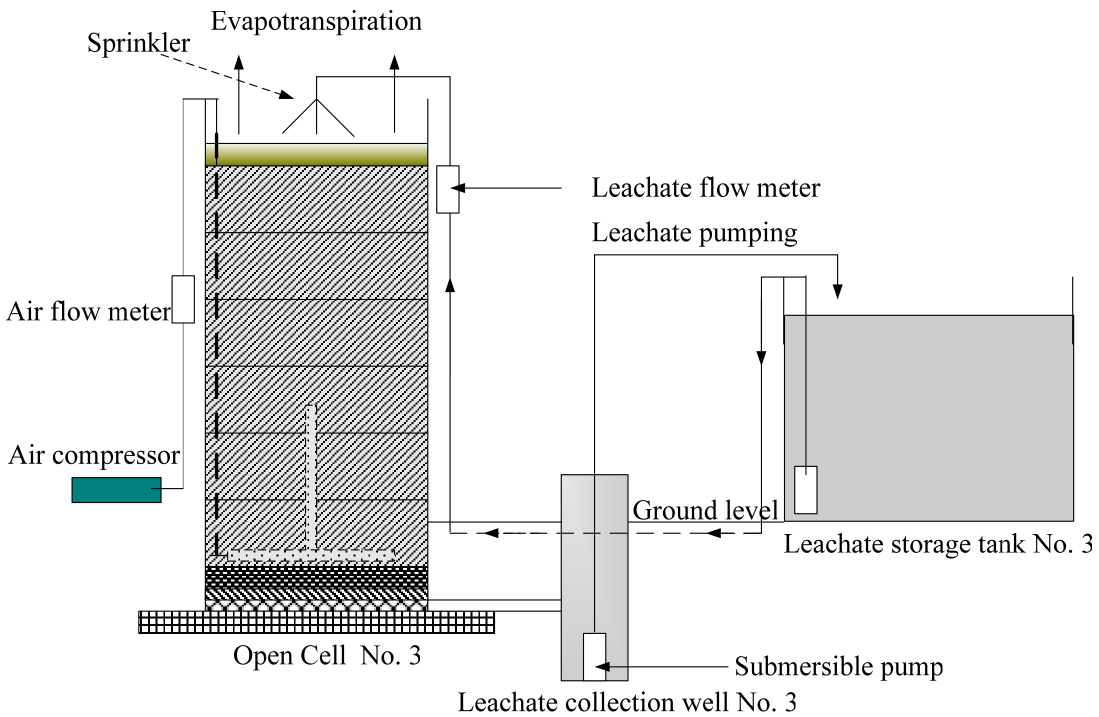


Figure 3.7 Aeration and leachate recirculation System in OC 3

Chapter 4

Results and Discussion

4.1 Physical and Chemical Properties of MSW in Landfill Lysimeters

Generally, low and middle income Asian countries have a high percentage of food waste or compostable organic matter in the waste stream. The ranges of food waste in low and middle income countries are around 40-85% and 20-65% of the total, respectively. In Thailand, MSW consists of food waste 62% of total waste, Paper 4%, Plastic 24%, Glass 4%, Leather and rubber 3%, Textile 1% and other waste 2%. In this study, all four landfill lysimeters had same source of MSW taken from Taklong Municipality, Pathumthani. Figure 4.1 indicates that the major portion of MSW is food waste and the minor portions of solid waste are plastic and paper.

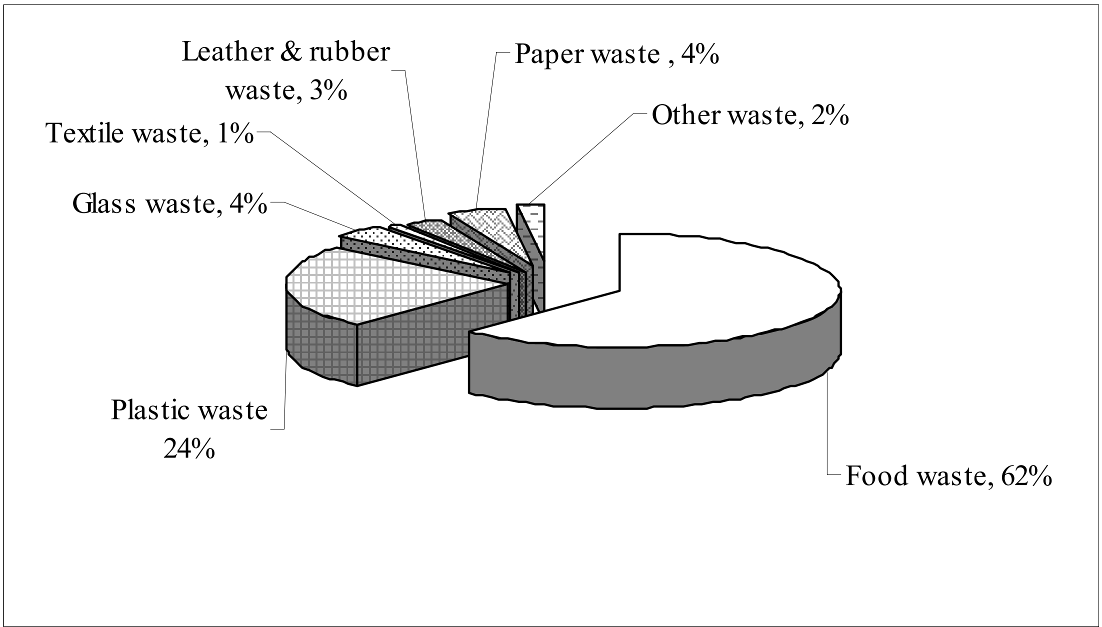


Figure 4.1 MSW compositions from Pathumthani Municipality

Results of analysis of solid waste samples showed that the average initial moisture content of MSW was 46% and the average bulk density was 316 kg/m^3. Table 4.1 showed the percentage values of moisture content, Total solid, Volatile solid, Ash content, Total organic Carbon and Nitrogen of MSW in 4 lysimeters set up OC1, OC2, OC3 were loaded MSW in six times, one time 300 kg of MSW, compaction density 490 kg/m^3 and CLF were loaded only one time of MSW amount 1,800 kg in compaction density 500 kg/m^3. It is noted that the results of properties of MSW were determined based on the representative solid waste samples taken from entire MSW before placing it into each lysimeters. Moreover, the heavy metals concentration in MSW were loaded into each landfill lysimeters such as Mn, Cr, Cd, Pb, Ni, Zn and Cu are also analyzed and the result are presented in Table 4.2 and 4.3

Table 4.1 Physical and Chemical composition of MSW

MSW by % weight	4 Nov 06	11Nov 06	18 Nov 06	25 Nov 06	2 Dec 06	9 Dec 06	Average (%)
I. Physical properties							
Food	63	59	60	64	65	60	62
Plastic	24.5	26	23	28	19	24	24
Paper	2.5	2	6.2	3	6	3.5	4
Textile	3.5	3	2.3	1	1	1	1
Leather/Rub	2	6	1.5	1	3	2.5	3
Glass	3	2.5	4.8	2	4	5.5	4
Others	1.5	1.5	3.3	1	2	3.5	2
Bulk density (kg/m^3)	320.83	295.83	310.83	299.99	335.83	333.33	316 (kg/m^3)
II. Chemical properties							
Moisture content (%)	45.18	49.91	53.41	49.06	41	36.93	46
TS	54.82	50.09	46.59	50.94	58.77	63.07	54
VS	52	59.34	52.6	62.25	49.75	34.67	52
Ash	48	40.66	47.4	37.75	50.25	65.33	48
% Carbon	28.88	32.96	29.22	34	27.63	19.26	29
% Nitrogen	3.71	4.23	3.75	4.44	3.55	2.47	4

Table 4.2 Heavy metal analysis in MSW

Sample Name	Weight of Sample (g)	Concentration (mg/kg)						
		Mn	**Cr**	**Cd**	**Pb**	**Ni**	**Zn**	**Cu**
OC 1	0.96	107.05	15.78	0.23	13.24	11.28	130.31	21.60
OC 2	1.01	127.59	19.52	19.52	20.55	12.09	158.91	26.79
OC 3	1.01	119.37	19.85	19.85	14.23	12.00	118.12	21.56
CLF	1.01	120.16	16.98	16.98	17.67	11.71	130.20	22.26

Table 4.3 Heavy metal analysis in total weight of MSW

Sample Name	Total weight Of MSW (kg)	Weight of Sample (g)	Heavy metals load (kg) from total weight of MSW						
			Mn	Cr	Cd	Pb	Ni	Zn	Cu
OC 1	1,800	0.96	193	28	0.4	24	20	23	39
OC 2	1,800	1.01	230	35	35	37	22	29	48
OC 3	1,800	1.01	215	36	36	26	22	22	39
CLF	1,800	1.01	216	31	31	32	21	21	40

4.2 Influence of Operational on Leachate Generation and Leachate Characteristics

Four landfill lysimeters were operated in different modes as discussed in Chapter 3. The different operations affected the quantity and quality of leachate which are discussed in following section.

4.2.1 Leachate Generation

Leachate generation is not constant and it depends on the initial moisture content, decomposition of solid waste, and the influence of climate (Tränkler et al., 2005). The study period covers only dry season (November 2006 – April 2007). MSW was started loading one time per week into Open Cell landfill lysimeters No.1, No.2, and No.3 on 4 November, 2006 and finish loading on 9 December, 2006 the total volume of MSW IS 1,800 kg. However, Conventional landfill was loaded only one time the total volume of MSW is 1,800 kg. Leachate collection was started on 22 December, 2006 the amount of leachate generated from four landfill lysimeters in this period (4 November to 22 December, 2006) are show in Table 4.4.

Table 4.4 Leachate generation from different landfill lysimeters

Period	Quantity of Leachate generation (L) from Open cell landfill lysimeters			
	Open Cell No. 1	Open Cell No. 2	Open Cell No. 3	Conventional Landfill
4 Nov - 22 Dec 06	88	115	98	100

Leachate generation from Open Cell No.2 and Open Cell No. 3 are not enough for using recirculation back into both landfill in the flow rate of 3 L/min in 10 min/day and 3 days/week. Therefore, water has been used for flushing into both landfills as substitute of rainfall amount 335 liters and continuous recirculating of water amount 35 L/day until leachate to be collected amount 500 liters. Leachate recirculation was introduced on Open Cell No.2 and No. 3 started from 15 January, 2007 in the flow rate 3L/min in 10 min/day in three times /week. The operation application of Open Cell No. 3 is different from Open Cell No. 2 via aeration supply in the flow rate 4L/min in the process 2 hours aeration per 4 hours stop.

The leachate generated from all lysimeters was small amount. Table 4.5 and Figure 4.2 show the quantity and cumulative of leachate generated from all landfill lysimeters. Leachate generated from OC 2 and OC 3 was stored in storage tank No.2 and No.3 for recirculation purpose. Lechate recirculation was to provide the moisture content for accelerating the biodegradation in landfill. In addition, the recirculation and evaporation of collected leachate was leading to the reduction in total amount of leachate remaining for treatment. The details will be further discussed in leachate management for open cell landfill

4.2.2 Leachate Characteristics

Table 4.6 presents the concentration range of leachate characteristics from four landfill lysimeters and Table 4.7 and 4.8 presents the concentration range of heavy metal in leachate and heavy metal load in total volume of leachate per month and Table 4.9 presented the total heavy metal load (mg) leached out from landfill lysimeters after five months operation. Open Cell Landfill operated with leachate recirculation and aeration supplied is show higher load heavy metal leached out more than Open Cell Landfill operation without leachate recirculation and aeration supply.

Leachate characteristics can be divided in four groups for discussing the results. This consists of the pH and physical properties of landfill leachate, organic contents of landfill leachate, inorganic contents and Carbon and Nitrogen load of landfill leachate. The changes of leachate concentration can be used as biodegradation indicators (Yuen, 2001)

Table 4.5 Leachate generation (L) from four landfill lysimeters

Date	OC. 1	Cumula-tive (L)	OC. 2	Cumula-tive (L)	OC. 3	Cumula-tive (L)	CLF	Cumula-tive (L)
22-12- 06	88	88	115	115	98	98	100	100
27-12-06	45	133	18	133	5	103	30	130
29-12-06	4	137	100	233	130	233	3	133
30-12-06	7	144	55	288	25	258	6	139
31-12-06	2	146	47	335	20	278	1	140
01-01-07	2	148	19	354	10	288	1	141
04-01-07	4	152	12	366	19	307	3	144
12-01-07	4	156	98	464	178	485	7	151
19-01-07	4	160	153	617	110	595	2	153
26-01-07	4	164	55	672	45	640	3	156
02-02-07	4	168	53	725	40	680	3	159
09-02-07	3	171	64	789	59	739	2	161
16-02-07	8	179	70	859	63	802	4	165
23-02-07	6	185	43	902	40	842	3	168
02-03-07	6	191	22	924	26	868	3	171
09-03-07	6	197	33	957	39	907	3	174
16-03-07	5	202	49	1006	54	961	4	178
23-03-07	5	207	56	1062	63	1024	4	182
30-03-7	9	216	40	1102	37	1061	2	184
02-04-07	3	219	18	1120	14	1075	2	186

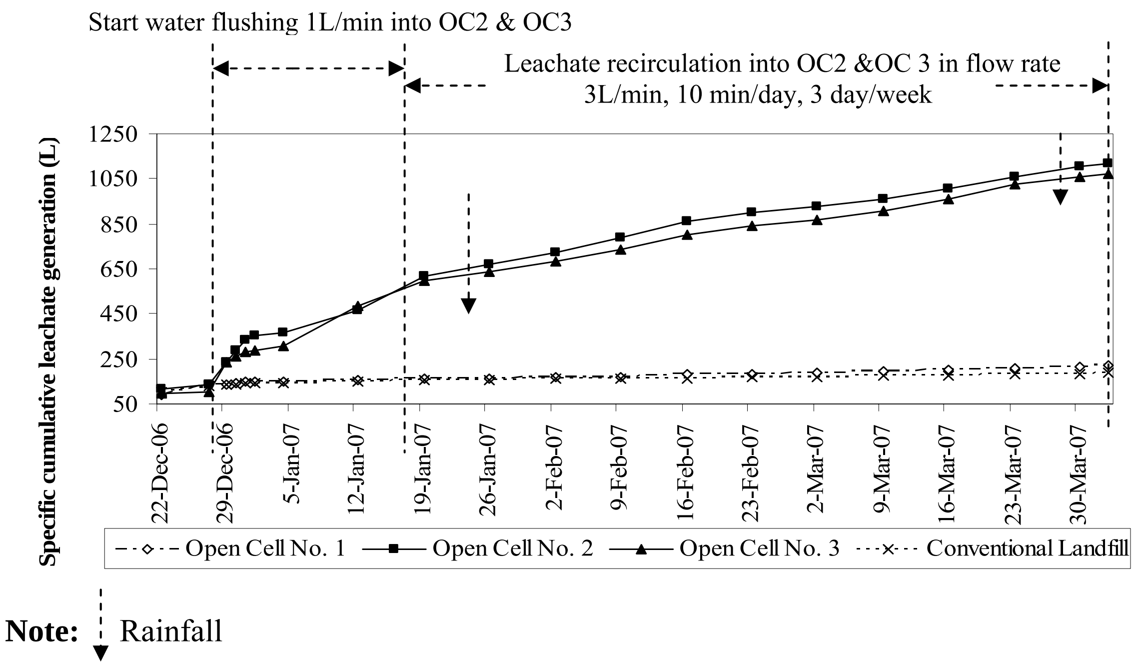


Figure 4.2 Cumulative of Leachate generation from landfill lysimeters

Table 4.6 Leachate characteristics of four landfill lysimeters

Parameters	Unit	Open Cell No.1	Open Cell No. 2	Open Cell No. 3	Conven - landfilll
pH		7.26 – 7.81	7.16 – 8.35	6.61 – 7.89	7.18 – 8.83
Conductivity	(mS/cm)	40.15 – 62.85	17.53 – 42.13	19.45 – 44.48	34.75 – 61.20
Alkalinity	(mg/L)	8,300 – 13,500	5,800 – 10,100	3,300 – 8,700	8,120 – 12,200
COD	(mg/L)	1,600 – 17,200	1,920 – 33,998	3,264 – 32,130	2,000 -22,000
BOD	(mg/L)	359 – 14,726	853 – 23,581	963 – 20,589	897 – 18,509
BOD/COD	(mg/L)	0.1 – 0.9	0.1 – 0.9	0.1 – 0.9	0.1 – 0.9
TKN	(mg/L)	1,280 – 2,176	918 – 1,512	902 – 1,266	1,338 – 2,276
NH_3 -N	(mg/L)	994 – 1,952	664 – 1,246	412 – 1,128	1,005 – 1,952
Organic-N	(mg/L)	23 - 734	16 - 506	17 - 532	90 -737
DOC	(mg/L)	368 – 5,815	241 – 9,345	280 – 9,355	351 – 6,500
TN	(mg/L)	923 – 2,554	619 – 2,337	261 – 1,824	831 – 2,500
Nitrate	(mg/L)	22 - 493	4 - 598	7 - 658	10 - 428
Nitrite	(mg/L)	52 - 553	42 - 633	66 - 644	68 - 470
TS	(mg/L)	5,108 – 97,620	3,812 – 80,836	2,859 – 72,724	4,260 – 46,004
VS	(mg/L)	3,312 – 91,364	2,960 – 41,144	3,016 – 36,404	3,096 – 15,962
TDS	(mg/L)	3,676 – 16,320	3,036 – 32,904	3,004 – 29,308	608 – 5,036
TSS	(mg/L)	152 – 4,436	148 – 35,080	248 – 2,412	288 – 4,244
TVSS	(mg/L)	120 – 1,732	64 – 780	96 - 684	112 - 652

Table 4.7 Heavy metal concentration in Leachate

Date	Sample Name	Volume of Sample (ml)	Heavy metals concentration (mg/L)						
			Mn	**Cr**	**Cd**	**Pb**	**Ni**	**Zn**	**Cu**
22-Dec-06	OC 1	50	50.66	17.75	0.21	0.78	17.05	30.04	2.31
	OC 2		187.49	6.65	0.61	1.26	16.04	34.19	4.59
	OC 3		71.72	6.44	0.48	0.62	13.92	33.97	6.12
	CLF		29.14	6.56	0.60	2.12	14.77	61.01	6.94
26-Jan-07	OC 1	50	1.29	0.66	0.02	0.02	1.11	1.08	0.12
	OC 2		4.00	0.46	0.08	0.04	2.28	7.10	0.49
	OC 3		1.97	0.35	0.05	0.02	2.07	1.96	0.43
	CLF		0.43	0.29	0.03	0.00	1.00	1.27	0.13
23-Feb-07	OC 1	50	1.30	0.84	0.02	0.00	1.22	1.08	0.17
	OC 2		0.75	0.20	0.08	0.04	0.78	1.06	0.22
	OC 3		1.70	0.29	0.11	0.05	1.83	3.17	0.65
	CLF		0.25	0.42	0.03	0.03	1.12	1.38	0.12
23-Mar-07	OC 1	50	1.22	0.70	0.02	0.00	1.07	1.21	0.13
	OC 2		1.94	0.45	0.15	0.05	2.00	2.98	0.54
	OC 3		6.00	0.50	0.21	0.38	3.83	6.22	1.63
	CLF		0.22	0.53	0.05	0.03	1.32	1.66	0.12
2-Apr-07	OC 1	50	1.01	0.43	0.01	0.01	0.71	0.82	0.09
	OC 2		7.45	0.49	0.12	0.24	2.11	4.21	0.86
	OC 3		1.85	1.93	0.11	0.06	4.46	4.05	0.50
	CLF		0.81	0.05	0.02	0.03	0.54	0.61	0.16

Table 4.8 Heavy metal load in leachate per month

Months	Sample Name	Volume of leachate (L)	Heavy metal load (mg) from total volume of leachate every month						
			Mn	**Cr**	**Cd**	**Pb**	**Ni**	**Zn**	**Cu**
Dec-06	OC 1	146	84.1	29.4	0.3	1.3	28.3	49.8	3.8
	OC 2	339	552.7	19.6	1.8	3.7	47.3	100.8	13.5
	OC 3	258	188.8	16.9	1.3	1.6	36.6	89.4	16.1
	CLF	139	40.5	9.1	0.8	2.9	20.5	84.8	9.6
Jan-07	OC 1	164	53.1	27.0	0.8	0.8	45.6	44.4	4.9
	OC 2	672	149.2	17.2	3.1	1.4	85.0	265.2	18.1
	OC 3	640	126.3	22.6	3.4	1.3	132.6	125.6	27.5
	CLF	156	22.6	14.9	1.6	0.3	52.2	66.3	6.7
Feb-07	OC 1	185	40.1	25.9	0.7	0.1	37.5	33.4	5.3
	OC 2	902	84.8	22.7	8.7	4.2	88.3	119.0	25.0
	OC 3	842	142.7	24.3	9.2	4.4	153.7	266.7	55.1
	CLF	168	14.0	23.5	1.5	1.6	62.6	77.4	6.7
Mar-07	OC 1	216	52.8	30.2	0.7	0.1	46.3	52.1	5.5
	OC 2	1102	119.0	27.7	9.5	3.1	122.5	182.5	32.9
	OC 3	1061	289.4	24.2	10.4	18.4	184.7	299.9	78.4
	CLF	184	10.3	24.3	2.3	1.4	60.6	76.4	5.6
Apr-07	OC 1	219	73.4	31.7	0.8	0.8	51.6	59.6	6.2
	OC 2	1120	463.8	30.4	7.7	14.9	131.4	261.7	53.6
	OC 3	1075	141.9	148.1	8.3	4.4	342.4	310.9	38.1
	CLF	186	75.0	4.4	2.2	2.7	49.9	56.5	15.1

Table 4.9 Total Heavy metal load (mg) leached out from landfill lysimeters after five months operation

Landfills	Total heavy metal load (mg) leached out from leachate						
	Mn	**Cr**	**Cd**	**Pb**	**Ni**	**Zn**	**Cu**
OC 1	304	144	3.30	3	209	239	26
OC 2	1370	118	31	27	475	929	143
OC 3	889	236	33	30	850	1093	215
CLF	163	76	9	9	246	362	44

1) Physical Properties of Landfill Leachate

• ***pH***

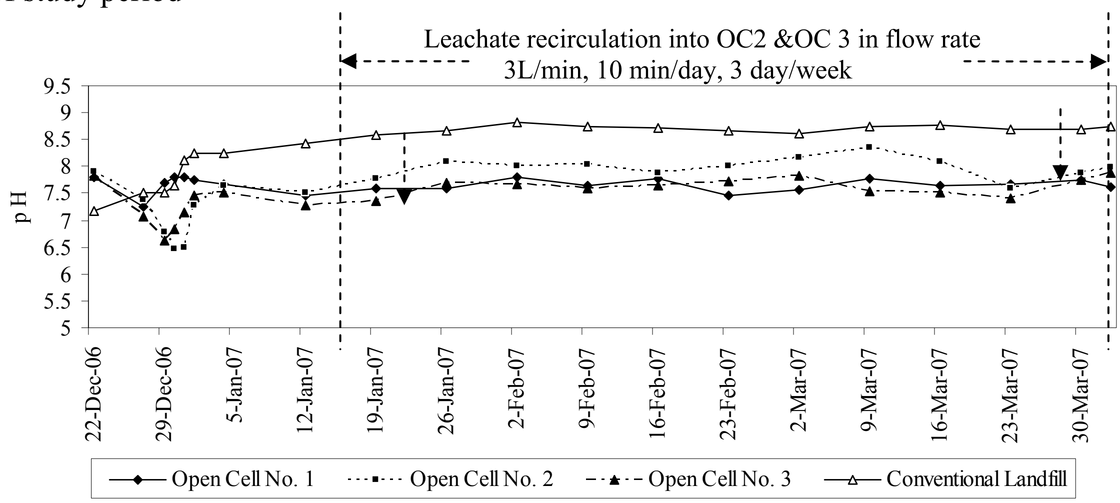
Initial pH of all lysimeters was in range 6.4 - 8.8. Figure 4.3 illustrates the variation of Ph with time of landfill lysimeters. However, the pH values were not stable and the level is not the same of all landfill lysimeters normally pH of Open Cell No. 1 was range from 7.26 -7.81, Open Cell No. 2 range from 7.16 – 8.35, Open Cell No.3 range from 6.61– 7.89 and Conventional landfill pH range 7.18 – 8.83. According to five sequential phase of stabilization of MSW, the pH of leachate from all landfill lysiemters indicated that the decomposition phase was moved from acidogenic to methanogenic phase within four months of operation and remained in range 6.61 – 8. 83

• Conductivity

Conductivity is a means to measure the ionic concentration within a solution. Solution of most inorganic compound is in the ionized form lead to conductivity. From Table 4.6, the conductivity of all lysiemters was in range 17.53 – 62.85 mS/cm. Figure 4.4 presents the fluctuation of conductivity. Similarly, during leachate recirculation period of Open Cell No.2 and 3 were presented in Appendix A (Table A-5 to A-6) the conductivity values were decreased more than another two lysimeters. However, the difference was not much.

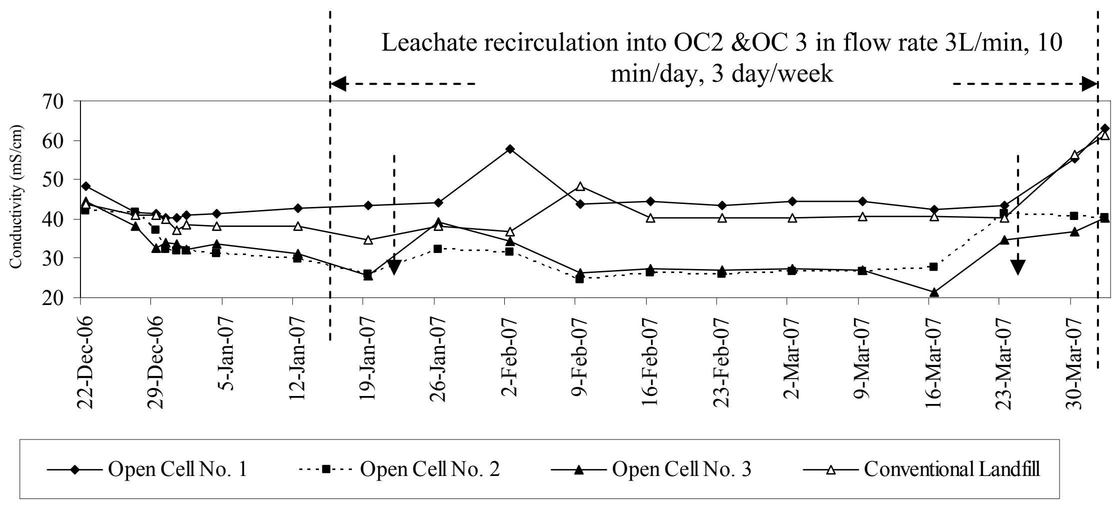
· Alkalinity

Similarly, alkalinity of lysimeters had the variation pattern as pH and Conductivity. Figure 4.5 show the change of alkalinity of all lysimeters. In methanogenic phase, the pH values is elevated, being controlled by the bicarbonate buffering capacity system, and consequently supports the growth of methanogenic bacteria (Reinhart et al., 1996). Alkalinity showed the high value at the beginning and then maintained around 3,000 - 8,000 mg/L at the end of study period



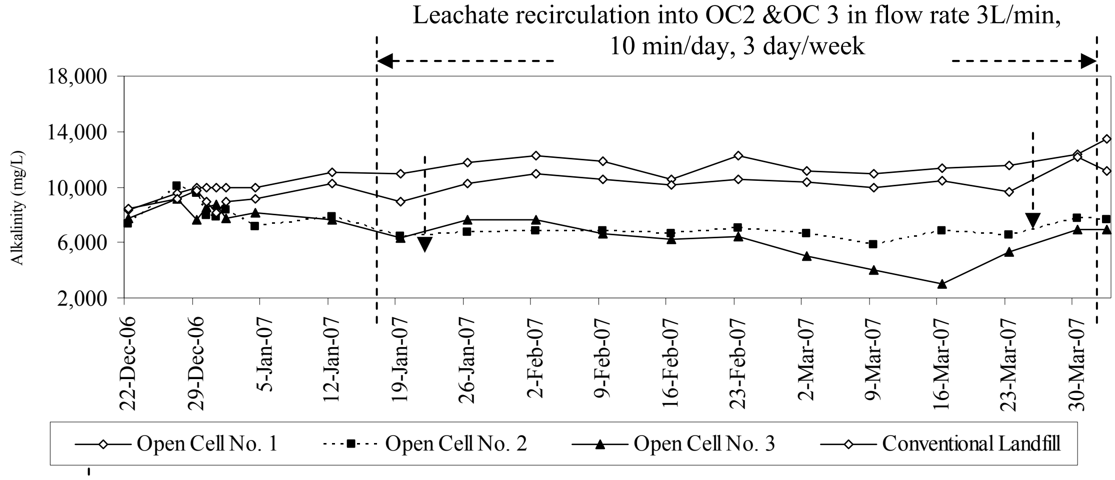
Note: Rainfall

Figure 4.3 pH of leachate from landfill lysimeters



Note: Rainfall

Figure 4.4 Conductivity of leachate from landfill lysimeters



Note: ▼ Rainfall

Figure 4.5 Alkalinity of leachate from landfill lysimeters

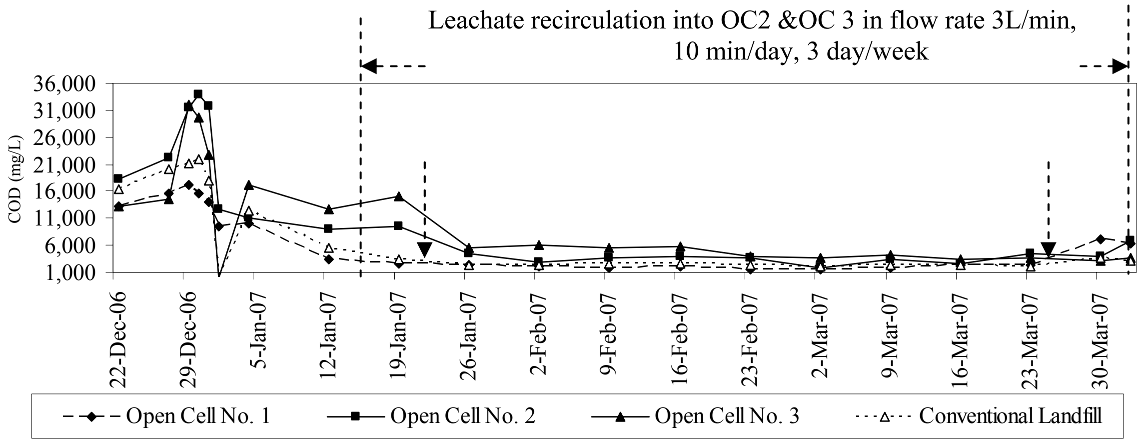
•TS, VS, TDS, TSS and TVSS

Total Solid means the summation of dissolved (filterable) and non-dissolved (no filterable) solids. Refer to Table 4.6 TDS was the main fraction of TS. TDS also fluctuated widely had followed similar trend as conductivity. The results analysis of TS, VS, TDS, TSS and TVSS are presented in Appendix A (Table A-1 to A-4).

2) Organic Contents of Landfill Leachate

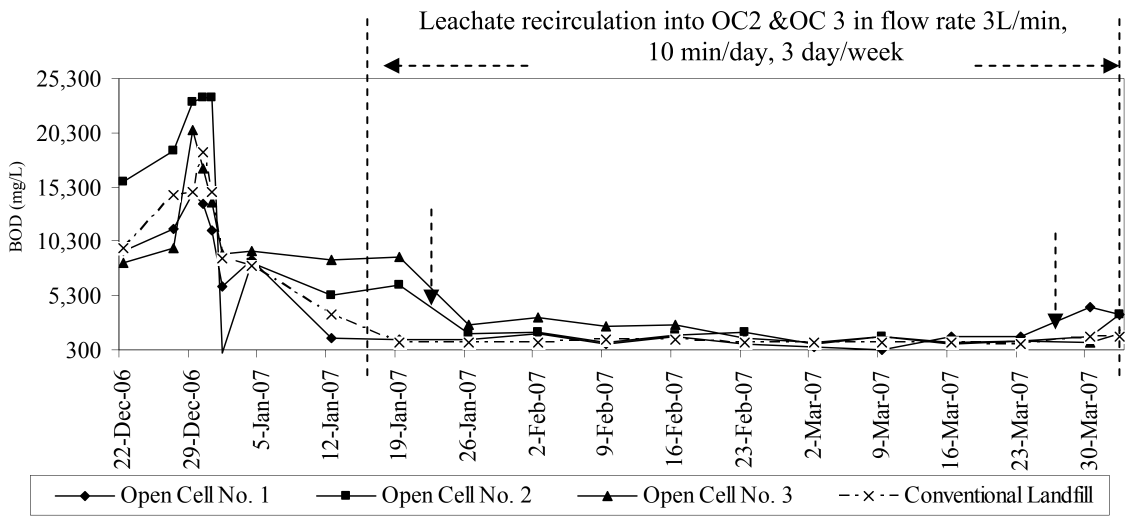
• COD

At the beginning of operation, the COD and BOD concentration of all lysimeters was high concentration and then gradually decreased with time. Figure 4.6 to 4.7 presents the fluctuation of COD and BOD concentration from landfill lysimeters. The rapid decreasing concentration of organic pollutant was presented in short time during rainfall day due to leaching out of pollutant. After that, the concentration was significantly increased due to the acceleration of biodegradation by moisture infiltrated. The concentration of organic contents in leachate was fluctuated and the trend of strength was declined with time.



Note: ▼ Rainfall

Figure: 4.6 COD of Leachate from landfill lysimeters



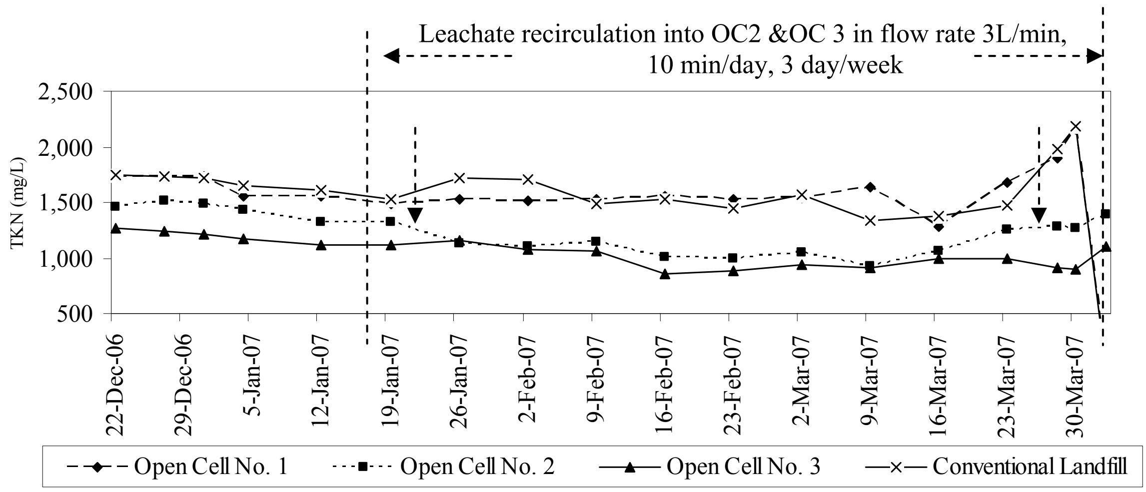
Note: Rainfall

Figure 4.7 BOD of Leachate from landfill lysimeters

3) Inorganic Contents of Landfill Leachate

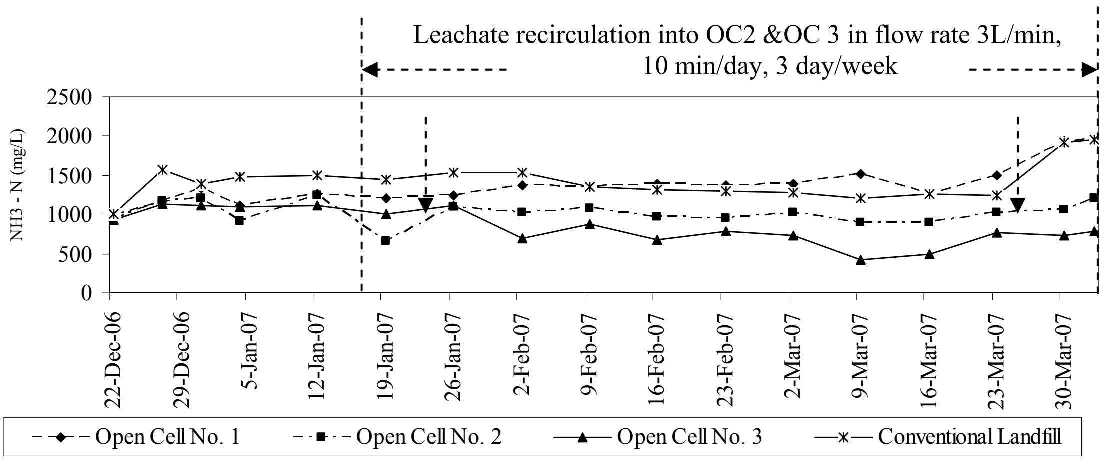
• ***TKN, NH_4-N and Organic-N***

The great majority of Total Kjeldahl Nitrogen (TKN) content is found to be in ammoniacal form (Tatsi and Zouboulis, 2002). Refer to Table 4.6, the leachate contained high concentration of NH_3-N which was about 75-98% of TKN. Figure 4.8, 4.9 and 4.10 illustrates the variation of TKN, NH_3 –N and Organic Nitrogegn from all lysimeters. The concentration values of TKN were fluctuating and showed a decreased trend with time as like COD. However, at comparable time, it was observed that the fluctuation of TKN concentration was less than the COD concentration. The TKN values of Conventional Landfill were not fluctuated much as Open Cell landfill lysimeters. During recirculation period, Open Cell No.2 and 3 also produced lower concentration of TKN than other lysimeters. After four months of operation, the TKN, NH_3 –N and Org-N concentrations of Open Cell No.1, 2, 3 and Conventional Landfill were 2,176; 1,392; 1,100 and 2,276 mg/L , 1,952 ; 1,201; 788, 1,952 mg/L and 224; 191; 316 and 324 respectively.



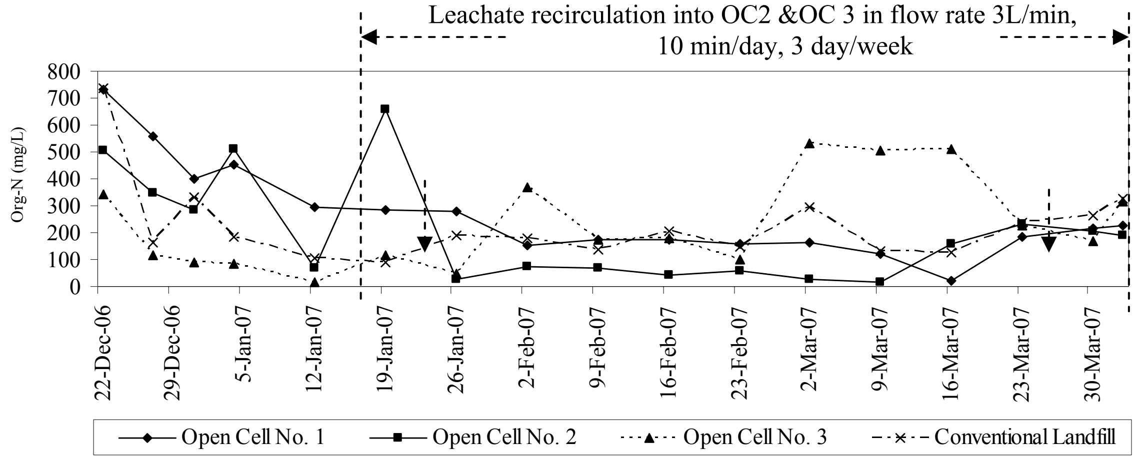
Note: Rainfall

Figure 4.8 TKN of Leachate from Landfill lysimeters



Note: Rainfall

Figure 4.9 NH_3 –N of Leachate from Landfill lysimeters



Note: Rainfall

Figure 4.10 Org - N of Leachate from Landfill lysimeters

• ***Heavy metals***

The contamination of heavy metals in leachate was investigated five times during five months of the study period. Therefore, the concentration of heavy metals from landfill lysimeters was observed very high because neutral pH was supporting the immobilization of metals and MSW was loaded into landfill lysimeters is fresh and unsorted. Comparison the concentration of heavy metals with the surface water quality standard (type III) in Thailand was found that it was not higher than the standard values. The results of heavy metal concentration in leachate and in MSW were shown in Table 4.7 and 4.2.

4) Carbon and Nitrogen Load

The specific cumulative load of the COD and TKN is calculated from the leachate generation and its composition is based from the starting weight (wet basis) of waste in the individual lysimeter (Tränkler et al., 2005). The specific cumulative COD and TKN load from landfill lysimeters were presented in Figure 4.11 and 4.12 and 4.13 respectively. The results showed that the specific COD and TKN load discharged from all Open Cell lysimeters were higher than Conventional Landfill. At the end of study period, the specific cumulative COD load presented the constant trend as results of low concentration of COD and low leachate generation. After four months of operation, the specific cumulative COD load values of Open Cell No.1, 2, 3 and Conventional Landfill were 1,294; 7,535; 7,369 and 1,461 mg/kg solid waste, respectively.

The specific cumulative load pattern of TKN differed slightly from that of COD. The loading of TKN from all lysimeters gradually increased during recirculation. The Open Cell No.1 presented the highest specific cumulative TKN load. Whereas, the Conventional Landfill produced the low specific cumulative TKN load. Tränkler et al. (2005) also indicated with the results of open cell simulation that the low compaction density with high Leachate recirculation. After four months of operation, the specific cumulative TKN load values of Open Cell No.1, 2, 3 and Conventional Landfill were 195; 795; 652 and 167 mg/kg solid waste, respectively

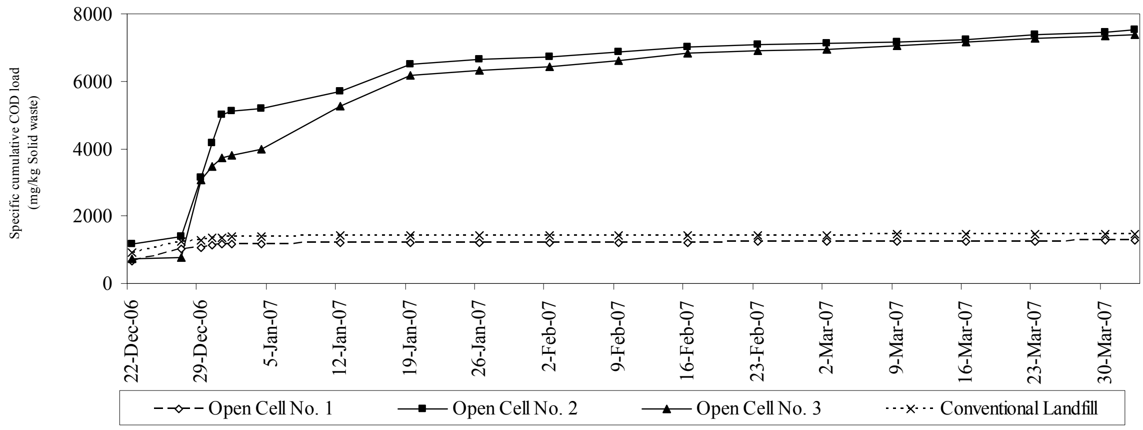


Figure 4.11 Specific cumulative COD load from Landfill lysimeters

Organic content and without a cover may have permitted the system to obtain a partial aerobic condition. This could have improved the stability of the inorganic compounds followed by an instant leaching of solid waste by direct rainfall. As mentioned above, the upper surface of lysimeters was partial-aerobic condition as a result of no top cover while the bottom of lysimeters was anaerobic condition. The specific cumulative Org - N load values of open Cell No.1, 2, 3 and Conventional Landfill were 58.12; 162.56; 109.21 and 48.29 mg/kg solid wastes. Normally in OC2 all pollutants concentration are higher than the other because of amount leachate generated in Open Cell is much more than other but in case of Open Cell No.3 operation by leachate recirculation with aeration supply the pollutants concentration consisting in leachate are lower than in Open Cell No.2 because of pollutants react with oxygen to make pollutant in gases form and released into atmosphere.

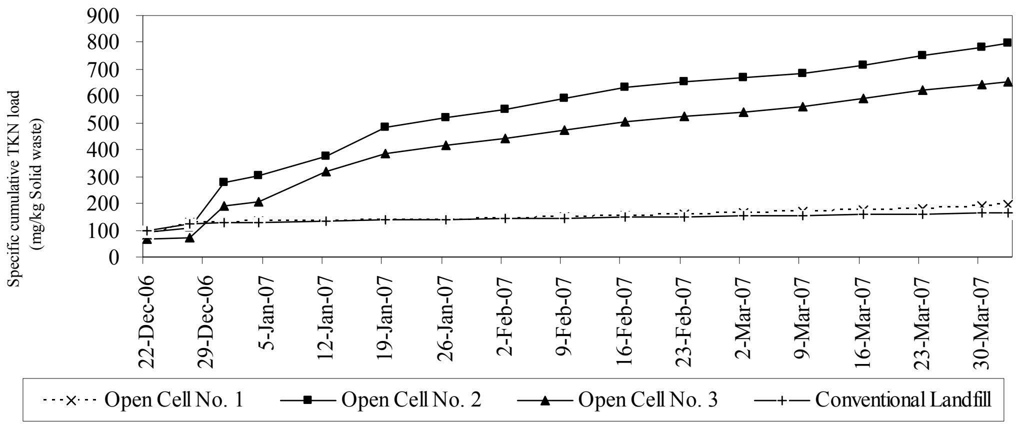


Figure 4.12 Specific cumulative TKN load from Landfill lysimeters

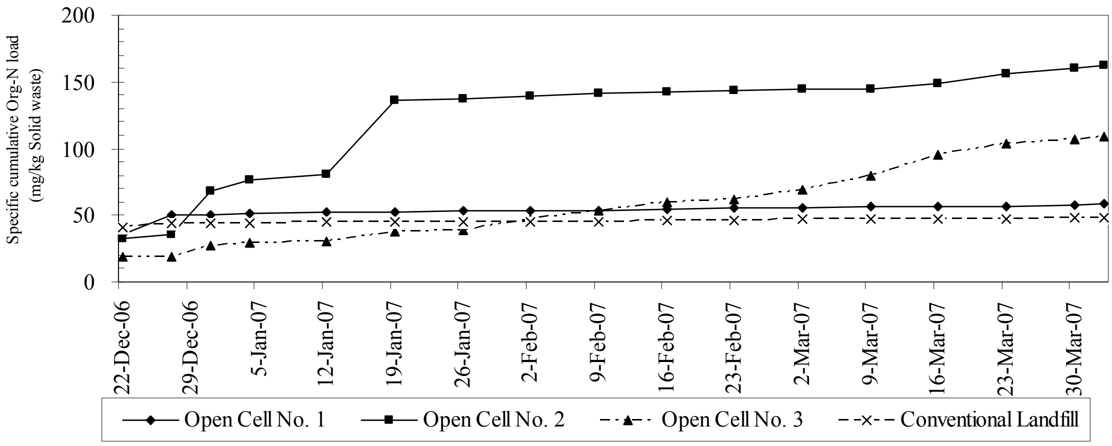


Figure 4.13 Specific cumulative Org - N load from Landfill lysimeters

5) Carbon and Nitrogen Load in dissolve form

The specific cumulative load of the Total Dissolve Carbon (DOC), Total Dissolve Nitrogen (TN), Nitrate and Nitrite are calculated from the leachate generation and its composition and is based from starting weight (wet basis) of waste in the individual lysimeter (Tränkler et al., 2005). Refer to Table 4.6 the concentration of DOC in leachate from Open Cell No. 1 is in the range of 368 – 5,815 mg/L, Open Cell No 2 in the range of 241 – 9,345 mg/L, Open Cell No 3 in the range of 280 – 9,355 and CLF in the ranges of 351 – 6,500 mg/L. Concentration TN in leachate from Open Cell No. 1 in the range of 923 – 2,554 mg/L, Open Cell No 2 in the range of 619 – 2,337mg/L, Open Cell No 3 in the range of 261 – 1,824 mg/L and CLF in the range of 831 – 2,500 . The concentration of NO_3 in leachate from Open Cell No. 1 in the range of 22 – 493 mg/L, Open Cell No 2 in the range of 4 – 598 mg/L, Open Cell No 3 in the range of 7 – 658 mg/L and CLF in the range of 10 – 428 mg/L. Concentration NO_2 in leachate from Open Cell No. 1 in the range of 52 – 553 mg/L, Open Cell No 2 in the range of 42 – 633 mg/L, Open Cell No 3 in the range of 66 – 644 mg/L and CLF in ranges of 68 – 470 mg/L.

The specific cumulative DOC, TN, NO_3 and NO_2 load from landfill lysimeters were presented in Figure 4.14 and 4.15 and the level concentration of NO_3 and NO_2 presented in figure 4.16 and 4.17 respectively. The results showed that the specific DOC and TN load discharged from all Open Cell lysimeters were higher than Conventional Landfill. At the end of study period, the specific cumulative DOC load presented the constant trend as results of low concentration of DOC and low leachate generation. After four months of operation, the specific cumulative DOC load values of Open Cell No.1, 2, 3 and Conventional Landfill were 410; 1,361; 1,187 and 391 mg/kg solid waste, respectively.

The specific cumulative load pattern of TN differed slightly from that of DOC. The loading of TN from all lysimeters gradually increased during recirculation. The Open Cell No.1 presented the lowest specific cumulative TN load. Whereas, the Conventional Landfill produced the low specific cumulative TN load. Tränkler et al. (2005) also indicated with the results of open cell simulation that the low compaction density with high Leachate recirculation. After four months of operation, the specific cumulative TN load values of Open Cell No.1, 2, 3 and Conventional Landfill were 191.13; 698.39; 399.04 and 163.20 mg/kg solid waste, respectively

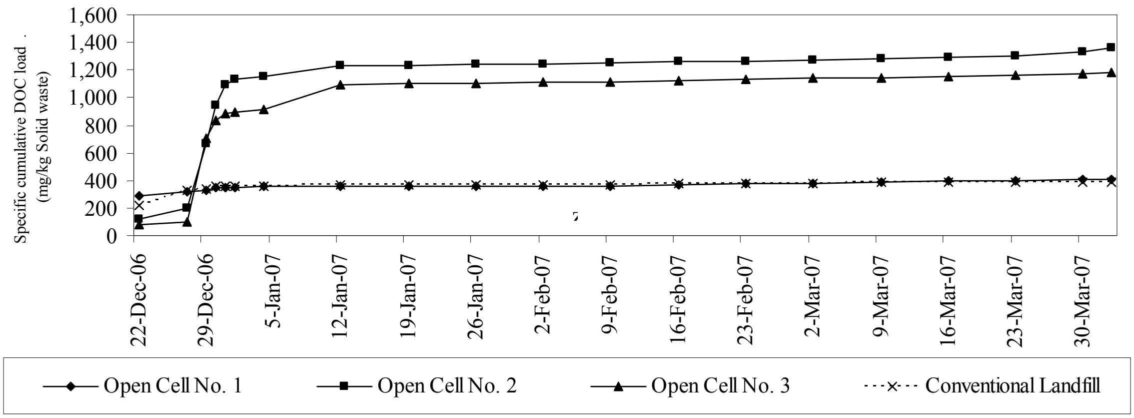


Figure 4.14 Specific cumulative DOC load from Landfill lysimeters

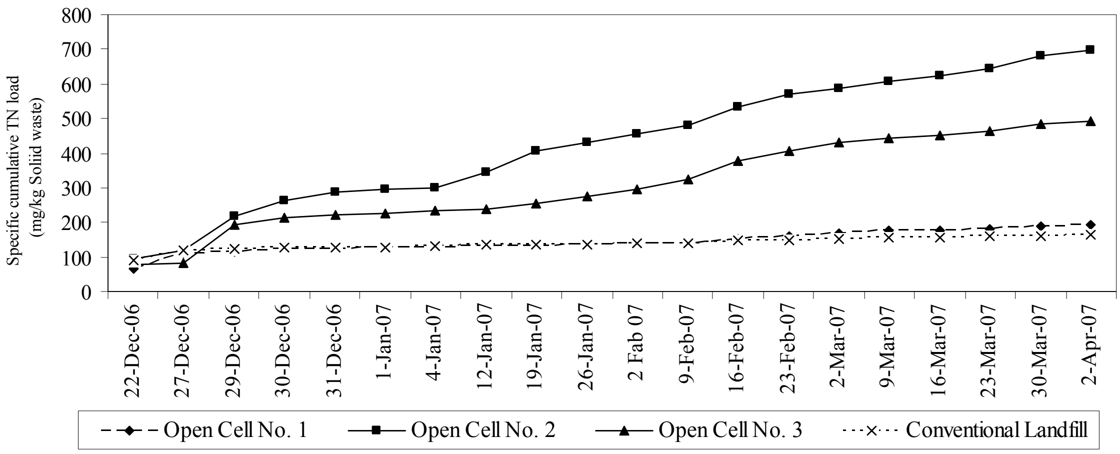


Figure 4.15 Specific cumulative TN load from Landfill lysimeters

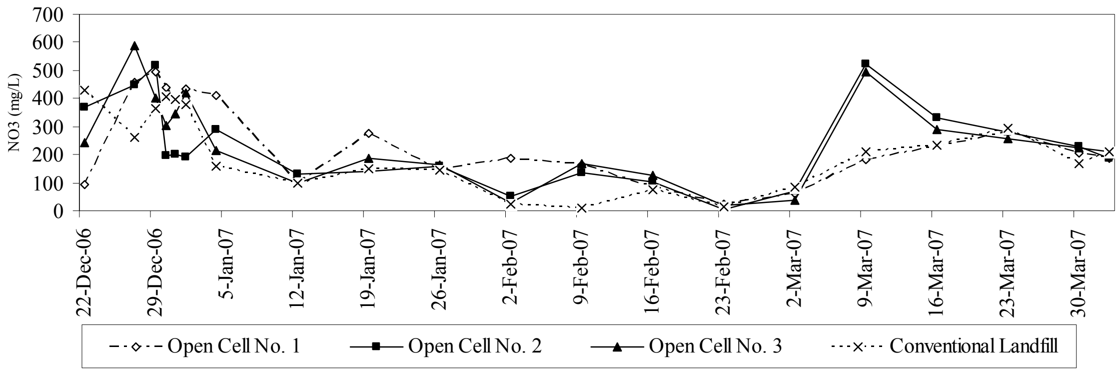


Figure 4.16 NO_3 in leachate from landfill lysimeters

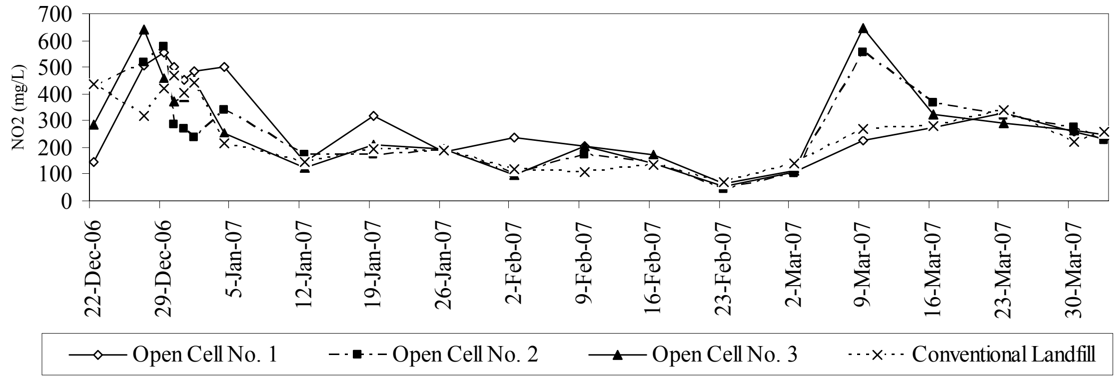


Figure 4.17 NO_2 in leachate from landfill lysimeters

4.3 Settlement of Landfill Lysimeters

Settlement allows additional waste to be placed on completed areas and it can extends the life of the landfill because the final site development is limited by elevation and not by volume or quantity (Reinhart and Townsend, 1998). The settlement variation depends on many factors such as the degree of initial compaction, solid waste compositions and the biological processes that cause the landfill settlement follow a non-uniform pattern (Tabtimthai, 2003). Primary settlement will occur rapidly, usually within the first month of landfill, followed by a substantial amount of secondary compression over and extended period of time (Ashford et al., 2000).

In this study there are two steps in measurement the level settlement of MSW in different landfill operation after finish loading of MSW the first monitoring one time per week after finish loading and the second measurement everyday. Table 4.10 shows the level settlement of MSW in different landfill operation every week.

Landfill lysimeters operation after one month of MSW loaded into each landfill the level settlement of Open Cell No.1, 2, 3 and Conventional Landfill were 10; 15; 17 and 10.90 cm of initial height, respectively, settlement of MSW was high because of primary compression due to self-weight and the decomposition of waste.

Table 4.10 Level settlement of MSW in Landfill lysimeters

Date	Level Settlement (cm)			
	OC 1	OC 2	OC 3	CLF
9-Dec-06	0.00	0.00	0.00	10.90
16-Dec-06	4.00	8.00	10.00	11.00
23-Dec-06	6.00	0.1	13.00	11.10
30-Dec-06	8.00	13.00	15.00	11.20
6-Jan-07	9.00	14.00	17.00	11.30
13-Jan-07	11.00	16.00	18.00	11.30
20-Jan-07	12.00	17.00	20.00	11.40
27-Jan-07	13.00	17.00	20.00	11.40
3-Feb-07	13.00	18.00	21.00	11.50
10-Feb-07	14.00	19.00	22.00	11.50
17-Feb-07	14.00	19.00	23.00	11.50
24-Feb-07	15.00	20.00	24.00	11.50
3-Mar-07	16.00	21.00	24.00	11.60
10-Mar-07	16.00	22.00	25.00	11.60
17-Mar-07	17.00	23.00	26.00	11.70
24-Mar-07	17.00	24.00	27.00	11.80
2-Apr-07	18.00	25.00	28.00	12.00

Note: CLF, MSW loaded only one time (4 November 2006)

All Open Cell lysimeters with low compaction (490 kg/m^3) had high settlement, while Conventional Landfill with high compaction (500 kg/m^3) had the lowest settlement and after starting recirculation into Open Cell No.2 and 3, the settlement rates increased higher other two lysimeters but incase of Open Cell No.3 the level settlement of MSW is faster than Open Cell No. 2 it operation with aeration that can increase level of biodegradable of MSW faster than Open Cell No. 2. The settlement was enhanced by liquid flow and accelerated biodegradation by leachate recirculation. The variation of settlement was attributed to the biodegradation of solid waste.

After five months of operation, the settlement of each lysimeters resulted in 18;25;28 and 12 cm of initial height of Open Cell No.1, 2, 3 and Conventional Landfill, respectively Settlement of Open Cell No.3 which had highly biodegradable organic fraction waste and leachate recirculation showed the highest settlement rate

4.4 Leachate Management for Open Cell Landfill Lysimeters

The previous studies (Tabtimthai, 2003) and (Wisiterakul, 206) demonstrated that tropical seasonal variations influenced on landfill leachate generation and its characteristics. The open cell landfill simulation showed that the highest cumulative leachate generation during monsoon and leachate ceased during the dry period due to heavy loss of moisture by evaporation. Water management can be conducted by leachate storage during rainy season and recirculation during the dry season enhanced the waste stabilization (Tränkler et al., 2005). The study period in dry season from November, 2006 to April, 2007 the cumulative leachate generated from all landfill lysimeters are low as shown in Table 4.4 and 4.5. Leachate generation from Open Cell No. 2 and No. 3 to be used for leachate recirculation ware collected and store in close storage tank to avoid evaporation.

4.5 Leachate Recirculation and Aeration

The leachate recirculation was provided into Open Cell No.2 and No. 3 in the flow rate 3L/min in 10 min/day in 3day/week by considering the average daily rainfall from weather data (2000 – 2006)

After installing the aeration supply with leachate recirculation into Open Cell No. 3, there were observed that the level of MSW settlement and leachate generation are faster and much more than the other landfill lysimeters in the same period of operation as shown in Table 4.4 and 4.7. It was observed that with aeration supply leachate recirculation should be recirculated at high flow rate in dry season that can increase level of biodegradation and faster settlement of MSW in landfill.

4.6 Leachate recirculation analysis

From the day of 15 January 2007 to the end of study period, monitoring the characteristics of leachate recirculated (ROC2 and ROC3) into both open cell landfills are shown in Table 4.11.

Table 4.11 Leachate characteristics from ROC2 and ROC3

Parameters	ROC 2	ROC3
pH	7.7 – 8.99	7.80 – 9.03
Conductivity	18.45 – 41.25	19.74 – 41.15
Alkalinity (mg/L)	2,900 – 6,400	2,800 – 6,380
COD	1,600 – 9,660	1,120 – 9,440
TKN	258 - 580	204 - 818
NH_3 -N	28 - 260	39 - 417
Organic-N	98 - 496	92 - 740
DOC	384 – 2,080	346 – 1,996
TN	60 - 765	61 - 652
Nitrate	91 - 750	99 - 522
Nitrite	32 - 710	51 - 482
TS	3,768 – 85,808	2,720 – 63,804
VS	288 – 9,096	3,004 – 49,888
TDS	3,316 – 9,268	3,334 – 49,796
TSS	136 – 5,900	100 – 11,220
TVSS	84 - 724	88 – 1,280

The results showed pH in range 7.7 - 9.03, conductivity in range 18.45 – 41.25 mS/cm, TSS in range 100 – 11,220 mg/L and TVSS in range 84 – 1,280 mg/L. TSS values were very low because the partial suspended solid was settled in storage tanks (as primary sedimentation tanks). However, it was observed that the trend of pollutants concentration are high all parameters but the quantity of leachate generation is low not enough for using in recirculation so leachate generation in rainy season can keep for use in dry season in case of this it can reduce environmental pollution via leachate and reduce cost in waste water treatment. The results of leachate characteristics are presented in Appendix A (Table A-5 to A-6)

4.7 Influence of Operational on Leachate Management

Refer to water management for open cell landfill in tropical climate. It consisted of storage, evaporation and recirculate of leachate. In this study, leachate generation from Open Cell No.1 and Conventional Landfill was collected and stored in closed tanks without use for recirculation. While, leachate generation from Open Cell No.2 and 3 was managed by storing it into the separate close tanks (not allow leachate evaporation

The results of water management of Open Cell No.2 and 3 showed the low leachate remaining in the tanks at the end of study period. The peak leachate remaining of Open Cell No.2 and 3 was 213 and 201 L, respectively. While the remaining leachate from Open Cell No.1 and Conventional Landfill was 250 and 200 L, respectively. Furthermore, the volume of leachate remaining in the close tanks of Open Cell No.2 and 3 was gradually reduced until the next rainy season because it have some still evaporation occur. Therefore, water management reduced the amount of leachate for treatment. At the same time, leachate recirculation accelerated the stabilization of waste and increased the settlement of landfill lysimeters.

The concentration of pollutant of leachate generation and leachate remaining in the storage tank are high. The small amount of leachate with high concentration of pollutant was easy to handle. In addition, the excess leachate remaining less than requirement in dry period was necessary. Therefore, the reduction excess leachate remaining should be considered. Refer to the flowchart of water management of landfill lysimeters (Figure 3.6 and 3.7); the main points which were considered for water management were leachate generation from landfill lysimeter and leachate remaining in storage tank. In this case, the simple option to improve the water management of Open Cell landfill lysimeters was determined.

Two options were suggested to improve water management for open cell landfill lysimeter;

- Option 1: In real action in dry season operation leachate use for recirculate should keep and store in close storage tank to protect evaporation but for leachate doesn't use for recirculate keep in large surface area of storage and evaporation tank this option can reduce volume leachate remaining from experimental result. This option provided high peak of leachate remaining during rainy season but it also reduced the leachate remaining during dry season by high evaporation.

- Option 2: In rainy season have to limiting rainfall come in the storage and evaporation tank by covering1/4 open space of the tank by transparent roof. This option can reduce volume leachate remaining from experimental result. It was noted that prohibiting the rain fall into the tank lead to not enough water remaining for recirculation because of high evaporation during dry season.

The results indicated that there are two important factors of water management from landfill first in dry season have to keep leachate volume for prevention lack of leachate for using recirculate and reduce the remaining leachate was evaporation. Thus, decreasing the evaporation rate was necessary for water management to achieve the small amount of leachate to be use for recirculate. However, selecting any option based on the minimum leachate remaining requirement. Leachate should be remained enough for recirculation

purpose through the cycle of operation period. The second factor, in rainy season should limit amount of rainfall allow into storage tank that can keep for use in dry season.
Determining the disposal of cumulative sludge in leachate remaining was also importance because high cumulative sludge was not appropriate for recirculation system. In practice, the water management of Open Cell landfill should be considered the whole system. The design and operation open cell landfill should provide enough leachate for recirculation and at the same time minimize the leachate remaining. Figure 4.18 shows the water management components. The water management can estimate by following equation;

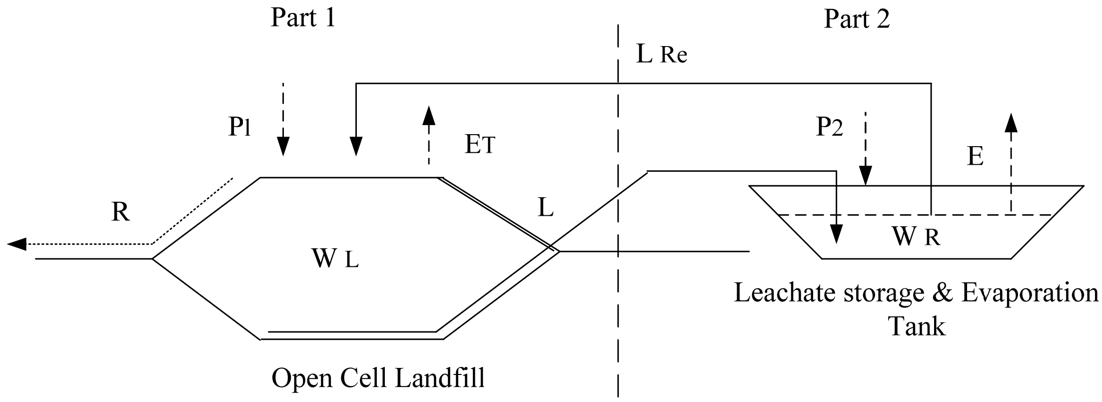


Figure 4.18 Water management components of Open Cell landfill

Water management equation;

WL = (P1 + LRe) - (R + ET + L) (Eq. 4.1)

WR = (P2 + L) - (E + LRe) (Eq. 4.2)

Combine Equation 4.1 and 4.2;

WL + WR = P1 + LRe - R - ET - L+ P2 + L - E – Lre

Thus, WR = (P1 + P2) - (ET + E) - R - WL (Eq. 4.3)

WL = the quantity of moisture storage in landfill (Liter)
WR = the quantity of water remaining in the storage tank (Liter)
P1 = the quantity of precipitation come in landfill (Liter)
P2 = the quantity of precipitation come in storage tank (Liter)
R = the quantity of runoff from landfill (Liter)
ET = the quantity of evapotranspiration from landfill (Liter)
E = the quantity of evaporation from storage tank (Liter)
L = the quantity of leachate generation from landfill (Liter)
LRe = the quantity of leachate recirculation (Liter)

From Equation 4.3, each water management component has other factors to determine. For example, the surface runoff relates with the top cover design. The vegetation enhances the evapotranspiration and storage partial moisture within the surface of open cell landfill. The increasing or decreasing surface area of storage tank influences the water remaining.

Therefore, the understanding of water management for open cell landfill can be conducted by considering in details of these parameters. The minimum water remaining was also investigated to balance the system.

Chapter 5

Conclusion and Recommendations

5.1 Conclusions

The experiments were conducted in pilot scale lysimeter focusing on the aeration and leachate recirculation in open cell landfill with leachate management strategies. The following conclusions are drawn based on the observed results.

1. Open cell operation by combining with leachate recirculation (Open Cell No.2 and 3) showed higher concentration in COD, BOD, TKN,TOC, TN than without leachate recirculation (Open Cell No. 1) and Conventional Landfill (CLF). The operation was started in dry season (December 2006 to April 2007) and leachate was recirculated to provide enough moisture to accelerate the decomposition.

2. Open Cell No.3 operated with leachate recirculation combined with aeration showed the lowest specific cumulative load of COD, BOD, DOC, TN,TKN , cumulative leachate generation and higher settlement compared to Open Cell No. 2 without aeration.

3. After five months of operation period, the specific cumulative of load of COD, BOD, DOC, TKN, NH_3 – N, Org – N and TN from Open Cell No.1, 2, 3 and Conventional Landfill were COD :1,294; 7,535; 7,369 and 1,461 mg/kg , BOD : 930; 5,211; 4,387 and 926 mg/kg, DOC : 410; 1,361; 1,187 and 391 mg/kg, TKN : 195; 795; 652 and 167 mg/kg, NH_3 – N : 135; 633; 547 and 124 mg/kg, Org – N : 58; 163; 109 and 48 mg/kg, TN :191; 698, 399 and 163 mg/kg solid waste, respectively

4. In lysimeter with leachate recirculation combining with aeration, the pollutants concentration in leachate is lower than that of without aeration.

5. The faster settlement was observed in Open Cell No.3 (Leachate recirculation with aeration) than Open Cell No.2, No. 1 and Conventional Landfill due to faster waste volume reduction. Similarly, concentration pollutants in Open Cell No 3 were also found lower than Open Cell No. 2, No.1 and CLF.

6. The water management of open cell landfill lysimeters by storage, evaporation and recycle of leachate showed the reduction in amount of leachate remaining. The Open Cell No.2 and 3 had lowest leachate remaining compared with Open Cell No.1 and Conventional Landfill are 300; 213; 201 and 250L respectively. In this case, the evaporation plays key role in water management.

5.2 Recommendations

This is observed that leachate recirculation strategy can be effectively applied to accelerate waste stabilization and reduce the amount of leachate remaining for treatment. Therefore, the water management equation was provided for application in design and operation open cell landfill. The following recommendation is proposed for future study

1. The operation of open cell landfill by leachate recirculation combining with aeration supply should be continued for long period including evaluation of landfill waste stability, pollutants concentration and waste settlement.

2. Heavy metal balance can be conducted to understand the fate of heavy metal in the landfill cell.

3. Carbon and Nitrogen balance in the open cell lysimeter can be investigated.

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Appendices

Appendix A: Tabulation of Data

Table A-1 Characteristics of Leachate from Open Cell No. 1 (OC1)

Date	pH	Cumulative Leachate (L)	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	BOD_5 (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
22 Dec 06	7.8	88	48.29	8,300	13,200	9,381	1,728	994	734	147	94
27 Dec 06	7.26	45	41.68	9,500	15,680	11,400	1,728	1,170	558	508	458
29 Dec 06	7.7	4	41.33	10,000	17,200	14,726	-	-	-	553	493
30 Dec 06	7.79	7	40.35	10,000	15,600	13,740	-	-	-	503	438
31 Dec 06	7.8	2	40.15	10,000	14,000	11,295	1,728	1,330	398	455	392
01 Jan 07	7.75	2	41.08	10,000	9,600	6,145	-	-	-	487	432
04 Jan 07	7.68	4	41.5	10,000	10,000	8,580	1,560	1,106	454	499	411
12 Jan 07	7.46	4	42.75	11,100	3,400	1,375	1,548	1,252	296	143	100
19 Jan 07	7.6	4	43.5	11,000	2,600	1,210	1,490	1,204	286	316	276
26 Jan 07	7.6	4	44	11,760	2,400	1,200	1,526	1,246	280	184	146
02 Feb 07	7.81	4	57.78	12,220	2,000	1,820	1,518	1,364	154	239	189
09 Feb 07	7.64	3	43.86	11,900	1,800	784	1,532	1,358	174	206	163
16 Feb 07	7.77	8	44.6	10,600	2,000	1,565	1,560	1,386	174	138	85
23 Feb 07	7.45	6	43.6	12,300	1,600	782	1,532	1,372	160	52	22
02 Mar 07	7.56	6	44.45	11,200	1,600	548	1,540	1,378	162	110	60
09 Mar 07	7.77	6	44.65	11,000	1,800	359	1,632	1,509	123	225	182
16 Mar 07	7.65	5	42.47	11,400	2,200	1,475	1,280	1,257	23	275	227
23 Mar 07	7.67	5	43.5	11,600	2,200	1,475	1,672	1,490	182	329	281
30 Mar 07	7.75	9	55.38	12,400	7,040	4,198	2,153	1,935	218	256	206
2 Apr 07	7.62	3	62.85	13,500	6,400	3,587	2, 176	1,952	224	233	188

Table A-1 Characteristics of Leachate from Open Cell No. 1 (cont)

Date	DOC (mg/L)	TN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
22 Dec 06	5,815	1,370	17,172	11,448	16,320	940	760
27 Dec 06	1,382	1,762	26,844	16,296	4,576	1,004	684
29 Dec 06	4,725	2,062	21,936	14,404	4,048	960	330
30 Dec 06	3,967	1,996	20,836	14,472	4,132	1,076	552
31 Dec 06	2,088	923	20,624	14,100	3,856	988	340
01 Jan 07	2,076	1,028	97,620	91,364	4,056	940	350
04 Jan 07	1,810	1,138	20,832	3,876	4,056	824	344
12 Jan 07	646	1,106	59,496	3,848	3,924	632	336
19 Jan 07	368	1,088	15,952	5,112	4,908	596	516
26 Jan 07	701	1,285	12,488	3,744	3,924	604	372
02 Feb 07	378	1,450	35,116	3,312	3,508	296	280
09 Feb 07	369	1,301	5,108	3,600	3,676	352	272
16 Feb 07	2,499	2,291	18,212	4,032	4,052	400	120
23 Feb 07	2,444	2,554	14,044	3,860	3,844	304	144
02 Mar 07	1,070	2,533	16,380	3,735	3,868	152	280
09 Mar 07	2,608	1,826	43,956	6,284	6,372	3,868	1,732
16 Mar 07	1,241	1,160	41,904	8,388	8,464	4,436	200
23 Mar 07	1,033	1,051	35,620	3,808	3,908	384	244
30 Mar 07	1,594	1,469	38,808	3,816	3,876	384	156
2 Apr 07	2,978	1,935	15,396	3,744	3,844	340	240

Table A-1 Characteristics of Leachate from Open Cell No. 1 (cont)

Date	Heavy metals (mg/L)						
	Mn	Cr	Cd	Pb	Ni	Zn	Cu
22 Dec 06	50.662	17.748	0.209	0.775	17.052	30.039	2.310
26 Jan 07	1.294	0.658	0.020	0.019	1.111	1.084	0.120
23 Feb -7	1.300	0.839	0.022	0.005	1.216	1.083	0.172
23 Mar 07	1.222	0.699	0.015	0.003	1.072	1.207	0.126
02 Apr 07	1.006	0.434	0.011	0.011	0.707	0.816	0.086

Table A-2 Characteristics of Leachate from Open Cell No. 2 (OC2)

Date	pH	Cumulative Leachate (L)	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	BOD_5 (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
22 Dec 06	7.9	115	42.13	7,300	18,148	15,737	1,464	958	506	427	367
27 Dec 06	7.38	18	41.57	10,100	22,320	18,582	1,512	1,162	350	516	446
29 Dec 06	6.78	100	37.2	9,520	31,382	23,137	-	1,123	-	576	516
30 Dec 06	6.47	55	32.38	7,900	33,998	23,581	-	1,182	-	285	197
31 Dec 06	6.5	47	31.85	7,800	31,756	23,492	1,492	1,209	283	271	201
01 Jan 07	7.28	19	31.86	8,340	12,560	9, 368	-	916	-	236	191
04 Jan 07	7.63	12	31.25	7,160	11,208	8,254	1,428	916	512	341	288
12 Jan 07	7.51	98	29.75	7,800	8,966	5,376	1,316	1,246	70	170	130
15 Jan 07	7.16	99	39.87	6,900	-	-	-	1,154	-	229	206
17 Jan 07	7.64	29	35.26	6,660	-	-	-	1,042	-	215	185
19 Jan 07	7.77	25	25.8	6,400	9,600	6,259	1,321	664	657	174	139
24 Jan 07	7.92	37	21.17	6,300	-	-	-	1,044	-	178	143
26 Jan 07	8.08	18	32.33	6,700	4,416	1,847	1,126	1,100	26	186	161
29 Jan 07	8.2	16	23.36	6,720	-	-	-	1,072	-	180	150
31 Jan 07	8.16	14	33.5	6,600	-	-	-	1,187	-	128	78
02 Feb 07	8.02	23	31.62	6,820	2,880	1,948	1,103	1,028	75	100	52
05 Feb 07	8.24	16	17.53	6,680	-	-	-	1,162	-	75	37
07 Feb 07	8.14	28	35.76	6,740	-	-	-	1,064	-	99	64
09 Feb 07	8.03	20	24.67	6,800	3,648	972	1,148	1,078	70	172	134
12 Feb 07	7.93	22	25.37	6,700	-	-	-	1,176	-	137	99
14 Feb 07	7.9	25	24.82	7,360	-	-	-	1,201	-	128	90
16 Feb 07	7.89	23	26.32	6,600	3,840	1,597	1,008	966	42	145	105
19 Feb 07	7.85	20	37.35	6,840	-	-	-	1,148	-	129	89
21 Feb 07	8.5	15	31.94	6,600	-	-	-	1,084	-	404	366
23 Feb 07	8.01	8	25.99	7,000	3,648	1,985	1,000	944	56	42	4

Table A-2 Characteristics of Leachate from Open Cell No. 2 (cont)

Date	pH	Cumulative Leachate (L)	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	BOD_5 (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
26 Feb 07	7.95	10	26.58	7,100	-	-	-	1,095	-	42	4
28 Feb 07	8.13	4	26.64	6,700	-	-	-	1,120	-	217	172
02 Mar 07	8.16	8	26.55	6,600	1,920	894	1,047	1,019	28	103	68
05 Mar 07	8.08	17	28.59	6,000	-	-	-	1,092	-	293	265
07 Mar 07	8.18	8	27.34	6,000	-	-	-	1,092	-	252	217
09 Mar 07	8.35	8	26.5	5,800	3,264	1,479	918	902	16	555	522
12 Mar 07	8.71	9	26.5	6,200	-	-	-	938	-	633	598
14 Mar 07	8.24	20	26.99	6,500	-	-	-	809	-	491	436
16 Mar 07	8.08	20	27.56	6,800	2,688	853	1,056	899	157	368	330
19 Mar 07	8.11	20	27.2	6,900	-	-	-	910	-	393	358
21 Mar 07	7.86	18	41.72	6,800	-	-	-	1,140	-	296	258
23 Mar 07	7.6	18	41.35	6,480	4,370	1,093	1,252	1,019	233	317	279
26 Mar 07	7.88	22	41.65	7,580	-	-	1,285	1,047	238	273	223
30 Mar 07	7.89	18	40.75	7,700	3,840	1,456	1,268	1,061	207	273	228
02 Apr 07	7.99	18	40.2	7,600	6,720	3,587	1,392	1,201	191	227	187

Table A-2 Characteristics of Leachate from Open Cell No. 2 (cont)

Date	DOC (mg/L)	TN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
22 Dec 06	1,805	1,482	12,332	9,252	3,844	472	292
27 Dec 06	8,225	2,337	23,556	13,116	4,308	2,772	684
29 Dec 06	8,325	1,793	25,128	14,044	4,048	772	325
30 Dec 06	9,345	1,427	53,456	41,144	32,904	936	340
31 Dec 06	5,625	868	24,500	13,236	3,996	1,092	420
01 Jan 07	4,118	798	21,740	12,032	4,076	1,084	405
04 Jan 07	1,968	763	15,468	3,288	3,672	652	310
12 Jan 07	1,436	836	80,836	3,352	3,828	4,132	780
15 Jan 07	3,162	845	32,348	1,908	3,596	416	225
17 Jan 07	2,168	780	14,124	3,280	3,356	356	200
19 Jan 07	677	738	9,728	3,604	3,484	100	97
24 Jan 07	600	723	9,248	3,104	3,528	388	244
26 Jan 07	398	740	8,644	3,548	3,776	532	351
29 Jan 07	349	752	8,312	3,140	3,680	272	214
31 Jan 07	378	746	13,704	3,448	3,760	576	328
02 Feb 07	287	822	23,800	3,312	3,508	96	280
05 Feb 07	431	732	3,676	3,528	3,784	232	324
07 Feb 07	408	698	5,500	3,644	3,780	248	196
09 Feb 07	241	773	9,052	3,940	3,960	288	284
12 Feb 07	2,103	1,455	9,152	3,472	3,604	224	208
14 Feb 07	1,288	1,442	4,056	3,700	3,800	216	156
16 Feb 07	1,029	1,364	23,516	3,820	3,964	228	188
19 Feb 07	630	1,413	7,856	3,756	3,936	256	220
21 Feb 07	1,449	1,453	5,292	4,972	5,056	216	164
23 Feb 07	1,212	1,444	3,812	3,708	3,772	300	128
26 Feb 07	1,762	1,440	8,004	3,836	3,944	300	224
28 Feb 07	1,106	1,340	5,624	5,076	5,304	148	380

Table A-2 Characteristics of Leachate from Open Cell No. 2 (cont)

Date	DOC (mg/L)	DTN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
02 Mar 07	1,977	1,458	3,828	3,392	3,548	152	260
05 Mar 07	1,732	1,065	17,648	3,748	3,808	280	92
07 Mar 07	1,535	1,070	12,200	3,392	3,728	1,460	460
09 Mar 07	1,573	1,139	24,572	6,184	6,212	1,172	696
12 Mar 07	1,001	688	41,032	5,716	5,796	2,556	616
14 Mar 07	839	632	40,988	3,960	3,992	356	64
16 Mar 07	773	664	44,036	35,420	35,464	35,080	128
19 Mar 07	695	619	9,204	3,724	3,892	448	376
21 Mar 07	610	628	14,696	4,812	5,060	3,080	764
23 Mar 07	1,205	651	13,832	3,824	3,912	512	452
26 Mar 07	1,579	928	21,092	3,896	3,916	368	168
30 Mar 07	2, 825	1,548	23,936	3,908	3,936	336	152
2 Apr 07	2, 957	1,812	11,340	2,960	3,036	2,356	208

Table A-2 Characteristics of Leachate from Open Cell No. 2 (cont)

Date	Heavy metals (mg/L)						
	Mn	Cr	Cd	Pb	Ni	Zn	Cu
22 Dec 06	187.485	6.653	0.609	1.264	16.043	34.190	4.594
26 Jan 07	3.996	0.462	0.083	0.037	2.277	7.103	0.485
23 Feb 07	3.996	0.462	0.083	0.037	2.277	7.103	0.485
23 Mar 07	1.944	0.452	0.155	0.051	2.002	2.981	0.538
02 Apr 07	7.454	0.488	0.123	0.239	2.111	4.207	0.861

Table A-3 Characteristics of Leachate from Open Cell No. 3 (OC3)

Date	pH	Cumulative Leachate (L)	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	BOD_5 (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
22 Dec 06	7.83	98	44.48	7,700	13,148	15,737	1,266	924	342	283	243
27 Dec 06	7.07	5	38.16	9,100	14,440	18,582	1,243	1,128	115	642	589
29 Dec 06	6.61	130	32.48	7,600	32,130	23,137	-	1,120	-	458	403
30 Dec 06	6.84	25	34	8,500	29,514	23,581	-	1,120	-	371	303
31 Dec 06	7.15	20	33.5	8,700	22,790	23,492	1,210	1,120	90	386	346
01 Jan 07	7.45	10	32.3	7,700	13, 640	9, 368	-	1,134	-	454	421
04 Jan 07	7.51	19	33.8	8,100	17,280	8,254	1,176	1,092	84	254	214
12 Jan 07	7.28	178	31.1	7,660	12,702	5,376	1,123	1,106	17	124	99
15 Jan 07	7.09	70	40.27	7,200	-	-	-	1,154	-	67	17
17 Jan 07	7.42	13	36.97	7,100	-	-	-	1,106	-	192	169
19 Jan 07	7.35	27	25.48	6,300	14,976	6,259	1,117	1,000	117	211	188
24 Jan 07	7.77	35	25.73	6,500	-	-	-	1,028	-	256	228
26 Jan 07	7.69	10	39.2	7,620	5,568	1,847	1,156	1,106	50	194	164
29 Jan 07	7.61	13	26.21	7,000	-	-	-	1,148	-	174	134
31 Jan 07	7.72	12	32.6	7,120	-	-	-	644	-	81	7
02 Feb 07	7.67	15	34.5	7,680	5,952	1,948	1,070	700	370	97	27
05 Feb 07	7.87	15	19.45	7,100	-	-	-	703	-	67	32
07 Feb 07	7.74	26	37.25	6,740	-	-	-	658	-	186	153
09 Feb 07	7.6	18	26.4	6,660	5,376	972	1,056	882	174	205	170
12 Feb 07	7.6	20	26.39	6,560	-	-	-	1,106	-	196	151
14 Feb 07	7.68	23	35.19	6,800	-	-	-	1,078	-	188	140
16 Feb 07	7.63	20	27.5	6,200	5,760	1,597	860	683	177	172	127
19 Feb 07	7.57	18	38.9	6,600	-	-	-	1,064	-	162	109
21 Feb 07	7.75	12	22.71	6,000	-	-	-	1,039	-	114	71
23 Feb 07	7.73	10	27.01	6,400	3,840	1,985	888	790	98	66	18

Table A-3 Characteristics of Leachate from Open Cell No. 3 (cont)

Date	pH	Cumulative Leachate (L)	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	BOD_5 (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
26 Feb 07	7.64	11	27.25	6,200	-	-	-	1,070	-	73	28
28 Feb 07	7.86	7	27.35	6,600	-	-	-	1,134	-	137	99
02 Mar 07	7.83	8	27.5	6,000	3,648	894	944	728	532	112	37
05 Mar 07	7.75	18	28.34	6,400	-	-	-	1,000	-	320	285
07 Mar 07	7.71	10	26.2	6,200	-	-	-	804	-	400	345
09 Mar 07	7.53	11	27	6,600	4,224	1,479	916	412	504	644	496
12 Mar 07	7.43	12	20.58	6,000	-	-	-	454	-	713	658
14 Mar 07	7.26	21	20.92	6,400	-	-	-	871	-	712	622
16 Mar 07	7.52	21	21.3	6,200	3,264	853	1,000	487	513	323	290
19 Mar 07	7.66	21	22.35	6,600	-	-	-	364	-	625	595
21 Mar 07	7.34	20	35.2	6,000	-	-	-	484	-	269	247
23 Mar 07	7.4	22	34.84	6,400	3,648	1,093	988	764	224	292	259
26 Mar 07	7.61	25	36.75	6,200	-	-	-	664	-	221	181
30 Mar 07	7.74	12	36.81	6,600	3,200	1,456	902	734	168	266	226
2 Apr 07	7.89	14	40.4	6,000	3,680	3,587	1,100	784	316	246	208

Table A-3 Characteristics of Leachate from Open Cell No. 3 (cont)

Date	DOC (mg/L)	TN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
22 Dec 06	1,480	1,401	12,460	3,968	9,588	697	340
27 Dec 06	7,230	1,824	33,196	14,116	4,348	728	432
29 Dec 06	8,420	1,517	24,264	12,268	3,688	556	342
30 Dec 06	9,355	1,509	25,544	13,656	4,044	916	497
31 Dec 06	4,087	843	44,328	36,404	3,940	908	515
01 Jan 07	2,333	832	16,868	10,664	3,804	752	416
04 Jan 07	1,420	829	12,196	3,556	4,048	792	421
12 Jan 07	1,787	770	72,724	3,928	7,833	572	325
15 Jan 07	3,475	767	19,808	3,016	3,576	424	204
17 Jan 07	858	738	11,112	3,404	3,472	408	217
19 Jan 07	1,068	723	2,859	3,224	3,004	472	225
24 Jan 07	648	690	9,712	3,432	3,296	492	244
26 Jan 07	346	787	9,712	3,819	3,740	744	260
29 Jan 07	624	794	10,560	3,208	3,340	928	344
31 Jan 07	319	1813	6,660	3,432	3,636	828	276
02 Feb 07	483	967	7,344	3,064	3,356	956	480
05 Feb 07	451	763	7,892	4,712	4,956	1,444	304
07 Feb 07	341	701	11,188	3,740	3,800	304	180
09 Feb 07	280	766	6,428	5,060	5,160	312	236
12 Feb 07	1,888	1,329	4,072	3,692	3,848	352	304
14 Feb 07	1,111	1,285	3,984	3,460	3,740	316	408
16 Feb 07	968	1,536	5,364	3,808	3,840	172	136
19 Feb 07	692	1,433	8,588	3,704	3,920	280	240
21 Feb 07	1,351	1,381	6,740	3,536	3,560	248	164
23 Feb 07	1,041	1,415	3,856	3,724	3,808	376	184
26 Feb 07	1,701	1,481	8,352	3,868	3,952	344	212
28 Feb 07	803	1,344	5,860	3,544	3,600	300	304

Table A-3 Characteristics of Leachate from Open Cell No. 3 (cont)

Date	DOC (mg/L)	DTN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
02 Mar 07	1,867	1,480	4,368	3,764	3,924	156	244
05 Mar 07	1,735	1,043	16,636	3,772	3,829	176	96
07 Mar 07	1,186	835	42,192	3,860	3,880	280	124
09 Mar 07	1,031	591	43,700	3,792	3,896	388	252
12 Mar 07	681	354	40,676	15,148	15,316	1,792	412
14 Mar 07	549	197	42,704	5,384	5,488	1,888	140
16 Mar 07	545	261	40,936	29,140	29,308	2,412	292
19 Mar 07	443	273	39,488	4,004	4,060	436	100
21 Mar 07	549	277	43,012	24,716	24,916	1,524	684
23 Mar 07	642	385	9,076	3,792	3,896	388	252
26 Mar 07	958	573	48,908	3,936	3,952	412	136
30 Mar 07	1,350	1,027	30,724	3,892	3,904	392	152
2 Apr 07	2,138	1,258	11,884	3,828	3,936	248	216

Table A-3 Characteristics of Leachate from Open Cell No. 3 (cont)

Date	Heavy metals (mg/L)						
	Mn	Cr	Cd	Pb	Ni	Zn	Cu
22 Dec 06	71.717	6.437	0.483	0.620	13.916	33.967	6.124
26 Jan 07	1.974	0.353	0.053	0.020	2.072	1.962	0.429
23 Feb 07	1.695	0.289	0.109	0.053	1.825	3.167	0.655
23 Mar 07	6.002	0.502	0.215	0.382	3.830	6.219	1.625
02 Apr 07	1.848	1.929	0.108	0.057	4.459	4.049	0.497

Table A-4 Characteristics of Leachate from Conventional landfill (CLF)

Date	pH	Cumulative Leachate (L)	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	BOD_5 (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
22 Dec 06	7.18	100	43.93	8,460	16,400	9,641	1,742	1,005	737	438	428
27 Dec 06	7.51	30	41.11	9,140	20,080	14,573	1,739	1,576	163	318	260
29 Dec 06	7.5	3	40.82	9,700	21,200	14,875	-	-	-	421	366
30 Dec 06	7.63	6	39.84	8,900	22,000	18,509	-	-	-	470	405
31 Dec 06	8.11	1	37.26	8,120	18,000	14,894	1,716	1,386	330	404	398
01 Jan 07	8.25	1	38.4	8,900	11, 480	8,750	-	-	-	440	380
04 Jan 07	8.24	3	38.2	9,160	12,400	8,061	1,607	1,470	182	213	160
12 Jan 07	8.43	7	38.2	10,300	5,400	3,548	1,532	1,504	103	145	97
19 Jan 07	8.58	2	34.75	8,900	3,400	971	1,716	1,442	90	192	149
26 Jan 07	8.66	3	38.35	10,260	2,200	959	1,705	1,526	190	188	145
02 Feb 07	8.83	3	36.85	11,000	2,400	985	1,490	1,526	179	120	25
09 Feb 07	8.74	2	48.37	10,600	2,600	1,247	1,526	1,352	138	108	10
16 Feb 07	8.72	4	40.45	10,200	2,600	1,269	1,448	1,319	207	135	77
23 Feb 07	8.67	3	40.35	10,600	2,400	978	1,571	1,302	146	68	15
02 Mar 07	8.62	3	40.25	10,400	2,000	929	1,338	1,274	297	139	86
09 Mar 07	8.75	3	40.5	10,000	2,400	986	1,378	1,207	131	267	212
16 Mar 07	8.78	4	40.72	10,440	2,200	975	1,476	1,252	126	282	234
23 Mar 07	8.69	4	40.25	9,600	2,000	897	1,982	1,238	238	341	293
30 Mar 07	8.7	2	56.35	12,200	3,520	1,581	2,181	1,918	263	223	170
2 Apr 07	8.74	2	61.2	11,120	3,200	1,474	2, 276	1,952	324	258	210

Table A - 4 Characteristics of Leachate from Conventional landfill (cont)

Date	DOC (mg/L)	TN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
22 Dec 06	4,006	1,643	21,092	12,556	4,188	1,096	567
27 Dec 06	6,500	1,655	25,892	15,692	4,128	968	458
29 Dec 06	5,390	1,890	22,396	14,468	4,232	956	445
30 Dec 06	4,889	1,676	22,276	13,796	3,964	952	441
31 Dec 06	2,791	899	33,912	14,300	4,096	984	460
01 Jan 07	1,965	890	20,572	14,284	4,024	872	368
04 Jan 07	1,677	831	21,020	3,924	608	890	359
12 Jan 07	928	950	11,392	3,656	3,876	580	492
19 Jan 07	540	1,089	15,860	7,716	3,552	1,152	550
26 Jan 07	392	1,170	15,620	3,096	3,628	288	652
02 Feb 07	367	1,425	9,556	3,656	3,928	380	316
09 Feb 07	351	1,187	26,340	3,824	3,836	408	192
16 Feb 07	1,355	2,304	6,316	3,992	4,036	384	112
23 Feb 07	2,616	1,446	4,532	3,332	3,384	284	248
02 Mar 07	1,575	2,500	4,260	3,524	3,440	308	428
09 Mar 07	1,998	1,680	41,644	3,772	3,876	492	256
16 Mar 07	1,086	1,092	46,004	4,804	5,036	4,244	288
23 Mar 07	934	979	15,344	3,772	3,876	404	256
30 Mar 07	1,058	1,571	20,852	3,964	3,976	404	132
2 Apr 07	1,579	1,649	16,240	3,748	3,884	412	244

Table A-4 Characteristics of Leachate from Conventional landfill (cont)

Date	Heavy metals (mg/L)						
	Mn	Cr	Cd	Pb	Ni	Zn	Cu
22 Dec 06	29.141	6.563	0.605	2.122	14.770	61.010	6.938
26 Jan 07	0.434	0.287	0.030	0.005	1.003	1.274	0.129
23 Feb 07	0.249	0.419	0.026	0.028	1.119	1.383	0.119
23 Mar 07	0.225	0.529	0.050	0.030	1.317	1.661	0.122
02 Apr 07	0.806	0.047	0.023	0.029	0.537	0.608	0.163

Table A-5 Characteristics of Leachate from Evaporation storage Tank No. 2 (ROC2)

Date	pH	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
15 Jan 07	7.8	41.25	6,400	3,200	-	76	-	128	117
17 Jan 07	7.77	28.88	6,200	9,660	-	76	-	273	240
19 Jan 07	8.09	29.24	6,300	8,640	560	64	496	262	234
24 Jan 07	8.22	27.88	6,000	6,080	-	260	-	244	120
26 Jan 07	8.35	26.61	6,000	3,200	538	252	286	248	267
29 Jan 07	8.4	26.58	5,960	4,800	-	190	-	278	291
31 Jan 07	8.46	34.56	5,900	3,840	-	199	-	168	71
02 Feb 07	8.56	24.21	5,420	3,520	552	244	308	128	104
05 Feb 07	8.5	18.54	5,560	2,880	-	87	-	219	129
07 Feb 07	8.54	24.65	5,780	3,520	-	81	-	155	61
09 Feb 07	8.57	23.15	5,880	2,560	496	28	468	145	95
12 Feb 07	8.63	23.72	5,300	2,240	-	42	-	359	203
14 Feb 07	8.51	22.66	5,400	3,200	-	216	-	157	142
16 Feb 07	8.75	23.7	5,000	3,200	580	218	362	182	143
19 Feb 07	8.57	32.45	4,800	2,048	-	126	-	196	106
21 Feb 07	8.67	19.4	4,600	2,240	-	59	-	136	260
23 Feb 07	8.66	21.6	3,600	3,520	560	232	328	91	51
26 Feb 07	8.74	21.5	4,100	3,680	-	249	-	77	54
28 Feb 07	8.67	21.7	3,000	640	-	148	-	136	153
02 Mar 07	8.72	21.74	3,200	1,920	406	182	224	114	75
05 Mar 07	8.78	22.54	3,000	1,600	-	134	-	594	216
07 Mar 07	8.85	21.65	3,200	1,600	-	137	-	275	195
09 Mar 07	8.8	22.25	3,100	3,200	440	90	350	541	326
12 Mar 07	8.86	21.25	3,400	2,240	-	90	-	407	431
14 Mar 07	8.87	21.34	2,900	2,560	-	81	-	750	482

Table A-5 Characteristics of Leachate from Evaporation storage Tank No. 2 (cont)

Date	pH	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
16 Mar 07	8.99	21.52	3,200	3,200	426	56	370	725	252
19 Mar 07	8.55	21.64	3,500	3,840	440	28	286	308	268
21 Mar 07	8.61	34.64	4,300	3,200	-	280	-	300	256
23 Mar 07	8.82	33.73	4,160	3,200	328	154	286	319	276
26 Mar 07	8.82	34.52	4,420	3,520	-	148	180	433	192
30 Mar 07	8.82	33.58	4,500	4,160	258	160	98	267	191
2 Apr 07	8.82	24.05	4,400	2,560	322	176	146	213	170

Table A-5 Characteristics of Leachate from Evaporation storage Tank No. 2 (cont)

Date	DOC (mg/L)	TN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
15 Jan 07	2,080	646	38,608	3,536	7,896	696	576
17 Jan 07	1,790	645	16,912	3,608	3,772	670	724
19 Jan 07	1,433	637	85,808	3,688	3,816	652	468
24 Jan 07	1,184	582	14,352	288	3,316	516	376
26 Jan 07	898	582	13,936	3,648	3,768	492	364
29 Jan 07	762	521	14,696	4,808	4,880	392	332
31 Jan 07	645	489	6,108	3,540	3,872	380	380
02 Feb 07	384	480	19,628	9,096	9,268	5,900	376
05 Feb 07	489	435	5,160	3,688	4,004	496	384
07 Feb 07	406	389	17,592	3,876	3,884	376	200
09 Feb 07	393	390	6,452	3,444	3,452	316	232
12 Feb 07	1,669	716	4,812	3,680	3,752	304	208
14 Feb 07	1,037	762	11,228	3,768	3,920	216	180
16 Feb 07	879	765	7,444	3,808	3,964	220	184

Table A-5 Characteristics of Leachate from Evaporation storage Tank No. 2 (cont)

Date	DOC (mg/L)	DTN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
19 Feb 07	641	668	9,356	3,368	3,948	232	300
21 Feb 07	1,092	520	3,768	3,704	3,748	292	160
23 Feb 07	873	404	13,624	3,892	3,976	356	140
26 Feb 07	1,306	383	9,340	3,848	3,888	376	212
28 Feb 07	889	322	12,924	3,760	3,792	264	328
02 Mar 07	712	409	4,232	3,820	3,992	112	288
05 Mar 07	1,162	229	43,160	3,772	3,800	324	148
07 Mar 07	1,094	194	43,628	3,836	3,852	292	132
09 Mar 07	1,001	242	53,904	3,784	3,848	360	228
12 Mar 07	679	150	40,572	3,680	3,732	136	152
14 Mar 07	599	99	40,572	5,380	5,408	1,824	84
16 Mar 07	499	76	45,800	3,688	3,808	320	120
19 Mar 07	445	60	47,876	3,516	7,636	3,880	256
21 Mar 07	556	178	35,748	3,652	3,800	2,040	223
23 Mar 07	531	171	42,036	3,736	3,868	360	268
26 Mar 07	749	259	23,844	3,744	3,888	356	208
30 Mar 07	1,626	467	18,632	3,876	3,932	344	136
2 Apr 07	1,836	495	42,000	3,792	3,908	378	232

Table A-6 Characteristics of Leachate from Evaporation storage Tank No. 3 (ROC3)

Date	pH	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
15 Jan 07	7.8	41.15	6,360	4,160	-	56	-	145	117
17 Jan 07	7.85	29.38	6,100	9,440	-	249	-	275	240
19 Jan 07	8.22	28.67	6,000	9,120	804	238	566	264	234
24 Jan 07	8.35	28.22	6,100	5,920	-	109	-	155	120
26 Jan 07	8.47	26.9	5,800	3,840	818	84	734	297	267
29 Jan 07	8.49	35.25	5,780	3,520	-	59	-	314	291
31 Jan 07	8.49	34.1	5,840	3,520	-	56	-	149	71
02 Feb 07	8.59	24.24	5,820	3,840	756	45	711	159	104
05 Feb 07	8.52	19.74	5,620	3,360	-	76	-	182	129
07 Feb 07	8.55	24.58	5,840	4,320	-	258	-	106	61
09 Feb 07	8.55	24.02	5,680	3,360	776	36	740	130	95
12 Feb 07	8.58	25.12	5,660	2,880	-	188	-	258	203
14 Feb 07	8.5	23.96	5,500	2,720		417	-	192	142
16 Feb 07	8.6	24.68	4,900	4,320	739	154	322	186	143
19 Feb 07	8.63	34.5	4,700	3,360	-	316	-	176	106
21 Feb 07	8.61	20.64	4,700	960	-	319	-	308	260
23 Feb 07	8.7	23.09	4,060	2,720	650	232	418	99	51
26 Feb 07	8.7	22.95	4,000	2,720	-	230	-	99	54
28 Feb 07	8.71	23.13	3,740	480	-	171	-	203	153
02 Mar 07	8.7	22.92	3,900	1,600	571	255	316	120	75
05 Mar 07	8.79	24.04	3,300	1,760	-	137	-	256	216
07 Mar 07	8..46	23.06	3,000	1,120	-	132	-	235	195
09 Mar 07	8.78	23.35	3,100	2,240	412	64	348	384	326
12 Mar 07	8.95	21.59	3,200	2,240	-	81	-	469	431
14 Mar 07	8.93	22.26	2,800	2,240	-	64	-	522	482

Table A-6 Characteristics of Leachate from Evaporation storage Tank No. 3 (cont)

Date	pH	Conductivity (mS/cm)	Alkalinity (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	Organic-Nitrogen (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)
16 Mar 07	9.03	22.58	3,200	2,560	356	39	317	292	252
19 Mar 07	8.5	23.02	2,960	3,200	-	39	-	306	268
21 Mar 07	8.6	35.5	3,500	4,160	-	160	-	296	256
23 Mar 07	8.69	35.08	3,600	3,840	344	160	184	314	276
26 Mar 07	8.81	35.46	4,000	3,840	286	101	185	240	192
30 Mar 07	8.91	35.57	4,100	3,200	204	112	92	234	191
2 Apr 07	8.91	24.8	4,200	3,520	244	109	135	215	170

Table A-6 Characteristics of Leachate from Evaporation storage Tank No. 3 (cont)

Date	DOC (mg/L)	DTN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
15 Jan 07	1,996	573	11,520	3,152	3,664	580	928
17 Jan 07	1,462	579	63,804	49,888	49,976	680	720
19 Jan 07	1,240	590	15,972	3,640	3,764	572	460
24 Jan 07	1,011	537	14,848	3,428	3,536	684	828
26 Jan 07	650	478	14,424	3,584	3,612	556	452
29 Jan 07	548	423	13,508	3,004	3,320	472	588
31 Jan 07	509	433	4,144	3,660	3,972	560	437
02 Feb 07	592	418	10,136	3,660	4,020	560	168
05 Feb 07	438	341	9,264	3,408	3,344	4,900	460
07 Feb 07	448	376	4,804	3,848	3,900	360	196
09 Feb 07	346	311	4,784	3,808	3,948	416	288
12 Feb 07	1,617	652	4,108	3,804	3,868	264	212
14 Feb 07	1,486	609	2,720	3,580	4,964	256	232

Table A-6 Characteristics of Leachate from Evaporation storage Tank No. 3 (cont)

Date	DOC (mg/L)	DTN (mg/L)	TS (mg/L)	VS (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)
16 Feb 07	687	567	13,584	3,752	3,808	100	88
19 Feb 07	687	542	10,440	3,816	3,824	224	88
21 Feb 07	1,090	552	4,364	3,788	3,800	348	180
23 Feb 07	1,251	427	3,956	3,672	3,728	384	208
26 Feb 07	1,380	443	11,732	3,908	3,996	436	212
28 Feb 07	930	398	5,028	3,884	3,996	444	567
02 Mar 07	658	304	3,980	3,444	3,604	240	288
05 Mar 07	1,150	236	42,692	3,717	3,816	324	260
07 Mar 07	1,035	215	44,976	3,796	3,848	308	100
09 Mar 07	993	150	40,744	3,736	3,868	360	268
12 Mar 07	657	106	42,488	6,404	6,480	2,888	160
14 Mar 07	638	112	45,088	13,612	14,856	11,220	1,280
16 Mar 07	501	71	20,016	3,792	3,808	500	144
19 Mar 07	481	61	51,084	3,444	3,496	224	124
21 Mar 07	506	134	31,904	24,812	5,012	2,548	276
23 Mar 07	473	117	7,844	3,784	3,848	360	228
26 Mar 07	850	247	5,476	3,948	4,028	640	296
30 Mar 07	1,258	296	46,204	3,908	3,992	400	168
2 Apr 07	1,532	315	13,584	3,784	3,924	284	240

Appendix B: Photographs

Figure B-1 Landfill lysimeters at Environmental Research Station of AIT

Figure B-2 Landfill lysimeter installation by Aeration & Leachate Recirculation systems

Figure B-3 MSW Composition analysis

Figure B-4 Waste balances before load into Open Cell Landfill lysimeters

Figure B-5 Waste compaction in Open Cell Landfill lysimeters

Figure B-6 Measurement layer by layer after of MSW loaded

Figure B-7 Final loading of MSW

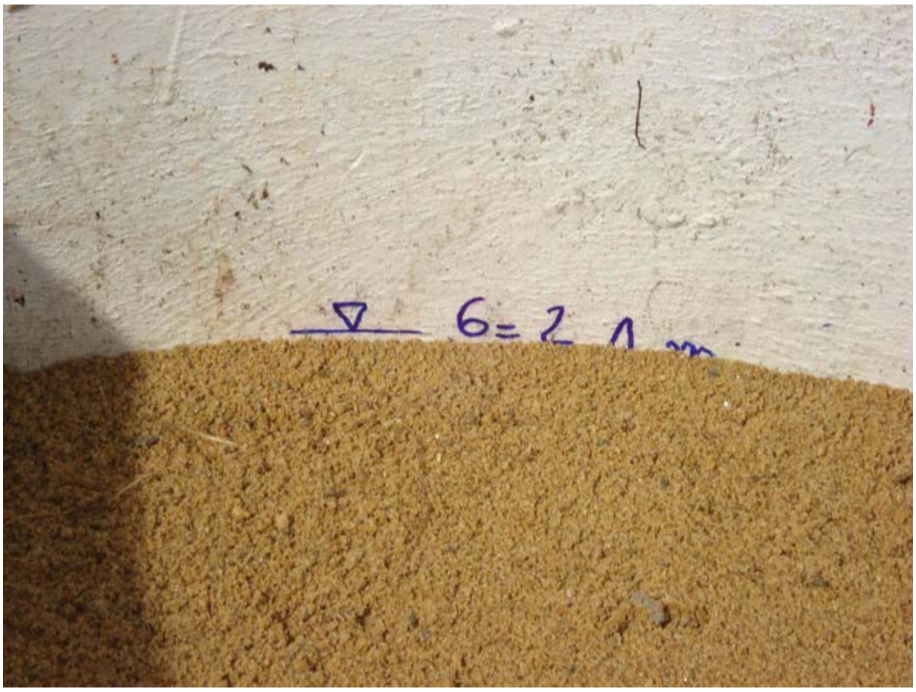


Figure B-8 Final cover of MSW in Landfill lysimeter by Sand layer (5 cm)

Assessment of Aeration and Leachate Recirculation in Open Cell Landfill Operation with Leachate Management Strategies

By

Khim Nora

Examination Committee:

Prof. C. Visvanathan (Chairperson)

Dr. Preeda Parkpian

Dr. U. Glawe

April 27, 2007

Contents

- Introduction
  - Problems Statement
  - Objectives of the Study
- Methodology
- Results and Discussions
- Conclusions and Recommendations

Problems Statement

- ☞ Amount of Solid Waste generation is increasing with socio-economic activities and population growth
- ☞ Common problems for solid waste management in developing countries include:
  - Institutional deficiencies & Inadequate legislation
  - Lack of human resources & Public participation
  - Lack of environmental & regulations effective enforcement

Problems Statement

- Open dump and land filling are commonly used in developing countries cause several problems to human health and environment

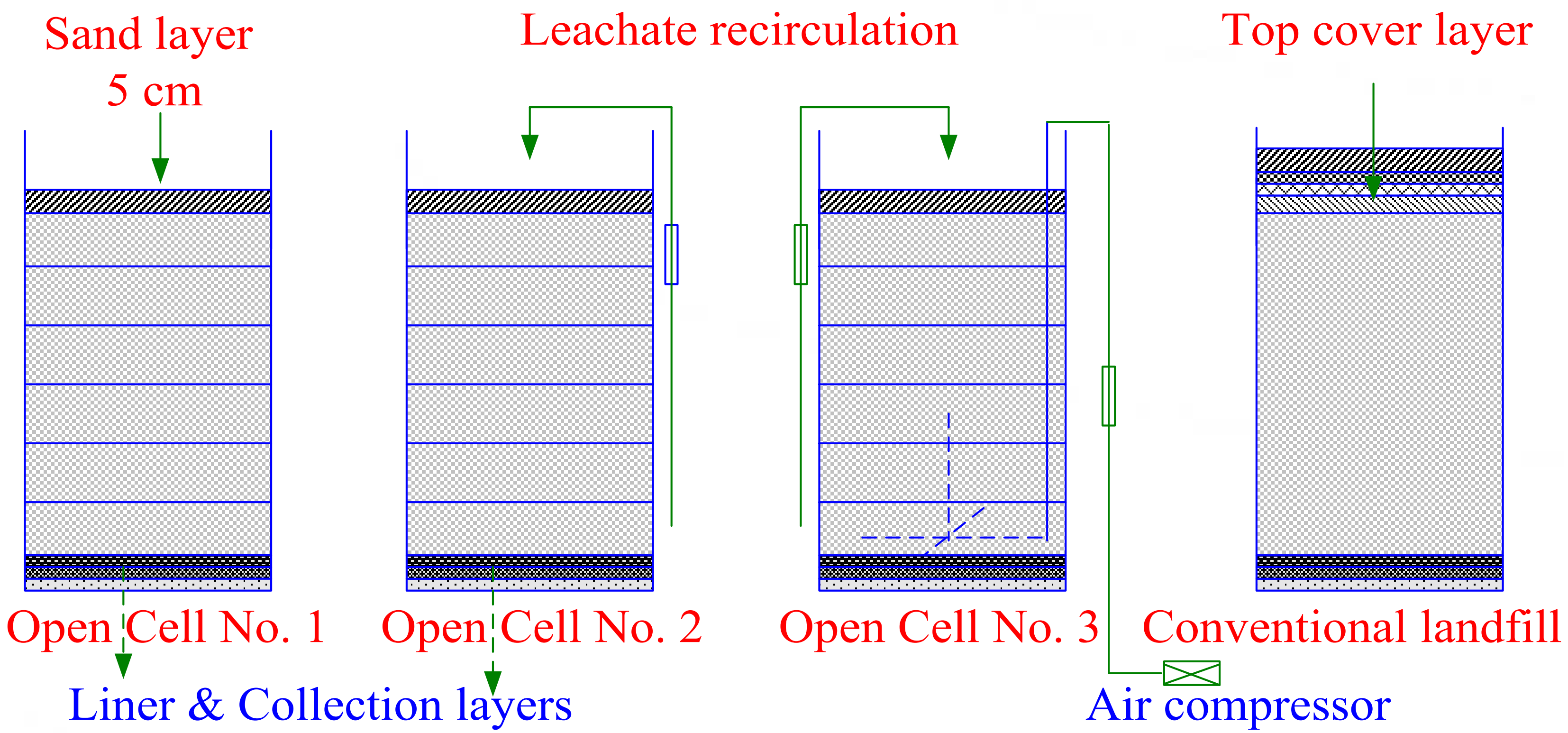
- Leachate recirculation provides a means of :
  - Optimizing environmental conditions in within the landfill
  - Enhancing stabilization of landfill contents as well as treatment of leachate moving through the landfill
  - Enhancing settlement of solid waste in landfill

Objectives of the Study

- To simulate the open cell landfill technique under aeration and leachate recirculation to determine the degree of waste stabilization in landfill
- To determine the Carbon, Nitrogen and Heavy metals balances in open cell landfill under different operation
- To recommend and appropriate operation for open cell landfill with leachate management option for sustainable land-filling in correlation with the Asian tropical climate

Methodology

Task I: Monitoring the open cell landfill lysimeters	Task II: Leachate management at different lysimeters operation



Task I. Monitoring the open cell landfill lysimeters

Sampling and Analysis

1. Determination of leachate generation and leachate characteristics
2. Determination of Carbon and Nitrigen balances in leacahate
3. Determination of Heavy metals profile in lysimeters

Determination of settlement variation of solid waste in landfill lysimeters

Interpretation and Comparison of results

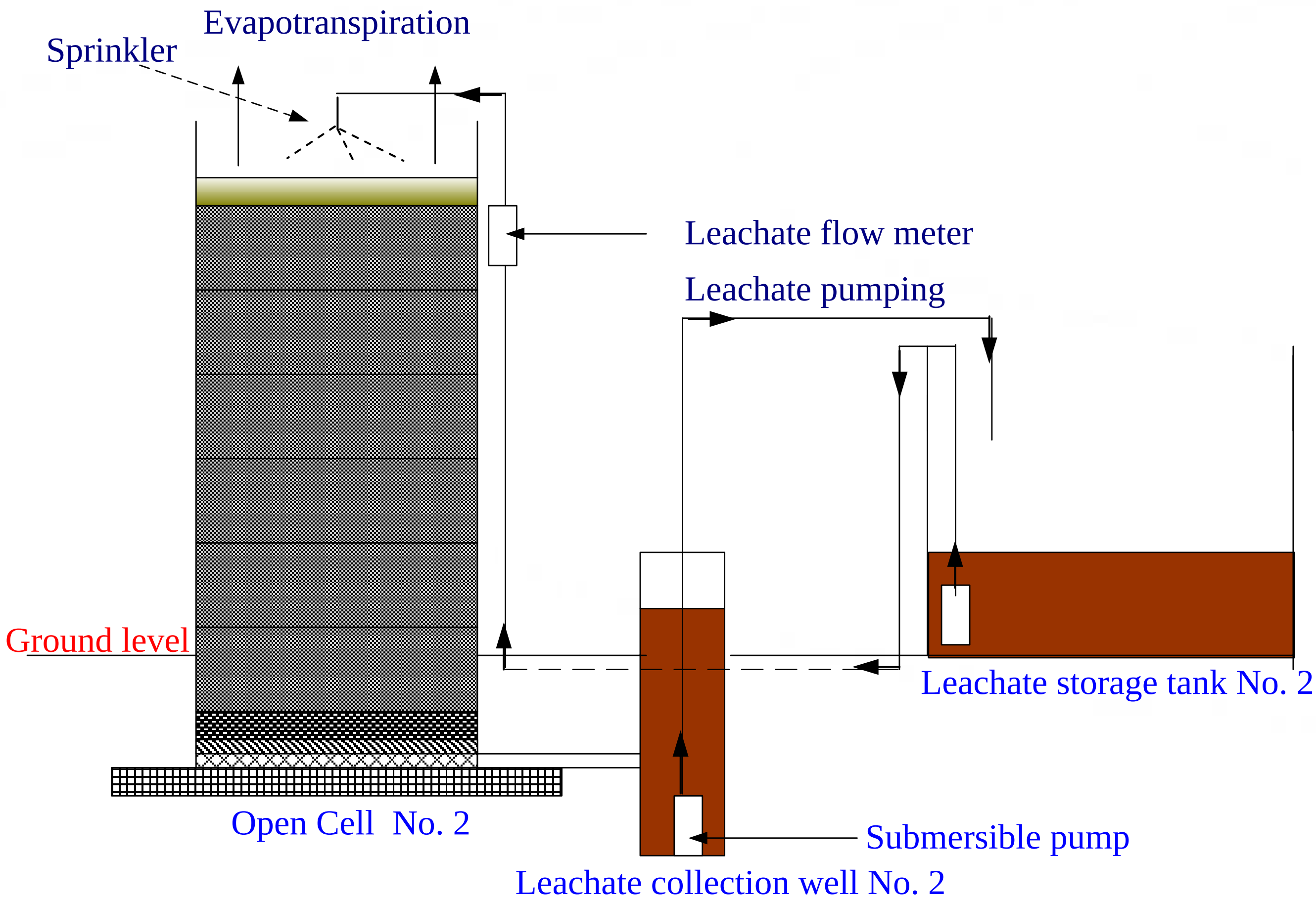
Task II: Leachate management at different lysimeters operation

Leachate recirculation into CO2 with OC3 aeration supply

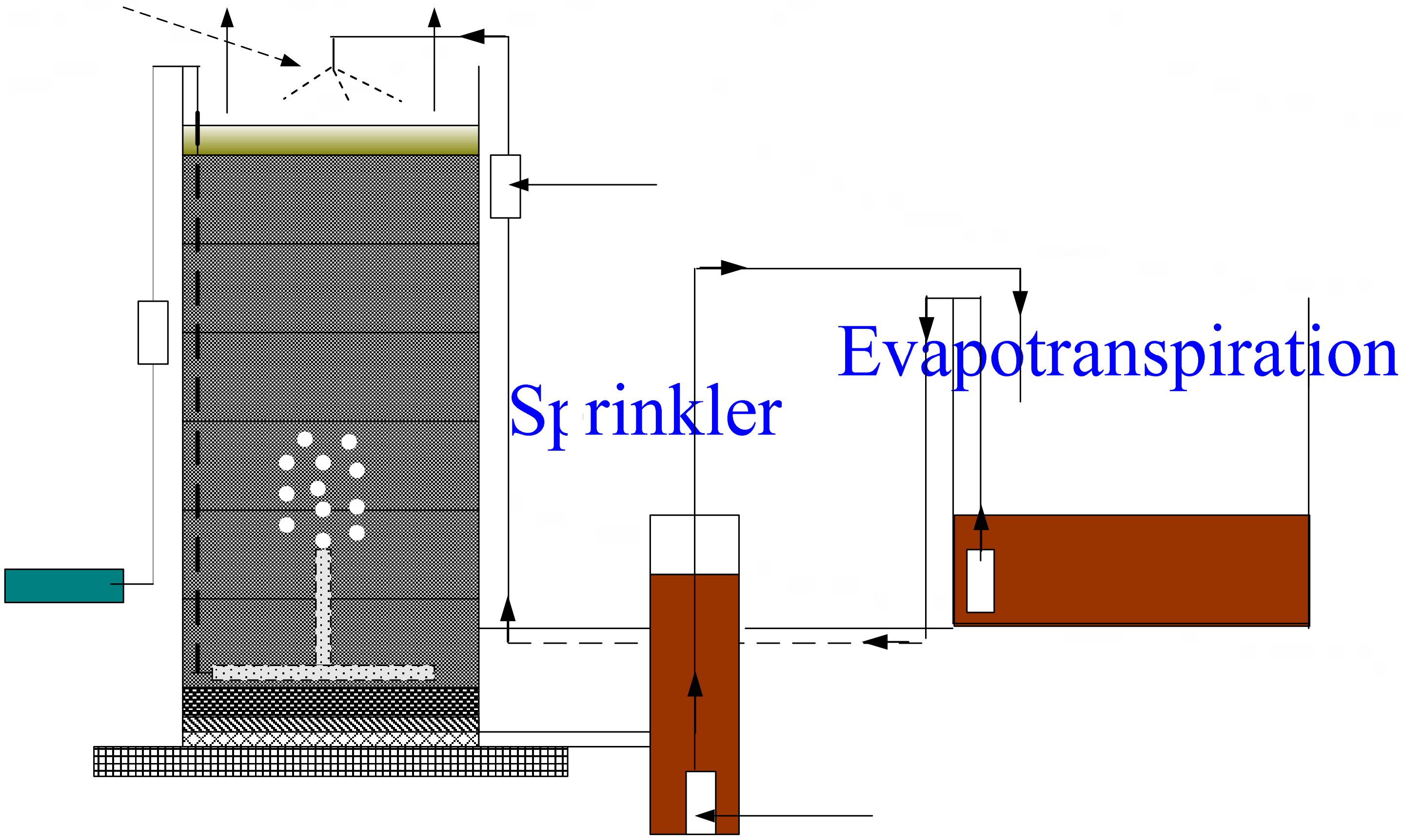
1. Determining C, N and Heavy metals balances in leachate
2. Determine volume of leachate remaining
3. Determining level settlement of solid waste

To recommend an improved operation application of open cell landfill lysimeters

Leachate Recirculation System in OC 2

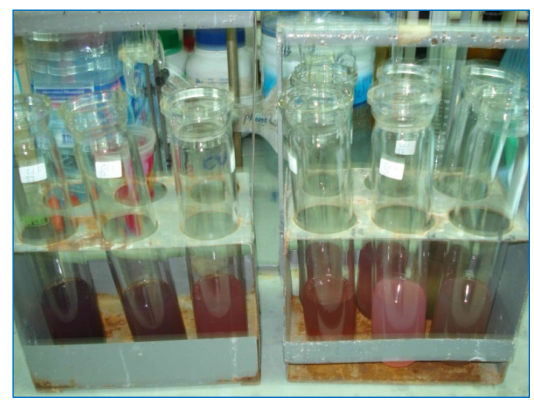


Leachate Recirculation & Aration System in OC 3



Analytical Parameters

Solid Waste Characteristics	Leachate Characteristics
Physical composition	p H, Akalinity, Conductivity
Chemical composition	COD, BOD, TKN, NH_3 –N
Heavy metals (Mn, Cr, Cd, Pb, Ni, Zn and Cu)	Org-N, TN, DOC, NO_2 , NO_3 TS, VS, TDS, TSS & TVSS
Bulk density	Heavy metals (Mn, Cr, Cd, Pb, Ni, Zn and Cu)



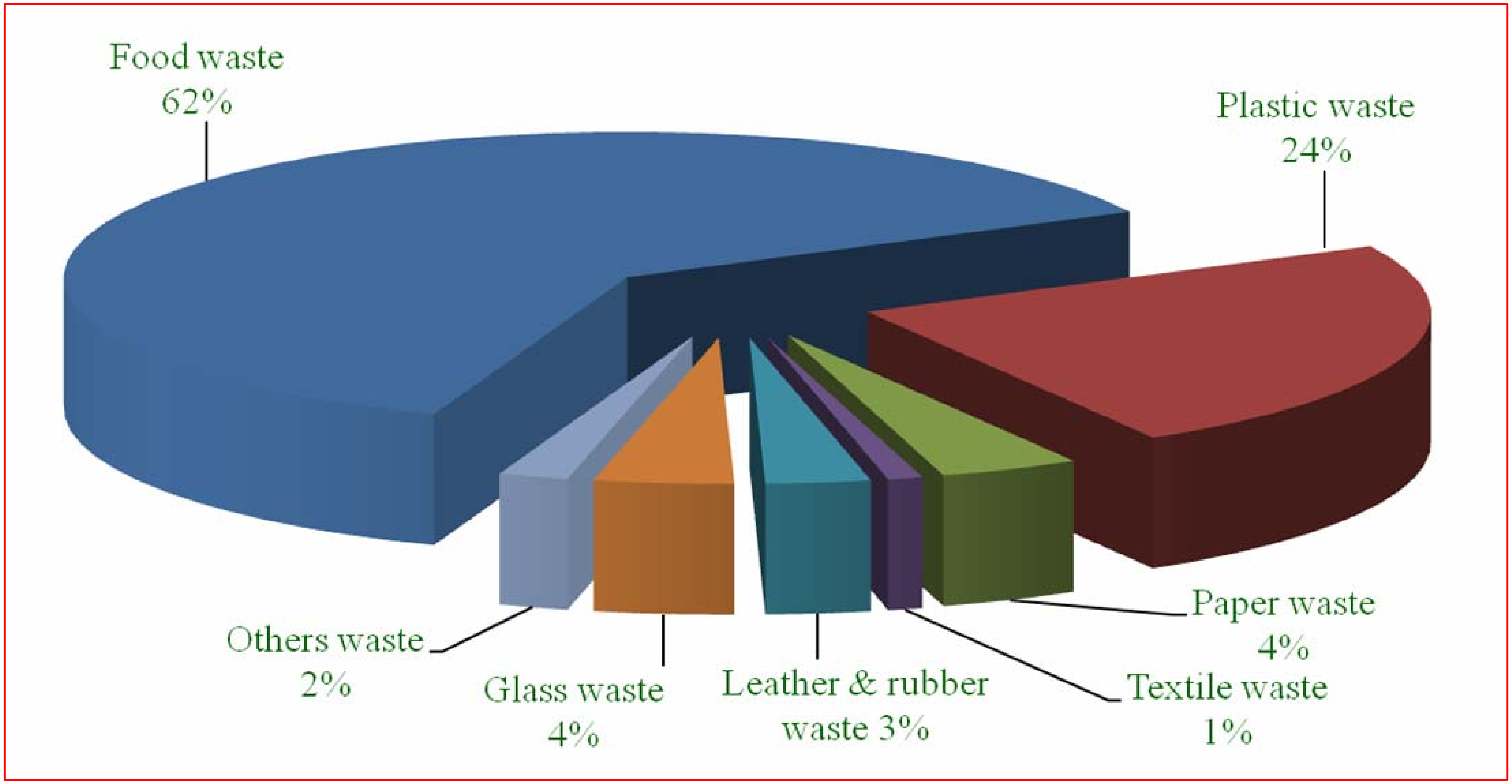
Physical & Chemical Composition of MSW

Physical Properties	Sampling Date						Average (%)
	4 Nov	11Nov	18 Nov	25 Nov	2 Dec	9 Dec	
	Properties of MSW (% by weight)						
Food	63	59	60	64	65	60	62
Plastics	24.5	26	23	28	19	24	24
Paper	2.5	2	6.2	3	6	3.5	4
Textile	3.5	3	2.3	1	1	1	1
Leather/Rub	2	6	1.5	1	3	2.5	3
Glass	3	2.5	4.8	2	4	5.5	4
Others	1.5	1.5	3.3	1	2	3.5	2
Bulk density (kg/m^3)	320.83	295.83	310.83	299.99	335.83	333.33	**316 (kg/m^3)**

Physical & Chemical Composition of MSW (cont')

Chemical Properties	Sampling Date						Average (%)
	4 Nov	11Nov	18 Nov	25 Nov	2 Dec	9 Dec	
Moisture content (%)	45.18	49.91	53.41	49.06	41	36.93	46
TS (%)	54.82	50.09	46.59	50.94	58.77	63.07	54
VS (%)	52	59.34	52.6	62.25	49.75	34.67	52
Ash (%)	48	40.66	47.4	37.75	50.25	65.33	48
% Carbon	28.88	32.96	29.22	34	27.63	19.26	29
% Nitrogen	3.71	4.23	3.75	4.44	3.55	2.47	4

MSW Composition



Heavy Metals analysis in MSW

Sample Name	Weight of Sample (g)	Sample Concentration (g/kg)						
		Mn	Cr	Cd	Pb	Ni	Zn	Cu
OC 1	0.96	193	29	0.4	24	20	23	39
OC 2	1.01	230	35	35	37	22	29	48
OC 3	1.01	215	36	36	26	22	22	39
CLF	1.01	216	31	31	32	21	21	40

A similar heavy metals concentrations in all four lysimeters was observed

Heavy Metals Analysis in Leachate

Date	Volume of Leachate (L)	Sample Name	Sample concentration (mg/L)						
			Mn	Cr	Cd	Pb	Ni	Zn	Cu
22 Dec 06	88	OC 1	50.662	17.748	0.209	0.775	17.052	30.039	2.310
	115	OC 2	187.485	6.653	0.609	1.264	16.043	34.190	4.594
	98	OC 3	71.717	6.437	0.483	0.620	13.916	33.967	6.124
	100	CLF	29.141	6.563	0.605	2.122	14.770	61.010	6.938
26 Jan 07	4	OC 1	1.294	0.658	0.020	0.019	1.111	1.084	0.120
	18	OC 2	3.996	0.462	0.083	0.037	2.277	7.103	0.485
	10	OC 3	1.974	0.353	0.053	0.020	2.072	1.962	0.429
	3	CLF	0.434	0.287	0.030	0.005	1.003	1.274	0.129
23 Feb 07	6	OC 1	1.300	0.839	0.022	0.005	1.216	1.083	0.172
	8	OC 2	0.752	0.201	0.077	0.037	0.783	1.055	0.222
	10	OC 3	1.695	0.289	0.109	0.053	1.825	3.167	0.655
	3	CLF	0.249	0.419	0.026	0.028	1.119	1.383	0.119

Heavy Metals Analysis in Leachate (cont')

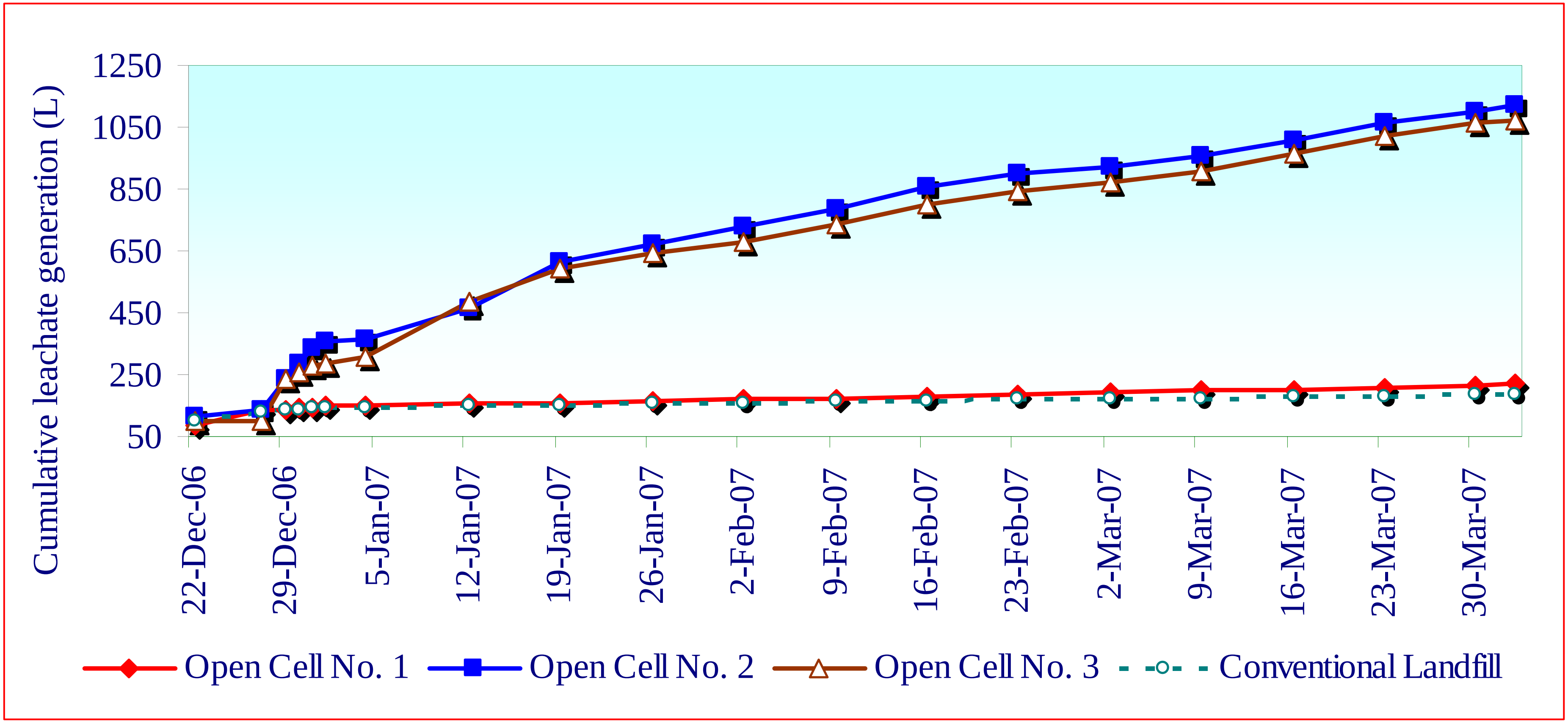
Date	Volume of Leachate (L)	Sample Name	Sample concentration (mg/L)						
			Mn	Cr	Cd	Pb	Ni	Zn	Cu
23 Mar 07	5	OC 1	1.222	0.699	0.015	0.003	1.072	1.207	0.126
	18	OC 2	1.944	0.452	0.155	0.051	2.002	2.981	0.538
	22	OC 3	6.002	0.502	0.215	0.382	3.830	6.219	1.625
	4	CLF	0.225	0.529	0.050	0.030	1.317	1.661	0.122
2 Apr 07	3	OC 1	1.006	0.434	0.011	0.011	0.707	0.816	0.086
	18	OC 2	7.454	0.488	0.123	0.239	2.111	4.207	0.861
	14	OC 3	1.848	1.929	0.108	0.057	4.459	4.049	0.497
	2	CLF	0.806	0.047	0.023	0.029	0.537	0.608	0.163

Low heavy metals concentrations in was leached out from solid wastes

Leachate generation from Landfill lysimeters

Date	OC. 1	Cumulative (L)	OC 2	Cumulative (L)	OC 3	Cumulative (L)	CLF	Cumulative (L)
22Dec 06	88	88	115	115	98	98	100	100
12-Jan-07	4	156	98	464	178	485	7	151
19-Jan-07	4	160	153	617	110	595	2	153
26-Jan-07	4	164	55	672	45	640	3	156
2-Feb-07	4	168	53	725	40	680	3	159
9-Feb-07	3	171	64	789	59	739	2	161
16-Feb-7	8	179	70	859	63	802	4	165
23-Feb-07	6	185	43	902	40	842	3	168
2-Mar-07	6	191	22	924	26	868	3	171
9-Mar-07	6	197	33	957	39	907	3	174
16-Mar-07	5	202	49	1006	54	961	4	178
23-Mar-07	5	207	56	1062	63	1024	4	182
30-Mar-7	9	216	40	1102	37	1061	2	184
2-Apr-07	3	**219**	18	**1120**	14	**1075**	2	**186**

Cumulative leachate generation from Landfill lysimeters

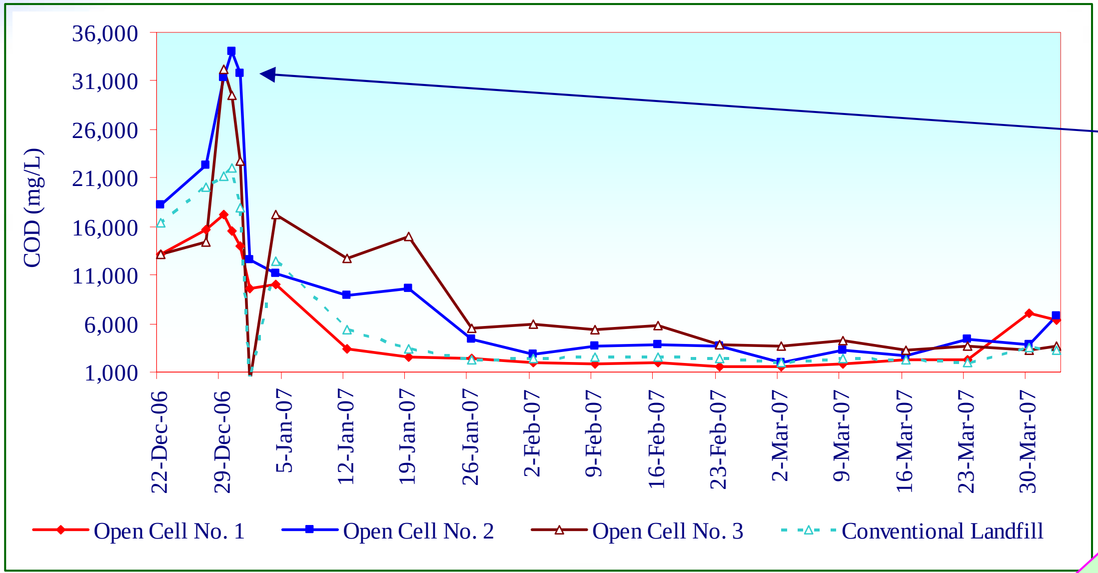


Significant Higher cumulative leachate generation from OC2 and OC3

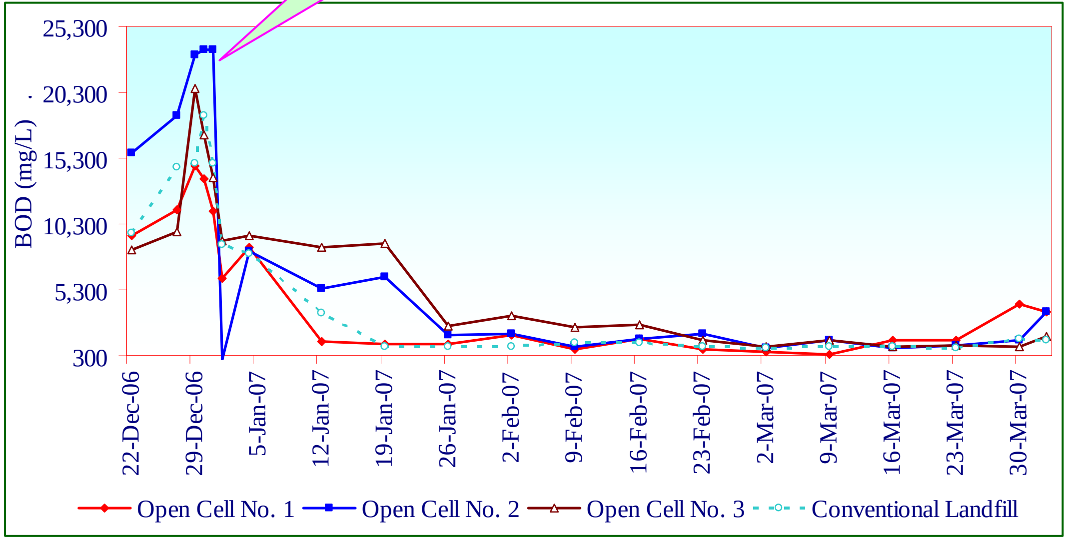
Leachate Characteristics from Landfill lysimeters

Parameters	Unit	Open Cell No.1	Open Cell No. 2	Open Cell No. 3	Conventional landfill
pH		7.26 – 7.81	7.16 – 8.35	6.61 – 7.89	7.18 – 8.83
Conductivity	(mS/cm)	40.15 – 62.85	17.53 – 42.13	19.45 – 44.48	34.75 – 61.20
Alkalinity	(mg/L)	8,300 – 13,500	5,800 – 10,100	3,300 – 8,700	8,120 – 12,200
COD	(mg/L)	1,600 – 17,200	1,920 – 33,998	3,264 – 32,130	2,000 -22,000
BOD	(mg/L)	359 – 14,726	853 – 23,581	963 – 20,589	897 – 18,509
BOD/OCD	(mg/L)	0.1 – 0.9	0.1 – 0.9	0.1 – 0.9	0.1 – 0.9
TKN	(mg/L)	1,280 – 2,176	918 – 1,512	902 – 1,266	1,338 – 2,276
NH_3 -N	(mg/L)	994 – 1,952	664 – 1,246	412 – 1,128	1,005 – 1,952
Organic-N	(mg/L)	23 - 734	16 - 506	17 - 532	90 -737
DOC	(mg/L)	368 – 5,815	241 – 9,345	280 – 9,355	351 – 6,500
TN	(mg/L)	923 – 2,554	619 – 2,337	261 – 1,824	831 – 2,500
Nitrate	(mg/L)	22 - 493	4 - 598	7 - 658	10 - 428
Nitrite	(mg/L)	52 - 553	42 - 633	66 - 644	68 - 470

COD and BOD Analysis in Leachate

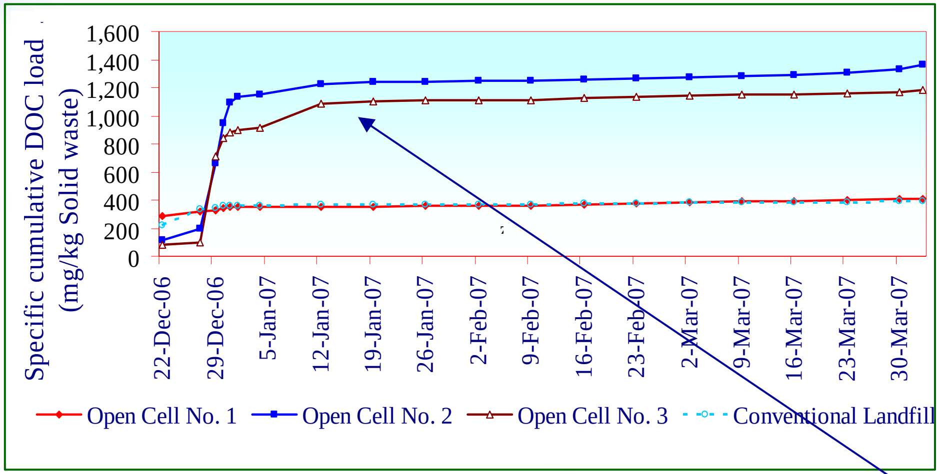


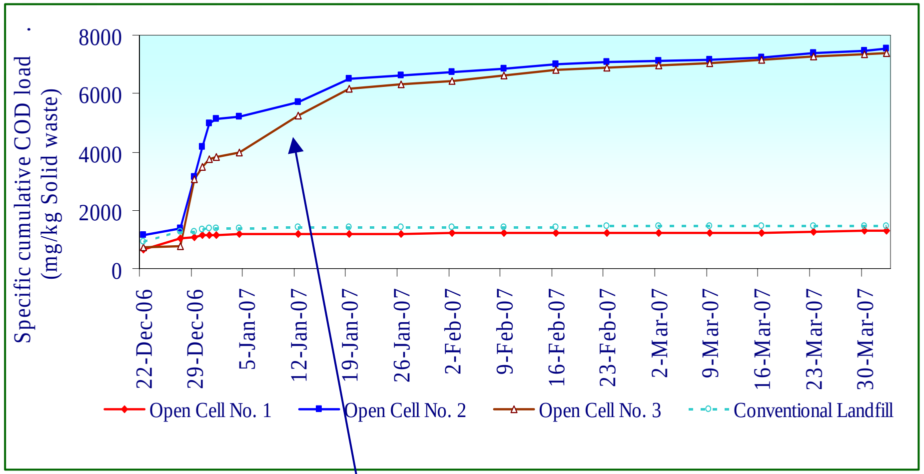
Higher COD and BOD during flushing period

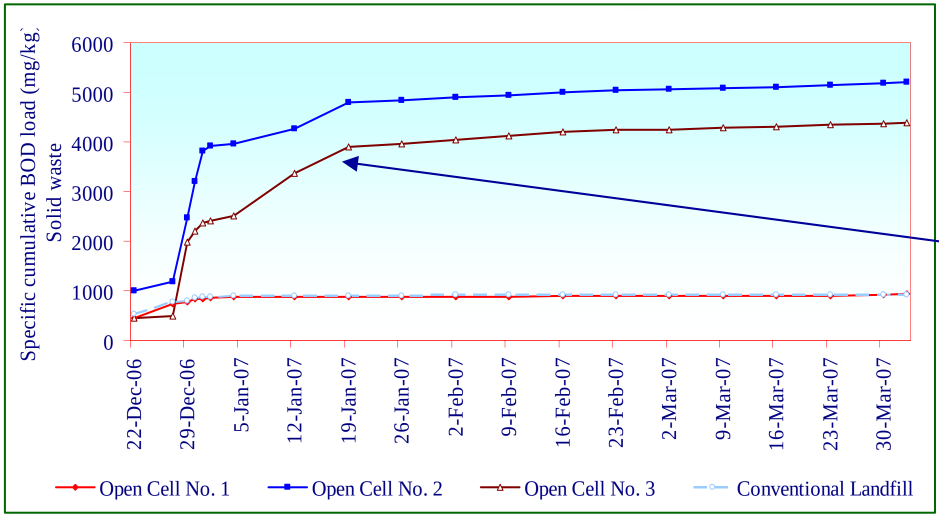


The decreasing trend of COD and BOD was observed for longer operation time for four all lysimeters

Specific COD, BOD and DOC

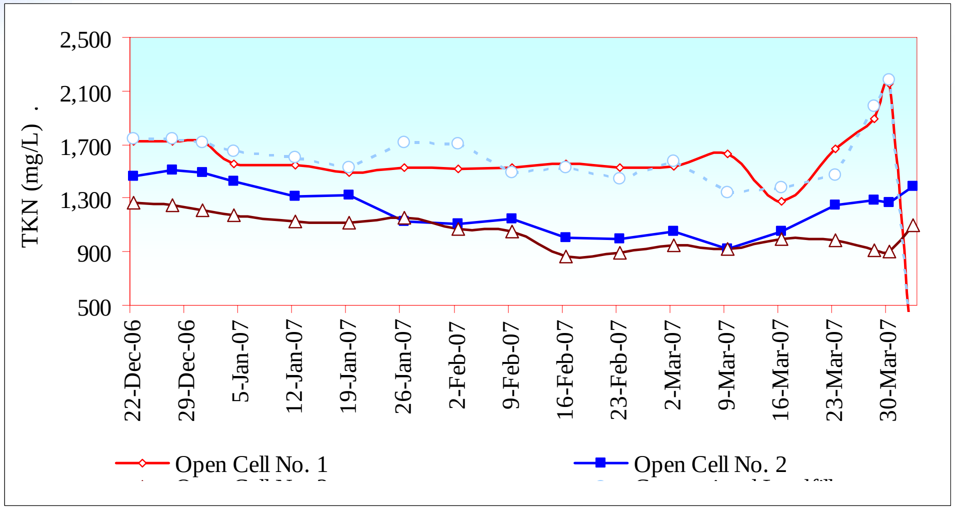


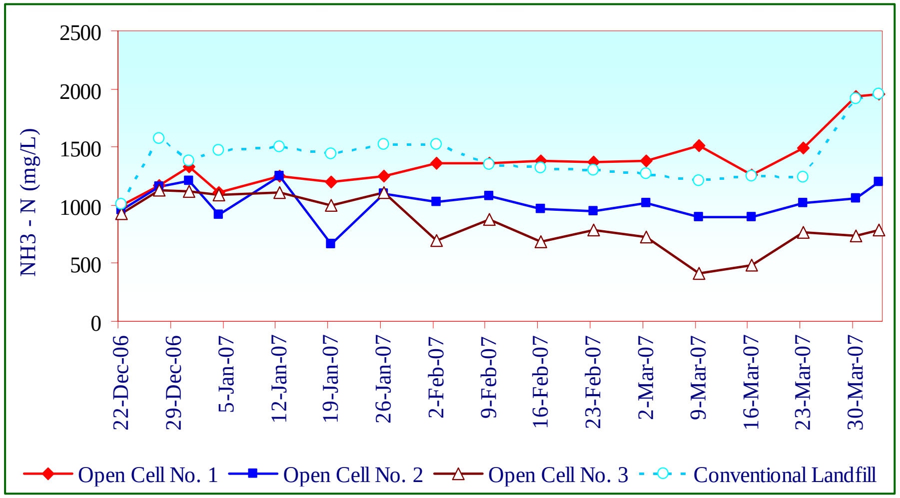


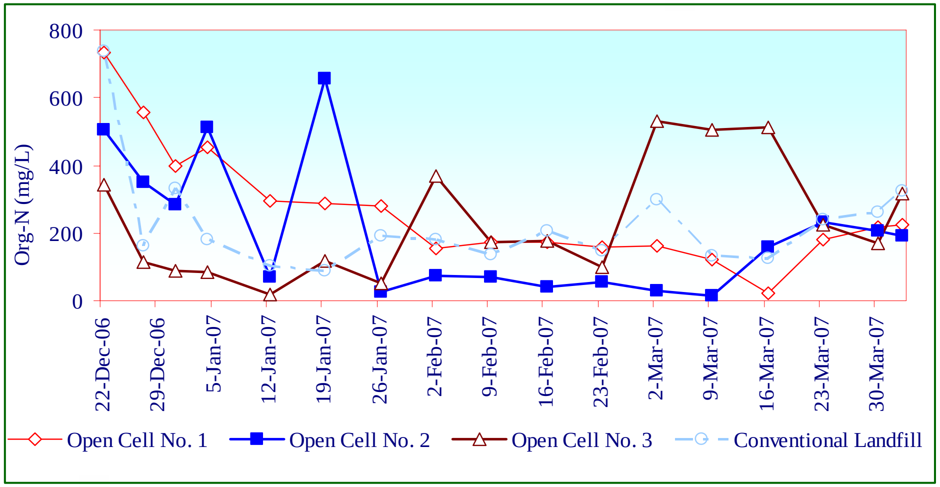


The higher cumulative COD, BOD and DOC were obtained in OC2 and OC3

TKN, NH_3- N & Org – N in Leachate

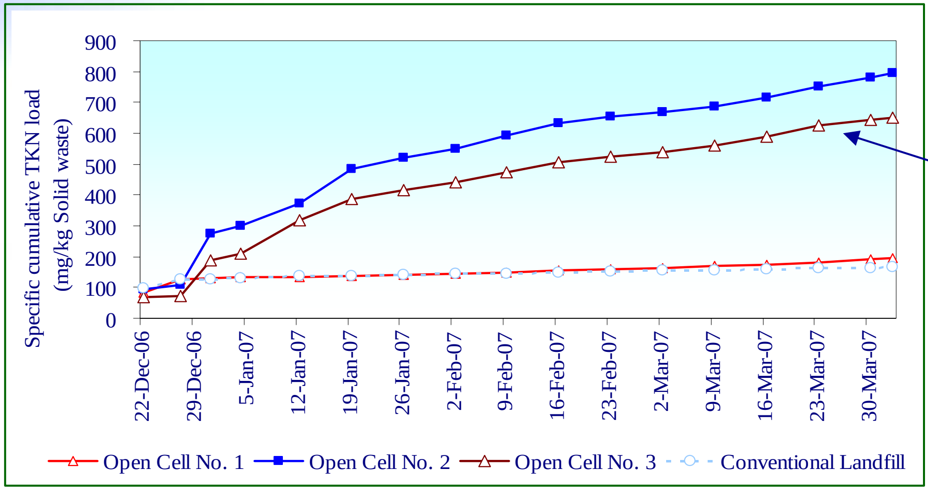






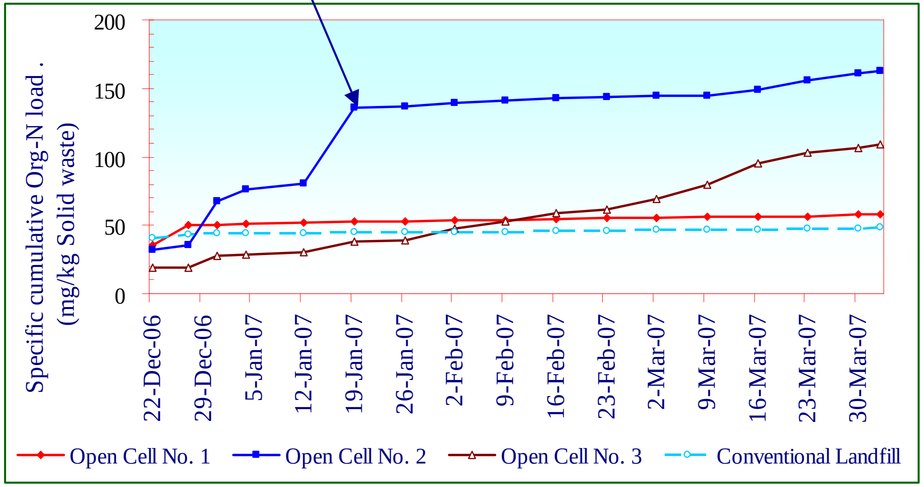
The similar trend of all three parameters in the lysimeters

Specific TKN & Org-N in Leachate



Higher TKN and Org-N Concentratin in OC2 and OC3 lysimeters

A parallel increased of TKN and Org-N from all lysimeters



Settlement variation of MSW in lysimeters

Date	Level Settlement (cm)			
	OC 1	OC 2	OC 3	CLF
9-Dec-06	0.0	0.0	0.0	10.9
16-Dec-06	4.0	8.0	10.0	11.0
23-Dec-06	6.0	0.1	13.0	11.1
30-Dec-06	8.0	13.0	15.0	11.2
6-Jan-07	9.0	14.0	17.0	11.3
13-Jan-07	11.0	16.0	18.0	11.3
20-Jan-07	12.0	17.0	20.0	11.4
27-Jan-07	13.0	17.0	20.0	11.4
3-Feb-07	13.0	18.0	21.0	11.5
10-Feb-07	14.0	19.0	22.0	11.5
17-Feb-07	14.0	19.0	23.0	11.5
24-Feb-07	15.0	20.0	24.0	11.5
3-Mar-07	16.0	21.0	24.00	11.6
10-Mar-07	16.0	22.0	25.0	11.6
17-Mar-07	17.0	23.0	26.0	11.7
24-Mar-07	17.0	24.0	27.0	11.80
2-Apr-07	18.0	25.0	28.0	12.0

Conclusions

1. Open Cell No.2 and 3 showed higher concentration in COD, BOD, TKN,TOC, TN than without leachate recirculation (Open Cell No. 1) and Conventional Landfill (CLF)

2. Open Cell No.3 showed the lowest specific cumulative load of COD, BOD, DOC, TN,TKN , cumulative leachate generation and higher settlement compared to Open Cell No. 2

3. In lysimeters with leachate recirculation combining with aeration, the pollutants concentration in leachate is lower than that of without aeration.

Conclusions (cont')

4. After five months of operation period, the specific cumulative of load of COD, BOD, DOC, TKN, NH_3–N, Org–N and TN from Open Cell No.1, 2, 3 and Conventional Landfill were:

COD	: 1,294; 7,535; 7,369 and 1,461 mg/kg
BOD	: 930; 5,211; 4,387 and 926 mg/kg
DOC	: 410; 1,361; 1,187 and 391 mg/kg
TKN	: 195; 795; 652 and 167 mg/kg
NH_3–N	: 135; 633; 547 and 124 mg/kg
Org–N	: 58; 163; 109 and 48 mg/kg
TN	: 191; 698, 399 and 163 mg/kg solid waste

Conclusions (cont')

5. The faster settlement was observed in Open Cell No.3 than Open Cell No.2, No. 1 and Conventional Landfill due to faster waste volume reduction. Similarly, concentration pollutants in Open Cell No 3 were also found lower than Open Cell No. 2, No.1 and CLF

6. The water management of open cell landfill lysimeters by storage, evaporation and recycle of leachate showed the reduction in amount of leachate remaining. The Open Cell No.2 and 3 had lowest leachate remaining compared with Open Cell No.1 and Conventional Landfill are 300; 213; 201 and 250L respectively. In this case, the evaporation plays key role in water management.

Recommendations

Leachate recirculation strategy can be effectively applied to accelerate waste stabilization and reduce the amount of leachate remaining for treatment

1. The operation of open cell landfill by leachate recirculation combining with aeration supply should be continued for long period including evaluation of landfill waste stability, pollutants concentration and waste settlement.
2. Heavy metal balance can be conducted to understand the fate of heavy metal in the landfill cell.
3. Carbon and Nitrogen balance in the open cell lysimeter can be investigated.

Thank You!