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Appendix Figure

LIST OF ABBREVIATIONS

BOD	=	Biochemical Oxygen Demand
BOD/COD	=	Biochemical Oxygen Demand to Chemical Oxygen Demand ratio
COD	=	Chemical Oxygen Demand
DT	=	Digested Solids
FC	=	Field Capacity
MC	=	Moisture Content
MSW	=	Municipal Solid Waste
NH_4-N	=	Ammonia Nitrogen
PCD	=	Pollution Control Department
SO_4^{-2}	=	Sulfate
TDS	=	Total Dissolved Solids
SS	=	Suspended Solids
TS	=	Total Solids
TKN	=	Total Kjeldahl Nitrogen
TS	=	Total Solids
VFA	=	Volatile Fatty Acids
VS	=	Volatile Solid
WP	=	Wilting Point
RF	=	Rain Fall
St	=	Storm condition
LR	=	Leachate Recirculation condition
IS	=	Internal Storage condition
LC	=	Low compacted waste
HC	=	High Compacted waste
HC-w/p	=	High Compacted waste Without Plastic
PT	=	Pre-Treated waste
OW	=	Old Waste
St_{C1}	=	low compacted waste at storm condition
St_{C2}	=	High compacted waste at storm condition

LIST OF ABBREVIATIONS (Continued)

St_{P1}	=	High compacted waste at storm condition (waste with plastic)
St_{P2}	=	High compacted waste without plastic at storm condition
St_{S1}	=	High compacted waste at storm condition
St_{S2}	=	Pre-treated waste at storm condition
St_{S3}	=	Old waste at storm condition
LR_{C1}-100	=	Low compacted with 100% leachate recirculation.
LR_{C1}-75	=	Low compacted waste with 75% leachate recirculation.
LR_{C1}-50	=	Low compacted waste with 50% leachate recirculation.
LR_{C1}-35	=	Low compacted waste with 35% leachate recirculation.
LR_{C2}-100	=	High compacted waste with 100% leachate recirculation.
LR_{C2}-35	=	High compacted waste with 35% leachate recirculation.
LR_{P1}-100	=	High compacted waste with 100% leachate recirculation (waste with plastic)
LR_{P2}-100	=	Sanitary landfill waste without plastic with 100% leachate recirculation.
LR_{S1}-100	=	High compacted waste with 100% leachate recirculation
LR_{S2}-100	=	Pre-treated waste with 100% leachate recirculation.
LR_{S2}-35	=	Pre-treated waste with 35% leachate recirculation.
IS_{C1}	=	Low compacted waste at internal storage condition
IS_{C2}	=	High compacted waste at internal storage condition

EFFECT OF SOLID WASTE DISPOSAL CONDITIONS ON LEACHATE CHARACTERISTICS IN TROPICAL LANDFILL

INTRODUCTION

Leachate can be defined as liquid that percolated through solid waste or another medium. (Tchobanoglous *et al.*,1993).Leachate arising from domestic waste landfills can contain high concentration of organic and inorganic substances, such as nitrogen compounds and heavy metals and it has the potential to pollute ground and surface waters. (Tränkler *et al.*,2001a).

Leachate characteristics and leachate generation depend on the type and depth of solid waste, age of landfill, the rate of water application, landfill design and operations and the interaction of leachate with its environment.(Qasim, 1994). The quality variations can also be attribute to sampling procedures, sample preservation, handling and storage, and analytical methods used to characterize the leachate (Chian and DeWalle,1976).

A most significant limitation for the successful treatment of landfill leachate is the complexity in identifying and quantifying their typical composition and characteristics. If leachate plants were designed to handle the average leachate quality only, they would occasionally be overloaded in practice, due to high discharge of leachate during certain time periods. Hence, climatic differences need to be considered.

As mentioned above, leachate generation and its characteristic in a landfill, the influence of the climate on leachate production is complex: In relatively warm climates, like the region, the leachate production after precipitation is generally increasing quite rapid and leachate production is generally greater (Lema *et al.*,1988)

Thailand has a warm climate and is located in the tropical region where a distinct dry season up to 150 days a year, a wet season with intensive rainfalls within a few hours, elevated temperature around 25 -40 ˚C and high solar radiation influence the water management of landfills and the characteristics of leachate produced in that region. (Tränkler *et al*.,2001b)

Because of this complexity in leachate under tropical climatic conditions, this study was focused on finding leachate characteristics in tropical climatic condition at different solid waste disposal conditions and operation factors.

OBJECTIVES

This study is conducted to investigate the characteristics of leachate mainly the extraction, affected by various influencing factors. The objectives can be summarized as follows,

1. To determine the characteristics of leachate in solid waste leaching during storm events in tropical climatic conditions in landfills.

2. To determine the characteristics of leachate in solid waste leaching in the landfill at leachate recirculation condition and internal storage condition.

Scope of the study

1. The Study was conducted in a lab scale. Landfill simulation reactors were simulated with 6 columns to carry out the experiment.

2. Various types of solid wastes (sanitary landfill waste, pre-treated waste, open dump fresh waste, open dump old waste) were considered for starting landfill body with different rainfall rates of storm condition.

3. Various types of solid wastes (sanitary landfill waste, pre-treated waste and open dump fresh waste) were considered for starting landfill body with different leachate re-circulation rates.

4. Various types of solid wastes (sanitary landfill waste, pre-treated waste and open dump fresh waste) were considered for starting landfill body with different leachate re-circulation rates.

5. All types of waste were obtained from Nonthaburi dumpsite, Thailand and simulated tropical climatic conditions for all lysimeters

6. The leachate quality will be considered in terms of BOD, COD, TKN, NH_3-N, Total solids, Total dissolved solids, Total suspended solids and pH

LITERATURE REVIEW

1. Landfill Leachate

1.1 Leachate Generation

Leachate can be defined as liquid that has percolated through solid waste or another medium. Leachate from landfills usually contain extracted, dissolved and suspended materials, some of which may be harmful (Tchobanoglous *et al*., 1993)

Leachate is generated when water penetrates into a landfill and leaches out water soluble compounds and decomposition products. Sources of water entering the landfill include liquid present in the refuse at placement (inherent moisture in the solid waste), precipitation falling on refuse at placement and infiltration after cover application and intrusion of groundwater from outside into the landfill. In addition, a small amount of water is formed as a by-product of decomposition of the wastes.

There are three ways of minimizing the amount of compounds, which are removed from landfills with the leachate:

- Reducing the leachate volume
- Collection and treatment
- Improvement in deposition methods or pre-treatment of certain types of waste.

Water passing trough a sanitary landfill carries with it various dissolved and suspended materials. The more water flows through the solid wastes, the more pollutants are leached. It is important to review the methods that can be estimate the amount of leachate generation at a sanitary landfill site.

The rate of production of leachate can be calculated by performing a water balance. A water balance involves an accounting of all of the serious of water entering and leaving the landfill, including the water used in bio-chemical reactions and water leaving the landfill in the form of water vapor in the landfill gas. The quantity of leachate that could potentially be generated is that which exceeds the moisture-holding capacity of the material in the landfill.

The total amount of moisture that can be stored in a unit volume of soil is a function of two variables: the field capacity (FC) and the wilting point (WP) of the soil. The field capacity of a soil is defined as the quantity of liquid, which remains in the pore space following a prolonged period of gravitational drainage. The wilting point of a soil is defined as the quantity of water that remains in a soil after plants are no longer capable of extracting any more water. The different between the field capacity and the wilting point is equivalent to the quantity of moisture that can be stored in a particular type of soil. The quantity of leachate generated is shown in equation 1

$$L = P - R - E_T - \Delta S \quad (1)$$

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 pee unit area (mm)

E_T = Quantity of moisture lost trough evapotranspiration per unit area (mm)

ΔS = Change in the amount of moisture stored in a unit volume of landfill (mm). (Tchobanoglous *et al*., 1993)

1.2 Composition of Leachate

When water percolates through solid wastes that are undergoing decomposition, both biological materials and chemical constituents are leached into solution.

The composition of the leachate and the content varies with respect to the type of pollutants, with the age of the landfill, the characteristics of the disposed waste and the degree of dilution with surface water and groundwater. The components, which are normally considered pollutants regarding treatment, are:

- Organic substances
- Nitrogen (primarily in ammonium ions)
- Heavy metals

The composition of leachate changes as the biological decomposition of the waste which undergoes different phases. After a short aerobic phase (several weeks) it is possible to identify two decomposition phases; an acid generating anaerobic phase, and a methanogenic anaerobic phase. A list of typical leachate components during the acid-and methane generating phases are presented in Table1

Table 1 Average values of leachate contents

Parameter	Unite	Acid phase	Methanogenic phase	Independent from lifetime
pH		6.1	8	
SCOD	mg/L	22,000	3000	
$SBOD_5$	mg/L	13,000	180	
Fe	mg/L	925	15	
Ca	mg/L	1300	80	
Mg	mg/L	600	250	
Mn	mg/L	24	0.65	
Zn	mg/L	5.6	0.64	
Sr	mg/L	7.2	0.94	
SO_4	mg/L	<1745	<884	
NH_4-N	mg/L			741
NO_3-N	mg/L			3.3
Org.N	mg/L			592
Cl	mg/L			2119
K	mg/L			1085
Na	mg/L			1343
Total P	mg/L			5.7
As	mg/L			0.126
Pb	mg/L			0.087
Cd	mg/L			0.0052

Table 1 Average values of leachate contents (Continued)

Parameter	Unite	Acid phase	Methanogenic phase	Independent from lifetime
Cr	mg/L			0.275
Co	mg/L			0.05
Cu	mg/L			0.065
Ni	mg/L			0.166

Source: Ehrig (1983)

In the acidic phase, simple compounds are formed, such as fatty acids, amino acids and carboxylic acids. Due to the heterogeneous nature of the waste, such acid decomposition phases can continue for several years after disposal. The leachate during this phase characterized by

- High concentrations of volatile fatty acids
- Acid pH
- High BOD
- High BOD/COD ratio
- High content of NH_4 and organic N

In the methane-generating phase, methane producing bacteria dominate the organic flora. The methane bacteria replace the acid compounds, the main final products being methane and carbon dioxide. The methane phase can continue for up to 100 years and perhaps even longer. The composition of the leachate during this phase is characterized by:

- Very low concentrations of volatile fatty acids
- Neutral/basic pH
- Low BOD

- Low BOD/COD ratio
- High content of NH_4

The BOD/COD ratio is an indication of the proportion of organic material in the leachate, which is easily decomposed. This is decisive regarding treatment of the leachate biologically.

In 1988 Pollution Control Department (PCD) collected the leachate from landfills in Thailand and characterized the characteristics as shown in Table 2

Table 2 The characteristics of Leachate from Landfills in Thailand

Parameters	Unit	PCD 1988	Phitsanulok
pH	-	6.3-8.2	5.8-8.9
Total solids	mg/L	2,700-20,800	3,800-20,900
Total dissolved solids	mg/L	2,120-19,400	2,160-13-380
COD	mg/L	250-17,900	1,280-25,440
BOD_5	mg/L	47-10,900	100-18,600
BOD/COD	mg/L	0.06-0.88	0.07-1.00
TKN	mg/L	nd	195-1,405
NH_4-N	mg/L	23-806	85-1,250
Sulfide	mg/L	0.3-5.76	nd
Hg	mg/L	0.400-9.500	0.370-2.600
Pb	mg/L	0.100-0.258	0.022-0.480
Cd	mg/L	0-0.021	0.037-1.020
Ni	mg/L	0-0.649	0.007-1.563

nd = not detected

Source: Tränkler *et al*. (2001)b.

1.3 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 (upto 80mm/ 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 four 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%

Figure1 shows that one of the water balance components that are mostly influencing the outcome is evapotranspiration. Tropical climate like Thailand has raised some issues like the effect on water balance by variations of short-term intensive rainfall, which might have greater input into evaporation and run-off than infiltration.(Tränkler *et al.*, 2001b)

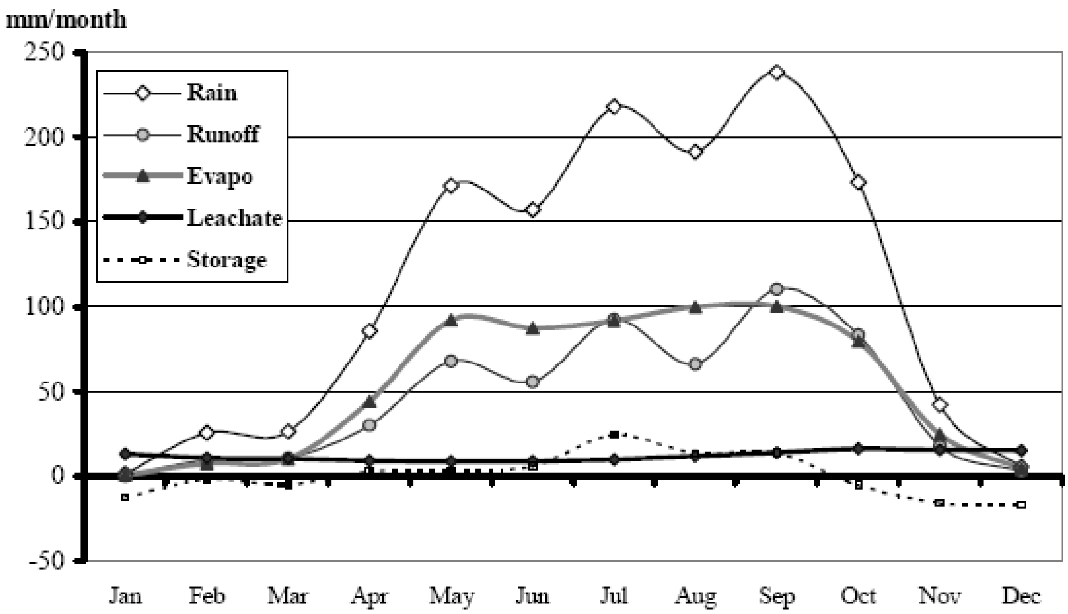

Figure 1 Monthly mean values of water balance elements (basis 20 years)

Source: Tränkler *et al*. (2001)b.

Climatic variation can significantly affect the leachate quality and quantity (Visvanathan *et al*., 2003) During dry season leachate and gas production nearly stop and restarts immediately with the merge of the rainy season (Tränkler and Ranaweera, 2001b)

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 will be observed in this study for determining relationship of weather condition verses leachate quality.

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 have intensive rainfall, more leachate generation and highly cumulative than dry season. Furthermore, in terms of leachate characteristics were found that fluctuation with phase of decomposition and rainfall pattern.

1.4 Biodegradability of Leachate

Different levels of biodegradability of leachate and their ranges are presented in table 3

Table 3 Relative biodegradability of leachate

Biodegradability	BOD/COD	COD/TOC
Low	<0.5	<2
Medium	0.5-0.75	2-3
High	>0.75	>3

Biodegradable leachate can contain low molecular organic acids and alcohols, humic substances with high molecular weight, fulvic acid like materials with high molecular weight. The first group is made out of easily bio-degradable compounds, mainly fatty acids. In acidic leachate, the amount may be more than 90% of TOC. The second group consists of rather stable organics derived from cellulose and lignin. This group is present carboxylic and hydroxylic groups, which are predominant in methanogenic leachate and are difficult to degrade. Other than these organics, benzene, amino acids, phenols and halogenated compounds, i.e. absorbable organic halides (AOX) may be detected in methanogenic leachates. Moreover, extremely high levels of ammoniacal nitrogen (500 to 3000mg/L) can be observed too (Cossu *et al*.,2003)

Stabilized leachate has the following properties according to Baig and Liechti,2001;

- COD <2,000 mg/LSlightly alkaline pH
- Biodegradability (expressed as BOD $_5$/COD) of 0.1

2. Effect of Leachate on the Environment

Leachate contains many substances and can be classified into 5 groups:

- Major ions such as Ca, Mg, Na, K, SO_4, NO_3, NH_4, Cl, etc.
- Trace inorganic compounds such as Fe, Mn, Cr, Ni, Pb, etc.
- Organic such as COD, BOD, TOC
- Bacteriological such as pathogenic microorganisms, coliforms, etc.
- Physical such as pH, redox potential.

The major environmental problems at landfills have resulted from the loss of leachate from the site and the subsequent contamination of surrounding land and water. Leachate may contaminate on the surface water and ground water.

3. Treatment and disposal of landfill leachate

If the solid waste has very low biodegradability and toxicity, prevention of precipitation on the landfill would be a mail treatment option. But, in general water input is essential for biodegradation of wastes to achieve high biostabilization.

Compared to municipal waste water treatment, leachate treatment has a relatively limited history. Also, leachate treatment regulations vary from country to country. Some countries have strict regulations, some countries require simply collection of leachate and some countries have no definite requirements. Germany is one such country having a treated leachate requirement.

COD, BOD_5, AOX and Nitrogen are the main parameters to be considered in leachate treatment. Variety of alternatives are available for partial and complete treatment of landfill leachate.

Few treatment options are:

- Leachate channeling
    - Combined treatment with domestic wastewater
    - Recycling
    - Lagooning with recycling
- Biological processes
    - Aerobic treatment
    - Anaerobic treatment
- Chemical/Physical treatment
    - Chemical precipitation
    - Chemical Oxidation
    - Adsorption and activated carbon
    - Reverse osmosis
    - Ammonia stripping

4. Leachate Re-circulation

Leachate is collected and returned to the top of the landfill. This approach has the benefit of accelerating the sterilization of the organic materials present in the waste. (Edward *et al*, 1995)

Leachate re-circulation can be utilized during the early stages of landfill development, when leachate production quantities are low. In addition, re-circulation can be utilized in later stages of development to eliminate problems of off-site transport during peak production period or during downtimes of transport devices. Re-circulation reduces the hydraulic peaks and can serve to even out the chemical and biological concentration variations of the liquid wastes (Edward *et al.*, 1995)

Apparent advantages of using leachate re-circulation include the following:

- It delays disposal of leachate
- It provides treatment for BOD and speeds up decomposition
- It enhances CH_4 production rate
- It lowers the treatment cost
- It allows buffers and nutrients to be added if needed to accelerate anaerobic decomposition

Disadvantages of leachate re-circulation include field pumping problems settling, clogging and freeze up, odors and the necessity to design the leachate collection system to handle higher hydraulic loading (Edward *et al.*, 1995)

Leachate quality data from five full-scale re-circulating landfills are illustrated in Table 4 and Table 5 provides leachate characteristics as a function of landfill stabilization phase for both conventional and re-circulating landfills, while Table 5 compares all data.

Table 4 Landfill constituent concentration ranges as a function of the degree of landfill stabilization

Parameter	Phase II		Phase III		Phase IV		Phase V	
	Transition		Acid formation		Methane formation		Final Maturation	
	Conventional	Re-circulation	Conventional	Re-circulation	Conventional	Re-circulation	Conventional	Re-circulation
BOD; mg/L	100-1000	0-6893	1000-57700	0-28000	600-3400	100-10000	4-120	100
COD;mg/L	480-18000	20-20000	1500-71000	11600-34550	580-9760	1800-17000	31-9000	770-1000
TVA (mg/L as acitic acid)	100-3000	200-2700	3000-18800	0-30730	250-4000	0-3900	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
Ammonia(mg/L as N)	120-125	76-125	2-1030	0-1800	6-430	32-1850	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 (μmhos/cm)	2450-3310	2200-8000	1600-17100	10000-18000	2900-7700	4200-16000	1400-5400	-

Source: Reinhart (1996)

Table 5 Leachate constituents of conventionally operated landfills and landfills with leachate re-circulation

Parameter	Conventional	Re-circulating
Iron; (mg/L)	20-2100	4-1095
BOD; (mg/L)	20-40000	12-28000
COD ; (mg/L)	500-60000	20-34560
Ammonia; (mg/L)	30-3000	6-1850
Chloride; (mg/L)	100-5000	9-1884
Zinc ; (mg/L)	6-370	0.1-66

Source: Reinhart (1996)

From these data, it appears that leachate characteristics of re-circulating landfills follow a pattern similar to that of conventional landfill, i.e. moving through phases of acidogenesis methanogenesis and maturation (although few re-circulating landfills have reached maturation) (Reinhart and Yousfi,1996). As a matter of fact, the overall magnitudes of various leachate components, during the consecutive phases of landfill stabilization, are quite comparable in both types of landfill. However, the acidogenic phase tends to be more pronounced in leachate recycling landfills as opposed to conventional landfills.

5. Lysimeter studies with Leachate Re-circulation in Asia

Recently many researches were aimed at sequential operation with leachate recirculation in laboratory scale. A few examples of laboratory and pilot scale bioreactor studies in Asia are illustrated in Table 6.

Table 6 Few examples of laboratory and pilot scale bioreactor studies in Asia

Research Title	Reference	Country
The effect of precipitation on municipal solid waste decomposition and methane production in simulated landfill bioreactor with leachate recirculation	Petchsri *et al*., 2006	Thailand
Bioreactor landfill lysimeter studies on Indian urban refuse	Swati *et al*., 2005	India
'Landfill Bioreactor': A Biotechnological solution for waste management.	Swati *et al*., 2006	India
Performance of bioreactor landfill with waste mined from a dumpsite.	Kurian *et al*., 2006	India
Impacts of aeration and active sludge addition on leachate recirculation bioreactor	Jun *et al*., 2007	China
Performance of leachate nitrogen removal in bioreactor landfill system	He *et al*,2006-a	China
Characteristics of the bioreactor landfill system using anaerobic–aerobic process for nitrogen removal	He et al., 2006-b	China
Pilot-scale experiment on anaerobic bioreactor landfills in China	Jianguo *et al*., 2006	China
Leachate pretreatment for enhancing organic matter conversion in landfill bioreactor	He,P-J *et al*., 2006-a	China
Effect of acidification percentage and volatile organic acids on the anaerobic biological process in simulated landfill bioreactors	Wang *et al*., 2006	China
Dissolved organic matter (DOM) in recycled leachate of bioreactor landfill	He,P-J *et al*., 2006-b	China
Landfill leachate treatment in assisted landfill bioreactor	He,P-J *et al*.,2006-c	China

Table 6 Few examples of laboratory and pilot scale bioreactor studies in Asia (Continued)

Research Title	Reference	Country
Comparison between controlled landfill reactor and conditioned landfill bioreactor	Luo *et al*., 2004	China
Effect of leachate recycling and inoculation on the biochemical characteristics of municipal refuse in landfill bioreactors	Shen *et al*., 2002	China
Evaluation of in situ ammonia removal in an aerated landfill bioreactor	Mertoglu *et al*., 2006	Japan and Turkey

MATERIALS AND METHODS

Materials

1. Reactor design and configuration

The experiment was carried out using a lab scale lysimeters with batch operation. The lysimeter design is illustrated in Figure 2. The height of the lysimeter was 1m and the diameter was 0.2m. So the total volume was about 32L.But out of that volume 6L were separated to drain and extract leachate.

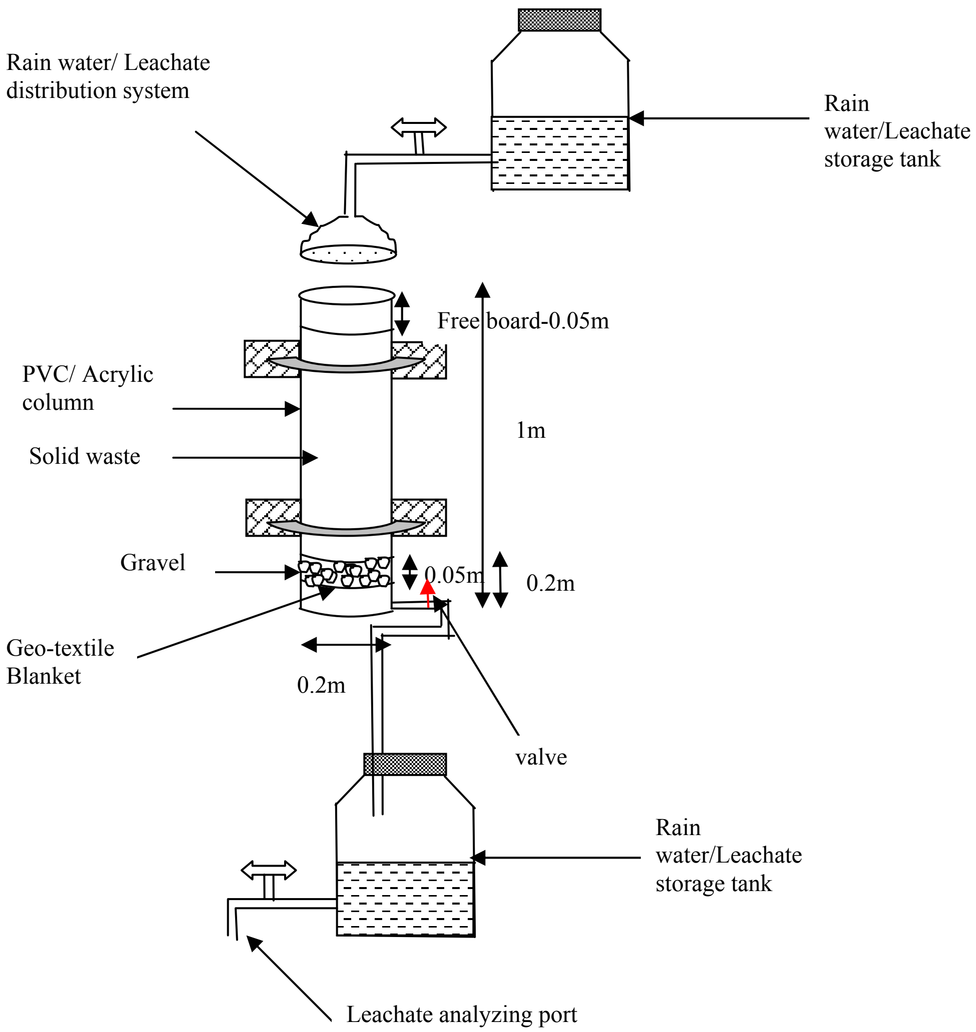

Figure 2 Lab scale vertical batch reactor design

The lysimeters were made of PVC and there was a leachate outlet at the bottom and leachate was collected to a container at the bottom and goes for the analysis. Leachate or rain water was distributed over the surface evenly using a porous shower. There were 6 lysimeters under different operational conditions.

2. Solid waste

2.1 Feedstock preparation

Solid waste was collected from Nonthaburi dumpsite, in the Nonthaburi province of Thailand.

High Compacted waste(HC): - Fresh Solid waste was taken from Nonthaburi open dumpsite and shredded to a size where it can be put in to the lysimeters and compacted them similar to the density of sanitary landfill waste ($437kg/m^3$)

High Compacted waste without Plastic (HC-w/p):- Separated polythene, plastic like substances from fresh waste and compacted to a density of $437kg/m^3$.

Low Compacted Waste(LC): - Fresh waste was shredded as before and fed it to in lysimeters.

Old Waste(OW):- 8 years old waste was taken from Nonthaburi dumpsite and shredded as before and fill it to lysimeters.

Pre treated waste(PT):- Non biodegradable waste was separated from open dump fresh waste composted for a period of 2 months before filling the lysimeters for leachate recirculation condition where some waste was composted for a period of 6 months for storm condition..

2.2 Feed stock characteristics

Physically, the fresh waste was characterized by high fraction of fruit peels, vegetable straps and garden waste. It is the reason for the waste to have very high moisture content and high organic fraction (volatile solid). Physical composition of high compacted waste and high compacted waste without plastic are illustrated in Table 7. In pre-treated waste, the composition was assumed to be almost same to high compacted waste since they were taken from same landfill site.

Physical and chemical characteristics of solid waste before feeding in to lysimeters are presented in Table 8.It was noted that characteristics of solid waste were almost similar for three runs in each waste type except in pre-treated waste. In 2^{nd} run solid waste was composted for about 2 months period and fed in to lysimeters as pre-treated waste. In the 1st Run solid waste was composted about 6 months and fed in to lysimeters as pre-treated waste. Therefore except pre-treated waste, it was satisfied the attempt to have similar characteristics for easy comparison.

Table 7 Physical composition of solid waste

Components	HC or LC[% -wet basis]	HC-w/p[% -wet basis]
Plastic	20.8±2.85	
Paper	11.9±6.26	15.1
Textile	3.6±2.99	4.6
wood	0	0.0
Metal	0.4±0.00	0.5
Rubber and foam	0.4±0.00	0.5
Bone and shell	0.9±1.13	1.1
Glass	2.1±2.11	2.7
Others	5.5±4.51	6.9
Garden waste	31.2±10.14	39.3
Food waste	23.2±1.89	29.3
Rice & Noodles	2.2±1.75	2.8
Vegetable and fruit	16.1±1.36	20.3
egg shell	0.8±0.84	1.0
Meat & fish	1.3±0.41	1.6
others	2.8±2.20	3.5
Total	100	100.0

Table 8 Physical and Chemical characteristics of solid waste

Parameter	Unit	Low Compacted waste(LC)	Pre-treated waste for 2 months(PT)	Pre-treated waste for 6 months(PT)	High Compacted waste(HC)	High Compacted waste without plastic(HC-w/p)	8 years old waste(OW)
Density	[kg/m3]	221±5.81	650±6.20	850±15.5	437±10.8	437±10.8	177±08.6
Porosity	[-]	0.71±0.01	0.41±0.02	0.19±0.01	0.46±0.03	0.45±0.03	0.80±0.05
FC	[mm/m]	744±11	737±05	718±06	694±14	669±37	317±20
TS	[%]	35.72±2.75	30.36±1.76	27.27±0.60	35.72±2.75	33.46±1.00	97.44±0.16
MC	[%-wet basis]	64.28±2.75	69.64±1.76	72.73±0.60	64.28±2.75	66.54±1.00	2.56±0.16
Ash	[%-wet basis]	4.65±0.77	14.10±1.23	14.02±0.81	4.65±0.77	9.40±2.72	67.88±10.91
VS	[%-wet basis]	31.07±3.52	16.26±0.53	13.25±0.61	31.07±3.52	24.05±1.96	29.56±11.03
TKN	[mg N/kg]	25200.00	34253	34253	25200	17220	6627
Sulfur	[%-dry weight]	0.023±0.002	0.026±0.000	0.023±0.000	0.023±0.001	0.013±0.002	0.007±0.001
Chlorine	[%-dry weight]	0.44±0.006	1.95±0.040	1.29±0.146	0.44±0.038	5.78±0.230	2.00±0.297
Cellulose	[%-dry weight]	38.10±0.1	13.78±0.95	7.33±0.11	38.10±0.1	50.67±0.06	2.33±0.02
Lignin	[%-dry weight]	41.27±1.35	30.33±0.32	24.13±0.85	41.27±1.35	26.27±2.59	40.70±0.44

Methods

1. Reactor operation

In the first run, two months period storm conditions was simulated according to the past 6 years historical rainfall data of Thailand with low compacted waste, high compacted waste, pre treated waste and old waste.

Simultaneously, one lysimeter was analyzed for leachate under high compacted waste without plastic. There also two months period storm conditions were simulated.

For the process of second run, four lysimeters were taken with low compacted waste and leachate recirculation was done by adding 100% , 75%, 50% And 35% of maximum rainfall intensity , the data obtained from historical rainfall data of Thailand for past 6 years. They are 1100, 825, 550, 385 ml respectively for lysimeters. Leachate was recirculated in weekly basis.

Simultaneously, the other lysimeter with low compacted waste was simulated with internal storage (submerged condition) and leachate was not being recirculated and leachate was analyzed in weekly basis

For the process of third, four lysimeters were taken to analyze two different leachate recirculation rates with high compacted waste and pre treated waste. The rates were 100%(1100ml) and 35%(385ml) of maximum rainfall intensity. One lysimeter was taken to analyze one leachate recirculation rate with high compacted waste without plastic. The rate was 100% (1100ml).

Simultaneously; one lysimeter was simulated to analyze the leachate quality under internal storage (submerged conditions) only with high compacted waste.

Following table explains the abbreviations used in different conditions and different types of waste at results and discussion.

Table 9 Abbreviations used in different conditions and different solid waste types

Solid waste type	Operation condition					
	Storm	Leachate recirculation				Internal storage
		100%	75%	50%	35%	
Low Compacted waste (LC)	St_{C1}	LR_{C1}-100	LR_{C1}-75	LR_{C1}-50	LR_{C1}-35	IS_{C1}
	St_{C2}	LR_{C2}-100			LR_{C2}-35	IS_{C2}
High Compacted waste (HC)	St_{P1}	LR_{P1}-100				
	StP_{S1}	LR_{S1}-100				
High Compacted waste without Plastic (HC-w/p)	St_{P2}	LR_{P2}-100				
Pre-treated waste (PT)	St_{S2}	LR_{S2}-100			LR_{S2}-35	
Old waste (OW)	St_{S3}					

Flow chart of the reactor operation is described in Figure 3

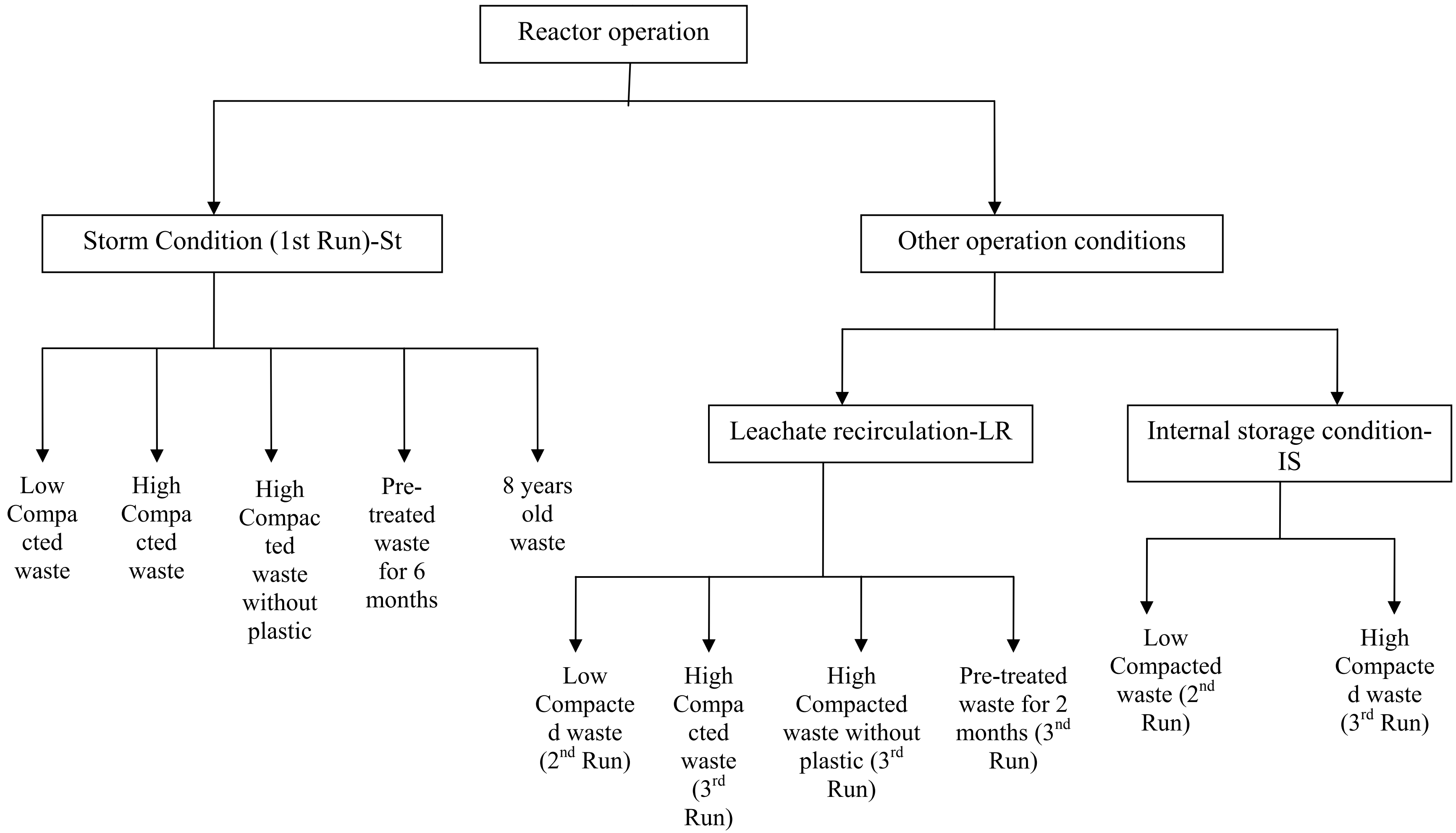

Figure 3 Flow diagram of reactor operation

At leachate recirculation condition, there were several leachate recirculation conditions and they are described in Figure 4

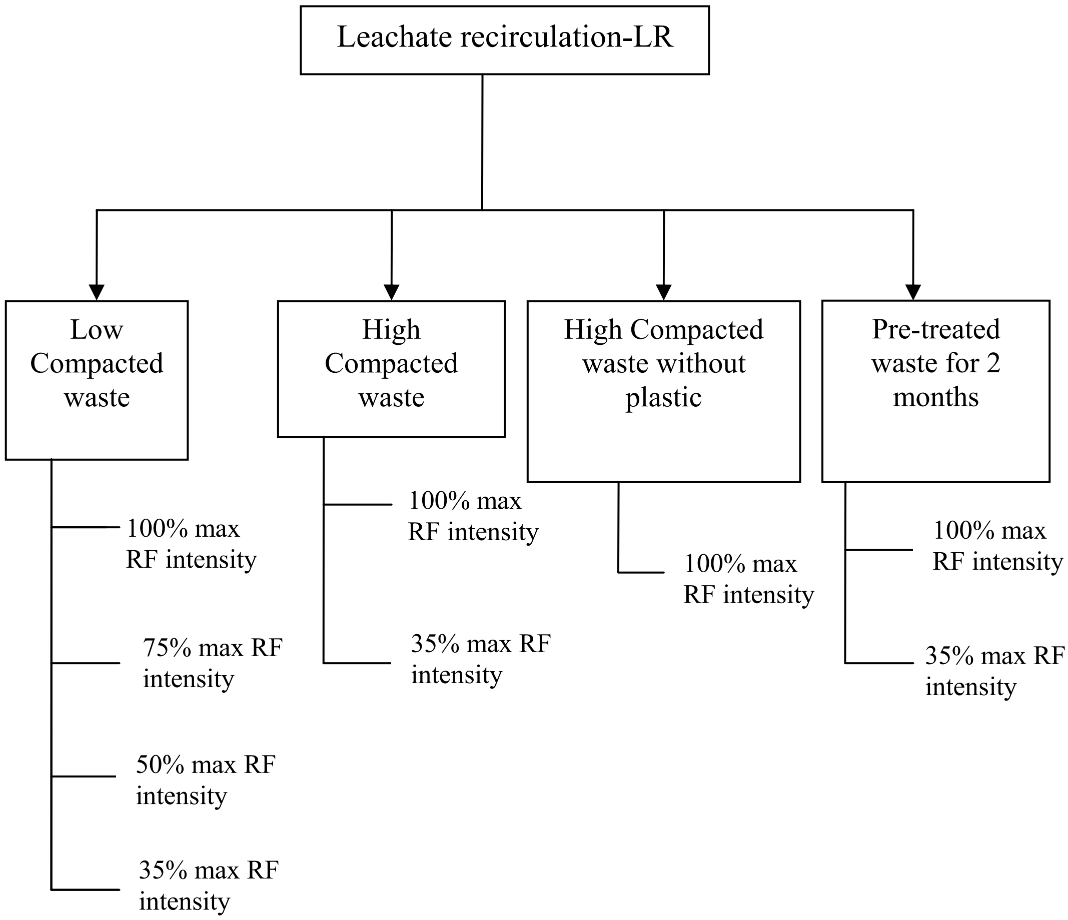

Figure 4 Reactor operation under leachate recirculation condition

2. Sampling and analysis

Sampling and analysis in this study were comprised of, solid waste (fresh and digestate) and leachate. Nutrients were analyzed both in solid (TKN) waste and leachate (TKN and NH_4-N) The procedure of each experiment will be described in detail in the following section.

a) Solid waste analysis

Solid waste analysis was done at the initial stage, where loading period of lysimeter and final stage where remove solid waste from lysimeters.

Homogenous samples were taken to determine the solid waste characteristics of the original sample. The general information on solid waste analysis is depicted in Table 10. Both fresh and digestate waste were analyzed for physical parameters

Table 10 Physical parameters analyzed in fresh waste and digestate waste

Parameters	Method/Instrument	Frequency
Moisture content (%)	Gravimetric analysis	Before fill solid waste to lysimeters and after the whole operation
Total solid (%)	Gravimetric analysis	
Volatile solid	Muffle furnace	
Ash content	Muffle furnace	
Compaction density	See Appendix B	
Porosity		
Field Capacity		

Both fresh and digested waste were analyzed for nutrients. In general, N,P,K are the major components found in MSW. N, P, K are the macro nutrient which are essential for the growth of microorganisms. But in the analysis, only N(TKN) was analyzed as a Nutrient at the beginning of feeding lysimeters. Together with N, S and Cl were analyzed at the beginning and after the whole process. Cellulose and Lignin were analyzed in all types of waste at the beginning and only analyzed in sanitary landfill waste and sanitary landfill waste without plastic after the removal from lysimeters. Table 11 depicted the general information on Nutrient analysis.

Table 11 General information on nutrients analysis

Parameters	Method/instruments	Frequency
N (% by dry weight)	Macro- Kjeldahl analysis	Before fill SW in to lysimeters
Cl (% by dry weight)	Bomb calorie meter + Argentometric method	Before and after the operation
S (% by dry weight)	Bomb calorie meter + Turbidimetric method	Before and after the operation
Cellulose (% by dry weight)	ASTM E 1758-95^{e1} method + Spectrophotometer	Before and after the operation
Lignin (% by dry weight)	ASTM E 1758-95^{e1}	Before and after the operation

b) Leachate analysis

Leachate analysis was carried out from the starting up of the process until the end. Leachate sampling and analysis were conducted once a week. Following parameters were measured in the laboratory:

- Biological Oxygen Demand (BOD)- Total and Soluble
- Chemical oxygen demand (COD) – Total and Soluble
- Nitrogenous species: $NH_4 - N$, TKN (Total Kjeldahl Nitrogen)
- Total Solids
- Total Suspended solids
- Total Dissolve solids
- pH

Leachate analysis was conducted by following the Standard Method for Examination of Water and Wastewater (APHA *et al.*, 1997). Table 12 lists the methods of analyzing those parameters.

Consider the storm conditions, some sample volumes in St_{S2} and St_{S3} were not enough for the analysis. To overcome that obstacle, samples were composite proportionate to their output volume to achieve the required volume for analysis

Table 12 General information on leachate analysis parameters

Parameters	Method/instrument	Frequency
COD (mg/L)	Closed dichromate-reflux titration method	Weekly basis in leachate recirculation condition and continuously in storm condition
BOD (mg/L)	5-day BOD test-standard method 5210B	
NH_4-N	Standard method 4500B: Distillation method	Weekly basis in leachate recirculation condition and selected dates in storm condition
TKN (mg/L)	Standard method 4500B: Macro kjeldahl method	
pH	pH meter	
Total Solids	Standard method 2540B	
Total Dissolved Solids	Standard method 2540C	
Total Suspended Solids	Standard method 2540D	

c) Water Balance in lysimeters

Water balance in the lysimeters were determined by the measurement of leachate amount drained from each lysimeter. The water balance equation can be described as follows.

$$V_I = V_L + V_E - V_R \qquad (2)$$

Where V_I = Volume of rainwater added

V_L = Volume of drained leachate

V_E = Volume of water loss through evaporation

V_R = Volume of water produced during waste biodegradation

RESULTS AND DISCUSSION

1. Leaching during Storm Events

According to the historical rainfall data obtained from Bangkok, it was observed the storm condition prevails for about 2 months period per year (Appendix Figure B1). This condition was simulated in the experiment and observed that intensive daily rainfall events can extract more pollutant loads to the leachate, despite the overall leaching behavior is decreasing with the time. This situation is true both for organic and nitrogenous leaching from the lysimeters and for all types of waste.

1.1 Leachate characteristics in different kind of solid waste

a) Leachate characteristics of low compacted waste

As mentioned above, with the intensive rainfall events, this lysimeter leached high pollutant loads regardless of organic or nitrogenous pollutants. But the overall trend seems to be reducing over the time. Figure 5 depicts the Total BOD, TCOD,TKN and TDS load in mg per Kg of TS. All parameters were measured for selected dates except for TCOD. It was measure continuously. The cumulative specific pollutant loads were 11109, 9566, 65838, 15716, 16688, 864, 985, 696 mg/kg TS (see appendix C) for TBOD, SBOD, TCOD, SCOD, TDS, SS, TKN and NH_4-N respectively.

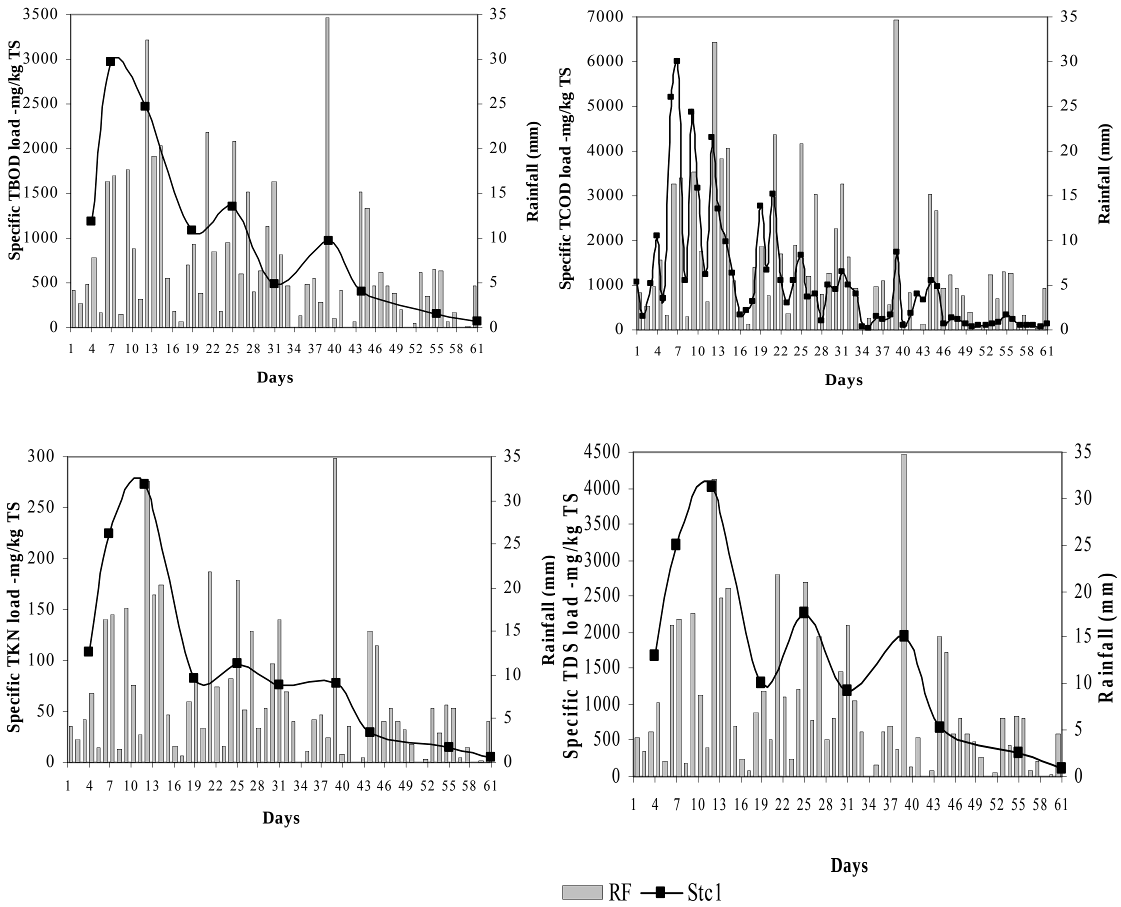

Figure 5 Variation of Total BOD_5, Total COD, TKN and TDS in Open dump fresh waste in terms of specific pollutant loads

b) Leachate characteristics of high compacted waste

The leaching pattern of pollutants is similar to low compacted waste. But this waste type leaches more pollutant loads. The cumulative specific pollutant loads are 13106, 11024, 101325, 18112, 14754, 388, 1303 and 1081 mg/kg TS (see appendix C) for TBOD, SBOD, TCOD, SCOD, TDS, SS, TKN and NH_4-N respectively.

c) Leachate characteristics of high compacted waste without plastic

The leaching pattern of pollutants is similar to high compacted waste and all other types of waste. The cumulative specific pollutant loads are 14657, 12126, 98290, 24151, 16190, 909, 1059 and 795 mg/kg TS (see appendix C) for TBOD, SBOD, TCOD, SCOD, TDS, SS, TKN and NH_4-N respectively.

d) Leachate characteristics of pre treated waste

As mentioned above like other types of waste, the pattern is more or less similar to other types of waste. But Cumulative specific pollutant loads seems to be lower than above waste types. The cumulative specific pollutant loads are 3.32, 2.22, 464, 83.53, 2065, 43.8, 6.39 and 1.14 mg/kg TS (see appendix C) for TBOD, SBOD, TCOD, SCOD, TDS, SS, TKN and NH_4-N respectively.

e) Leachate characteristics of old waste

The pollutant load leaching pattern is similar to other waste types but the cumulative specific load is lower than above waste types except pre-treated waste. The cumulative specific pollutant loads are 7.87, 5.41, 526, 133, 1730, 63.8, 10.38 and 1.86 mg/kg TS for TBOD, SBOD, TCOD, SCOD, TDS, SS, TKN and NH_4-N respectively.

1.2 Comparison of leachate characteristics in different kind of solid waste

a) Effect of waste compaction density

In this section leachate characteristics of St_{C1} (low compacted waste) and St_{C2} (high compacted waste) will be compared. High compacted waste was achieved by increasing the compaction density of open dump fresh waste (from

221kgm^{-3} to 437kgm^{-3}) which was obtained from Nonthaburi dumpsite. So the results will show the effect of compaction in leaching under heavy storm events.

Figure 6 presents the organic concentration variation in St_{C1} and St_{C2} in terms of total BOD_5, and Total COD. Soluble BOD_5 and Soluble COD concentration variation also behave similar to Total BOD_5 and COD.

The result shows that $TBOD_5$ and TCOD concentration in leachate reduced with run time. The same trends were observed for SBOD and SCOD. Also substantial decline in concentrations (plateaus) can be seen along with heavy rainfall events despite the reducing concentration trend. As depicted in the Figure 6, St_{C2} organic concentration is higher compared to St_{C1}. It seems the organic pollutant concentration leaching out from the lysimeters increases with the level of compaction of solid waste.

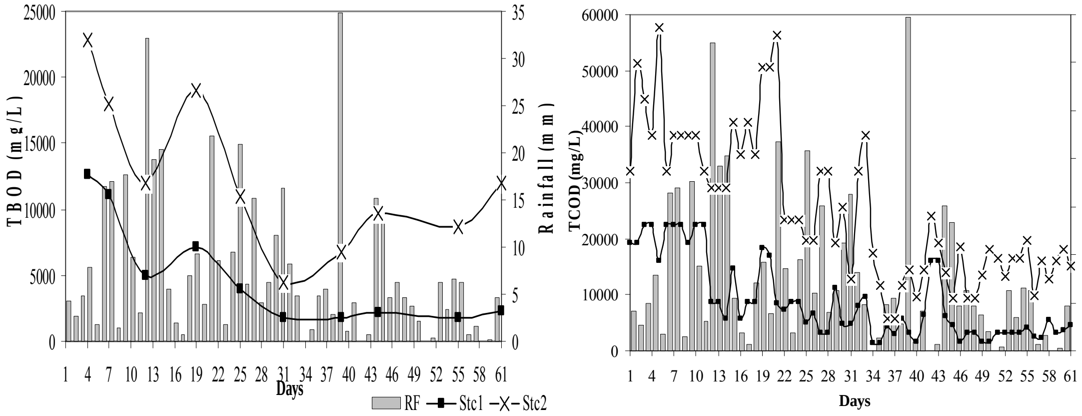

Figure 6 Organic concentration variation in St_{C1} and St_{C2}

Beside the organic pollutant concentration variation, St_{C2} got the highest specific organic pollutant load (mg/kg TS) both in terms of total and soluble BOD_5 and COD compared to St_{C1}. From the variation of $TBOD_5$, $SBOD_5$, TCOD and SCOD it seems that the specific organic load in leachate reduces with time. With in 2 months period storm event, daily flushing of organic pollutants could be the possible reason to reduce organic load except other than microbial activities going on this short time of operation. Even together with this pattern also higher specific organic loads can be observe with higher rainfall events though the pollutant concentration were decreased with high rainfall events. Figure 7 illustrates the specific organic load variation over the time in $TBOD_5$ and TCOD. $SBOD_5$ and SCOD also behave similar to this pattern. In specific organic loads variation also, level of compaction density should be the possible reason to get high specific organic loads to the leachate in St_{C2}. Figure 8 shows the organic loads variation in terms of cumulative specific loads in $TBOD_5$ and TCOD. The other cumulative specific organic loads also behave similar to above patterns ($SBOD_5$ and SCOD)

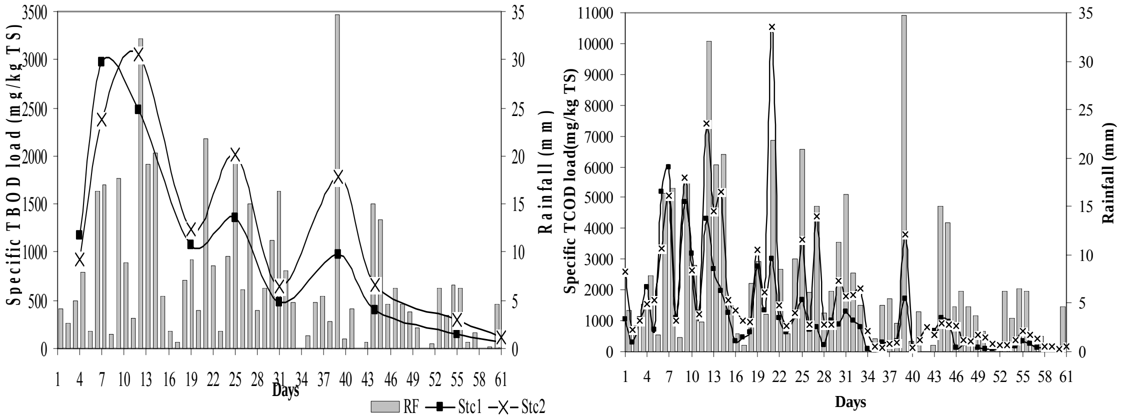

Figure 7 Specific organic load variation in St_{C1} and St_{C2}

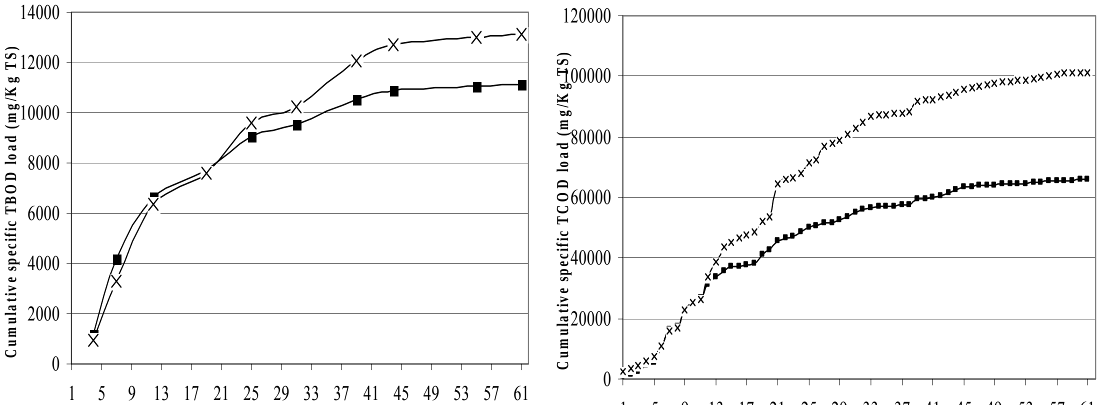

Figure 8 Cumulative specific organic load variation in St_{C1} and St_{C2}

Figure 9 presents the nitrogen concentration variation in St_{C1} and St_{C2}. The result shows that NH_4-N and TKN concentration in leachate reduced with run time similarly to organic concentration variations. This is because flushing effect of nitrogenous substances due to heavy rainfall events. But along with that decreasing trend substantial decline in concentrations can be observed with intensive storm events.

Looking in to nitrogen leaching, it can be seen that St_{C2} got the higher nitrogen concentration than St_{C1}. This reveals that level of compaction density has an impact on nitrogen leaching from solid waste. That is higher the compaction density, higher the nitrogen leaching from solid waste. But both types of waste got reducing trends over the time.

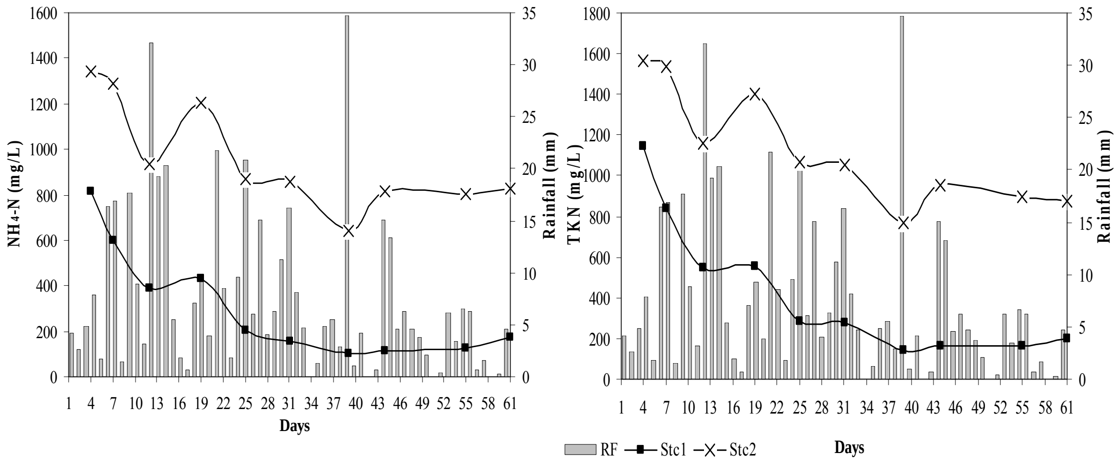

Figure 9 Nitrogen concentration variation in St_{C1} and St_{C2}

Specific nitrogen load variation over the time also has a quite similar trend to specific organic load variation and with the intensive rainfall events it shows high specific nitrogen load leaching from the lysimeters despite the nitrogen concentration decreases with heavy rainfall events. But overall specific nitrogen load leaching pattern is decreased over the time. This is because of flushing effect of nitrogenous pollutants from lysimeters due to storm conditions. Figure 10 shows the cumulative specific nitrogen load leaching from solid waste over 61 days. From the cumulative values it can be clearly see, that the St_{C2} has higher value of Sp. nitrogen load over the St_{C1}. This impresses that, with the increasing compaction densities of solid waste can extract more pollutants to the leachate in terms of organic and nitrogen pollutants at storm conditions.

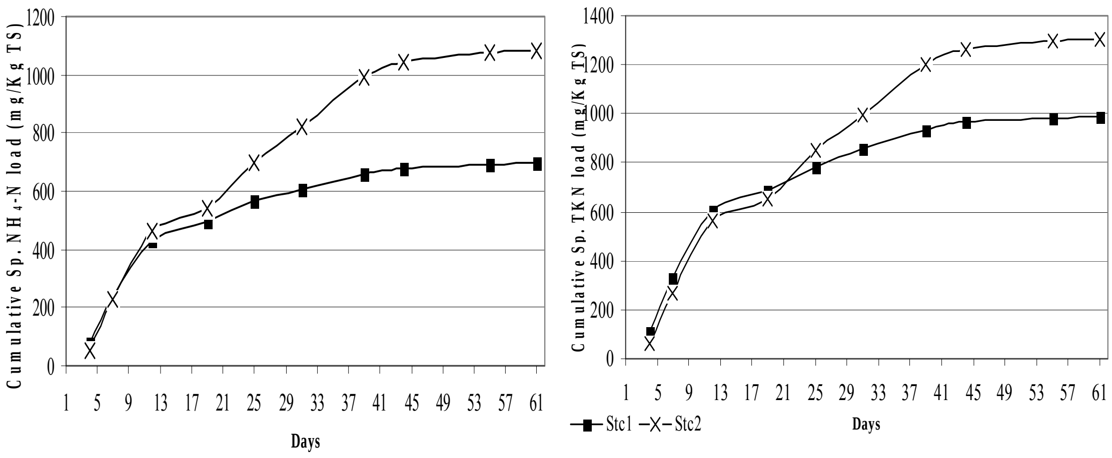

Figure 10 Cumulative Sp. Nitrogen load variation in St_{C1} and St_{C2}

Total Dissolve Solid (TDS) concentration in lysimeters brings the same trends as organic and nitrogen pollutant concentration variation in lysimeters where Dissolve solids representing for the hydrolysis product of particulate substrate in all lysimeters. It has a reducing trend over the operation time and TDS load also got a reducing trend. But both in 2 types of waste the sp. load was increased by high rainfall events similar to sp. organic and nitrogen load leaching from lysimeters. Also St_{C2} got the highest value for both concentration and load of TDS than St_{C1}. But when compares the cumulative TDS load per kg of TS (solid waste), the highest value was from S_{op} regardless of the compaction density. This situation is also true for Suspended Solid (SS).This reveal that the difference in pollutant loads(mg) or pollutant concentrations(mg/L)in TDS and SS over the time between St_{C2} and St_{C1} is not significant compared to organic and nitrogen pollutant concentrations. So when cumulative sp. loads comes per a kg TS (of solid waste), since the weight of initial solid waste is higher in St_{C2} than St_{C1}, the final value becomes lower in St_{C2}. Figure 11 shows the TDS and SS concentration variation over the time and Figure 12 shows

TDS and SS loads variation over the time and Figure 13 presents their cumulative sp. loads variation.

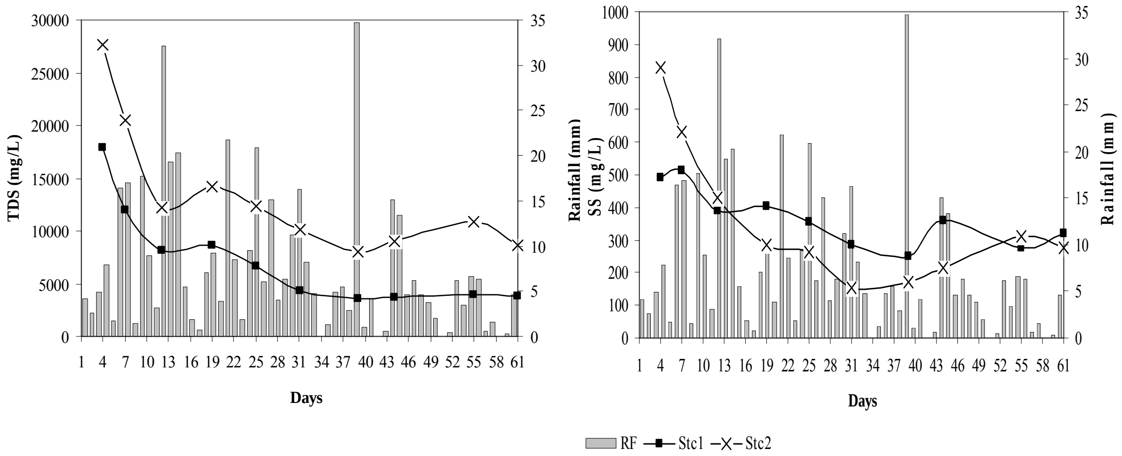

Figure 11 TDS and SS concentration variation in St_{C1} and St_{C2}

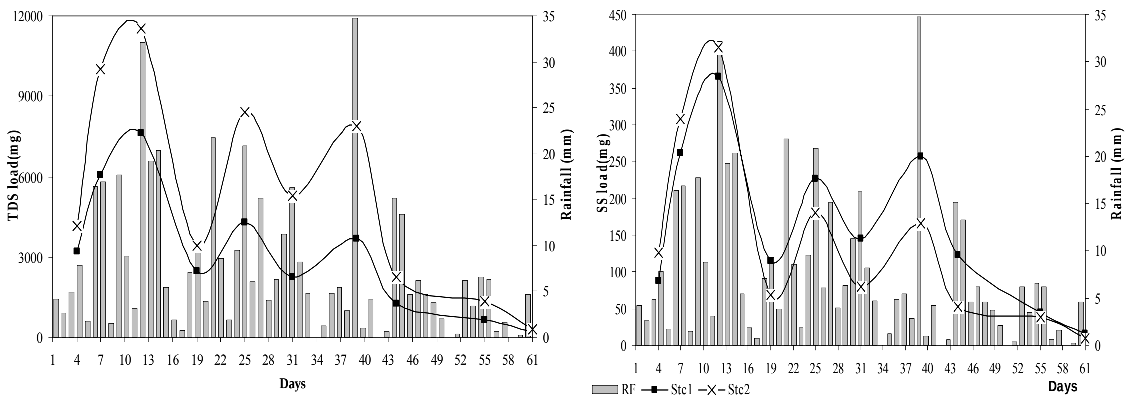

Figure 12 TDS and SS load (mg)variation in St_{C1} and St_{C2}

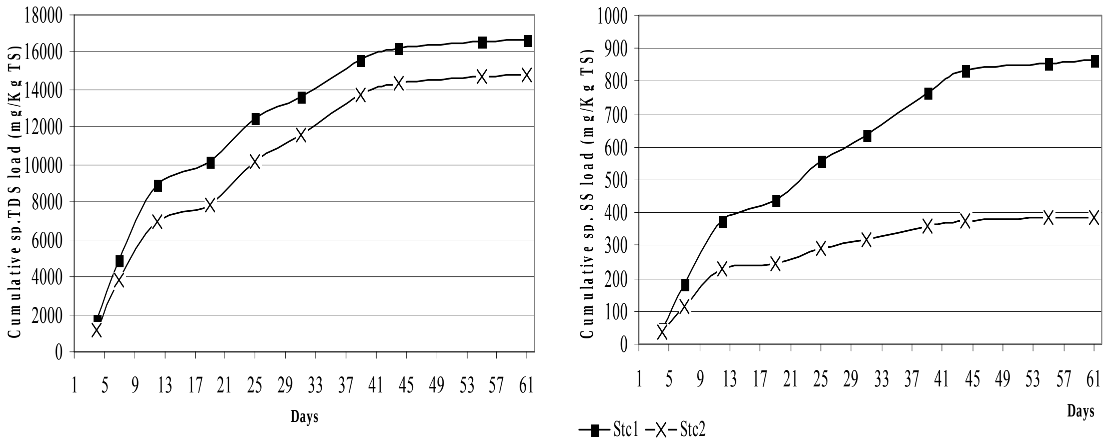

Figure 13 Cumulative sp. TS, TDS and SS load variation in St_{C1} and St_{C2}

b) Effect of waste stabilization

In this section leachate characteristics of St_{S1}(high compacted waste),St_{S2} (pre-treated waste)and St_{S3} (old waste) will be compared. St_{S1} is the fresh waste which was obtained from Nonthaburi dumpsite and compacted up to a density of 437kgm-^{3}. St_{S2} is the same waste which was obtained from that dumpsite and removed their non biodegradable part from the waste and composted for a period of 6 months. So this is more stabilized than fresh waste. St_{S3} is the waste kept at the same dump site for a period of 8 years without any pre-treatment. In this section effect of these stabilization stages to the leachate quality will be discussed.

Table 13 presents the organic concentration variation in St_{S1}, St_{S2} and St_{S3} in terms of total BOD, and Soluble COD.

Table 13 TBOD and SCOD concentration variation in St_{S1}, St_{S2} and St_{S3}

Day	RF(mm)	Total BOD_5 (mg/L)			Soluble COD(mg/L)		
		St_{S1}	St_{S2}	St_{S3}	St_{S1}	St_{S2}	St_{S3}
4	7.9	22800	14.40	32.40	32000	320	160
7	16.9	18000	6.00	19.20	32000	160	400
12	32.1	12000	7.80	9.00	11648	73	87
19	9.3	19000	7.50	10.20	39424	282	211
25	20.9	11000	6.60	5.70	13184	66	49
31	16.3	4500	1.20	1.50	6400	144	96
39	34.7	6750	2.30	2.20	9600	160	96
44	15.1	9750			9312	93	78
55	6.6	8700	1.10	0.00	13184	132	115
61	4.6	12000			12032		75

The result shows that TBOD and SCOD concentration in leachate reduced with run time. SBOD and TCOD also varied similar to TBOD and SCOD, they are expressed in Appendix Table C25 and C26. Drastic plateaus can be seen along the reducing trend with heavy rainfall events. There is a significant reduction in organic loads in pre-treated waste(St_{S2}) and old waste($St_{S3)}$ compared to high compacted waste(St_{S1}). But compare the results of St_{S2} and $St_{S3,}$ there is no significant difference can be seen. Table 14 shows the organic loads variation along the time in $St_{S1,}$ St_{S2} and St_{S3} in terms of total BOD, and Soluble COD.

Table 14 $TBOD_5$ and SCOD load variation in St_{S1}, St_{S2} and St_{S3}

Day	RF(mm)	Total BOD_5 (mg)			Soluble COD(mg)		
		St_{S1}	St_{S2}	St_{S3}	St_{S1}	St_{S2}	St_{S3}
4	7.9	3443	1.6	6.7	4832	35	33
7	16.9	8802	2.9	9.1	15648	78	189
12	32.1	11304	6.5	7.9	10972	60	77
19	9.3	4560	1.1	2.4	9462	40	50
25	20.9	7458	3.8	3.5	8939	38	30
31	16.3	2358	0.5	0.7	3354	59	43
39	34.7	6615	1.8	2.0	9408	128	89
44	15.1	2428			2319	13	17
55	6.6	1079	0.1	0.0	1635	8	13
61	4.6	444			445		2

Soluble BOD_5 and Total COD load fluctuations also behave similar to above results and they are presented in Appendix Table C25 and C26 (multiply concentrations with Appendix Table C5, Run 3 values). Organic loads also have a reducing trend over the time but high peaks with heavy rainfall events. This is due to the amount of water leach out from the lysimeters. As the amount of water is high, it can extract more pollutants to the water. But it is obvious, that from high compacted waste (St_{S1}), it leaches more organic loads than pre-treated (St_{S2}) waste and old waste ($St_{S3)}$. But there is no significant difference in organic load leaching between St_{S2} and St_{S3}. But when consider the cumulative values; it is significant that highest sp.organic load is from St_{S1}, St_{S3} and then St_{S2} respectively. Table 15 presents their cumulative values in terms of $TBOD_5$ and SCOD. As other sp. organic pollutant loads also behave similar to these patterns, they are expressed in Appendix Table C25 and C26.

Table 15 Cumulative sp. $TBOD_5$ and SCOD load variation in St_{S1}, St_{S2} and St_{S3}

Day	RF(mm)	Cumulative sp. $TBOD_5$ load (mg/Kg TS)			Cumulative sp. SCOD load(mg/Kg TS)		
		St_{S1}	St_{S2}	St_{S3}	St_{S1}	St_{S2}	St_{S3}
4	7.9	930	0.29	1.63	1306	6.34	8.04
7	16.9	3309	0.82	3.84	5535	20.57	54.19
12	32.1	6365	1.99	5.77	8501	31.54	72.85
19	9.3	7597	2.19	6.36	11058	38.86	85.11
25	20.9	9613	2.88	7.21	13474	45.79	92.47
31	16.3	10250	2.97	7.37	14380	56.58	102.93
39	34.7	12038	3.31	7.87	16923	79.82	124.59
44	15.1	12694	3.31	7.87	17550	82.14	128.85
55	6.6	12986	3.32	7.87	17991	83.53	132.11
61	4.6	13106	3.32	7.87	18112	83.53	132.70

Above table reveals that with the level of stabilization, solid waste leach less organic pollutants to the leachate. More over, by pre treating solid waste can shorten the waste stabilization time. So this will enhance the low leaching of organics to the environment. $TBOD_5$ to TCOD ratio also suggests that pre-treated waste is more stabilized than old waste and it is presented in table 16.

Table 16 BOD_5 to COD ratio in St_{S1}, St_{S2} and St_{S3}

Day	BOD/COD		
	St_{S1}	St_{S2}	St_{S3}
4	0.59	0.03	0.20
7	0.47	0.02	0.04
12	0.41	0.05	0.07
19	0.37	0.02	0.04
25	0.56	0.05	0.12
31	0.35	0.01	0.01
39	2.11	0.01	0.02
44	1.57		
55	2.10	0.00	0.00
61	2.66		

Table 17 presents the nitrogen concentration variation in St_{S1}, St_{S2} and $St_{S3.}$ The result shows that NH_4-N and TKN concentration in leachate reduced with run time similarly to organic concentration variations.

The reduction in nitrogen concentration is drastic up to day 12 and then tends to fluctuate until up to day 61 in St_{S2} and St_{S3}. But there is a slight reduction can be seen during that period. Like in the organic pollutant concentrations, drastic reductions in nitrogen concentrations with the heavy rainfall events cannot be seen in this scenario except in St_{S1}. Nitrogen load leaching also shows a similar trend as nitrogen concentration variation over the time as well as organic load variation over the time. But high peaks cannot be seen with intensive rainfall events like organic loads except St_{S1} and TKN load variation in St_{S2} and St_{S3}. But the overall pattern tends to reduce over the time in all types of waste. This reducing trend is due to the flushing of nitrogenous substances from solid waste, because of storm conditions. Table 18 shows the cumulative sp. nitrogen load variation along the time in St_{S1}, St_{S2} and St_{S3} in terms of TKN load and NH_4-N load.

Table 17 TKN and NH_4-N concentration variation in St_{S1}, St_{S2} and St_{S3}

Day	RF(mm)	TKN (mg/L)			NH_4-N(mg/L)		
		St_{S1}	St_{S2}	St_{S3}	St_{S1}	St_{S2}	St_{S3}
4	7.9	1568	64.0	40.0	1344	16.80	11.20
7	16.9	1540	9.8	19.6	1288	6.72	5.60
12	32.1	1157	8.4	11.2	933	0.47	0.93
19	9.3	1400	10.9	11.5	1204	0.84	2.00
25	20.9	1064	9.5	8.2	868	0.0	0.70
31	16.3	1050	6.0	6.0	854	0.0	0.56
39	34.7	770	7.3	4.0	644	0.8	0.56
44	15.1	952	5.6	2.2	818	0.0	0.34
55	6.6	896	4.5	4.0	801	0.3	0.78
61	4.6	875	0.0	3.6	826	0.0	0.60

Table 18 Cumulative sp. TKN and NH_4-N load variation in St_{S1}, St_{S2} and St_{S3}

Day	RF(mm)	Cumulative sp. TKN load (mg/Kg TS)			Cumulative sp. NH_4-N load(mg/Kg TS)		
		St_{S1}	St_{S2}	St_{S3}	St_{S1}	St_{S2}	St_{S3}
4	7.9	64	1.27	2.01	55	0.33	0.56
7	16.9	268	2.14	4.27	225	0.93	1.21
12	32.1	562	3.41	6.66	463	1.00	1.41
19	9.3	653	3.69	7.33	541	1.02	1.52
25	20.9	848	4.69	8.55	700	1.02	1.63
31	16.3	997	5.14	9.20	821	1.02	1.69
39	34.7	1201	6.20	10.11	991	1.14	1.82
44	15.1	1265	6.34	10.23	1046	1.14	1.83
55	6.6	1295	6.39	10.35	1073	1.14	1.86
61	4.6	1303	6.39	10.38	1081	1.14	1.86

Above results reveals that St_{S1} has the highest sp. nitrogen loads compared to St_{S2} and St_{S3}.

Further the lowest vales are from St_{S2}. This suggests with the level of waste stabilization, it leaches low nitrogenous pollutants to the leachate. More over by pre-treating solid waste; can enhance the stabilization level of solid waste and there by can reduce the pollutant leaching to the environment.

TDS concentration reduced substantially up to day 12 and subsequently tends to fluctuate within a constant range up to day 61 in St_{S2} and St_{S1}. In St_{S3} it tends to fluctuate within a constant range. SS reduced up to day 12 in all three types of waste and subsequently try to fluctuate within a constant range until up to day 61 except St_{S2}. But pollutant loads not acting similar to this pattern. In St_{S2} and St_{S3} TDS and SS loads fluctuate within a constant range whilst in St_{S1} the fluctuations are significant. St_{S1} has high peaks with heavy rainfall events as it flushes more pollutants with amount of water loads to the lysimeters. But when consider about the cumulative sp. TDS load, it is clear that initially higher pollutant load is from St_{S3} and after about 35 days, it becomes lower than $St_{S2,}$ but the highest is still from St_{S1}. When compare the results of cumulative SS load variation in St_{S2} and St_{S3}; St_{S3} has the higher pollutant load than the St_{S2}. Figure 14 depicts the TDS and SS concentration variation, Figure 15 presents the TDS and SS load variation and Figure 16 depicts the cumulative sp. TDS and SS load variation over time.

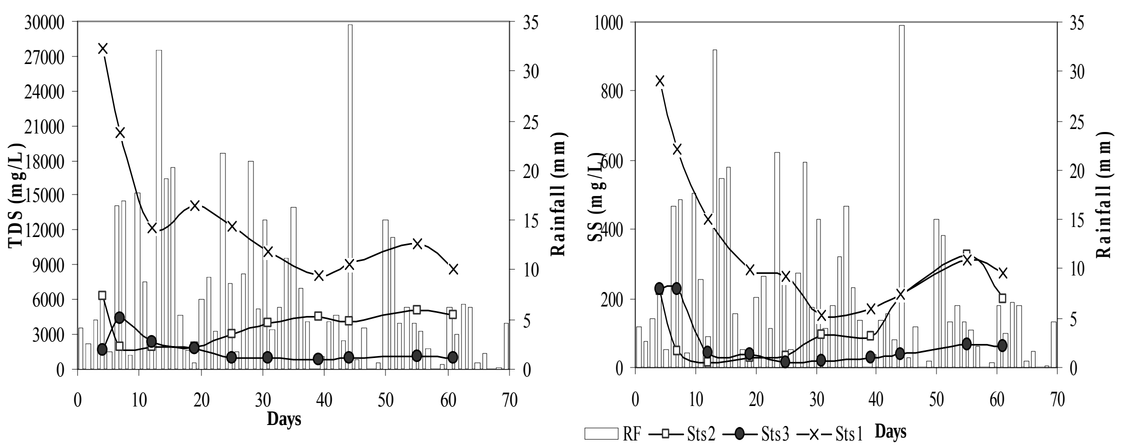

Figure 14 TDS and SS concentration variation in St_{S1}, St_{S2} and St_{S3}

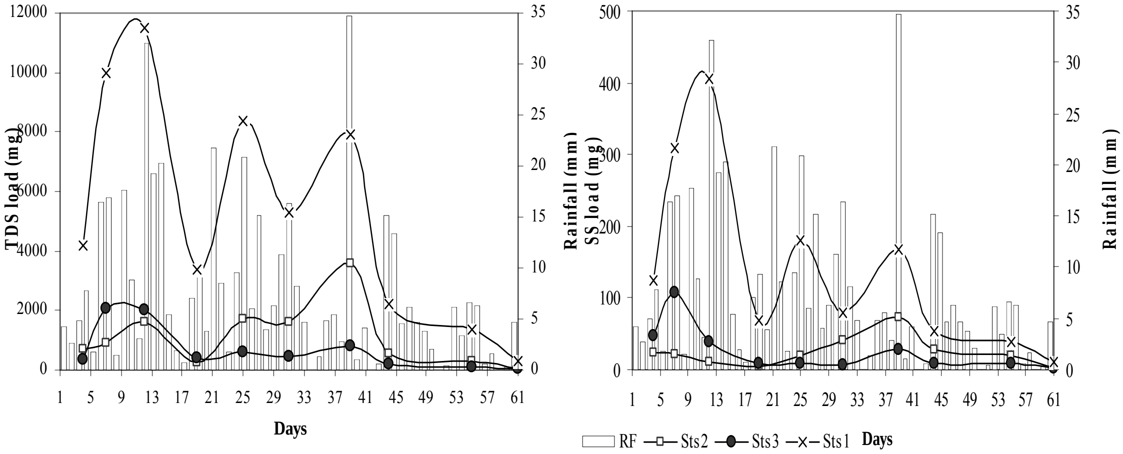

Figure 15 TDS and SS load variation in St_{S1}, St_{S2} and St_{S3}

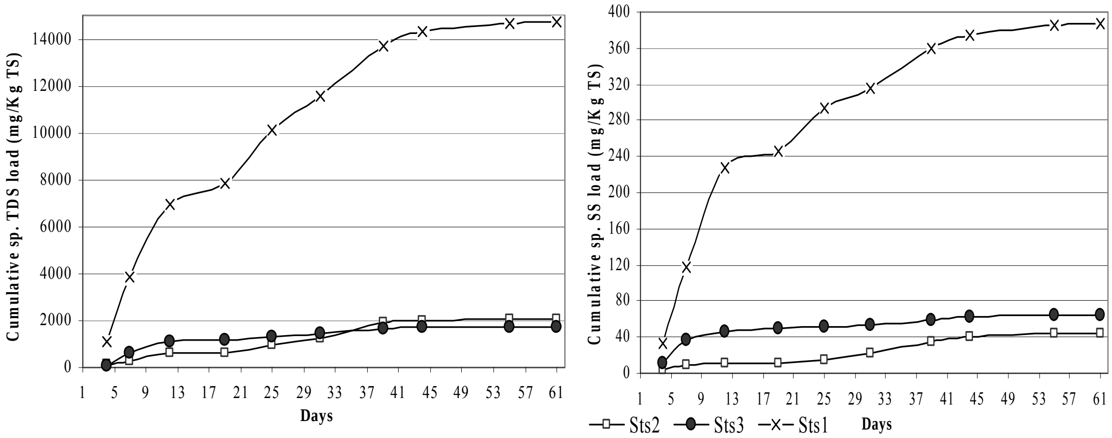

Figure 16 Cumulative sp. TDS and SS load variation in St_{S1}, St_{S2} and St_{S3}

As depicted in Figure 16, St_{S1} has the highest cumulative sp. pollutant load. Subsequently in St_{S2} where in cumulative sp. TDS load and in St_{S3} in cumulative sp. SS load.

c) Effect of plastic in waste

In this section leachate characteristics of St_{P1} (high compacted waste) and St_{P2} (high compacted waste without plastic) will be compared. St_{P1} is high compacted waste which was obtained from Nonthaburi dumpsite and compacted up to 437kgm^{-3}. St_{P2} is the same waste which was from Nonthaburi dumpsite and removed all the plastic and polythene substances from solid waste manually subsequently compacted up to 437kgm^{-3}.Then those 2 types of waste were fed in to lysimeters and facilitated with storm conditions over a period of 61 days. So in this section, effect of plastic on final leachate quality will be discussed by comparing the results of those two types of waste.

Figure 17 depicts the organic pollutant concentrations in St_{P1} and St_{P2} in terms of Total BOD_5 and Total COD. Of course, the Soluble BOD_5 and Soluble COD behave quite similar to this pattern. Figure 17 indicate, that no significant difference in pollutant concentration variation between St_{P1} and St_{P2}. Also there is no significant difference in sp.organic pollutant loads (mg/kg TS) between those two types of waste as pollutant concentrations.

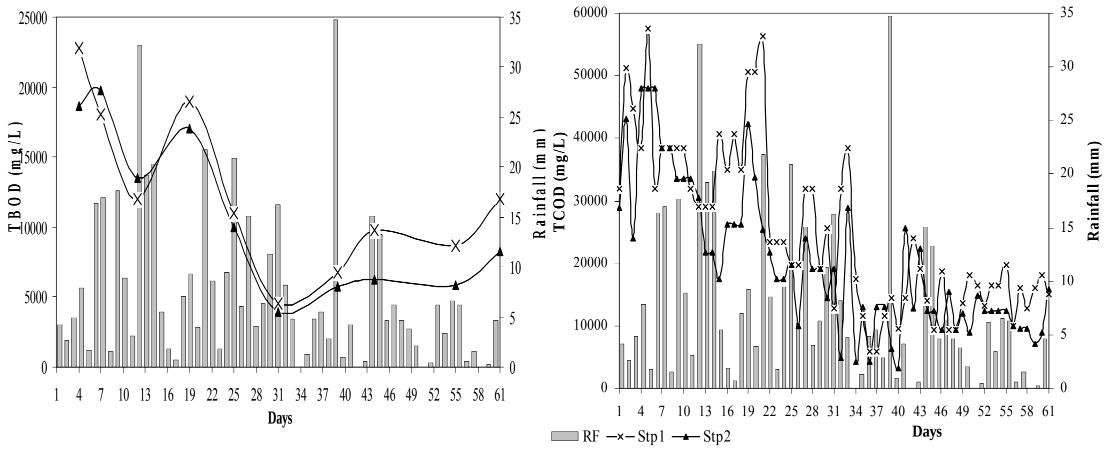

Figure 17 Organic concentration variation in St_{P1} andSt_{P2}

Figure 18 depicts the cumulative sp. organic load variation over time. The results demonstrated the fact that, high compacted waste without plastic (St_{P2}) has higher cumulative pollutant load over high compacted waste with plastic (St_{P1}) except in Total COD. It seemed that in TCOD, initially the higher COD was from St_{P2}, but then it tends to decline after 21 days over St_{P1} . But as a whole, St_{P2} got the higher cumulative sp.organic pollutant load leaching in to the leachate than St_{P1} . So possible reason might be due to high amount of moisture in St_{P2} than St_{P1} As the initial weight of both type of waste were same, of course there should be high dry weight in St_{P1}

than St_{P2} since St_{P1} has more polythene than St_{P2} . Though there is no significant difference in organic pollutant load between those two types of waste, as the weight of TS is in St_{P2} is low compared to St_{P1} , the final cumulative sp. organic pollutant load becomes higher in St_{P2} than St_{P1} . There might be other reasons as well, such as the cumulative loads were measured intermittently except for TCOD, so St_{P1} got higher values for TCOD than St_{P2}. If the other parameters were also measures continuously, the results may be other way around.

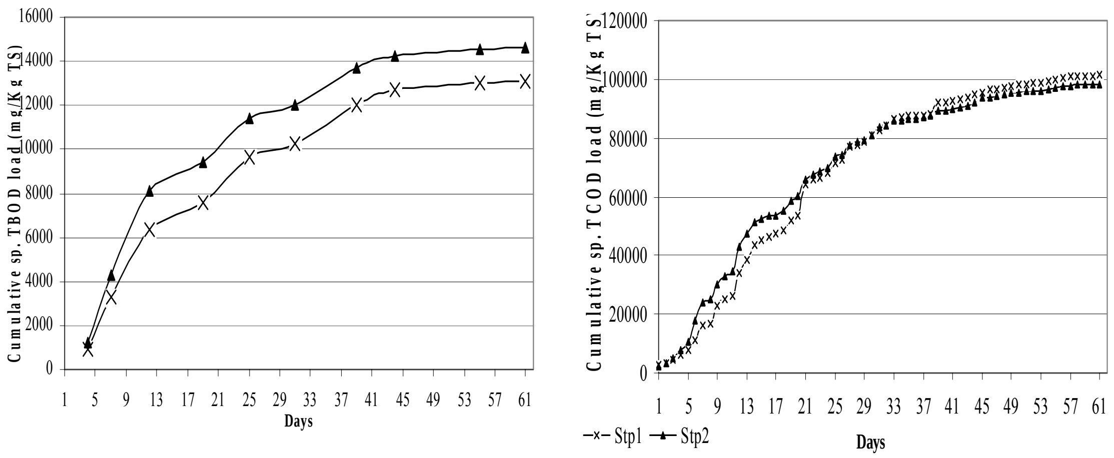

Figure 18 Cumulative sp. Organic load variation in St_{P1} and St_{P2}

Figure 19 presents the concentration of total soluble nitrogen and ammonia nitrogen in St_{P1} and St_{P2}. It could be seen that same configuration as carbonaceous materials were depicted. There was no difference in behavior of hydrolysis for carbonaceous and nitrogenous organic. Initially, high concentration of both TKN and NH_4-N was noticed. Then they were reduced gradually. However St_{P1} appeared to have higher concentrations as well as higher sp. pollutant load over St_{P2} where it was not significant in organic concentrations. For this situation plastic might be the possible reason to have high nitrogen content in St_{P1}. However, the results were still equivocal.

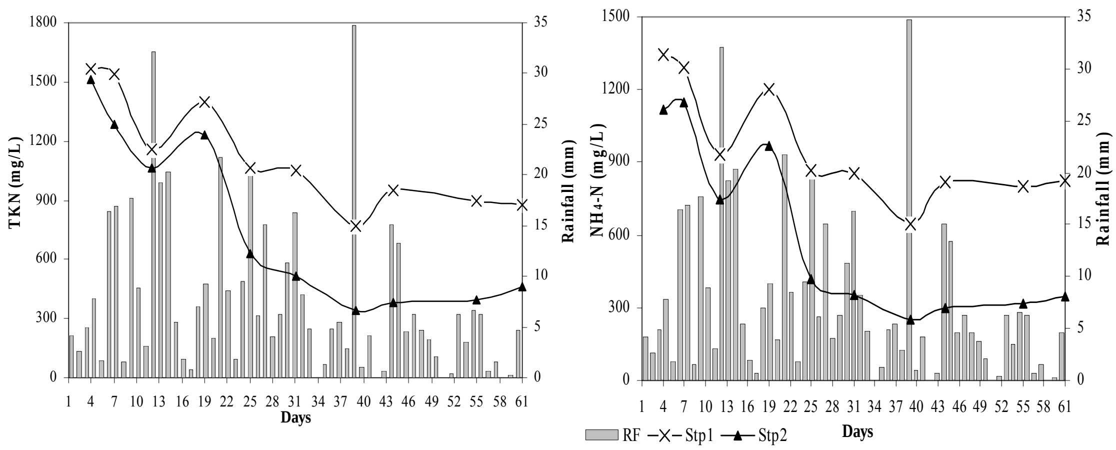

Figure 19 Nitrogen concentration variation in St_{P1} and St_{P2}

Figure 20 illustrates the cumulative sp. nitrogen load variation in terms of TKN and NH_4-N.

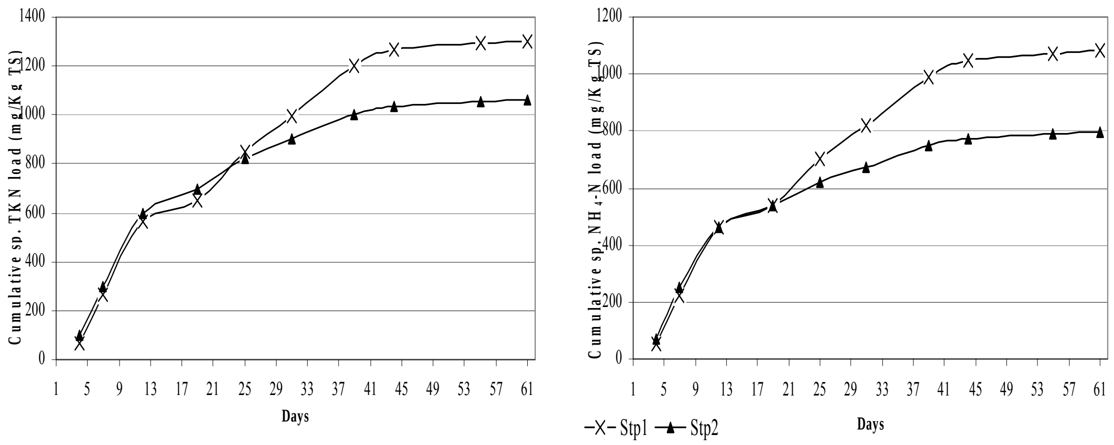

Figure 20 Cumulative sp. Nitrogen load variation in St_{P1} and St_{P2}

It is clear that St_{P1} got the higher pollutant load over St_{P2}. As mentioned earlier, plastic might be the possible reason to get higher values for cumulative nitrogen loads for St_{P1}. But this is still equivocal.

TDS concentration also has the same trend as appeared in nitrogen and organic concentration variation. Nevertheless there is no significant difference in concentrations between St_{P1} and St_{P2}. Neither have a remarkable decline with high rainfall intensities. Also there is no significant difference in pollutant load between St_{P1} and St_{P2}.

However, cumulative sp. loads of TDS and SS reveal that higher load is from St_{P2} over St_{P1}. This configuration is more or less similar to the pattern of cumulative sp. organic load variation in lysimeters. The reason should be the same as mentioned under cumulative sp. organic load variation. Figure 21 presents their cumulative sp load values.

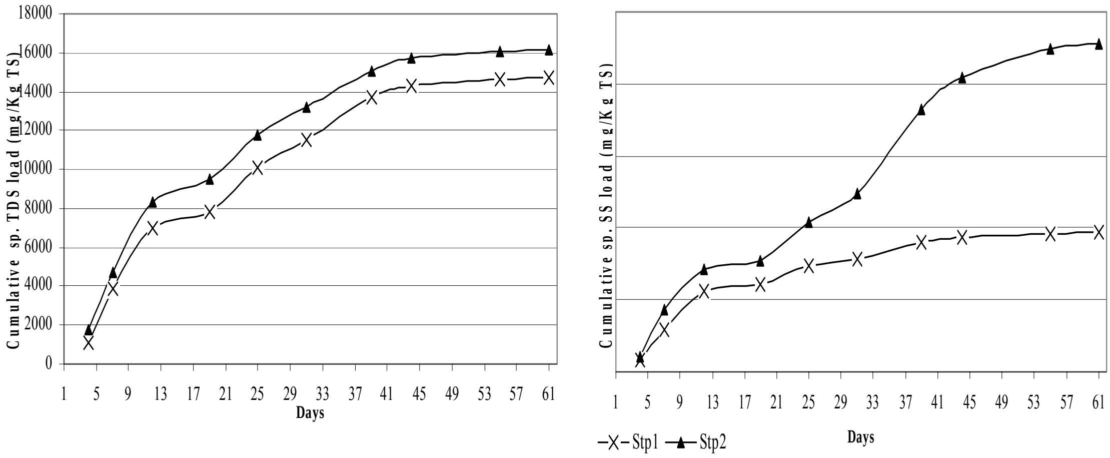

Figure 21 Cumulative sp. TDS and SS load in St_{P1} and St_{P2}

2. Leaching in the landfill at leachate recirculation condition

2.1 Leachate characteristics in different kind of solid waste

a) Leachate characteristics of low compacted waste

In low compacted waste there were 4 rates of leachate recirculation. They are 100%, 75%, 50% and 35% where a volume of 1100, 825, 550 and 385 ml respectively for each lysimeter. But there are no significant different in pollutant concentrations among those 4 rates. But the tendency is higher the recirculation rate, higher the pollutant load leach from the lysimeters. Figure 22 shows the pollutant concentration variation in terms of $TBOD_5$ and TKN. However, it is clear from cumulative sp. Load values; the highest sp. load was from highest leachate recirculation rate. The cumulative values for $TBOD_5$ are 13203, 10315, 7504 and 6818 for 100%, 75%, 50% and 35% of maximum rainfall intensity (see appendix C). This order of values from higher to lower in pollutant loads are also true for organic, nitrogen and TDS,SS leaching from lysimeters.

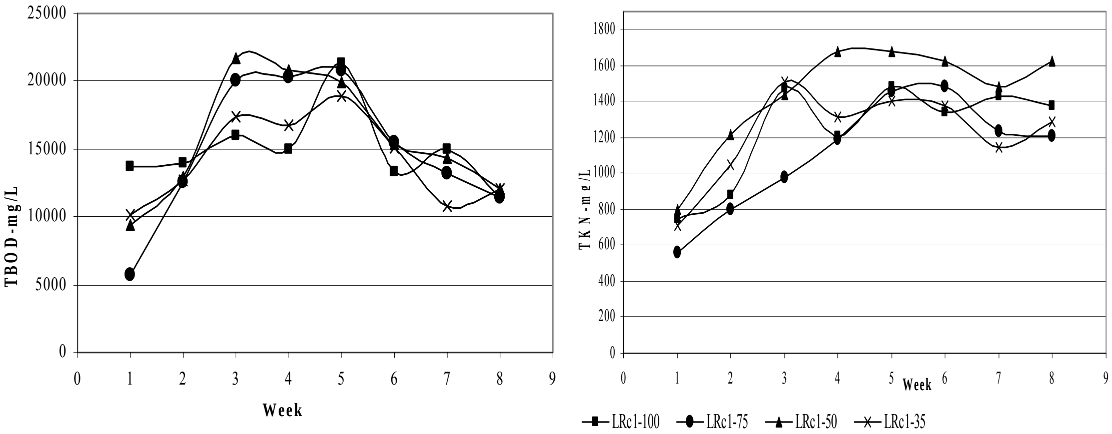

Figure 22 $TBOD_5$ variation in low compacted waste (LR_{C1})

b) Leachate characteristics of high compacted waste

In high compacted waste there were only 2 rates of leachate recirculation. They are 100% and 35%. The difference in 2 rates is significant in pollutant concentrations as well as sp. pollutant load. The lowest concentration was from 100% and highest cumulative sp. pollutant load was also from 100% max. RF intensity. Figure 23 shows the pollutant concentration variation in terms of $TBOD_5$ and TCOD.

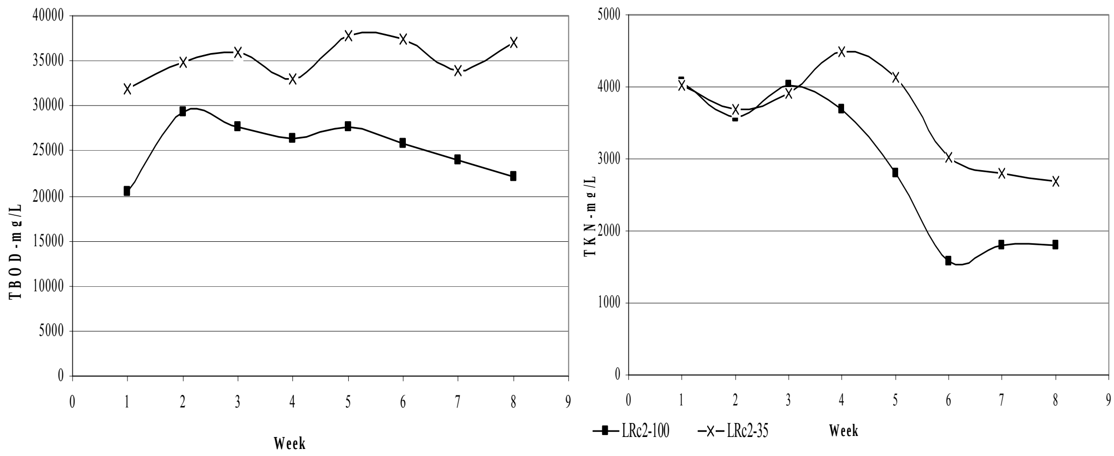

Figure 23 $TBOD_5$ variation in high compacted waste (LR_{C2})

c) Leachate characteristics of high compacted waste without plastic

In high compacted waste without plastic, there were only 1 rate of leachate recirculation. That is only 100%. The variation pattern of pollutant concentration as well as pollutant load is more or less similar to high compacted waste.

d) Leachate characteristics of pre treated waste

In pre-treated waste also there were only 2 rates of leachate recirculation. They are 100% and 35%. The difference in 2 rates is significant in pollutant concentrations as well as sp. pollutant load. The lowest concentration was from 100% max. RF intensity (LR_{C2}-100). However, the highest cumulative sp. load was not from 100% like in LC and HC. It is contradictory to LC and HC waste. Beside that there is a notable decline in organic concentrations as well as cumulative sp. organic load over the time, which were not can be seen in other types of waste. The results reveals the fact that pre-treated waste is more stabilize than low compacted and high compacted waste. Figure 24 depicts the organic concentration and cumulative sp. load in terms of $TBOD_5$.

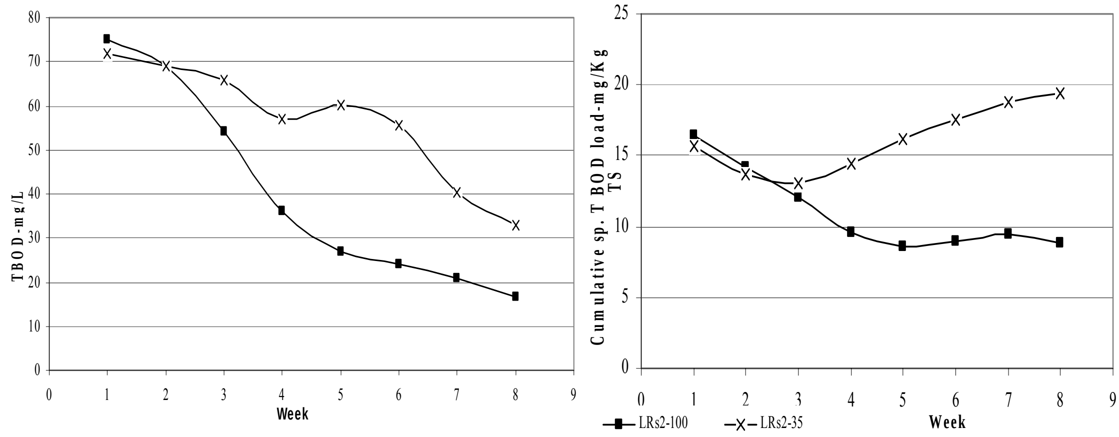

Figure 24 $TBOD_5$ concentration and cumulative sp. load variation in pre-treated waste (LR_{S2})

2.2 Comparison of leachate characteristics in different kind of solid waste

a) Effect of waste compaction density

In this section leachate characteristics of LR_{C1}-100(LC-100%) and LR_{C2}-100 (HC-100%) will be compared.

Figure 25 presents the organic concentration variation in LR_{C1}-100 and LR_{C2}-100 in terms of total BOD, and Total COD. Soluble BOD and Soluble COD concentration variation also behave similar to Total BOD and COD.

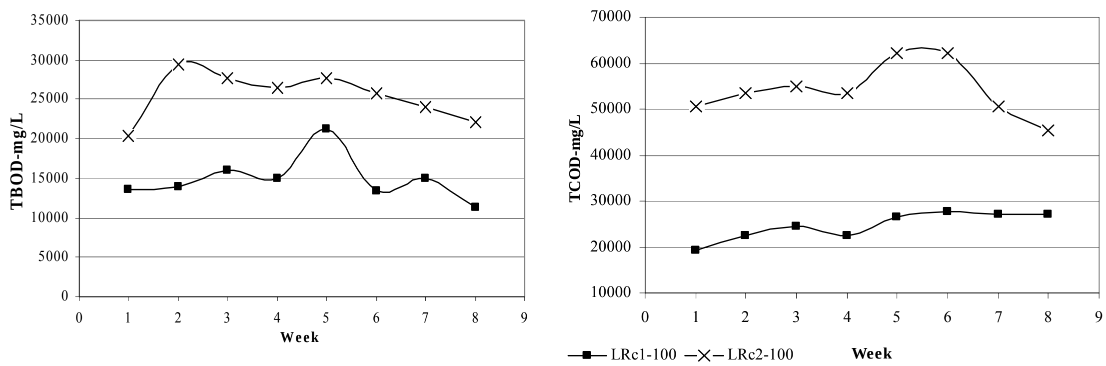

Figure 25 Organic concentration variation in LR_{C1}-100 and LR_{C2}-100

Organic concentrations vary within a constant range along the time both in LR_{C1}-100 and LR_{C2}-100. But the highest values are from LR_{C2}-100. This indicates that higher the compaction density, higher the organic concentration leaching under leachate recirculation condition. The scenario is also agreed with the situation under storm event. But the only difference is there are no plateaus and peaks can be observe like in storm condition. In addition to that there is no reduction in concentrations over the time since the leachate was recirculated weekly.

In spite to above tendency, cumulative sp. loads in each waste type behave in a different manner. Figure 26 presents their cumulative sp. organic loads .

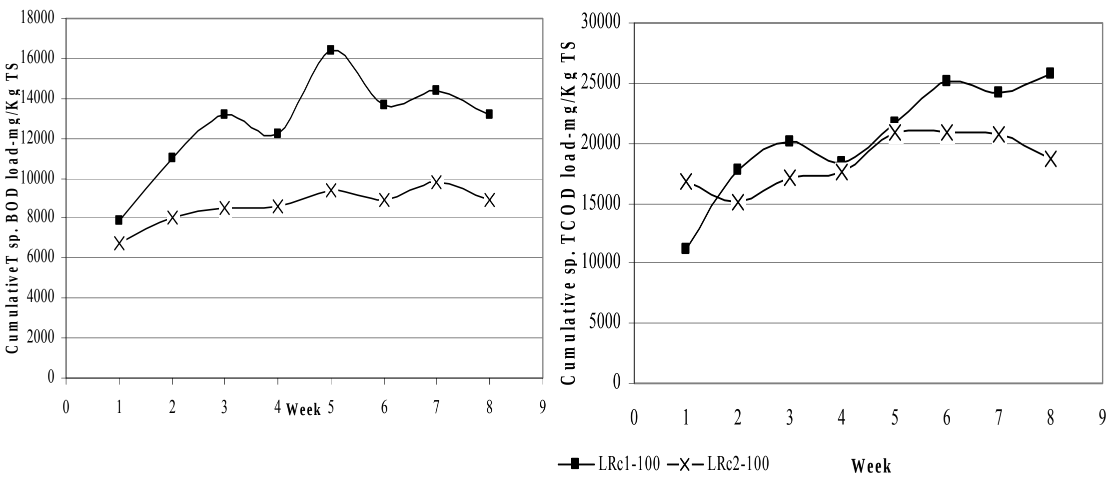

Figure 26 Cumulative sp. organic load in LR_{C1}-100 and LR_{C2}-100

The figure exhibits the highest values are from LR_{C1}-100 over LR_{C2}-100. This is not the trend what was expected in storm events. Under storm events, organic concentration as well as cumulative sp. organic load was from St_{C2}. Under storm events the gap of cumulative organic load (mg) between St_{C2} and St_{C1} was higher compared to leachate recirculation condition. But under leachate recirculation condition, this gap was not much compared to storm events. Figure 27 presents the cumulative organic load (mg) in terms of TBOD, both under storm condition and leachate recirculation condition.

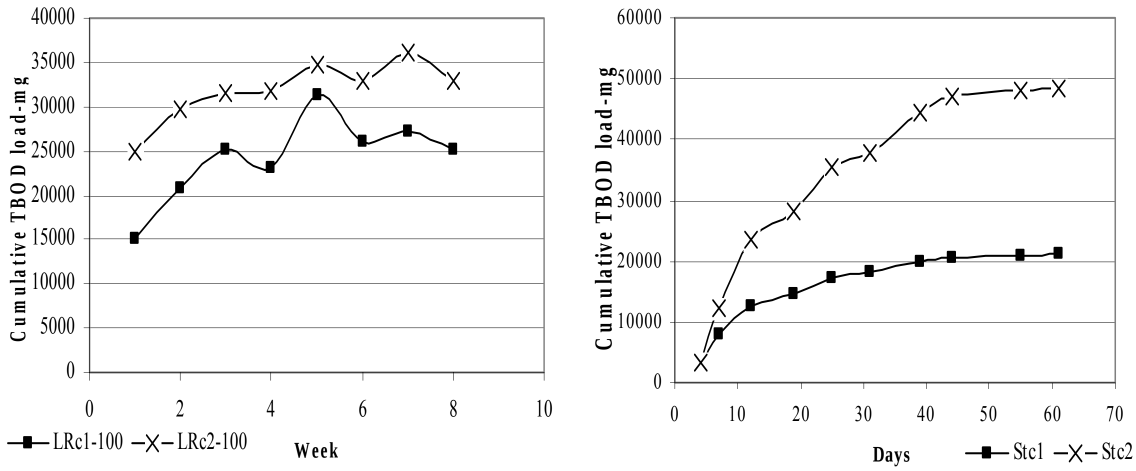

Figure 27 Cumulative Organic load-mg in LC and HC under leachate recirculation (LR) and storm conditions (IS)

Therefore when it appears as the cumulative sp. load, low compacted waste (LC) got the highest value than high compacted waste (HC) as the gap is not much in cumulative load (mg) graph. This would be the possible reason to get a higher value for LR_{C1} when compared to LR_{C2}. This results reveals the fact that cumulative sp. organic load not depends on the compaction density, but highly depends on the weight of TS in the solid waste. Also other cumulative sp. organic loads are behaving to the above trend.

Nitrogen leaching also behaves similar to the organic leaching from lysimeters. Figure 28 depicts the nitrogen concentration and cumulative sp. load in terms of TKN variation in LR_{C1}-100 and LR_{C2}-100. NH4-N also varies more or less similar to TKN variation.

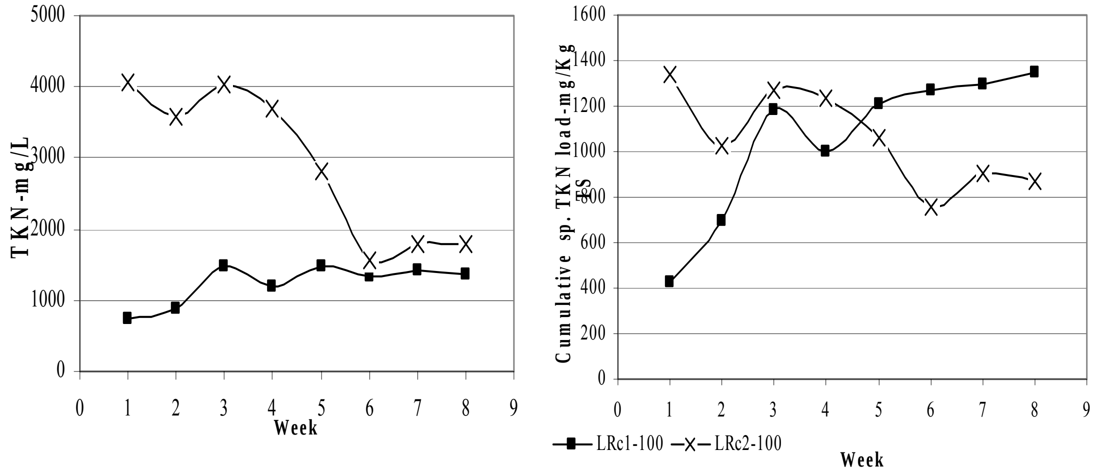

Figure 28 TKN concentration and cumulative sp. load in LR_{C1}-100 and LR_{C2}-100

It seemed that cumulative sp. nitrogen load also not depends on the compaction density as cumulative sp. organic loads, in contrary nitrogen concentrations depend on the compaction density. Therefore it can be concluded that pollutant concentration is proportionate to the compaction density where as cumulative sp. pollutant load is not depends on the compaction density.

TDS and SS also behave similar to organic and nitrogen leaching from lysimeters.

When compared the results of leachate recirculation condition and storm condition, the notable fact that can be seen in all concentrations (organic, nitrogen and TDS, SS) is, under leachate recirculation condition, concentrations fluctuate within a constant range where it has high peaks and plateaus and reducing over the time under storm condition. However when consider the overall leachate load; it is higher in storm conditions than leachate recirculation condition, although the initial pollutant load may be same under leachate recirculation condition and storm condition, which was also pointed out by Chugh *et al*. (1998). Figure 29 exhibit the overall pollutant load as a cumulative value in TCOD.

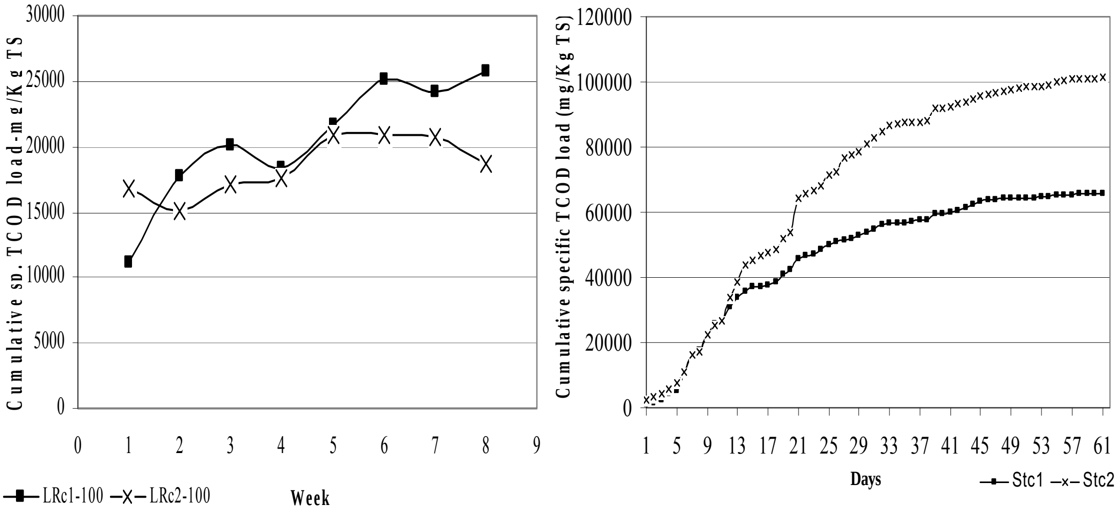

Figure 29 Cumulative sp. TCOD load in LC and HC at LR and St.

b) Effect of waste stabilization

In this section results of LR_{S1}-100 (HC-100%) and LR_{S2}-100 (PT-100%) will be discussed. LR_{S1}-100 is the fresh waste which was obtained from Nonthaburi dumpsite and compacted up to a density of 437kgm-^{3}. LR_{S2}-100 is the same waste which was obtained from that dumpsite and removed their non biodegradable part from the waste and composted for a period of 2 months. But as mentioned above, for storm conditions, pre-treated waste was obtained by composting the same waste up to 6 months.

It was found LR_{S2}-100 has lower concentration over the time compared to LR_{S1}-100. Cumulative sp. organic pollutant load also behave similar to the above pattern and the values are presented in Table19.

Table 19 Cumulative sp. Organic load variation in LR_{S1}-100 and LR_{S2}-100

Week	Cumulative sp. $TBOD_5$ load (mg/Kg TS)		Cumulative sp. $SBOD_5$ load (mg/Kg TS)		Cumulative sp. TCOD load(mg/Kg TS)		Cumulative sp. SCOD load(mg/Kg TS)	
	LR_{S1}-100	LR_{S2}-100	LR_{S1}-100	LR_{S2}-100	LR_{S1}-100	LR_{S2}-100	LR_{S1}-100	LR_{S2}-100
1	6738	16.4	6539	14.5	16741	617	14881	617
2	8023	14.1	7403	11.8	15047	575	12750	575
3	8504	12.1	7326	10.2	17172	745	13473	611
4	8604	9.6	7681	7.5	17625	441	16005	324
5	9373	8.6	7760	6.9	20858	258	16122	235
6	8923	9.0	7460	6.4	20858	385	14826	255
7	9767	9.5	8738	6.8	20799	654	16719	389
8	8896	8.8	8365	5.8	18645	577	16019	401

But they are fluctuating in a constant range where, increment is not obvious as storm event. Figure 30 shows the cumulative values in terms of TCOD in leachate recirculation and storm condition.

These stable values in leachate recirculation condition prove the means that it leaches less organic pollutants compared to storm condition and it is recirculated within the system. In addition to that these results reveals that stabilized waste like pre-treated waste leach less organic pollutants than other none stabilized waste.

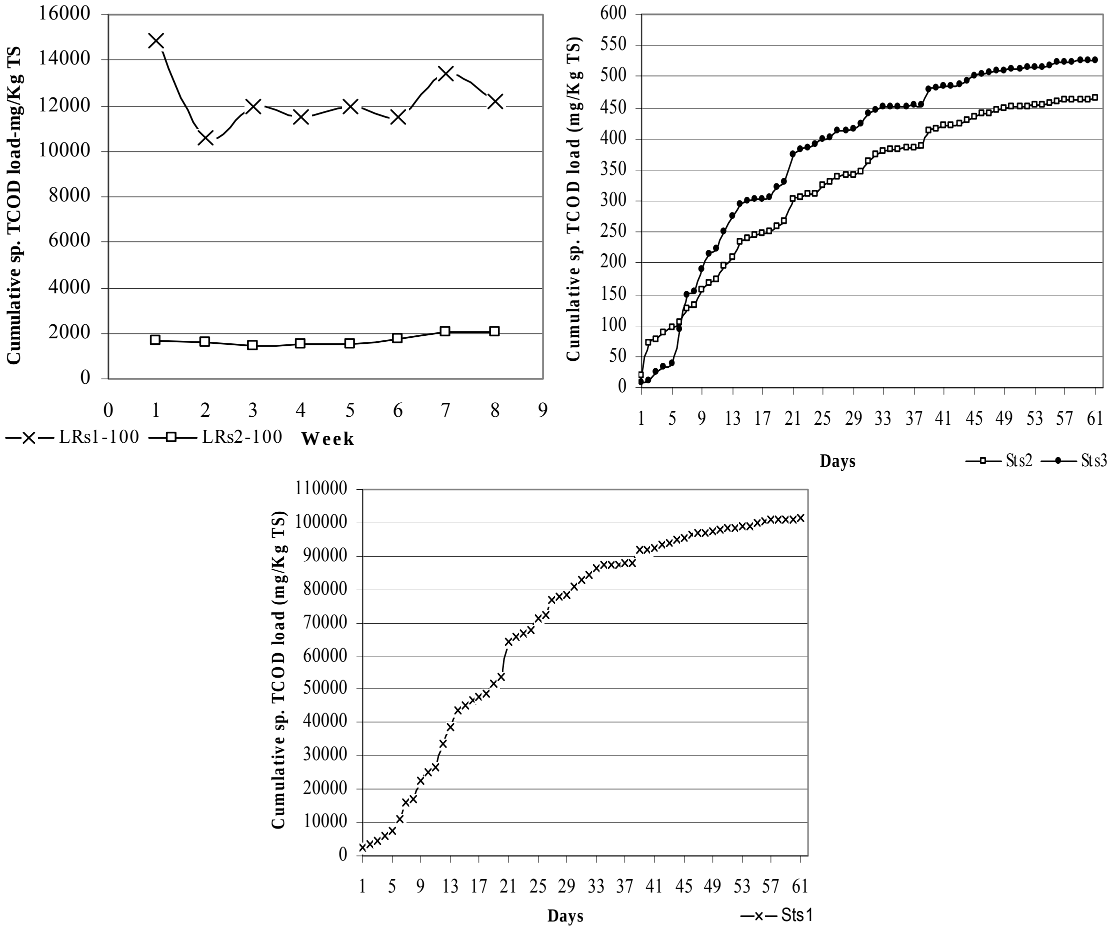

Figure 30 Cumulative sp. TCOD in HC,PT and OW in St and LR condition.

Nitrogen leaching also has similar trend as organic leaching behavior. (Kuruparan and Nisvanathan, 2003) found that pre treated landfill cell had minimum TKN concentration (4 fold) and minimum TKN loads (5 fold) compare to the engineered landfill cell. Leikam and Stegmann , 1999 also observed a similar trend in mechanically biologically pre-treated waste in pilot-scale lysimeters in Germany operated for 14 months, where a five fold reduction in TKN between non-treated wastes and pre-treated waste (1000 to200 mg/L) But in this experiment though the minimum TKN concentration and TKN loads were recorded from treated organic waste, TKN concentration was 4 fold and TKN load was 45 fold compared to high compacted waste.

Further treated organic waste had a minimum NH_4-N concentration (35 fold) and minimum NH_4-N load (78fold) compared to the high compacted waste cell.

Mentioned above results have shown that, the fold of reduction in nitrogen leaching vary depend on composition of waste, time consumed for the pre treatment, compaction density, moisture content in the waste and some other environmental factors. However, by pre treating waste; can reduce final nitrogen leaching in to the environment. Therefore pre treatment could be considered to minimize nitrogen concentration to a large extent in future land filling activities.

TDS and SS also varies similar to organic and nitrogen leaching in lysimeters.

From the above results it can be concluded that, stabilized waste like pre-treated waste leach less pollutant concentrations as well as less sp. pollutant load compared to high compacted waste.

c) Effect of plastic in waste

In this section, leachate characteristic of LR_{P1}-100 (high compacted waste) and LR_{P2}-100 (high compacted waste without plastic) will be compared.

Unlike in storm event, there is a considerable difference in organic concentration between LR_{P1}-100 and LR_{P2}-100. LR_{P1}-100 got the highest concentration levels for organic leaching compared to LR_{P2}-100. But in storm event there is no such significant difference among them. Figure 31 depicts the concentration variation of organic pollutants between LR_{P1}-100 and LR_{P2}-100. They are presented in terms of TBOD and TCOD and SBOD and SCOD values also behaving similar to these trends.

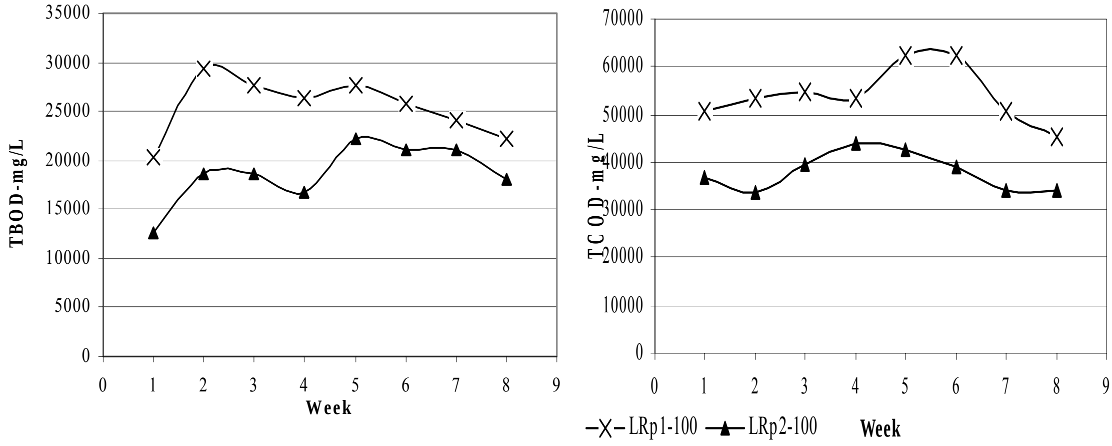

Figure 31 Organic concentration variation in LR_{P1}-100 and LR_{P2}-100

Even the cumulative sp. organic load is high in LR_{P1}-100 than LR_{P2}-100. In addition to that there is no remarkable increase in cumulative values, like in storm event.

Plastic has organic origin and consist of monomers, polymers or elastomers. This organic fraction is chemically digested when determining for COD and, might give a higher values for TCOD and SCOD when compared to LR_{P1}-100. Also 1%-2% of plastic undergoes decomposition and some plastic bags contain some sticky residues which contributed for the final BOD_5 value. This may be the possible reason for giving higher BOD_5 value for LR_{P1}-100than LR_{P2}-100. So the end result is high compacted waste without plastic provides a low organic leaching to the environment compared to high compacted waste with plastic.

Nitrogen leaching is also same as organic concentration variation. Moreover, in storm events also, waste with plastic obtained the highest values over the waste without plastic.

For this situation plastic might be the possible reason to have high nitrogen content in LR_{P1}-100. However, the results were still equivocal and it is recommended that waste without plastic has to be closely investigated in future test cells.TDS and SS also obtained higher values for LR_{P1}-100 than LR_{P2}-100 for pollutant concentrations as well as for cumulative pollutant load.

3. Leaching in the landfill at internal storage condition

Under this condition two lysimeters were filled with low compacted waste(IS_{C1}) and high compacted waste(IS_{C2}) by using same waste which was obtained from Nonthaburi dumpsite. High compacted waste was obtained by compacting waste up to 437kgm^{-3}.

3.1 Comparison of leachate characteristics

a) Effect of waste compaction density

In this section IS_{C1} (low compacted waste) and IS_{C2} (high compacted waste) will be compared. All pollutant concentrations show a similar trend along the time. In all pollutant concentrations, IS_{C2} seems to be having the highest compared to IS_{C1}. Figure 32 presents the pollutant concentrations (Organic, Nitrogen and TDS, SS) variation in terms of TBOD, TCOD, TKN and TDS concentrations. Other pollutant concentrations are also behaving equal to this pattern.

However when compare the total sp. pollutant leaching from the cell; IS_{C1} obtained the highest value than IS_{C2}. It was expected the volume of water to make it submerge could be the reason to have a highest sp. pollutant load in IS_{C1}. Which means it needed more volume of water to submerge IS_{C1} than IS_{C2}. This volume of water has a proportional relationship on final pollutant leaching load from the lysimeters. Figure 33 illustrates the pollutant load leaching from IS_{C1} and IS_{C2}.

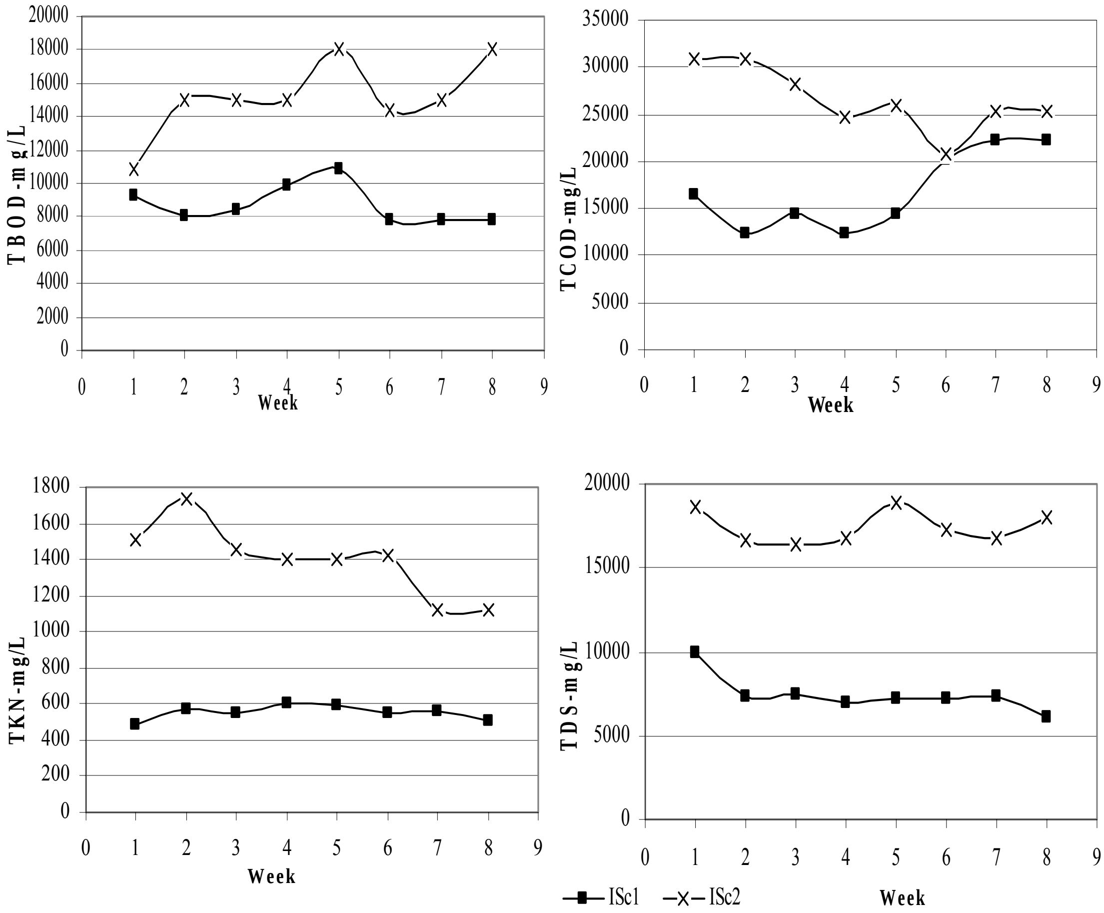

Figure 32 Pollutant concentration variation in IS_{C1} and IS_{C2}

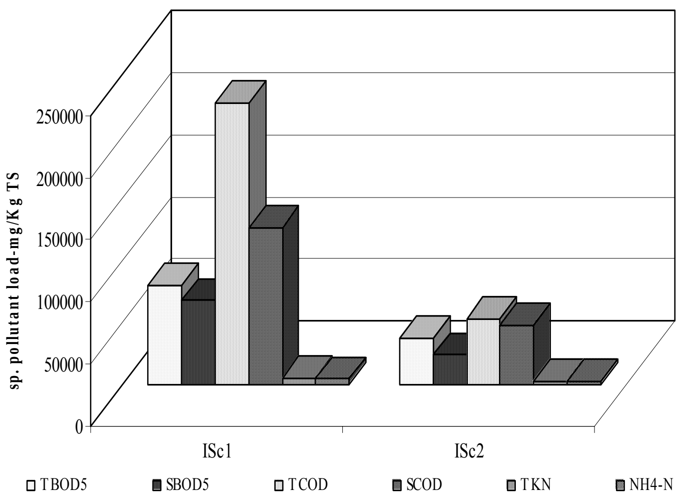

Figure 33 Sp. Pollutant load leach in IS_{C1} and IS_{C2}

a) Compare with leachate recirculation condition

When consider the pollutant concentration variation in submerged condition, there is a remarkable decline in values compared to leachate recirculation condition. However it has the highest sp. pollutant load leaching since it contains more volume of water to submerge the cell. Figure 34 depicts the concentration variation in terms of TCOD compared to leachate recirculation condition.

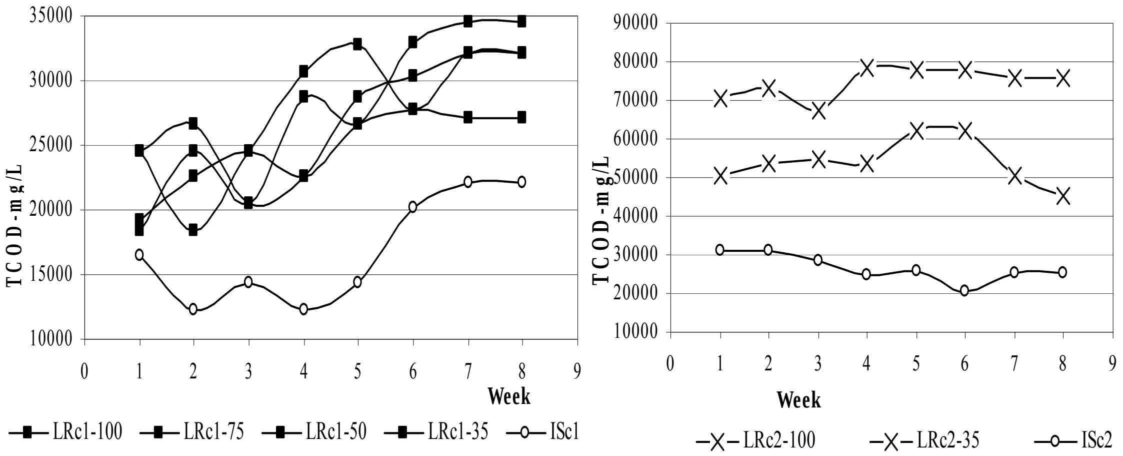

Figure 34 TCOD concentration variation in leachate recirculation and submerged condition

Table 20 presents the sp. pollutant load leach compared to leachate recirculation condition both in low compacted waste and high compacted waste.

Table 20 Sp. pollutant load leach in LC and HC at leachate recirculation and internal storage condition

Parameter	Unit	Low compacted waste					High compacted waste		
		LR_{C1}-100	LR_{C1}-75	LR_{C1}-50	LR_{C1}-35	IS_{c1}	LR_{C2}-100	LR_{C2}-35	IS_{c2}
$TBOD_5$	mg/kg TS	6450	4800	3411	2684	79847	5616	2650	37459
$SBOD_5$	mg/kg TS	5092	4800	3411	1611	67563	5464	2578	23724
TCOD	mg/kg TS	15320	13487	9104	7716	227012	11511	5432	52610
SCOD	mg/kg TS	12534	10375	6303	4409	126118	10232	5070	47349
TKN	mg/kg TS	776	507	462	288	5159	453	192	2331
NH4-N	mg/kg TS	404	348	291	210	4299	439	181	2302

4. pH Variation in Lysimeters

4.1 pH Variation in Storm condition

pH is an important factor which governs the process that occurs within a landfill. It can influence the rate at which the landfill stabilizes. Figure 35 presents the pH variation in lysimeters. It is obvious that St_{C1}, St_{C2} and St_{P2} ranged between 5 to 6 where it is 7 to 8 in St_{S2} and St_{S3}. Similar observations were also made by Trankler et al., 2005b in lysimeter studies, Bangkok, Thailand as well as under temperate climate by Khattabi et al., 2002 at Etueffont landfill, France.

This indicates that St_{C1}, St_{C2} and St_{P2} are in the stage of acidogenic and St_{S2} and St_{S3} are almost reached to a more stabilization stage. But in St_{C1} pH has increased up to 7.72 at the latter stage of experiment seems it is becoming to a more stabilization stage.

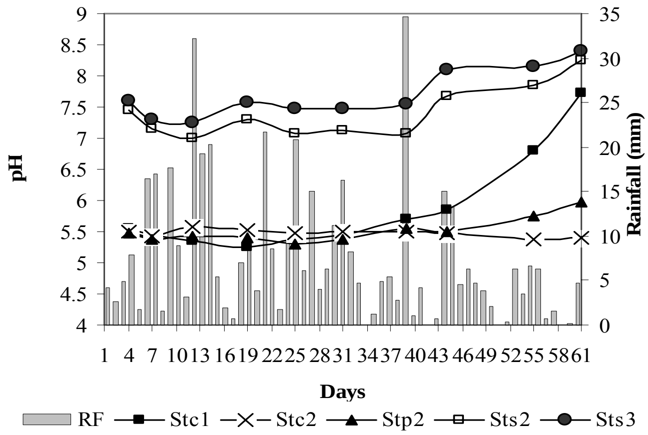

Figure 35 Variation of pH in lysimeters at storm condition

4.2 pH Variation in leachate recirculation and internal storage condition

Figure 36 depicts the pH variation in lysimeters at LR and IS

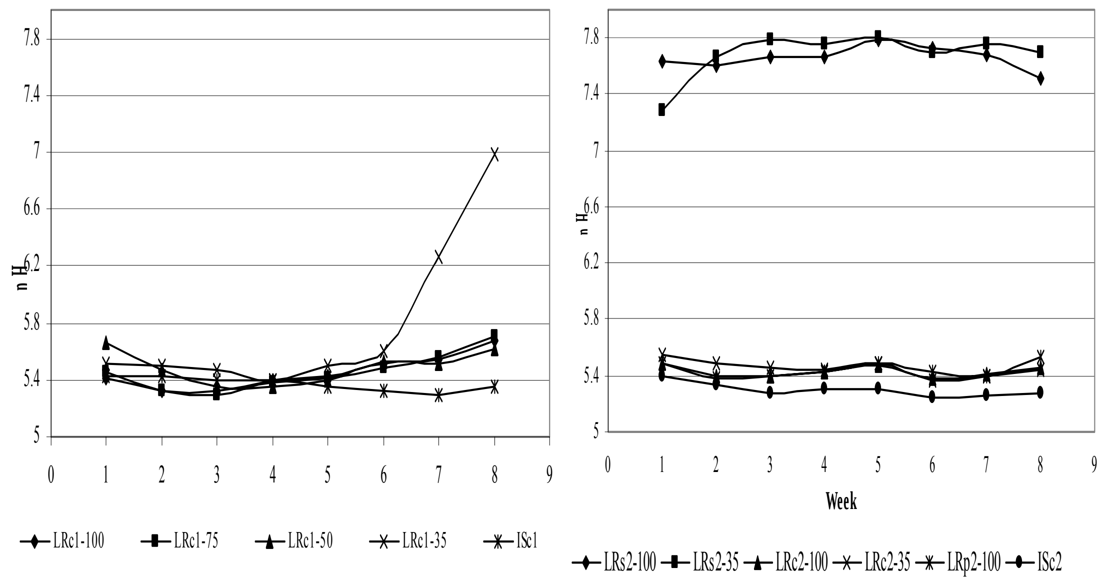

Figure 36 pH variation in lysimeters at leachate recirculation and internal storage condition

Except in pre-treated waste, pH is varied between 5.2 and 5.6 in other lysimeters. But in LR_{C1}-35 tried to achieve to a more stabilize stage at the end of operation by reaching to pH 7. This situation is more or less similar with the situation existed in the low compacted waste under storm condition. The results demonstrated the fact that pre-treated waste has already reached to a stabilized stage where other types of waste are at the acidogenic phase.

5. Water Balance in Lysimeters

Figure 37 shows the water balance in lysimeters and Table 21shows the percentage leach out from the lysimeters.

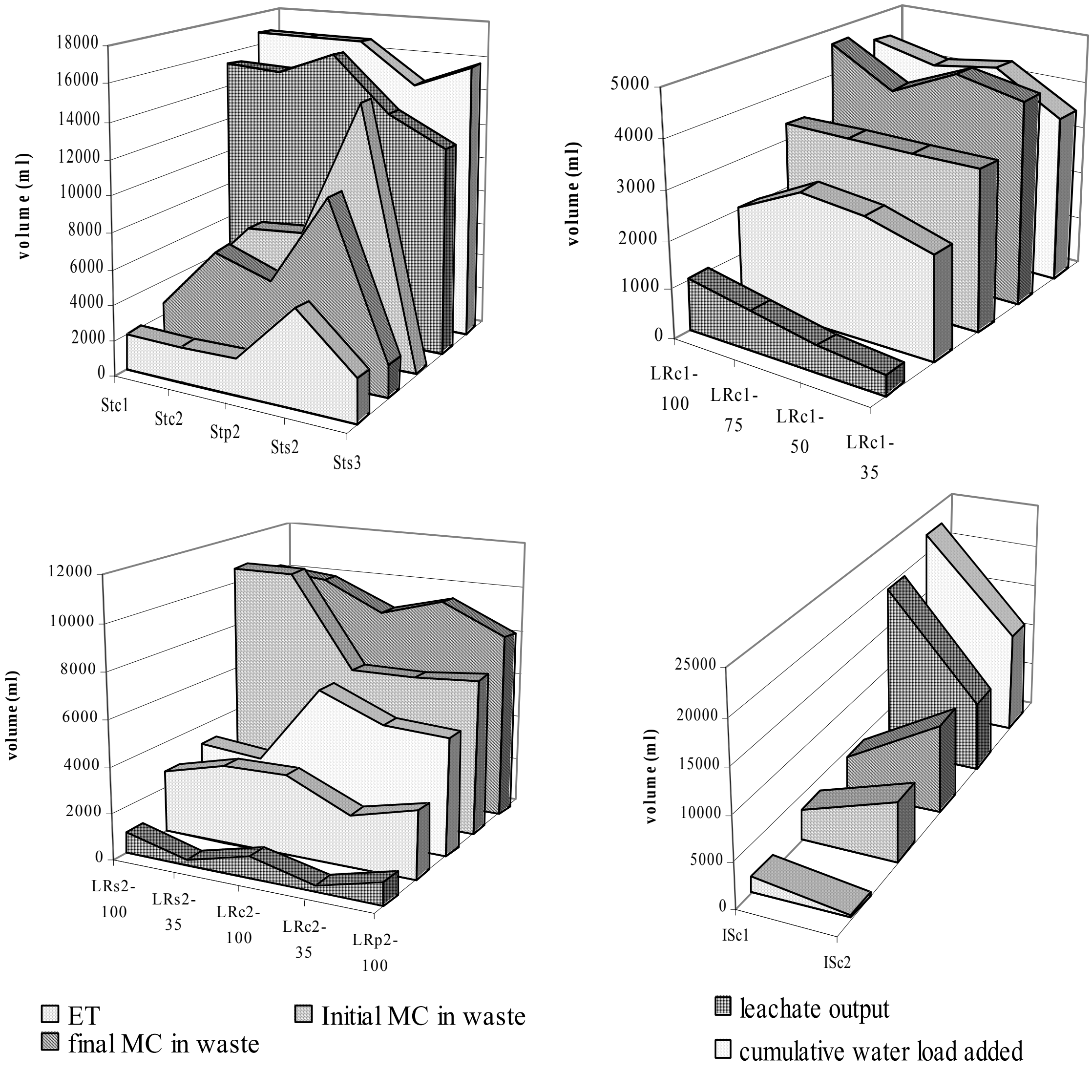

Figure 37 Water balance in lysimeters

Table 21 Percentage leach from lysimeters

Leaching in landfill		Leaching during storm events	
Lysimeter name	% leach from lysimeters	Lysimeter name	% leach from lysimeters
LR_{C1}-100	24	St_{C1}	92
LR_{C1}-75	20		
LR_{C1}-50	13		
LR_{C1}-35	12		
LR_{C2}-100	15	St_{C2}	90
LR_{C2}-35	5		
LR_{P2}-100	19	St_{P2}	98
LR_{S2}-100	31	St_{S2}	92
LR_{S2}-35	10		
IS_{C1}	88	St_{S3}	74
IS_{C2}	67		

6. Carbon and Nitrogen balance in lysimeters

To investigate the portion of organic carbon removed with leachate, Total organic carbon (TOC) measured in random samples and linear relation ship was drawn with COD values. The random leachate samples were analyzed for each type of waste and found 5 linear relationships in accordance to the each waste type. Thereafter the required TOC values were derived with the help of linear relationship. The equations derived from this relationship for each waste type has been given in the appendix B. Used Cumulative TOC values at storm condition to find the amount of TCOD leach. At internal storage condition and leachate recirculation condition, the final COD value was taken to calculate the amount of TCOD leach. VS in each waste type was used to find the approximate carbon in solid waste. Figure 38 explains the C balance in lysimeters.

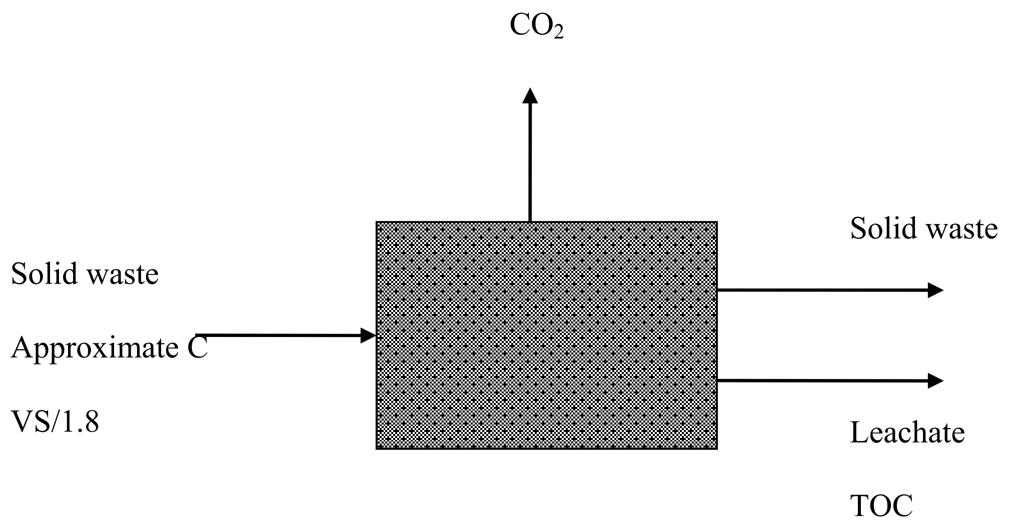

Figure 38 Carbon Balance in lysimeters

The percent Carbon leach from each lysimeter can be found from the following equation.

$$\% \text{ carbon leach from lysimeters} = \frac{\text{Total COD load in leachate}}{\text{Approximate C in Solid waste}} \times 100 \qquad (3)$$

Table 22 depicts the percent C leach in each lysimeter

Table 22 Percent Carbon leach from each lysimeter

Storm		Leachate recirculation		Internal storage	
Lysimeter	% leach	Lysimeter	% leach	Lysimeter	% leach
St_{C1}	9.27	LR_{C1}-100	1.87	IS_{C1}	27.78
St_{C2}	9.62	LR_{C1}-75	1.65	IS_{C2}	4.44
St_{P2}	13.46	LR_{C1}-50	1.11		
St_{S2}	0.09	LR_{C1}-35	0.94		
St_{S3}	0.14	LR_{C2}-100	0.97		
		LR_{C2}-35	0.46		
		LR_{P2}-100	1.26		
		LR_{S1}-100	0.04		
		LR_{S1}-35	0.01		

To investigate the portion of nitrogen removed with leachate, TKN was measured before solid waste was fed into lysimeters. At the storm condition, since the leachate was measured for TKN intermittently, the exact TKN leach cannot be determined. But

at leachate recirculation condition and internal storage condition, the final leachate TKN value was taken to determine the percent N leach from lysimeters. Figure 39 explains the Nitrogen balance in lysimeters.

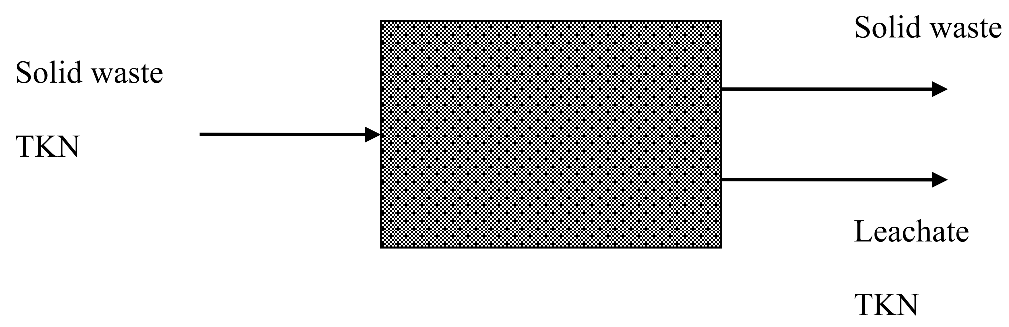

Figure 39 Nitrogen Balance in lysimeters

The percent Nitrogen leach from each lysimeter can be found from the following equation.

$$\%\text{nitrogen leach from lysimeters} = \frac{\text{Total TKN load in leachate}}{\text{TKN in Solid waste}} \times 100 \qquad (4)$$

Table 23 depicts the percent N leach in each lysimeter

Table 23 Percent Nitrogen leach from each lysimeter

Leachate recirculation		Internal storage	
Lysimeter	% leach	Lysimeter	% leach
LR_{C1}-100	3.08	IS_{C1}	20.5
LR_{C1}-75	2.01	IS_{C2}	9.2
LR_{C1}-50	1.83		
LR_{C1}-35	1.14		
LR_{C2}-100	1.80		
LR_{C2}-35	0.76		
LR_{P2}-100	2.54		
LR_{S1}-100	0.02		
LR_{S1}-35	0.08		

7. Changes to the solid waste characteristics after the operation

Run 1

Table 24 reveals that moisture content has increased when compared to initial moisture content of low compacted waste, high compacted waste and high compacted waste without plastic. In old waste the increment in moisture content is substantial when compared to initial moisture content. But initial moisture content of pre-treated waste (for 6 months) is higher than the final moisture content after remove solid waste from the lysimeters. Density also behaves similarly to the moisture content of solid waste. Porosity has increased in all waste types compared to initial values except other than pre-treated waste (for 6 months). In high compacted waste without plastic and old waste, field capacity has increased compared to initial values but in pre-treated waste, it has reduced and in low compacted waste and high compacted waste, no change can be observed to the field capacity. Other parameters are described in Table 24.

Run 2

Table 25 reveals that moisture content has increased when compared to initial moisture content of low compacted waste. Substantial increase in density, along with leachate recirculation rate and internal storage condition.

Porosity has decreased with leachate recirculation rate and lowest was recorded in internal storage condition. But there was no any drastic change in field capacity when compared with initial low compacted where slight increase in all lysimeters except submerged cell.

Run 3

Table 26 reveals that moisture content has increased when compared to initial moisture content of high compacted waste, high compacted waste without plastic and pre-treated waste. Highest moisture content has recorded in IS_{C1} as it was under submerged condition. Substantial increment in density along with leachate recirculation rate and internal storage condition can be seen in all lysimeters, except LR_{S2}-100 and 35. Increase in density of LR_{S2}-100 and 35 seems more or less same. Porosity has decreased with leachate recirculation rate and lowest was recorded in internal storage condition. Filed capacity has increased drastically in LR_{C2}-100 and 35 when compared to initial value (high compacted waste). There is slight increase in field capacity in LR_{S2}-100 and 35when compared to initial pre-treated waste. But in all those 4 lysimeters, field capacity has reduced along with leachate recirculation rate. In LR_{P2} also, field capacity has increased drastically when compared to initial value of high compacted waste without plastic. In IS_{C2}, increase in field capacity is slight when compared to LR_{C2}-100 and 35. It reveals the process of leachate recirculation has an effect on final field capacity compared to internal storage condition.

Table 24 The changes to the physical, chemical characteristics of solid waste after 61 days in Run 1(storm condition)

Parameter	Unit	LC	HC	HC-w/p	PT	OW
Density	[kg/m3]	327	488	523	758	324
Porosity	[-]	0.53±0.09	0.38±0.02	0.45±0.01	0.31±0.01	0.63±0.03
FC	[mm/m]	744±22	694±13	776±31	688±11	463±11
TS	[%]	32.00±1.66	29.84±0.73	23.55±2.42	34.04±0.79	67.16±2.59
MC	[%-wet basis]	68.00±1.66	70.16±0.73	76.45±2.42	65.96±0.79	32.84±2.59
Ash	[%-wet basis]	4.26±0.14	5.05±0.40	4.82±0.36	18.29±0.83	31.03±5.24
VS	[%-wet basis]	27.74±1.79	24.78±0.84	18.73±2.09	15.75±0.04	36.13±2.65
Sulfur	[%-dry weight]	0.016±0.001	0.009±0.001	0.031±0.002	0.017±0.000	0.015±0.001
Chlorine	[%-dry weight]	1.49±0.136	1.91±0.040	0.69±0.032	1.12±0.188	4.75±0.178
Cellulose	[%-dry weight]		22.00±0.04	33.11±0.11		
Lignin	[%-dry weight]		51.73±0.95	29.17±2.03		

Table 25 The changes to the physical, chemical characteristics of solid waste after 60 days in Run 2

Parameter	Unit	Leachate recirculation (LR)				Internal storage(IS)
		LC-100	LC-75	LC-50	LC-35	LC
Density	[kg/m3]	403	377	375	349	450
Porosity	[-]	0.41±0.02	0.45±0.02	0.45±0.01	0.47±0.02	0.38±0.01
FC	[mm/m]	757±10	745±22	795±17	777±09	730±08
TS	[%]	24.49±0.70	32.08±0.66	22.90±1.38	24.04±1.14	26.99±0.75
MC	[%-wet basis]	75.51±0.70	67.92±0.66	77.10±1.38	75.96±1.14	73.01±0.75
Ash	[%-wet basis]	3.40±0.40	4.05±0.32	4.47±0.28	3.76±0.28	4.08±0.62
VS	[%-wet basis]	21.09±0.31	21.34±1.60	18.43±1.66	20.28±1.42	22.91±0.13
Sulfur	[%-dry weight]	0.005±0.002	0.011±0.001	0.009±0.002	0.004±0.000	0.006±0.001
Chlorine	[%-dry weight]	2.34±0.156	1.19±0.096	1.69±0.081	1.10±0.040	1.27±0.080

Table 26 The changes to the physical, chemical characteristics of solid waste after 60 days in Run 3

Parameter	Unit	Leachate recirculation (LR)					Internal storage(IS)
		PT-100	PT-35	HC-100	HC-35	HC-w/p	HC
Density	[kg/m3]	697	698	565	561	552	627
Porosity	[-]	0.38±0.02	0.40±0.02	0.32±0.02	0.35±0.04	0.42±0.02	0.32±0.02
FC	[mm/m]	760±06	765±15	775±11	794±18	740±11	726±15
TS	[%]	26.59±0.47	27.24±2.48	31.34±1.76	26.06±1.46	26.97±0.05	25.65±0.54
MC	[%-wet basis]	73.41±0.47	72.76±2.48	68.66±1.76	73.94±1.46	73.03±0.05	74.35±0.54
Ash	[%-wet basis]	12.73±0.61	12.51±3.12	6.20±1.79	6.86±2.16	8.67±0.33	4.38±0.92
VS	[%-wet basis]	13.85±0.15	14.73±0.63	25.13±0.27	19.21±1.04	18.30±0.37	21.28±0.39
Sulfur	[%-dry weight]	0.013±0.001	0.026±0.001	0.007±0.000	0.005±0.001	0.007±0.000	0.059±0.002
Chlorine	[%-dry weight]	0.62±0.021	1.02±0.064	1.71±0.240	2.22±0.283	2.09±0.140	1.73±0.038
Cellulose	[%-dry weight]			22.87±0.12		33.43±0.12	
Lignin	[%-dry weight]			28.89±1.82		33.57±1.30	

CONCLUSION

The study worked on finding leachate characteristic in different solid waste disposal conditions and operation techniques in tropics. These findings can be categorized into two sectors namely, leaching during storm conditions and leaching in the landfill due to leachate recirculation and submerged condition. The leachate characteristics were obtained in different solid waste disposal conditions such as; effect of solid waste compaction density on leaching, effect of waste stabilization techniques on leachate quality, effect of plastic in waste on leachate quality and effect of leachate recirculation rate in leaching. From the results obtained for previously mentioned factors, following conclusions can be drawn.

1. Under heavy rainfall events, waste cells leach more pollutant loads to the leachate in spite of reducing trend over the time. Moreover, higher the leachate recirculation rate, higher the pollutants discharge from the lysimeters in fresh waste. In contrary, pre-treated waste leach lower cumulative pollutant load per kg of TS with higher leachate recirculation rate. This reveals that leachate recirculation rate is not a fact on leaching in stabilized waste. However recirculation would help in gradual leaching of pollutants from the lysimeters.

2. However, internal storage condition leach highest sp. pollutant loads compared to leachate recirculation condition and storm conditions, when fed with low compacted waste. However, when fed with high compacted waste, storm condition leaches highest sp. pollutant load compared to other conditions.

The lowest sp. pollutant loads were from leachate recirculation condition, storm condition and then submerge condition respectively in low compacted waste. In leachate recirculation condition, the percent decrease in TCOD is 61% than storm condition and in storm condition it is 71% of TCOD than submerge condition. In high compacted waste the lowest sp. pollutant loads were from leachate recirculation, internal storage and storm condition respectively. In leachate recirculation condition, the percent decrease in TCOD is 65% than internal storage condition and in IS condition it is 48% TCOD than storm condition

3. Under leachate recirculation condition and submerged condition, sanitary landfill waste obtained the lowest cumulative pollutant load per kg of TS over open dump fresh waste where it was not same under storm condition.

4. There is a remarkable decline in pollutant load discharging in to the leachate with the stage of solid waste stabilization compared to sanitary landfill waste. Further, by pre-treating solid waste can reduce the pollutant leaching in to the leachate. When compare the cumulative pollutant load per kg of TS of pre-treated waste with 8 years old waste at storm condition, the percentage reduction is 58% of $TBOD_5$, 12% of TCOD and 38% of TKN. So this reveals that pre-treatment is more appropriate technique to reduce pollutant leaching in to the leachate and also a technique of waste stabilization. At leachate recirculation condition, the percent reduction in pre-treated waste compared to sanitary landfill waste is, 100% $TBOD_5$, 97% of TCOD and 92% of TKN.

5. According to the results obtained, it can be concluded that by removing polythene and plastic from the waste, can reduce the pollutant leaching in to the leachate. This was more obvious at leachate recirculation condition. In sanitary landfill waste without plastic, the percent reduction in cumulative pollutant load per kg of TS is 16% $TBOD_5$, 22% TCOD and 19% TKN than sanitary landfill waste with plastic under leachate recirculation condition.

However, in storm conditions; since the cumulative pollutant loads were obtained by intermittent values, the results cannot be compared as it interprets fewer figures than what should be expected. On the other hand it presents higher cumulative loads for sanitary landfill waste without plastic since they were not taken continuously. But for the TCOD, it gave a lower value for sanitary landfill waste without plastic and possible reason seemed it was measured continuously. There the percent decrease is 3% TCOD than sanitary landfill waste with plastic.

RECOMMENDATION

Based on the results, the following recommendations are made for future works:

1. The Experiment should be carry out pilot scale to find whether there are any changes to the results obtained by lab scale study.

2. Since sanitary landfill waste without plastic leached less pollutant loads to the leachate, this should be closely investigate in future test cells, as this could be a new way of dumping solid waste in future landfills, because it leaches less pollutant loads to the landfill body.

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APPENDICES

Appendix A

Photographs

Feed Stock Preparation

Lab Scale Experiment

Leachate samples

Lab scale vertical batch reactors

Leachate collection containers

Leachate outlet port

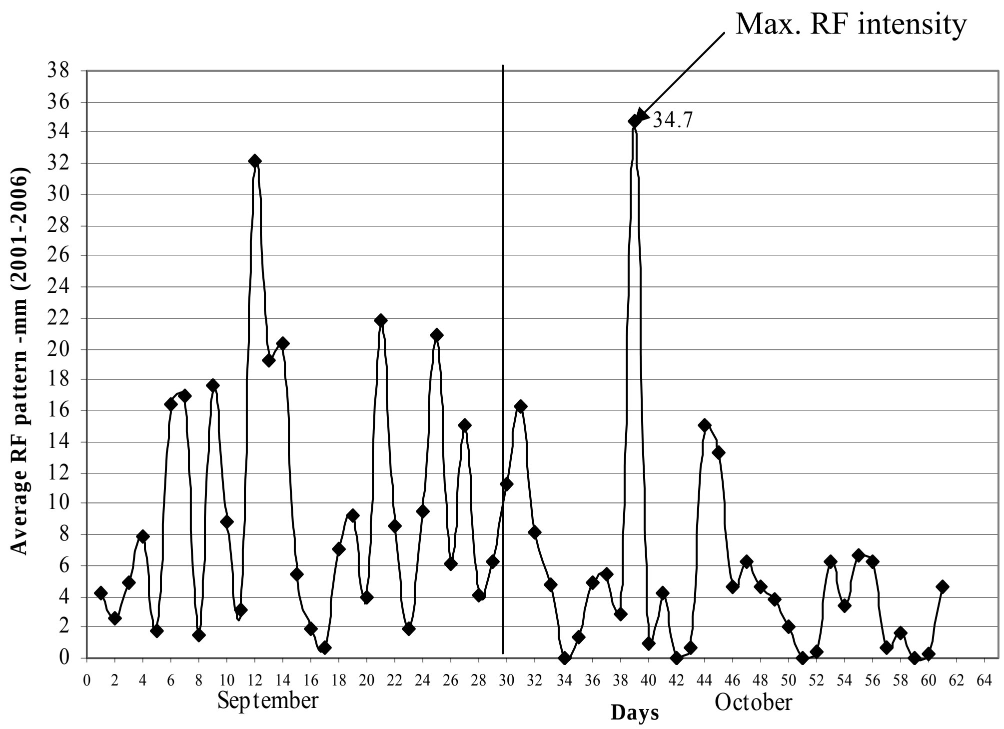
Solid waste to fill lysimeters

Analyzing for BOD_5, COD, TKN, NH_4-N and etc.

Waste samples after remove from lysimeters

Appendix B

Figures and calculations



Appendix Figure B1 Average rainfall pattern (year 2001 to 2006); storm period from September to October

Compaction Density

$$\rho_{waste} = \frac{M1}{V1}$$

ρ_{waste} : Density of waste

M1 : Weight of waste (kg)

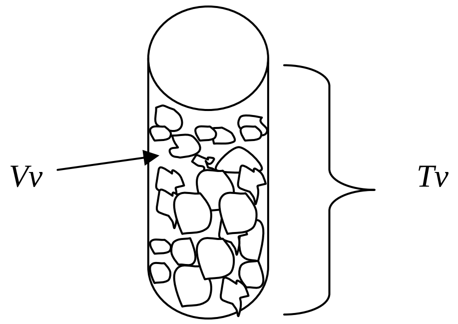
V1 : Volume of waste (m^3)

Porosity

$$\text{Porosity} = \frac{Vv}{Tv}$$

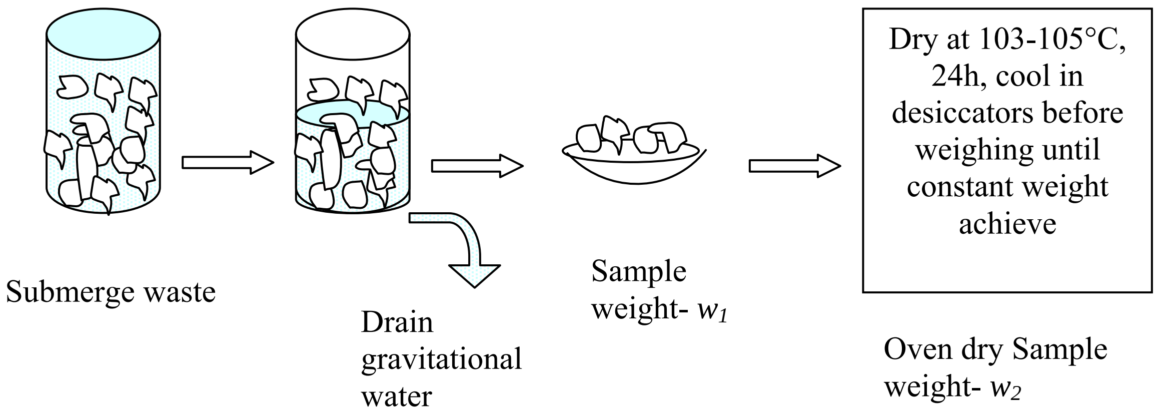
Vv = Void volume (m^3)

Tv = Total volume (m^3)



Field Capacity

The field capacity of solid waste is the total amount of moisture that can be retained in a waste sample subjected to the downward pull of gravity.



w_0 - Empty crucible weight

$$\text{Field capacity \%} = \frac{w_1 - w_2}{w_2 - w_0} \times 100\%$$

$$\text{Field capacity (mm/m)} = \frac{w_1 - w_2}{w_2 - w_0} \times 1000$$

Calculation of cumulative pollutant load at leachate recirculation condition

BOD output-BOD load for sample = BOD input

Actual BOD output = BOD output –BOD input

Cumulative BOD = Initial BOD out put+ actual BOD output 1+ actual BOD output 2..

Eg:- at low compacted waste with 100% LR

BOD leach	BOD input	actual BOD output-mg	Cumulative BOD leach-mg		Cumulative sp. BOD leach-mg/kg
15015		15015	15015	15015/1.9	7903
20228	14333	5895	20910	20910/1.9	11005
23674	19530	4144	25054	25054/1.9	13186

Appendix C

Tables

Appendix Table C1 pH Variation in Lysimeters -Run 2(LR and IS)

Week	Date	LR				IS
		LC-100	LC-75	LC-50	LC-35	LC
1	4/3/2007	5.41	5.45	5.66	5.51	5.42
2	17/4/2007	5.32	5.32	5.47	5.5	5.42
3	18/4/2007	5.33	5.3	5.35	5.47	5.4
4	24/4/2007	5.4	5.38	5.35	5.4	5.39
5	1/5/2007	5.42	5.41	5.4	5.5	5.35
6	8/5/2007	5.52	5.49	5.53	5.6	5.32
7	14/5/2007	5.55	5.56	5.51	6.26	5.29
8	23/5/2007	5.67	5.71	5.62	6.99	5.36

Appendix Table C2 pH Variation in Lysimeters -Run 3 (LR and IS)

Week	Date	LR					IS
		PT-100	PT-35	HC-100	HC-35	HC-w/p	HC
1	25/6/2007	7.63	7.29	5.48	5.55	5.48	5.4
2	27/6/2007	7.61	7.66	5.4	5.49	5.39	5.33
3	2/7/2007	7.66	7.79	5.4	5.46	5.4	5.28
4	9/7/2007	7.66	7.75	5.43	5.44	5.42	5.3
5	16/7/2007	7.78	7.8	5.47	5.48	5.48	5.31
6	23/7/2007	7.73	7.69	5.38	5.37	5.42	5.24
7	31/7/2007	7.68	7.75	5.41	5.40	5.40	5.26
8	6/8/2007	7.51	7.69	5.46	5.44	5.53	5.28

Appendix Table C3 pH Variation in Lysimeters -Run 1(storm)

Day	Date	LC	HC	HC-w/p	PT	OW
4	26/9/2007	5.54	5.49	5.47	7.46	7.59
7	29/9/2007	5.46	5.42	5.38	7.16	7.3
12	4/10/2007	5.34	5.58	5.42	6.99	7.25
19	11/10/2007	5.24	5.53	5.39	7.29	7.58
25	17/10/2007	5.37	5.48	5.3	7.07	7.47
31	23/10/2007	5.46	5.51	5.37	7.12	7.48
39	31/10/2007	5.7	5.49	5.55	7.08	7.56
44	5/11/2007	5.86	5.47	5.5	7.68	8.10
55	16/11/2007	6.81	5.37	5.75	7.85	8.14
61	24/11/2007	7.72	5.39	5.97	8.25	8.39

Appendix Table C4 Weight of each type of waste fill into lysimeters at initially and their TS amount

Solid waste type	Symbol	Weight to lysimeter-kg	TS%-wet basis	Dry weight-kg
Low compacted waste	LC	5.2	35.72	1.9
High compacted waste	HC	10.3	35.72	3.7
High compacted waste without plastic	HC-w/p	10.3	33.46	3.4
Pre treated waste[a]	PT	15.3	30.36	4.7
Pre treat waste[b]	PT	20.0	27.27	5.5
8 years old waste	OW	4.2	97.44	4.1

[a] = composted for about 2 months

[b] = composted for about 6 months

Appendix Table C5 Leachate output from Lysimeters-ml

	Week	Date	LC-100	LC-75	LC-50	LC-35	IS-LC	
Run 2 (LR and IS)	1	3/4/2007	1100	825	550	385		
	2	10/4/2007	1450	775	500	500		
	3	17/4/2007	1475	1100	665	587		
	4	23/4/2007	1050	800	450	300		
	5	30/4/2007	1100	800	530	350		
	6	5/5/2007	1175	875	575	425		
	7	15/5/2007	1065	825	540	400		
	8	21/5/2007	1075	800	540	425	19450	
	Week	Date	PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC
Run3 (LR and IS)	1	25/6/2007	1030	1020	1222	250	1000	
	2	27/6/2007	900	270	925	170	955	
	3	2/7/2007	897	175	986	239	925	
	4	9/7/2007	925	250	982	235	1035	
	5	16/7/2007	900	255	985	282	1015	
	6	23/7/2007	967	268	925	287	1035	
	7	31/7/2007	1040	300	1060	315	1085	
	8	6/8/2007	935	255	936	265	982	7700
	Day	Date	LC	HC	HC-w/p	PT	OW	
Run 1(St)	4	26/9/2007	178	151	222	109	206	
	7	29/9/2007	508	489	534	489	473	
	12	4/10/2007	939	942	955	829	876	
	19	11/10/2007	285	240	265	143	238	
	25	17/10/2007	640	678	668	578	610	
	31	23/10/2007	511	524	524	412	447	
	39	31/10/2007	1025	980	1008	799	925	
	44	5/10/2007	340	249	289	137	225	
	55	16/10/2007	160	124	166	58	116	
	61	22/10/2007	52	37	48	12	32	

Appendix Table C6 Total BOD_5 variation in lysimeter- Run 2 (LR and IS)

Week	Date	Total BOD_5													
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS			
		LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35
1	4/4/2007	13650	5700	9450	10200	9300	7903	2475	2736	2584		7903	2475	2736	2584
2	13/4/2007	13950	12600	12900	12750	8100	10646	5139	3395	4579		11005	5289	3643	4914
3	20/4/2007	16050	20100	21750	17400	8400	12460	11637	7613	5190		13186	12118	8201	5984
4	26/4/2007	15000	20250	20850	16800	9900	8289	8526	4938	2984		12184	11917	6843	5564
5	3/5/2007	21300	20850	19950	18900	10800	12332	8779	5565	2791		16423	12703	8238	5768
6	9/5/2007	13350	15450	15300	15150	7800	8256	7115	4630	2416		13693	11807	7828	5792
7	16/5/2007	15000	13200	14400	10800	7800	8408	5732	4093	2526		14372	10830	7693	6187
8	23/5/2007	11400	11400	12000	12000	7800	6450	4800	3411	2684	79847	13203	10315	7504	6818

Appendix Table C7 Soluble BOD_5 variation in lysimeters- Run 2 (LR and IS)

Week	Date	Soluble BOD_5													
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS			
		LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35
1	4/4/2007	6600	4200	6300	6000	5700	3821	1824	1824	1216		3821	1824	1824	1216
2	13/4/2007	9600	10500	10200	9300	6000	7326	4283	2684	2447		7500	4393	2850	2605
3	20/4/2007	11400	10800	10800	12000	6900	8850	6253	3780	3707		9276	6639	4214	4110
4	26/4/2007	12000	12000	17400	13800	9900	6632	5053	4121	2179		9308	7003	5209	3857
5	3/5/2007	16800	16200	16500	14700	9600	9726	6821	4603	2708		12561	9087	6332	4677
6	9/5/2007	12900	14700	15000	12900	7500	7978	6770	4539	2886		11873	9632	6703	5241
7	16/5/2007	11400	12600	13800	6000	7200	6390	5471	3922	1263		10794	8721	6480	3958
8	23/5/2007	9000	11400	12000	7200	6600	5092	4800	3411	1611	67563	10097	8447	6441	4543

Appendix Table C8 Total COD variation in lysimeters- Run 2 (LR and IS)

Week	Date	Total COD													
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS			
		LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35
1	8/4/2007	19200	24511	24576	18432	16384	11116	10643	7114	3735		11116	10643	7114	3735
2	18/4/2007	22528	26624	18432	24576	12288	17192	10860	5928	6467		17698	11505	6575	6952
3	24/4/2007	24576	20480	24576	20480	14336	19079	11857	8602	6327		20177	13202	9841	7459
4	2/5/2007	22528	22528	30720	28672	12288	12450	9485	7276	4527		18398	13795	10003	7836
5	6/5/2007	26624	28672	32768	26624	14336	15414	12072	9141	4904		21659	16975	12999	8817
6	9/5/2007	27789	30336	27808	32864	20224	17186	13971	8416	7351		25112	19930	13137	11965
7	15/5/2007	27104	32032	32032	34496	22176	15193	13909	9104	7262		24216	20666	14557	12741
8	23/5/2007	27077	32032	32032	34496	22176	15320	13487	9104	7716	227012	25770	21256	15653	14556

Appendix Table C9 Soluble COD variation in lysimeters- Run 2 (LR and IS)

Week	Date	Soluble COD													
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS			
		LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35
1	8/4/2007	13714	6816	13632	9088	11360	7940	2960	3946	1842		7940	2960	3946	1842
2	18/4/2007	18176	20448	18176	20448	11360	13871	8341	4783	5381		14232	8520	5142	5620
3	24/4/2007	22720	18176	22720	18176	11360	17638	10523	7952	5615		18477	11240	8789	6393
4	2/5/2007	21818	21760	23936	26112	10880	12057	9162	5669	4123		17381	12510	7881	6833
5	6/5/2007	19584	19584	23936	19584	13056	11338	8246	6677	3608		16949	12167	9771	6867
6	9/5/2007	17408	23936	21760	23936	13056	10765	11023	6585	5354		17613	15666	10309	9129
7	15/5/2007	22176	24640	24992	20448	9088	12430	10699	7103	4305		19965	15971	11400	8709
8	23/5/2007	22154	24640	22176	19712	12320	12534	10375	6303	4409	126118	21236	16425	11454	9621

Appendix Table C10 TKN variation in lysimeters- Run 2 (LR and IS)

Week	Date	TKN													
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS			
		LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35
1	5/4/2007	742	560	798	714	490	430	243	231	145		430	243	231	145
2	8/4/2007	882	798	1218	1050	574	673	326	321	276		693	340	342	295
3	19/4/2007	1470	980	1442	1512	546	1141	567	505	467		1184	603	558	514
4	26/4/2007	1204	1190	1680	1316	602	665	501	398	208		998	679	538	415
5	4/5/2007	1484	1456	1680	1400	588	859	613	469	258		1208	822	671	493
6	14/5/2007	1344	1484	1624	1372	546	831	683	491	307		1274	946	738	579
7	18/5/2007	1428	1232	1484	1148	560	800	535	422	242		1296	837	711	550
8	21/5/2007	1372	1204	1624	1288	504	776	507	462	288	5159	1347	847	802	641

Appendix Table C11 NH_4-N variation in lysimeters- Run 2 (LR and IS)

Week	Date	NH4-N													
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS			
		LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35
1	5/4/2007	487	353	610	532	409	282	153	177	108		282	153	177	108
2	19/4/2007	742	644	910	721	385	566	263	239	190		579	272	256	204
3	19/4/2007	658	693	973	763	322	511	401	341	236		543	427	381	269
4	26/4/2007	840	859	1223	980	383	464	362	290	155		626	488	388	269
5	4/5/2007	826	868	1078	980	462	478	365	301	181		651	515	445	315
6	14/5/2007	770	840	1022	966	420	476	387	309	216		702	568	482	377
7	18/5/2007	714	840	1022	756	406	400	365	290	159		656	568	490	345
8	22/5/2007	714	826	1022	938	420	404	348	290	210	4299	697	578	525	426

Appendix Table C12 TS variation in lysimeters – Run 2 (LR and IS)

Week	Date	TS													
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS			
		LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35
1	5/4/2007	13605	10445	13215	13150	10425	7877	4535	3825	2665		7877	4535	3825	2665
2	15/4/2007	17695	16555	18035	16405	9385	13504	6753	4746	4317		13862	7028	5094	4663
3	18/4/2007	20705	19915	23625	20895	9255	16074	11530	8269	6455		16897	12240	9091	7233
4	24/4/2007	21660	21430	26095	22725	9025	11970	9023	6180	3588		16880	12616	8433	6587
5	2/5/2007	21305	22050	23980	23420	9690	12334	9284	6689	4314		17530	13441	9903	7792
6	8/5/2007	19825	21420	21350	21945	9060	12260	9864	6461	4909		18801	14834	10306	9003
7	15/5/2007	18175	18820	21250	18605	8140	10188	8172	6039	3917		17511	13705	10446	8588
8	22/5/2007	17310	19105	20545	17890	7840	9794	8044	5839	4002	80257	18074	14171	10973	9408

Appendix Table C13 TDS variation in lysimeters – Run 2 (LR and IS)

Week	Date	TDS													
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS			
		LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35
1	5/4/2007	13,055	9,950	11,410	12,470	9,945	7558	4320	3303	2527		7558	4320	3303	2527
2	17/4/2007	13,832	12,773	13,560	11,873	7,293	10556	5210	3568	3125		10900	5472	3869	3453
3	19/4/2007	15,847	15,200	19,747	16,440	7,507	12302	8800	6911	5079		13010	9398	7568	5720
4	24/4/2007	17507	17620	21367	18760	6900	9675	7419	5061	2962		13510	10217	6913	5351
5	2/5/2007	16013	17147	17220	17500	7160	9271	7220	4803	3224		13336	10481	7443	6007
6	8/5/2007	16547	18247	17320	17280	7240	10233	8403	5242	3865		15310	12296	8334	7109
7	15/5/2007	15447	17000	17473	15540	7340	8658	7382	4966	3272		14388	11755	8515	6970
8	22/5/2007	14560	15893	16173	13487	6107	8238	6692	4597	3017	62513	14781	11602	8743	7329

Appendix Table C14 SS variation in lysimeters – Run 2 (LR and IS)

Week	Date	SS													
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS			
		LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35	IS-LC	LC-100	LC-75	LC-50	LC-35
1	5/4/2007	655	625	1165	735	505	379	271	337	149		379	271	337	149
2	17/4/2007	1387	833	1360	1360	713	1059	340	358	358		1076	356	389	377
3	19/4/2007	1433	1227	887	1253	613	1113	710	310	387		1166	749	377	442
4	24/4/2007	1167	707	1100	900	627	645	298	261	142		981	513	381	330
5	2/5/2007	1060	780	1367	1340	627	614	328	381	247		966	563	542	454
6	8/5/2007	600	480	760	1,100	520	371	221	230	246		790	484	427	489
7	15/5/2007	813	647	1,147	1,067	580	456	281	326	225		899	557	543	496
8	22/5/2007	607	520	1,000	1,053	433	343	219	284	236	4436	829	515	540	549

Appendix Table C15 Total BOD_5 variation in lysimeters – Run 3 (LR and IS)

Week	Date	Total BOD_5																
		Concentration- mg/L						Sp. Load-mg/Kg of TS						Cumulative sp. load-mg/Kg of TS				
		PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p
1	27/6/2007	75	72	20400	31800	12600	10800	16.4	15.6	6738	2149	3706		16.4	15.6	6738	2149	3706
2	2/7/2007	69	69	29400	34800	18600	15000	13.2	4.0	7350	1599	5224		14.1	13.7	8023	2072	5447
3	5/7/2007	54	66	27600	36000	18600	15000	10.3	2.5	7355	2325	5060		12.1	13.1	8504	3362	5611
4	9/7/2007	36	57	26400	33000	16800	15000	7.1	3.0	7007	2096	5114		9.6	14.5	8604	3717	5993
5	16/7/2007	27	60	27600	37800	22200	18000	5.2	3.3	7348	2881	6627		8.6	16.2	9373	5037	7803
6	23/7/2007	24	56	25800	37500	21000	14400	4.9	3.2	6450	2909	6393		9.0	17.5	8923	5678	7960
7	31/7/2007	21	41	24000	34000	21000	15000	4.6	2.6	6876	2895	6701		9.5	18.8	9767	6272	8639
8	6/8/2007	17	33	22200	37000	18000	18000	3.3	1.8	5616	2650	5199	37459	8.8	19.4	8896	6578	7507

Appendix Table C16 Soluble BOD_5 variation in lysimeters– Run 3 (LR and IS)

Week	Date	Soluble BOD_5 Concentration- mg/L PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	Sp. Load-mg/Kg of TS PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	Cumulative sp. load-mg/Kg of TS PT-100	PT-35	HC-100	HC-35	HC-w/p
1	27/6/2007	66	66	19800	31200	12000	10500	14.5	14.3	6539	2108	3529		14.5	14.3	6539	2108	3529
2	2/7/2007	57	60	27000	34200	18000	11700	10.9	3.4	6750	1571	5056		11.8	12.4	7403	2035	5268
3	5/7/2007	45	57	23400	35400	18000	14400	8.6	2.1	6236	2287	4897		10.2	11.8	7326	3305	5426
4	9/7/2007	27	51	23400	32400	16200	12600	5.3	2.7	6210	2058	4931		7.5	13.1	7681	3650	5779
5	16/7/2007	21	36	22200	34800	18600	12600	4.0	2.0	5910	2652	5553		6.9	13.7	7760	4770	6686
6	23/7/2007	15	38	21000	34500	19800	12600	3.1	2.1	5250	2676	6027		6.4	14.7	7460	5358	7489
7	31/7/2007	14	29	21600	33000	20400	12600	3.0	1.8	6188	2809	6510		6.8	15.7	8738	6051	8321
8	6/8/2007	8	24	21600	36000	17400	11400	1.5	1.3	5464	2578	5026	23724	5.8	16.1	8365	6355	7196

Appendix Table C17 Total COD variation in lysimeters– Run 3 (LR and IS)

Week	Date	Total COD																
		Concentration- mg/L						Sp. Load-mg/Kg of TS						Cumulative sp. load-mg/Kg of TS				
		PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p
1	28/6/2007	2816	2816	50688	70400	36608	30976	617	611	16741	4757	10767		617	611	16741	4757	10767
2	30/6/2007	2816	3520	53504	73216	33792	30976	539	202	13376	3364	9492		575	583	15047	4410	10138
3	3/7/2007	3529	2194	54912	67584	39424	28160	674	82	14633	4366	10726		745	507	17172	6599	11968
4	11/7/2007	1646	1097	53486	78171	43886	24686	324	58	14195	4965	13359		441	512	17625	8295	15297
5	18/7/2007	519	1555	62208	77760	42768	25920	99	84	16561	5927	12768		258	566	20858	10524	15480
6	24/7/2007	1038	2074	62208	77760	38880	20736	214	118	15552	6032	11836		385	636	20858	11890	15303
7	1/8/2007	2021	2022	50560	75840	34128	25280	447	129	14485	6457	10891		654	717	20799	13576	15044
8	7/8/2007	1516	2022	45504	75840	34128	25280	302	110	11511	5432	9857	52610	577	767	18645	13781	14613

Appendix Table C18 Soluble COD variation in lysimeters– Run 3 (LR and IS)

Week	Date	Soluble COD																
		Concentration- mg/L						Sp. Load-mg/Kg of TS						Cumulative sp. load-mg/Kg of TS				
		PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p
1	28/6/2007	2816	2112	45056	67584	33792	22528	617	458	14881	4566	9939		617	458	14881	4566	9939
2	30/6/2007	2816	2112	45056	64768	33792	22528	539	121	11264	2976	9492		575	407	12750	3980	10088
3	3/7/2007	2824	1408	42240	63360	36608	22528	539	52	11256	4093	9960		611	365	13473	6148	11152
4	11/7/2007	1097	549	49371	74057	38400	21943	216	29	13103	4704	11689		324	359	16005	7786	13528
5	18/7/2007	519	1037	46656	72576	38880	23328	99	56	12421	5531	11607		235	401	16122	9815	14123
6	24/7/2007	519	1037	41472	72576	31104	18144	107	59	10368	5630	9468		255	428	14826	11090	12671
7	1/8/2007	1011	1517	40448	65728	30336	20224	224	97	11588	5596	9681		389	501	16719	12233	13432
8	7/8/2007	1011	1517	40448	70784	30336	22752	201	82	10232	5070	8762	47349	401	538	16019	12773	13048

Appendix Table C19 TKN variation in lysimeters– Run 3 (LR and IS)

Week	Date	TKN																
		Concentration- mg/L						Sp. Load-mg/Kg of TS						Cumulative sp. load-mg/Kg of TS				
		PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p
1	26/6/2007	252	196	4060	4032	1960	1512	55.2	42.5	1341	272	576		55	43	1341	272	576
2	29/6/2007	289	271	3584	3696	2464	1736	55.4	15.5	896	170	692		59	42	1030	230	727
3	4/7/2007	373	401	4032	3920	2464	1456	71.3	14.9	1074	253	670		78	45	1266	373	748
4	10/7/2007	416	400	3696	4480	2464	1400	81.9	21.3	981	285	750		94	56	1238	468	872
5	20/7/2007	456	432	2800	4144	2464	1400	87.3	23.4	745	316	736		110	69	1063	572	901
6	24/7/2007	456	544	1568	3024	2016	1428	93.8	31.0	392	235	614		127	86	755	558	822
7	2/8/2007	456	536	1792	2800	1568	1120	100.9	34.2	513	238	500		149	108	902	611	744
8	7/8/2007	40	488	1792	2688	1512	1120	8.0	26.5	453	193	437	2331	72	119	871	610	708

Appendix Table C20 NH_4-N variation in lysimeters– Run 3 (LR and IS)

Week	Date	NH_4-N																
		Concentration- mg/L						Sp. Load-mg/Kg of TS						Cumulative sp. load-mg/Kg of TS				
		PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p
1	26/6/2007	56	70	2086	2450	1274	924	12.3	15.2	689	166	375		12	15	689	166	375
2	29/6/2007	162	157	1792	2240	1400	980	31.1	9.0	448	103	393		32	18	517	139	416
3	4/7/2007	174	207	2184	2576	1848	980	33.1	7.7	582	166	503		36	19	680	239	550
4	10/7/2007	185	280	2072	2576	1568	980	36.4	14.9	550	164	477		41	29	683	278	557
5	20/7/2007	174	308	1792	2296	1400	994	33.2	16.7	477	175	418		43	38	644	331	525
6	24/7/2007	179	364	1512	2296	1400	1008	36.9	20.8	378	178	426		51	49	574	372	558
7	2/8/2007	73	403	1680	2352	1316	1106	16.1	25.7	481	200	420		36	67	702	431	577
8	7/8/2007	22	420	1736	2520	1372	1106	4.5	22.8	439	180	396	2302	27	77	687	449	576

Appendix Table C21 TS variation in lysimeters– Run 3 (LR and IS)

Week	Date	TS																	
		Concentration- mg/L						Sp. Load-mg/Kg of TS						Cumulative sp. load-mg/Kg of TS					
		PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p	
1	25/6/2007	7510	7180	44875	54345	27830	20220	1646	1558	14821	3672	8185		1646	1558	14821	3672	8185	
2	28/6/2007	7750	6955	36540	54785	28435	18650	1484	400	9135	2517	7987		1580	1370	10615	3325	8478	
3	3/7/2007	6605	6880	37205	54705	29940	18875	1261	256	9915	3534	8145		1455	1315	11987	5230	9138	
4	10/7/2007	6326	6755	33410	48300	28435	18905	1245	359	8867	3068	8656		1524	1506	11543	5651	10177	
5	17/7/2007	5810	6815	32980	51845	27885	18285	1113	370	8780	3951	8324		1553	1689	11997	7318	10348	
6	24/7/2007	5715	6675	30880	49940	25715	18300	1176	381	7720	3874	7828		1752	1859	11472	8081	10343	
7	1/8/2007	5725	6995	31865	50545	28495	20065	1267	446	9129	4303	9093		2038	2152	13382	9320	12062	
8	6/8/2007	5355	6365	29400	49265	26660	18450	1065	345	7437	3528	7700	38396	2031	2289	12207	9365	11172	

Appendix Table C22 TDS variation in lysimeters– Run 3 (LR and IS)

Week	Date	TDS																	
		Concentration- mg/L						Sp. Load-mg/Kg of TS						Cumulative sp. load-mg/Kg of TS					
		PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p
1	26/6/2007	6,587	6,440	32,560	38,500	25,107	18627	1443	1398	10754	2601	7384		1443	1398	10754	2601	7384
2	27/6/2007	6,233	5,880	32,793	40,360	26,387	16633	1194	338	8198	1854	7412		1278	1208	9272	2427	7855
3	2/7/2007	5,527	5,907	31,793	40,030	25,740	16373	1055	220	8472	2586	7003		1218	1165	10078	3813	7912
4	9/7/2007	5547	6320	27540	40420	24733	16793	1092	336	7309	2567	7529		1326	1357	9430	4443	8892
5	16/7/2007	5607	6700	34080	52007	29369	18867	1074	364	9073	3964	8768		1449	1545	11640	6495	10567
6	23/7/2007	4733	5473	30113	45133	24620	17280	974	312	7528	3501	7495		1481	1651	10649	6876	9812
7	31/7/2007	5433	6373	28780	40353	24740	16773	1202	407	8245	3435	7895		1870	1932	11854	7542	10647
8	7/8/2007	5547	6453	29447	41050	24233	18027	1103	350	7449	2940	6999	37515	1957	2092	11524	7701	10188

Appendix Table C23 SS variation in lysimeters– Run 3 (LR and IS)

Week	Date	SS																
		Concentration- mg/L						Sp. Load-mg/Kg of TS						Cumulative sp. load-mg/Kg of TS				
		PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p	IS-HC	PT-100	PT-35	HC-100	HC-35	HC-w/p
1	26/6/2007	607	427	3230	4350	1540	1673	133	93	1067	294	453		133	93	1067	294	453
2	27/6/2007	273	160	1587	2660	900	1207	52	9	397	122	253		60	67	503	187	280
3	2/7/2007	300	407	960	2730	940	707	57	15	256	176	256		68	75	388	284	299
4	9/7/2007	247	267	1093	1807	800	533	49	14	290	115	244		64	79	438	267	303
5	16/7/2007	273	247	1107	1947	660	487	52	13	295	148	197		74	85	460	330	271
6	23/7/2007	187	260	1173	2167	800	653	38	15	293	168	244		66	92	477	381	329
7	31/7/2007	207	293	947	1813	700	540	46	19	271	154	223		80	105	474	402	323
8	7/8/2007	187	213	913	2200	907	607	37	12	231	158	262	1263	78	108	449	435	374

Appendix Table C24 Total BOD_5 variation in lysimeters– Run 1 (St)

Day	Date	Total BOD_5														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
4	26/9/2007	12600	22800	18600	14	32	1180	930	1214	0.29	1.63	1180	930	1214	0.29	1.63
7	1/10/2007	11100	18000	19800	6	19	2968	2379	3110	0.53	2.22	4148	3309	4324	0.82	3.84
12	5/10/2007	5000	12000	13500	8	9	2471	3055	3792	1.18	1.92	6619	6365	8116	1.99	5.77
19	11/10/2007	7200	19000	17000	8	10	1080	1232	1325	0.20	0.59	7699	7597	9441	2.19	6.36
25	17/10/2007	4000	11000	10000	7	6	1347	2016	1965	0.69	0.85	9047	9613	11406	2.88	7.21
31	23/10/2007	1800	4500	3900	1	2	484	637	601	0.09	0.16	9531	10250	12007	2.97	7.37
39	31/10/2007	1800	6750	5775	2	2	971	1788	1712	0.33	0.50	10502	12038	13719	3.31	7.87
44	5/11/2007	2200	9750	6300			394	656	536			10895	12694	14255	3.31	7.87
55	16/11/2007	1800	8700	5850	1	0	152	292	286	0.01	0.00	11047	12986	14540	3.32	7.87
61	24/11/2007	2250	12000	8250			62	120	116			11109	13106	14657	3.32	7.87

Appendix Table C25 Soluble BOD_5 variation in lysimeters– Run 1 (St)

		Soluble BOD_5														
Day	Date	Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
4	26/9/2007	10800	21000	16200	14	23	1012	857	1058	0.27	1.15	1012	857	1058	0.27	1.15
7	1/10/2007	8700	16800	16800	5	11	2326	2220	2639	0.43	1.25	3338	3077	3696	0.70	2.39
12	5/10/2007	4800	10000	11000	4.2	7.8	2372	2546	3090	0.63	1.67	5710	5623	6786	1.33	4.06
19	11/10/2007	7000	16500	16000	6.6	7.2	1050	1070	1247	0.17	0.42	6760	6694	8033	1.50	4.48
25	17/10/2007	3400	7500	8000	4.5	3.3	1145	1374	1572	0.47	0.49	7905	8068	9605	1.98	4.97
31	23/10/2007	1400	3900	3300	0.9	0.3	377	552	509	0.07	0.03	8282	8620	10113	2.05	5.00
39	31/10/2007	1450	6300	3975	1.2	1.8	782	1669	1178	0.17	0.41	9064	10289	11292	2.22	5.41
44	5/11/2007	1800	6000	5600			322	404	476			9386	10693	11768	2.22	5.41
55	16/11/2007	1500	6600	4950			126	221	242			9513	10914	12010	2.22	5.41
61	24/11/2007	1950	11000	8250			53	110	116			9566	11024	12126	2.22	5.41

Appendix Table C26 Total COD variation in lysimeters– Run 1 (St)

Day	Date	Total COD														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
1	24/9/2007	19200	32000	28800	480	480	1051	2612	2033	20	8	1051	2612	2033	20	8
2	24/9/2007	19200	51200	43200	320	640	303	720	1271	52	4	1354	3331	3304	73	12
3	28/9/2007	22400	44800	24000	320	800	1049	993	1489	5	13	2403	4324	4793	78	25
4	28/9/2007	22400	38400	48000	480	160	2099	1567	3134	10	8	4502	5891	7927	88	33
5	28/9/2007	16000	57600	48000	480	480	707	1681	2781	10	5	5209	7573	10708	97	37
6	28/9/2007	22400	32000	48000	160	640	5187	3338	7087	9	55	10397	10911	17795	106	92
7	3/10/2007	22400	38400	38400	240	480	5989	5075	6031	21	55	16386	15986	23826	127	148
8	3/10/2007	22400	38400	38400	160	480	1096	996	1457	4	6	17482	16982	25283	131	153
9	3/10/2007	19200	38400	33600	400	400	4861	5635	5020	27	37	22343	22618	30304	158	191
10	3/10/2007	22400	38400	33600	240	480	3183	2646	2797	10	24	25526	25264	33100	168	215
11	3/10/2007	22400	32000	33600	240	480	1238	1211	1482	6	8	26764	26475	34583	174	223
12	10/10/2007	8727	29120	30576	146	131	4313	7414	8588	22	28	31077	33889	43171	196	251
13	10/10/2007	8736	29120	21840	146	175	2694	4549	4040	15	24	33771	38438	47211	211	275
14	10/10/2007	5824	29120	21840	218	131	1962	5179	4400	25	19	35733	43617	51611	235	295
15	10/10/2007	14560	40768	17472	146	175	1257	1653	1028	5	5	36990	45269	52639	240	300
16	10/10/2007	5824	34944	26208	218	131	343	1332	956	5	2	37333	46601	53595	245	302

Appendix Table C26 Total COD variation in lysimeters– Run 1 (St) (Continued)

Day	Date	Total COD														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
17	10/10/2007	8736	40768	26208	73	175	446	1025	162	1	2	37779	47626	53757	247	304
18	10/10/2007	8736	34944	26208	218	175	639	973	1742	3	3	38418	48599	55499	249	307
19	15/10/2007	18353	50688	42240	338	253	2753	3288	3292	9	15	41171	51886	58791	258	322
20	15/10/2007	16896	50688	33792	338	338	1334	1904	1759	8	10	42505	53791	60550	266	331
21	15/10/2007	8448	56320	25344	338	296	3023	10549	5203	36	44	45529	64339	65753	302	375
22	16/10/2007	7273	23296	21840	116	131	1106	1517	1933	5	8	46635	65857	67687	307	383
23	16/10/2007	8736	23296	17472	116	131	607	819	822	4	3	47242	66675	68509	310	386
24	16/10/2007	8736	23296	17472	58	131	1113	1240	1336	2	6	48354	67916	69845	312	392
25	19/10/2007	4966	19776	19776	132	49	1673	3624	3885	14	7	50027	71539	73730	326	399
26	19/10/2007	6592	19776	9888	132	99	725	882	614	5	4	50752	72421	74344	330	403
27	22/10/2007	3200	32000	24000	96	96	805	4394	3388	7	10	51557	76815	77732	337	413
28	22/10/2007	3200	32000	19200	144	48	216	891	751	4	1	51773	77706	78483	341	414
29	22/10/2007	11200	19200	19200	48	96	1008	893	1028	1	3	52781	78598	79511	342	417
30	22/10/2007	4800	25600	14400	96	96	884	2297	1423	4	7	53665	80895	80934	346	424
31	25/10/2007	4800	12800	19200	240	144	1291	1813	2959	18	16	54956	82708	83893	364	440

Appendix Table C26 Total COD variation in lysimeters– Run 1 (St) (Continued)

Day	Date	Total COD														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
32	25/10/2007	8000	32000	4800	288	144	998	1842	333	9	7	55954	84550	84226	373	447
33	25/10/2007	9600	38400	28800	288	144	803	2034	1711	8	4	56757	86584	85938	381	450
34	30/10/2007	1455	17472	4368	87	87	74	656	113	1	1	56831	87241	86051	383	452
35	30/10/2007	1456	11648	13104	44	44	31	186	243	0	0	56862	87426	86293	383	452
36	30/10/2007	4368	5824	4368	131	44	290	145	108	1	0	57152	87571	86401	384	452
37	30/10/2007	2912	5824	13104	175	44	238	271	586	2	1	57389	87842	86987	386	453
38	30/10/2007	5824	11648	13104	87	87	319	293	366	1	1	57708	88135	87353	387	454
39	7/11/2007	3200	14400	6400	176	112	1726	3814	1897	26	25	59434	91949	89251	413	479
40	7/11/2007	1600	9600	3200	208	144	88	125	102	4	3	59522	92073	89352	417	482
41	7/11/2007	6400	14400	25600	208	112	357	362	700	3	2	59879	92435	90053	420	484
42	7/11/2007	16000	24000	12800	208	128	800	798	418	2	2	60679	93233	90470	422	486
43	7/11/2007	16000	19200	22400	176	96	682	540	501	2	1	61361	93773	90971	424	487
44	10/11/2007	6194	13968	12416	155	109	1108	940	1055	4	6	62469	94713	92026	428	493
45	10/11/2007	4656	9312	12416	155	109	980	881	1479	8	9	63450	95594	93505	436	502
46	10/11/2007	1552	18624	9312	124	109	132	820	375	3	3	63581	96414	93881	439	505

Appendix Table C26 Total COD variation in lysimeters– Run 1 (St) (Continued)

Day	Date	Total COD														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
47	10/11/2007	3104	9312	15520	124	78	261	357	634	2	2	63843	96771	94515	441	507
48	10/11/2007	3104	9312	9312	217	78	234	322	359	3	2	64076	97094	94874	445	509
49	13/11/2007	1500	13536	12032	241	90	118	541	428	4	2	64195	97635	95302	448	510
50	13/11/2007	1504	18048	9024	211	75	71	468	220	2	1	64266	98103	95522	450	511
51	13/11/2007	3310	16480	14832	180	135	94	258	244	1	1	64360	98362	95767	452	513
52	15/11/2007	3310	13184	12360	231	99	94	228	211	1	1	64454	98590	95978	452	513
53	15/11/2007	3296	16480	12360	198	115	137	218	153	1	1	64591	98808	96130	453	514
54	15/11/2007	3296	16480	12360	165	115	156	361	287	1	1	64747	99169	96417	454	515
55	24/11/2007	4138	19776	12360	264	132	348	663	603	3	4	65096	99831	97021	457	518
56	24/11/2007	2472	9888	9888	165	115	232	524	497	2	4	65327	100355	97518	460	522
57	27/11/2007	2400	16000	9600	160	96	105	432	291	2	2	65432	100788	97809	462	524
58	27/11/2007	5600	12800	9600	160		115	149	161	1	0	65547	100936	97970	463	524
59	27/11/2007	3200	16000	7200		112	93	156	89	0	1	65640	101092	98059	463	525
60	30/11/2007	3750	18048	9024	120		75	83	8	0	0	65715	101175	98067	463	525
61	30/11/2007	4512	15040	15792	180	120	123	150	223	0	1	65838	101325	98290	464	526

Appendix Table C27 Soluble COD variation in lysimeters– Run 1 (St)

Day	Date	Soluble COD														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
4	28/9/2007	19200	32000	38400	320	160	1799	1306	2507	6.34	8.04	1799	1306	2507	6.34	8.04
7	3/10/2007	19200	32000	33600	160	400	5133	4229	5277	14.23	46.15	6932	5535	7784	20.57	54.19
12	10/10/2007	5818	11648	17472	73	87	2875	2966	4908	10.97	18.67	9808	8501	12692	31.54	72.85
19	15/10/2007	12706	39424	38016	282	211	1906	2557	2963	7.32	12.26	11713	11058	15655	38.86	85.11
25	19/10/2007	3310	13184	14832	66	49	1115	2416	2914	6.93	7.36	12829	13474	18569	45.79	92.47
31	25/10/2007	3200	6400	14400	144	96	861	906	2219	10.79	10.47	13689	14380	20788	56.58	102.93
39	7/11/2007	1600	9600	6400	160	96	863	2543	1897	23.24	21.66	14552	16923	22686	79.82	124.59
44	10/11/2007	4645	9312	9312	93	78	831	627	792	2.32	4.26	15384	17550	23477	82.14	128.85
55	24/11/2007	2483	13184	9888	132	115	209	442	483	1.39	3.26	15593	17991	23960	83.53	132.11
61	30/11/2007	4500	12032	13536		75	123	120	191		0.59	15716	18112	24151	83.53	132.70

Appendix Table C28 TKN variation in lysimeters– Run 1 (St)

Day	Date	TKN														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
4	27/9/2007	1148	1568	1512	64	40	108	64	99	1.27	2.01	108	64	99	1.27	2.01
7	30/9/2007	840	1540	1288	10	20	225	204	202	0.87	2.26	332	268	301	2.14	4.27
12	5/10/2007	551	1157	1064	8	11	272	295	299	1.27	2.39	604	562	600	3.41	6.66
19	12/10/2007	553	1400	1232	11	11	83	91	96	0.28	0.67	687	653	696	3.69	7.33
25	18/10/2007	287	1064	630	10	8	97	195	124	1.00	1.22	784	848	820	4.69	8.55
31	24/10/2007	280	1050	518	6	6	75	149	80	0.45	0.66	859	997	900	5.14	9.20
39	5/11/2007	144	770	343	7	4	77	204	102	1.06	0.91	937	1201	1001	6.20	10.11
44	7/11/2007	162	952	381	5.6	2.2	29	64	32	0.14	0.12	966	1265	1034	6.34	10.23
55	27/11/2007	165	896	398	4.5	4.0	14	30	19	0.05	0.11	980	1295	1053	6.39	10.35
61	29/11/2007	199	875	459	0	3.6	5	9	6	0.00	0.03	985	1303	1059	6.39	10.38

Appendix Table C29 NH_4-N variation in lysimeters– Run 1 (St)

Day	Date	NH_4-N														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
4	27/9/2007	812	1344	1120	17	11	76	55	73	0.33	0.56	76	55	73	0.33	0.56
7	30/9/2007	602	1288	1148	6.7	5.6	161	170	180	0.60	0.65	237	225	253	0.93	1.21
12	5/10/2007	392	933	747	0.5	0.9	194	238	210	0.07	0.20	431	463	463	1.00	1.41
19	12/10/2007	434	1204	966	0.8	2.0	65	78	75	0.02	0.12	496	541	538	1.02	1.52
25	18/10/2007	203	868	420	0	0.7	68	159	83	0.00	0.10	564	700	621	1.02	1.63
31	24/10/2007	154	854	350	0	0.56	41	121	54	0.00	0.06	606	821	675	1.02	1.69
39	5/11/2007	102	644	252	0.78	0.56	55	171	75	0.11	0.13	660	991	750	1.14	1.82
44	7/11/2007	115	818	297	0.00	0.34	21	55	25	0.00	0.02	681	1046	775	1.14	1.83
55	27/11/2007	123	801	319	0.28	0.78	10	27	16	0.00	0.02	691	1073	790	1.14	1.86
61	29/11/2007	176	826	347	0	0.60	5	8	5	0.00	0.00	696	1081	795	1.14	1.86

Appendix Table C30 TS variation in lysimeters– Run 1 (St)

Day	Date	TS														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
4	27/9/2007	14800	21595	22020	6660	1533	1387	881	1438	132	77	1387	881	1438	132	77
7	30/9/2007	11755	21765	20430	1835	4995	3143	2877	3209	163	576	4529	3758	4646	295	653
12	5/10/2007	8744	14848	14652	2000	2480	4321	3780	4115	301	530	8851	7538	8762	597	1183
19	12/10/2007	12768	20980	20212	2253	2210	1915	1361	1575	59	128	10766	8899	10337	655	1311
25	18/10/2007	5704	12884	10612	3088	1000	1921	2361	2085	325	149	12687	11260	12422	980	1460
31	24/10/2007	4163	10157	9307	3817	940	1120	1438	1434	286	102	13807	12698	13857	1266	1563
39	1/11/2007	3200	6760	6627	4017	763	1726	1790	1965	584	172	15533	14489	15821	1849	1735
44	6/11/2007	3947	10040	9417	4424	1052	706	676	800	110	58	16240	15164	16622	1959	1793
55	18/11/2007	4777	12953	11980	5390	1130	402	434	585	57	32	16642	15598	17207	2016	1825
61	24/11/2007	4115	8870	9247	4860	1087	113	89	131	11	8	16755	15687	17337	2027	1833

Appendix Table C31 TDS variation in lysimeters– Run 1 (St)

Day	Date	TDS														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
4	26/9/2007	17955	27635	26695	6347	1633	1682	1128	1743	126	82	1682	1128	1743	126	82
7	30/9/2007	11945	20440	19010	1870	4370	3194	2701	2986	166	504	4876	3829	4729	292	586
12	4/10/2007	8140	12225	12780	1943	2317	4023	3112	3590	293	495	8899	6942	8318	585	1081
19	11/10/2007	8650	14175	14890	1923	1797	1298	919	1161	50	104	10196	7861	9479	635	1185
25	17/10/2007	6725	12380	11500	2993	1027	2265	2269	2259	315	153	12461	10130	11738	950	1338
31	23/10/2007	4376	10124	9656	3963	990	1177	1434	1488	297	108	13638	11563	13227	1246	1446
39	31/10/2007	3610	8067	6220	4487	873	1948	2137	1844	652	197	15586	13700	15071	1898	1643
44	5/11/2007	3720	8993	7527	4148	896	666	605	640	103	49	16252	14305	15710	2002	1692
55	16/11/2007	3953	10833	7382	5065	1065	333	363	360	53	30	16584	14668	16071	2055	1723
61	24/11/2007	3795	8595	8427	4660	1023	104	86	119	10	8	16688	14754	16190	2065	1730

Appendix Table C32 SS variation in lysimeters– Run 1 (St)

Day	Date	SS														
		Concentration- mg/L					Sp. Load-mg/Kg of TS					Cumulative sp. load-mg/Kg of TS				
		LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW	LC	HC	HC-w/p	PT	OW
4	26/9/2007	490	830	620	220	227	46	34	40	4.36	11.39	46	34	40	4.4	11.4
7	30/9/2007	515	630	850	45	225	138	83	133	4.00	25.96	184	117	174	8.4	37.3
12	4/10/2007	390	430	395	13	43	193	109	111	2.01	9.26	376	227	285	10.4	46.6
19	11/10/2007	405	285	325	27	40	61	18	25	0.69	2.32	437	245	310	11.1	48.9
25	17/10/2007	355	265	535	33	13	120	49	105	3.50	1.98	557	294	415	14.6	50.9
31	23/10/2007	284	152	532	97	17	76	22	82	7.24	1.82	633	315	497	21.8	52.7
39	31/10/2007	250	170	784	90	30	135	45	232	13.07	6.77	768	360	730	34.9	59.5
44	5/11/2007	360	213	1053	204	36	64	14	90	5.08	1.98	832	375	819	40.0	61.5
55	16/11/2007	277	310	1600	325	65	23	10	78	3.43	1.84	856	385	897	43.4	63.3
61	24/11/2007	320	275	820	200	63	9	3	12	0.44	0.49	864	388	909	43.8	63.8

Appendix Table C33 Carbon balance

Storm (St)				Leachate recirculation(LR)				Internal storage(IS)			
Lysimeter	sp. C(kg)-solid waste	sp. TOC (kg)-leachate	% leach	Lysimeter	sp. C(kg)-solid waste	sp. TOC (kg)-leachate	% leach	Lysimeter	sp. C(kg)-solid waste	sp. TOC (kg)-leachate	% leach
St_{C1}	0.483	0.045	9.3	LR_{C1}-100	0.483	0.0091	1.87	IS_{C1}	0.4832	0.134	27.78
St_{C2}	0.483	0.047	9.6	LR_{C1}-75	0.483	0.0080	1.65	IS_{C2}	0.4832	0.021	4.44
St_{P2}	0.399	0.054	13.5	LR_{C1}-50	0.483	0.0054	1.11				
St_{S2}	0.270	0.00023	0.09	LR_{C1}-35	0.483	0.0046	0.94				
St_{S3}	0.169	0.00024	0.14	LR_{S1}-100	0.298	0.0001	0.04				
				LR_{S1}-35	0.298	0.00004	0.01				
				LR_{C2}-100	0.483	0.0047	0.97				
				LR_{C2}-35	0.483	0.0022	0.46				
				LR_{P2}-100	0.399	0.0050	1.26				

Appendix Table C34 Nitrogen balance

Leachate recirculation(LR)				Internal storage(IS)			
Lysimeter	sp. TKN(kg) in solid waste	sp. TKN(kg) in leachate	% leach	Lysimeter	sp. TKN(kg) in solid waste	sp. TKN(kg) in leachate	% leach
LR_{C1}-100	0.0252	0.00078	3.08	IS_{C1}	0.0252	0.0052	20.47
LR_{C1}-75	0.0252	0.00051	2.01	IS_{C2}	0.0252	0.0023	9.25
LR_{C1}-50	0.0252	0.00046	1.83				
LR_{C1}-35	0.0252	0.00029	1.14				
LR_{S1}-100	0.0343	0.00001	0.02				
LR_{S1}-35	0.0343	0.00003	0.08				
LR_{C2}-100	0.0252	0.00045	1.80				
LR_{C2}-35	0.0252	0.00019	0.76				
LR_{P2}-100	0.0172	0.00044	2.54				

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