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School of Civil Engineering, Surveying and Construction

DENITRIFICATION OF LEACHATE USING DOMESTIC WASTE AT DIFFERENT LEVELS OF STABILITY: SIMULATIONS IN BATCH TEST

Nathaniel .O. Sawyerr

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Supervisor: Professor C Trois

SUPERVISOR AGREEMENT

As the candidate"s Supervisor I have approved this dissertation for submission.

……..……………………………. ……………………………

Prof. Cristina Trois Date

Research Supervisor

DECLARATION

I... declare that

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(ii) This dissertation has not been submitted for any degree or examination at any other university.

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Date Signature

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ABSTRACT

Disposing of waste on land has been a method practiced by many countries because it is relatively inexpensive. This has led to the fast increase of landfilling option which is also due to increase of waste generation, resulting in the increase in the urgency of investigating cheap measures of treating wastewater (leachate) that is generated from landfills prior to its discharge to the environment. After the application of the process of nitrification using Sequencing Batch Reactor (SBR) such as is applied at Mariannhill landfill site, Durban, the treated leachate still contains high level of nitrate ranging from 500 – 2000 mg/ℓ, which greatly exceeds the discharge limit of 12 mg/ℓ. Ex-situ bio-denitrification has been used widely around the world in various technological applications (SBRs, anaerobic trickling filters, etc.) that generally employ expensive chemicals. Hence the need to investigate the removal of nitrates using in-situ bio-denitrification processes using readily available carbon sources such as fresh commercial garden refuse (CGR_{raw}) and composted commercial garden refuse (CGR_{10}). Both carbon sources were mixed with waste that had been treated for 8 weeks (Cell 1) and 16 weeks (Cell 2).

The aim of this study is to determine the viability of pre-treated general waste at different degrees of stability (carbon contents) as carbon sources for in-situ bio-denitrification in landfills. The focus was mainly on determining the suitability, the kinetics and the performance of the different substrate.

The suitability of the substrates to perform denitrification was assessed based on the carbon content and carbon to nitrogen ratio in the substrate. On establishing suitability, the kinetic rate of denitrification was assessed for each substrate. The kinetics analysis was based on the time taken for full denitrification to occur and the concentration of the byproducts of the denitrification process such as Ammonia.

Characterization tests were performed to determine the suitability of the substrates to be used as carbon sources for denitrification. In situ denitrification processes were simulated at smaller scale in the laboratory using anaerobic batch reactors, with biologically treated leachate and seeded Treated leachate from the Sequencing Batch Reactor. Batch tests were conducted at a nitrate concentration level of 500 mg/ℓ.

The combination of 8 weeks treated waste with Fresh Commercial Garden Refuse (Cell 1 + CGR_{raw}) and with Commercial Garden Refuse (Cell 1 + CGR_{10}), respectively, provided the

most suitable substrates for denitrification as they contained the highest carbon content as well as relatively high carbon to nitrogen ratio (C:N) . Although the 16 weeks treated waste together mixed with Commercial Garden Refuse (Cell 2 + CGR_{10}) had the lowest C:N ratio, this could be due to a lack of homogeneity within the sample. The results of the batch tests confirms that 8 weeks treated waste (Cell 1) and 16 weeks treated waste (Cell 2) substrates were both too stable and contained too little carbon to attain full denitrification. In addition to the inability to attain full denitrification, Cell 2 leached out nitrate of approximately 500 mg/ℓ NO_3-N back into the batch. The batch test results showed that the cells substrates augmented with CGR_{raw} and CGR_{10} achieved positive results as full denitrification was achieved within a maximum of 7 days for Cell 1 and 14 days for Cell 2.

LIST OF ACRONYMS

Ammonia	NH_3
Biochemical Oxygen Demand	BOD_5
Carbon to Nitrogen Raito	C/N
Chemical Oxygen Demand	COD
Composted Commercial Garden Refuse	CGR_{10}
Fresh Commercial Garden Refuse	CGR_{raw}
Liquid to Solid Ratio	L/S
Moisture Content	MC
Nitrates	NO_3
Nitrites	NO_2
Oxides of Nitrogen	NO_x
Respiration Index	RI_7
Sequencing Batch Reactor	SBR
Total Carbon	Tot C
Total Nitrogen	Tot N
Total Solids	TS
Volatile Solids	VS
8 weeks Treated Waste (Fines)	Cell 1
16 weeks Treated Waste (Fines)	Cell 2

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1. INTRODUCTION

1.1. Motivation

Land filling is the most common way of disposing waste in many countries because it is relatively inexpensive and in the same situation the only available method of disposing waste (Stegmann, 1995). As a result the option of landfilling is increasing fast due to the increasing generation of waste, hence the need to treat the wastewater (leachate) that is generated from landfills before it is discharged back into the environment in order to protect the environment for future generations (Strachan, 2000).

In two of the largest solid waste landfills in the eThekwini Municipality (Mariannhill and Buffelsdraai) leachate is extracted and aerobically treated in sequencing batch reactors (SBR) where unsafe organic compounds which are measured as Chemical Oxygen Demand (COD) and ammonia (NH_3) are removed are within the discharge limits (DWAF, 1998). The effluent from the SBRs is then polished in aerobic wetlands before being discharged into the natural environment, or used as dust suppressant. The treated effluent, although complies with DWA requirements for COD, ammonia and various other contaminants, still displays high concentrations of nitrates ranging between 500 to 2000 mg/, which vastly exceeds the discharge limits (NO_3-N=12 mg/ℓ).

Ex-situ bio-denitrification is widely used around the world in various technological applications (SBRs, anaerobic trickling filters etc.) that generally employ expensive chemicals (such as methanol, ethanol, acetic acid etc.) or low-cost substrates (such as compost, garden refuse etc.) as carbon sources (Etchebehere et al., 2001a,b; Trois et al., 2010a,b). An interesting alternative to the ex-situ treatments is the in-situ treatment in anaerobic landfills through leachate recirculation and using the disposed waste as a carbon source.

As the methanogens actively compete with the denitrifiers in the anaerobic waste body, in-situ bio-denitrification is difficult to achieve in large landfills and available research is limited to laboratory scale studies (Tsui et al., 2007; Einola et al, 2008; Zhong et al., 2009).

The Environmental Engineering group within CESC has been working on in-situ and ex-situ bio-denitrification processes using garden refuse and solid waste as carbon sources for the past five years (Trois et al, 2010a,b) in collaboration with Durban Solid Waste, with the aim of designing a low-cost solution.

This study aims to investigate the feasibility of a cost effective and low energy consuming approach for the in-situ denitrification of treated landfill leachate using readily available domestic waste as carbon source. The in-situ denitrification will be investigated by mean of re-circulation treated leachate into the landfill using organic waste as a carbon source for denitrification. However, in-situ bio-denitrification is not a common method because of its inherent difficulty. The re-circulation of leachate could compromise the geo-stability of the landfill (Read et al, 1998, Zhong et al., 2009).

At the Bisasar Road landfill site Durban five mini shallow (1.5 m deep) landfills (cells) were constructed in 2005 to accommodate a volume of 40 m^3 treated waste. These landfills were designed as part of a Mechanical Biological pre-treatment project which the first South African pilot-project. The five cells consist of treated wastes which were composted to different degree of stability mainly 8 and 16 weeks. Of the five cells, one cell acted as a control which was filled with unsorted waste. The wastes from the mini landfill were used for the batch test reactor.

1.1. Research Question(s):

- Is municipal solid waste a suitable carbon source for denitrification of leachate?
- Can nitrate removal be achieved in landfills using waste as a carbon source for the denitrifiers?
- How and at which extent does the level of stability of the general waste affect the kinetics of the bio-denitrification process?

1.2. Aims & Objectives

Aims:

The aim of the study is to determine the viability of pre-treated general waste at different degrees of stability (8 and 16 weeks composted) as carbon source for in-situ bio-denitrification in landfills.

Objectives:

The purpose of this research is to investigate the kinetics, suitability and performance pre-treated waste for in-situ bio-denitrification of leachate. The specific objectives of this research were:

- To determine the kinetics of nitrate removal in leaching batch tests using general waste at different degrees of stability as carbon sources.

- To use the laboratory small scale anaerobic batch tests to design the larger scale experiments in the columns test.
- To provide recommendations on the applicability of treated and untreated MSW as a carbon source for denitrification.

1.3. Methodological Approach

Domestic refuse that was disposed into the test cells (miniature landfill) at Bisasar Landfill site was sampled by means of core sampling. This substrate from the test cells mainly cell 1 and cell 2 (8 weeks and 16 weeks pre-treated fine waste respectively) was used to carry out the research.

The solid substrates and Treated leachate to be used for the experiment were fully characterized. The leachate to be used in the small scale anaerobic batch test was sampled from the SBR tank at Mariannhill landfill site and it was tested to know the initial parameter before it was used. The initial parameter is important to be able to assess the efficiency of the chosen substrate that was sampled. Both the solid substrate and the treated leachate were characterised and the following tests were performed NH_3, COD, BOD_5 and NH_3-N to know the level of this parameter before using it. Leaching test was conducted with the treated leachate with a NO_3 of 500mg/l.

The output substrates and effluent were analyzed for NO_3, COD, NH_3-N, NOx, pH and temperature at the Environmental Engineering Laboratory at the University of KwaZulu-Natal in accordance with the standard methods to determine the rate of nitrate removal (kinetics) and the conditions at which the substrates perform optimally. The test results obtained from the batch tests will enable the design of treatment method i.e. the recirculation of leachate through domestic waste landfill. The batch tests were monitored daily for over a period of time or until it reach full denitrification to assess the efficiency (kinetics) of nitrate removal and also to assess the availability of carbon within the substrate at the end of the batch test.

1.4. Thesis Layout

Chapter 1 gives a brief explanation of landfills and the reason for carrying out this research. The outline of the research includes research questions, aims, objectives, methodology and expected outcomes of the research. The later part of the chapter gives the research layout.

Chapter 2 contains detailed literature review, which describes the processes in landfills, the nitrogen cycle and how leachate is formed. It also describes leachate treatment methods with more focus on the biological treatment processes and their efficiency. At the end of the chapter a case study of the Bisasar Road landfill is presented.

Chapter 3 describes the type of materials used for this research, why those materials were chosen and the experimental procedures adopted.

Chapter 4 presents and discusses the analytical results.

Chapter 5 presents conclusions and recommendations.

The overall research layout is shown in Figure 1.4-1.

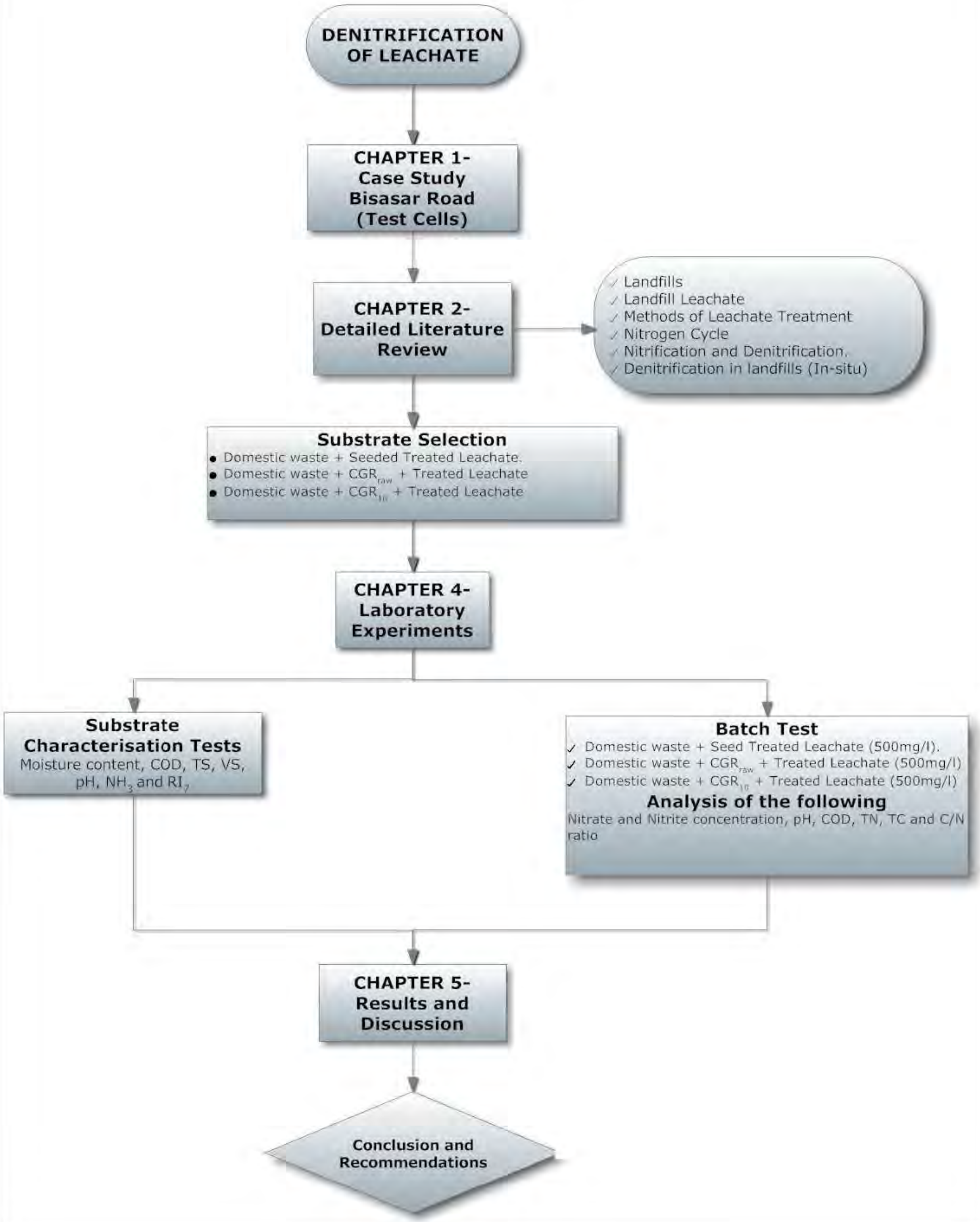


Figure 1.4-1: Research Layout

2. LITERATURE REVIEW

2.1. Chapter Overview

The aim of this research is to denitrify leachate using domestic waste. Consequently, the following aspect will be reviewed: how nitrogen is formed and what danger it poses to the environment. Influent type and characteristics plays an important role in the selection of the type of treatment, hence in this chapter different methods will be discussed. For the purpose of this research focus will be on the denitrification of leachate using domestic waste: column/ series studies. The benefits of treated leachate will be discussed. The Mariannhill landfill case study is presented at the end of this chapter.

2.2. Landfilling

2.2.1. Definition of landfilling

"The term „landfilling" refers to the deposition of waste on land, whether it be the filling in of excavations or the creation of a landfill above grade, where the term „fill" is used in the engineering sense" (DWAF, 1998).

2.2.2. Landfill waste disposal management

Waste management is defined as the management of waste from the generation stage to the ultimate disposal stage (Dictionary of Civil and Environmental Engineering, 1998) which involves collecting, transporting, processing and disposing of waste material. Figure 2.2-1shows the waste management for waste out of the waste stream. There are several methods of waste disposal but the most common ones are incinerations and landfilling.

Landfilling is one of the most common methods of waste disposal that is practice in many countries including South Africa (DWAF, 1998). The main reason why landfilling is common practice is because it is regarded as the cheapest and most convenient method of waste disposal (DWAF, 1998).

According to DWAF (1998) it is estimated that 95% of waste generated in South Africa is disposed of in landfills, while it is estimated as 85% in the world figure. Figure 2.2-1below shows that no matter what technology available to minimize waste, some form of residue will always remain which indicate that waste will continue to be generated, therefore the ultimate disposal is landfill as indicated in Figure 2.2-1.

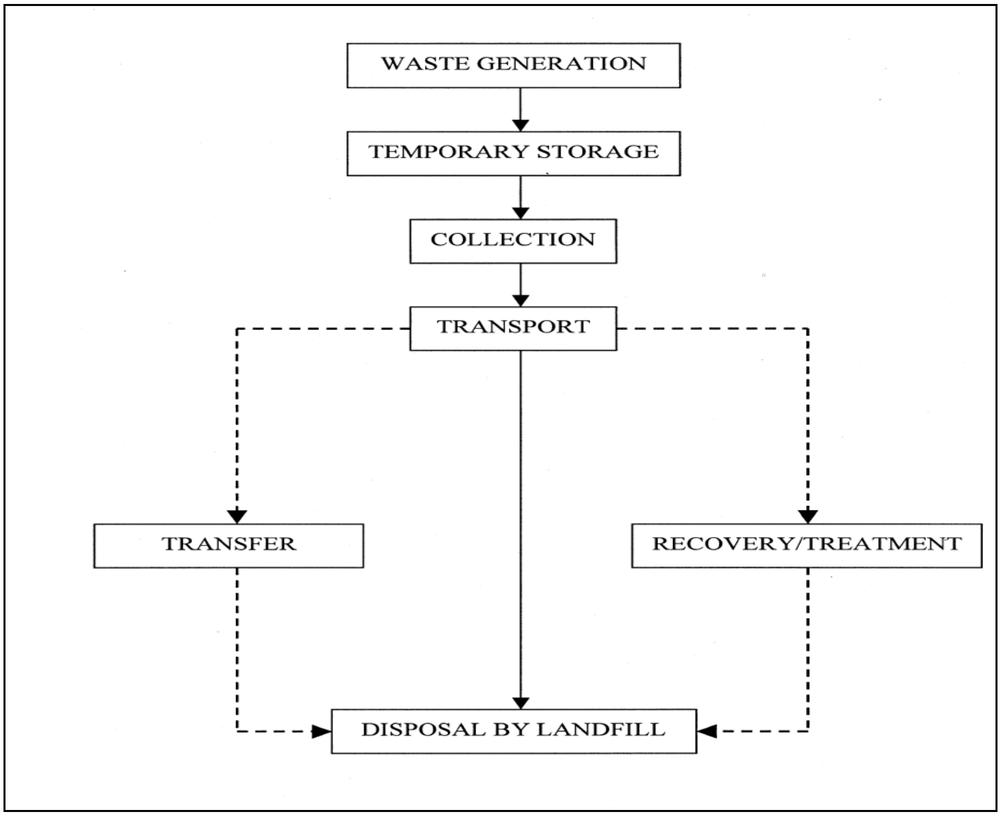


Figure 2.2-1: The role of landfill in the waste management system (DWAF, 1998)

2.2.3. Landfill decomposition stages

The decomposition of waste in a landfill has 5 stages of biodegradation as identified by different studies. Each decomposition stage affects the characteristic of the leachate. On the first day all landfills will be aerobic because of the surplus of air, but soon all landfills becomes anaerobic in parts of the landfill because of the inability for air/oxygen to diffuse into the waste mass. The degradation of waste takes several years and it involves the following stages which can be represented in a diagram as indicated in Figure 2.2-2. The waste degradation diagram shows the complexity of the stages of the biological decomposition of landfill. Each stage will be discussed below.

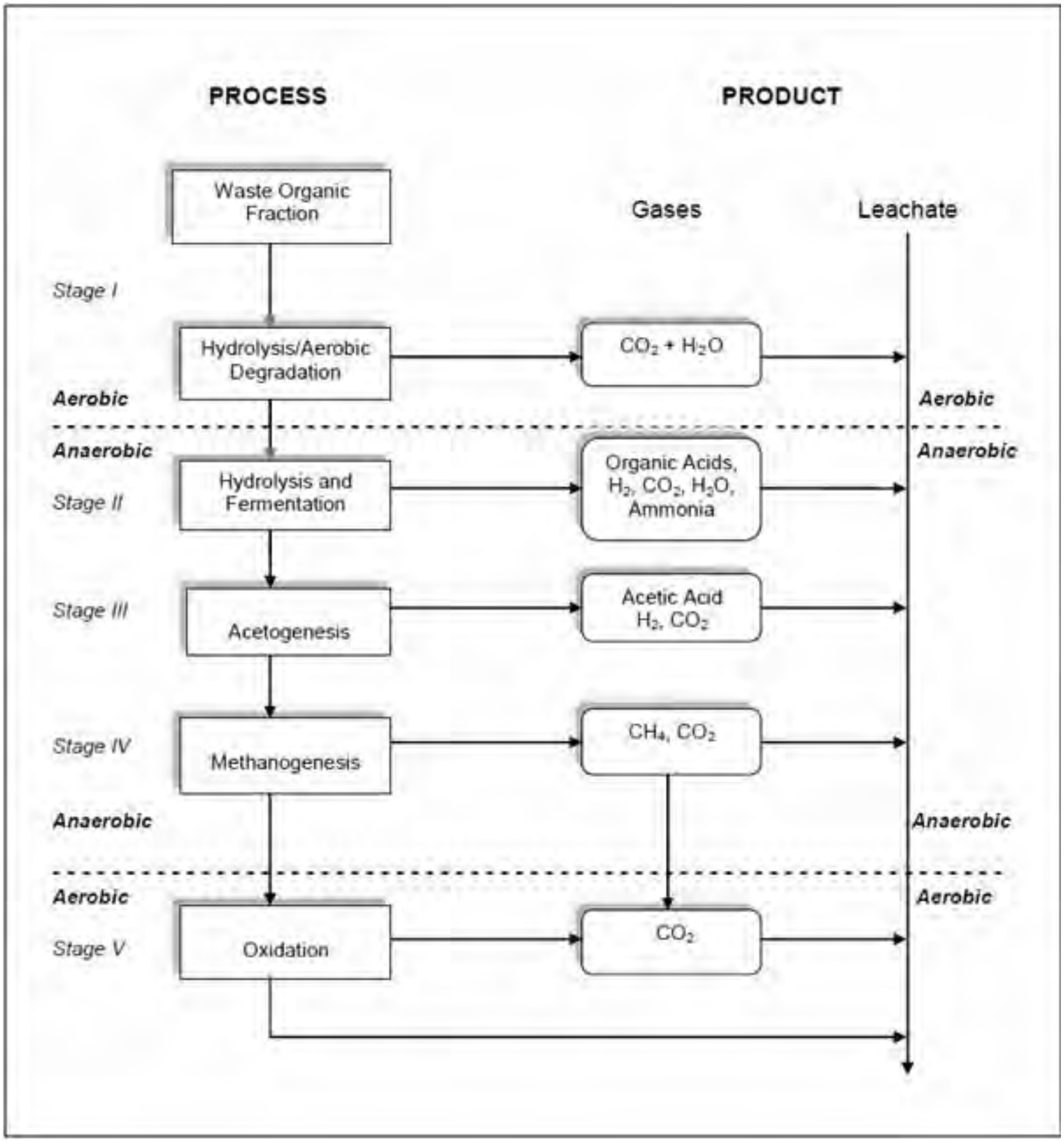


Figure 2.2-2: Main stages of waste degradation in landfill (Hester and Harrison, 2003)

Stage 1: Hydrolysis and Aerobic Degradation

Hydrolysis and Aerobic degradation is the first phase of degradation. This phase involves hydrolyzing of polysaccharides into monosaccheries, fats into glycerin and fatty acids and proteins into amino acids as indicated in Figure 2.2-2. This phase occurs in aerobic condition and it could take few days or weeks depending on how much oxygen is available (Lyilade, 2009). Enzymatic catalysis quickly/accelerate the hydrolysis process, this occurs by the oxygen present in the waste (landfill mass) causing the decomposition/degradation of the organic matter/waste via a process called aerobic biological processes (Pisano, 2007) and this process produces stable hydrocarbons, heat, carbon dioxides and water (Hester & Harrison, 2003). During the early placement of waste and on the top surface of the landfill, aerobic decomposition normally occurs. Equation 2.2.1 represents the aerobic digestion reaction that occurs.

$$C_aH_bO_cN + O_2 \xrightarrow{yields} CO_2 + H_2O + NH_3 \dots\dots\dots\dots\dots\dots\dots\dots Equation\ 2.2.1$$

During the hydrolysis and aerobic degradation phases some important biochemical reactions are performed (Pisano, 2007):

- Carbon dioxide, water, nitrates and sulphate are produced from amino acids due to the aerobic process that occurs.
- Monosaccharides are transformed into carbon dioxide and water
- The enzymes degrade cellulose into glucose, which are eaten up by bacteria hence converting it into carbon dioxide and water.

The degradation process which is exothermic may increase the temperature in the landfill up to 70 to 90 ^{o}C (Bricken, 2003 and Pisano, 2007). The hydrolysis and aerobic degradation process is a fast reaction process and the biogas produced is transformed into carbon dioxide from oxygen (Ghiani, 1997 citied by Pisano, 2007). The leachate generated during this phase is little but the COD is much having a high pH of 6 to 7 (Bricken, 2003).

Stage 2: Hydrolysis and Fermentation

The aerobic degradation and hydrolysis which is the first stage of waste decomposition uses up all the oxygen present in the waste mass and anaerobic condition is created. The unavailability of oxygen (anaerobic condition) favors the activity of facultative anaerobic bacteria. These bacteria are responsible for hydrolyzing long and complex organic molecule chains to simpler organic units such as glucose. Acid fermentation is the first stage of anaerobic decomposition/ degradation which involves the biodegradation (hydrolysis) of organic materials such as glucose molecules (Ghiani, 1997 cited by Pisano, 2007). According to Ehrig (1989) cited by Pisano (2007) during this phase glucose molecules are broken down into simpler organic acetic acid(CH_3COOH), ethanol(CH_3CH_2OH), butyric acid $(CH_3C_2H_4COOH)$, propionic acid (C_3H_2COOH), and pyruvic acid $(CH_3COCOOH)$.

During the hydrolysis and fermentation stage the following biochemical processes takes places:

- According to Hester and Harrison (2003) cited by Masuku (2010) carbohydrate hydrolysis into polysaccharides and monosaccharides which then further biodegrades into CO2, H2O, H2, NH4 and organic acetic acid mainly.
- According to Pisano (2007) fats are hydrolyzed into fatty acid and glycerine into CO2 and H2O through the formation of volatile fatty acid (VFA) and alkalis.
- Lipids and Proteins are hydrolysed into acids which then decompose further to produce ammonia, carbon dioxide

The ammonia nitrogen concentration in the leachate is high during this phase with a temperature of 30-50 ^{o}C which is less than that of stage 1 (Hester & Harrison, 2003). According to Bricken (2003) the gas produced during this stage may increase up to 80% of carbon dioxide and 20% hydrogen by volume, however both nitrogen and oxygen decreases (Mulamoottil et al. , 1998 citied by Pisano, 2007).

Stage 3: Acetogenesis

In the third stage of landfill decomposition, there are traces of methane gas that is produced. This process of acetogenesis transforms the organic acid that is produced during the stage 2 into acetic acid, acid derivatives, carbon dioxide and hydrogen. This transformation occurs under anaerobic condition. There is a continuous reduction of hydrogen level and carbon dioxide throughout the acetogenesis stage because of the micro-organism in the landfills that converts carbohydrates to acetic acid in carbon dioxide and hydrogen prevalent environment (Williams, 2005).

Some important chemical reactions that take place during the acetogenic stage are shown by the equations below:

$$CH_3CH_2COOH + 2H_2O \xrightarrow{yields} CH_3COOH + CO_2 + 3H_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots. Equation\ 2.2.2$$

$$CH_3C_2H_4COOH + 2H_2O \xrightarrow{yields} 2CH_3COOH + 2H_2 \ldots\ldots\ldots\ldots\ldots\ldots Equation\ 2.2.3$$

$$CH_3CH_2OH + H_2O \xrightarrow{yields} CH_3COOH + 2H_2 \ldots\ldots\ldots\ldots.. Equation\ 2.2.4$$

$$C_6H_5COOH + 4H_2O \xrightarrow{yields} 3CH_3COOH + H_2 \ldots\ldots\ldots\ldots Equations\ 2.2.5$$

In this stage the methanogens which is caused by a low hydrogen level begins to convert the organic acids and other end products that have been produced in the earlier stages of the degradation into end product of this stage (Acetogenesis) such as methane and carbon dioxide (Lyilade, 2009, Hester & Harrison, 2003). An increase in the solubility of metal ions such as Ca^{2+}, Mg2+ and Na+ due to the acidic conditions of the acetogenic phase causes an increase in the concentrations of this metal ions in the leachate that is been generated. According to William (2005) the leachate from this stage is characterized by high concentration of organic acid and other ions such as NH_4^+ , $PO_4^{3-}, and\ Cl^-$.

The reduction in the bacteria break down in the sulphate compounds in the waste is due to the anaerobic decomposition of the waste. The sulphate are produced by the anaerobic decomposition, they are produce as hydrogen of hydrogen sulphide as the sulphate (William, 2005).

The leachate produced during this phase is characterized by the following:

- Due to the high generation of VFA the pH is low of around 4-5 with a high pressure of CO_2 (Qasim and Chiang, 1994)
- The leachate contains a high concentration of inorganic ions like Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-} and Na^+ and also high concentration of volatile acids.
- It contains a high proportion of soluble biodegradable organic with a BOD_5: COD ratio of 0.7 and greater (Andreottola and Cannas, 1994).
- The leachate generated in this stage (acetogenic stage) is known as “Young leachate” (Bricken, 2003) which is characterized by high concentration of ammonia (500-1000 mg/ℓ).

Stage 4: Methanogenesis

Methane is produced by methanogensis bacteria in this stage (Methanogensis stage). The reactions in this stage take place at a very slow rate. Methanogenesis is regarded as the stage where by major gases are generated, whereby approximately 40% of carbon dioxide and 60% methane are generated. This stage consists of two groups: the first group which is the hydrogenophilic group, where hydrogen and carbon dioxide is converted into methane, while the second group which is the acetogenic group where acetic acid is converted into methane and carbon dioxide (Kjedsen et al., 2002). Methanogenic bacteria can also convert formic acid and methanol. Below are some important reactions that take place in the methanogensis stage

$$CH_3COOH \xrightarrow{yields} CH_4 + CO_2 \ldots\ldots\ldots. Equation\ 2.2.6$$

$$4H_3 + CO_2 \xrightarrow{yields} CH_4 + 2H_2O \ldots\ldots\ldots. Equation\ 2.2.7$$

$$HCOOH + 3H_2 \xrightarrow{yields} CH_4 + 2H_2O \ldots\ldots\ldots. Equation\ 2.2.8$$

$$CH_3OH + H_2 \xrightarrow{yields} CH_4 + H_2O \ldots\ldots\ldots. Equation\ 2.2.9$$

The important part of the methane formation process is the stage in which the acetic acid is converted to methane. The major abiotic factors that affect the formation of methane in landfills are as follow:

- pH and alkalinity
- Temperature

pH and alkalinity

pH change affect the methane bacteria as they are very sensitive to the change of pH. A range in pH of 6.8 and 7.5 is what is required for the optimal generation of biogas, however according to William (2005) methanogenic activity may take place at pH 5 and pH 9.

Enough alkalinity is important for control of pH in anaerobic treatment as it acts as buffer to the system. This alkalinity can be improved significantly by the presence of buffering materials such as soil, demolition waste in the landfill and hence maintain a reasonable pH range within the landfill environment. The pH level of the leachate generated in this stage may rise to between 7 and 8 (Pisano, 2007).

Temperature

Temperature affects the anaerobic waste decomposition rate greatly just as it does for all other microbic processes. Temperature has effect on the biological systems in two, which is "*by influencing the rates of enzmetically catalyzed reaction and also by affecting the rate of diffusion of substrate to the cell*" (Ingenieurin, 2004). At temperature below 15 ^{o}C to 65 ^{o}C biogas can still be generated but the production level is low (Williams, 2005).

Stage 5: Oxidation

Oxidation is the final stage of decomposition in the landfill. During the methanogesis stage most of the acids have been depleted and the decomposable substrate has been degraded, therefore new aerobic bacteria and in this case the aerobic condition is hereby restored (William, 2005 and Pisano, 2007).

The leachate generated in stage 4 and 5 has low BOD and COD concentration, therefore the BOD:COD ratio is low (Pisano, 2007). According to Trois et al (2010) the concentration of ammonia is very high in the leachate (up to 2000 mg/ℓ)

2.3. Landfill Leachate

2.3.1. Definition of landfill leachate

Landfill leachate can be defined as water in the form of rain water, surface water, runoff or groundwater seepage that has seeped through solid waste in a landfill carrying dissolved or suspended material in the process which is a form of soil and groundwater contamination and biogas produced by the fermentation of organic matter which is a form of air pollution (Ahn, W.Y.et al, 2002).

2.3.2. Leachate characteristics

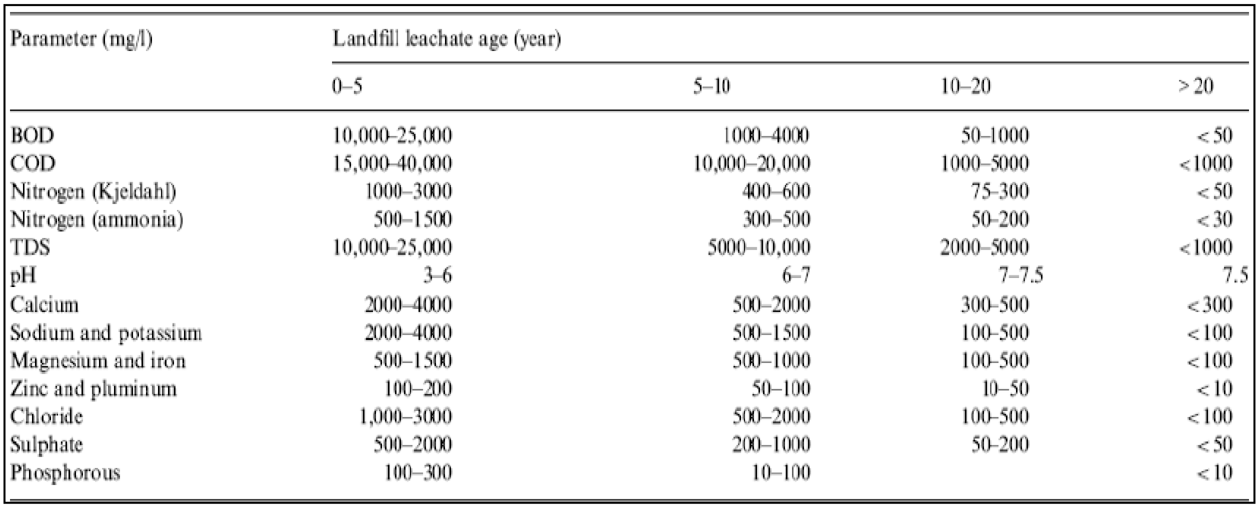
Several factors affect the quantity and quality of leachate, i.e. age, precipitation, seasonal weather variation, waste type and composition. Particularly the composition of landfill leachate differs depending on the landfill age. Leachate can be classified into three types i.e. ***Young***, ***Medium*** and ***Old (Mature)*** as indicated in Table 2.3-1.

As landfill gets older the concentration of organics (COD) in the leachate decreases and the ammonia nitrogen concentration decreases (Kulikowska et al, 2008). Older site leachate usually are highly contaminated with ammonia due to the hydrolysis and fermentation of nitrogen containing fractions of biodegradable refuse substance (Cheung et al, 1997)

The most effective criteria to choose the most suitable leachate treatment is by looking at the relationship between age and the organic matter composition. As indicated in section 2.3.1leachate generally contains large amounts of organic matter which are biodegradable, ammonia nitrogen heavy metals chlorinate organic and inorganic salts.

Landfill leachate characteristics are usually represented by the following basic parameters COD, BOD, BOD/COD ratio, pH, Suspended Solid (SS), ammonium nitrogen ($NH_3 - N$) and total kjeldbhl Nitrogen (TKN) as indicated in Table 2.3-1.

Table 2.3-1: Leachate characteristics at different Landfill Ages (El Fadel et al, 2001 and Héctor et al, 2004)



Parameter (mg/l)	Landfill leachate age (year)			
	0–5	5–10	10–20	> 20
BOD	10,000–25,000	1000–4000	50–1000	< 50
COD	15,000–40,000	10,000–20,000	1000–5000	<1000
Nitrogen (Kjeldahl)	1000–3000	400–600	75–300	< 50
Nitrogen (ammonia)	500–1500	300–500	50–200	< 30
TDS	10,000–25,000	5000–10,000	2000–5000	<1000
pH	3–6	6–7	7–7.5	7.5
Calcium	2000–4000	500–2000	300–500	<300
Sodium and potassium	2000–4000	500–1500	100–500	<100
Magnesium and iron	500–1500	500–1000	100–500	<100
Zinc and pluminum	100–200	50–100	10–50	<10
Chloride	1,000–3000	500–2000	100–500	<100
Sulphate	500–2000	200–1000	50–200	<50
Phosphorous	100–300	10–100		<10

2.3.3. Leachate Production

The fluid that emanates from the base of a landfill is called leachate and it is highly contaminated. This leachate is composed of water, organic and inorganic chemicals from decomposition of waste (Kostova, 2006) and it is formed as a result of biological and chemical reaction that occur as the water passes through the landfill and the solid waste (Robinson, 1986). The landfill leachate has highly polluted fluid containing dissolved or suspended substances that leach out from the waste. . Solid waste in the form of dissolved or suspended solid are extracts as the water moves through the landfill as indicated in Figure 2.3-1. The substances that leach out of the waste are substance such as nutrients, large bacterial population, heavy metal, pathogens and toxins which are very harmful (Peavy et al, 1985). For a certain area the leachate volume prediction can be represented by the following equation:

$$L = P - R - \Delta U_s - ET - \Delta U_w \ldots \ldots \ldots . Equation\ 2.3.1$$

Where:

$L = Leachate\ Production$

$P = Precipitation$

$R = Surface\ Runoff$

$\Delta U_s = Change\ in\ Soil\ Mositure\ Storage$

$ET = Actual\ Evaporative\ losses\ from\ the\ bare\ soil/vegetated\ surface$

$\Delta U_w = Actual\ change\ in\ mositure\ content\ of\ the\ refuse\ components$

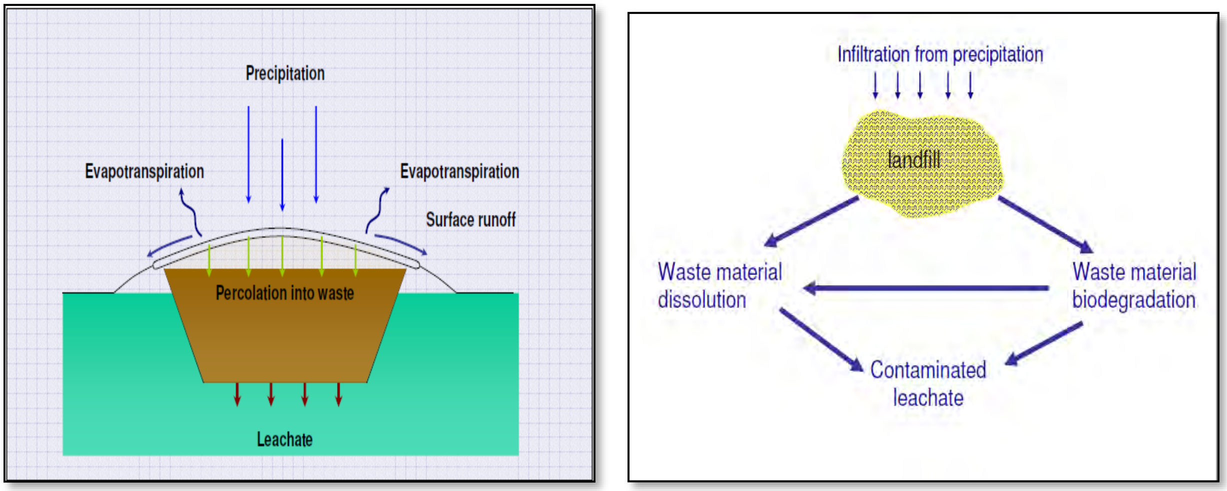


Figure 2.3-1: Leachate production and formation of contaminated leachate (Kostova, 2006)

2.3.4. Leachate composition and Quality

Leachate composition

The composition of leachate or its variability is due to the composition of refuse, its depth, permeability of the landfill, method of landfilling, age of landfill, collection system as well as the region climatologic condition (EPA, 2000).Figure 2.3-2 illustrates the leachate composition at different decomposition phase in the landfill over time. The stage in the decomposition phase in a landfill indicates the leachate composition, which is the amount of leachate generated and its concentration.

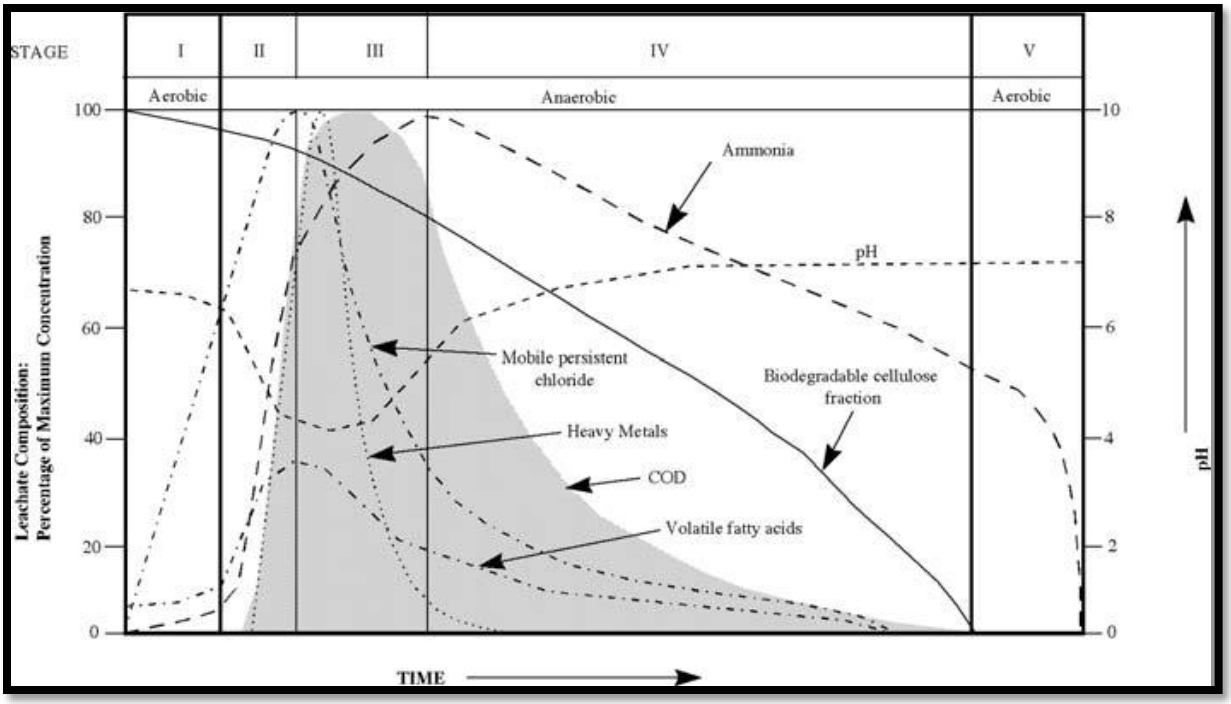


Figure 2.3-2: Summary of chemical changes in the landfill (EPA, 2000)

Leachate Quality

Leachate quality plays an important role as it has direct impact on the environment, which is due to the toxic substances that emit from it and affect the environment and even the groundwater (Assmutha and Penttila, 1995 cited by Nordin, 2006).

Phase 3 leachate is often referred to as „stabilized‟ (Nordin, 2006).Leachate produced during phase III are characterized by relatively low BOD values and low ratios of BOD to COD. However, ammonia nitrogen continues to be released by the first-stage acetogenic process and will be present at high levels in the leachate. Inorganic substances such as iron, sodium, potassium, sulfate and chloride may continue to dissolve and leach from the landfill refuse for many years.

2.3.5. Factors affecting the leachate composition

The composition of leachate varies greatly from one landfill to the other, and can also vary within a particular landfill (site). The factors that affect the composition of leachate include (Renou et al, 2007):

- Age of landfill

- Type of waste contained in the landfill (waste composition)
- Seasonal climatic variation
- Operational procedure and design
- Physical modification of the waste

Age of the landfill

The stage of decomposition in which the landfill is can be determined by the age of the landfill. Hence the age of landfill has a significant effect on the quality of the leachate.

In the early years of a landfill life, that is to say in younger landfills, the dominate process is hydrolysis and fermentation where the organic matter is hydrolyzed to simpler organic compounds, which are then fermented to volatile fatty acids and acetic acid. This stage is referred to as the acidogenic and acetonic phase. According to Welander et al (1997) 80-90% of the organic matter in younger landfill contains organic matter in the form of Volatile fatty Acids (VFAs) that are readily biodegradable. During this phase the leachate produced has low pH (5 or lesser) as a result of the acid generated, high BID reported to be above 10 000 mg/ℓmg/ℓ ((William, 2005) and high COD concentrations.

In mature landfill (older landfill) Methanogenesis is the most dominant biological process, where by the VFA‟s and acetic acid are converted in biogas (CH_4 and CO_2) (Welander et al, 1997). The leachate produced has a pH of approximate 7.5, and low BOD and low COD. Older landfills have a high concentration of ammonia nitrogen that is due to the hydrolysis and fermentation of the biodegradable waste that has a high nitrogen fraction (Onay and Pohland, 1998, Renou et al, 2007)

Type of Waste contained in the landfill (Waste Composition)

Waste that has a high organic biodegradable carbon contain will increase the decomposition rate of the waste. Some types of wastes may result in high strength leachate concentration such as industrial waste. The presence of toxins in waste affects the biodegradability of the waste (Crawford & Smith, 1985). If heavy metals such as copper, lead and tin are present as well as hazardous organic compound, they can be toxic to certain type of bacteria which in turn reduce the decomposition process (Crawford & Smith, 1985)

Seasonal Climatic Variations

The composition of the leachate can be affected by the seasonal variations. The moisture content and temperature influence the extent to which the waste decomposes (Browne, 2010). According to Crawford and Smith (1985) the optimal moisture content and temperature that affect the biological activity in the landfill are approximately 40% at a temperature of 20-40°C. The biological activity is reduced if the moisture content is less than 40%, therefore reducing the BOD concentration in the leachate (Browne, 2010).

During rainy season the amount of leachate generated increases greatly but the pH generally decreases during high rainfall.

Design and Operational procedure

The concentration of the leachate can be influenced by the way a landfill is design and the way it is operated. As stated in section 2.3.5 (seasonal variation) moisture content plays an important role in the biodegrading of waste in the landfill. The design landfill and controlling of the surface waters is of great importance. Hence the landfill liming installation and collection drains for the leachate is very important (Crawford & Smith, 1985). Landfill cell that operated uncovered have a higher concentration of COD compared to covered landfill cells, this is due to the moisture content (Robinson, 1986). Therefore the establishment of vegetation cover over the landfill and the recirculation of partially treated leachate are techniques to manage the landfill leachate (Crawford & Smith 1985). Contaminated groundwater can be cleaned up at a very high cost hence landfill today does undergo rigorous siting, design to control leachate migration. During the designing of landfill a lining system which this lining system lowers permeability and also limit the movement of leachate into groundwater (DWAF, unknown).

Physical Modification of waste

According to Robinson (1986) studies shows that waste that are shredded produce higher contaminant concentration than unshredded waste, but the concentration in shredded waste decline quickly after some time while in unshredded waste it declined slowly. This shows that the physical modification of landfill waste has great impact on the leachate quality.

2.4. Methods of Landfill Leachate Treatment

The production and management of leachate has been of great concern to the environment, due to the fact that leachate pollutes the surface and ground water including the surrounding soil if not treated well (Strachan et al, 2000).When the leachate containing high strength organic matter and ammonia is discharged to the environment without treatment, it can simulate algae growth through nutrient enrichment, deplete dissolved oxygen and cause toxic effects in the surrounding water environment. The leachate treatment methods can be categorized into two groups namely the ***Physico-chemical Treatment Method*** and the ***Biological Treatment Method***, however more focus will be on the biological treatment methods. For this reason some different method of leachate treatment will be discussed as indicated below.

2.4.1. Physico-chemical Treatment Method

2.4.1.1. Leachate transfer (Channeling)

Co-disposal with municipal waste (combined treatment with domestic sewage)

Piping of leachate into the sewer system for it to be discharged into the sea or to be combined into the domestic sewage treatment plant was seen to be an attractive method for treatment of landfill leachate since it was simple and had a low operating cost. In recent years this option has been questioned due to the fact that this disposal method introduces compounds with low biodegradability and heavy metals from the leachate. According to Ceçen et al. (2004) this method may reduce the efficiency of the treatment and increase the concentration in the effluent.

The use of sequencing batch reactors (SBR) as a co-disposal has shown when the ratio on sewage to leachate dilution was 9:1, about 95% BOD and 50% nitrogen removal was achievable. When the ratio of landfill leachate: sewage increases, COB and NH_3-N decrease. If the leachate input in the domestic wastewater exceed 10%, to improve the quality of the effluent Powered Activated Carbon (PAC) maybe added (Abbas et al, 2009).

Recirculation of leachate (recycling)

Recirculation of leachate assists in stabilizing the leachate which contains low concentration of carbon compound which is degradable but has a high amount of ammonia concentration. This process removes COD and BOD but the concentration of ammonia will increase.

This technique (Recirculation/Recycling) involves putting back leachate into the system to be treated by the waste (Zhong et al, 2009). Even thou these techniques is considered to be inexpensive (Lema et al, 1988), it is still not a widely implemented method because of some operational problems associated with it. Problems such as running of the landfill bio-reactor and hydraulic issues like clogging of the pipes. Moisture content is increased by recirculation leachate and it also provides nutrients and enzymes that are distributed between methanogens and solid/liquids (Abbs et al, 2009). Anaerobic bacteria colonies are produced by reticulating leachate; it also increases the speed of stabilization of a landfill (Craw ford & Smith, 1985). Recycling of leachate lowers the production of methane but increases the organic content in the leachate (Rodriguez et al, 2004).

According to Rodriguez et al (2004) 63% - 70% of COD is lowered by recirculation leachate. The stabilization of landfill is reduced from several decades to 2-3 years by recycling leachate; it also improves the leachate quality (Rodriguez et al, 2004). As much as recycling or recirculation has positive benefits the high recirculation rates may affect anaerobic degradation of solid waste (Abbs et al, 2009). In addition, high rate of recirculation can promote excessive acid formation (fermentation) and this can cause the pH to increase above 5 and lead to the inhibition of methanogenesis (Craw ford & Smith, 1985). Some problems are associated with high volume of recirculation of leachate, problems such as saturation, ponding and acidic condition (Ledakowicz et al, 2004).

In Situ Denitrification of Leachate

Ex-situ bio-denitrification is widely used around the world in various technological applications such as SBRs, anaerobic trickling filters etc. which generally employ expensive chemicals (such as methanol, ethanol, acetic acid etc.) or low-cost substrates (such as compost, garden refuse etc) as carbon sources (Etchebehere et al., 2001a,b; Trois et al., 2010a,b). According to Mehta et al., (2002) over 20 years ago the method of leachate recirculation was proposed, this method enhanced waste decomposition. Leachate recirculation can stimulate the biogas production as a higher moisture content can be achieved, an higher mobility of nutrients can increase the biological activity of methanogens, dissolved organic compounds can be available for fermentative and methanogens bacteria (Jokela et al., 2002).

The process of nitrification removes ammonia which is the first step of the process, which occurs under aerobic conditions. Hence during the nitrification process nitrate is produced which is then removed via denitrification using a suitable carbon source under anaerobic conditions.

The method of leachate recirculation through waste increases the contact between the microorganisms, nutrients which are soluble and organic which are necessary for the growth of bacteria (Reinhart et al., 2002). A number of advantages such as decrease the production of methane emission from the landfill, as well as using the landfill waste as an in situ denitrifier leachate, arise by increasing the microbial activity within a landfill (Mehta et al, 2002). In recent years the denitrification of leachate by means of recirculation has made it a popular choice because of its relatively low cost. However some form of pre-treatment and nitrification process have to be achieved before recirculating the leachate, by nitrifying the and sending it back through the landfill it results in complete denitrification (Benson et al., 2007, Zhong et al., 2009).

Studies done by Zhong et al., (2009) and Ding et al. (2001) involved a simulation of laboratory based in situ (recirculation) leachate treatment. In the study done by Ding et al (2001), eight species of microorganisms proved to be effective in the removal of organic pollutant. The experimental conducted by Ding et al. (2001) showed promising results as 95% of COD was removed and 100% of inorganic nitrogen.

2.4.2. Biological Treatment Method

2.4.2.1. Wetlands

Definition of wetlands

Wetlands can be defined as a land in which water covers the soil or is at ground level, all year or for a longer period of time to maintain a saturated soil condition and allow the growth of micro-organisms and related vegetation (Vymazal, 2010).

Constructed wetlands (CW)

Constructed wetlands are engineered systems that has been designed and constructed to make use of the natural processes which involves wetland vegetation, soils and their associated microbiology to treat the wastewater. Constructed wetlands have been used for treatment of different wastewater such as landfill leachate, storm-water runoff and agricultural runoff (Kadlle & Knight, 1996). Due to the high cost of treatment of wastewater CWs are regarded as the most economical and technically feasible approach to treat wastewater. Constructed Wetlands can be divided into two general types, which are ***Free Water Surface (FWS) wetlands*** and ***Vegetative Submerged Bed (VSB) wetlands***.

Advantages and disadvantages of CW

Detail advantages and disadvantages of the use of CW are listed below:

Advantages

- The operation, maintenance cost are low (Reed et al, 1995)
- It can be integrated with other treatment method that already exists
- Wastewater with low organic loads can easily be treated with CW as opposed to activated sludge treatment method.
- CW has an aesthetic appeal and allows for the wetland organisms to habitat in them (Bricken, 2003)

There are some limitations associated with CW treatment system. According to Wood, 1999 and Reed et al, 1995 the limitations includes:

- Requires large area of land like four to ten times for standard treatment but if a zero discharge is required the area of land required would increase up to 100 times.
- The removal of nutrient such as phosphate and total nitrogen is limited.
- The efficiency of the treatment is decreased during winter period because of the cold temperature (Bricken, 2003).

Types of constructed wetlands

As stated in section 2.4.2.1 there are two general types of CW which includes the free water surface wetland (FWS) and subsurface flow wetland (SSF).

Free water surface (FWS) constructed wetlands

The FWS constructed wetland is constructed to resemble a natural wetland including its operation. It consists of dense vegetation of plant of different species (IWA, 2001). The depths of the water in the CW are typically shallow of about 0.3meters but can range up to 0.8meters depending on the use of the wetland system. As stated already, the FWS follows a natural wetland where the wastewater slowly flows and spread throughout the vegetated surface area thus allowing the solid particles in the wastewater to settle and the vegetation absorbs the nutrients from the wastewater (Bricken, 2003) thereby destroying the pathogens. On the outlet the treated effluent is allowed to flow out as shown in Figure 2.4-1. In the FWS the water is allowed to flow from above ground, thereby exposing the water to the atmosphere and direct sunlight. As the wastewater flows slowly through the wetland it undergoes a physical, chemical and biological process whereby the solid are filtered, the organic degrade and nutrients are removed from the wastewater.

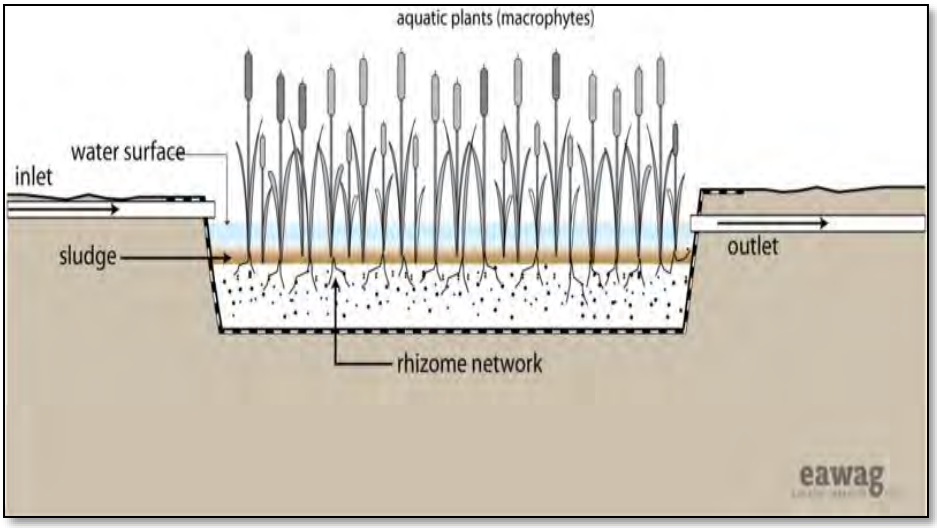


Figure 2.4-1: Free-water surface constructed wetland (Source: Sandec/Eawag, 2009)

Advantages

- Pleasing aesthetically and provides habitation for animals.
- Building and repairs can be done using readily available materials locally.
- Electrical energy not required for operation.
- If operated correctly no real problems with odours and flies.
- There is high reduction of BOD and solids.
- Labour intensive hence can provide short-term employment during construction phase.

According to Sandec/ Eawag, 2009 there are some limitations associated with FWS which are listed below:

- Requires large area of land
- For effective use long start up time required
- Design and supervision of experts is required.

Subsurface flow wetland (SSF)

The treatment of wastewater in a SSF is done by sending water through a permeable shallow medium. The submerged bed constructed wetland can be categorized into two types namely vertical flow constructed wetland and horizontal flow constructed wetland. SSF wetland has a bed depth between 0.6meter and 1.0meter. The SSF wetland does not allow any free standing water (Bricken, 2003) and this is normally achieved by slopping the bed. The main difference between VF and HF is the aerobic conditions.

Vertical flow (VF) constructed wetland

VF constructed wetland consist of a filter bed that is planted with aquatic plants. A mechanical dosing system is used to pour the wastewater from above onto the wetland surface as shown in Figure 2.4-2 thereby allowing the water to flow vertically down through the filter bed (Sandec/Eawag, 2009).

The wastewater is dosed four to ten times a day, the dosing of the wastewater should be timed so that the wastewater that was dosed previously could have time to percolate through the bed filter and allowing the oxygen to diffuse through the bed media filling up the voids space.

VF is normally design to treat wastewater that has already undergone primary treatment. The VF consists of a drainage that has a limit of 20cm in depth followed by sand and gravel to allow the effluent to settle. The bed filter media act as solid removal and a fixed surface upon which the bacteria can be attached to and also a base for the growth of vegetation.

Process

The wastewater percolates through the unsaturated media downwards where the solids are filtered by the gravel matrix. The nutrient and organic material in the wastewater are absorbed and allowed to degrade by the microbial population which is attached to the surface of the bed filter. During the gap of dosing of wastewater the organisms in the bed filter are forced to starve thereby decreasing the excessive growth of the biomass and increasing the porosity in the media.

Advantage

- No mosquito problems as water always flows
- Lesser space is required compared to FWS wetland
- BOD, suspended solids and pathogens are reduced greatly

Disadvantages

- To prevent clogging pre-treatment of the wastewater is required
- Requires constant source of electrical energy

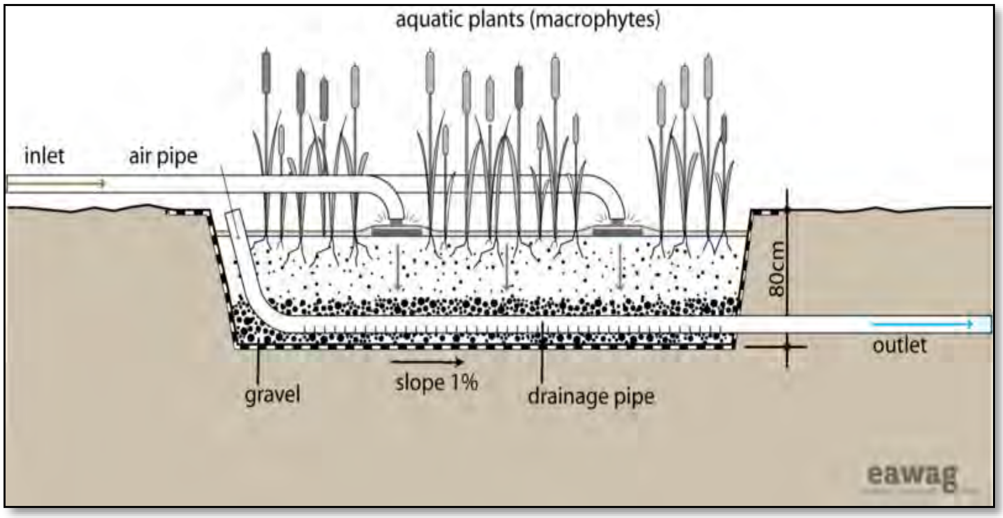


Figure 2.4-2: FWS Wetland systems (Source: Sandec/Eawag, 2009)

Horizontal Subsurface Flow Constructed Wetland (HSF)

The HF wetland system is a system whereby wastewater flows from the inlet point through the filter material (Permeable material) filtering out the particles. The outlet point in the system is under the bed surface as shown in Figure 2.4-3. In the HF system physical and chemical processes takes please thereby cleaning the wastewater. The HF wetland performs a good nitrogen removal which is mostly done by nitrification and denitrification (Cooper et al, 1996). The ammonia in the wastewater is converted to nitrates by the nitrifying bacteria in the aerobic zone and then converted into nitrogen gas by denitrification bacteria in the anaerobic zone.

According to IWA, 2001 the presence of carbon source in the HF improves the nitrate removal efficiency by 30%-80%, carbon sources such as grass and wetland plants.

Advantage

- No mosquito problems as water always flows
- Lesser space is required compared to FWS wetland
- BOD, suspended solids and pathogens are reduced greatly
- Can be built and repaired with locally available materials.
- Construction can provide short-term employment to local labourers.

Disadvantages

- To prevent clogging pre-treatment of the wastewater is required

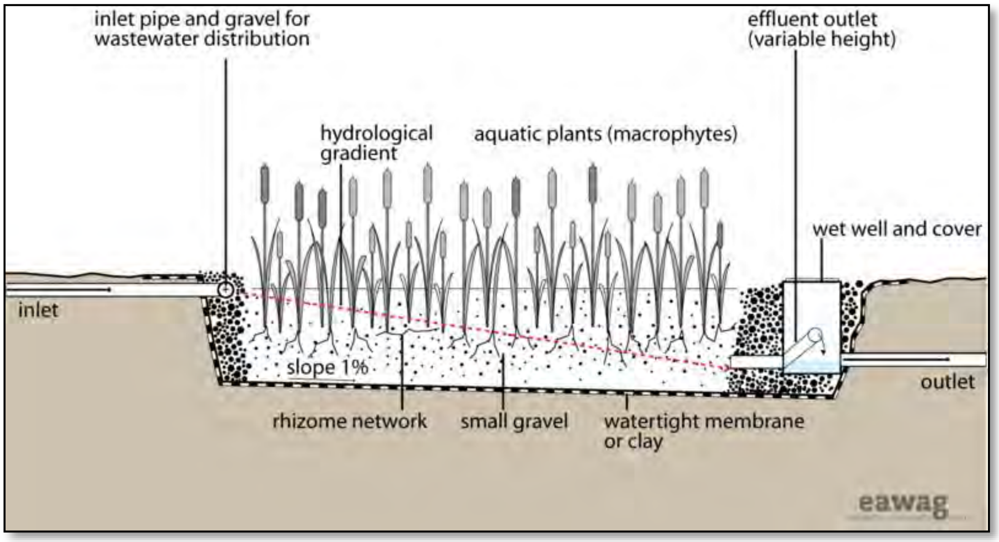


Figure 2.4-3: HSF Wetland systems (Source: Sandec/Eawag, 2009)

Ammonia (NH_3^+), ammonium (NH_4^+), Nitrite (NO_2^-), Nitrate (NO_3^-), Nitrous Oxide (N_2O) and dissolved Nitrogen element or dinitrogen gas (N_2) are the most important form of inorganic nitrogen in constructed wetland. Some mechanism can be used to remove the organic nitrogen which is in the suspended solids.

2.4.2.2. Suspended growth process

The treatment of landfill leachate by biological process is regarded as an easy to operate process, reliable and cost effective. The process of biological treatment is very effective in removing both BOD (organic) and nitrogen in immature leachate when the ratio of BOD/COD is greater than 0.5 (Renou et al, 2007).

Depending on the presence of oxygen or not the biological treatment process can be classified into two categories namely aerobic and anaerobic. The aerobic process involves the reduction of organic matter biologically in the presence of oxygen. The organic pollutants are transformed into CO_2 and bacterial biomass/solid biological products (sludge).

In anaerobic treatment process there is a conversion of organic matter to biogas. Unlike aerobic treatment, anaerobic digester has an advantage that it requires low energy and it produces very little solids with a low reaction rate (Renou et al, 2007). The anaerobic process solids are more stable compared to that of the aerobic process so the solids can be used to cover waste in landfill (Browne, 2010)

Brief description of biological treatment process will be discussed below. The cons and pros of each process relating to leachate treatment will be discussed as well.

Up flow anaerobic sludge blanket reactors (UASB)

UASB is considered to be an anaerobic process as the presence of oxygen is not required, this treatment method has a high treatment efficiencies with short hydraulic retention time (Renou et al, 2008). The UASB consist of anaerobic digester and fluid bed anaerobic filter, the bottom of the tank is where the influent (wastewater) get into the reactor and flows upwards through a blanket of sludge blanket as indicated as indicated in Figure 2.4-4 (Metcalf and Eddy, 2003). The biological granular particle in the sludge blanket tank allows the sludge to be retained in the blanket (Metcalf and Eddy, 2003). The up-flow velocities are recommended to be between 0.6 and 0.9 m/sec to allow maximum settlement of the sludge that is formed during the process (Metcalf and Eddy, 2003 cited Browne, 2010).

The use of UASB has some benefits and detriments which shall be discussed below:
Benefits of up flow Anaerobic sludge blanket reactor.

- It can treat highly polluted water (Kennedy and Lentz, 2000).
- Since aeration is not required therefore low energy is required
- The maintenance cost is low and requires less operation
- The production of sludge is less and the sludge can be used as fertilizer.

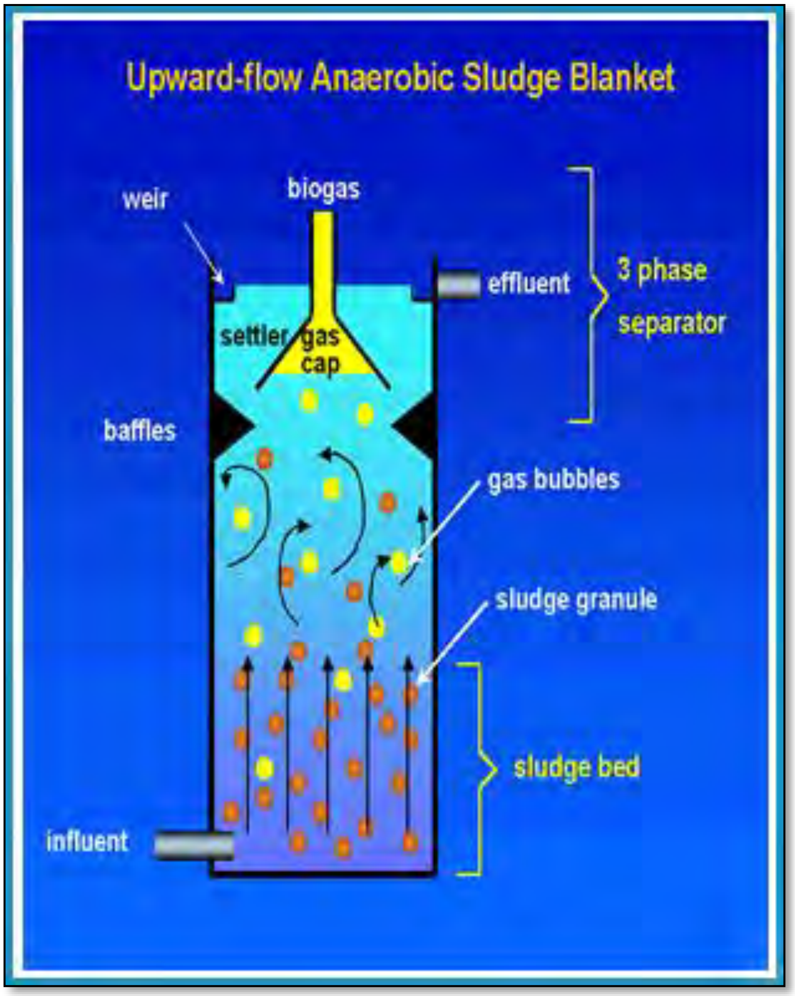


Figure 2.4-4: Treatment of Wastewater using an Up flow anaerobic sludge blanket reactors (PEE, 2010)

Lagoons

There are two categories of lagoons namely ***ANAEROBIC*** and ***AERATED***. Lagoons consist of one basin or a series of basins that are filled with wastewater that needs to be treated. Lagoons are also considered as stabilization pond. Lagoons depend greatly on temperature variation which mostly affects the microbial activities (Renou et al, 2007). Lagoons are considered as the most effective and low cost method of treatment of wastewater (Renou et al, 2007). Lagooning is an effective and cheap method of removing organic matter and pathogens, which does not require specialized skills (Maynard et al, 1999).

Despite the low cost, effectiveness and easiness to operate, lagooning is not considered a satisfactory treatment method/option because of the increasing strict discharge limit (Renou et al, 2007).

Aerated lagoons

An **aerated lagoon** sometime called an **aerated basin** is a holding and/or a treating pond which is supplied with artificial aeration to encourage the biological oxidation.

According to Metcalf and Eddy, 2003 aerated lagoons are in-situ treatment plant which has mechanical aerators used to supply oxygen and keep solids suspended.

Aerated lagoons consist of three types:

a) Aerobic flow through with partial mixing
b) Facultative partial mixed
c) Aerobic with solid recycling and normal complete mixing.

The types of aerated lagoons all differ from each other depending on the way the solids are treated (Metcalf and Eddy, 2003).

Below are some advantages and disadvantages of anaerobic lagoons (EPA, 2002):

Advantages

- Effective in removing pathogens, organic and inorganic matter at low cost.
- Allows for different flow rate for different leachate strength
-

Anaerobic lagoons

“An anaerobic lagoon is a deep impoundment essentially free of dissolved oxygen promotes anaerobic condition” (EPA, 2002). The depth of anaerobic lagoon ranges from 5m-10m and anaerobic lagoons are not aerated, mixed or heated except on the surface to control odor. The depth of 5m-10m minimizes the effect of oxygen diffusion from the surface and hence allowing the anaerobic condition to prevail. There are two major purposes of anaerobic lagoons according to EPA (2002) that is to pretreated high strength industrial wastewater and also to pretreated municipal wastewater by allowing preliminary sedimentation of suspended solids as a pretreatment process. Anaerobic lagoons are very effective in the pretreatment of organic wastewater with high strength.

Process

Wastewater enters the pond at the bottom and it mixes with the available active microbial mass. Aeration is sometimes provided to control odor and this aeration is provided to the surface. The effluent point is located on the opposite side of the influent point. The effluent cannot be discharged into the environment has the anaerobic lagoons are followed by aerobic or facultative lagoons to treat the wastewater to the required standard (EPA, 2002).

Below are some advantages and disadvantages of anaerobic lagoons (EPA, 2002):

Advantages

- More effective for rapid stabilization of strong organic wastes, making higher influent organic loading possible.
- Produce methane, which can be used to heat buildings, run engines, or generate electricity, but methane collection increases operational problems.
- Produce less biomass per unit of organic material processed. Less biomass produced equates to savings in sludge handling and disposal costs.
- Do not require additional energy, because they are not aerated, heated, or mixed.
- Less expensive to construct and operate.
- Ponds can be operated in series.

Disadvantages

- Require a relatively large area of land
- Anaerobic lagoons are sensitivity to environmental conditions, and objectionable odours.
- Long retention times are required in anaerobic process, especially in cold climates between 50 and 100 days (Metcalf and Eddy, 2003).
- Anaerobic bacteria are not effective in temperatures lower than 15° C.

Activated sludge systems

The activated sludge system is a treatment process that is extensively used for domestic wastewater or co-treatment of leachate and sewage. According to Lin et al (2000) the method of activated sludge system has shown to be inadequate for treating landfill leachate.

The activated sludge method is effective for the removal of organic carbon, nutrients and ammonia content, but has some disadvantages such as:

- The sludge takes longer to settle hence requires longer aeration time (Loukrdou et al, 2001).

- Requires high energy and production of sludge is excessive (Hoilijoki et al, 2008).
- Microbial inhibition due to high ammonium-nitrogen strength (Lema et al, 1998).

The activated sludge system can be grouped into single sludge process or multiple sludge process system. The single sludge process uses one activated sludge tank for the separation of solids during the process. The single tank can then be divided into subdivision of anoxic zone and an aerobic zone. Nitrification and denitrification occurs at the same time in single sludge system and are performed by the bio-mass.

An example of a single sludge system is the Wuhrmanr process (1957). The tank is divided into two subdivision where the contaminated is pumped from one zone (aerobic zone) to the other zone (anoxic zone).

Denitrification in the Wuhrmann is very slow and volume in the anoxic reactor becomes large which make nitrification efficiency limited (Pisano, 2007).
The anoxic zone in the single sludge system can be further grouped / divided into pre-anoxic, post-anoxic and simultaneous nitrification and denitrification process (Metcalf and Eddy, 2003).

PRE-ANOXIC DENITRIFCATION PROCESS: This process is known as ***PRE-ANOXIC DENITRIFICATION*** because the anoxic process precedes the aeration tank (Metcalf and Eddy, 2003). Nitrification occurs in the aerobic zone. The nitrate produced in the aeration tank / aerobic zone is recycled back to the anoxic tank. The organic substrate in the influent wastewater provides the electron donor for oxidation reduction reaction using nitrate (Metcalf and Eddy, 2003). The following factors such as the detention time in the anoxic zone, the flow rate, temperature, the availability of COD within the effluent and the rate at which recycling is allowed plays an important role in the efficiency of the nitrogen removal which occurs in the anoxic zone.

POST-ANOXIC DENITRIFICATION PROCESS: The removal of BOD occurs first and it is not present to drive the reduction of nitrate reaction hence it is referred to as ***POST-ANOXIC DENITRICATION*** (Metcalf and Eddy, 2003). In the post anoxic denitrification the electron donor source is from endogenous decay (Metcalf and Eddy, 2003). The reaction rate in the post anoxic process is much slower with a reaction rate of 0.01-0.049 NO_3-N/g in range, it"s because the reaction depends on endogenous respiration for energy while the pre anoxic process uses the wastewater BOD.

Sequencing batch reactors

The sequencing batch reactor (SBR) process is a fill and draw activated sludge system for wastewater treatment (EPA, 2000). In SBR a single "batch" reactor is used where wastewater is added and then treated before been discharged (EPA, 2000). In SBRs influent is allowed into the tank that performs aeration, setting of the water and recycling of solids (Metcalf and Eddy, 2003). The advantage of using SBR system is that it has the ability to treat different influent flow rates unlike the activated sludge system which works with a fixed flow rate. According to Metcalf and Eddy (2003) the operation of SBR occurs in batch condition and it is effective in removing up to 75% of COD and 95% NH_3-N during the aerobic treatment with the residence time of 20-40 days.

The mixed filled non-aerated period is the most effective method of denitrification because it also eliminates the bulking of sludge (Metcalf and Eddy, 2003).

The SBR consist of five stages namely fill, react, settle, draw and idle stage as indicated in Figure 2.4-5. The process begins with a fill of which during this fill operation, volume and substrate (Raw wastewater or primary effluent) are added to the reactor. During the fill process the reactor mixed only or mixed and aerated to promote biological reactions with the influent wastewater (Metcalf and Eddy, 2003).

Figure 2.4-5: Operation sequence of SBR (Source: Metcalf and Eddy, 2003)

The operation process of a SBR is described as follow:

Anoxic Fill: The wastewater influent is distributed onto the settled sludge, thereby providing better contact between the micro-organisms and the substrate. Either gravity or pumping system can be used to distribute the influent. During this period aeration is absence to create favourable environment for the procreation of micro-organisms while settling down. After this period aeration is allowed to consume (Metcalf and Eddy, 2003).

Aerated Fill: Mixed liquid is drawn which is then mixed into the influent that is flowing. By mixing the sludge and the influent this creates the feast period. Feasting is defined as the substrate consumption caused by the micro-organisms which has been in contact with the substrate and a large amount of oxygen. At the beginning of this stage nitrification and denitrification occurs. The ending of this period is when the maximum time has been reached or the tank is full.

Settle: During the settling stage the aeration process is stopped and the solids are allowed to settle thereby causing separation to takes place, leaving a clear treated effluent above the sludge blanket. To avoid turbulence no liquids is allowed to enter or leave the tank that is during the clarifying period.

Decant: The decant period is the period whereby the treated effluent is withdrawn from below the surface of the mixed liquor by the floating solids excluding decanter. The removal must be done with care to avoid the disturbing of the settled sludge.

Idle: The time in this stage can be used to waste sludge or perform backwashing of the jet aerator. The wasted sludge is pumped to an anaerobic digester to reduce the volume of the sludge to be discarded. The frequency of sludge wasting ranges between once each cycle to once every two to three months depending upon system design.

Advantages and Disadvantages

Some advantages and disadvantages of SBRs are listed below;

Advantages

- Equalization, primary clarification (in most cases), biological treatment, and secondary clarification can be achieved in a single reactor vessel.
- The operation is flexible and can be control.
- Minimal footprint.
- Capital cost can be saved by eliminating clarifiers and other equipment.

Disadvantages

- A higher level of sophistication is required (compared to conventional systems), especially for larger systems, of timing units and controls.
- Higher level of maintenance (compared to conventional systems) associated with more sophisticated controls, automated switches, and automated valves.
- Potential of discharging floating or settled sludge during the DRAW or decant phase with some SBR configurations.

- Potential plugging of aeration devices during selected operating cycles, depending on the aeration system used by the manufacturer.
- Potential requirement for equalization after the SBR, depending on the downstream processes.

2.5. Nitrogen Cycle

2.5.1. Overview on nitrogen

“The elements nitrogen and phosphorous are essential to the growth of microorganisms, plants, and animals, are known as nutrients or biostrimulants” (Metcalf and Eddy, 2003). Nitrogen is important to life on earth of which nitrogen gas makes up 78% of the atmospheric gas (Metcalf and Eddy, 2003).

Definition of Nitrogen Cycle

The nitrogen cycle refers to a continuous series of natural processes by which nitrogen passes from its inert gaseous state (air) to the soil, to plants and finally to sustain all animal life / biological process, and then returns back to the atmosphere or soil through denitrification/decay. The nitrogen cycle can be divided naturally into four processes namely: Nitrogen fixation, nitrogen decay / decomposition, nitrification and denitrification. Figure 2.5-1shows the nitrogen cycle.

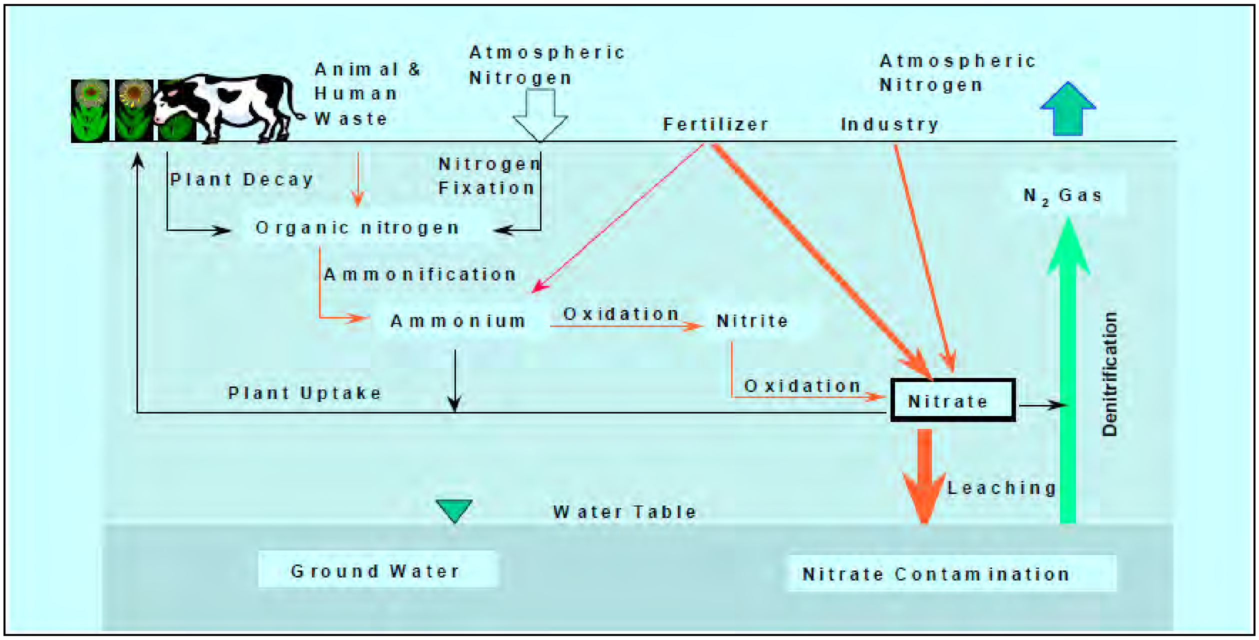


Figure 2.5-1: The Nitrogen cycle (Deng, 1998)

2.5.2. Fixation of Nitrogen gas

Nitrogen fixation is a natural process which can either be biological or abiotic by which nitrogen (N_2) in the atmosphere is transformed / converted into ammonia (NH_3) by an enzyme called nitrogenase (Postage, 1998). The fixation of nitrogen is carried out by microorganisms called Diazotrophs.

Nitrogen fixation includes a number of oxidation reduction process / reaction. The reaction reduction process can be represented by

$$N_2 + 6e^- + 8H^+ \rightarrow 2NH_4^+ (ammonium\ ion)$$

Diazotrophs are found in the roots nodules of legume plants. Nitrogen fixing bacteria can also be found in landfills as anaerobic condition continues in the landfill.

The introduction of nitrogen into landfill can also be through precipitation of water and or surface runoff from agricultural lands. Some nitrogen content maybe found within this water because of the accumulation of the leached ammonia in fertilizer.

According to Harrison (2003) once the nitrogen is added into organic matter it can be converted back into an inorganic state by decay. During the decay process large amount of nitrogen that has be converted to ammonium by the dead organism, the nitrogen is then available for the plants to use and can then be transformed further into nitrate through the process of nitrification (Harrison, 2003).

2.6. Nitrification and Denitrification

2.6.1. Nitrification

Nitrification is defined as the process whereby ammonia ion is oxidized into nitrate ion and then nitrite ions in wastewater by bacterial or chemical reactions (Metcalf and Eddy, 2003).

2.6.1.1. Microbiology

In nitrification there are two main bacteria which are responsible for the nitrification/converting ammoniacal nitrogen ($NH_3\ or\ NH_4^+$) into nitrate (NO_3^-) namely *Nitrosomonas* and *Nitrobacter*, this process is performed by autotrophic bacteria called nitrifying bacteria. The process of nitrification occurs under aerobically condition.

The two step process involves the oxidation of ammoniacal nitrogen to nitrite as indicated in the equations below and it is performed by bacteria called nitrosomonas which is the main one while the second step/phase involves the oxidation of nitrite to nitrate as indicated in the equation and this is performed by autotrophic bacterium called nitrobacter.

Oxidation of Ammoniacal Nitrogen to Nitrite

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$$

Nitrosomonas

Oxidation of Nitrite to Nitrate

$$2NO_2^- + O_2^- \rightarrow 2NO_3^-$$

Nitrobacter

Synthesis reaction (the oxidation of ammonium, biomass growth expression)

$$15CO_2 + 13NH_4^+ \rightarrow 10\ NO_2^- + 3C_5H_7NO_2 + 4H_2O + 23H^+$$

Nitrate Oxidation, biomass growth expression

$$5CO_2 + NH_4^+ + 10\ NO_2^- + 4H_2O \rightarrow 10\ NO_3^- + C_5H_7NO_2 + H^+$$

The overall reaction for nitrification from ammonium to nitrate

$$14\,NH_4^+ + 1.856\,O_2 + 1.979\,HCO_3^- \rightarrow 0.0206\,C_5H_7NO_2 + 0.979\,NO_3^- + 1.876\,H_2O_3$$

The nitrification process is greatly influenced by pH (acidity), temperature, moisture content, inorganic carbon source, and ammonium – nitrogen concentration and dissolved oxygen (Vymazal, 1995 citied by Pisano, 2007). Although each of the factors will be discussed separately below, they are interrelated. There is a range of 25 – 35 °C in temperature in pure culture and in soil the optimal temperature range is 30 – 40 °C for the growth of nitrosomonas and nitrobactor.

2.6.1.2. Factors influencing nitrification

As stated in the section above, nitrification is influenced by pH (acidity), temperature, moisture content, inorganic carbon source, concentration of ammonium-nitrogen and dissolved oxygen (Vymazal, 1995 cited by Pisano, 2007).

pH (Acidity): During the conversion of ammonium to nitrite to nitrate acid is produced therefore this conversion is an acid producing reaction as nitrate is produced in form of nitric acid and the nitrifiers are very sensitive to acid. According to Gerber (1999) every $1mg.l^{-1}$ of ammoniacal nitrogen that is converted about $7.14mg.l^{-1}$ of alkalinity is consumed. If the leachate does not have enough alkalinity the reactor will be unable to buffer against the decreasing pH. In acid soil nitrification process proceeds slowly.

Reaction are most rapid at pH=7 then at pH=8.5 and at pH=6.5, therefore a pH range from 7 to 8.5 are more favorable than 6.5 to 7 (Dockhorn et al, 1997). Ammonia (NH_3) and Ammonium ion (NH_4^+) exist at different concentration, this concentration depends on the pH and temperature of the solution which means high temperature and pH produces a high concentration of ammonia while low temperature and pH inturn produces higher concentration of ammonium ion.

Moisture content: the nitrification process or nitrifer does not perform well in an acid condition hence moisture is needed for nitrification.

Dissolved oxygen: oxygen is an important requirement for nitrification to occur even though nitrification does occur in the bottom of the waste where oxygen hardly get, however the diffused oxygen is transferred down with the help of water hence enabling nitrification to occur in the soil.

Organic carbon source (waste): nitrification process depends on the C:N ratio for it to occur. Nitrification performs well in a low C:N ratio that is where the nitrogen containing organic matter is slightly high.

Temperature: Ammonical nitrogen is sensitive to temperature for example at 15°C and 35°C the pH is 9.564 and 8.947 respectively (Gerber, 1999). At higher temperature ammonica nitrogen solution is more toxic. A higher temperature or an increasing temperature ammoniacal nitrogen solution decreases so the nitrification process of ammoniacal nitrogen by bacteria increases (Burton & Watson-Craik, 1999 citied by Gerber, 1999). The production of nitrate is normally high at a temperature between 30 – 35 °C. 5 °C and 4 °C are the minimum temperature for the growth of nitrosomonas and nitrobacter that are responsible the nitrification process (Cooper et al, 1996 cited by Pisano, 2007). At higher temperature and pH denitrification is much more efficient.

2.6.2. Denitrification

The biological removal or reeducation of Nitrate (NO_3) to Nitrogen gas (N_2) by facultative heterotrophic bacteria is called ***denitrification*****.** For the denitrification process to take place the heterotrophic bacteria requires a carbon source which will act as a food for it to live (Metcalf & Eddy, 2003).

The process of denitrification occurs under anaerobic conditions, where the carbon is used as food source for the bacteria as stated above (Metcalf & Eddy, 2003). Facultative bacteria are responsible for the denitrification process, this bacteria utilizes the oxygen which they get by taking dissolved oxygen out of the water or by taking oxygen out of the Nitrate Molecules (Metcalf & Eddy, 2003). The molecular oxygen in the nitrate is used as an electron acceptor under anoxic condition. Anoxic condition is when free oxygen (O_2) is absent but molecular oxygen eg NO_2^-& NO_3^- are present.

The steps at which denitrification proceed is as follow:

$$2NO_3^- \rightarrow 2NO_2^- \rightarrow 2NO \rightarrow N_2O \rightarrow N_2$$

According to Pisano, 2007 in order for bio-denitrification to occur a supplement of carbon source is required. The following organisms are required for the denitrification process to occur diazotrophic, phototrophs,Organotrophs, and lithotrophs. According to Metcalf and Eddy (2003) the equation below shows the reduction of nitrate using carbon source.

$$Carbon\ Source + aNO_3^- \rightarrow xN_2 + yCO_2 + 2H_2O + aOH^-$$

For the denitrification process to occur the system should be under anaerobic and anoxic conditions which achievable by either one of the treatment process suspended growth processes or attached growth processes (Metcalf and Eddy, 2003).

2.6.2.1. Factors influencing denitrification

Heterotrophic denitrification is influenced by the following factors Oxygen, Temperature, pH and the availability of Organic Carbon and type.

Oxygen Availability: Dissolved oxygen prevents the necessary enzymes for the electron transfer but act as a strong inhibitor in the denitrification process (Karnaros and Hyberatos, 1998). The bacteria responsible for denitrification are facultative anaerobe. They use atmospheric oxygen for the oxidization process of organic molecules in order to obtain energy, but in the unavailability of oxygen the bacteria uses oxygen from the nitrate (NO_3) for the oxidation process.

The concentration of atmospheric oxygen is dependent on the rate at which oxygen is consumed as well as on the rate of replenished and the soil pore space that is filled with air. According to studies done by Karnaros and Hyberatos (1998) citied by Naidoo (1999) it shows that for Pseudomonas denitrification the reduction of nitrate was less sensitive while for reduction of NO and / N_2O there was a complete suppression by dissolved oxygen.

At a concentration of 6mg/ℓ of dissolved Oxygen (DO) denitrification process can be obtained, but it has been found that an increase in DO from 0.2 to 2.0 mg/ℓ decreases the denitrification rate by 50% to 10% of the anoxic valves (Naidoo, 1999). Low DO is not helpful for the denitrification process but it is possible. However, it is recommended that to prevent the preferential usage of DO as an electron acceptor instead of NO3 the concentration of the DO should be < 0.5mg/ℓ in suspended culture (Naidoo, 1999). It is agreed by most researchers that if the micro-environment is anoxic then the denitrification process will continue even if they DO concentration is noticeable on the macro-environment (Naidoo, 1999).

Temperature: Temperature is an important factor in the denitrification process as it has been found by researchers that the denitrification rate doubles to triple with 10°C increase in the soil temperature of 10-30°C. The denitrification rate is optimum at a temperature between 28-60°C however in thermophic condition (50-60°C) nitrate removal rate is approximately 50% greater than those at mesophilic condition of 35°C (Henze et al, 1997).

Generally an increase in temperature up to a maximum of 50-60°C increases the denitrification rate, any further increase above 60°C drops the denitrification rate (Abufayed and Schroeder, 1986).

pH: During the denitrification reaction carbon alkalinity and pH are produced, however the pH is elevated when nitrate is produced (Naidoo, 1999). According to studies conducted by Dodd and Bone (1997) cited by Naidoo (2000) on batches having a pH valve of 7.0, 7.5, 8.0 and 8.5 it was discovered that at a pH of 7.5 denitrification occurs optimally. It was also observed that nitrate release reduced quicker at a pH above the optimum. However, at a pH range of 6.0 and 8.0 the denitrification rates are high and an optimum rate of denitrification is obtained at a pH of 7.5 (Plug et al, 2010).

During the denitrification process a pH increase is expected but the magnitude of increase depends on the wastewater buffering capacity (Christensen and Harremoes, 1997 citied by Nadioo, 1999). For denitrification kinetics optimization the pH should be regulated between 7 and 8. Hence pH control is essential for achieving complete denitrification.

Organic Carbon Substrate: The availability of organic carbon (biodegradable substrates) influences the denitrification rate greatly. These biodegradable substrates are used as electron donors.

2.7. Biological Denitrification Process and Technology

2.7.1. Attached growth process

The process of attach growth biological treatment process uses microorganisms that are fixed on the solid surface. The microorganisms remove organic materials from the water as the water passes through and around the solid. There are a number of different types of attached growth process but the most common is the trickling filter which is commonly used for municipal wastewater treatment. Other form of attached growth processes includes the moving bed biological reactor (MBBR) and the rotating biological contactor.

Trickling filters: a trickling filter is a bed of gravel of plaster media over which pretreated wastewater is spread (Lesikar and Persyn, unknown date)

Selection of treatment process

The selection of the treatment process is based on a lot of factors such as age of the leachate, installation and operational cost including the requirement of skilled personnel. **Error! eference source not found.**compares the different treatment techniques in terms of treatment efficiency, space utilization, installation and operational cost.

Table 2.6-1: Comparison base on treatment efficiency, space utilization, installation and operational cost (Madu, Unknown date).

Treatment process	Young leachate	Medium leachate	Old leachate	Space utilization	Installation and operational cost	Requiring less skilled personnel
Biological						
Activated sludge	Good	Fair	Poor	Poor	Expensive	No
RBC	Good	Fair	Poor	Good	Expensive	Yes
SBR	Good	Fair	Poor	Good	Less expensive	No
Reed beds	Fair	Fair	Good	Poor	Less expensive	Yes
BAF	Good	Fair	Fair	Good	Expensive	Yes
Lagoons	Good	Fair	Poor	Poor	Expensive	Yes
UASB	Good	Fair	Fair	Good	Less expensive	Yes
AF	Good	Fair	Fair	Good	Expensive	Yes
MBBR	Good	Fair	Poor	Poor	Expensive	No
MBR	Good	Fair	Fair	Poor	Expensive	No
Physicochemical						
Coag. & flocculation	Poor	Fair	Fair	Fair	Less expensive	No
Precipitation	Poor	Fair	Poor	Fair	Less expensive	No
Adsorption	Poor	Fair	Good	Good	Less expensive	No
Flotation	Poor	Fair	Fair	Poor	Expensive	Yes
Chem. Oxidation	Poor	Fair	Fair	Good	Expensive	No
Ammonia stripping	Poor	Fair	Fair	Poor	Expensive	No
Membrane process						
Microfiltration	Poor	Poor	Poor	Good	Expensive	Yes
Ultrafiltration	Fair	Fair	Fair	Good	Expensive	Yes
Nanofiltration	Good	Good	Good	Good	Expensive	Yes
Reverse Osmosis	Good	Good	Good	Good	Expensive	Yes

2.8. Case Study

This chapter presents a brief discussion of the two major landfills within the eThekwini Municipality namely Mariannhill landfill site and Bisasar Road Landfill. The purpose for selecting this landfills because at Mariannhill landfill site the SBR treatment plant is well established, the leachate from the SBR has undergone the process of nitrification hence this research is on denitrifying the leachate from the SBR plant by means recirculating of leachate through the organic waste, for this reason Bisasar Road Landfill was selected because there are mini-landfill (cells) to run the experiments. The chapter will give an insight of the waste management within these two landfills and will also explain the construction of the mini landfill (test cells) at Bisasar Road Landfill.

2.8.1. The Mariannhill Landfill site

As stated in chapter 1 of the document, the aim of this research is to determine the viability of using pre-treated domestic waste of different degree of stability (carbon contents) as a carbon source for the in-situ bio-denitrification of leachate by means of leachate recirculation through the landfill. This carbon source (organic substrate) will be used in the future in a full scale reactor at Mariannhill landfill site to polish the wastewater (leachate) that has been treated in the SBR.

The polishing treatment is essential as the leachate should adhere to the environmental and conservation standard before its discharge into stream or the environment.

Mariannhill landfill site is situated about 20km west of Durban in the KwaZulu-Natal municipality as shown in Figure 2.8-1. The landfill is managed by the eThekwini municipality. The landfill was opened in 1997 and it receives between 550 and 700 tons of solid waste per day (Strachan et al, 2002).

Figure 2.8-1: Mariannhill Landfill Site (Source: Google map, 2011)

This waste received by Mariannhill is collected from eThekwini area by trucks. As the truck enters the landfill it is weight of waste and also weighed on departure to that the weight of waste entering the landfill can be monitored. The waste are deposited at their specific cell and compacted after being sorted and separated. At the end of a day work each layer is covered with a soil layer which could allow vegetation to grow that is done after that layer has being compacted to a suitable strength.

The leachate from the Mariannhill landfill contains a high concentration of ammonia-nitrogen. This ammonia-nitrogen is harmful to the plants and an animal including the aquatic life, for this reason treatment of the leachate is of great importance. The leachate undergoes a biological treatment using the SBR treatment process (Figure 2.8-2). The SBR unit is a reinforced concrete unit with has a diameter of 10mand a depth of 6m. According to Trois et al, 2010a the SBR is allowed to treat up to 50m^3 of leachate daily.

As a polishing treatment reed bed system (Figure 2.8-2) is being used because of the low cost and other factors. The reed bed is 280m^2 which is used to remove specifically residual BOD, COD and solids.

Figure 2.8-2: Aerial view of Mariannhill Leachate Treatment Plant (Novella et al, 2005)

The operation treatment of leachate at Mariannhill is as follow, the raw leachate is fed into the SBR tank where it is treated for ammonia-nitrogen after the treatment has been achieved the treated effluent from the SBR is fed into the balance tank. The SBR treats leachate for NH_3-N but most ammonia is converted into Nitrate through the process of Nitrification. Hence this leachate contains high concentration of Nitrate which exceeds the discharge limit of DWAF (DWAF, 1998). A portion of the effluent in the balance tank is used to control dust (dust suppresser) and the other portion of the effluent is fed into the reed bed after which the effluent from the need bed is used for irrigating the conservancy area at the landfill.

2.8.2. Bisasar Road Landfill

Bisasar Road landfill site is situated in the Springfield District within the eThekwini Municipality area. According to Strachan et al, (2002) the landfill has a capacity of 21 million m^3 which has over 20 operational cells and can accommodate up to 130 deposition cells. The landfill was opened in 1980 and it receives between 3500 and 5200 tons of municipal solid waste per day (Strachan et al, 2002) hence it is considered the largest landfill in Africa (Robinson et al, 1997)

Construction and filling of test cells

A series of five cells were constructed in 2007 at Bisasar Landfill site in Durban by Oscar Simelane (2007) these test cells simulates the shallow landfills. The test Cells had an overall dimension of 12.5 m x 12.5 m x 1 m high with an average volume of 35 m^3.

The construction of these test cells was as follow (Simelane, 2007)

- Site clearing and marking of dimensions
- Construction of cell walls (Figure 2.8-3)
- Installation of Geosynthetic Clay Liner (G.C.L)
- Installation of protective layer (Geofabric liner)
- Installation of leachate drainage layer (53 mm stone and leachate pipe)
- Installation of biogas probes

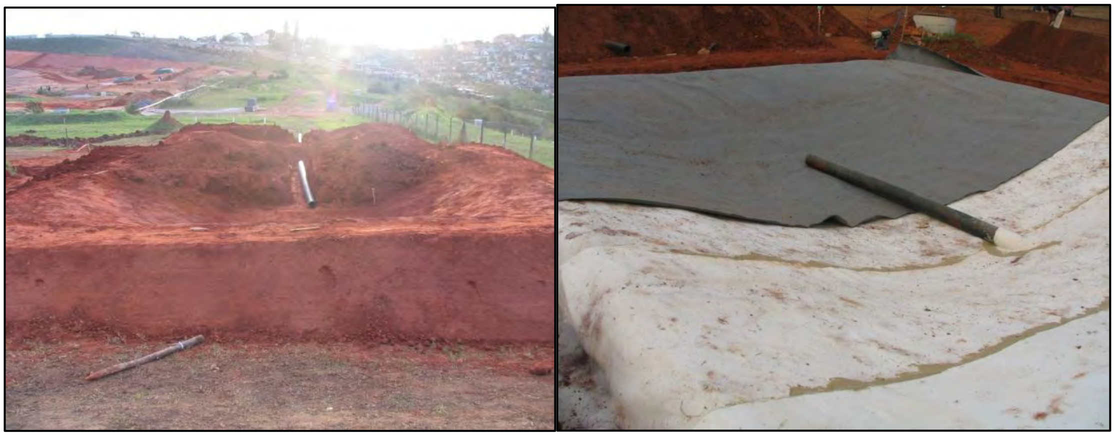


Figure 2.8-3: Construction of cell walls and installation of GCL and protective (Simelane, 2007)

Different waste types were filled into the test cells at Bisasar Landfill. The waste type was differentiated with respect to the treatment period of the waste and their size (particles) namely 8 weeks fine, 16 weeks fines, 8 weeks treated MSW, 16 weeks MSW and Un-treated MSW (Control) as indicated in Figure 3.2-2. The 8 weeks fine was filled in Cell 1 and the 16 weeks fine was filled in Cell 2. In order to obtain the 8 and 16 weeks pre-treated waste a 50mm sieve was used to sieve the 8 and 16 weeks unsorted global pre-treated waste (Simelane, 2007). As the research was based on investigating the viability of pre-treated general waste at different degrees of stability (carbon contents) as carbon source for in-situ bio-denitrification in landfills, therefore it was necessary to use the separated level of stability mainly the 8 weeks treated fine and 16 weeks treated fines. The cell No., type of waste filled in each cell, the volume of waste including its mass of waste is shown in table.

Table 2.8-1: Summary of the Cell No, volume and mass of waste in the test cells (Simelane, 2007)

Test Cell No.	Type Of Waste	Volume Of Waste (m^3)	Mass Of Waste (Metric Tonnes)
1	08 weeks treated fines	41.1	20.6
2	16 weeks treated fines	40.1	20.1
3	08 weeks treated MSW	35.5	17.8
4	Un treated MSW	32.1	16.1
5	16 weeks treated MSW	38.8	19.4

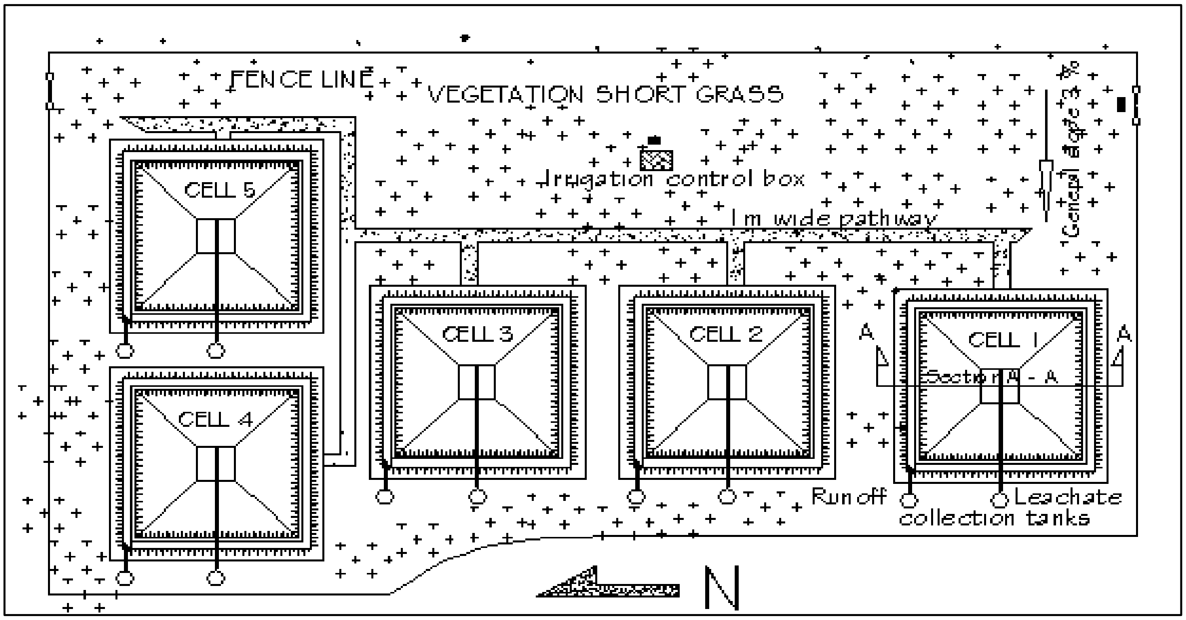


Figure 2.8-4: General layout of the test cells (Simelane, 2007)

As the research was based on investigating the viability of pre-treated general waste at different degrees of stability as carbon source for in-situ bio-denitrification in landfills by means of recirculation of leachate, the test cells substrate were used to test viability of the pre-treated waste.

The domestic wastes (substrates) were sampled from the test cells (mini-landfills) at the Bisasar Road landfill in Durban. In this research, treated leachate with a concentration of 500 mg/ℓ was used. However, due to the unavailability of bacteria, the treated leachate had to be seeded with untreated leachate.

Treated Leachate was collected from the SBR balance tank at Mariannhill landfill in Durban, the treatment of leachate was done using a small scale batch tests. The composted domestic waste was used as a carbon source.

In order to carry out the investigation, the first step was to collect sample from the mini-landfills (cells) mainly Cell 1 and Cell 2 which was then characterized as explained in chapter 3. Samples from the other cells could not be collected because the waste was not sorted, which made sampling very difficult; hence cell 1 and cell 2 samples were used. The tests were conducted on the solid substrates (dry solid) and on the eluate sample.

3. METHODOLOGY AND MATERIALS

3.1. Introduction

The experiments carried out in this research were developed in order to investigate the feasibility of using composted domestic waste to remove nitrates from landfill leachate (Denitrification) in order to implement the in-situ denitrification by means of recirculation of leachate.

The Civil Engineering Department Environmental laboratory was used to conduct the experiments. All experiments and analysis were done in accordance with the ***Standard Methods for Examination of Water and Wastewater (20th Edition).***

A summary of the approach to the research work is indicated by Figure 3.1-1:

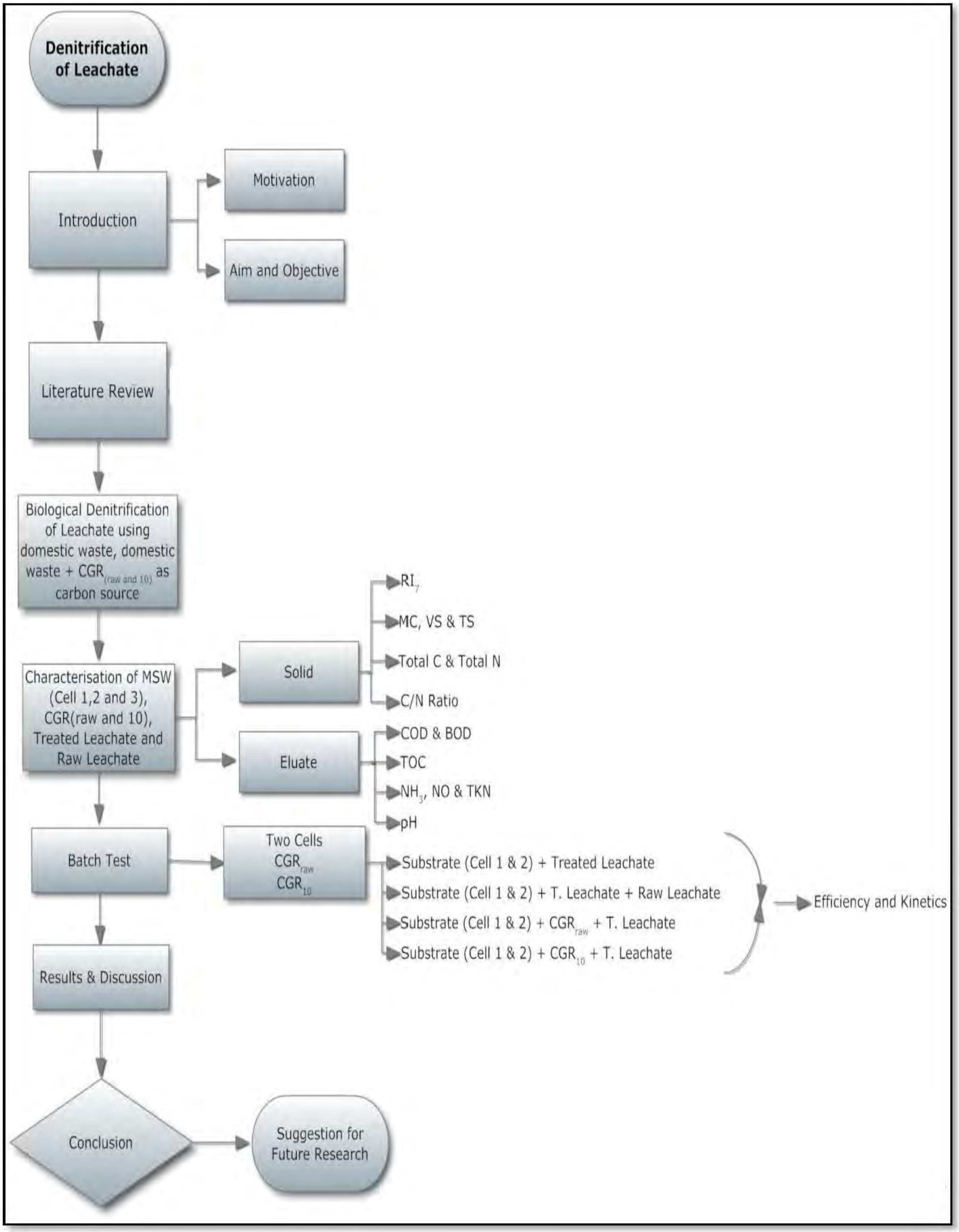


Figure 3.1-1: Research Framework

3.2. Materials

3.2.1. Substrates

Pre-Treated Domestic Waste

The composted domestic waste (Figure 3.2-1) used for this research were sourced from test cells at Bisasar Road Landfill site, the domestic waste were grouped into 8 weeks fine, 16 weeks fines as indicated in Figure 3.2-2 and Figure 3.2-3 respectively. The test cells were filled with different types of wastes. The waste type was differentiated with respect to the treatment period of the waste and their size (particles). Cell 1 contained MSW which were composted for 8 weeks while Cell two contained MSW that had been composted for 16, in order to obtain the fine the unsorted global MSW had undergone a sieving process using a 50mm sieve. As the research is on investigating, the feasibility of using composted domestic waste to denitrify leachate by means of recirculation of leachate through MSW hence this substrate from the test cell at Bisasar Road landfill was chosen.

Figure 3.2-1: Composted Domestic Solid waste

Figure 3.2-2: Cell 1-8 weeks treated waste fines (mini-landfill)

Figure 3.2-3: Cell 2-16 weeks treated waste fines (mini-landfill)

Fresh Commercial Garden Refuse (CGR_{raw}) and Commercial Garden Refuse (CGR_{10})

The Fresh Commercial Garden Refuse (CGR_{raw}) consists of organic deposit that is mainly of branches and plant trimmings from parks and green municipal areas, this organic deposit are reduced into approximately 4-5 cm in length by passing them (CGR_{raw}) through a chipper to reduce the size as shown in Figure 3.2-4. This material is separated from the waste main stream.

The Commercial Garden Refuse (CGR_{10}) consists of the same organic waste, the CGR_{raw} the organic waste were mainly branches from plant trimmings and green municipal areas. The substrate (CGR_{10}) was composted for ten weeks.

Figure 3.2-4: CGR_{raw} and CGR_{10}

Leachate

Leachate samples used was collected from the Sequencing Batch Reactor (SBR) at the Mariannhill landfill site. Treated and untreated (mixed liquor) leachate were collected. The treated leachate from the SBR was diluted with distilled water in order to obtain a concentration of 500 mg/ℓ of NO_3.

Mixing of different substrates

Cell 1 + treated leachate batch was conducted and the duration of nitrate removal was observed. As a form of comparison, Cell 1 was mixed with other substrate such as CGR_{raw} and CGR_{10} respectively using a ratio of 1:1, this both batch where conducted in the presence of treated leachate. This was done to observe if the mixing of Cell 1 with other substrates would increase the kinetics efficiency of the batch tests. The same mixtures were also done to the Cell 2 substrates.

3.3. Sampling

All substrates were sampled from Bisasar landfill from the respective test cells (Mini-landfill) as shown in Figure 3.3-1and Figure 3.3-2. The substrates from the test cells (cell 1 and cell 2) had to be sieved to remove plastics and large stones as indicated in Figure 3.3-3.

Figure 3.3-1: Cell 1 (8 weeks treated waste fines)

Figure 3.3-2: Cell 2 (16 weeks treated waste fines)

Figure 3.3-3: Substrates sieved to remove plastic and large stones

3.3.1. Solid Sampling

CGR_{raw} and CGR_{10} solid matter were cut into small particles of 50mm in size to make it easy to handle and all foreign substances such as plastics bags were removed.

In order to obtain a representative sample size, each pile (Cell 1, Cell 2, CGR_{raw} and CGR_{10}) of substrates was quartered using the standard method (Pisano, 2007).

To obtain a more homogenous sample each substrate pile was thoroughly mixed thoroughly. Thereafter, each pile was then divided into four parts after which two diagonally opposite quarters were mixed while the other two diagonally opposite quarters removed, as indicated in Figure 3.3-4. The remaining two diagonals that were mixed were again divided into 4 parts. This procedure was repeated until a small size of sample was achieved. The above procedure was done for all the substrates.

Figure 3.3-4: Quartering method to get a representative sample

3.3.2. Eluate Samples

The quartering method was used to obtain a representative sample to be used in preparing the samples for eluate tests. The amount of sample to be weighted was calculated using the %MC, %TS and %VS. The solid samples was weighed into a Ezlenmyen flask and distilled water was added to reach a certain pre-calculated weight, bearing in mind that the sample already contains a certain %MC. A ratio of 10:1 of liquid to solid (L/S) was used (Tsui et al, 2007). The flasks were sealed and shaken and left for 24 hrs. After 24 hrs, shaken sample was filtered through a $63\mu m$ sieve in order to separate the eluate from the solid (EN 12457-2:2002). The following parameters pH, BOD_5, COD, NH_3 and NO_x (Nitrogen Oxide) were measured on the filtered/sieved eluate after it has been shaken and left for 24 hrs in distilled water.

To obtain a relative amount of organic compounds that can leach out from the solid waste in the presence of water (liquid), an Eluate Test had to be done (Tsui et al, 2007). Using the eluate test the quality of the leachate could be predicted. According to Tsui et al (2007), the eluate test, was conducted to assess the amount and nature of the compound released by the substrates when it was in contact with distilled water for 24 hours.

3.3.3. Leachate Sample

Treated and untreated leachate samples were collected from the Mariannhill Landfill site. The untreated leachate (mixed liquor) was collected from the sequencing batch reactor (SBR) before it was treated (Figure 3.3-5), while the treated leachate sample was collected in the SBR balance tank, before entering the wetland. The untreated leachate was collected as to seed the treated leachate so as to provide some bacteria to facilitate denitrification. A ratio of 1:100 of untreated leachate to treated leachate was used as the untreated leachate is high in ammonia

(Eaton et al., 2005). The untreated leachate from the SBR contained a high amount of ammonia as the process of nitrification occurs in the SBR tank (Metcalf and Eddy, 2003).

Figure 3.3-5: Sampling of untreated leachate (Mixed Liquor)

3.4. Characterization Test

The characterization tests were carried out in the Environmental Engineering laboratory at the University of KwaZulu-Natal, Durban, unless otherwise stated. Some specialist tests were outsourced to Bemlab laboratories in Cape Town and Stewart Group Inspection Labs in Durban. The main purpose for conducting the characterization tests is to determine and understand the physical and chemical characteristics of the substrates that are being used, thereby creating a reference point for the experiments. This will help in accessing how effective the substrate is in denitrifying.

An extensive characterization of the substrates including the untreated (mixed) liquor and treated leachate used was conducted. The analyses were conducted using the American Standard Methods for Examination of Water and Wastewater (ASTM) and tests were repeated in triplicate for accuracy and repeatability (Eaton et al., 2005).

Solid

On the solid material, the following tests were conducted:

- Moisture Content (MC),
- Total Solid (TS),

- Volatile Solid (VS),
- Respiration Index (RI_7),
- Total Nitrogen (Tot N),
- Total Carbon (Tot C) and

The parameter Carbon to Nitrogen ratio was calculated from the total carbon divided by the total nitrogen.

Table 3.4-1 shows a summary of the analysis (Characterization Tests) conducted in the UKZN environmental engineering lab and those outsourced.

Eluate

On the eluate test the following analysis were conducted:

- pH,
- Total Solid (TS),
- Volatile Solid (VS),
- Chemical Oxygen Demand (COD),
- Biochemical Oxygen Demand (BOD_5),
- Ammonia (NH_3),
- Total Carbon (Tot C) and
- Total Nitrogen (Tot N).

The aim of the eluate test as stated in section 3.3.2 is to assess the amount and nature of the compounds leached out for the substrate when in contact with distilled water for 24 hours (Trois et al, 2010)

After the leachate was sampled characterization tests were conducted to understand the nature of the leachate. The following parameters were analyzed pH, TS, VS, COD, BOD_5, NH_3, NO_x (NO_2 and NO_3), Tot N and Tot C. The results of characterization are presented in Chapter 4 (Section 4.2). The experiments were performed in duplicates, triplicates or more in order to verify precision, also remove biasness in results, and ensure repeatability.

Table 3.4-1: Summary of Characterization Tests each Substrate and Leachate

	Test Conducted	Standard Method	Laboratory
SOLIDS	Moisture Content (%)		
	Total Solids (%)	2540B	
	Volatile Solids (%)	2540E	
	RI_7 (mgO2/g DM)		
	Total Carbon (%)		BemLab
	Total Nitrogen (%)		BemLab
	C/N Ratio		BemLab
ELUATE	Total Solids (g/L)	2540B	
	Volatile Solids (g/L)	2540E	
	pH		
	Cond. (mS/cm)		
	COD (mg/L)	5220D	
	BOD_5 (mg/L)	DIN38409-H52	
	NH_3-N (mg/L)		Stewart Group
	NO_X-N (mg/L)		Stewart Group
	Total Carbon (%)		BemLab
	Total Nitrogen (%)		BemLab
	C/N Ratio		BemLab
LEACHATE	Total Solids (g/L)	2540B	
	Volatile Solids (g/L)	2540E	
	pH		
	Cond. (mS/cm)		
	COD (mg/L)	5220D	
	BOD_5 (mg/L)	DIN38409-H52	
	NH_3-N (mg/L)		Stewart Group
	NO_X-N (mg/L)		Stewart Group
	Total Carbon (%)		BemLab
	Total Nitrogen (%)		BemLab
	C/N Ratio		BemLab

Tests done on Solid Substrate

3.4.1. Moisture Content (MC)

The ratio of the mass of water to the total mass of the sample is defined as Moisture Content, MC can be illustrated by the following equation below:

Moisture Content Formula

$$MC(\%) = \frac{Mass\ of\ wet\ sample - Mass\ of\ dry\ sample}{Mass\ of\ wet\ sample}\, x\ 100 \text{............Equation 3.4-1}$$

The procedure used to measure the moisture content is as follow: Approximately 100 g of solid sample (each substrate) was weighed into crucibles at room temperature, after which it was placed into the oven at 105℃ for 24 hours as shown in the figure. Thereafter the heated samples were placed in desiccators to cool down. The desiccator contains silica gel underneath as illustrated in Figure 3.4-1. The silica gel inside the desiccators absorbs any moisture that is present. The desiccators should be moisture free. After cooling down the sample to obtain the mass of the dry sample the cooled down sample is weighed again. Thereafter the moisture content is calculated using equation 3.4-1.

Figure 3.4-1 : Dried samples in oven and cooling down of sample in dessicator after heating

3.4.2. Total Solids (TS) and Volatile Solids (VS)

Total Solids is the measurement that represents the quantity of total solid residue that remains after the sample has been oven dried at 105℃ for 24 hours. The test is conducted in accordance with the Standard Method for the examination of wastewater by Eaton et al., 2005no. 2540 G, D and it is calculated by equation

Total Solid Formula

$$Total\ Solids\ (\%) = \frac{Mass\ of\ dry\ sample}{Mass\ of\ total\ sample}\ x\ 100\ \ldots\ldots\ldots\ldots\ldots Equation\ 3.4-2$$

After oven-drying the sample and the TS calculated, the residue from TS test is placed in the furnace (Figure 3.4-2) which is fired / ignited at 550℃ for 2 hours in order to calculate the VS. Before placing the residue in the furnace it (furnace) should be pre-heated to 550℃.

Total VS test is used to determine the quantity of organic matter in the sample (Eaton et al, 2005). The test is conducted in accordance to the Standard Method of Examination of Wastewater and Water-no. 2540 G (Eaton et al., 2005) and Total VS calculated using equation 3.4-3

Equation 3.4-1: Total Volatile Solid Formula

$$Total\ Volatile\ Solids(\%) = \frac{Massof\ dry\ sample - Mass\ of sample\ fired\ in\ furnace}{Mass\ of\ total\ sample} x\ 100$$

Figure 3.4-2: Sample in furnace for 2 hours at 550 °C

3.4.3. Respiration Index at 7 Days (RI_7)

The biodegradability of each substrate including its stability level is determined by conducting the Respiration Index at 7 days test (RI_7); it was done using a respirometric system type oxitype (Pisano, 2007; Adani, 2006). According to Trois et al (2010) the biodegradability of the substrate is tested using RI_7 to determine how much carbon is available in the substrate to be used as an electron donor in order for denitrification process to take place. RI_7 is also used to determine the biological stability of the substrate specifying the degree of decomposition of the substrate (Plüg, 2010). The test is performed over seven days. In conducting the test the following procedure was followed:

- Four samples were measured into a flask to be above 20g.
- About 8mℓ of distilled water was added to reach field capacity. No free standing water was allowed. The field capacity is required just to create enough moisture for the microbial activities.
- A thimable was placed on the neck of the flask and 10 drops of KRH was added. The KRH was added because during the oxidation process oxygen is consumed and carbon dioxide is produced which is then absorbed by the KRH solution.
- The bottles (flask) are then sealed using clippers and placed into the incubator as indicated in Figure 3.4-3 and ran for 7 days.
- The sensor reads the pressure and the change in pressure is calculated using equation after 7 days.

Figure 3.4-3: RI_7 bottle inside incubator and measurement of RI_7

3.4.4. Total Carbon (TC), Total Nitrogen (TN) and C/N Ratio

The analyses of TC, TN and C/N ratio were conducted by Bemlab in Cape Town.

Tests done on Eluate Sample

3.4.5. pH

(Standard Methods No. 4500-H+ B, Eaton et al., 2005)

The acidity or alkalinity in a solution is measured by a pH test. The test was conducted in the eluate sample before and after the batch test using a Labotec Orion Model 410A pH meter as illustrated in Figure 3.4-4 below. According to Trios et al (2010a) the pH test is essential to determine if the effluent requires further treatment as per the discharge standard. Before using the pH meter it was first calibrated to a pH range of 4-10. The probe was dipped into the sample to obtain the pH readings. After the reading has been taken, the probe was rinsed with distilled water and wiped gently with tissue paper.

Figure 3.4-4: pH Meter

3.4.6. Total Solid (TS)

(Standard Methods No. 2540 B, D, Eaton et al., 2005)

According to Tchobanoglous et al (1985) citied by Plüg (2009), total solid tests measures the entire solid within a substance, whether suspended and dissolved, whether organic and inorganic. The TS parameter was measured by oven-drying the sample to dryness and thereafter weighing the oven-dried sample. The TS was measures in terms of grams per liter (g/l).

Empty clean crucibles were weighed and weight taken. Each crucible was filled with 24 mℓ of the eluate sample. The crucibles with the sample were then oven-dried at a temperature of 105ºC for 24 hours, thereby allowing the liquid to evaporate leaving a solid residue (TS) which was suspended and dissolved within the liquid. The crucibles were allowed to cool down in a desiccator. After the crucibles were cooled down they were weighed again to determine the mass of the dried solid residue. The TS is thereby calculated using the following equation:

$$TS\ (g/l) = W_d \frac{1000}{V_s} \ldots\ldots\ldots\ldots\ldots.\ Equation\ 3.4-4$$

where

W_d = dry mass of residue (grams)

= (Mass of oven dried sample + Mass of crucibles) – Mass of empty crucibles

V_s = Volume of sample (mℓ)

3.4.7. Volatile Solid (VS)

(Standard Methods No. 2540 E, Eaton et al., 2005)

Organic content which are represented in total and suspended solid are regarded as volatile solids (Eaton et al., 2005). VS are determined by firing the residues from the TS test in a furnace which is heated to a temperature of 550ºC, whereby the residues are fired in the furnace for 2 hours thereby converting the residue to ashes.

The crucibles with the TS residues were weighed to determine the mass before ignition. The residues were then fired and the mass taken after allowing it to cooling down, thereafter the VS are obtained using equation:

$$VS\ (g/l) = W_{vs} \frac{1000}{V_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ Equation\ 3.4-5$$

where

W_{vs} = Mass of the Volatile residue (ashes) remaining after firing (grams)

= (Mass of residue + Mass of Crucibles before ignition) – (Mass of residue + Mass of crucibles after ignition)

V_s = Volume of sample (mℓ)

3.4.8. Chemical Oxygen Demand (COD)

(Standard Methods No. 5220 D, Eaton et al., 2005)

COD is defined as the measurement of the amount of oxygen that is required for the chemical oxidation of organic matter in a sample (Metcalf and Eddy, 2003). The wastewater organic strength is determined by the COD. The COD is measured to have a rough and rapid indication of the organic pollutant inside a wastewater.

The procedure followed in measuring the COD is outlined in ASTM standard no. 5220. The COD test is carried out by combining a known amount sample of effluent with 1.5 mℓ of a solution of potassium dichromate ($K_2Cr_2O_7$). This solution was used as the oxidising agent. Sulphuric acid (H_2SO_4) of 3.5 mℓ was added to the test to create the acidic condition required for the oxidation of samples (effluent). Potassium Hydrogen phthalate (KHP) was also tested as a standard evaluation of tests. Four (4) blanks samples were also used as a baseline measurement.

The vials were placed in the digester for two (2) hours at a temperature of 180 °C as indicated in Figure 3.4-5, thereafter left to cool down at room temperature. The remaining dichromate is measured using a spectrophotometer which is set to a wavelength of 600nm (Figure 3.4-6).

The oxidant consumed is expressed in terms of oxygen equivalent using the equation below:

$$COD\ (mg\, O_2/l) = \frac{(A - B).a}{V} \dots\dots\dots\dots Equation\ 3.4 - 6$$

Where:

A= absorbance of the sample

B=absorbance of the blank sample

a= conversion coefficient (6189)

V=Volume of the sample in mℓ

Figure 3.4-5: Preparation of COD test

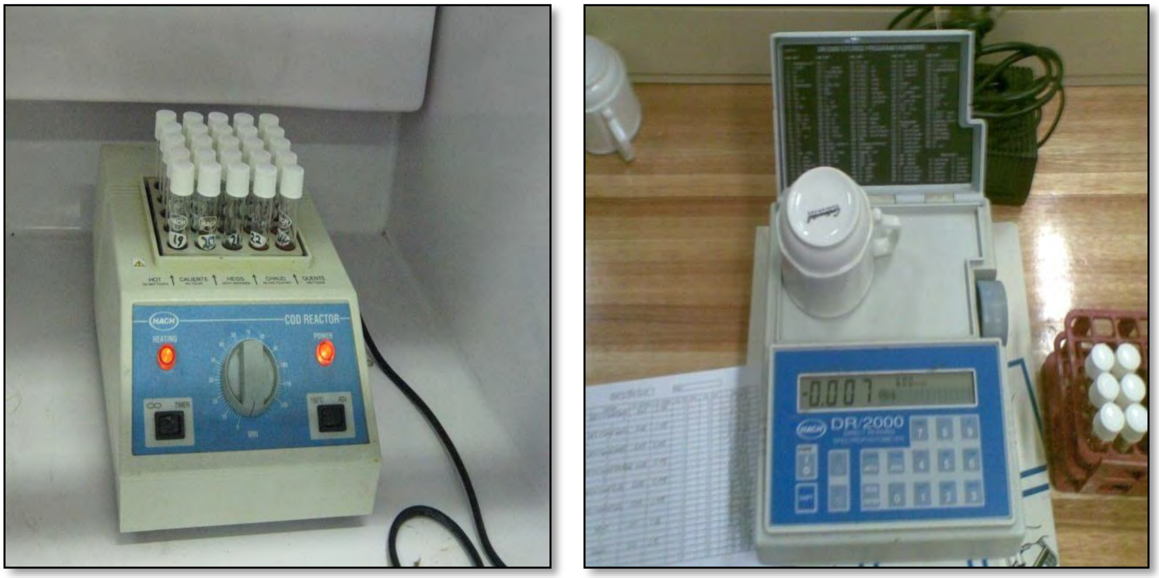


Figure 3.4-6: COD Digester and Measurement of dichromate using a Spectrophotometer with a wavelength of 600nm

3.4.9. Biochemical Oxygen Demand (BOD)

Biochemical oxygen Demand is defined as the amount of oxygen that is used up in the aerobic degradation of an organic substance (eluate) by a micro flora (microorganisms) (Metacalf and Eddy, 2003). Biochemical Oxygen Demand test gives an indication of the proportion of the amount of biodegradable matter available in the sample. BOD levels are measured in mg/ℓ of oxygen and there are usually measured over a period of 5 days (BOD_5).

Principle of Biochemical Oxygen Demand

The organic compound within the wastewater sample is consumed by the micro-organisms (bacteria, fungi, protozoa and archaca), and it all occurs in the presence of oxygen.

Carbon dioxide (CO_2), Salt (inorganic) and water are released during the oxidation process of the organic material (C_{org}) that occurs by using oxygen to oxidize the organic material biochemically as expressed in equation

$$C_{org} + O_2 \xrightarrow{microorganism} CO_2 + Salt + Water$$

In conducting the BOD test, a certain measurement range had to be selected, but since for this substrate the BOD level was unknown therefore an estimate of 80% of the COD level was taken as the maximum BOD level for the substrate under consideration. From Table 3.4-2, a sample volume of 428 mℓ, 0 – 40 mg/ℓ BOD range was used for cell 1 and cell 2. While a sample volume of 244 mℓ was used for the mixture of the cells substrates with the other substrate (CGR_{raw} and CGR_{10}), 428 mℓ and 244 mℓ were measured into the BOD test bottle using a measuring cylinder. Thereafter a magnetic stirring rod was inserted into each sample flask to ensure correct gas exchange that is by agitation the sample during the incubation period of 5 days. A clean gasket filled with 5 drops of potassium hydroxide solution (ATH) was placed on the neck of the flask. The purpose of the ATH is to suppress the nitrification process.

Table 3.4-2: Measurement Ranges with the associated sample volumes and the required amount of nitrification inhibitor (ATH) from AQUALYTIC

Measurement Range mg/l BOD	Sample Volume ml	ATH drops
0 - 40	428	10
0 - 80	360	10
0 - 200	244	5
0 - 400	157	5
0 - 800	94	3
0 - 2000	56	3
0 - 4000	21.7	1

The ATH also absorbs the carbon dioxide produced during the oxidation process. The BOD vessel is sealed by screwing the oxytop OC110 BOD sensor onto the BOD, which is then placed into the incubator for testing as indicated in Figure 3.4-7. The incubator temperature was kept at 20℃.

Measurement reading was done by taking an oxytop OC110 remote control system as shown in Figure 3.4-7. The sensomat collect the pressure value from the oxytop OC110 BOD sensor and processes it thereby giving us a BOD value in mg/ℓ.

Figure 3.4-7: BOD bottle inside incubator and measurement of BOD level using oxytop OC110 remote control

3.4.10. Ammonia (NH_3)

(Standard Methods No. 4500 B,Eaton et al., 2005)

Ammonia nitrogen ($NH_3 - N$) exists in its aqueous form and as well as an ion of ammonia (NH_4^+). The form in which it exists depends on the pH level of the solution. Ammonium ion (NH_4^+) exists in the solution if the solution has a pH of 7 while NH_3 as a dissolved gas is contained in the solution if the pH is at 12 (Pisano, 2007).

To determine the amount of ammonia-nitrogen present in a solution, the distillation and titration method was used. The procedure followed is outlined below.

20 mℓ of eluate sample was placed into a glass flask thereby distilling it into a boric acid solution as shown in Figure 3.4-8. Once a distilled sample of 250 mℓ and boric acid has been produced, the solution is titrated with a standard hydrochloric acid (HCl) of 0.1 N as shown in Figure 3.4-9, to obtain the amount of ammonia-nitrogen present in the solution which is measure in mg/ℓ.

Figure 3.4-8: Ammonia Distillation apparatus

Figure 3.4-9: Titration of 250 mℓ of Distilled sample and Boric acid using HCL of 0.1N

3.4.11. Nitrates (NO_3)

Colorimetric method was used to determine the nitrate concentration level in the solution. The Merckoquant (MERCK) stick type was used.

About 1-5 mℓ of solution was extracted from the batch bottle using a precision syringe which was then filtered through 0.45 µm filter paper as shown in Figure 3.5-2. The Merckoquant stick was dipped into the sample solution for approximately 1 second, thereafter the Nitrate (NO_3) reading is taken after 1 minute. If nitrites were observed on the stick, about four (4) drops of 2% sulphuric acid was added to the extracted solution, the sulphuric acid absorbs the nitrites in the extracted solution. The above procedure is repeated to solution in which the 2% sulphuric acid has been added thereby the NO_3 level measured as shown in Figure 3.5-3.

3.5. Batch Test

A batch test is taken as a small scale anaerobic reactor that is used to evaluate the optimal kinetic constant for denitrification. The batch test allows for optimal solid to liquid contact, therefore allowing the assessment of the efficiency of the substrate in the denitrification process.

A ratio of 10:1 (Tsui et al, 2007) of liquid-to-solid was used for the batch tests of Cell 1 while a ratio of 5:1 was used for Cell 2 batch tests, this was because the carbon-to-nitrogen ratio of cell 2 was less than that of the cell 1 batch test.

3.5.1. Batch Setup

The tests were conducted using three replicates (R1, R2 and R3) which consist of leachate solution which has a 500 mg/ℓ nitrate concentration level and substrate (solid) and one control (blank) which consists of distilled water and substrate. The equipment used in conducting the tests was a 1.5 l anaerobic vessel which is equipped with two airtight silicone septa which allows the sampling from the vessel without allowing ingress of air.

A known amount of substrate was mixed with the leachate using a ratio of 10:1 (liquid-to-solid) and the total volume of the liquid was 750 mℓ. To ensure an anaerobic condition, nitrogen gas was used to remove any air inside the bottle as the denitrification process requires an anaerobic condition. After thoroughly flushing with nitrogen (to eliminate any oxygen in the system), the bottles were sealed with the silicon seal. The sample was then placed on a shaker that was operated at 150 rpm so as to ensure a continuous and full contact of the solid with the liquid as indicated in Figure 3.5-1.

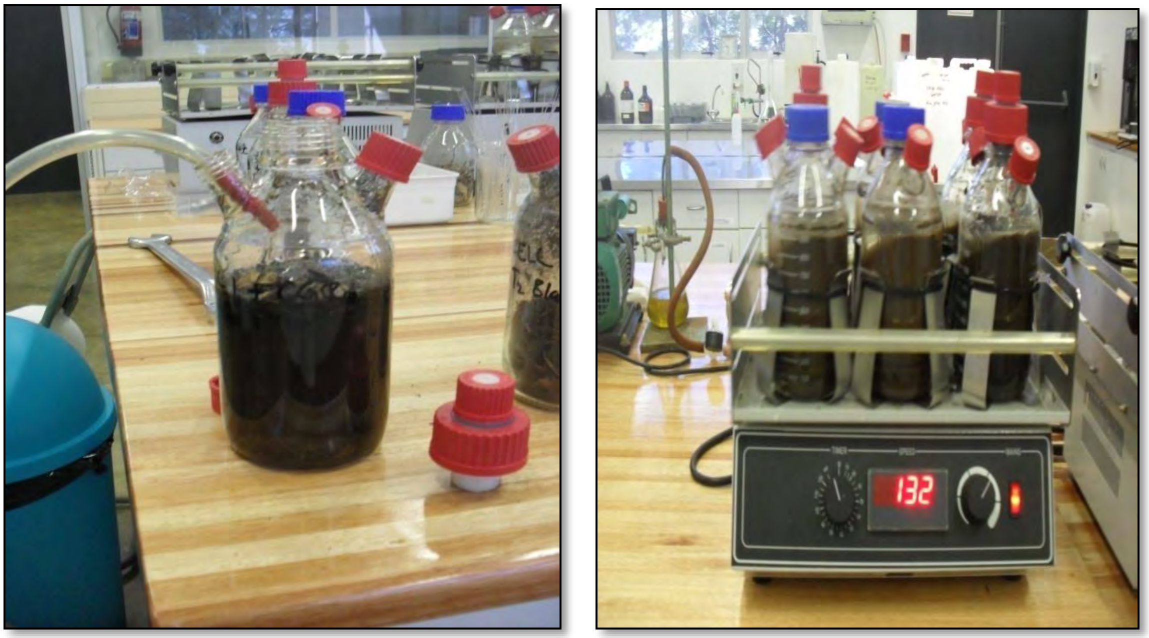


Figure 3.5-1: Vacuuming (Deoxygening) of the batch test bottle and Sample bottle on shaker.

3.5.2. Sample Extraction and Nitrate Concentration Testing

Sampling was conducted every hour for the first day and after that once a day as it was noted that the nitrate concentration did not drop within the first day. The sampling was done with a precision syringe which is connected with a 0.45μm filter paper (Figure 3.5-2). The solution extracted during the batch test was tested (analyzed) for nitrate and nitrite concentration using a nitrate test stick type Merckoquant (MERCK) which uses a colorimetric method. The colour changes in the nitrate test stick depending on the concentration of the nitrate at that time.

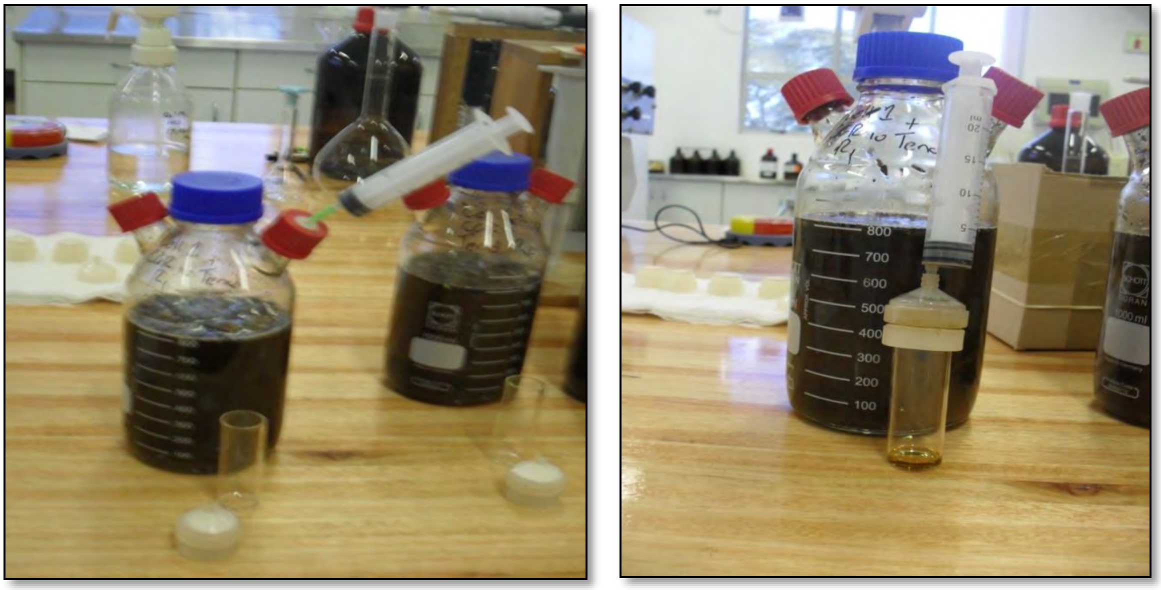


Figure 3.5-2: Extraction of eluate for analysis using precision syringe and filtering of sample through 0.45µm filter paper

Figure 3.5-3: Testing of Nitrate concentration using stick type Merckoquant

3.5.3. Sample Analysis

At the end of the batch test the eluate solution were analyzed for pH, Nitrates and Nitrites concentration, ammonia and COD. The solid matter was then analyzed for total carbon and total nitrogen in order to calculate the C/N ratio. As much as the kinetics of denitrification process was mainly focused on the T_{end} other set of results were also evaluated to add to the accuracy, and also enhance a better understanding of the population dynamics of the bacteria responsible for denitrification at different critical times.

The following critical times used:

T0 –bottle is filled with substrate and leachate and analyzed immediately for Nitrate, pH, COD, NH_3–N and NO_x after time 0 hours.

T1 – Nitrate level, pH, COD, NH_3–N and NO_x measured at 1/3 the duration time of Tend.

T2 – Nitrate level, pH, COD, NH_3–N and NO_x measured at 2/3 the duration time of Tend.

Tend – Nitrate level, pH, COD, NH_3-N and NO_x measured at full denitrification or when the nitrate level remains constant.

3.5.3.1. pH

pH measurement analysis was done as explained in the procedure in section 3.4.7 of this document.

3.5.3.2. Nitrates and Nitrites

The eluate was tested for nitrates and nitrites concentrations using Merckoquant nitrate test sticks using the procedure explained in section 3.4.11.

4. RESULTS AND DISCUSSIONS

4.1. Introduction

The experiments were carried out for 10 months using cell 1 and cell 2 as the main substrate, a mixture of cell 1 and other substrate such as CRG_{raw} and CGR_{10} the following substrates

In order to meet the listed objectives, the concentration of NO_3 was regularly measured to observe the efficiency of the substrate. After the batch test has been completed the following parameters (NH_3, NO_x, COD and pH) were measured. This tables and graphs presented in this chapter are the summaries of the large quantity of data collected and the raw data in obtaining these results can be found in the appendices of this document.

4.2. Characterization Test Results

Table 4.2-1 and Table 4.2-2 show the summaries of the full characterization tests of both solid substrate and its eluate respectively using the method outlined in chapter 3 of this document. The characterization tests were carried out on all the organic substrates used in carrying out the research. The results summary shown in this chapter represents an average of the raw data that were obtained. Most of the tests were done in triplicate to minimize errors.

4.2.1. Solid

Table 4.2-1: Characterization of the solid substrates

Sample	MC (%)	TS (%)	VS (%)	RI_7 (mg 0_2 /g DM)	Tot C (%)	Tot N (%)	C:N Ratio
Cell 1	25.26 ± 2.24	74.74 ± 6.33	15.38 ± 1.58	2.60 ± 1.09	7.16	0.47	15.23
Cell 1 + CGR_{raw}	34.71 ± 0.07	65.29 ± 0.38	59.50 ± 0.30	19.33 ± 3.78	19.84	0.77	25.77
Cell 1 + CGR_{10}	23.53 ± 0.28	76.47 ± 16.39	45.12 ± 5.58	15.21 ± 3.38	16.55	1.10	15.05
Cell 2	27.18 ± 2.17	72.82 ± 3.38	18.06 ± 5.22	1.77 ± 0.69	8.84	0.49	18.04
Cell 2 + CGR_{raw}	31.11 ± 0.02	68.89 ± 1.73	56.85 ± 0.95	18.25 ± 0.54	11.87	0.86	13.80
Cell 2 + CGR_{10}	28.72 ± 0.17	71.28 ± 2.73	39.15 ± 5.49	11.14 ± 2.78	9.00	0.73	12.33
CGR_{raw}	45.15 ± 3.57	54.85 ± 13.81	85.22 ± 1.77	110.35 ± 9.60	44.00	1.98	22.22
CGR_{10}	34.50 ± 0.94	65.51 ± 2.86	65.75 ± 9.35	44.11 ± 8.36	25.80	1.54	16.75

Whereby: TS: Total Solid
VS: Violate Solid
MC: Moisture Content

Tot C: Total Carbon
Tot N: Total Nitrogen
RI_7: Respiration Index

4.2.2. Eluate

Table 4.2-2: Characterization of the Eluate after 24 hours

Sample	TS (%)	VS (%)	pH	COD (mg/l)	BOD (mg/l)	NH_3 (mg/l)	NO_x (mg/l)	Tot C (%)	Tot N (%)	C:N Ratio
Cell 1	11.69 ± 2.41	2.84 ± 0.28	7.20	1437.26 ± 73.69	21.50	2.10	0.35	1.69	0.07	24.14
Cell 1 + CGRraw	8.14 ± 0.15	4.99 ± 0.78	7.03	3298.60 ± 818.52	137.00	0.70	0.70	1.69	0.04	42.25
Cell 1 + CGR10	15.52 ± 0.4	8.47 ± 0.40	7.47	4323.94 ± 815.28	148.00	1.40	1.12	0.82	0.04	20.50
Cell 2	10.6 ± 0.17	4.77 ± 0.63	7.23	3328.45 ± 186.93	39.17	11.55	12.60	0.71	0.03	23.67
Cell 2 + CGRraw	8.3 ± 0.85	3.61 ± 0.34	7.03	3249.98 ± 244.51	108.97	11.20	12.60	0.83	0.04	20.75
Cell 2 + CGR10	11.48 ± 0.20	4.98 ± 0.15	7.18	4136.24 ± 487.48	127.97	16.80	15.40	0.62	0.03	20.67
CGR_{raw}	5.83 ± 0.19	4.17 ± 0.65	7.47	3471.48 ±	1720.33	14.00	6.10	0.58	0.02	29.00
CGR_{10}	7.17 ± 0.42	4.96 ± 0.58	7.47	3876.23 ±	370.33	<1	<1	0.63	0.05	12.60

pH

The results in Table 4.2-2 shows that the pH in all the substrates that were used is closer to neutrality. This pH level is more favorable on the rate of nitrate removal as the optimum pH required for the biological denitrification range between 6 and 8 (Plug et al 2010). It could be observed that the composting of the solid waste has produced a favorable pH for the denitrification compared to other research results done by Plug (2009) where CGR_{raw} , CGR_{10} only were used-their pH was low as 5.45 (Plug, 2009). Low pH could negatively affect the rate of nitrate removal as discussed in section 2.7.2.1.

Ammonia-N

The results presented in Table 4.2-2 shows a high level of NH_3-N present in all the substrates especially Cell 2 which may cause the NH_3-N to leach from the substrate into the wastewater being treated, thereby causing an increase in nitrate level through a process known as bioleaching. In the event of sufficient oxygen in the bioreactor the NH_3 that has leached out of the substrate could be converted from NH_3 to NO_2 thereby increasing the NO_2present, therefore lowering the nitrate removal efficiencies within the reactor.

Total Nitrogen and Total Carbon

The carbon-to-nitrogen ratio affects the decomposition because organisms use carbon as a source of energy. A higher carbon content than nitrogen content within a substrate was necessary for denitrification to occur. Correct proportion of carbon is required for energy and nitrogen for the production of protein (Composting101, 2006). Cell 1 + CGR_{raw} was found to have the highest C/N ratio which indicate that Cell 1 + CGR_{raw} is the most suitable carbon source when compared to the other substrates used-that is: Cell 1, Cell 2, Cell 1 + CGR_{10}, Cell 2 + CGR_{10} and Cell 2 + CGR_{raw}. According to Wu et al (2002) citied by Tsui et al, (2007) the typical range for stabilized composted waste is between13-16. It could be observed from Table 4.2-1 that Cell 1 + $CGR_{raw}$and Cell 2 falls above the range while Cell 2 + CGR_{10}fall below that range. Cell 1 + $CGR_{raw}$and Cell 2 should be the appropriate for denitrification as more carbon is required than nitrogen.

Cell 2 + CGR_{10} has the lowest C/N ratio compared to the other substrate of 12.22.This could be due to the less carbon and more nitrogen which could cause it to achieve the lowest denitrification efficiencies in comparing to the other substrates. However C/N ratio is not the only factor that is used to determine the suitability of the substrate as stated in section 2.7.2.1.

Cell 1 + CGR_{10}have the highest COD of 4324 mg/ℓ while it has a BOD_5 of 127.97 mg/ℓ as presented in Table 4.2-2. This suggests that despite the high COD only a small portion is readily available for the biological denitrification of nitrates hence the effluent will requirefurther treatment prior to discharge. The substrate with low BOD_5 : COD ratio as indicated in Table 4.2-2 suggest that the substrate has been extensively biodegraded

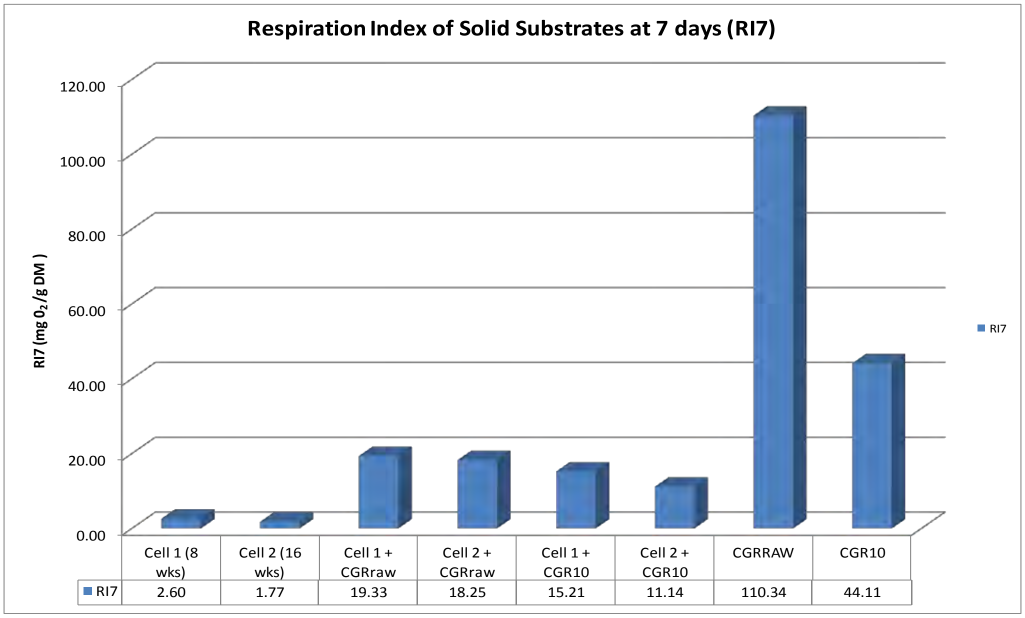


Figure 4.2-1: RI7 of Solid Substrates

RI_7

The respiration Index (RI_7) test as stated in section 3.4.3 is used to determine the biodegradability of each substrate including it stability level. Figure 4.2-1 suggests that CGR_{raw} has a higher RI_7 compared to the other substrates which is expected since CGR_{raw} consist of fresh commercial garden refuse.The high $RI_7$of CGR_{raw} indicates that it has notdegraded, therefore it is unstable. As expected the Cell 2‟s substrates have a lower RI_7 (Figure 4.2-1) compared to Cell 1 and Cell 1 mixtures.This shows that while composting process was taking place the Cell 2 has become more stable and maturedthan the Cell 1‟s substrates. It could be observed that Cell 1 state has high biodegradable material compared to Cell 2 and Cell 2 mixtures. The Cell 2 and Cell 2 mixture is slowly biodegrading because it is more stable than Cell 1 and Cell 1 mixtures. As suggested by Trois et al (2010), a lower RI_7 values suggests high level of stability in the compost to maintain denitrification.

4.2.3. Leachate

The leachate (Treated and Untreated-Mixed liquor) was collected from the SBR treatment plant at Mariannhill landfill site. Before any experiments were conducted the quality of the leachate was measured (Characterization of leachate) and the summary result of the initial quality of the leachate used is shows in Table 4.2-3.

Table 4.2-3: Results of input Leachate Quality

Sample	NO_3 (mg/l)	TS (%)	VS (%)	pH	COD (mg/l)	BOD (mg/l)	NH_3 (mg/l)	NO_x (mg/l)	Tot C (%)	Tot N (%)	C:N Ratio
Treated Leachate	500	1.55 ± 0.032	0.25 ± 0.024	7.40	203	40.9 ± 4.58	7.70	27.30	0.54	0.05	10.8
Seeded Treated Leachate	500	1.62 ± 0.02	0.28 ± 0.026	7.73	206	45.17 ± 17.64	9.10	44.10	0.75	0.02	37.5
Mixed liquor	2500	13.42 ± 0.26	4.93 ± 0.23	7.11	5406	105.93 ± 4.98	11.90	4.90	0.54	0.06	9.00

From Table 4.2-3, it is observed that the leachate is characterised by low level of ammonia except the mixed liquor leachate as it was sampled from the SBR tank where the raw leachate is treated for ammonia. The BOD_5 level was also low except the mixed liquor. However the nitrate level in the treated leachate is high. This is because the leachate in the SBR is treated for ammonia which is then converted to nitrate: and hence is the need for this research.

4.3. Batch Tests Results

The batch test was carried out to investigate the kinetics of the substrate that will be used in the column test which will eventually be used in a wetland as a polishing treatment. The batch test was performed at optimal condition by ensuring maximum contact between the substrate and solution. The initial concentration used in all the batch tests was 500mg/ℓ. The main batch test substrate was Cell 1 and Cell 2. Cell 1 consist of 8 weeks fine pre-treated domestic waste while Cell 2 consists of 16 weeks fines pre-treated domestic waste as explained in section 3.2.1.

4.3.1. Cell 1 Batch Test

4.3.1.1. Nitrate Concentration Evolution of Cell 1 Batch Tests And Their Kinetic Rate

1. Cell 1 + Treated Leachate

After the batch test was concluded the end point (Tend) effluent (solid and eluate) was characterised. Table 4.3-1shows the initial input and final output parameter on the solid and eluate.

Table 4.3-1: Input and Output characterization results of Cell 1 + Treated Leachate batch Test

Parameter	Eluate Input	Solid Input	0 mg/l (Blank)		500 mg/l	
			Eluate Output	Solid Output	Eluate Output	Solid Output
pH	7.20		7.70		7.86	
COD (mg/l)	1437		15359		18165	
NH_3-N (mg/l)	9.10		20.0		22.0	
NO_3 (mg/l)	27.30		1.4		68.0	
Total C (%)	1.69	7.16		2.24		1.57
Total N (%)	0.07	0.47		0.12		0.08
C/N Ratio	24.14	15.23		18.67		21.22

Table 4.3-2: Output characterization results of Cell 1 + Treated Leachate batch Test at different time set

Sample		Time (Days)	pH	NH_3 (mgN/l)	COD (mg/l)	C (%)
Cell 1 + Treated Leachate	T0	0	7.49	17.00	6539.71	7.52
	T1	6	7.58	20.00	20075.74	5.53
	T2	13	7.64	11.67	6480.57	4.38
	Tend	30	7.86	22.00	18164.72	1.57

pH

From **Error! Reference source not found.** it is observed that the pH for the input and output luate remained around neutrality with a pH of 7.70 for the batch containing distilled water and 7.86 for the batch that contained treated leachate with a concentration of 500 mg/ℓ. The pH remained within the boundary value of 6-8 for denitrification as observed in Table

4.3-2.However caution should be taken since the pH is closer to the upper pH boundary of 8, meaning that an alkaline supplement might be required.

The nitrate concentration in this batch test failed to reach full denitrification (Zero). This could be due to the reduction of the total carbon present in the substrate from 7.16% solid input to 1.57% solid output. The results in Table 4.3-1 indicate an increase in NH_3 which could relate to the reduction of the total nitrogen presence from 0.47% - 0.08% in the solid.

COD

The batch test shows an evident of bioleaching of carbon this can be seen by the increase of the COD from 1437 mg/ℓ – 18165 mg/ℓ. The C/N ratio also shows an evident of bioleaching by the increase of it from 15.23 – 20.43 in the solid as shown in Table 4.3-1. The high level of carbon as shown in Table 4.3-2 contributed to the increase in COD, the increase in COD is as a result of bioleaching which is clearly demonstrated in the Table 4.3-2 above.

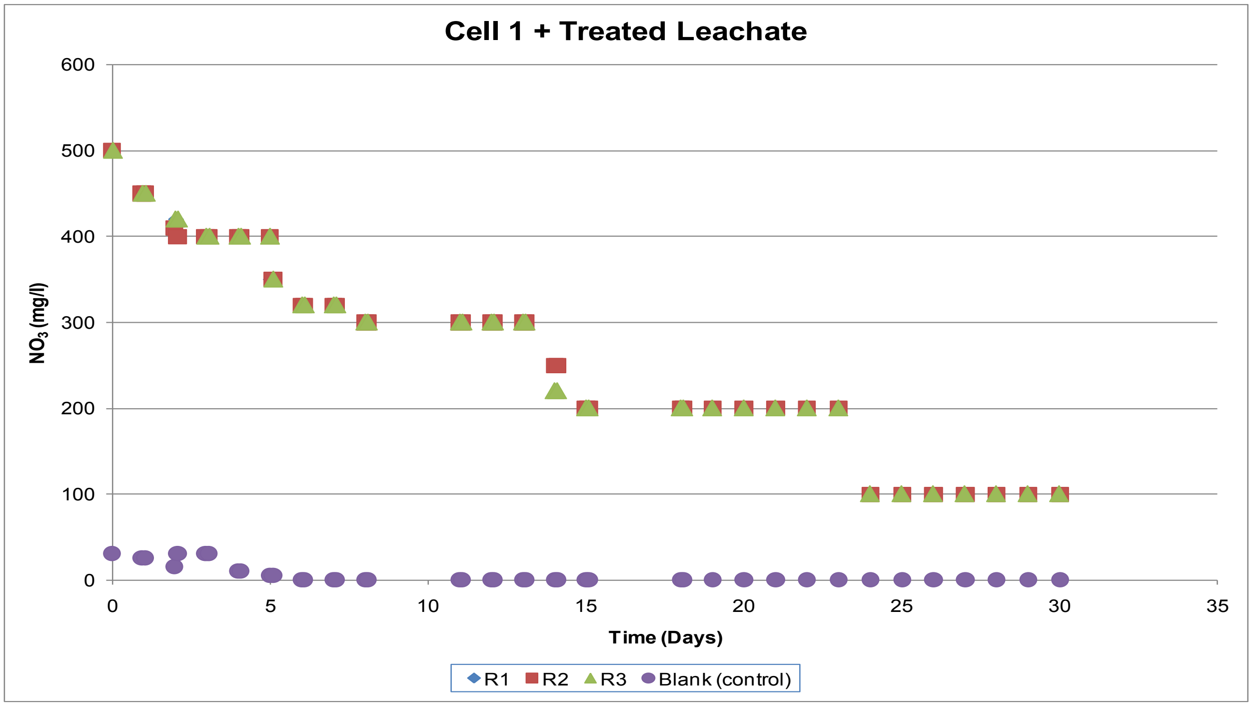


Figure 4.3-1: Evolution of nitrate concentration in Cell 1 + Treated Leachate at 500 mg/ℓ

Figure 4.3-1 shows the nitrate evolution for the Cell 1 + Treated Leachate. The initial concentration of the treated leachate was 500 mg/ℓ. The nitrate evolution graph shows the change in nitrate concentration (NO_3) in mg/ℓ over time in days. As observed in Figure

4.3-1,there was a sudden drop in the nitrate concentration. At the initial stage it dropped from 500 mg/ℓ to 450 mg/ℓ that occurred with 22.3 hours from the start of the batch test. This sudden drop is due to the readily avaliable carbon which are easily accessed by the microbial population which are responsible for the denitrification process (Trois et al, 2009).

It is observed in Figure 4.3-1 that the batch test could not reach full nitrate removal (full denitrification). After 15 days the nitrate concentration remained constant at 200 mg/ℓ for a duration of 8 days between (15 days – 23 days) after which it further dropped to 100 mg/ℓ where it remained constant (no further nitrate removal). According to De Combret (2009), the period in which the nitrate removal remains constant maybe due to the inhibitory effect of NO_3 saturation within the batch test.

Kinetic Rate of Cell 1 Batch Test

A zero order reaction kinetic model was used to model the average of the three replicates.

$$Zero\ Order\ Reaction: \frac{dc}{dt} = -k \rightarrow c = c_o - kt$$

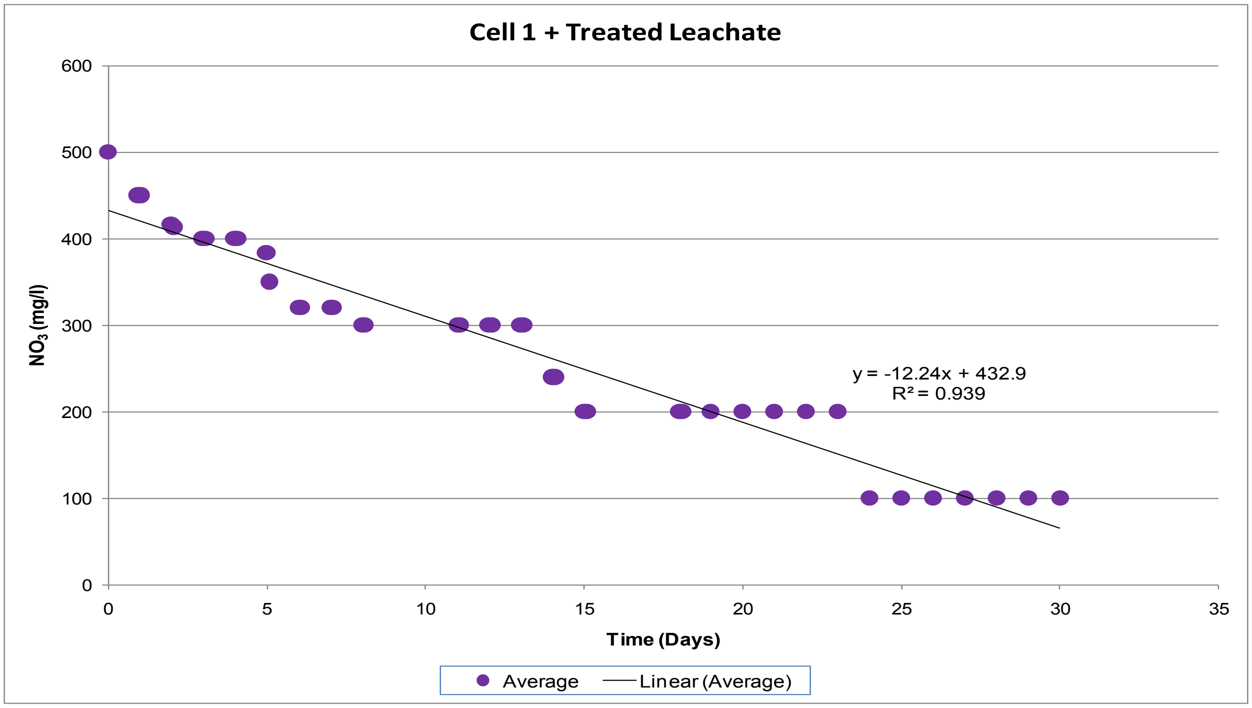


Figure 4.3-2: Kinetics of Cell 1 + Treated Leachate at 500 mg/ℓ

The results of Cell 1 + Treated Leachate which was performed at 500 mg/ℓ did not perform well since it could not reach full denitrification. Although some nitrates were removed, only 80% efficiency could be seen within this batch test and it occurred after 30 days of running the batch test. Summary of the kinetic rate is presented in Table 4.3-9. When the nitrate concentration had decreased by 80%, after 25 days from the start of the batch, no further reduction was achieved and the concentration stabilized at 100 mg/ℓ till the batch test was sacrificed. A linear relationship as shown in Figure 4.3-2 was used to approximate the denitrification rate (k in mg/ℓ/day).

2. Cell 1 + Seeded Treated Leachate (Mixed Liquor)

Table 4.3-3 presents the summary results of the characterization of the eluate and solid input and output for Cell 1 + Seeded Treated Leachate batch test. These results are based on the average of R1, R2 and R3.

Table 4.3-3: Input and Output characterization results of Cell 1 + Treated Leachate Seeded with Mixed Liquor batch Test

Parameter	**Eluate Input**	**Solid Input**	**0 mg/l (Blank)**		**500 mg/l**	
			Eluate Output	**Solid Output**	**Eluate Output**	**Solid Output**
pH	**7.20**		**7.66**		**7.53**	
COD (mg/l)	1437		14606		13850	
NH_3-N (mg/l)	**9.10**		**13.0**		**7.30**	
NO_3 (mg/l)	27.30		1.80		117.7	
Total C (%)	**1.69**	**7.16**		**4.75**		**6.27**
Total N (%)	0.07	0.47		0.27		0.29
C/N Ratio	**24.14**	**15.23**		**17.59**		**21.22**

Table 4.3-4: Output characterization results of Cell 1 + Treated Leachate Seeded with Mixed Liquor batch Test at different time set

Sample		**Time (Days)**	**pH**	**NH_3 (mgN/l)**	**COD (mg/l)**	**C (%)**
Cell 1 + Treated Leachate Seeded with Mixed Liqour	**T0**	0.00	7.59	10.33	9372.90	4.58
	T1	5.88	7.57	28.00	24205.87	4.23
	T2	21.00	7.67	12.00	8829.64	4.53
	Tend	30.54	7.53	7.30	13849.61	6.27

pH

Comparing the pH of the input with the pH of the output it is noted that there is an increase. The pH remained around the optimum pH range for denitrification of (6 - 8) as shown in Table 4.3-3. From Table 4.3-4, it could be that as much as they was a change in the pH level at different time duration, the pH still remained within the optimum pH range of 6 – 8 as suggested by Plug et al (2010).

The batch test could not achieve full denitrification that is to say, the nitrate concentration could not reach zero at the end of the batch.

The NH_3-N results in this batch test was high than the initial NH_3-N value of 9.10. From Table 4.3-3 it is evident that NH_3 leached out from the substrate. According to Trois (2010), within the first 74 hours of a batch test both nitrifiers and denitrifers are present with a substrate.

COD

From Table 4.3-3 it is evident that there was positive bioleaching of carbon which could be seen by the increase of both COD and C/N Ratio from 1437 – 13850 mg/ℓ and 15.23 – 21.39 respectively. The decrease in the total carbon indicated that carbon was leaching out of the solid matter into the liquid phase thereby increasing the COD. The increase in COD as per Table 4.3-4 relates to the decrease in the total carbon which indicates positive. The COD level at T1 was higher than the COD at the end of the batch test (Tend) which relate to much carbon content leaching out of the substrate hence decreasing the total carbon in the solid substrate.

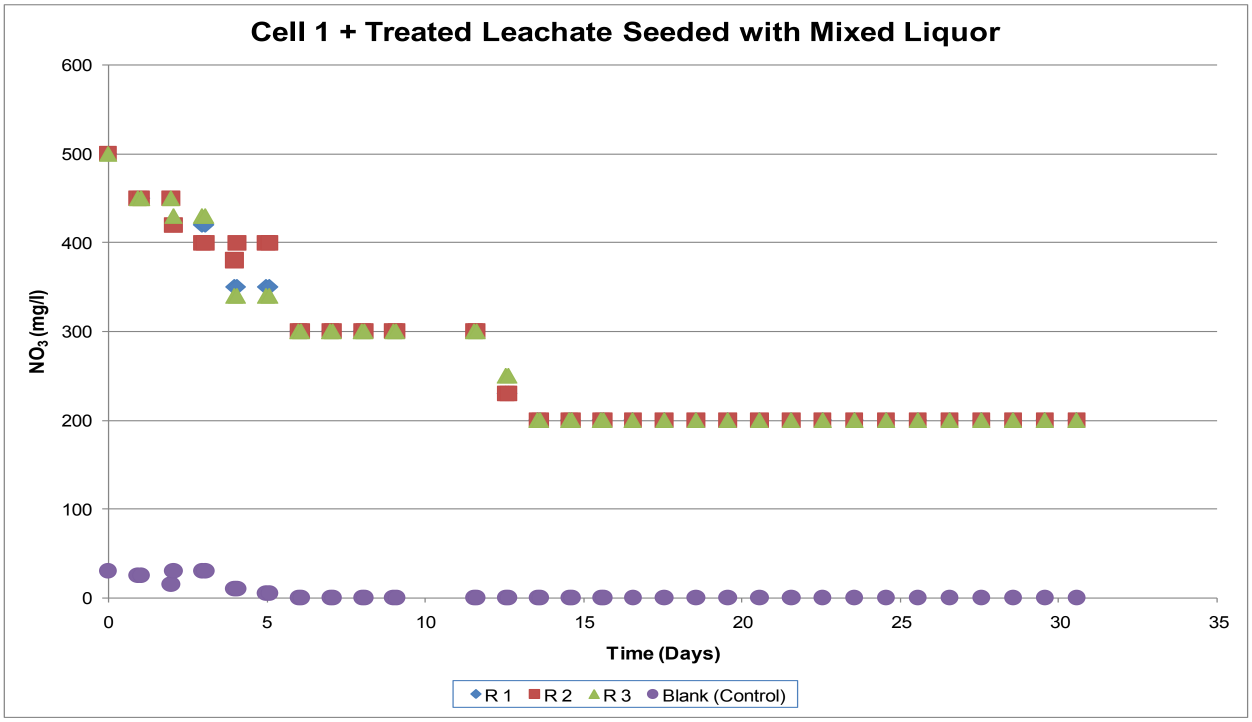


Figure 4.3-3: Evolution of nitrate concentration in Cell 1 + Seeded Treated Leachate at 500 mg/ℓ

It is observed in Figure 4.3-3that the batch test could not reach full denitrification. After 12.6 days the nitrate concentration remained constant at 200 mg/ℓ for duration of 17.9 days between (12 days – 30.54 days) after which it did not drop any further (no further nitrate removal). This batch at 500 mg/ℓ showed an initial plateau and an acclimatization at which there was a pH buffering which included nitrifiers and denitrifiers competing as stated by Trois et al, 2009. In order for denitrification to occur the environment should be suitable for the denitrification as temperature, carbon, and pH are important factors for denitrification. This batch test did not show a positive result as full denitrification could not be achieved.

Kinetic Rate of Cell 1 (Seeded Leachate) Batch Tests

A zero order reaction kinetic model was used to model the average of the three replicate.

$$Zero\ Order\ Reaction: \frac{dc}{dt} = -k \rightarrow c = c_o - kt$$

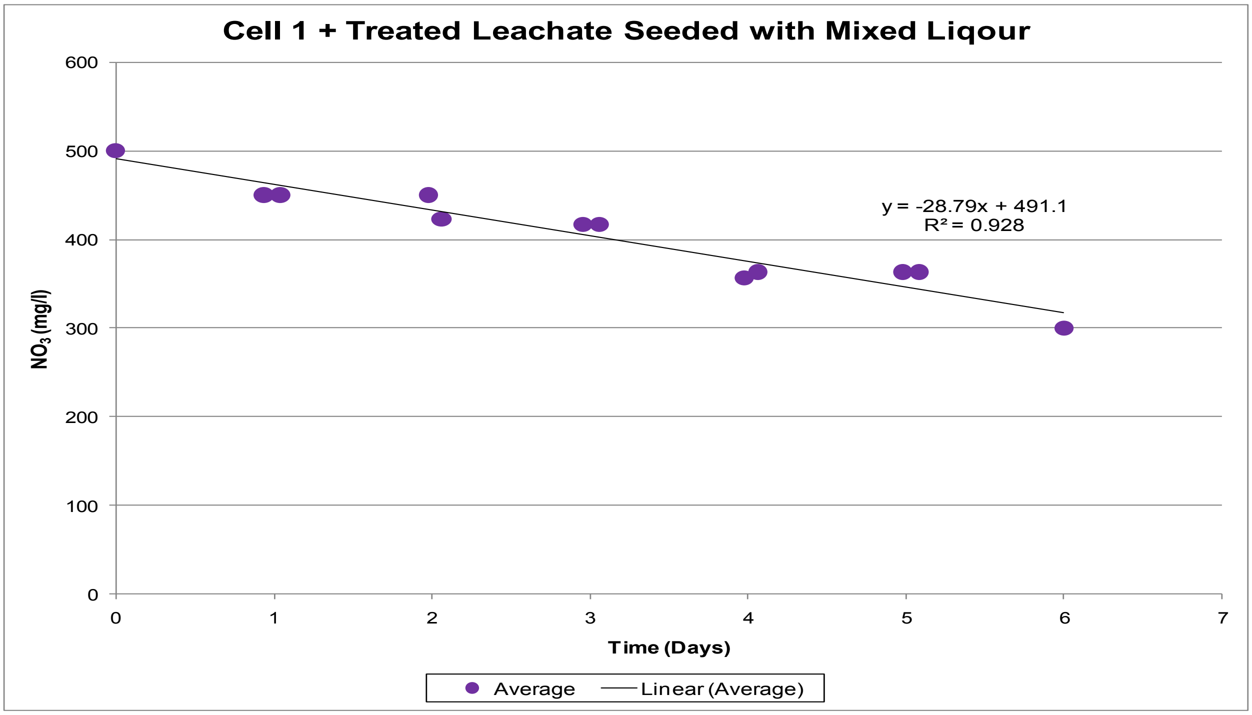


Figure 4.3-4: Kinetics of Cell 1 + Seeded Treated Leachate at 500 mg/ℓ

The results presented in Table 4.3-9 and Figure 4.3-4 shows that full denitrification could not be achieved. However some nitrate removal did occur but only 60% of nitrate could be removed. The nitrate removal followed a linear rate.

3. Cell 1 + CGR_{raw} + Treated Leachate

Table 4.3-5 shows the characterization results of the batch test at end point (Tend). The characterization was conducted on both solid and eluate. The results in Table 4.3-5 show the initial input and final output parameter on the solid and eluate.

Table 4.3-5: Input and Output characterization results of Cell 1 + CGRraw + Treated Leachate batch Test

Parameter	Eluate Input	Solid Input	0 mg/l (Blank)		500 mg/l	
			Eluate Output	Solid Output	Eluate Output	Solid Output
pH	7.03		7.28		7.43	
COD (mg/l)	3299		5601		5408	
NH_3-N (mg/l)	<1		<1		12.7	
NO_3 (mg/l)	<1		0.0		0.0	
Total C (%)	1.69	19.84		24.46		22.13
Total N (%)	0.04	0.77		0.98		0.89
C/N Ratio	42.25	25.77		24.96		24.84

Table 4.3-6: Output characterization results of Cell 1 + CGRraw + Treated Leachate batch Test at different time set

Sample		Time (Days)	pH	NH_3 (mgN/l)	COD (mg/l)	C (%)
Cell 1 + CGRraw + Treated Leachate	T0	0	7.43	15.17	3202.81	21.03
	T1	1	7.52	13.00	4456.08	26.70
	T2	3	7.80	39.00	6911.05	19.23
	Tend	7	7.43	12.67	5408.50	22.13

pH

The results in Table 4.3-5 shows an increase in the pH valve from the initial eluate input of 7.03 to 7.43 of the batch eluate output. The pH remained within the denitrification range as suggested by Trois et al (2007). From Table 4.3-6, it could be observed that there was an increase in the pH especial at T2.However it remained with the pH denitrification range but it was closer to the up pH boundary of 8. The interesting part of this results is that at the end of the experiment when full denitrification has been achieved, the pH dropped from 7.79 – 7.43.

The NH_3-N value was higher within the batch test containing the 500 mg/ℓ nitrate concentration. The increase in NH_3 from the initial NH_3 of less than 1 mg/ℓ to 12.7 mg/ℓ could be related to the reduction in the total N (%) as shown in Table 4.3-5.

COD

It is observed that there was an evidence of bioleaching of carbon which could be seen by the increase of COD in relation to the initial COD of the eluate input shown in Table 4.3-6. The COD results in Table 4.3-5shows that the COD increased from 3299 – 5408 mg/ℓ. As much as there was an increase in the % C, it was not much compared to the initial % C present in the initial solid as indicated in Table 4.3-6.

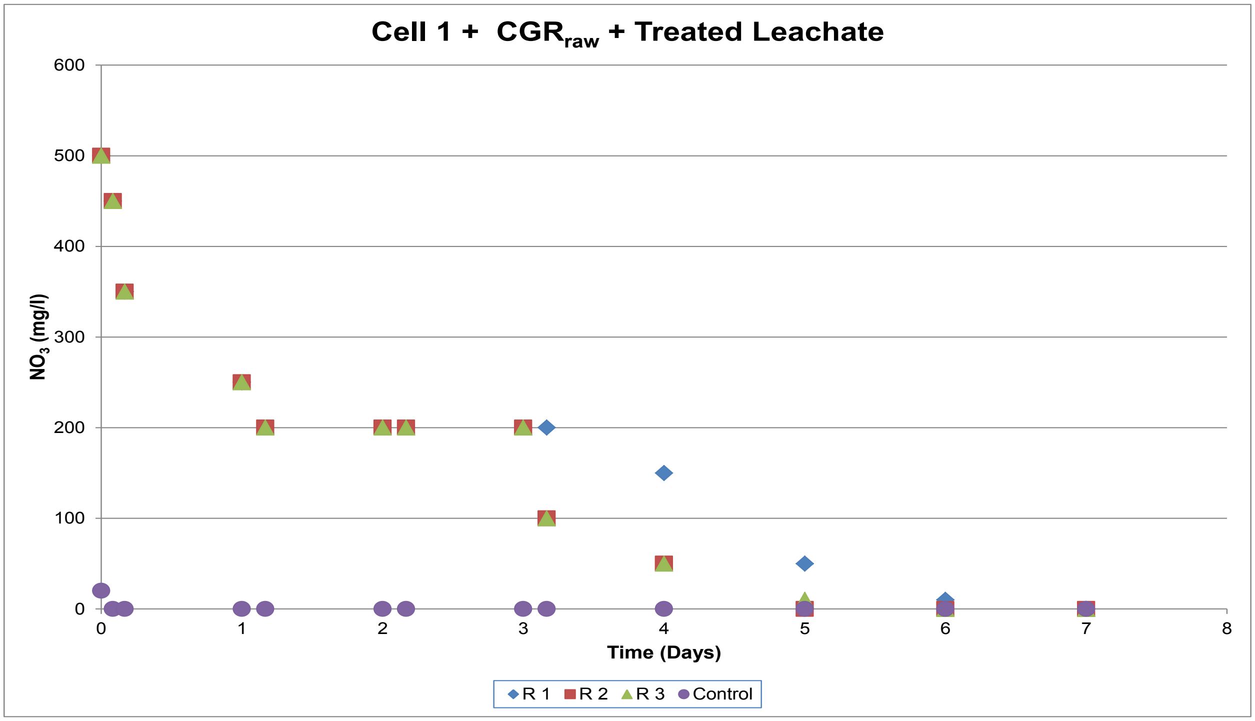


Figure 4.3-5: Evolution of nitrate concentration in Cell 1 + CGR$_{raw}$ + Treated Leachate at 500 mg/ℓ

In Figure 4.3-5 it is observed that the Cell 1 + CGR$_{raw}$ exhibited a rapid nitrate removal in the initial stage which relates to the presence of easily available biodegradable carbon as indicated in Table 4.3-5. After 1 day of nitrate removal a plateau period could be observed which lasted for 2 days before the nitrate removal continued.

The initial stage (phase 1) of the nitrate removal followed an exponential relationship then the plateau phase after which the later stage (phase 2) of the denitrification process occurred at an exponential rate until a zero nitrate concentration was achieved after 7 days as shown in Figure 3.4-6, Figure 4.3-7 and Table 4.3-9.

Kinetic Rate of Cell 1 + CGR$_{raw}$ Batch Test

A first order reaction kinetic model was used to model the average of the three replicates.

$$First\ Order\ Reaction: \frac{dc}{dt} = -kC \rightarrow c = c_o e^{-kt}$$

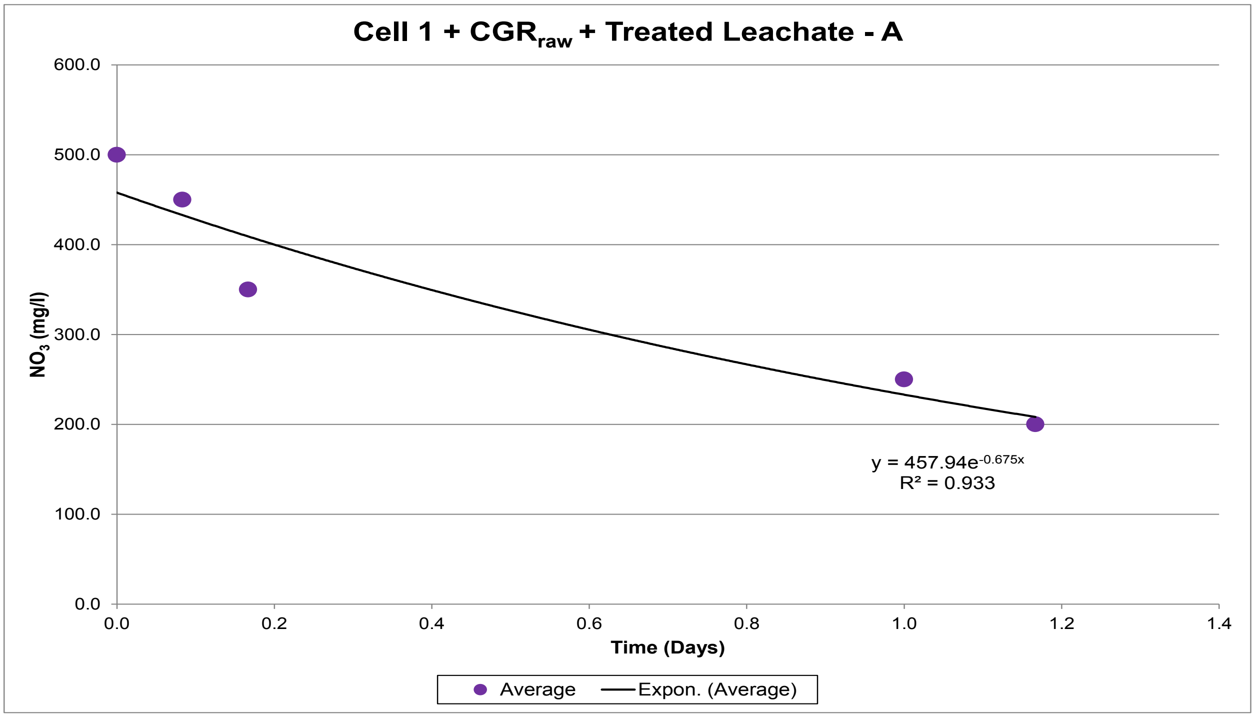


Figure 4.3-6: Kinetics of Cell 1 + CGR$_{raw}$ + Treated Leachate at 500 mg/ℓ (Phase 1)

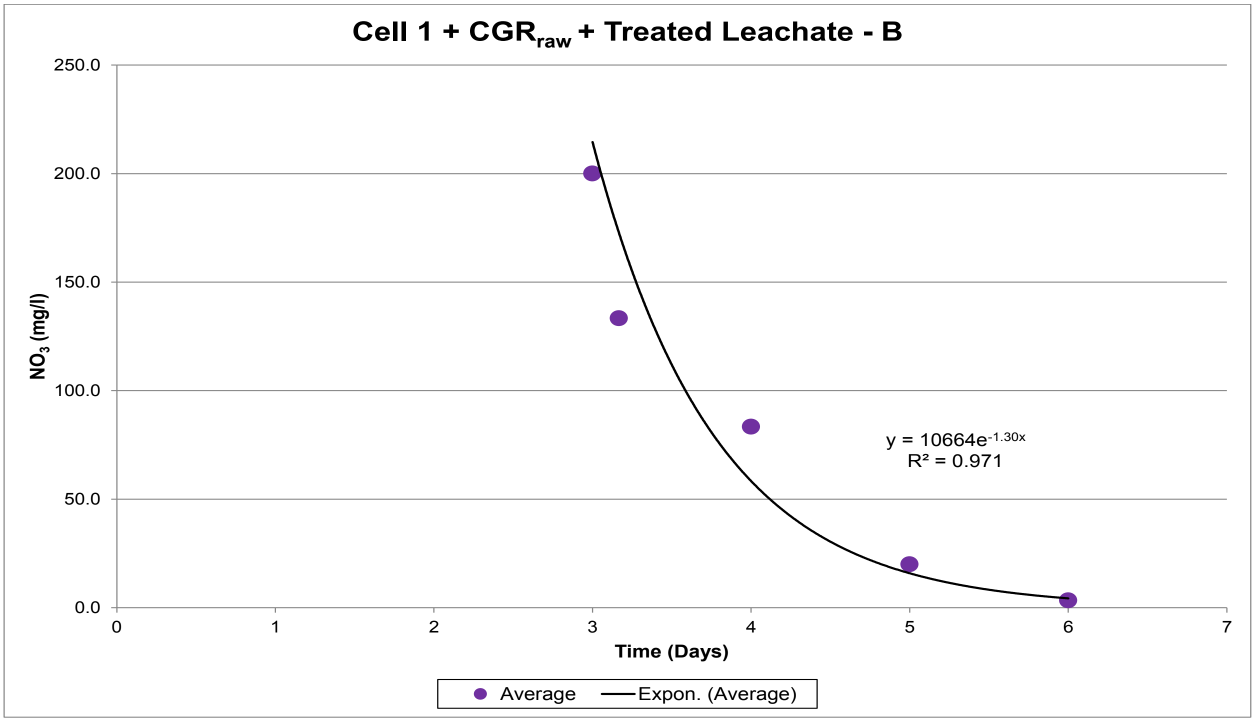


Figure 4.3-7: Kinetics of Cell 1 + CGR$_{raw}$ + Treated Leachate at 500 mg/ℓ (Phase 2)

Note: Day 0 – 1.167 days – Exponential Rate
Day 3 – 6 days – Exponential Rate

The nitrate removal followed an exponential relationship from day 0 to 1.2 days as shown in Figure 4.3-6 after which it was followed by a small plateau which lasted for 1.83 days. The denitrification process then followed an exponential relationship until full denitrification was achieved after 3.83 days after the plateau as shown in Figure 4.3-7. Full nitrate removal was achieved after 7 days as shown in Table 4.3-9.

4. Cell 1 + CGR_{10} + Treated Leachate

After the batch test was conducted the end point (Tend) effluent (solid and eluate) was characterised and the results are presented in Table 4.3-7.The results show the initial input and final output parameter of both the solid and eluate.

Table 4.3-7: Input and Output characterization results of Cell 1 + CGR_{10} + Treated Leachate batch Test

Parameter	Eluate Input	Solid Input	0 mg/l (Blank)		500 mg/l	
			Eluate Output	Solid Output	Eluate Output	Solid Output
pH	7.47		7.70		7.84	
COD (mg/l)	4324		4136		5649	
NH_3-N (mg/l)	1.40		27.3		32.4	
NO_3 (mg/l)	1.12		0.0		0.0	
Total C (%)	0.82	16.55		19.20		20.00
Total N (%)	0.04	1.10		0.81		0.82
C/N Ratio	20.50	15.05		23.70		24.59

Table 4.3-8: Output characterization results of Cell 1 + CGR10 + Treated Leachate batch Test at different time set

Sample		Time (Days)	pH	NH_3 (mgN/l)	COD (mg/l)	C (%)
Cell 1 + CGR10 + Treated Leachate	T0	0	7.41	18.43	2107.70	20.23
	T1	2	7.41	24.73	4686.45	20.07
	T2	5	7.70	28.00	4631.44	28.60
	Tend	8	7.84	32.43	5649.18	20.00

pH

The pH values in the blank and 500 mg/ℓ concentration increased from the initial pH of 7.47 as indicated in Table 4.3-7. However the pH the results still fall within the optimum range for denitrification of 6 – 8 as suggested by Trois et al., 2007. As pH is one of the limiting factors in the process of denitrification, it is important that it fall within the stated range. Table 4.3-8 shows an increase in the pH level from the initial pH level at the beginning (T0) of the batch test. As much as the pH remained within the optimum range at the end of the batch test (Tend) the pH level is closer to the upper pH boundary of 8 hence there will be a need for alkaline supplement.

COD

Evidence of bioleaching of carbon could be observed as there was an increase of the COD from the initial eluate. The COD increased from 4324 – 5649 mg/ℓ as shown in Table 4.3-7. Table 4.3-8 shows evidence of bioleaching of carbon from the solid substrate, it could be observed from the Table 4.3-8 above that as the total carbon decrease the COD level increase. The end (Tend) COD level is greater than the initial (T0) COD hence the need of further treatment to reduce the COD present.

NH_3 - N

A low level of NH_3-N could be noticed within the initial input material (substrate). An increase of NH_3-N from 1.40 – 32.4 mg/ℓ is observed this increase could be as a reduction in the total N (%) from 1.10 – 0.81. The increase in NH_3-N and the decrease in total nitrogen indicate bioleaching of nitrogen in the batch.

Table 4.3-8 shows the evolution of nitrate concentration for the Cell 1 + CGR_{10} substrate which was conducted at an initial concentration of 500 mg/ℓ. From the Figure 4.3-8, it could be seen that the blank test showed some leaching out of nitrates.

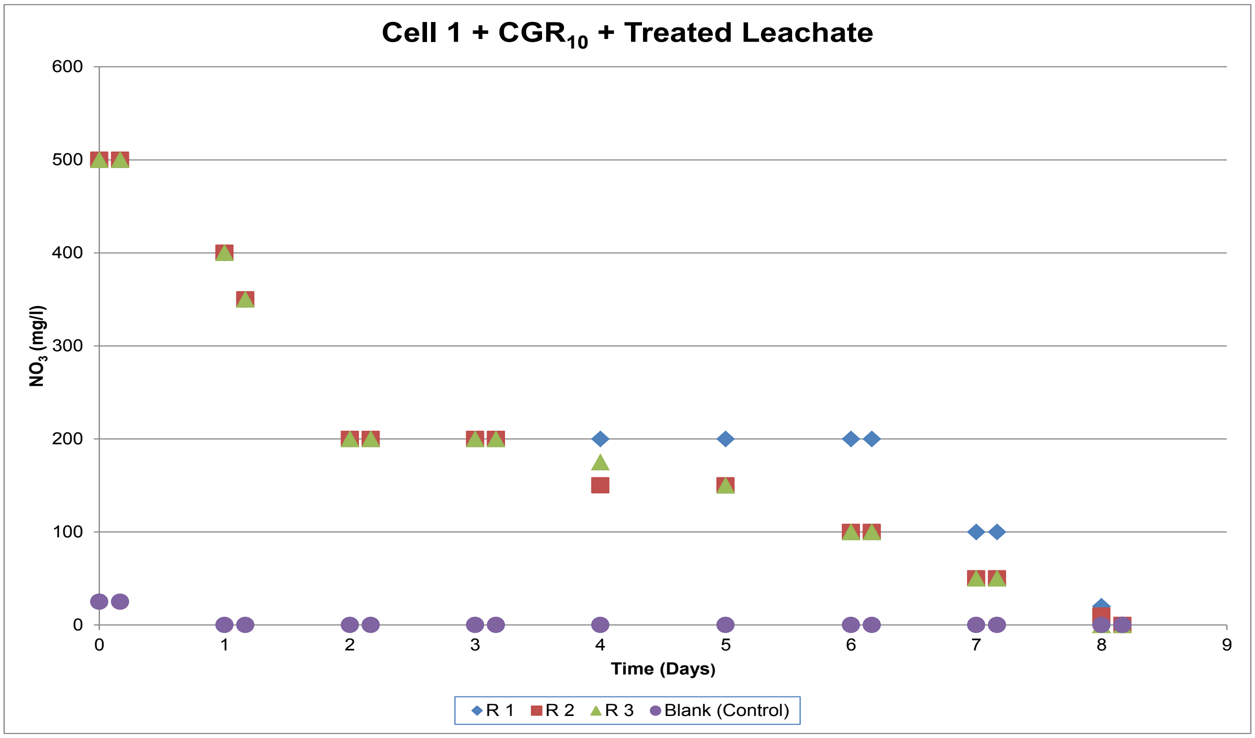


Figure 4.3-8: Evolution of nitrate concentration in Cell 1 + CGR_{10} + Treated Leachate at 500 mg/ℓ

The Figure 4.3-8 shows a process of acclimatisation at the start of the batch test where the batch test is stabilizing the environment for nitrate removal. This process lasted for 0.17 days. The test goes to a plateau period after 1.17 days after which the microflora acclimatises and the nitrate removal continues till all nitrates have been removed. The plateau lasted for 2 days.

After the acclimatisation had occurred, denitrification process occurred at a linear rate until a zero nitrate concentration was achieved which lasted for 8.2 days as shown in Figure 4.3-9 and Table 4.3-9.

Full denitrification was achieved within this batch test using Cell 1 + CGR_{10} as a carbon source. Cell 1 which consists of 8 weeks pre-treated DSW. Zero nitrate (NO_3) concentration was achieved at the end of the test after 8.2 days as shown in Figure 4.3-8 and Table 4.3-9.

Kinetic Rate of Cell 1 + CGR_{10} Batch Test

A zero order reaction kinetic model was used to model the average of the three replicate.

$$Zero\ Order\ Reaction: \frac{dc}{dt} = -k \rightarrow c = c_o - kt$$

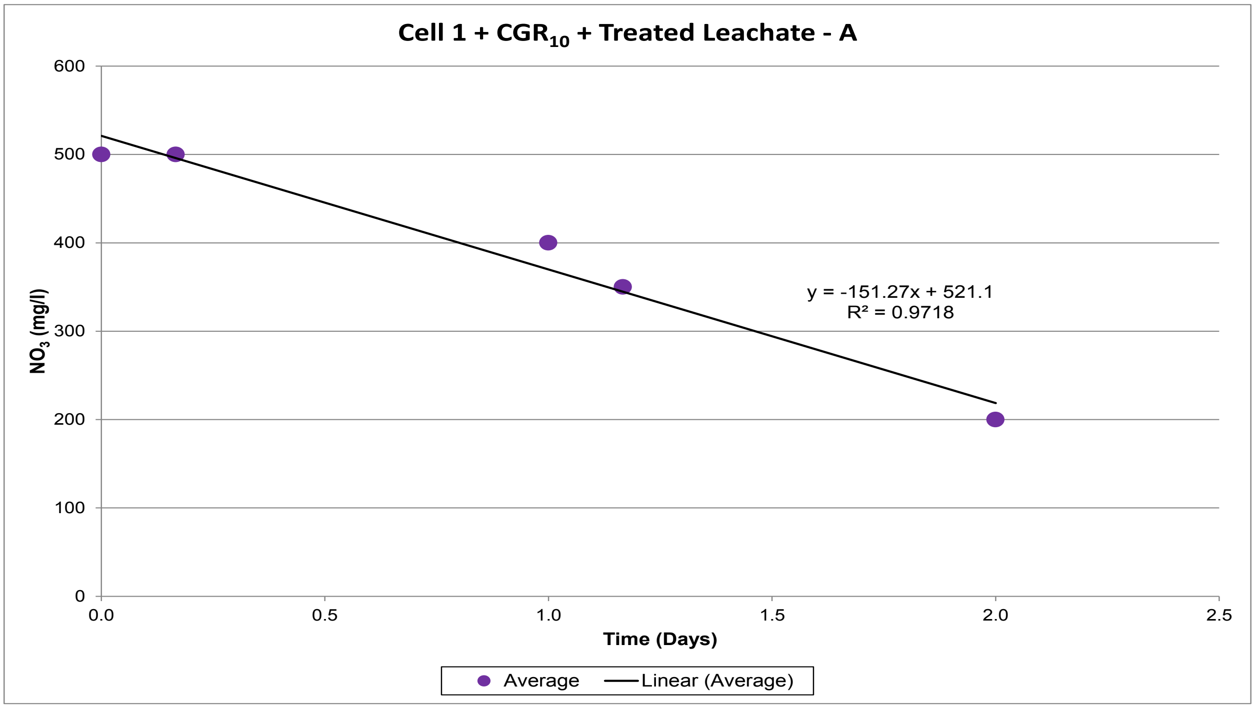


Figure 4.3-9: Kinetics of Cell 1 + CGR_{10} + Treated Leachate at 500 mg/ℓ (Phase 1)

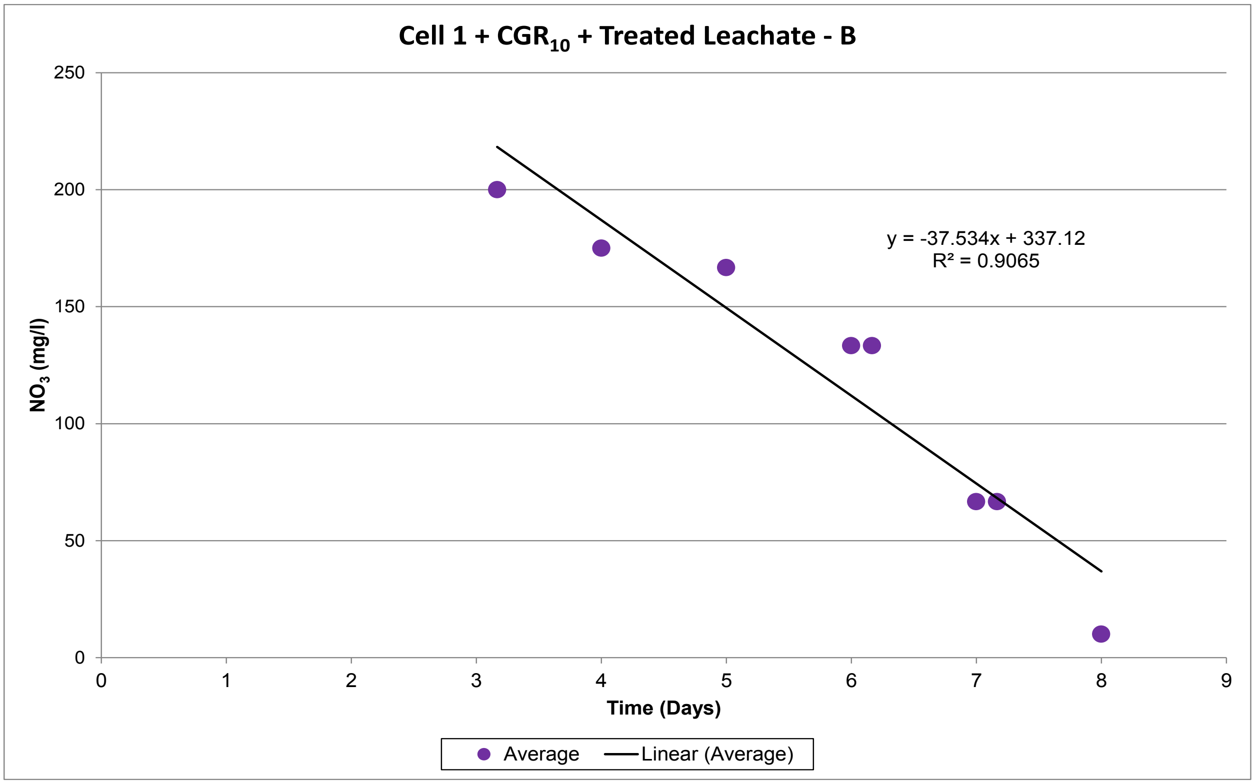


Figure 4.3-10: Kinetics of Cell 1 + CGR10 + Treated Leachate at 500 mg/ℓ (Phase 2)

Note: Day 0 – 2 days – Linear Relationship Phase 1
Day 3.17 – 8 days – Linear Relationship Phase 2

At the initial stage of the batch test an acclimation phase was observed which lasted for then followed by nitrate removal at a rapid linear relationship as indicated in Figure 4.3-9, which could relate to the availability of easily biodegradable carbon (Trois et al 2010) as shown in Table 4.3-5. The second phase of the denitrification process as observed in Figure 4.3-10 still followed a linear relationship which was slower compared to the initial denitrification phase until full denitrification was achieved after 8.2 days as shown in Table 4.3-9.

Table 4.3-9: Kinetics Summary of Cell 1 Batch Tests

Sample	Initial Nitrate Concentration (mg/l)	100 % Nitrate Removal Time (Days)	k (mg/l/days)	R^2	Removal Percentage (%)
Cell 1 + Treated Leachate	500	-	0.082	0.94	80
Cell 1 + Seeded Treated Leachate	500	-	0.035	0.93	60
Cell 1 + CGRraw + Treated Leachate	500	7.0	1.493	0.93	100
	500	7.0	0.769	0.97	100
Cell 1 + CGR10 + Treated Leachate	500	8.2	0.007	0.97	100
	500	8.2	0.027	0.91	100

4.3.2. Cell 2 batch Test

4.3.2.1. Nitrate Concentration Evolution of Cell 2 batch Tests and Their Kinetic Rate

1. Cell 2 + Treated leachate

After the batch test was concluded the end point (Tend) of both solid and eluate were characterised and the results are presented in Table 4.3-10.

Table 4.3-10: Input and Output Characterization Results of Cell 2 + Treated Leachate Batch Test

Parameter	Eluate Input	Solid Input	0 mg/l (Blank)		500 mg/l	
			Eluate Output	Solid Output	Eluate Output	Solid Output
pH	7.23		7.15		7.15	
COD (mg/l)	3328		5642		7251	
NH_3-N (mg/l)	1.16		23.1		28.0	
NO_3 (mg/l)	12.60		13.3		10.50	
Total C (%)	0.71	8.84		20.90		21.03
Total N (%)	0.03	0.49		0.78		0.71
C/N Ratio	23.67	18.04		26.79		29.62

Table 4.3-11: Output characterization results of Cell 2 + Treated Leachate batch Test at different time set

Sample		Time (Days)	pH	NH_3 (mgN/l)	COD (mg/l)	C (%)
Cell 2 + Treated Leachate	T0	0	7.42	20.30	3957.52	6.50
	T1	10	7.21	25.20	6983.26	7.72
	T2	17	7.23	28.70	8320.77	6.37
	Tend	35	7.15	28.00	7251.45	7.40

pH

The pH in both the blank and the 500 mg/ℓ nitrate concentration remained constant around the optimum range of 6 - 8 for denitrification. From Table 4.3-10, it observed that the pH is favorable but it is important to take note that pH is not the only factor that affects the denitrification process as discussed in section 2.7.2.1. The variation between initial and end pH is great as shown in Table 4.3-11the initial pH was 7.42 while the end pH 7.15. However there was a great drop in the pH level, but it still remained within the range. This indicates that the pH in the batch is favorable for denitrification.

NO_3

The substrate used showed some evidence of nitrate as it could be seen from the blank (control batch test) shown in Table 4.3-11, the initial nitrate concentration of the blank (distilled water) was 0 mg/ℓ but after been in contact with the substrate it increase to 500 mg/ℓ which resulted in the 500 mg/ℓ batch test increasing to 1000 mg/ℓ. Zero nitrate concentration could not be achieved at the end of the batch tests.

NH_3 – N

It is noted that the initial NH_3 – N was high as shown in Table 4.3-10. There was an increase in NH_3 – N of 1.16 – 28.0 mg/ℓ. The increase in NH_3 – N is evident that there is bioleaching of N (%) that took place as it could be seen by the decrease in the total N (%).

COD

Table 4.3-10 shows that there was an increase in COD, this increase shows positive bioleaching of carbon which can also be seen by the increase of the C/N ratio. The carbon leached out from the substrate and evidence shown by the C/N ratio increasing from 18.04 – 29.62. The increase in the COD level as per Table 4.3-11 is an indication of the process of bioleaching of carbon from the solid to the batch test eluate. It could also be observed by the low level in the COD at time 0 (T0) where the carbon had not had enough time to leach out. However at time 35 days (Tend) the COD increase as the batch has had enough time for the carbon to leach out.

Figure 4.3-11 shows the evolution of nitrate concentration for the Cell 2 substrate which was conducted with an initial nitrate concentration of 500 mg/ℓ. From Figure 4.3-11, it could be seen that the blank test showed much leaching out of nitrates.

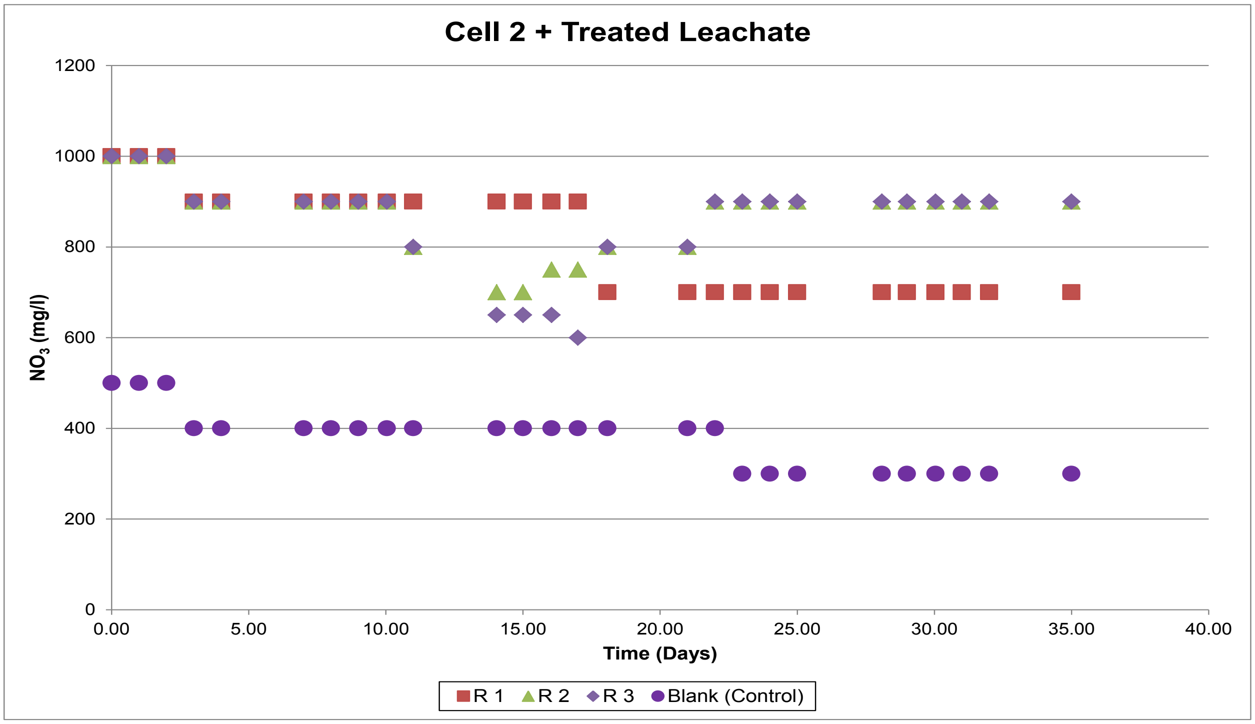


Figure 4.3-11: Evolution of nitrate concentration in Cell 2 + Treated Leachate at 500 mg/ℓ

It is observed from Figure 4.3-11 that the batch test could not reach full denitrification. However there was an increase in the nitrate concentration from 500 mg/ℓ to 1000 mg/ℓ in the first 2 days. This was attributed to the acclimatisation process that occurs at the start of the batch test where the batch test is stabilizing the environment for nitrate removal. After 2 days the nitrate concentration dropped to 900 mg/ℓ which lasted for 8.04 days (between 2 days – 10.04 days), after which it dropped further. After 22 days of running the batch test nitrate concentration increased from 766.67 mg/ℓ to 833.33 after which no further nitrate removal took place.

Kinetics of Cell 2 Batch Tests

A zero order reaction kinetic model was used to model the average of the three replicate.

$$Zero\ Order\ Reaction: \frac{dc}{dt} = -k \rightarrow c = c_o - kt$$

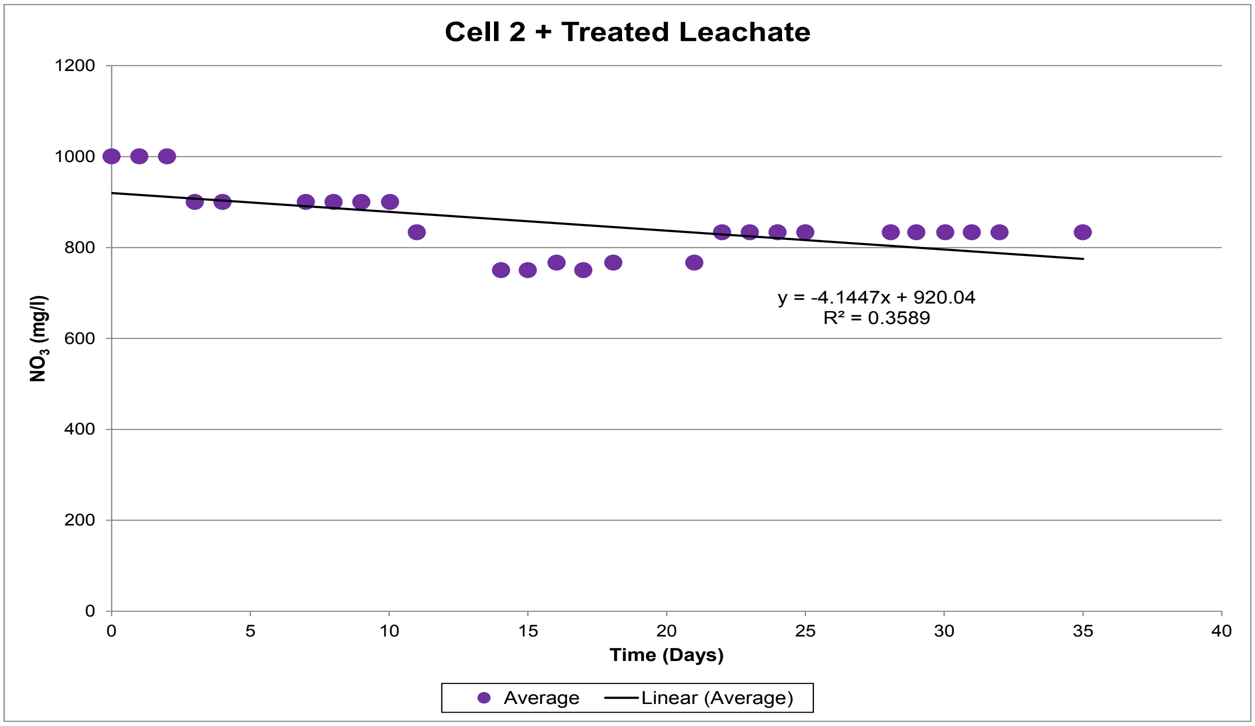


Figure 4.3-12: Kinetics of Cell 2 + Treated Leachate at 500 mg/ℓ

A plateau is observed at the initial stage of the batch test which was then followed by a linear nitrate removal as shown in Figure 4.3-12. Table 4.3-18 shows that 17% of nitrate removal was achieved.

2. Cell 2 + Seeded Treated Leachate

After the batch test was concluded the end point (Tend) of both solid and eluate were characterised. Table 4.3-12 presents the summary results of the characterization of the initial input and final output parameter on the solid and eluate.

Table 4.3-12: Input and Output characterization results of Cell 2 + Treated Leachate Seeded Mix Liquor batch Test

Parameter	Eluate Input	Solid Input	0 mg/l (Blank)		500 mg/l	
			Eluate Output	Solid Output	Eluate Output	Solid Output
pH	7.23		7.39		7.16	
COD (mg/l)	3328		9490		5996	
NH_3-N (mg/l)	1.16		17.50		18.67	
NO_3 (mg/l)	12.60		7.00		9.10	
Total C (%)	0.71	8.84		8.56		7.56
Total N (%)	0.03	0.49		0.41		0.39
C/N Ratio	23.67	18.04		20.88		19.23

Table 4.3-13: Output characterization results of Cell 2 + Treated Leachate Seeded Mix Liquor at different time set

Sample		Time (Days)	pH	NH_3 (mgN/l)	COD (mg/l)	C (%)
Cell 2 + Treated Leachate Seeded with Mixed Liquor	T0	0	7.15	12.37	3768.41	8.20
	T1	8	7.32	20.30	4249.78	7.61
	T2	21	7.43	19.60	6959.19	6.41
	Tend	34	7.16	18.67	5996.45	7.56

pH

The pH in this batch test falls within the optimum range for denitrification of 6 – 8 (Trois, et al, 2010), as shown in Table 4.3-12even though the pH remained within the optimum range full denitrification, it could not be achieved at the end of the test. This indicates that pH is not the only factor that should be considered when choosing the suitable substrate for denitrification. An increase in the pH level from the initial pH is observed in Table 4.3-13.This increase could relate to the release of hydroxyl ions OH^- which occurs during the denitrification process (Trois et al, 2010).

NH_3 – N

From Table 4.3-12, it could be observed that the blank and 500 mg/ℓ showed a high amount of NH_3 - N at the end of the tests, the 500 mg/ℓ increased above that of the initial NH_3-N input of 1.16 mg/ℓ. This increase in NH_3 relates to the reduction in total N (%) from 0.49 – 0.39, which indicates evidence of bioleaching of nitrogen.

COD

Table 4.3-13 shows an increase in the COD level which is a positive bioleaching of carbon from the solid to the batch test eluate and it could also be seen by the an increase in the initial eluate COD, the COD increased from 3328 to5996 mg/ℓ. It could also be observed by the low level in the COD at time 0 (T0) where the carbon had not had enough time to leach out. Additionally a positive evidence of bioleaching of carbon could be seen in this batch by the increase of the C/N ratio as shown in Table 4.3-12.

The evolution of the nitrate concentration for Cell 2 + Seeded Treated leachate with an initial concentration of 500 mg/ℓ is shown in Figure 4.3-13.

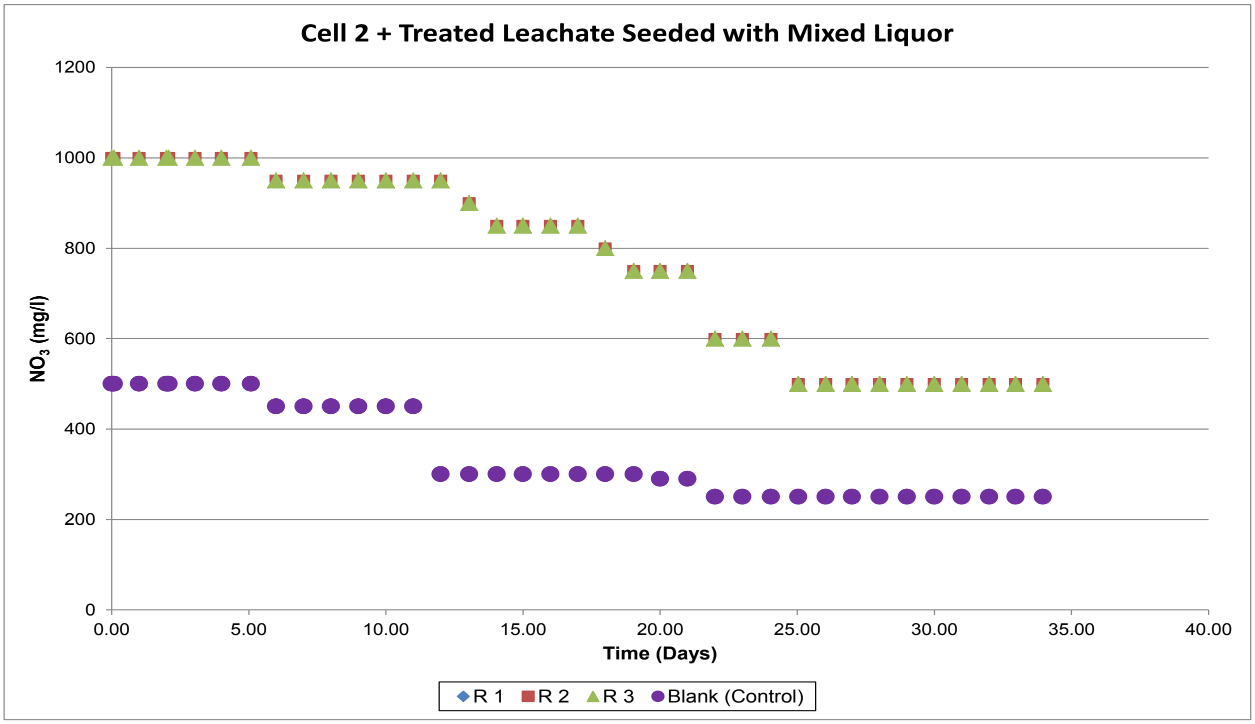


Figure 4.3-13: Evolution of nitrate concentration in Cell 2 + Seeded Treated Leachate at 500 mg/ℓ

An acclimatisation process could be observed at the start of the batch test which lasted for 5.083 days as shown in Figure 4.3-13. At this phase the environment within the batch is becoming stable for nitrate removal. This batch was not promising as after 33.958 days of running the batch full denitrification could not be achieved compared to Cell 2 + CGR_{raw} and Cell 2 + CGR_{10} which achieved full denitrification after 14 days, as indicated in Table 4.3-18.

After the acclimatisation had occurred, the curve showed a denitrification process followed an exponential rate until the nitrate concentration remained constant till the batch was scarified after 33.958 days. Full denitrification could not be achieved as shown in Figure 4.3-14 and Table 4.3-18.

As noticed in Table 4.3-12the Cell 2 + Seeded Treated leachate batch exhibited the same behave as the above batch (Cell 2 + Treated Leachate), that is the substrate used showed some evidence of nitrate as it could be seen from the blank, the initial nitrate concentration of the blank (distilled water) was 0 mg/ℓ but after been in contact with the substrate it increase to 500 mg/ℓ which also resulted in the batch with the initial concentration of 500 mg/ℓ to increase to 1000 mg/ℓ also as shown in Figure 4.3-13. Full denitrification was not accomplished in the 500 mg/ℓ batch.

Kinetics of Cell 2 Batch Tests

A zero order reaction kinetic model was used to model the average of the three replicate.

$$Zero\ Order\ Reaction: \frac{dc}{dt} = -k \rightarrow c = c_o - kt$$

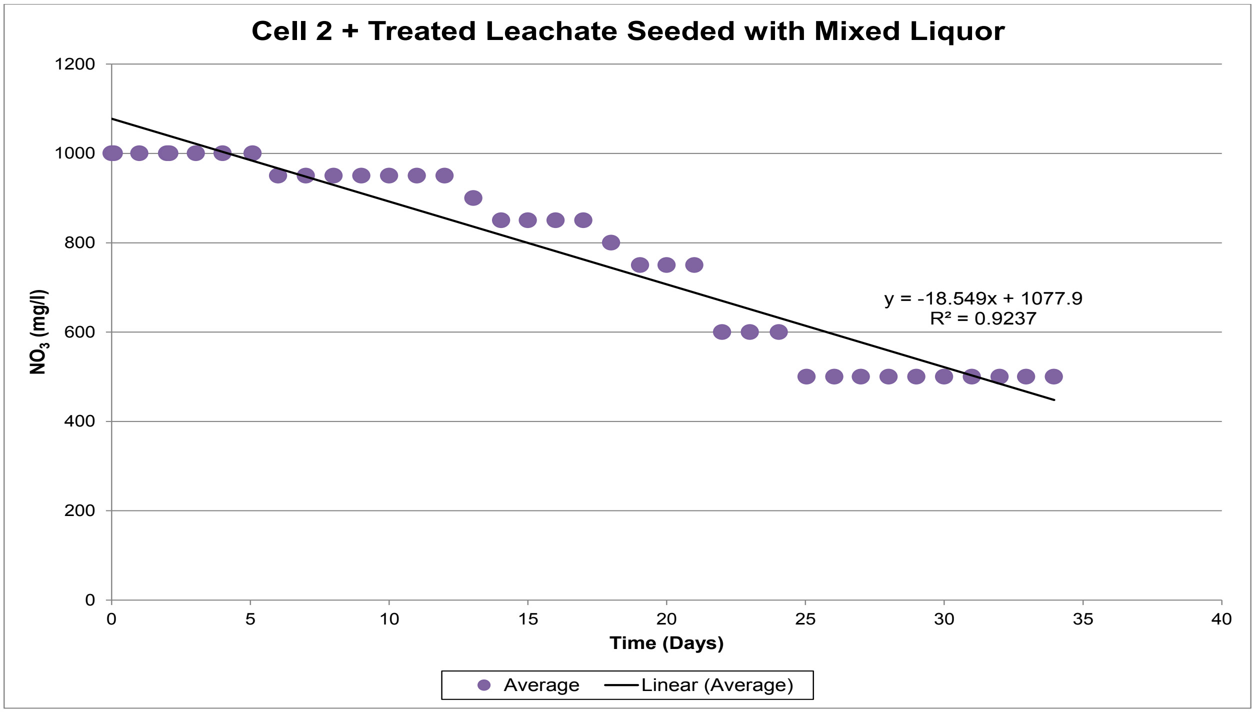


Figure 4.3-14: Kinetics of Cell 2 + Seeded Treated Leachate at 500 mg/ℓ

An acclimatisation period is presented in the initial stage of this batch test which lasted for 5.083 days. The nitrate removal followed a step process of denitrifying where a plateau is seen for an average of 2 days after which nitrate is removed again. To model the nitrate removal a linear relationship was used as presented in Figure 4.3-14.

3. Cell 2 + CGR_{raw} + Treated Leachate

After the batch test was concluded the end point (Tend) was characterised and the summary of results is presented in Table 4.3-14 .

Table 4.3-14: Input and Output characterization results of Cell 2 + CGR_{raw} + Treated Leachate batch Test

Parameter	**Eluate Input**	**Solid Input**	**0 mg/l (Blank)**		**500 mg/l**	
			Eluate Output	**Solid Output**	**Eluate Output**	**Solid Output**
pH	**7.03**		**7.22**		**7.37**	
COD (mg/l)	3250		8871		9455	
NH_3-N (mg/l)	**1.12**		**2.80**		**8.40**	
NO_3 (mg/l)	12.60		0.00		0.00	
Total C (%)	**0.83**	**11.87**		**14.20**		**14.33**
Total N (%)	0.04	0.86		0.93		0.88
C/N Ratio	**20.75**	**13.80**		**15.27**		**16.23**

Table 4.3-15: Output characterization results of Cell 2 + CGRraw + Treated Leachate batch Test at different time set

Sample		**Time (Days)**	**pH**	**NH_3 (mgN/l)**	**COD (mg/l)**	**C (%)**
Cell 2 + CGR_{raw} + Treated Leachate	**T0**	0	7.32	10.03	3957.52	20.13
	T1	5	7.38	8.40	5112.80	16.30
	T2	8	7.39	7.47	6195.19	15.60
	Tend	14	7.37	8.40	9455.42	14.33

pH

Table 4.3-14 shows that the test conducted at 500 mg/ℓ initial concentration exhibits a fairly neutral pH which falls within the optimum range for denitrification of 6 – 8. However it is important to always remember that even though the pH is with range of denitrification, pH is only one of the limiting factors in the process of denitrification - other factors will also need to be observed. As reported in Table 4.3-15, the pH at different time level still remained within the optimum pH range for denitrification.

COD

Table 4.3-15 above shows positive bioleaching of carbon was observed by the increase of both the COD relating to the initial eluate COD. The COD increased from 4250 – 9455 mg/ℓ as shown in Table 4.3-14.

NH_3 - N

It is observed that initial substrate contained low level of NH_3-N which later increased, the ammoniacal nitrogen released in this batch test tended to increase as shown in Table 4.3-14.

Figure 4.3-15shows the evolution of nitrate concentration for the Cell 2 + CGR_{raw} substrate which was conducted at an initial concentration of 500 mg/ℓ. From the Figure 4.3-15, it could be seen that the blank test showed some leaching out of nitrates.

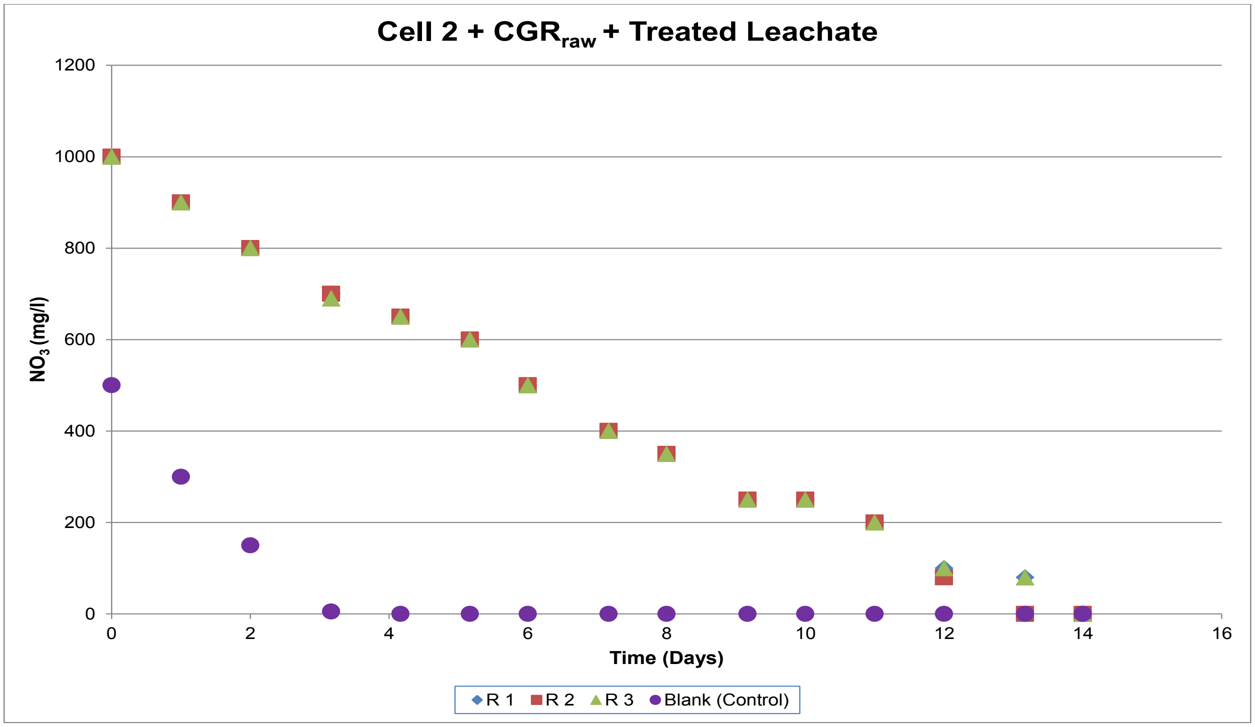


Figure 4.3-15: Evolution of nitrate concentration in Cell 2 + CGR_{raw} + Treated Leachate at 500 mg/ℓ

An acclimatisation phase was not evident in this batch test which relates to the presence of easily available biodegradable carbon. The decrease in the nitrate concentration is approximately linear. Full denitrification was achieved after 14 days.

From Figure 4.3-15, it could be seen that the substrate has a high level of nitrate present as it could be seen from the blank shown, the initial nitrate concentration of the blank (distilled water) was 0 mg/ℓ, but after been in contact with the substrate it increase to 500 mg/ℓ resulting in the 500 mg/ℓ batch test to increase to 1000 mg/ℓ.Cell 2 + CGR$_{raw}$ showed to be a promising carbon source mixture as full denitrification was achieved. Cell 2 + CGR$_{raw}$ achieved full denitrification after 14 days as shown in Figure 4.3-15 and Table 4.3-14.

Kinetics of Cell 2 Batch Tests

A zero order reaction kinetic model was used to model the average of the three replicates.

$$Zero\ Order\ Reaction: \frac{dc}{dt} = -k \rightarrow c = c_o - kt$$

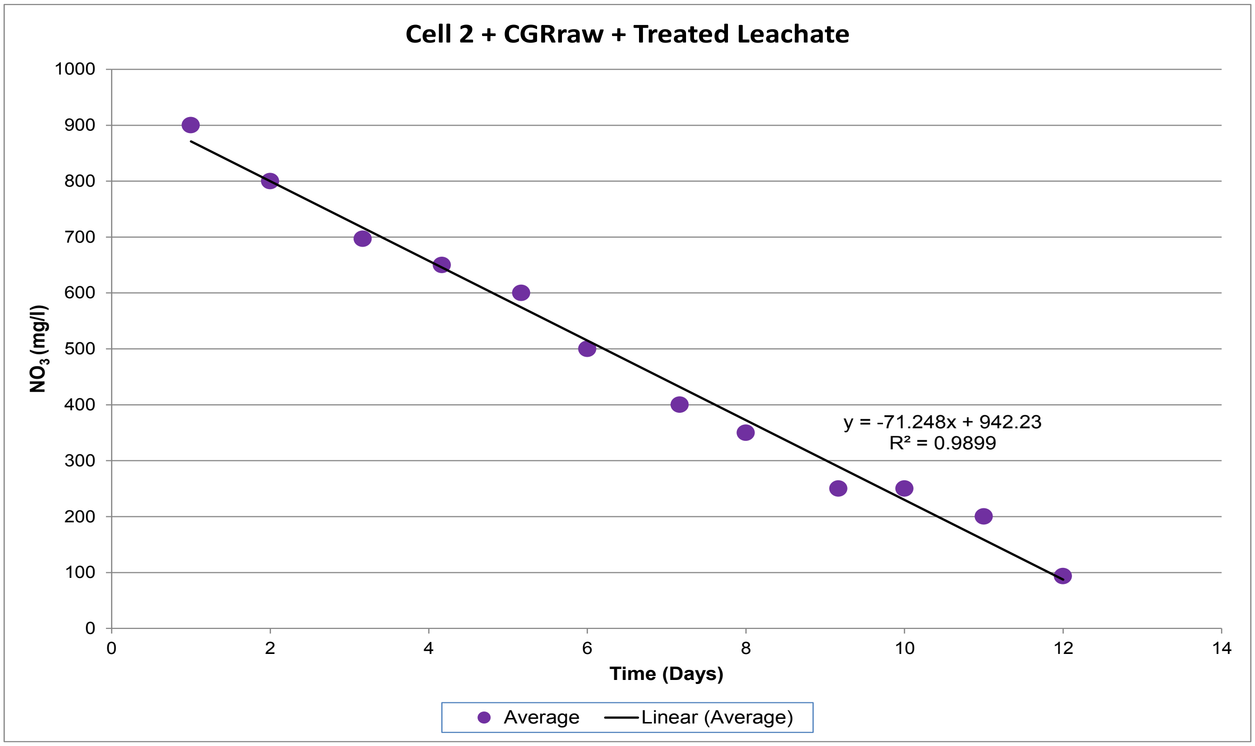


Figure 4.3-16: Kinetics of Cell 2 + CGR$_{raw}$+ Treated Leachate at 500 mg/ℓ

From Figure 4.3-16, it is observed that the nitrate removal in this batch was slower compared to the Cell 1 + CGR_{raw} batch test, a kinetic model of zero order was used as the nitrate removal was approximately linear as shown in Figure 4.3-16. This batch showed a high efficiency, compared to the other Cell 2 batch tests as reported in Table 4.3-14.

4. Cell 2 + CGR_{10} + Treated Leachate

After the batch test was concluded the end point (Tend) effluent (solid and eluate) was characterised and the results are presented in Table 4.3-16.

Table 4.3-16: Input and Output characterization results of Cell 2 + CGR10 + Treated Leachate batch Test

Parameter	Eluate Input	Solid Input	0 mg/l (Blank)		500 mg/l	
			Eluate Output	Solid Output	Eluate Output	Solid Output
pH	**7.18**		**7.50**		**7.70**	
COD (mg/l)	4136		8046		8252	
NH_3-N (mg/l)	**1.68**		**39.90**		**41.77**	
NO_3 (mg/l)	15.40		0.00		0.00	
Total C (%)	**0.62**	**9.00**		**16.40**		**16.30**
Total N (%)	0.03	0.73		0.98		0.93
C/N Ratio	**20.67**	**12.33**		**16.73**		**17.53**

Table 4.3-17: Output characterization results of Cell 2 + CGR10 + Treated Leachate batch Test at different time set

Sample		Time (Days)	pH	NH_3 (mgN/l)	COD (mg/l)	C (%)
Cell 2 + CGR10 + Treated Leachate	**T0**	0	7.23	17.03	3011.98	16.33
	T1	4	7.46	11.90	5607.92	15.63
	T2	8	7.57	26.37	8186.67	16.50
	Tend	14	7.70	41.77	8252.00	16.30

pH

The pH within this batch fell within the pH optimum range for denitrification of 6 – 8 as stated by (Plug et al 2010). Hence the pH was more favorable as shown in Table 4.3-16 but pH is not the only factor that affects the nitrate removal process other factors will also need to be observed. The increase in pH from T0 confirms the theory that when denitrification occurs there is an increase in pH as indicated in Table 4.3-17.

COD

The increase in COD indicates positive bioleaching of carbon relating to the initial eluate COD, as indicated in Table 4.3-16.Table 4.3-17 shows a high percentage of Total carbon in the batch test at T0 which is what is expected as the substrate should provide carbon for the denitrification process to occur. However it can also be observed that as the percentage of total carbon decreases, there is an increase of the COD level which indicate that bioleaching of carbon is occurring, this is confirmed by the results presented in Table 4.3-16

NH_3 - N

It is noted that the initial NH_3-N level of this substrate was low which later increased significantly as reported in Table 4.3-16.

Figure 4.3-17shows the evolution of nitrate concentration for the Cell 2 + CGR_{10} substrate which was conducted at an initial concentration of 500 mg/ℓ.

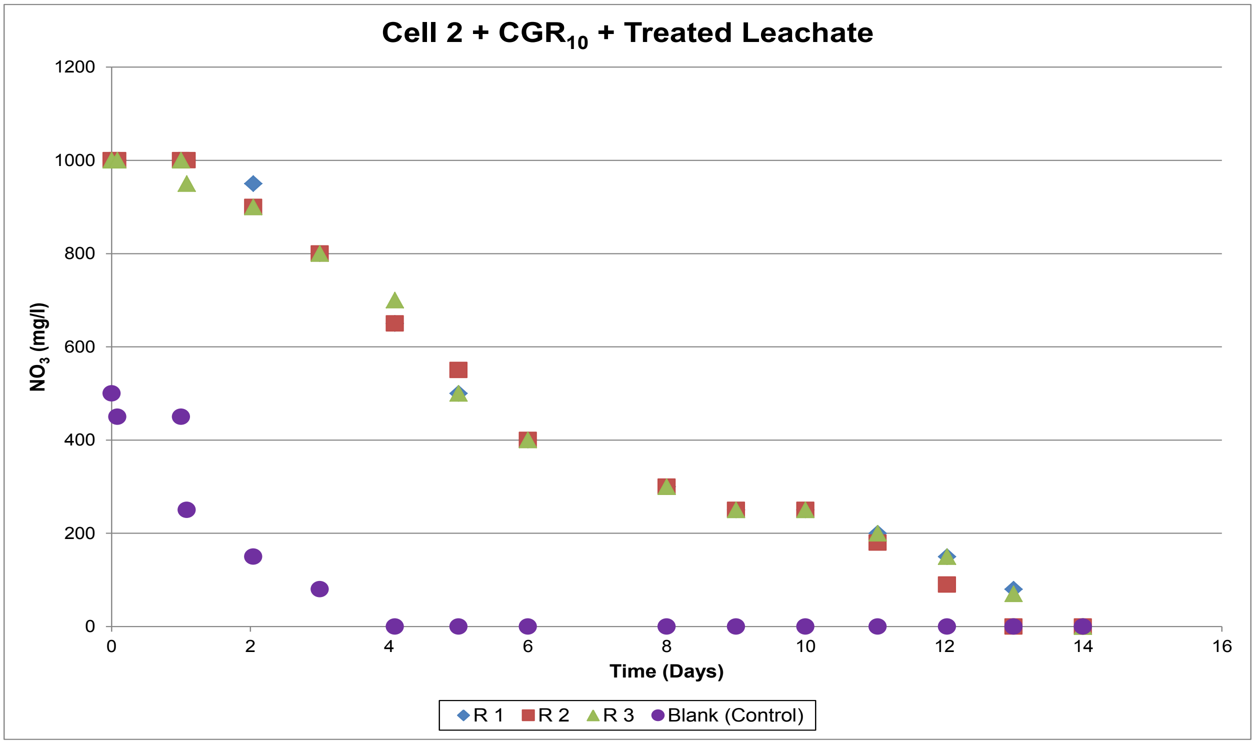


Figure 4.3-17: Evolution of nitrate concentration in Cell 2 + CGR_{10} + Treated Leachate at 500 mg/ℓ

NO_3

As observed in other Cell 2 batches this batch also exhibited a high level of nitrate in its initial stage as it could clearly observed in the blank batch test which had an initial nitrate concentration of 0 mg/ℓbut after been in contact with the substrate it increase to 500 mg/ℓ resulting in the 500 mg/ℓ batch test to increase to 1000 mg/ℓ as well as shown in Figure 4.3-17. Cell 2 + CGR_{10} showed to be a promising carbon source as full denitrification was achieved within 14 days as shown in Figure 4.3-17 and Table 4.3-18.

Kinetics of Cell 2 Batch Tests

A first order reaction kinetic model was used to model the average of the three replicate.

$$First\ Order\ Reaction: \frac{dc}{dt} = -kC \rightarrow c = c_o e^{-kt}$$

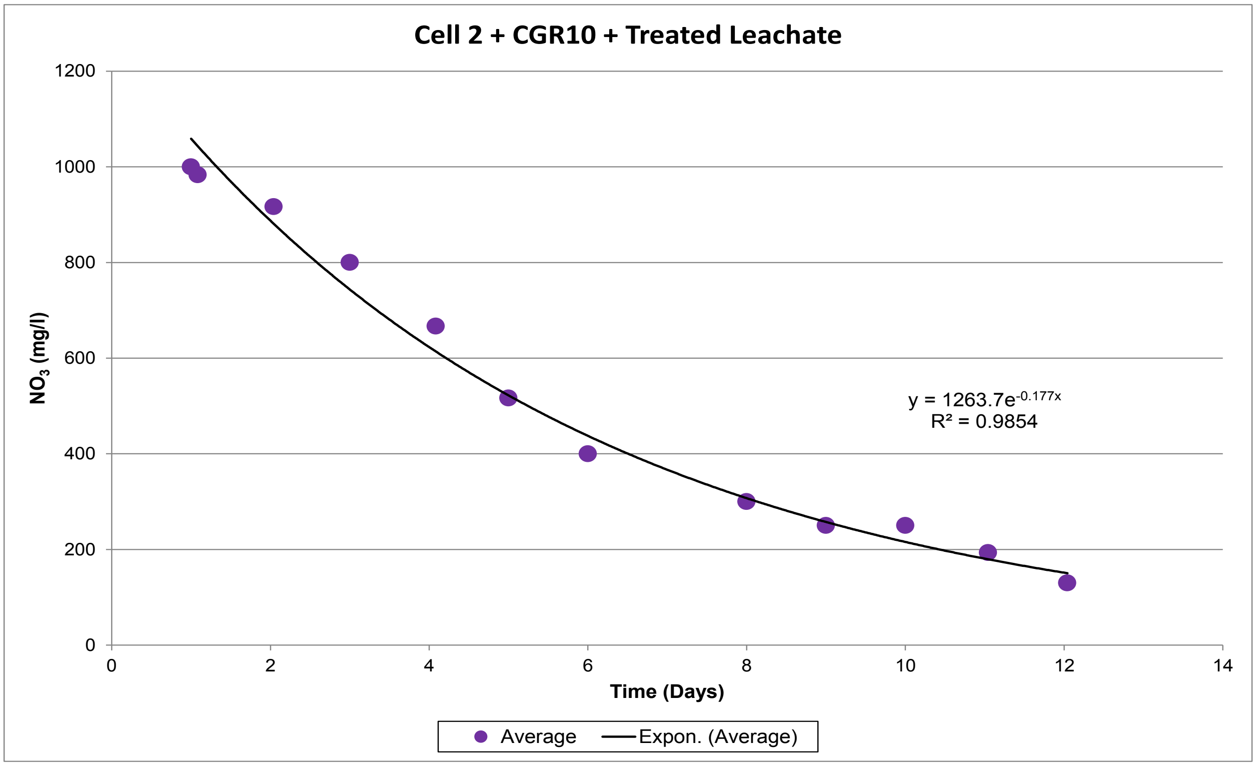


Figure 4.3-18: Kinetics of Cell 2 + CGR_{10} + Treated Leachate at 500 mg/ℓ

After the acclimatisation phase had been completed, denitrification process occurred at an exponential rate (first order reaction) as shown in Figure 4.3-18 until a zero nitrate concentration was achieved which lasted for 14 days as reported in Table 4.3-18.

Table 4.3-18: Kinetics Summary of Cell 2 batch tests

Sample	Initial Nitrate Concentration (mg/l)	100 % Nitrate Removal Time (Days)	k (mg/l/days)	R^2	Removal Percentage (%)
Cell 2 + Treated Leachate	500	-	0.24	0.36	17
Cell 2 + Seeded Treated Leachate	500	-	0.05	0.92	50
Cell 2 + CGRraw + Treated Leachate	500	14.0	0.01	0.99	100
Cell 2 + CGR10 + Treated Leachate	500	14.0	5.88	0.99	100

4.4. Important Observations

The temperature range throughout the investigation was between 19°C and 24°C as shown in the appendices which is within the 60°C range which is considered suitable for denitrification according to Henze et al (1997). It was observed that the batch that consist of treated general waste only without the mixture with other substrate did not have good contact with the liquid as it consists of fines which settles to the bottom of the batch bottle hence reducing the solid to liquid contact. However the treated waste fines (8 weeks and 16 weeks) mixed with other substrates such as CGR_{raw} and CGR_{10} increase the liquid to solid contact as this added substrates tenders to float when shake on the shakers when in the liquid. It was observed that the effluent samples from the batch test had a brown colour as it contained the fine particles that have been washed from the fine pre-treated waste.

4.5. Comparing the Different Substrates Used

Table 4.5-1 shows the summary of results of the different substrates used. These results are based on the end points of the batch tests.

Table 4.5-1: Summary Results of different Substrates Used

Substrate	Initial NO_3 (mg/L)	Time (Days)	Reaction Rate (mgN/l/day)	COD (mg/L)	pH	NH_3 (mgN/L)	Total C (%)	Total N (%)	C:N Ratio
Cell 1	500	-	0.082	18164.72 ± 168.51	7.86	22.00 ± 2.65	1.57	0.08	21.22
Cell 1 (Seeded)	500	-	0.035	13849.61 ± 221.65	7.53	7.30 ± 1.74	6.27	0.29	21.22
Cell 1 + CGR_{raw}	500	0 - 1.17	1.493	5408.50 ± 12.50	7.43	12.67 ± 2.08	22.13	0.89	24.84
		3.0 - 6.0	0.769						
Cell 1 + CGR_{10}	500	0 - 2.0	0.007	5649.18 ± 50.76	7.84	32.43 ± 4.27	20.00	0.82	24.59
		3.17 - 8.0	0.027						
Cell 2	500	-	0.242	7251.45 ± 83.03	7.15	28.00 ± 3.05	7.40	0.33	29.75
Cell 2 (Seeded)	500	-	0.054	5996.45 ± 162.70	7.16	18.67 ± 1.45	7.56	0.39	19.26
Cell 2 + CGR_{raw}	500	14.0	0.014	9455.42 ± 164.44	7.37	8.40 ± 1.40	14.33	0.88	16.23
Cell 2 + CGR_{10}	500	14.0	5.882	8252.00 ± 37.34	7.70	41.77 ± 5.82	16.30	0.93	17.51

The acclimatization phase is not evident in the cell 1 substrates this can be as a result of the presence of easily biodegradable carbon. For the cell 2 batches an initial plateau is the acclimatization phase at the initial of the batch test can be observed as suggested by Trois et al (2010).This phase involves the buffering of the pH level and also the competition between nitrifiers and denitrifiers, and occurs until the environment with the batch is more stable for denitrification to take place.

Looking at the different substrates used for this research cell 1 + $CGR_{raw\&10}$ has been shown to achieve maximum denitrification within a shorter duration of 7 days compared to the other substrates used. These two mixtures (cell 1 + CGR_{raw} and cell 1 + CGR_{10}) had the lowest COD level of 5408 mg/ℓ and 5649 mg/ℓ respectively as indicated in Table 4.5-1.

The pH level in the all the batches ranged between 7.15 and 7.86 as shown in Table which is within the optimal range for denitrification of 6.0 to 8.0 as suggested by Naidoo & Buckley (2000).The increase in pH from the initial eluate pH is expected as the increase in pH indicates that denitrification is occurring and it also indicate that hydroxyl ions OH^- are being released during the denitrification process (Tsui et al, 2007).

5. CONCLUSION AND RECOMMENDATIONS

The aim of this study was to determine the viability of pre-treated general waste at different degrees of stability (carbon contents) as carbon source for in-situ bio-denitrification in landfills, focusing on the efficiency, the kinetics and the performance of the substrate in use.

5.1. Efficiency and Performance of Substrates

Is municipal solid waste a suitable carbon source for denitrification of leachate? And can nitrate removal be achieved in landfills using waste as a carbon source for the denitrifiers?

In order to assess the suitability and performance of the substrates characterization tests were conducted on the substrates to be used for denitrification. The cells used for the research at Bisasar Road landfill site were constructed and filled in 2005.They were sampled for this study in 2011, which is about 6 years later, and hence it resulted in a substantial amount of carbon being leached out of the already stabilised municipal solid waste. The nitrate removal rate results of cell 1 and cell 2 confirm that both this substrates were both too stable and contained too little carbon (7.16% and 8.84% respectively) to attain full denitrification. In addition to the inability to attain full denitrification, cell 2 leached out nitrate of approximately 500mg/ℓ NO_3-N, thus increasing the NO_3 concentration of the treated leachate from 500mg/ℓ to 1000mg/ℓ. At the end of cell 2 batch test, the NO_3 concentration went down from 1000 mg/ℓ to 800mg/ℓ, which indicated partial denitrification. Cell 1 did achieve partial denitrification, with the nitrate concentration dropping from 500mg/ℓ to 100mg/ℓ. Cell 1 and cell 2 samples were also inoculated with mixed liquor from the sequencing batch reactor at Mariannhill landfill site because the carbon content in the cells was low. Seeding the samples with mixed liquor impeded the denitrification process in cell 1 but enhanced it in cell 2. As a result of this limitation, Cell 1 and cell 2 samples were augmented with CGR_{raw} and CGR_{10} thereby increasing the carbon content.

With regards to efficiency and performance the augment substrates (cell 1 and cell 2 with CGR_{raw} and CGR_{10}) were the only substrates to reach full denitrification with a 100% nitrate removal. However, the other substrates cell 1 and cell 2 without augmentation could not achieve full denitrification, but did result in partial denitrification which indicates a propensity to denitrify a nitrate containing effluent.

5.2. The kinetics of the substrates

How and at which extent does the level of stability of the general waste affect the kinetics of the bio-denitrification process?

Augmenting the samples with CGR_{raw} and CGR_{10} resulted in full denitrification, which was in line with previous studies (Trois et al., 2010). Cell 1 augmented with both CGR_{raw} and CGR_{10} (K = 0.67 mg/ℓ/day (phase 1), K = 1.30 mg/ℓ/day (phase 2) and K = 151.27 mg/ℓ/day (phase 1), K = 37.53 mg/ℓ/day (phase 2) respectively) resulted in full denitrification faster than Cell 2 augmented with CGR_{raw} and CGR_{10} (K = 71.25 mg/ℓ/day and K = 0.17 mg/ℓ/day). It is important to note however, that a negative drawback of adding CGR_{raw} and CGR_{10} result in a high effluent COD.

5.3. Recommendation for Further Research

However, the tests with the pre-treated domestic waste did achieve partial denitrification, it is recommended that for further investigations a fresher composted domestic substrate be used as both an external alternative carbon source, as well as a better mixture of the CGR from the test cells that is by constructing one test cell with the mixture of the pre-treated domestic waste and commercial garden refuse.

REFERENCES

Abbas A.A, Jingsong G, Ping LZ, Ying Ya P, Al-Rekabi W.S. (2009), Review on Landfill Treatments. Journal of Applied Science Research, 5 (5): 534 – 545.

Abufayed A.A and Schroeder E.D. (1986) Performance of SBR/denitrification with a primary sludge carbon source. J. Wat. Poll Contr. Fed. 58(5), 387-396.

Adani, F., Ubbiali, C. & Generini, P. (2006), The determination of biological stability of composts using the Dynamic Respiration Index: The results of experience after two years, Waste Management, vol. 26, no. 1, pp. 41-48.

Ahn, W.Y., M.S. Kang, S.K. Yim and K.H. Choi, (2002).Advanced landfill leachate treatment using an integrated membrane process. Desalination, 149: 109-114. DOI: 10.1016/S0011-9164(02)007 40-3.

Benson, C.H., Barlaz, M.A., Lane, D.T., Rawe, J.M. (2007) Practice Review of five Bioreactor Landfills. Waste Management 27, 13–29.

Browne, A. J. (2010) Investigation into the denitrification of high strength landfill leachate using pine bark and raw and composted commercial garden refuse as a carbon source: Column studies. MSc. Eng. Dissertation, School of Civil Engineering, Surveying and Construction, University of KwaZulu-Natal, Durban, RSA.

Bricken, E. C. (2003) Constructed Wetlands as an appropriate treatment of landfill leachate, MSc. Eng. Dissertation, School of Civil Engineering, Surveying and Construction, University of Natal, Durban, RSA.

Ceçen, F., O. Aktas, (2004) Aerobic co-treatment of landfill leachate with domestic wastewater. Environmental Engineering Science, 21: 303-312.

Cheung, K.C., L.M. Chu, M.H. Wong, (1997) Ammonia stripping as a pretreatment for landfill leachate. Water air and soil pollution, 94: 209-221.

Christensen, M.H. and Harremoes P. (1977) Biological denitrification of sewage: Literature Review. Prog. Wat Tech. 8(4-5), 509-555.

Cooper, P.F., Job, GD., Green, M.B. and Shutes, RB.E. (1996). Reed Beds and Constructed Wet/ands for Wastewater Treatment. WRc Swindon, Frankland Road, Blagrove, Swindon, Wiltshire, SN5 8YF.

Crawford, JF and Smith, PG, (1985) Landfill Technology, Butterworths

Deng, L. J., (1998) In situ biological denitrification of ground water", Master Thesis - University of New Mexico, Department of Chemical and Nuclear Engineering.

De Combret, C. (2009). Master of Science Thesis in Civil Engineering: Microbiological study of the biological denitrification of non-hazardous landfill leachate using garden refuse compost and pine bark as a carbon source.

DWAF,Second Edition (1998)Minimum Requirements for Waste Disposal by landfill, RSA

Ding, A., Zhang, Z., Fu, J., Cheng, L., (2001) Biological Control of Leachate from Municipal Landfills. Chemosphere 44 (2001) 1-8

Eaton, A.D, Clesceri, L.S., Rice, E.W and Greenberg, A.E.,(2005) Standard Methods for Examination of Water and Wastewater. American Public Health Association, 21th edition, Washington DC. USA

*El-Fadel, M., Alayli, B., Bou-Zeid, E. and Chahine (2001), W. Temporal Variation of Leachate Quality From Pre-Sorted and Baled Municipal Solid Waste With High Organic and Moisture Content. Waste Management 2001**,** 22 (1), 269 – 282.*

Ehrig, H.J. (1989). Leachate Quality.Sanitary Landfilling: Process, Technology and Environmental Impact, ed. By T.H. Christensen, R Cossu and Stegmann, Academic Press, London, pp 213-229.

Einola JKM, Sormunen KM, Rintala JA. Methane oxidation in a boreal climate in an experimental landfill cover composed from mechanically- biologically treated waste. Sci Total Environ 2008;407:67–83.

EPA. (2000). Manual: Constructed wetlands treatment of municipal wastewaters. Cincinnati. US.

Etchebehere, C, Errazquin, MI, Dabert, P, Moletta, R, Muxi, L (2001a) Comamonas nitrativoranssp. nov., a novel denitrifier isolated from a denitrifying reactor treating landfill leachate. International Journal of Systematic and Environmental Microbiology51:977-983.

Etchebehere, C, Errazquin, MI, Barrandeguy, E, Dabert, P, Moletta, R, Muxi, L (2001b) Evaluation of denitrifying microbiota of anoxic reactors. FEMS Microbiology Ecology 35:259-265.

European Standard EN 12457-2.(2002). Characterization of waste – Leaching Compliance test for leaching of granular waste materials and sludges.

Ghiani M, (1997) Dispense del corso "Impianti di trattamento dei rifiuti solidi urban/', Universita di Cagliari, Dipartimento di Geoingegneria e Tecnologie Ambientali

Héctor, Alvarez-Vazquez, Bruce Jefferson, J. Simon Judd, (2004) Membrane bioreactors vs conventional biological treatment of landfill leachate: a brief review. Journal of chemical technology and biotechnology, 79: 1043-1049.

Harrison, J. A. (2003) The nitrogen cycle of microbes and men, Vision learning, EAS-2(4).

Henze, M., Harremoes,P., LaCaur Hansen, J.and Arvin, E. (1997)Wastewater Treatment, Biological and chemical processes. 2nd Edition, U. Forstne, R. J Murphy and W. H Rulkens (eds), Springer Verlag, Berlin.

Hester, R. E. and Harrison, R. M. (2003) Environmental and health impact of solid waste management activities: Issues in Environmental Technology, The Royal Society of Chemistry, UK.

IWA Specialist Group. (2000) Constructed wetlands for pollution control: Processes, performance, design and operation, IWA Publishing, London, UK.

Jokela, J.P.Y., Kettunen, R.H., Sormunen, K.M., Rintala, J.A. (2002) Biological nitrogen removal from municipal landfill leachate: low-cost nitrification in biofilters and laboratory scale in-situ denitrification. Water Research 36 , 4079–4087.

Jude Ifeanyichukwu Madu, (unknown)New leachate treatment methods, Lund, Sweden

Kadlec H.R & Knight L.R. (1996).Treatment Wetlands.Lewis Publishers.

Kjedsen P, Barlaz M.A, Rooker A.P, Baun A, Ledin A, Christensen T.H. (2002) Present and long-term composition of MSW landfill leachate: A review. Environmental Science and Technology. 32 (4): 297 –336.

Kang K-H., Shin H.S., Park H. (2002) Characterization of humic substances present in landfill leachates with different landfill ages and its implications. Water Research, 36: 4023-4032.

Kostova I (2006), Leachate from sanitary landfills-origin, characteristics, treatment, university of Architecture, Civil Engineering and Geodesy

Kulikowska, D., E. Klimiuk, (2008)The effect of landfill age on municipal leachate composition. Bioresource technology, Sep., 99(13): 5981-5985.

Lema, J.M., R. Mendez, R. Blazquez, 1988. Characteristics of landfill leachates and alternatives for their treatment: a review. Water air and soil pollution, 40: 223-250.

Loizidou, M., N. Vithoulkas, E. Kapetanios, (1992) Physical chemical treatment of landfill leachate from landfill. Journal of Environmental Science and Health, A27: 1059-1073.

Iyilade, Y. 2009. An investigation into the mechanical biological pretreatment of garden waste using forced aeration and its impact on carbon emissions reduction potential.MSc. Eng.

Dissertation, School of Civil Engineering, Surveying and Construction, University of KwaZulu-Natal, Durban, RSA.

Masuku, N. (2010) Nitrate removal using compost & Pine Bark as a carbon source, B.Sc. Eng. Dissertation, School of Civil Engineering, Surveying and Construction, University of KwaZulu-Natal, Durban, RSA

Metcalf and Eddy. 2003. Wastewater Engineering Treatment and Reuse. McGraw – Hill Higher education, New York, USA.

Mehta, R., Barlaz,, M.A., Yazdani, R., Augenstein, D., Bryars, M., Sinderson, L. (2002) Refuse Decomposition in the Presence and Absence of Leachate Recirculation. Journal of Environmental Engineering, 228-236.

Mulamoottil, G., McBean, E.A and Rovers, F. (1998).Constructed Wetlands for the Treatment of Landfill Leachate.Lewis Publishers.

Naidoo, V. and Buckley,C. A. (2000)Application of denitrification batch tests, Water Research Commission, Report No. 820/1/00, RSA.

Naidoo, V, (1999) Application of denitrification batch tests, PhD. Eng. Dissertation, School of Chemical Engineering, University of Natal, Durban, RSA

Noor Ida Amalina Binti Ahamad Nordin, (2006)Leachate Treatment Using Constructed Wetland with Magnetic Field, Master of Engineering (Civil – Environmental Management) Thesis, Faculty of Civil Engineering Universiti Teknologi Malaysia.

Novella, P., Robinson, H., Haider, S., Strachan, L., Last, S., And Traut, M. (2006) Landfill leachate treatment in a developing country: the South African experience. *Proceedings Sardinia 2005, Tenth International Waste Management and Landfill SymposiumS. Margherita di Pula, Cagliari, Italy; 3 - 7 October 2005*

Onay, T.T. and Pohland, F.G. (1998) In-Situ Nitrogen Management in Controlled Bioreactor Landfills, Water Resources 32 (5), 1383-1392.

Peavy, H.S., Rowe, DR. and Tchobanoglous, G. (1985).Environmental Engineering.McGraw-Hill International Editions.

Pisano, G. (2007) Nitrate removal using compost & Pine Bark as a carbon source, MSc. Eng. Dissertation, School of Civil Engineering, Surveying and Construction, University of KwaZulu-Natal, Durban, RSA.

Plug, B. (2008) Nitrate Removal using immature compost and Pine Bark as a carbon source; simulation in columns, BSc. Eng. Dissertation, School of Civil Engineering, Surveying and Construction, University of KwaZulu-Natal, Durban, RSA.

Plüg, B, (2009) Alternative Leachate Treatment Solutions using Garden Refuse, The 20th WasteCon Conference & Exhibition, Institute of Waste Management of Southern Africa, Gauteng, RSA.

Plüg, B., Trois, C., Coulon, F. and Oxarango, L. (2010) Alternative Leachate Treatment Solutions using Garden Refuse, The 20th WasteCon Conference & Exhibition, Institute of Waste Management of Southern Africa, Gauteng, RSA.

Postgate, J (1998).Nitrogen Fixation, 3rd Edition. Cambridge University Press, Cambridge UK

Read, AD, Philloips, P, Robinson, G (1998) Landfill as a future waste management option in England: The view of landfill operators. The Geographical Journal 164:55-66.

Reinhart, D, R., Al-Yousfi, A, B. (1996) The Impact of Leachate Recirculation on Municipal Solid Waste Landfill Operating Characteristics. Waste Management and Research, 14, 337-346.

Renou S, Givaudan J.G, Poulain S, Dirassouyan F and Moulin P. 2007. Landfil leachate treatment: Review and opportunity. Journal of Hazardous Materials. 150 (2008) 468 – 493.

Rodriguez, J., L. Castrillon, E. Maranon, H. Sastre, E. Fernandez, (2004) Removal of non-biodegradable organic matter from landfill leachates by adsorption. Water Research, 38: 3297-3303.

Robinson W. D. (1986). The Solid Waste Handbook. A practical Guide.John Wiley and Sons, Inc.

Robinson H.D., Harris G.R, Carvill M.S. and Formby RW.(1997). Engineered Reed Bed Treatment of Old Leachates. Proceedings Sardinia 1997: the Sixth International Waste Management and Landfill Symposium, Cagliari, Italy

Simelane, O.T., (2007),The study of the kinetics of degradation of mechanical-biological pre-treated waste using test cells. MSc. Eng. Dissertation, School of Civil Engineering, Surveying and Construction, University of KwaZulu-Natal, Durban, RSA.

Strachan L.J, Trois C, Robinson H.D and Olufsen J.S. (2000).Appropriate biological treatment of landfill leachates with full nitrification and denitrification. WISA 2000 Biennial Conference, Sun City, South Africa, 28 May – 1 June 2000.

Stegmann R. (1995). Concepts Of Waste Landfilling. Proceedings of Sardinia 95.

Trois, C., Pisano, G.. and Oxarango, L. (2010) Alternative solutions for the bio-denitrification of landfill leachates using pine bark and compost, Journal of Hazardous Material, 178 (1-3), 1100-1105.

Trois, C., Coulon, F., de Combret, CP., Martins, JMF., Oxarango, L. (2010b) Effect of compost and pine bark on the biological denitrification process of non-hazardous landfill leachate: focus on microbiology. Journal of Hazardous Materials, 181 (2010) 1-3, 1163-1169.

Tsui, L., Kaprac, G. and Roy, WR. (2007) The feasibility of applying immature yard-waste compost to remove nitrate from agricultural drainage effluents: a preliminary assessment. J. Hazard. Mater. 144 (2007) 585-589.

*Vymazal J. 2010(b). Constructed wetlands for wastewater treatment. *Water*. 2 (2010): 530 – 549.*

Welander U., Herrysoson T., and Welander T. (1997). Wat.Res. Vol 31, Issue 9, pp 2351-2355.

Williams, P.T. (2005) Waste Treatment & Disposal, 2nd Edition, John Wiley & Sons Ltd, UK.

Wong, CH., Barton, GW., Barford, JP. (2003) The nitrogen cycle and its application in wastewater treatment. The Handbook of Water and Wastewater Microbiology.Academic Press. London, England.

Zhong, Q., Li, D., Tao, Y., Wang, X., He X., Zhang, J., Zhang J., Guo, W., Wang, L. (2009).Nitrogen removal from landfill leachate via ex situ nitrification and sequential in situ denitrification.Waste Management. 29 (2009) 1347-1353.

Websites

Composting101 (2006),A Composting Guide for the Home Gardener[Online]. Available: http://www.composting101.com/c-n-ratio.html [Accessed 23 April 2011].

DWAF, (Unknown) Guidelines For Leachate ControlRSA, [Online].Available:http://www.dwaf.gov.za/Documents/Policies/WDD/LeachateControl.pdf [Accessed 23 April 2011].

Kostova I (2006) .Leachate from sanitary landfills – origin, characteristics, treatment.University of Architecture, Civil Engineering and Geodesy, "Iskar's Summer School" – Borovetz, 26-29 July 2006http://www.aquastress.net/share/img_events_file/130_5-Leachate%20from%20sanitary%20landfills.pdf

Google Map, (2011) [Online]. Available: http://maps.google.co.za/maps?hl=en&tab=wl [Accessed 23April 2011].

Sandec/Eawag.(2009)Free-Water Surface Constructed Wetland, [Online]. Available: http://www.akvo.org/wiki/index.php/Vertical_Flow_Constructed_Wetland [Accessed 23March 2011].

Prakruti Environmental Engineers (P.E.E),(2010) Upflow Anaerobic Sludge.[Online]. Available: http://www.prakruti.co.in/images/upflowanaerobic_img.jpg [Accessed 23 April 2011].

APPENDICES

APPENDIX A: CHARACTERIZATION TESTS

This Appendix contains the charaterization data which is used to create a reference point for the experiment.

TS and VS

Analysis on Eluate

Date analysed	Sample	Cruc No	Dry initial	After drying	After firing	TS g/l	VS g/l	Cruc No	Dry initial	After drying	After firing	TS g/l	VS g/l	Cruc No	Dry initial	After drying	After firing	TS g/l	VS g/l	TS (g/l) Average	VS (g/l) Average	TS (g/l) Std Dev	VS (g/l) Std Dev
10/06/2009	DGR 10	C	43.3862	43.7225	43.4268	13.452	11.828	16	52.8987	53.3529	53.0531	18.168	11.992	1	53.9079	54.3662	54.0617	18.332	12.180	16.651	12.000	2.771	0.176
14/02/2011	Cell 1 (8 wks)	6	54.1723	54.4332	54.3609	10.436	2.892	M	45.4143	45.6683	45.6049	10.160	2.536	15	46.9802	47.3418	47.2645	14.464	3.092	11.687	2.840	2.409	0.282
03/06/2011	Cell 1 + CGR10	20	54.4859	54.8806	54.668	15.788	8.504	Z	40.5601	40.9364	40.7153	15.052	8.844	19	49.3361	49.7289	49.5277	15.712	8.048	15.517	8.465	0.405	0.399
09/06/2011	Cell 1 + CGRraw	25	57.1729	57.3807	57.2363	8.312	5.776	M	45.5149	45.7166	45.6111	8.068	4.220	23	53.839	54.0398	53.9151	8.032	4.988	8.137	4.995	0.152	0.778
09/06/2011	CGR RAW	29	56.4139	56.5568	56.4583	5.716	3.940	9	54.5568	54.708	54.6155	6.048	3.700	20	54.4784	54.6217	54.4987	5.732	4.920	5.832	4.187	0.187	0.646
09/06/2011	CGR10	21	52.469	52.6523	52.5197	7.332	5.304	W	41.2216	41.389	41.2819	6.696	4.284	29	56.42	56.6069	56.4748	7.476	5.284	7.168	4.957	0.415	0.583
03/06/2011	Cell 2	23	53.8411	54.106	53.999	10.596	4.280	W	41.2226	41.4918	41.378	10.768	4.552	1	53.9019	54.1627	54.0258	10.432	5.476	10.599	4.769	0.168	0.627
03/06/2011	Cell 2 + CGR$_{10}$	6	54.2508	54.5383	54.4114	11.500	5.076	15	47.1445	47.4363	47.3099	11.672	5.056	61	48.8640	49.1458	49.0256	11.272	4.808	11.481	4.980	0.201	0.149
03/06/2011	Cell 2 + CGR$_{raw}$	55	44.7010	44.933	44.8330	9.280	4.000	58	46.1160	46.3113	46.2261	7.812	3.408	59	45.5118	45.7073	45.6217	7.820	3.424	8.304	3.611	0.845	0.337

Analysis on Dry Solid

Date analysed	Sample	Cruc. No	Cruc.dry	Cruc+wet sample	Cruc+dried residue	Cruc+Fired residue	Mass of wet sample	TS (%)	VS (%)
02/06/2009	DGR 10	29	56.4304	62.8789	58.5242	57.2397	6.4485	32.4696	61.3478
09/02/2011	Cell 1 (8 wks)	50	46.8900	64.7500	61.8737	59.2652	17.86	83.8953	17.4089
07/03/2011	Cell 1 (8 wks)	55	44.7051	56.6298	53.4301	52.0404	11.9247	73.1675	15.9278
03/06/2011	Cell 1 + CGR$_{raw}$	55	44.7051	54.0811	50.7849	47.1645	9.376	64.8443	59.5480
03/06/2011	Cell 1 + CGR$_{10}$	56	48.5508	56.1225	53.1253	50.7744	7.5717	60.4158	51.3914
06/04/2011	CGRraw	Z	40.5618	48.796	45.6658	41.25	8.2342	61.9854	86.5165
16/05/2011	CGR 10	50	46.8900	55.6152	52.8205	49.5084	8.7252	67.9698	55.8486
05/04/2011	Cell 2 (16 wks)	59	45.5160	57.8479	54.4125	52.8728	12.3319	72.1422	17.3068
05/04/2011	Cell 2 + CRGraw	9	54.5676	64.4876	61.1905	57.5092	9.92	66.7631	55.5844
05/04/2011	Cell 2 +CGR10	29	56.5164	65.3164	62.4899	59.7502	8.8	67.8807	45.8642

Date analysed	Sample	Cruc. No	Cruc.dry	Cruc+wet sample	Cruc+dried residue	Cruc+Fired residue	Mass of wet sample	TS (%)	VS (%)
02/06/2009	DGR 10	P	40.7618	44.7700	41.9914	41.3383	4.0082	30.6771	53.1148
09/02/2011	Cell 1 (8 wks)	54	45.0300	58.2125	54.6955	53.2257	13.1825	73.3207	15.2067
07/03/2011	Cell 1 (8 wks)	60	45.3829	61.8330	56.4918	53.8206	16.4501	67.5309	24.0456
03/06/2011	Cell 1 + CGR$_{raw}$	54	45.0300	54.4876	51.1905	47.5092	9.4576	65.1381	59.7565
03/06/2011	Cell 1 + CGR$_{10}$	50	46.8900	54.7511	54.6987	51.6645	7.8611	99.3334	38.8567
06/04/2011	CGRraw	23	53.844	60.143	57.6596	54.3415	6.2990	60.5747	86.9614
16/05/2011	CGR 10	56	48.5508	55.6518	52.9776	49.5083	7.1010	62.3405	78.3704
05/04/2011	Cell 2 (16 wks)	55	44.7059	57.1476	53.633	52.1055	12.4417	71.7514	17.1108
05/04/2011	Cell 2 + CRGraw	P	44.4162	54.3362	51.2449	47.3763	9.9200	68.8377	56.6521
05/04/2011	Cell 2 +CGR10	50	46.894	55.7511	53.4753	51.3033	8.8571	74.3054	33.0026

Date analysed	Sample	Cruc. No	Cruc.dry	Cruc+wet sample	Cruc+dried residue	Cruc+Fired residue	Mass of wet sample	TS (%)	VS (%)
02/06/2009	DGR 10	6	54.2631	61.3894	57.1795	54.9569	7.1263	40.9245	76.2104
09/02/2011	Cell 1 (8 wks)	56	48.5508	66.1185	60.7453	59.0924	17.5677	69.4143	13.5545
07/03/2011	Cell 1 (8 wks)	58	46.1190	62.5977	57.3763	54.9917	16.4787	68.3142	21.1827
03/06/2011	Cell 1 + CGR$_{raw}$	61	48.8700	58.4311	55.1541	51.4427	9.5611	65.7257	59.0602
03/06/2011	Cell 1 + CGR$_{10}$	60	45.3829	53.3411	51.2803	48.7816	7.9582	74.1047	42.3695
06/04/2011	CGRraw	19	49.3369	54.4041	52.5123	49.8563	5.0672	62.6658	83.6430
16/05/2011	CGR 10	55	44.7051	51.4246	49.2661	46.3687	6.7195	67.8771	63.5255
05/04/2011	Cell 2 (16 wks)	56	48.5492	65.4136	60.3101	57.347	16.8644	69.7380	25.1945
05/04/2011	Cell 2 + CRGraw	25	57.1719	67.0919	64.2149	60.1645	9.9200	70.9980	57.5096
05/04/2011	Cell 2 +CGR10	57	48.181	56.6568	54.1633	51.7247	8.4758	70.5809	40.7636

Date analysed	Sample	Cruc. No	Cruc.dry	Cruc+wet sample	Cruc+dried residue	Cruc+Fired residue	Mass of wet sample	TS (%)	VS (%)
02/06/2009	DGR 10	19	49.3383	55.3494	51.2455	50.1230	6.0111	31.7280	58.8559
09/02/2011	Cell 1 (8 wks)	61	48.8700	63.7149	59.6060	57.9592	14.8449	72.3211	15.3390
07/03/2011	Cell 1 (8 wks)	53	42.9258	59.6303	54.9171	52.6400	16.7045	71.7848	18.9896
03/06/2011	Cell 1 + CGR$_{raw}$	58	46.1190	55.6313	52.3452	48.6331	9.5123	65.4542	59.6206
03/06/2011	Cell 1 + CGR$_{10}$	61	48.8700	56.2040	54.1532	51.6247	7.3340	72.0371	47.8593
06/04/2011	CGRraw	1	44.4183	57.5927	48.9202	45.1497	13.1744	34.1716	83.7535
16/05/2011	CGR 10	61	48.87	55.654	53.1999	50.3739	6.7840	63.8252	65.2671
05/04/2011	Cell 2 (16 wks)	61	48.8675	63.7462	60.4182	58.9582	14.8787	77.6325	12.6399
05/04/2011	Cell 2 + CRGraw	19	49.4386	59.3986	56.3073	52.3478	9.9600	68.9629	57.6456
05/04/2011	Cell 2 +CGR10	20	47.5825	56.204	53.8193	51.514	8.6215	72.3401	36.9629

Date analysed	Sample	TS (%)	VS (%)	MC (%)	MC (%)	TS (%)	VS (%)
		Average	Average		Std Dev	Std Dev	Std Dev
02/06/2009	DGR 10	**33.9498**	**62.3822**	**66.0502**	1.3411	4.7076	9.8422
09/02/2011	Cell 1 (8 wks)	**74.7379**	**15.3773**	**25.2621**	2.2447	6.3258	1.5791
07/03/2011	Cell 1 (8 wks)	**70.1994**	**20.0364**	**29.8006**	2.3127	2.7079	3.4334
03/06/2011	Cell 1 + CGRraw	**65.2906**	**59.4963**	**34.7094**	0.0794	0.3823	0.3033
03/06/2011	Cell 1 + CGR10	**76.4727**	**45.1192**	**23.5273**	0.2838	16.3882	5.5866
06/04/2011	CGRraw	**54.8494**	**85.2186**	**45.1506**	3.5672	13.8127	1.7655
16/05/2011	CGR 10	**65.5031**	**65.7529**	**34.4969**	0.9434	2.8599	9.3540
05/04/2011	Cell 2 (16 wks)	**72.8160**	**18.0630**	**27.1840**	2.1696	3.3793	5.2200
05/04/2011	Cell 2 + CRGraw	**68.8904**	**56.8479**	**31.1096**	0.0200	1.7297	0.9502
05/04/2011	Cell 2 +CGR10	**71.2768**	**39.1483**	**28.7232**	0.1738	2.7277	5.4851

BOD$_5$

	BOD							
	CELL 1	**Cell 1 + CGRraw**	**Cell 1 + CGR10**	**CGRraw**	**CGR10**	**CELL 2**	**CELL 2 + CGR$_{raw}$**	**CELL 2 + CGR$_{10}$**
	17.6	129	138	1795	363	42.7	120.0	153.0
	29.3	153	156	1742	406	32.1	95.9	80.9
	17.6	129	150	1624	342	42.7	111.0	150.0
AVERAGE	21.50	137.00	148.00	1720.33	370.33	39.17	109	128
STDEV	6.75	13.86	9.17	87.53	32.62	6.12	12.18	40.79

COD

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
ELUATE SAMPLE														
Standard	17/03/2011	1	0.0023	0.073	0.079	0.079	0.077	462.63	0.003	0.000	437.87	475.01	475.01	21.44
CELL 1 Eluate	17/03/2011	0.20	0.0023	0.064	0.065	0.062	0.064	1900.54	0.002	0.000	1910.85	1941.80	1848.96	47.27
	17/03/2011	0.16	0.0023	0.052	0.059	0.054	0.055	2040.44	0.004	0.000	1924.39	2195.16	2001.75	139.47
	17/03/2011	0.12	0.0023	0.029	0.030	0.030	0.030	1414.01	0.001	0.000	1379.63	1431.21	1431.21	29.78
	17/03/2011	0.08	0.0023	0.012	0.012	0.016	0.013	857.43	0.002	0.000	754.28	754.28	1063.73	178.66
	17/03/2011	0.04	0.0023	0.006	0.008	0.009	0.008	838.09	0.002	0.000	580.22	889.67	1044.39	236.35
	17/03/2011	0.02	0.0023	0.008	0.007	0.007	0.007	1573.04	0.001	0.000	1779.34	1469.89	1469.89	178.66
								1437.26						73.69

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
ELUATE SAMPLE														
Standard	04/06/2011	1	0.0045	0.075	0.078	0.078	0.077	448.70	0.002	0.000	436.32	454.89	454.89	10.72
CELL 1 + CGRraw Eluate	04/06/2011	0.18	0.0045	0.138	0.123	0.125	0.129	4269.26	0.008	0.000	4590.18	4074.43	4143.19	280.04
	04/06/2011	0.14	0.0045	0.106	0.090	0.087	0.094	3971.28	0.010	0.000	4487.03	3779.71	3647.09	451.55
	04/06/2011	0.1	0.0045	0.061	0.074	0.073	0.069	4012.54	0.007	0.000	3496.79	4301.36	4239.47	447.72
	04/06/2011	0.06	0.0045	0.040	0.099	0.036	0.058	5552.91	0.035	0.001	3661.83	9747.68	3249.23	3638.63
	04/06/2011	0.04	0.0045	0.015	0.020	0.016	0.017	1934.06	0.003	0.000	1624.61	2398.24	1779.34	409.36
	04/06/2011	0.02	0.0045	0.004	0.005	0.005	0.005	51.58	0.001	0.000	-154.73	154.73	154.73	178.66
								3298.60						818.52

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
ELUATE SAMPLE														
Standard	14/06/2011	1	0.0095	0.087	0.084	0.085	0.085	469.33	0.002	0.000	479.65	461.08	467.27	9.45
CELL 1 + CGR10 Eluate	14/06/2011	0.18	0.0095	0.1370	0.128	0.135	0.133	4257.80	0.005	0.000	4383.88	4074.43	4315.11	162.49
	14/06/2011	0.14	0.0095	0.095	0.12	0.092	0.102	4103.90	0.015	0.000	3779.71	4884.89	3647.09	679.60
	14/06/2011	0.1	0.0095	0.063	0.076	0.068	0.069	3682.46	0.007	0.000	3311.12	4115.69	3620.57	405.84
	14/06/2011	0.06	0.0095	0.051	0.042	0.045	0.046	3764.98	0.005	0.000	4280.73	3352.38	3661.83	472.69
	14/06/2011	0.04	0.0095	0.035	0.040	0.035	0.037	4203.36	0.003	0.000	3945.49	4719.11	3945.49	446.65
	14/06/2011	0.02	0.0095	0.025	0.042	0.019	0.029	5931.13	0.012	0.000	4796.48	10057.13	2939.78	3691.85
								4323.94						815.28

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 2 Eluate														
Standard	27/05/2011	1	-0.0010	0.073	0.066	0.067	0.069	431.17	0.004	0.000	457.99	414.66	420.85	23.43
Cell 2 Eluate	27/05/2011	0.20	-0.0010	0.119	0.127	0.125	0.124	3857.81	0.004	0.000	3713.40	3960.96	3899.07	128.83
	27/05/2011	0.16	-0.0010	0.092	0.091	0.093	0.092	3597.36	0.001	0.000	3597.36	3558.68	3636.04	38.68
	27/05/2011	0.12	-0.0010	0.051	0.058	0.070	0.060	3128.88	0.010	0.000	2681.90	3042.93	3661.83	495.59
	27/05/2011	0.08	-0.0010	0.051	0.036	0.038	0.042	3300.80	0.008	0.000	4022.85	2862.41	3017.14	630.08
	27/05/2011	0.04	-0.0010	0.014	0.013	0.012	0.013	2166.15	0.001	0.000	2320.88	2166.15	2011.43	154.72
	27/05/2011	0.02	-0.0010	0.012	0.012	0.011	0.012	3919.70	0.001	0.000	4022.85	4022.85	3713.40	178.66
								3328.45						186.93

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 2 + CGR10 Eluate														
Standard	28/06/2011	1	0.0015	0.072	0.075	0.077	0.075	452.83	0.003	0.000	436.32	454.89	467.27	15.58
Cell 2 + CGR10 Eluate	28/06/2011	0.20	0.0015	0.161	0.164	0.157	0.161	4925.41	0.004	0.000	4935.73	5028.56	4811.95	108.68
	28/06/2011	0.16	0.0015	0.121	0.136	0.111	0.123	4686.88	0.013	0.000	4622.41	5202.63	4235.60	486.73
	28/06/2011	0.12	0.0015	0.082	0.079	0.081	0.081	4083.02	0.002	0.000	4151.79	3997.06	4100.21	78.78
	28/06/2011	0.08	0.0015	0.062	0.052	0.052	0.055	4164.68	0.006	0.000	4680.43	3906.81	3906.81	446.65
	28/06/2011	0.04	0.0015	0.029	0.040	0.033	0.034	5028.56	0.006	0.000	4254.94	5956.91	4873.84	861.47
	28/06/2011	0.02	0.0015	0.014	0.008	0.001	0.008	1928.91	0.006	0.000	3868.13	2011.43	-92.84	1981.77
								4136.24						487.48

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 2 + CGRraw Eluate														
Standard	28/06/2011	1	0.0023	0.073	0.071	0.070	0.071	427.56	0.002	0.000	437.87	425.49	419.30	9.45
Cell 2 + CGRraw Eluate	28/06/2011	0.20	0.0023	0.127	0.122	0.121	0.123	3746.92	0.003	0.000	3860.39	3705.66	3674.72	99.47
	28/06/2011	0.16	0.0023	0.090	0.090	0.092	0.091	3420.07	0.001	0.000	3394.28	3394.28	3471.64	44.67
	28/06/2011	0.12	0.0023	0.069	0.075	0.072	0.072	3597.36	0.003	0.000	3442.63	3752.08	3597.36	154.73
	28/06/2011	0.08	0.0023	0.044	0.055	0.045	0.048	3539.33	0.006	0.000	3229.88	4080.87	3307.25	470.58
	28/06/2011	0.04	0.0023	0.022	0.020	0.023	0.022	3004.24	0.002	0.000	3055.82	2746.37	3210.54	236.35
	28/06/2011	0.02	0.0023	0.006	0.012	0.010	0.009	2191.94	0.003	0.000	1160.44	3017.14	2398.24	945.39
								3249.98						244.51

Appendix A

RI 7

R	8.314	Temp	293	Press	101.3

Sample	Beaker Size	SG	Mass Sample	Volume Sample	Vol H_2O	Total vol	Press N2	Press O2	nTotal	n O2 (B)	n N2 (B)	Δ Press	Press After	Press O2	n O2 (After)	mg 02	TS	DM	mg 02 /g DM	AVE	STD DEV	
CGR 10	1	0.5	0.013	0.026	0	0.974	79.014	21.273	0.0405	0.00851	0.0316	2.0	99.3	20.286	0.00080	25.589	32.97	4.286	5.970	5.970	#DIV/0!	**Example**
Cell 1 (8 wks)	1	0.5	0.010	0.02	0.019	0.961	79.014	21.273	0.0400	0.00839	0.0312	13	88.3	9.286	0.00513	164.112	74.74	7.474	21.958	24.118	8.262	
	1	0.5	0.010	0.02	0.022	0.958	79.014	21.273	0.0398	0.00837	0.0311	8	93.3	14.286	0.00315	100.676	74.74	7.474	13.471			
	1	0.5	0.010	0.02	0.020	0.96	79.014	21.273	0.0399	0.00838	0.0311	19	82.3	3.286	0.00749	239.606	74.74	7.474	32.059			
	1	0.5	0.01	0.02	0.010	0.97	79.014	21.273	0.0403	0.00847	0.0315	17	84.3	5.286	0.00677	216.617	74.74	7.474	28.984			
Cell 1 + CGRraw (H$_2$0)	1.5	0.5	0.120	0.240	0.010	1.250	79.014	21.273	0.0520	0.01092	0.0405	105	-3.7	-82.714	0.05388	1724.137	65.29	78.349	22.006	19.335	3.790	
	1.5	0.5	0.136	0.272	0.010	1.218	79.014	21.273	0.0506	0.01064	0.0395	89	12.3	-66.714	0.04450	1423.999	65.29	88.795	16.037			
	1.5	0.5	0.124	0.248	0.010	1.242	79.014	21.273	0.0516	0.01085	0.0403	80	21.3	-57.714	0.04079	1305.221	65.29	80.960	16.122			
	1.5	0.5	0.124	0.248	0.010	1.242	79.014	21.273	0.0516	0.01085	0.0403	115	-13.7	-92.714	0.05863	1876.255	65.29	80.960	23.175			
Cell 1 + CGR10 (H$_2$0)	1	0.5	0.1120	0.224	0.010	0.766	79.014	21.273	0.0319	0.00669	0.0248	93	8.3	-70.714	0.02924	935.802	76.47	85.649	10.926	15.209	3.381	
	1	0.5	0.1150	0.23	0.010	0.76	79.014	21.273	0.0316	0.00664	0.0247	124	-22.7	-101.714	0.03869	1237.963	76.47	87.944	14.077			
	1	0.5	0.1100	0.22	0.010	0.77	79.014	21.273	0.0320	0.00672	0.0250	149	-47.7	-126.714	0.04710	1507.125	76.47	84.120	17.916			
	1	0.5	0.110	0.22	0.010	0.77	79.014	21.273	0.0320	0.00672	0.0250	149	-47.7	-126.714	0.04710	1507.125	76.47	84.120	17.916			
CGR RAW 2011	1.5	0.50	0.02	0.04	0.007	1.453	79.014	21.273	0.0604	0.01269	0.0471	92	9.3	-69.714	0.05488	1756.005	54.85	10.970	160.075	137.456	42.227	
	1.5	0.50	0.02	0.04	0.007	1.453	79.014	21.273	0.0604	0.01269	0.0471	94	7.3	-71.714	0.05607	1794.179	54.85	10.970	163.555			
	1.5	0.50	0.02	0.04	0.007	1.453	79.014	21.273	0.0604	0.01269	0.0471	51	50.3	-28.714	0.03042	973.438	54.85	10.970	88.737			
CGR 10 2011	1	0.50	0.02	0.04	0.0037	0.9563	79.014	21.273	0.0398	0.00835	0.0310	56	45.3	-33.714	0.02198	703.484	65.50	13.101	53.699	44.110	8.359517	
	1	0.50	0.02	0.04	0.0037	0.9563	79.014	21.273	0.0398	0.00835	0.0310	40	61.3	-17.714	0.01570	502.489	65.50	13.101	38.356			
	1	0.50	0.02	0.04	0.0037	0.9563	79.014	21.273	0.0398	0.00835	0.0310	42	59.3	-19.714	0.01649	527.613	65.50	13.101	40.274			
Cell 2 (16 wks)-H$_2$0	1	0.5	0.1719	0.34372	0.01	0.64628	79.014	21.273	0.0269	0.00564	0.0210	33	68.3	-10.714	0.00876	280.161	72.82	125.142	2.239	1.771	0.690	
	1	0.5	0.1720	0.34404	0.0049	0.65106	79.014	21.273	0.0271	0.00569	0.0211	25	76.3	-2.714	0.00668	213.813	72.82	125.258	1.707			
	1	0.5	0.1721	0.3442	0.0055	0.6503	79.014	21.273	0.0270	0.00568	0.0211	34	67.3	-11.714	0.00908	290.446	72.82	125.316	2.318			
	1	0.5	0.1721	0.34416	0.005	0.65084	79.014	21.273	0.0271	0.00568	0.0211	12	89.3	10.286	0.00321	102.595	72.82	125.302	0.819			
Cell 2 + CGR10 (H$_2$0)	1	0.5	0.1100	0.220	0.01	0.770	79.014	21.273	0.0320	0.00672	0.0250	95	6.3	-72.714	0.03003	960.919	71.28	78.404	12.256	11.141	1.232	
	1	0.5	0.1110	0.222	0.01	0.768	79.014	21.273	0.0319	0.00671	0.0249	89	12.3	-66.714	0.02806	897.891	71.28	79.117	11.349			
	1	0.5	0.1110	0.222	0.010	0.768	79.014	21.273	0.0319	0.00671	0.0249	77	24.3	-54.714	0.02428	776.827	71.28	79.117	9.819			
Cell 2 + CGRraw (H$_2$0)	1.5	0.5	0.1220	0.244	0.01	1.246	79.014	21.273	0.0518	0.01088	0.0404	39	62.3	-16.714	0.01995	638.344	68.89	84.046	7.595	7.564	2.781	
	1.5	0.5	0.1200	0.24	0.01	1.25	79.014	21.273	0.0520	0.01092	0.0405	24	77.3	-1.714	0.01232	394.088	68.89	82.668	4.767			
	1.5	0.5	0.1200	0.24	0.010	1.25	79.014	21.273	0.0520	0.01092	0.0405	52	49.3	-29.714	0.02668	853.858	68.89	82.668	10.329			

APPENDIX B: BATCH TESTS RESULTS

This Appendix contains the batch tests output data for different substrate

Batch Test- Nitrate

Cell 1 + Treated Leachate

Sample	Cell 1 (8 wks) + T.Leachate			Tend					
Date	**Time**	**Duration (min)**	**Duration (hours)**	**Duration (Days)**	**R 1**	**R 2**	**R 3**	**Average**	**Blank**
22-Mar-11	10:30		0	0.0000	500	500	500	500.0	30
23-Mar-11	09:00	1350	22.5	0.9375	450	450	450	450.0	25
	11:30	1500	25	1.0417	450	450	450	450.0	25
24-Mar-11	10:00	2850	47.5	1.9792	420	410	420	416.7	15
	12:00	2970	49.5	2.0625	420	400	420	413.3	30
25-Mar-11	09:30	4260	71	2.9583	400	400	400	400.0	30
	12:00	4410	73.5	3.0625	400	400	400	400.0	30
28-Mar-11	10:00	5730	95.5	3.9792	400	400	400	400.0	10
	12:00	5850	97.5	4.0625	400	400	400	400.0	10
29-Mar-11	10:00	7170	119.5	4.9792	350	400	400	383.3	5
	12:30	7320	122	5.0833	350	350	350	350.0	5
30-Mar-11	10:30	8640	144	6.0000	320	320	320	320.0	0
	12:00	8760	146	6.0833	320	320	320	320.0	0
31-Mar-11	10:00	10080	168	7.0000	320	320	320	320.0	0
	12:00	10200	170	7.0833	320	320	320	320.0	0
01-Apr-11	10:00	11520	192	8.0000	300	300	300	300.0	0
	12:00	11640	194	8.0833	300	300	300	300.0	0
04-Apr-11	10:00	15840	264	11.0000	300	300	300	300.0	0
	12:00	15960	266	11.0833	300	300	300	300.0	0
05-Apr-11	10:00	17280	288	12.0000	300	300	300	300.0	0
	12:00	17400	290	12.0833	300	300	300	300.0	0
06-Apr-11	10:00	18720	312	13.0000	300	300	300	300.0	0
	12:00	18840	314	13.0833	300	300	300	300.0	0
07-Apr-11	10:00	20160	336	14.0000	250	250	220	240.0	0
	12:00	20280	338	14.0833	250	250	220	240.0	0
08-Apr-11	10:00	21600	360	15.0000	200	200	200	200.0	0
	12:00	21720	362	15.0833	200	200	200	200.0	0
11-Apr-11	10:00	25920	432	18.0000	200	200	200	200.0	0
	12:00	26040	434	18.0833	200	200	200	200.0	0
12-Apr-11	10:00	27360	456	19.0000	200	200	200	200.0	0
13-Apr-11	10:00	28800	480	20.0000	200	200	200	200.0	0
14-Apr-11	10:00	30240	504	21.0000	200	200	200	200.0	0
15-Apr-11	10:00	31680	528	22.0000	200	200	200	200.0	0
16-Apr-11	10:00	33120	552	23.0000	200	200	200	200.0	0
17-Apr-11	10:00	34560	576	24.0000	100	100	100	100.0	0
18-Apr-11	10:00	36000	600	25.0000	100	100	100	100.0	0
19-Apr-11	10:00	37440	624	26.0000	100	100	100	100.0	0
20-Apr-11	10:00	38880	648	27.0000	100	100	100	100.0	0
21-Apr-11	10:00	40320	672	28.0000	100	100	100	100.0	0
22-Apr-11	10:00	41760	696	29.0000	100	100	100	100.0	0
23-Apr-11	10:00	43200	720	30.0000	100	100	100	100.0	0
21-Apr-11	**pH**				7.89	7.95	7.73	7.86	7.7
	Temperature				21	21	21	21	21

High Nitrite

Cell 1 + Seeded Treated Leachate (Tend)

High Nitrite

Sample	Cell 1 (8 wks) + Seeded T.Leachate			Tend					
Date	Time	Duration (min)	Duration (hours)	Duration (Days)	R 1	R 2	R 3	Average	Blank
6-Apr-11	10:30	0	0	0.0000	500	500	500	500.0	30
7-Apr-11	09:00	1350	22.5	0.9375	450	450	450	450.0	25
	11:30	1500	25	1.0417	450	450	450	450.0	25
8-Apr-11	10:00	2850	47.5	1.9792	450	450	450	450.0	15
	12:00	2970	49.5	2.0625	420	420	430	423.3	30
9-Apr-11	09:30	4260	71	2.9583	420	400	430	416.7	30
	12:00	4410	73.5	3.0625	420	400	430	416.7	30
10-Apr-11	10:00	5730	95.5	3.9792	350	380	340	356.7	10
	12:00	5850	97.5	4.0625	350	400	340	363.3	10
11-Apr-11	10:00	7170	119.5	4.9792	350	400	340	363.3	5
	12:30	7320	122	5.0833	350	400	340	363.3	5
12-Apr-11	10:30	8640	144	6.0000	300	300	300	300.0	0
	12:00	8760	146	6.0833	300	300	300	300.0	0
13-Apr-11	10:00	10080	168	7.0000	300	300	300	300.0	0
	12:00	10200	170	7.0833	300	300	300	300.0	0
14-Apr-11	10:00	11520	192	8.0000	300	300	300	300.0	0
	12:00	11640	194	8.0833	300	300	300	300.0	0
15-Apr-11	10:00	12960	216	9.0000	300	300	300	300.0	0
	12:00	13080	218	9.0833	300	300	300	300.0	0
18-Apr-11	10:00	16620	277	11.5417	300	300	300	300.0	0
	12:00	16740	279	11.6250	300	300	300	300.0	0
19-Apr-11	10:00	18060	301	12.5417	230	230	250	236.7	0
	12:00	18180	303	12.6250	230	230	250	236.7	0
20-Apr-11	10:00	19500	325	13.5417	200	200	200	200.0	0
	12:00	19620	327	13.6250	200	200	200	200.0	0
21-Apr-11	10:00	20940	349	14.5417	200	200	200	200.0	0
	12:00	21060	351	14.6250	200	200	200	200.0	0
22-Apr-11	10:00	22380	373	15.5417	200	200	200	200.0	0
	12:00	22500	375	15.6250	200	200	200	200.0	0
23-Apr-11	10:00	23820	397	16.5417	200	200	200	200.0	0
22-Apr-11	10:00	25260	421	17.5417	200	200	200	200.0	0
23-Apr-11	10:00	26700	445	18.5417	200	200	200	200.0	0
24-Apr-11	10:00	28140	469	19.5417	200	200	200	200.0	0
25-Apr-11	10:00	29580	493	20.5417	200	200	200	200.0	0
26-Apr-11	10:00	31020	517	21.5417	200	200	200	200.0	0
27-Apr-11	10:00	32460	541	22.5417	200	200	200	200.0	0
28-Apr-11	10:00	33900	565	23.5417	200	200	200	200.0	0
29-Apr-11	10:00	35340	589	24.5417	200	200	200	200.0	0
30-Apr-11	10:00	36780	613	25.5417	200	200	200	200.0	0
1-May-11	10:00	38220	637	26.5417	200	200	200	200.0	0
2-May-11	10:00	39660	661	27.5417	200	200	200	200.0	0
3-May-11	10:00	41100	685	28.5417	200	200	200	200.0	0
4-May-11	10:00	42540	709	29.5417	200	200	200	200.0	0
5-May-11	10:00	43980	733	30.5417	200	200	200	200.0	0
05 May 2011	pH				7.39	7.54	7.67	7.53	7.66
	Temperature				21	21	21	21	21

Cell 1 + CGRraw + Treated Leachate (Tend)

High Nitrite

Sample	Cell 1 (8 wks) + T.Leachate +CGRraw			Tend					
Date	**Time**	**Duration (min)**	**Duration (hours)**	**Duration (Days)**	**R 1**	**R 2**	**R 3**	**Average**	**Blank**
4-May-11	10:00	0	0	0.0000	500	500	500	500.0	20
	12:00	120	2	0.0833	450	450	450	450.0	0
	14:00	240	4	0.1667	350	350	350	350.0	0
5-May-11	10:00	1440	24	1.0000	250	250	250	250.0	0
	14:00	1680	28	1.1667	200	200	200	200.0	0
6-May-11	10:00	2880	48	2.0000	200	200	200	200.0	0
	14:00	3120	52	2.1667	200	200	200	200.0	0
7-May-11	10:00	4320	72	3.0000	200	200	200	200.0	0
	14:00	4560	76	3.1667	200	100	100	133.3	0
8-May-11	10:00	5760	96	4.0000	150	50	50	83.3	0
9-May-11	10:00	7200	120	5.0000	50	0	10	20.0	0
10-May-11	10:00	8640	144	6.0000	10	0	0	3.3	0
11-May-11	10:00	10080	168	7.0000	0	0	0	0.0	0
11-May-11	**pH**				7.46	7.35	7.47	7.43	7.28
	Temperature				22	22	22	22	22

Cell 1 + CGR10 + Treated Leachate (Tend)

High Nitrite

Sample	Cell 1 (8 wks) + T.Leachate +CGR10			Tend					
Date	**Time**	**Duration (min)**	**Duration (hours)**	**Duration (Days)**	**R 1**	**R 2**	**R 3**	**Average**	**Blank**
23-May-11	10:00		0	0	500	500	500	500.0	25
	14:00	240	4	0.16667	500	500	500	500.0	25
24-May-11	10:00	1440	24	1.00000	400	400	400	400.0	0
	14:00	1680	28	1.16667	350	350	350	350.0	0
25-May-11	10:00	2880	48	2.00000	200	200	200	200.0	0
	14:00	3120	52	2.16667	200	200	200	200.0	0
26-May-11	10:00	4320	72	3.00000	200	200	200	200.0	0
	14:00	4560	76	3.16667	200	200	200	200.0	0
27-May-11	10:00	5760	96	4.00000	200	150	175	175.0	0
	14:00	7200	120	5.00000	200	150	150	166.7	0
28-May-11	10:00	8640	144	6.00000	200	100	100	133.3	0
	14:00	8880	148	6.16667	200	100	100	133.3	0
29-May-11	10:00	10080	168	7.00000	100	50	50	66.7	0
	14:00	10320	172	7.16667	100	50	50	66.7	0
30-May-11	10:00	11520	192	8.00000	20	10	0	10.0	0
	14:00	11760	196	8.16667	0	0	0	0.0	0
30-May-11	**pH**				7.69	8.17	7.65	7.84	7.70
	Temperature				22	21	22	21.67	21

Cell 2 + Treated leachate (Tend)

Sample	Cell 2 (16 wks) + T.Leachate			Tend						High Nitrite
Date	Time	Duration (min)	Duration (hours)	Duration (Days)	R 1	R 2	R 3	Average	Blank	
6-Jun-11	10:00	0	0	0.00	1000	1000	1000	1000	500	
7-Jun-11	10:00	1440	24	1.00	1000	1000	1000	1000	500	
8-Jun-11	10:00	2880	48	2.00	1000	1000	1000	1000	500	
9-Jun-11	10:00	4320	72	3.00	900	900	900	900	400	
10-Jun-11	10:00	5760	96	4.00	900	900	900	900	400	
13-Jun-11	10:00	10080	168	7.00	900	900	900	900	400	
14-Jun-11	10:00	11520	192	8.00	900	900	900	900	400	
15-Jun-11	10:00	12960	216	9.00	900	900	900	900	400	
16-Jun-11	11:00	14460	241	10.04	900	900	900	900	400	
17-Jun-11	10:00	15840	264	11.00	900	800	800	833.33	400	
20-Jun-11	11:00	20220	337	14.04	900	600	600	700	400	
21-Jun-11	10:00	21600	360	15.00	900	500	500	633.33	400	
22-Jun-11	11:00	23100	385	16.04	900	500	500	633.33	400	
23-Jun-11	10:00	24480	408	17.00	900	500	500	633.33	400	
24-Jun-11	12:00	26040	434	18.08	1000	800	800	866.67	500	
27-Jun-11	10:00	30240	504	21.00	1000	800	800	866.67	500	
28-Jun-11	10:00	31680	528	22.00	1000	900	900	933.33	500	
29-Jun-11	10:00	33120	552	23.00	1000	900	900	933.33	500	
30-Jun-11	10:00	34560	576	24.00	1000	900	900	933.33	500	
1-Jul-11	10:00	36000	600	25.00	1000	900	900	933.33	500	
4-Jul-11	12:00	40440	674	28.08	1000	900	900	933.33	500	
5-Jul-11	10:00	41760	696	29.00	1000	900	900	933.33	500	
6-Jul-11	11:00	43260	721	30.04	1000	900	900	933.33	500	
7-Jul-11	10:00	44640	744	31.00	1000	900	900	933.33	500	
8-Jul-11	10:00	46080	768	32.00	1000	900	900	933.33	500	
11-Jul-11	10:00	50400	840	35.00	1000	900	900	933.33	500	
11-Jul-11	pH				7.12	7.08	7.25	7.15	7.15	
	Temperature				21	21	21	21.00	21	

Cell 2 + Seeded Treated leachate (Tend)

High Nitrite

Sample	Cell 2 (16 wks) + Seeded Treated Leachate			Tend					
Date	**Time**	**Duration (min)**	**Duration (hours)**	**Duration (Days)**	**R 1**	**R 2**	**R 3**	**Average**	**Blank**
23-Jul-11	10:00	0	0	0.000	1000	1000	1000	1000	500
	12:00	120	2	0.083	1000	1000	1000	1000	500
24-Jul-11	10:00	1440	24	1.000	1000	1000	1000	1000	500
25-Jul-11	10:00	2880	48	2.000	1000	1000	1000	1000	500
	12:00	3000	50	2.083	1000	1000	1000	1000	500
26-Jul-11	11:00	4380	73	3.042	1000	1000	1000	1000	500
27-Jul-11	10:00	5760	96	4.000	1000	1000	1000	1000	500
28-Jul-11	12:00	7320	122	5.083	1000	1000	1000	1000	500
29-Jul-11	10:00	8640	144	6.000	950	950	950	950	450
30-Jul-11	10:00	10080	168	7.000	950	950	950	950	450
31-Jul-11	10:00	11520	192	8.000	950	950	950	950	450
1-Aug-11	10:00	12960	216	9.000	950	950	950	950	450
2-Aug-11	10:00	14400	240	10.000	950	950	950	950	450
3-Aug-11	10:00	15840	264	11.000	950	950	950	950	450
4-Aug-11	10:00	17280	288	12.000	950	950	950	950	300
5-Aug-11	11:00	18780	313	13.042	900	900	900	900	300
6-Aug-11	11:00	20220	337	14.042	850	850	850	850	300
7-Aug-11	10:00	21600	360	15.000	850	850	850	850	300
8-Aug-11	10:00	23040	384	16.000	850	850	850	850	300
9-Aug-11	10:00	24480	408	17.000	850	850	850	850	300
10-Aug-11	10:00	25920	432	18.000	800	800	800	800	300
11-Aug-11	11:00	27420	457	19.042	750	750	750	750	300
12-Aug-11	10:00	28800	480	20.000	750	750	750	750	290
13-Aug-11	10:00	30240	504	21.000	750	750	750	750	290
14-Aug-11	10:00	31680	528	22.000	600	600	600	600	250
15-Aug-11	10:00	33120	552	23.000	600	600	600	600	250
16-Aug-11	11:00	34620	577	24.042	600	600	600	600	250
17-Aug-11	11:00	36060	601	25.042	500	500	500	500	250
18-Aug-11	11:00	37500	625	26.042	500	500	500	500	250
19-Aug-11	10:00	38880	648	27.000	500	500	500	500	250
20-Aug-11	10:00	40320	672	28.000	500	500	500	500	250
21-Aug-11	10:00	41760	696	29.000	500	500	500	500	250
22-Aug-11	10:00	43200	720	30.000	500	500	500	500	250
23-Aug-11	10:00	44640	744	31.000	500	500	500	500	250
24-Aug-11	10:00	46080	768	32.000	500	500	500	500	250
25-Aug-11	09:00	47460	791	32.958	500	500	500	500	250
26-Aug-11	09:00	48900	815	33.958	500	500	500	500	250
26-Aug-11	**pH**				7.08	7.04	7.36	7.16	7.39
	Temperature				22	21	21	21.33	22

Cell 2 + CGRraw (Tend)

Sample	Cell 2 (16 wks) + CGRraw + T.Leachate			Tend						High Nitrite
Date	**Time**	**Duration (min)**	**Duration (hours)**	**Duration (Days)**	**R 1**	**R 2**	**R 3**	**Average**	**Blank**	
5-Jul-11	10:00	0	0	0.00	1000	1000	1000	1000.00	500	
6-Jul-11	10:00	1440	24	1.00	900	900	900	900.00	300	
7-Jul-11	10:00	2880	48	2.00	800	800	800	800.00	150	
8-Jul-11	14:00	4560	76	3.17	700	700	690	696.67	5	
9-Jul-11	14:00	6000	100	4.17	650	650	650	650.00	0	
10-Jul-11	14:00	7440	124	5.17	600	600	600	600.00	0	
11-Jul-11	10:00	8640	144	6.00	500	500	500	500.00	0	
12-Jul-11	14:00	10320	172	7.17	400	400	400	400.00	0	
13-Jul-11	10:00	11520	192	8.00	350	350	350	350.00	0	
14-Jul-11	14:00	13200	220	9.17	250	250	250	250.00	0	
15-Jul-11	10:00	14400	240	10.00	250	250	250	250.00	0	
16-Jul-11	10:00	15840	264	11.00	200	200	200	200.00	0	
17-Jul-11	10:00	17280	288	12.00	100	80	100	93.33	0	
18-Jul-11	14:00	18960	316	13.17	80	0	80	53.33	0	
19-Jul-11	10:00	20160	336	14.00	0	0	0	0.00	0	
19-Jul-11	**pH**				7.36	7.36	7.40	7.37	7.22	
	Temperature				21	21	21	21.00	21	

Cell 2 + CGR10 (Tend)

Sample	Cell 2 (16 wks) + CGR$_{10}$ + T.Leachate			Tend						High Nitrite
Date	**Time**	**Duration (min)**	**Duration (hours)**	**Duration (Days)**	**R 1**	**R 2**	**R 3**	**Average**	**Blank**	
23-Jul-11	10:00	0	0	0.0000	500	500	500	500	250	
	12:00	120	2	0.0833	500	500	500	500	250	
25-Jul-11	10:00	1440	24	1.0000	500	500	500	500	250	
	12:00	1560	26	1.0833	500	500	500	500	250	
26-Jul-11	11:00	2940	49	2.0417	500	500	500	500	150	
27-Jul-11	10:00	4320	72	3.0000	500	500	500	500	80	
28-Jul-11	12:00	5880	98	4.0833	450	455	450	451.67	0	
29-Jul-11	10:00	7200	120	5.0000	400	400	400	400	0	
30-Jul-11	10:00	8640	144	6.0000	400	400	400	400	0	
1-Aug-11	10:00	11520	192	8.0000	300	300	300	300	0	
2-Aug-11	10:00	12960	216	9.0000	250	250	250	250	0	
3-Aug-11	10:00	14400	240	10.0000	250	250	250	250	0	
4-Aug-11	11:00	15900	265	11.0417	200	180	200	193.33	0	
5-Aug-11	11:00	17340	289	12.0417	150	90	150	130	0	
6-Aug-11	10:00	18720	312	13.0000	80	0	70	50	0	
8-Aug-11	10:00	20160	336	14.0000	0	0	0	0	0	
8-Aug-11	**pH**				7.66	7.76	7.69	7.70	7.50	
	Temperature				21	20	20	20.33	20	

Batch Test output COD

Cell 1 + Treated Leachate (Tend)

Sample	**Date**	**Volume**	**Blank**	**Reading**				**Average**	**Result**	**Std**	**Var**	**Results**		
	analysed		**Average**	**1**	**2**	**3**	**4**	**value**	**mg/l**	**Dev**		**1**	**2**	**3**
Cell 1 + Treated Leachate (Tend)														
Standard	**22/06/2011**	1	0.0013	0.075	0.079	0.082		0.079	**479.13**	0.004	0.000	**456.44**	**481.19**	**499.76**
Cell 1 Tend-R1	22/06/2011	0.05	0.0013	0.156	0.146	0.144		0.149	**18247.24**	0.006	0.000	**19154.96**	**17917.16**	**17669.60**
Cell 1 Tend-R2	22/06/2011	0.05	0.0013	0.140	0.145	0.158		0.148	**18123.46**	0.009	0.000	**17174.48**	**17793.38**	**19402.52**
Cell 1 Tend-R3	22/06/2011	0.05	0.0013	0.154	0.147	0.142		0.148	**18123.46**	0.006	0.000	**18907.40**	**18040.94**	**17422.04**
									18164.72					

Sample	**Date**	**Volume**	**Blank**	**Reading**				**Average**	**Result**	**Std**	**Var**	**Results**			**Std**
	analysed		**Average**	**1**	**2**	**3**	**4**	**value**	**mg/l**	**Dev**		**1**	**2**	**3**	**Dev**
Cell 1 + Treated Leachate (Tend)															
Standard	**22/06/2011**	1	0.0013	0.075	0.079	0.082		0.079	**479.13**	0.004	0.000	**456.44**	**481.19**	**499.76**	21.74
Cell 1 Tend-Blank	22/06/2011	0.05	0.0013	0.143	0.130	0.103		0.125	**15359.04**	0.020	0.000	**17545.82**	**15936.68**	**12594.62**	2525.64
									15359.04						

Cell 1 + Seeded + Treated Leachate (Tend)

Sample	**Date**	**Volume**	**Blank**	**Reading**			**Average**	**Result**	**Std**	**Var**	**Results**			**Std**
	analysed		**Average**	**1**	**2**	**3**	**value**	**mg/l**	**Dev**		**1**	**2**	**3**	**Dev**
Cell 1 + Treated Leachate + Untreated Leachate (Tend)														
Standard	**13/07/2011**	1	0.0030	0.069	0.072	0.074	0.072	**424.98**	0.003	0.000	**408.47**	**427.04**	**439.42**	15.58
Cell 1 Tend-R1	13/07/2011	0.05	0.0030	0.146	0.148	0.135	0.143	**17329.20**	0.007	0.000	**17700.54**	**17948.10**	**16338.96**	866.46
Cell 1 Tend-R2	13/07/2011	0.05	0.0030	0.124	0.119	0.124	0.122	**14771.08**	0.003	0.000	**14977.38**	**14358.48**	**14977.38**	357.32
Cell 1 Tend-R3	13/07/2011	0.05	0.0030	0.080	0.076	0.082	0.079	**9448.54**	0.003	0.000	**9531.06**	**9035.94**	**9778.62**	378.15
								13849.61						

Sample	**Date**	**Volume**	**Blank**	**Reading**			**Average**	**Result**	**Std**	**Var**	**Results**			**Std**
	analysed		**Average**	**1**	**2**	**3**	**value**	**mg/l**	**Dev**		**1**	**2**	**3**	**Dev**
Cell 1 + Treated Leachate + Untreated Leachate (Tend)														
Standard	**13/07/2011**	1	0.0030	0.069	0.072	0.074	0.072	**424.98**	0.003	0.000	**408.47**	**427.04**	**439.42**	15.58
Cell 1 Tend-Blank	13/07/2011	0.050	0.0000	0.130	0.115	0.109	0.118	**14606.04**	0.011	0.000	**15720.06**	**13863.36**	**13120.68**	1338.89
								14606.04						

Cell 1 + CGRraw + Treated Leachate (Tend)

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 1 + CGRraw + Treated Leachate (Tend)														
Standard	**02/07/2011**	1	-0.0073	0.077	0.078	0.083	0.079	**535.86**	0.003	0.000	**521.42**	**527.61**	**558.56**	19.89
Cell 1 Tend-R1	13/07/2011	0.05	-0.0073	0.023	0.016	0.017	0.019	**3207.97**	0.004	0.000	**3744.35**	**2877.89**	**3001.67**	468.62
Cell 1 Tend-R2	13/07/2011	0.05	-0.0073	0.057	0.064	0.061	0.061	**8406.73**	0.004	0.000	**7952.87**	**8819.33**	**8447.99**	434.70
Cell 1 Tend-R3	13/07/2011	0.05	-0.0073	0.027	0.034	0.029	0.030	**4610.81**	0.004	0.000	**4239.47**	**5105.93**	**4487.03**	446.30
								5408.50						

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 1 + CGRraw + Treated Leachate (Tend)														
Standard	**02/07/2011**	1	-0.0073	0.077	0.078	0.083	0.079	**535.86**	0.003	0.000	**521.42**	**527.61**	**558.56**	19.89
Cell 1 Tend-Blank	02/07/2011	0.050	-0.0073	0.040	0.036	0.038	0.038	**5601.05**	0.002	0.000	**5848.61**	**5353.49**	**5601.05**	247.56
								5601.05						

Cell 1 + CGR10 + Treated Leachate (Tend)

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 1 + CGR10 + Treated Leachate (Tend)														
Standard	**15/07/2011**	1	-0.0008	0.074	0.073	0.071	0.073	**454.38**	0.002	0.000	**462.63**	**456.44**	**444.06**	9.45
Cell 1 Tend-R1	15/07/2011	0.05	-0.0008	0.029	0.030	0.031	0.030	**3806.24**	0.001	0.000	**3682.46**	**3806.24**	**3930.02**	123.78
Cell 1 Tend-R2	15/07/2011	0.05	-0.0008	0.032	0.030	0.028	0.030	**3806.24**	0.002	0.000	**4053.80**	**3806.24**	**3558.68**	247.56
Cell 1 Tend-R3	15/07/2011	0.05	-0.0008	0.076	0.074	0.074	0.075	**9335.08**	0.001	0.000	**9500.12**	**9252.56**	**9252.56**	142.93
								5649.18						

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 1 + CGR10 + Treated Leachate (Tend)														
Standard	**15/07/2011**	1	-0.0008	0.074	0.073	0.071	0.073	**454.38**	0.002	0.000	**462.63**	**456.44**	**444.06**	9.45
Cell 1 Tend-Blank	15/07/2011	0.050	-0.0008	0.034	0.034	0.030	0.033	**4136.32**	0.002	0.000	**4301.36**	**4301.36**	**3806.24**	285.86
								4136.32						

Cell 2 + Treated Leachate (Tend)

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 2 + Treated Leachate (Tend)														
Standard	**25/07/2011**	1	0.0038	0.076	0.077	0.074	0.076	**445.09**	0.002	0.000	**447.16**	**453.34**	**434.78**	9.45
Cell 2 Tend-R1	25/07/2011	0.05	0.0038	0.052	0.055	0.058	0.055	**6343.73**	0.003	0.000	**5972.39**	**6343.73**	**6715.07**	371.34
Cell 2 Tend-R2	25/07/2011	0.05	0.0038	0.072	0.068	0.063	0.068	**7911.61**	0.005	0.000	**8447.99**	**7952.87**	**7333.97**	558.15
Cell 2 Tend-R3	25/07/2011	0.05	0.0038	0.060	0.069	0.064	0.064	**7499.01**	0.005	0.000	**6962.63**	**8076.65**	**7457.75**	558.15
								7251.45						

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 2 + Treated Leachate (Tend)														
Standard	**25/07/2011**	1	0.0038	0.076	0.077	0.074	0.076	**445.09**	0.002	0.000	**447.16**	**453.34**	**434.78**	9.45
Cell 2 Tend-Blank	25/07/2011	0.050	0.0038	0.050	0.047	0.051	0.049	**5642.31**	0.002	0.000	**5724.83**	**5353.49**	**5848.61**	257.67
								5642.31						

Cell 2 + Seeded Treated Leachate (Tend)

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 2 + Seeded Treated Leachate (Tend)														
Standard	**27/08/2011**	1	-0.0070	0.066	0.065	0.067	0.066	**451.80**	0.001	0.000	**451.80**	**445.61**	**457.99**	6.19
Cell 2 Tend-R1	27/08/2011	0.05	-0.0070	0.028	0.020	0.020	0.023	**3672.14**	0.005	0.000	**4332.30**	**3342.06**	**3342.06**	571.72
Cell 2 Tend-R2	27/08/2011	0.05	-0.0070	0.039	0.041	0.039	0.040	**5776.40**	0.001	0.000	**5693.88**	**5941.44**	**5693.88**	142.93
Cell 2 Tend-R3	27/08/2011	0.05	-0.0070	0.059	0.066	0.061	0.062	**8540.82**	0.004	0.000	**8169.48**	**9035.94**	**8417.04**	446.30
								5996.45						

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
BATCH ELUATE SAMPLE (Tend)														
Standard	**27/08/2011**	1	-0.0070	0.066	0.065	0.067	0.066	**451.80**	0.001	0.000	**451.80**	**445.61**	**457.99**	6.19
Cell 2 Tend-Blank	27/08/2011	0.050	-0.0070	0.066	0.069	0.074	0.070	**9489.80**	0.004	0.000	**9035.94**	**9407.28**	**10026.18**	500.25
								9489.80						

Cell 2 + CGRraw + Treated Leachate (Tend)

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 2 + CGRraw + Treated Leachate (Tend)														
Standard	**24/07/2011**	1	-0.0038	0.073	0.074	0.073	0.073	**477.07**	0.001	0.000	**475.01**	**481.19**	**475.01**	3.57
Cell 2 Tend-R1	24/07/2011	0.05	-0.0038	0.061	0.062	0.064	0.062	**8179.80**	0.002	0.000	**8014.76**	**8138.54**	**8386.10**	189.08
Cell 2 Tend-R2	24/07/2011	0.05	-0.0038	0.079	0.080	0.080	0.080	**10325.32**	0.001	0.000	**10242.80**	**10366.58**	**10366.58**	71.46
Cell 2 Tend-R3	24/07/2011	0.05	0.0000	0.084	0.079	0.076	0.080	**9861.14**	0.004	0.000	**10397.52**	**9778.62**	**9407.28**	500.25
								9455.42						

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
BATCH ELUATE SAMPLE (Tend)														
Standard	**24/07/2011**	1	0.0000	0.073	0.073	0.073	0.073	**451.80**	0.000	0.000	**475.01**	**475.01**	**475.01**	0.00
Cell 2 Tend-Blank	24/07/2011	0.050	0.0000	0.070	0.073	0.072	0.072	**8870.90**	0.002	0.000	**9128.78**	**9500.12**	**9376.34**	189.08
								8870.90						

Cell 2 + CGR10 + Treated Leachate (Tend)

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
Cell 2 + CGR10 + Treated Leachate (Tend)														
Standard	**13/08/2011**	1	0.0050	0.080	0.078	0.076	0.078	**451.80**	0.002	0.000	**464.18**	**451.80**	**439.42**	12.38
Cell 2 Tend-R1	13/08/2011	0.05	0.0050	0.073	0.067	0.066	0.069	**7880.66**	0.004	0.000	**8417.04**	**7674.36**	**7550.58**	468.62
Cell 2 Tend-R2	13/08/2011	0.05	0.0050	0.069	0.072	0.075	0.072	**8293.26**	0.003	0.000	**7921.92**	**8293.26**	**8664.60**	371.34
Cell 2 Tend-R3	13/08/2011	0.05	0.0050	0.072	0.073	0.078	0.074	**8582.08**	0.003	0.000	**8293.26**	**8417.04**	**9035.94**	397.90
								8252.00						

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
	analysed		Average	1	2	3	value	mg/l	Dev		1	2	3	Dev
BATCH ELUATE SAMPLE (Tend)														
Standard	**13/08/2011**	1	0.0050	0.080	0.078	0.076	0.078	**451.80**	0.002	0.000	**464.18**	**451.80**	**439.42**	12.38
Cell 2 Tend-Blank	13/08/2011	0.050	0.0050	0.068	0.068	0.074	0.070	**8045.70**	0.003	0.000	**7798.14**	**7798.14**	**8540.82**	428.79
								8045.70						