UNIVERSITY OF KWAZULU-NATAL

Masters Dissertation ENCV8FY

NITRATE REMOVAL FROM TREATED LANDFILL LEACHATE USING A MIX OF VEGETABLE WASTE AND IMMATURE COMPOST AS A CARBON SOURCE (SIMULATION IN BATCHES)

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In fulfillment of Maters of Engineering Degree, College of Agriculture, Engineering and Science, University of KwaZulu-Natal

28 November 2014

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DECLARATION

I, Muhammed Uzair Osman declare that:

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Acknowledgements

First and foremost I would like to thank my mum and dad. They made it possible for my brother and me to make it this far in our careers. They have worked hard to give me the opportunity to write this document in various ways. So, this one is for you. I hope it makes you proud. To my grandparents as they made me and my parents who they are today. I want to show appreciation to my brother as discussing this with him gave me thoughts to contribute in this document.

The credit for this topic belongs to Björn Plüg. Due to his previous research there was data to compare to. I am also thankful for all he has done to guide and help me with regard to this dissertation.

Professor Cristina Trois is the Godfather of my work and is responsible for all work done in this area of expertise for a number of years.

I am very grateful for all the time and patience shown by Miss Fathima Ali. Fathima taught me all I needed to know to take and test samples, offered guidance, motivation and even did some of the tests for the dissertation students when it was not possible for us to do it ourselves.

I a so have to e press than s to عبد ل مطلب ل زرق ل ي (Abdulmutaleb Zorgani) for sharing his knowledge with me.

Thank you to all my minions, head minion Tahseen Raiman, Ndumiso Mavundla, Sumanth Maharaj, Raeesa Khan, Riyadh Nabee and Pha amani "chic en" Buthe ezi that he ped me in the lab. I honestly could not have gotten these excellent results without you. A special thank you to Gloria made working in the lab much easier.

The very helpful Erna Du Plessis of Dube Tradeport and Peter Gouws of Living Earth both deserve a mention for providing the waste.

Thanks to Peter Dent who helped remove obstacles and delays, as well as all the support of Ooma, Fiona and Pria.

Thank for support from MSA and the Green Deen team. If you are reading this you will be interested in following them at greendeen.msa.org.za.

Lastly I would like to thank my uncle; you have always given me guidance and courage. I would have not made it into University if it were not for your help, prayers and guidance.

Abstract

The aim of this dissertation was to investigate how effective the process of removing nitrates from treated leachate, and if it is possible to apply to a landfill treatment plant. The leachate is high strength landfill leachate from Mariannhill Landfill Conservancy.

Nitrates are present in treated and untreated leachate, which emanate from landfill sites. An excess of nitrates are harmful to the environment and poses a risk to health to particularly pregnant women and infants. Thus there is a specific need for nitrate removal and leachate treatment as there are no shortage of landfills and leachate.

Most of the waste in South Africa is eventually dumped at landfill sites. A method for nitrate removal does exist. However, this is an expensive process and cheap or more effective method would be very useful for future leachate treatment. The method proposed for the removal of nitrate is the technology that would be used in an anaerobic bio-reactor.

It is already known that CGR_{RAW} works as a good substrate, thus various mixes with vegetable waste was investigated in order to improve the effectiveness and conclude which of the mix ratios is the most feasible.

Experiments (or lab tests) were carried out for mixes in batch shot bottles. The less time it takes to remove all of the nitrates, the more effective that particular mix, of vegetable waste and immature compost, is as carbon sources for nitrate removal. Other aspects were also judged to determine the feasibility.

It was found that combining vegetable waste and garden refuse can significantly improve the effectiveness of the nitrite removal. The result varies depending on the mix ratio. A 100% vegetable waste mix is not efficient at treating nitrates and too far from the standards set by DWAF compared to the other substrates, to be considered as an effective substrate. The most effective mix was found to be 1:3 mix of vegetable waste to CGR_{RAW} (25/75 mix). The 25/75 mix was feasible, considering the DWAF discharge stands. All of the substrates tested would require a polishing treatment if the 25/75 mix applied in a Flat bed reactor.

Glossary

Acidification: The action or process of making something (more) acidic; conversion into an acid; addition of acid, in this case.

Ammonium NH_4^+: Toxic pollutant found in leachate

Ammoniacal-N: Amount of measurable ammonia in leachate

Anaerobic: Functioning or occurring in the absence of oxygen; lacking oxygen. (Oxford English Dictionary, 2012)

BOD: Bio-chemical Oxygen Demand

Bioleaching: Refers to biological mass (substrate) that emits substances into liquid which it is submerged in.

Carcinogen: Any agent that (directly or indirectly) causes cancer or induces malignant transformation of cells.

CGR_{RAW}: Raw Commercial Garden Refuse

Cladocerans: A member of a sub-order of small branchiopod Crustacea, commonly known as water-fleas. (Oxford English Dictionary, 2012)

COD: Chemical Oxygen Demand

Cyanobacteria: Any of a division of prokaryotic micro-organisms that contain chlorophyll (green) and phycocyanin (blue), produce free oxygen in photosynthesis, and occur widely in unicellular, filamentous, and colonial forms; also called blue-green alga. (Oxford English Dictionary, 2012)

Denitrification: The reduction, especially by bacteria, of simple inorganic nitrogen compounds; the reduction of nitrates through several intermediates to gaseous nitrogen. (Oxford English Dictionary, 2012)

DEA: Department of Environmental Affairs

DSW: Durban Solid Waste, whom have a responsibility of providing solid waste solutions and services to Durban residence.

DWA: Department of Water Affairs

DWAF: Department of Water Affairs and Forestry (Currently it is not one single department)

Eutrophication: Of a lake, swamp, etc.: (over-)rich in organic or mineral nutrients and having as a result an excessive growth of algae and other plants, with depletion of oxygen and consequent extinction of aquatic animal life. (Oxford English Dictionary, 2012)

KHP: Potassium Hydro Phosphate

Leachate: a solution resulting from leaching, as of soluble constituents from soil, landfill, etc. (Dictionary.com, 2014)

Macrophytes: A (usually aquatic) plant visible to the naked eye. (Oxford English Dictionary, 2012)

Methemoglobinemia (the blue baby disease): is when a baby is born with a bluish or cyanotic tin to their skin. This disease got its name because of the colour of the babies. The babies are usually blue due to a heart malfunction. (xxhrtbrknbttrflyxx, 2009)

Moulting: That which is shed. (Oxford English Dictionary, 2012)

Nitrate (NO_3^-): an inorganic compound composed of one atom of nitrogen (N) and three atoms of oxygen (O); the chemical symbol for nitrate is NO_3. Nitrate is not normally dangerous for the health unless it is reduced to nitrite (NO_2). (Lenntech water treatment solutions, 2011)

Nitrification: The process of nitrifying; the production of, or conversion of a substance into, nitrite or nitrates; specifically the process by which certain soil bacteria oxidize ammonia in decomposing material into nitrates. (Oxford English Dictionary, 2012)

NH_3: Ammonia

NO_2^-: Nitrite

NO_3^+: Nitrate

NO_x: Refers to nitrogen products, for example NO_3 and NO_2

Planktonic: Of, relating to, characteristic of, or found in plankton; designating an organism that habitually floats or drifts in water, or a stage in the life cycle of an organism during which it does this. (Oxford English Dictionary, 2012)

Periphyton: The organisms, collectively, that live on the surfaces of submerged plants and other objects in fresh water; specifically submerged micro-flora. (Oxford English Dictionary, 2012)

Substrate: The substance that is being used to treat the nitrates in the leachate

T_{end}: The amount of time for the concentration of nitrates to reach zero

T_0: When the time is zero, at the time of the initial nitrate tests.

VW: Vegetable waste

WHO: World Health Organisation

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1. Introduction

1.1. Motivation

Nitrates are present in treated leachate which emanates from landfill sites. An excess of nitrates are harmful to the environment. Thus there is a specific need for nitrate removal and leachate treatment. A method for nitrate removal does exist. However this is an expensive process and a cheaper, similarly or more effective method would be very useful for future leachate treatment. CGR_{RAW} is an excellent substrate. However, further investigation to find a new substrate is important as some places in South Africa and the world do not have readily available garden refuse, such as desert or arid regions. Another reason to research another substrate is to determine if using vegetable waste as an additive to CGR_{RAW} improves the denitrification rate. Thus more leachate could be treated in a given time.

1.2. Aims

To determine the effectiveness of using a mix of vegetable waste and garden refuse as a carbon source to remove nitrates from treated landfill leachate by doing lab based testing. Thus ascertain how it would apply to a larger scale such as a leachate treatment facility.

1.3. Objectives

The following are the objectives of this dissertation.

- Research all appropriate alternatives of nitrate removal
- Doing experiments accurately using proper procedures
- Obtain results from experiments
- Interpret the results to form a conclusion,
- Thus determine the effectiveness of using a mix of vegetable waste and garden refuse is as a carbon source to remove nitrates from treated landfill leachate is.

1.4. Dissertation Layout

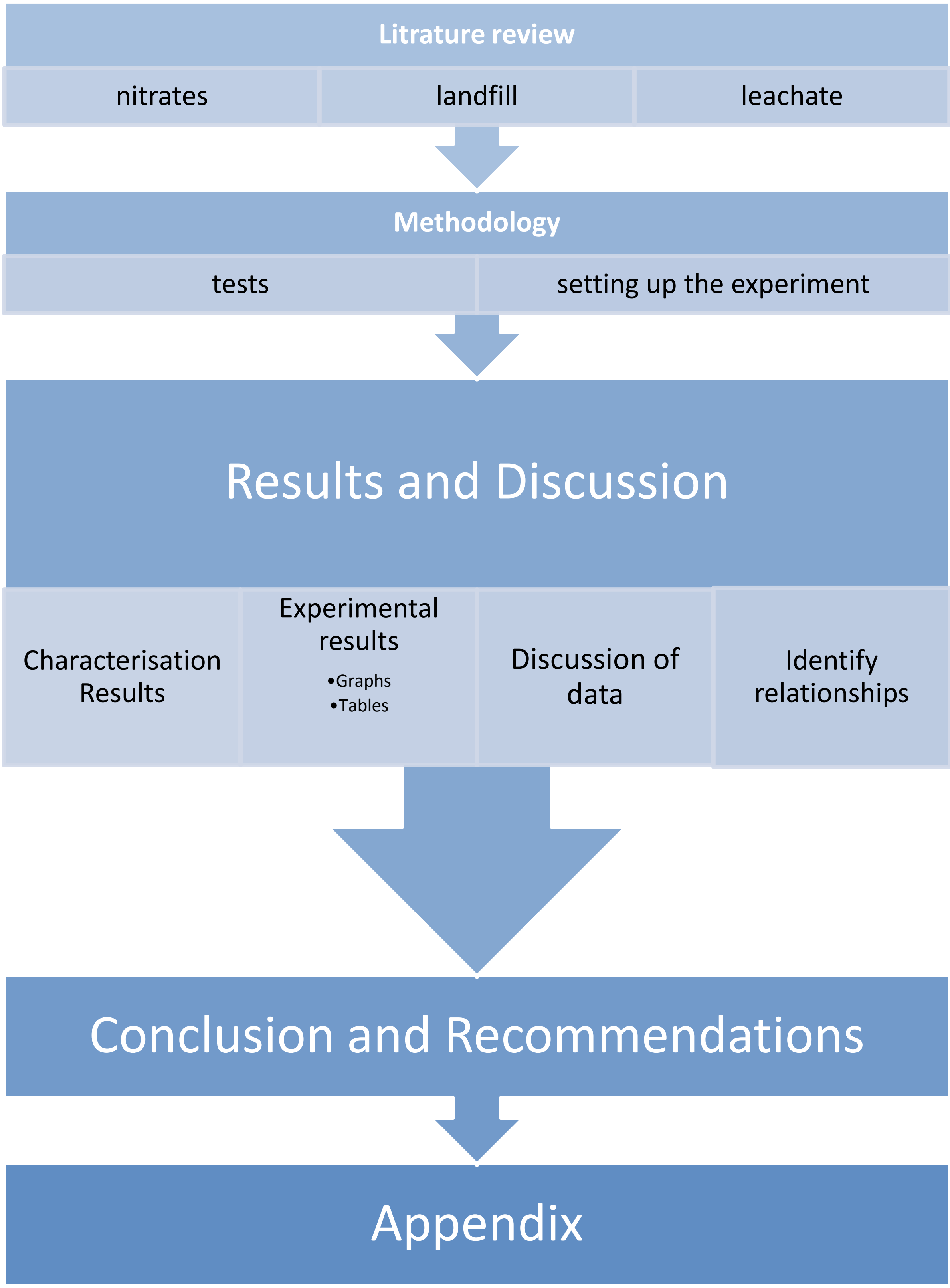


Figure 1-1 Document flow chart

2. Literature Review

2.1 Health effects of Nitrates and Nitrites

The effect of nitrate itself is described as *primary toxicity,* as its high intake causes abdominal pains, diarrhoea, vomiting, hypertension, increased infant mortality, central nervous system birth defects, diabetes, spontaneous abortions, respiratory tract infections and changes to the immune system. *Secondary toxicity* of nitrate is reduced to the reactive nitrite ion by intestinal bacteria. Nitrate has been proven to cause methemoglobinemia (the blue baby disease), especially to infants below of age six months (Pisano, 2007) and in a rural environment (Lenntech water treatment solutions, 2011). South Africa has a large population living in rural communities that could easily come into contact with untreated leachate, as there are informal townships near water sources. Thus, it is very likely that nitrates could cause significant damage to human health, especially with the high rate of death amongst babies and the poor state of health services in rural areas.

Nitrates and nitrites are also known to cause several health effects, of which the most common are:

- Reactions with haemoglobin in blood, causing the oxygen carrying capacity of the blood to decrease (nitrite)
- Decreased functioning of the thyroid gland (nitrate)
- Vitamin A shortages (nitrate)
- Fashioning of nitro amines, which is a carcinogen and known as one of the most common causes of cancer (nitrates and nitrites)

(Lenntech water treatment solutions, 2011)

2.2 Environmental effects of Nitrates

There are three main effects on the environment by an excess of nitrates:

- acidification,
- cultural eutrophication (including occurrence of toxic algae),
- and direct toxicity by inorganic nitrogenous compounds (ammonia, nitrite and nitrate)

(Julio A. Camargo, 2005)

2.2.1. Acidification

Water acidification adversely affects freshwater ecosystems without much acid neutralizing capacity. Adverse effects of acidification on freshwater plants and animals include:

- Decline of net photosynthesis in planktonic and attached algae
- Reduction of net productivity in planktonic and attached algae
- Increased bioaccumulation of aluminium and other trace metals in aquatic (especially submerged) macrophytes
- Increased abundance of filamentous green algae no longer attached to the substratum
- Declined species diversity in phytoplankton and periphyton communities, with the loss of sensitive species
- Disruption of ionic regulation, especially loss of body sodium and failure to obtain sufficient calcium, in molluscs, insects, crustaceans, fish and amphibians
- Respiratory and metabolic disturbances in molluscs, insects, crustaceans, fish, and amphibians
- Increased bioaccumulation and toxicity of aluminium and other trace metals in insects, crustaceans, fish, and amphibians
- Arrested development of fish and amphibian embryos, presenting in some cases skeletal deformities
- Hatching delay of fish and amphibian eggs
- Disruption of moulting and emergence in insects and crustaceans
- Reduced efficiency or activity by grazing zooplankton (cladocerans), producing ramifying effects on the phytoplankton community
- Reduced growth rates in cladocerans and fish
- Reduced efficiency or activity of prey capture by copepods, planarians, and fish, producing ramifying effects on prey populations and on populations of other predators
- Increased migration of aquatic insects
- Increased drift behaviour of benthic invertebrates to be transported downstream
- Avoidance of acid spawning sites by insects, fish, and amphibians
- Declined in biodiversity in zooplankton, macro benthic, fish and amphibian communities

(Julio A. Camargo, 2005)

2.2.2. Cultural eutrophication

Eutrophication reduces the dissolved oxygen in water. Thus most organisms will be challenged to survive. This leads to death of fish and invertebrates. (Julio A. Camargo, 2005)

The decline in dissolved oxygen concentrations due to eutrophication can also encourage the formation of reduced compounds (such as hydrogen sulphide), resulting in more adverse and toxic effects on aquatic animals. (Julio A. Camargo, 2005)

2.2.3. Direct toxicity of inorganic nitrogenous compounds

The fact that toxic algae occurs can considerably contribute to the extensive extermination of aquatic animals. (Julio A. Camargo, 2005). The fact that the leachate has a high strength and hazardous nature will undeniably affect the environment negatively.

2.3 Mariannhill landfill Conservancy

The Mariannhill landfill site is a DSW, domestic waste disposal landfill site. The landfill is classed as (H:h). The Mariannhill Landfill Site, located south-west of the centre of Pinetown and south of the N3 (refer to Figure 2-1) has been in operation since 1997. The site accepts between 550 and 700 tons of solid waste per day. (Sawyerr, 2011)

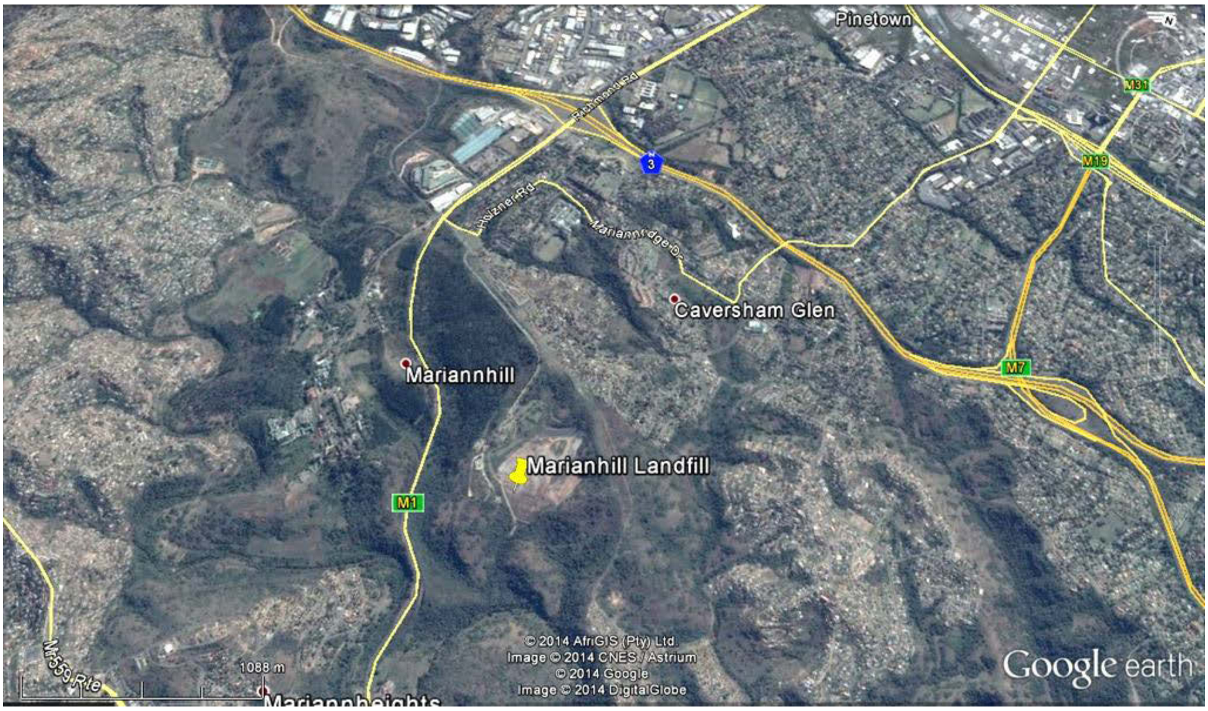


Figure 2-1 Location of Mariannhill landfill (Google, 2014)

Mariannhi is South Africa's first andfi site conservancy. The landfill represents a development where landfill-engineering methods have effectively combined with day to day procedure to develop the conservancy. The application of known natural processes, used in the engineering, to development the landfill is vital to environmental approval of the landfill site, specifically for creation of a sustainable conservation site. Naturalistic engineering includes numerous landfill features for example: the specification of landfill capping layers to encourage vegetation to grow; the utilizing simple and inexpensive, yet robust, natural systems to treat landfill leachate; and the implementation of wetlands to lower storm water energy and at the same time once again introduce valuable bird life into the site. In addition, landfill gas to electricity generation is now financially viable in South Africa and should be exploited. Methane gas is a major greenhouse gas. Gas to electricity generation will assist towards reducing global ER's (emission reductions) of carbon and lowering the stress on the local electricity demand which is not fully met by providers. (Durban Solid Waste, n.d.)

Figure 2-2 Mariannhill Landfill Site plan (Google, 2014)

Figure 2-3 Aerial view of Mariannhill Leachate Plant (Sawyerr, 2011)

2.4 Living Earth

Figure 2-4 freshly delivered vegetable waste at Living Earth

Living Earth is a company located in Ballito, South Africa that provides instant lawn and compost. It was founded by farmer Nic Jordan. Who had started composting, for use on his farm in 2005, by recycling the garden refuse that would have otherwise been sent to landfill sites. The goal was to create high quality, microbiologically rich compost. The results on the farm and feedback from others whom used it led to his decision to make it available to the public. Thus Living Earth was born. Now Living Earth Compost is available in bulk and environmentally friendly as it is not packaged in plastic bags. (Unless plastic bags are required) (Living Earth, 2008)

Living Earth gathers waste from various companies from the area. They often get offers to take waste off companies' hands. Waste found on the Living Earth compost generating farm consists of waste that large farms or factories wish to get rid of, such as garden refuse, bark, vegetable waste and other food waste. Vegetable waste is delivered from Dube Tradeport, erratically but often (3-5 times a week). The heaps of waste, used as a carbon source, are turned on a weekly basis. This moves the heap of a particular week across the farm. Such that after 10 weeks the heap is next to the rotating sieve. Their product cannot officially, by standards, be regarded to be compost, due to the ash content. (Gouws, 2013)

Figure 2-5 Living Earth compost site

2.5 Dube TradePort

Dube TradePort's aerotropo is (Airport city) consists of an airport, Cargo Terminal, AgriZone, TradeZone and Dube City all in an area of 2040-hectares. Dube Tradeport is Africa's first green precinct and a green development that is a flagship for sustainable development in Africa and beyond.

Figure 2-6 Site plan of Dube Tradeport (Dube Tradeport, 2014)

Dube Tradeport is location is on Sugar Cane road, La Mercy, 30km north of Durban. The Dube Tradeport is situated around and looks to combine the King Shaka International Airport. (Dube Tradeport, 2014)

Figure 2-7 Aerial View of the Dube Tradeport

Dube Tradeport promotes sustainable development through minimization of environmental impacts. There are numerous green initiatives in position to reduce the carbon footprint of travellers, developers, manufacturers, retailers, service providers, employees and others who use the facilities of Dube Tradeport. Initiatives are implemented to minimise or mitigate greenhouse gases (this also includes synthetic pollutants), protection of the ecosystem, run sustainable water and waste management systems, provide food security and boost the green economy. (Dube Tradeport, 2014)

Figure 2-8 Dube TradeZone 3D render (Dube Tradeport, 2014)

Dube Tradeport has the first smart, integrated, high-tech agricultural cluster hosting the largest climate-controlled growing area under glass in Africa. (Dube Tradeport, 2014)

Figure 2-9 Photovoltaic Solar Panels (Dube Tradeport, 2014)

Figure 2-10 AgricZone nursery (Dube Tradeport, 2014)

Dube AgriZone has the following several green initiatives, namely:

- Photovoltaic solar panels have been installed on one of the AgriZone pack houses to supplement the energy requirements of these facilities. Power is being generated by this system, thus reducing the dependence on the national grid and indirectly reducing the CO_2 emissions.
- Rainwater harvesting for each greenhouse platform and is being attenuated and stored in adjacent closed surface storage ponds.
- Water supply is also supplemented by boreholes.
- By being able to completely control the climate within the greenhouses, higher yields than conventional farming methods result.
- Clearing of alien species of the entire site.
- Rehabilitation of wetlands and terrestrial environments within the AgriZone has offset the impacts of the development. (13 000 indigenous plants reintroduced over 4 hectares)
- In the AgriZone nursery, indigenous, rare and endangered species are propagated and used in the rehabilitation areas

(Dube Tradeport, 2014)

Dube Tradeport exports various fruits and vegetables to overseas markets. Some of these are not up to the freshness standards, thus will not be exported, as it would still need an export and shelf life. Thereafter, the vegetables still have to be of great quality, to compete internationally against other sources of fruit and vegetables. The produce that does not meet these standards is disposed of. It is disposed of by delivering to Living Earth, who is nearby (see section 2.4.). This is a very responsible way of disposal.

2.6 Important composite in Leachate

2.6.1. Heavy Metals

There is a variety of metals that can be discovered in a sample of landfill leachate, especially as it is difficult to monitor what enters from garbage trucks. Non-disposable items such as electronics and batteries can be easily discarded into a bin then taken to the landfill site. Metals can very toxic to the environment, however concentrations of chromium particularly above 1mg/l inhibit the biological process used in removing nitrates from leachate. (Dawnarain, 2004)

2.6.2. pH

The pH is a representation of the hydrogen ion activity, measured from 1 (acidic) to 14 (basic), with 7 being neutral. It is important to measure pH as it has a great effect of the rate of denitrification. The suggested pH range is 6-8 if nitrite inhibition is not a limiting factor. (Plüg, 2008) The reaction is most rapid at a pH of 7. (Gerber, 1999)

2.6.3. Ammonia

Ammonia (NH_3) is an aqueous representation of nitrogen.

2.6.4. Nitrites

Nitrites (NO_2^-) inhibit the process of testing for nitrates. Thus the system would not be working at optimum if there is a presence of nitrates. The presence of nitrites inhibits the process of nitrate testing.

2.6.5. COD

Chemical Oxygen Demand (COD) is the total quantity of a specified oxidant that reacts with a sample under controlled conditions. The COD can be used to characterise the organic strength of waste water and is a measurable amount of non-biodegradable organics. (Plüg, 2008)

2.6.6. RI_7 test (Respiratory Index after 7 days)

The RI_7 test measures the amount of oxygen used by the sample as it decomposes, or the biodegradability, in a seven day period. The result representative of how much readily available carbon is present for the specific solid substrate being tested. (Plüg, 2008)

2.7 Leachate Management

Due to the toxic nature of leachate, there has to be control, monitoring and management of leachate that originates from the landfill.

The following is a list of leachate management solutions:

- Attenuation and dispersal landfills release a slow discharge of leachate into the environment. The pollution is reduced by natural dilution in the natural groundwater, then by the biological, physical and chemical degradation on the leachate. (Gerber, 1999)

- Containment landfills aim to contain the waste within the boundaries of the site and manage the gas and leachate produced by biological processes within the site. Managing the leachate involves either on-site biological or chemical treatment before discharge to the environment, or transfer of leachate from the site to an appropriate treatment facility such as sewage works. (Gerber, 1999)

2.8 Nitrate drinking water standards

Nitrate in drinking water is measured either in terms of the amount of nitrogen present or in terms of both nitrogen and oxygen. The federal standard for nitrate in drinking water is 10 mg/l nitrate-N, or 50 mg/l nitrate-NO_3, when the oxygen is measured as well as the nitrogen. Unless otherwise specified, nitrate levels usually refer only to the amount of nitrogen present, and the usual standard, therefore, is 10 mg/l. (Lenntech water treatment solutions, 2011) The DWAF standard is 11 mg/l nitrate-N, or 50 mg/ NO_3/l, 0.9 mg/l nitrite and 3mg/l of NO_2. (The Department of Water Affairs, 2010)

Short-term consumption of drinking water with a nitrate level above the health standard is a potential health problem particularly for babies. Babies drink sizeable quantities of water considering their body weight, especially if water is used to mix powdered or concentrated recipes or juices. Also, their digestive systems are immature, and thus more likely to allow the reduction of nitrate to nitrite. (Lenntech water treatment solutions, 2011)

According to the WHO, the concentration of Nitrate (NO_3^-) is recommended to be less than 50mg/l, acceptable between 50 and 100mg/l and it is not recommended to be more than 100mg/l. (Lenntech water treatment solutions, 2011)

2.9 Discharge standards

The natural concentrations of nitrate in water bodies are estimated to be less than 22mg/l nitrate.

Table 2-1 The discharge requirements as set out in the Special and General Standards for nitrogenous compounds and COD.

	Existing General Standards	**Future all discharge**
Ammoniacal nitrogen (assumed units is mg/l)	3	1
Nitrates (N mg/l)	15	15
COD (mg/l)	75	65
pH	5.5-9.5	5.5-7.5

(Department of Water Affairs, 2010)

2.10 Nitrogen cycle

“The nitrogen cyc e is the continuous flow of nitrogen through the biosphere by the processes of nitrogen fixation, ammonification (decay), nitrification, and denitrification. Nitrogen is vital to all living matter, both plant and animal; it is an essential constituent of amino acids, which form proteins of nucleic acids, and of many other organic materia s.” (Columbian Encyclopedia, n.d.)

2.10.1. Nitrification

Nitrification is a process where nitrogen in the form ammoniacal nitrogen can be removed from leachate. Ammoniacal nitrogen is oxidised by Nitrosomonas (aerobic bacteria) to form nitrite and then nitrate is formed due to Nitrobacteria. These reactions occur under aerobic conditions (process that consumes oxygen or requires oxygen present to occur). (Gerber, 1999). This predominantly occurs when soil bacteria convert Nitrogen gas into nitrogen products (nitrates) that plants absorption from the soil.

$$2\ NH_3 + 3\ O_2 \rightarrow 2\ NO_2 + 2\ H^+ + 2\ H_2O$$

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

(Helmenstine, 2012)

2.10.2. Ammonification

Ammonification is the process whereby nitrogen nutrients are converted back to ammonia products. It usually occurs during the decomposing process of plants and animals. (Helmenstine, 2012)

2.10.3. Nitrogen Fixation

Nitrogen fixation is one process by which molecular nitrogen is reduced to form ammonia. There are two ways of this happening, by light, where energy from the light combines nitrogen and water to form ammonia and nitrates. The other way is by biological fixation, where Cyanobacteria convert nitrogen ammonia and ammonium. (Helmenstine, 2012)

$$N_2 + 3\ H_2 \rightarrow 2\ NH_3$$

(Helmenstine, 2012)

2.10.4. Denitrification

Denitrification is the reduction of nitrate to nitrite, then to nitrous oxide and finally Nitrogen gas. This process occurs under anaerobic conditions. (Gerber, 1999)

$$NO_3^- + CH_2O + H^+ \rightarrow \tfrac{1}{2}\ N_2O + CO_2 + 1\tfrac{1}{2}\ H_2O$$

(Helmenstine, 2012)

2.11 Current Method of removing Nitrates from Leachate

The most valuable characteristic of an anaerobic SAA bioreactor is that it is cheaper and the by-products are relatively harmless (N_2, nitrogen gas). There is a sufficient amount of waste supply as a carbon source: “Current y, the three major eThe wini andfi s receive an average of 3000 tons of garden refuse monthly, separately from the main waste stream.” (Pisano, 2007).

2.12 Fixed-bed reactors

A fixed-bed reactor is a scheme used to facilitate chemical reactions and in this case vegetable waste, CGR_{RAW} or one of the mixes will be used to react with Mariannhill Landfill Leachate.

Leachate that emanates from Mariannhill Landfill has a high level of ammonia concentration. The raw leachate is fed into the Set Batch Reactor (SBR), where nitrification takes place and ammonia is converted to nitrates and nitrites. The SBR output is not suitable to deposit into the river. Therefore, to remove the excess nitrates and nitrites the SBR output is allowed to flow into a horizontal constructed wetland (anaerobic).

The leachate would flow from the SBR into the treatment effluent tank. Thereafter the output could flow into the Fixed-Bed reactor, where denitrification takes place (nitrates converts to nitrogen gas and oxygen). The batches will be used to identify if the substrates in question could treat nitrates and nitrites. The ultimate conclusion would be to identify if this can be used as a substrate in the fixed-bed reactor. The batch test studies are illustrative of how substrates will react in contact with leachate within the reactor on a very small scale.

Thereafter the fixed-bed reactor’s output, if the output complies with standards, can be discharged into a river or water source. If it does not comply with standards it will discharged into sewage system or flow through a horizontal constructed wetland then into an aerobic Reed bed for polishing treatment (Solids and COD). (Plüg, 2008)

3. Methodology

A number of tests were done on the eluate of the substrate, the leachate and the batch samples. These tests were done as the results would have to be compared in order to achieve the aim. The batches were run in triplicate with one control. The Mariannhill leachate was chosen for its availability and due to the fact it was landfill leachate.

All laboratory procedures are taken from Standard Methods for Examination of Water and Wastewater. (Eaten, 2005)

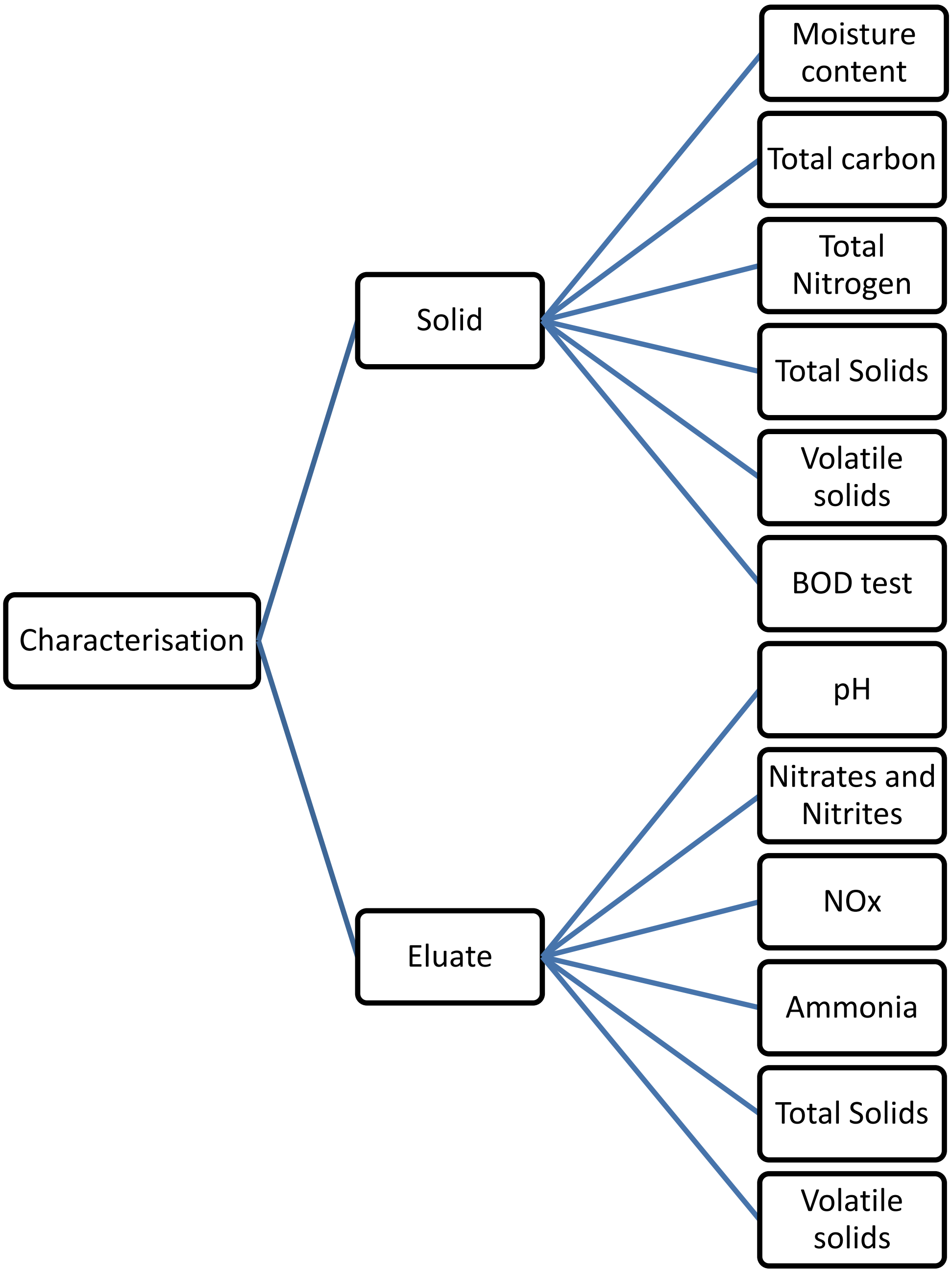


Figure 3-1 Summary of the characterisation tests done

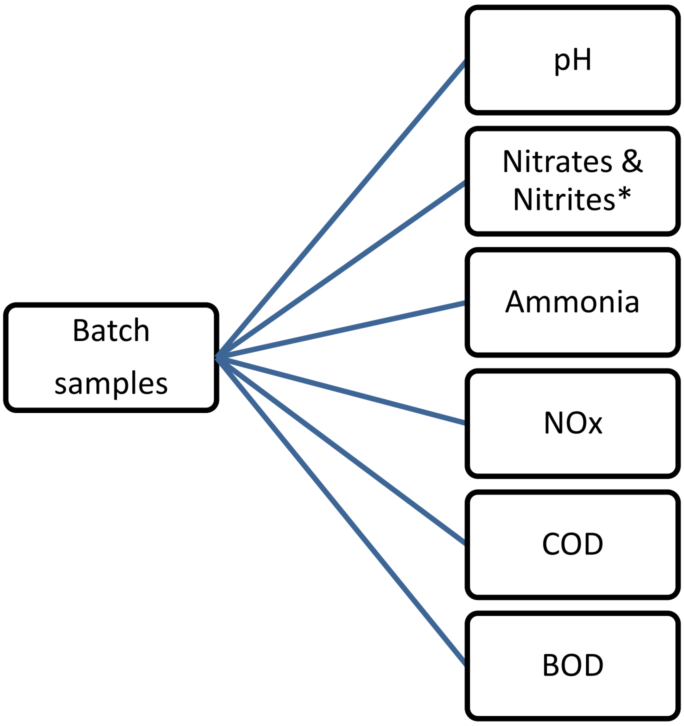


Figure 3-2 Summary of the tests done on the batches

* Nitrate testing was done continuously whilst the batch was running, the rest of the test were done once batch experiment was complete.

Substrates that were analysed include:

- Vegetable waste (VW)
- Commercial Garden Refuse (CGR_{RAW})
- 75% Vegetable waste, 25% Commercial Garden Refuse (75/25)
- 50% Vegetable waste, 50% Commercial Garden Refuse (50/50)
- 25% Vegetable waste, 75% Commercial Garden Refuse (25/75)

3.1. Sampling

3.1.1. Leachate

Treated landfill leachate was sampled from Mariannhill landfill conservancy. This was done using an electric pump, using a car battery as an electricity source. The treated landfill leachate was sampled from the Treated effluent balance tank. The leachate was sampled such that there were no noticeable solid particles in the liquid sample flowing into the storage drum.

Figure 3-3 Treated Effluent Tank were treated leachate was sampled

Figure 3-4 Sampling of treated leachate in progress

3.1.2. Vegetable waste

The vegetable waste had been sampled from the Living Earth Compost yard in Balito. The vegetable waste had been delivered by a truck from Dube Tradeport.

Figure 3-5 Vegetable waste at Living Earth

The vegetables were judged not to be to standard in order for them to be exported to international markets, also considering that the vegetables would have to still stay fresh for the duration of the trip to the place of sale and that it would need a reasonable shelf life and after sale storage life. Some vegetables are grown near the Tradeport in greenhouses as part of the AgriZone. The other vegetables are grown on farms in the vicinity of the Tradeport. At a glance, the fresh vegetable waste was mostly butternut, celery, jam squash, sweet potato, carrot and onion. However, it is worth noting that the samples vary daily.

During the second sampling, strawberries were discarded. This was done as it was not a vegetable and it may cause results to be very unstable as strawberries when decomposing can cause the pH to become even more acidic. This should not affect the result with regards to application onto a high scale as the amount of strawberries should be insignificant, thus the affect should be the same.

3.1.3. Commercial Garden Refuse (CGR_{RAW})

CGR_{RAW} was collected from the Sundown village in Pinetown. The village composts its own garden refuse, thus the waste is readily available separated from other waste. This was possible as the Sundown village practice composting on their premises of all garden refuse. As a result, garden refuse from the 20 acre green real estate is collected to a small area making it easier to sample. The newest pile of refuse was sampled as CGR_{RAW}.

Figure 3-6 Sundown village Compost heap

The substrates were broken down into smaller pieces so it could fit into the bottles used for the batch test. It was also done so that there would be more surface area for the bacteria to attach to; consequently the carbon is more available (for a quicker reaction). This was done with clippers and knives for the vegetable waste and a garden shredder was used for the CGR_{RAW}.

Figure 3-7 Chopped Vegetable Waste

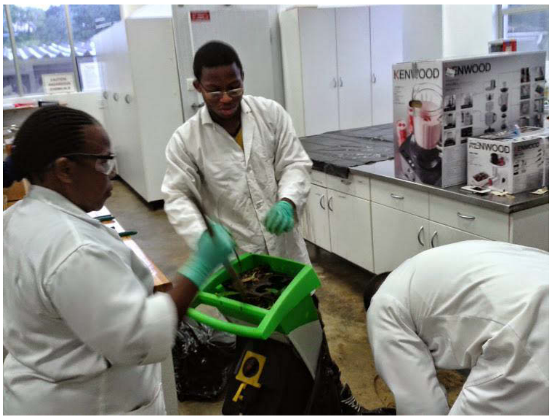


Figure 3-8 Using a garden shredder to process CGR raw

3.1.4. Cone and Quartering

The cone and quarter method was used on the large sample in order to obtain a smaller sample. Referring to the figure 3-9 below, the sample was mixed into a pile (a). Once the sample was flattened out (spread out to form a flat disk shape) (b).

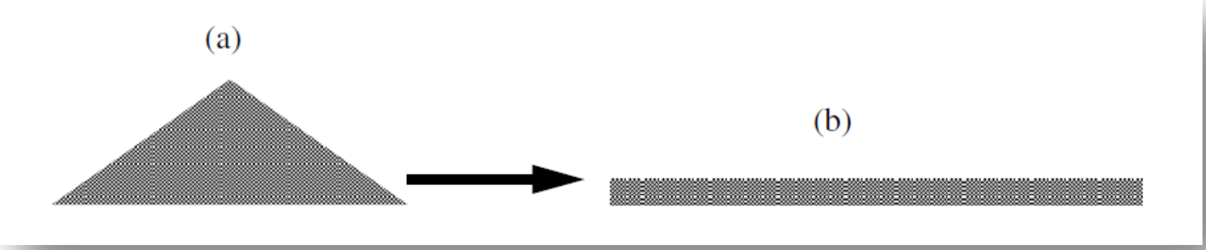


Figure 3-9 Cone and quart procedure (Michigan Technological University, 2009)

It was then divided into four and the diagonal quarters are mixed. One pair of opposite quarters was discarded. The other would be used to mix and quarter once again only this time the other pair of diagonals would be chosen to be discarded. This is repeated until appropriate samples were obtained.

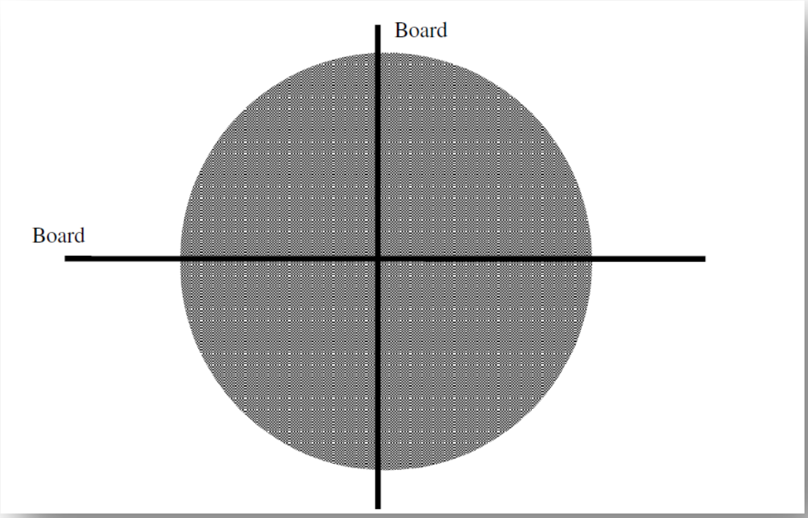


Figure 3-10 (Michigan Technological University, 2009)

The waste was stored in a cold room set to 4 degrees Celsius. All the decomposition was expected to be done during the experiment, thus it was attempted to keep the waste fresh.

Figure 3-12 Cone and quarter of CGR raw

Figure 3-11 Cone and quarter Vegetable waste

3.1.5. Different mixes between vegetable waste and CGR_{RAW}

Samples were then weighed on a mass balance to make up 2 kg mixes with the ratio 1:3, 1:1 and 3:1 of Vegetable waste: CGR_{RAW}. Thus these were named 75/25, 50/50 and 25/75 respectively.

In the first experiment (A), 5.04kg of woodchips was added as it is known that the woodier the CGR_{RAW} sample is the more bacteria is provided for denitrification (Ali, 2013), thus the more effective the substrate. This was done before the mixes were made.

The second experiment (B) used a sample of CGR_{RAW} substrate that already had sufficient amount of wood bits in it, thus no woodchips were added to the sample.

3.2. Moisture Content, Total Solids and Volatile Solids Tests

Moisture content is the percentage of water in the sample in question. Total solids refer to the percentage of the sample that is solid matter (residue without moisture). Volatile Solids refers to the percentage of the sample that is combustible (an estimate of organic material). (Sawyerr, 2011)

The following method was used for testing: Set up 4 crucibles per solid sample, filled roughly two thirds to the top and 3 for eluate samples, 25ml each. Obtain the mass of crucible using a 4 point mass balance (wet mass). Place into the oven, set to100°c, over night to dry. Use desiccators to store sample. Weigh the filled crucible and record all mass values (Dry mass). Thus determine the moisture content and Total Solids.

$MC(\%) = \frac{Wet\ mass - Dry\ mass}{Wet\ mass} \times 100$..............................Equation 3.2.1

$TS(\%) = \frac{Dry\ Mass}{Wet\ Mass} \times 100$.. Equation 3.2.2

Figure 3-13 Crucibles filed with solid samples

Figure 3-14 Crucibles filled with eluate samples

Thereafter samples were placed into the furnace for 2 hours, left to cool in the desiccator and weighed (Fired mass). From this Volatile Solids were determine.

$VS(\%) = \frac{Dry\ Mass - Fired\ Mass}{Wet\ Mass} \times 100$..............................Equation 3.2.3

Figure 3-15 Furnace

Figure 3-16 Crucible sample after removed from the furnace

3.3. RI_7 test (Respiratory Index after 7 days)

The RI_7 test measures the amount of oxygen used by the sample as it decomposes, or the biodegradability, in a seven day period. The result is representative of how much readily available carbon is present for the specific solid substrate being tested. (Plüg, 2008)

To conduct the RI_7 test, 25 grams of substrate was weighed using the mass balance. Testing for characterisation was done at field capacity, thus if the sample seems dry by inspection distilled water was added. It should appear damp at most. (The vegetable waste was moist thus no water was added to the samples). Lids were put on the jars containing samples and where fixed with metal clips. Thimbles were put into place and six drops of KOH were added to the thimbles. The Oxytop screw-on tops were used to seal the samples in and simultaneously record results. It was placed into the incubator set at 22°C. After seven days the values will be recorded of the Oxytop remote sensomat. This was done in triplicate.

Figure 3-17 BOD beakers in climate control incubator

3.4. Liquid tests: Setting up the substrate as a liquid (eluate)

Eluate allows analysis of solid samples in liquid tests. Calculations were done in order to find quantities of substrate and distilled water (or treated leachate for batches) that the sample would be comprised of. The solid to liquid ratio is 1:10 and the total volume of the sample is 1500ml. Substrate and distilled water was added to a 2 litre flask. The flask was sealed and placed on the shaker; speed was set to 150 rotations per minute, for 24 hours.

The sample is then passed through a 63 micron sieve to extract the liquid eluate. This was done for all substrates. Thus the samples can now be analysed by conducting tests such as pH, ammonia, NO_x, BOD, COD, total solids, moisture content, volatile solids nitrates and nitrites tests.

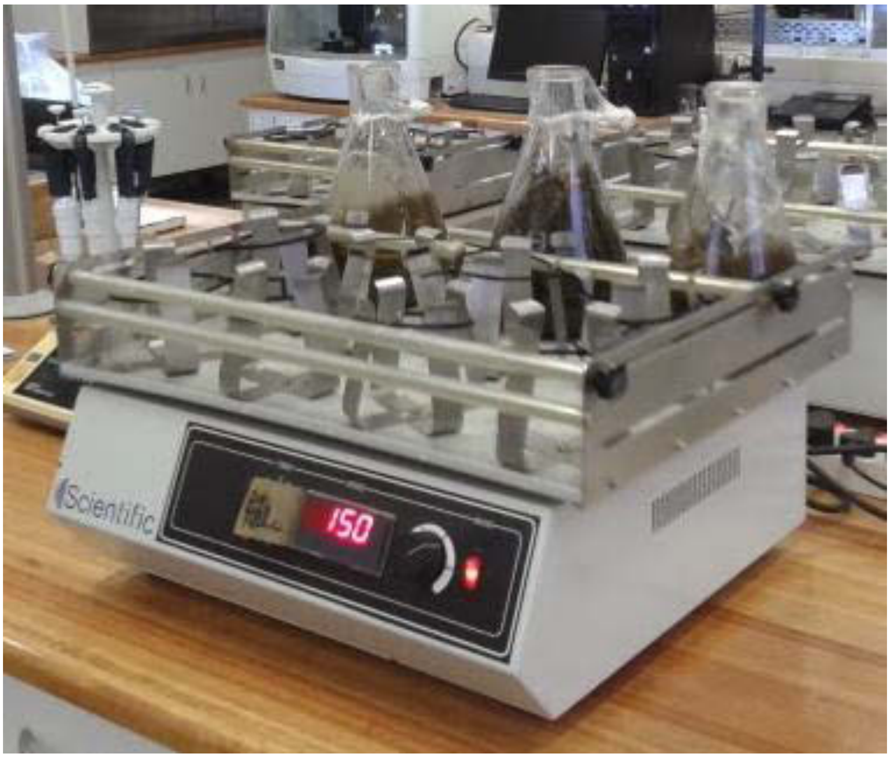


Figure 3-18 Eluate flasks on the shaker

Table 3-1 Summary of the ingredients when creating liquid samples or eluates (rounded off to the nearest whole unit)

No.	Substrate	Experiment A		Experiment B	
		Mass of substrate added (g)	Volume of water added (ml)	Mass of substrate added (g)	Volume of water added (ml)
1	Vegetable waste	1540	110	1318	332
2	75/25	748	902	754	896
3	50/50	650	1000	632	1018
4	25/75	468	1182	453	1197
5	CGR_{RAW}	309	1341	378	1272

3.5. Total Carbon, Total Nitrogen and Carbon/Nitrogen ratio

Firstly, the objective of this test was to determine the amount of carbon in the substrate, as the more carbon the substrate has the more of the fuel source to denitrifying bacteria.

Secondly it was to determine the amount of Nitrogen, as the more nitrogen the substrate has the more nitrogen products would leach into the effluent being treated. This would mean the substrate is counterproductive.

Lastly it was to determine the ratio between carbon and nitrogen to determine if it was a viable to use as a substrate. Usually a suitable substrate would have more carbon for denitrifying bacteria and less nitrogen. Theoretically, the higher the ratio the more effective the substrate in treating nitrates. There could be a ratio that allows the most efficient treatment of nitrate.

These tests were done by another analytical laboratory namely Bemlab. This was done as equipment used to test for total carbon and total nitrogen was not available locally. There were 5 samples (each substrate) sent for each experiment (A and B)

Table 3-2 Contents of samples sent to Bemlab

Substrate	**Samples**				
	1	2	3	4	5
Vegetable waste	100%	0%	75%	50%	25%
CGR_{RAW}	0%	100%	25%	50%	75%

The samples were put into a plastic jar and boxed and sent with an overnight delivery service.

3.6. pH test

The pH meter was used to measure the pH in all samples. It was calibrated before testing for either the Acidic or Alkaline range. Then the electrode of the pH meter was inserted into the sample. Once the meter was ready to be read the pH and temperature can be recorded.

The pH reading allows the understanding of conditions in which the denitrification bacteria are operating, as well as to determine if the resulting liquid complies with the DWAF discharge standards.

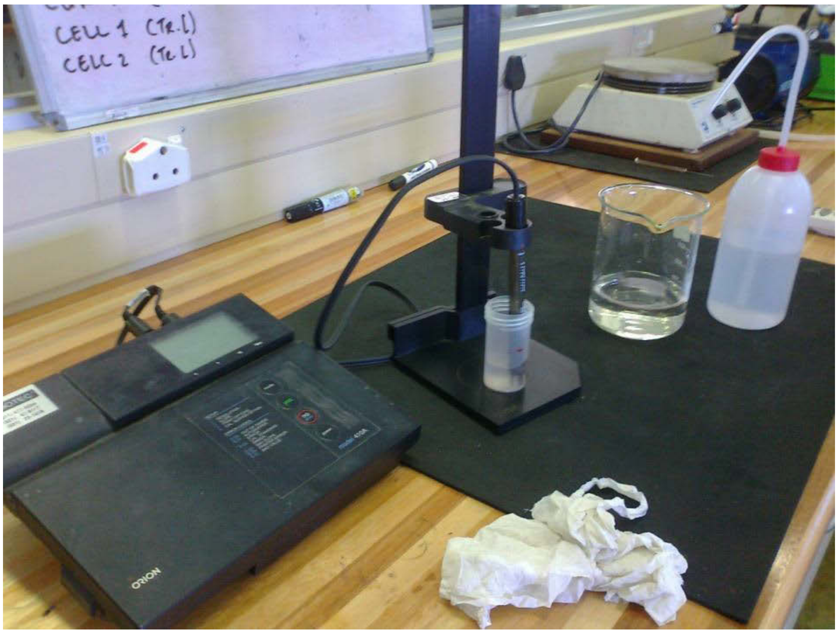


Figure 3-19 pH meter and other apparatuses used

3.7. Nitrates and Nitrites

Figure 3-20 Nitrate testing stick and the container

Nitrates are continuously tested throughout the batch tests. This is the main parameter of the dissertation. The values obtained will be recorded and plotted to determine a kinetic model.

To test nitrates, fully submerge the test strip into the sample for a second, remove, flick the test strip, wait one minute, compare the test strip to the colour spectrum, on the nitrate stick container, to estimate the nitrate reading.

If necessary, the sample was filtered through filter paper to attain a clear liquid, such that the sample does not stain the test strip.

The same strip has the capability to determine the presence of nitrites. If the sample contains nitrites (NO_2^-) the nitrate (NO_3^-) reading is compromised. To overcome this a few drops of sulfanic acid was added to the sample, thereafter, test again with a new strip.

The maximum level of nitrates that can be tested using the nitrate sticks is 500 mg/l. If the nitrate level is higher than 500 mg/l, the sample would have to be diluted such that the reading would fall within the range (0 to 500 mg/l).

Figure 3-21 Used NOx test strips

3.8. Ammonia Test and NO_x test (Using the distiller)

The ammonia test from the distiller reads NH_3 and NH_4^+ (ammonical Nitrogen).

The distiller was cleaned with a little distilled water before testing. Place large test tube into the distiller with 10ml of sample which was pipetted into each large test tube and placed on the test tube rack (10ml was used as there was not enough sample to use 25ml per test). Then 50ml of Boric acid indicator solution was put into a 250ml flask which was placed under the outlet of the distiller. If necessary, a few drops of anti-foam were added to the test tube, to prevent the sample from boiling over.

Figure 3-22 Samples and indicator ready to be inserted into the distiller for testing

Figure 3-23 Distiller

For the ammonia test there were no chemical additions. However, for the NOx test, two reagents were added to the sample: 0.5g of MgO and Devardas Alloy was added to the sample before testing.

The distillation unit was set to programme 1 for the ammonia test and programme 2 for the NO_x test.

Once the distillation process is complete the Boric acid indicator solution was removed. An HCl solution was slowly added to the indicator solution using the Titrator. Once the indicator solution changed back to its original colour, the volume of HCl was recorded from the digital Titrator. The amount of ammonical nitrogen and NO_x was then calculated. Using the following equation:

$$NH_4\ or\ NO_x\ (mg/l) = \frac{Volume\ of\ HCL\ (ml) \times [HCL] \times Nitrogen\ mol\ number}{Volume\ of\ Sample\ (l)} \text{ ....Equation 3.4}$$

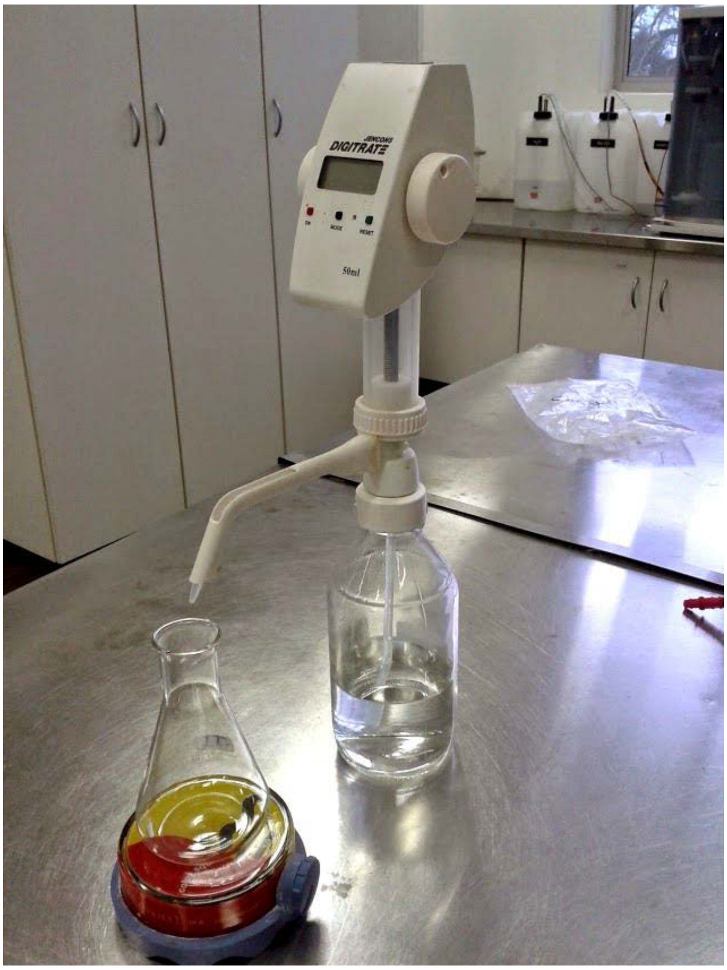


Figure 3-24 Titrator, magnetic stirrer

3.9. Chemical Oxygen Demand (COD) test

This test measures the oxygen required to allow the sample to fully react or degrade. Inorganic compounds are insignificant compared to organic compounds. This is understandable as the samples tested are organic. Thus in actual fact this test measures the oxygen required by organic compounds to degrade. (Eaten, 2005)

There are 18 test tubes (3 test tubes x 6 different samples) which have sample in them per COD test, 3 test tubes were used as a standard (KHP samples). The last 4 test tubes were Blanks (filled with 2.5ml of distilled water).

Each sample was done in triplicate. Thus each liquid sample was added to 3 test tubes (usually 0.05ml unless the result is out of the test range). Thereafter, distilled water was added to the sample, where the sum of the water and the sample is 2.5ml (For example, 0.05ml of sample and 2.45ml of distilled water).

The 3 standard samples contained 1ml of Potassium Hydrogen phthalate (KHP) and 1.5ml of distilled water. The 4 blank samples contained 2.5ml of distilled water. Then 1.5ml of Potassium dichromate indicator ($K_2Cr_2O_7$) and 3.5ml of Sulphuric acid reagent (H_2SO_4) was added to all test tubes.

The test tubes were then left in the digester for 2 hours at 150°C. After cooling, the test tubes were put into the Spectro-photometer set at a wavelength of 600 nanometres, where the COD was determined by how much light was absorbed by the sample.

$$COD\ (mgO_2/l) = \frac{(abs\ of\ sample - abs\ of\ blank)\times conversion\ coeff.}{volume\ of\ sample}$$ .... Equation 3.9.1

Figure 3-26 Micro pipettes

Figure 3-25 COD test tubes

3.10. BOD_5 test

BOD_5 or Biological Oxygen Demand is the amount of oxygen required, by the bacteria, to fully biodegrade the organic matter in the sample, in five days (this is the standard testing time period). (Eaten, 2005)

This effectively measures the amount of biodegradables in the sample. The limitation on time also reflects that it would have to be a more easily degradable matter, such that it will be degraded within 5 days.

Samples were measured out, using the measuring cylinders, according to Table3-3. The range would be estimated from the COD result, as BOD_5 is roughly 80% of the COD (mg/l). Then put into BOD bottles, along with magnetic stirrer bar and the appropriate number of drops of ATH (Allyl Thiourea).

The thimble was put onto the top of the bottle and 6 drops of KOH. Aqualytic tops are put on and the bottles are kept in an incubator, set at 22°C, which contained a stirrer tray. After five days, the results are recorded and the bottles are removed.

Table 3-3 Sample volume and drops of ATH for a specific range (Robertz, n.d.)

Range BOD (mg/l)	Sample volume (ml)	Drops ATH
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 BOD_5 test was conducted in BOD bottles which were dark and sealed using Aqualytic tops. During the BOD_5 test, microorganisms consume carbon and oxygen. As a result, carbon dioxide is given off. The carbon dioxide released then reacts with the KOH in the thimble. This reaction causes a pressure change. The Aqualytic tops measures pressure changes inside the BOD bottle. The experimental output is the BOD_5 concentration in mg/l and is reflected directly on screen of the sensomat. The more the biodegradables in the sample, the more carbon dioxide released, the greater the pressure change and the higher the BOD (mg/l).

Figure 3-27 BOD test in progress

3.11. Batches tests

After the substrates were processed, cone and quartered and mixes were made. The substrates were stored in the cold room set to 4°C.

Batches were then set up according to the results of the Total solids test. The mass and liquid quantities that were required to be added to the batch were calculated, such that a one to ten ratio of solid to liquid was maintained. (Refer to table 3-4 below)

The mass of substrate was added to the batch using a funnel, tweezers and mass balance. The leachate was then added according to calculation, using measuring cylinder.

Figure 3-28 setting up batchs

Each batch bottle was flushed out with nitrogen gas for 3-5 minutes and immediately sealed air tight to maintain anaerobic conditions. The batches were then left on the shaker for the duration of the experiment at a speed of 150rpm. (As long as the liquid within the batch has the swirling motion)

Figure 3-29 Flushing the batch with Nitrogen gas

Figure 3-30 Batches on the shaker

This was done, in triplicate, for five different mixes of substrate (100% vegetable waste, 100% CGR_{RAW}, 75% vegetable waste with 25% CGR_{RAW}, 50/50 of each and a 25% vegetable waste with 75% CGR_{RAW} mix) with one control for each batch.

Only one sample of leachate was used for all tests; Mariannhill Landfill Leachate. Control batches contained substrate and distilled water instead of leachate.

Samples would be taken as often as possible. Extraction of the sample for nitrate testing was done using a syringe and needle. This was done continuously until the nitrate reading was zero (0mg/l).

Thereafter the batch bottle was opened. The contents were sieved. The solid and liquid samples were stored in the cold room. The liquid samples were tested for pH, Ammonia, NO_x, COD. BOD_5. The solid sample was sent off to Bemlab for total carbon and total Nitrogen testing.

This experiment was done twice for two different samples of substrate, which was mixed to make up the five substrate mixes. However, the same sample of Mariannhill Landfill Leachate was used.

The results from the test conducted were tabulated on paper as well as on a spreadsheet (Microsoft Excel). Graphs were then obtained to identify patterns or relationships.

Figure 3-31 Vegetable waste Batch test on the shaker

Table 3-4 Batch arrangement summary (rounded off to the nearest whole unit)

Batch	Liquid being treated	Substrate constitution		What was added to each Batch				Short hand name
				A		B		
		%vegetable waste	% CGR_{RAW}	Substrate (grams)	Liquid (millilitres)	Substrate (grams)	Liquid (millilitres)	
1	Mariannhill Landfill Leachate	100	0	770	55	659	166	VW
2	Mariannhill Landfill Leachate	0	100	154	671	189	636	CGR_{RAW}
3	Mariannhill Landfill Leachate	75	25	374	451	377	448	75/25
4	Mariannhill Landfill Leachate	50	50	325	500	316	509	50/50
5	Mariannhill Landfill Leachate	25	75	234	591	227	598	25/75

4. Results and Discussion

4.1. Introduction

These results were based on batch tests, done in triplicate, with a control, for 5 mixes in different ratios:

- 100% vegetable waste,
- 100% CGR_{RAW},
- 75% vegetable waste with 25% CGR_{RAW},
- 50/50 of each and
- 25% vegetable waste with 75% CGR_{RAW} mix

It was observed for how effectively the substrate removed nitrates from Mariannhill Landfill leachate. This test was repeated once more. This was done to confirm results.

The two experiments were done with different samples of vegetable waste and CGR_{RAW} but the same sample of leachate. The first batches were started in November 2013. The second set was started in March 2014. Samples were taken for testing within 2 weeks.

Table 4-1 Estimated constitution of the vegetable samples

Contents of vegetable waste			
Vegetable	**Scientific name**	**Estimated Percentage**	
		A	**B**
Butternut	*Cucurbita moschata*	40	50
Celery	*Apium graveolens*	30	-
Onion	*Allium cepa*	5	-
Red onion	*Allium cepa*	-	10
Gem squash	*Cucurbita pepo*	10	20
Cauliflower	*Brassica oleracea botrytis cauliflora*	2	5
Potato	*Ipomoea batatas*	5	-
Carrot	*Daucus carota*	8	-
Broccoli	*Brassica oleracea botrytis asparagoides*	-	5
Cucumber	*Cucumis sativus*	-	10

The tests being done have been standardised. As a result, in this case, when testing samples that have a mixture of large fragments (relative to the sample needed to be tested) of different substances (mixture of different, cut up vegetables) the sample itself was not homogenous (therefore it was heterogeneous). The small amount of substrate that was used in each of these tests was quite possibly very different, in terms of characteristics, as the percentage of different types of vegetables (in substrates which contain vegetable waste) and/or vegetation (in substrates which contain CGR_{RAW}) making up the test sample, even to the untrained eye, it was evidently very different. The solution was to do tests in triplicate. Some tests were repeated to improve accuracy and reliability.

4.2. Characterisation of Leachate

Pretesting was carried out to determine the characteristics of the materials that were being used in the experiment. Thus the physical makeup of the substrate and eluate was determined. The eluate tests were done to determine the nature of the leachate. The following table shows characterisation results of Mariannhill Landfill treated Leachate as compared to the DWAF standards.

Table 4-2 Characterisation results of Mariannhill Landfill Leachate compared to DWAF Discharge Standards (Department of Water Affairs, 2010)

Tests	Mariannhill Landfill Leachate	DWAF Standards
TS (g/l)	13.441±0.008	
VS (g/l)	3.780±0.866	
pH	7.58±0.02	5.5-9.5
Nitrate (mg/l)	4000	<22 (natural est.)
COD (mg/l)	1031.50±257.67	75
BOD5 (mg/l)	203.33	
NH_3-N (mg/l)	10.73±0.81	3
NO_x-N (mg/l)	891.8 ±106.50	15

With exception of pH, all the other characterisation results were not within the Discharge Standards set by the Department of Water Affairs and Forestry (DWAF). In some areas, it was more than ten times the limit set. Thus Mariannhill Landfill Leachate requires treatment before being discharged into natural water bodies. It was expected that the nitrates and nitrogen compounds would be treated, the pH would be reduced (made more acidic) and the vegetable waste was expected to increase COD.

Total solid and volatile solid results were as expected for a liquid with solid particles within them. The pH was more alkaline but acceptable as it lies within the DWAF standard range. The COD, Ammonia (NH_3), NO_X and most relevantly the nitrate concentrations were greater than the discharge standards. Thus the Mariannhill Leachate is required to be treated before being discharged.

4.3. Characterisation of Solid Substrates

The table below shows the characterisation of two different samples of substrate, sampled on the 12 November 2013 (A) and 20 January 2014 (B). The mixes were derived from these samples. Tests were conducted as quickly as possible as to lessen the waste degradation. The results were presented in a collective fashion as to compare all the substrates against each other.

Table 4-3 Characterisation of the Solid substrate

Solid Characterisation							
Substrate/ Test	MC (%)	TS (%)	VS (%)	RI7 (mg O_2 /g DM)	Total C (%)	Total N (%)	C/N Ratio
VW A	90.26	9.74±1.68	90.65±1.35	193.00±107.64	41.10	2.62	15.69
VW B	88.62	11.39±0.47	91.16±1.45	753.99±110.84	41.80	0.51	81.96
CGR A	51.40	48.60 ±2.85	80.21±2.79	95.26±65.21	36.50	1.30	28.08
CGR B	60.30	39.70±1.21	74.75±4.26	135.05±79.36	42.20	1.60	26.38
75/25 A	79.94	20.06±1.15	80.75±1.76	350.85±36.95	39.20	1.83	21.42
75/25 B	80.11	19.89±2.87	76.91±4.72	338.34±170.63	48.30	2.12	22.78
50/50 A	76.92	23.08±2.32	77.69±2.63	298.22 ±7.62	35.20	1.43	24.62
50/50 B	76.28	23.72±0.22	67.17±8.93	361.08 ±65.72	42.20	1.63	25.89
25/75 A	67.97	32.03 ±3.24	78.46±2.05	234.84±13.17	35.50	1.42	25.00
25/75 B	66.91	33.09±7.63	71.94±4.91	309.23±8.12	39.40	1.54	25.58

The moisture content was relatively high thus Total Solids was relatively low for the vegetable waste substrate, compared to other substrates tested in the past. This was evident when the vegetables decompose and water would easily permeate out. This would mean there was less matter and therefore less carbon per kilogram. However, this was accounted for using the 1:10 solid to liquid ratio. As expected, the more vegetable waste contained in a particular substrate mix, the higher the moisture content reading and this was inversely proportional with respect to total solids readings.

The carbon content was vital as the denitrifying bacteria require carbon in the denitrifying process. It was more suitable if the carbon to nitrogen (C/N) ratio was in the optimum fraction to be appropriate for the bacteria during the denitrifying processes. The substrate should not introduce more nitrogen into the system than it is able to treat, thus a higher C/N ratio would also be desirable.

The carbon content readings were roughly the same for all substrate combinations. Most of the nitrogen content has similar values; however, there was a disparity between the VWA and VWB, this was similar when considering the carbon/nitrogen results. The nitrogen and C/N ratio value for VWA varies by a factor of five as compared to VWB. This was possible as the samples did not have exactly the same constituents. The samples were similar, in that a large percentage of vegetables were present in similar proportions in both samples, but some vegetables were only present in one of the samples.

The carbon to nitrogen results that have been received from and tested by Bemlab could have not been accurate. There could have been a delay in postage that resulted in VWA decomposing to a large extent before it was being tested. Furthermore, the percentages were small thus a two percent difference translates to a change by a factor of 5. The same phenomena did not reflect in the mixes. The RI_7 and C/N values for VWB both seem to be noticeably larger than all the other substrates.

The bar graph below was plotted as to more easily illustrate the nature of the RI_7 readings. It is also more easily comparable. The standard deviation can also be put into context and compared.

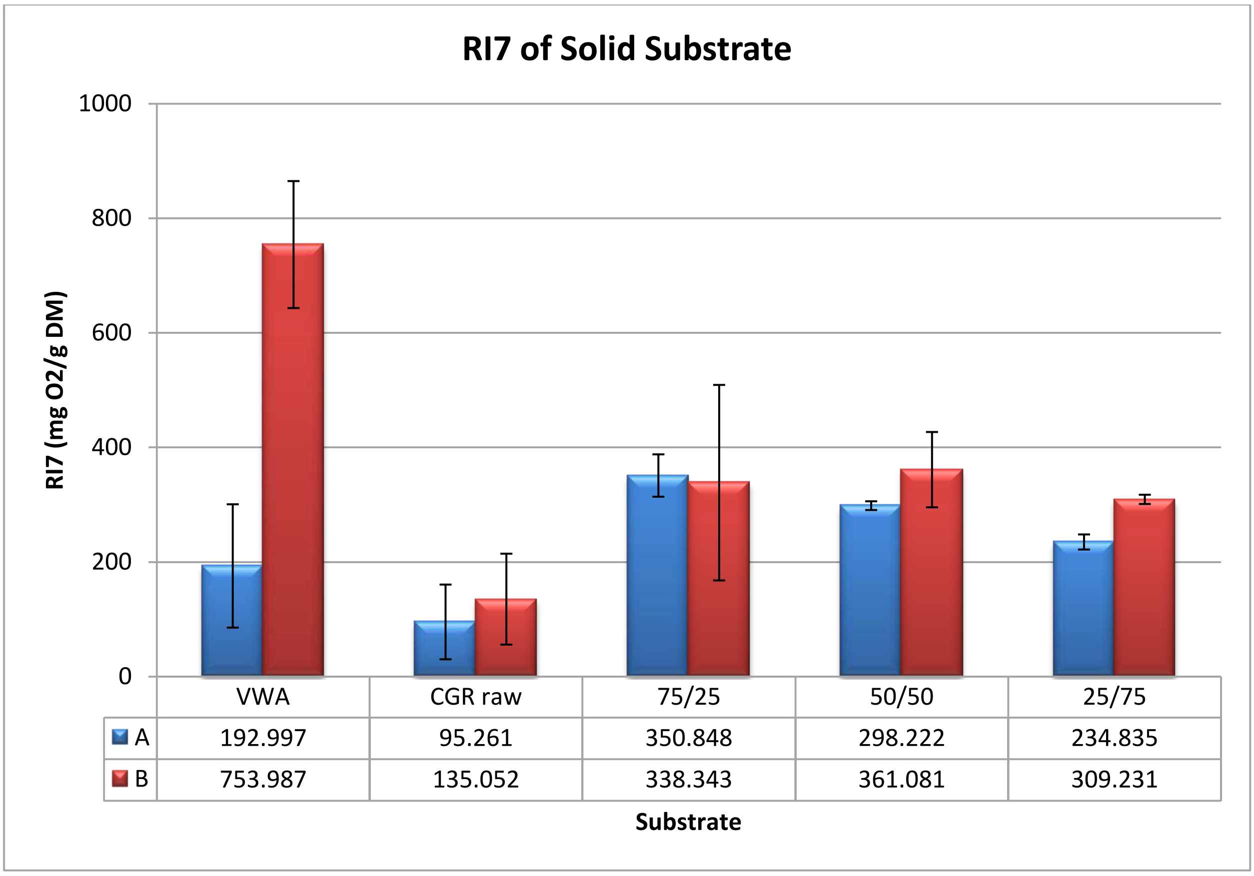


Figure 4-1 Bar graph summarizing all RI7 characterisation data

Respiration Index at seven days or RI_7 (refer to section 2.6.6 for explanation and 3.3 for method).

RI_7 was higher for vegetable waste as compared to CGR_{RAW}. This was further proved when a pattern emerges when the mixes were taken into account. The more vegetable waste in the mix, the higher the RI_7, and the more the biodegradability; therefore, showing more potential for a successful substrate for the denitrification of leachate.

Vegetable waste has carbon which was readily available and a high carbon nitrogen ratio (C/N). CGR_{RAW} has lower moisture content, as well as a relatively high level of carbon. The carbon, however, was not as readily available as vegetable waste, as displayed by the RI_7 test. It was clear that the addition of vegetable waste to the CGR_{RAW} improves the biodegradability, evident in the RI_7 test. From previous experience, CGR_{RAW} takes a few days to decompose after which the carbon begins to be more readily available.

In some results the standard deviation was very large. This means that results were not similar as to be absolutely sure of the accuracy of the result (as $p>0.05$ which is usually used to determine if results were statistically acceptable but due to the lack of uniformity in results which was due to the unstable nature of the substrate, these results were accepted). This could be due to human error or the method not being applied correctly. Human error could always occur in methods used to determine results; however, the disparities would be small in these circumstances. It was also sure that the correct method was repeated, thus the inaccuracy had to occur in some other manner. It was noticed that the solid sample used in the tests was not homogenous as the vegetables could not be made too small because it would then soon become a liquid sample, due to the quick degradation that occurs.

There were a limited number of repeat tests that could be performed at one time and, as the degradation rate was rapid, there was a limited time for the tests to be concluded. In this case repeat tests are a luxury that would be beneficial, as it would reduce the random error; however, it was most probable that the result and standard deviation would remain similar. A high standard deviation (maximum 68%) was expected as the maximum in a similar experiment by Sawyerr (2011) was 42%.

The vegetable waste was unique to what has been tested before as the amount of readily available carbon allows the present bacteria to work faster. As a result of these RI_7 results, theoretically, the denitrification should take place at a more rapid rate than previously seen from other substrates.

4.4. Characterisation of Eluate

The following table shows a compilation of results determined by doing liquid lab tests to characterise Eluate. The Eluate was extracted from a flask which contained the solid substrate which was left to mix with distilled water for 24 hours. The Mariannhill Landfill Leachate was included in this table for comparison purposes.

Table 4-4 Characterisation of Eluate substrate

Eluate Characterisation							
Substrate/Test	TS (g/l)	VS (g/l)	pH	COD (mg/l)	BOD5 (mg/l)	NH3-N (mg/l)	NOx-N (mg/l)
VW A	40.28±1.09	32.86±0.98	4.30	44767.1±5882.26	979.67	0.00	301.47
VW B	50.23±5.36	36.30±5.76	3.96	46582.54±71.46	1040.33	356.07	161.47
CGR A	7.08±0.04	4.15±0.01	6.64	4291.04±285.86	897.67	29.87	49.93
CGR B	5.14±0.05	2.82±0.02	6.23	3053.24±515.34	1514.33	49.00	36.40
75/25 A	30.23±6.47	25.59±3.35	4.36	24756.00±535.98	1221.67	0.00	193.20
75/25 B	28.80±0.48	21.97±0.29	3.85	32100.28±189.08	1257.33	218.40	139.07
50/50 A	17.47±0.34	12.305±0.335	4.89	18463.85±4737.05	1421.33	0.00	120.87
50/50 B	11.85±0.10	7.97±0.13	4.17	11965.40±397.90	1054.33	102.20	75.13
25/75 A	9.64 ±0.02	5.78±0.02	6.13	12460.52±4580.42	1817.00	33.13	51.33
25/75 B	13.78 ±0.04	8.04±0.04	4.76	10933.90±71.46	1204.00	77.00	46.20
MLS	13.44±0.01	3.78±0.87	7.58	7468.06±257.67	203.33	10.73	816.20

There was a fair amount of solid particles contained within the vegetable waste eluate as compared to CGR_{RAW}. It was also observed that the particles were small, to the extent that fines pass through a 63 micron filter. This was expected as vegetables were softer than CGR_{RAW}, and it easily disperses in liquid. Vegetable waste, as expected, would cause an increased acidity in the eluate.

4.4.1. pH

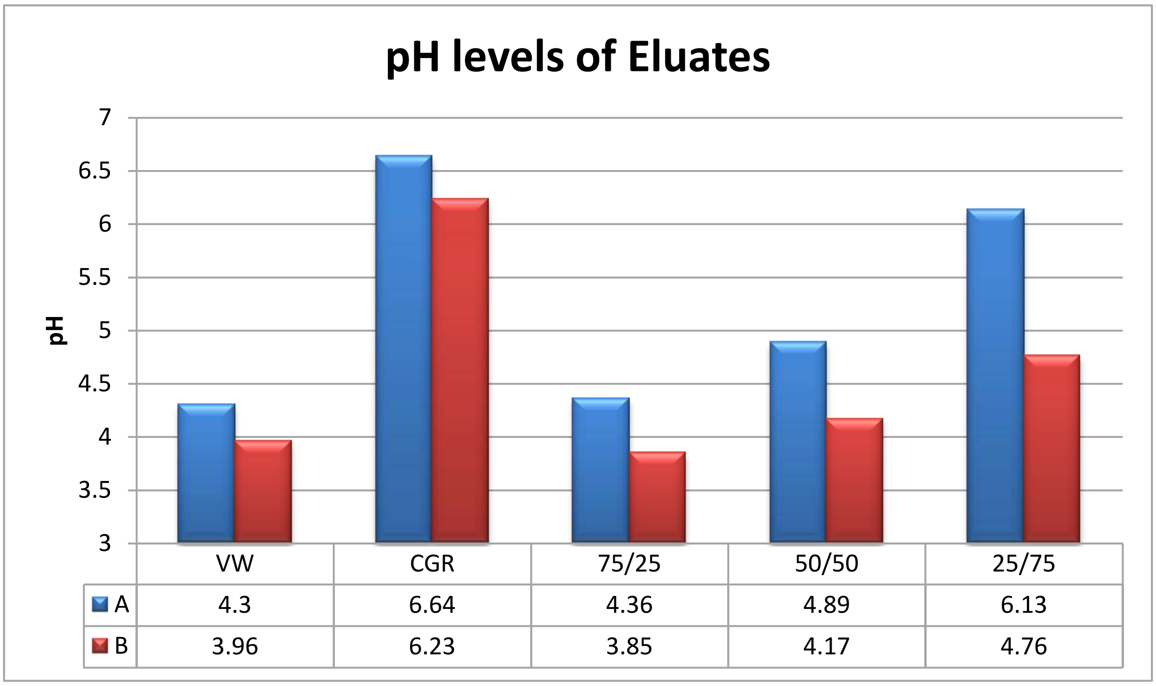


Figure 4-2 Graph of the pH levels in Eluates

A pattern can be identified in the pH results. As seen in the graph above, the more vegetable waste present, the lower the pH value, thus increasing the acidity in the mix. It has been shown that the pH range for the most optimum nitrate treatment was 6-8. Thus most of the eluates probably would not be in the best pH range for denitrification. The only pH level which was within the DWAF standards (5.5-9.5) was the CGR_{RAW}. Oddly 75/25B has an even lower pH than VWB. The prominent percentage in the 75/25 mix was vegetable waste, which then resulted in a lower acidity (denoted in Figure 4-2).

Standard deviations were not represented on the graph as they were too small to display on a graph of this scale.

4.4.2. COD

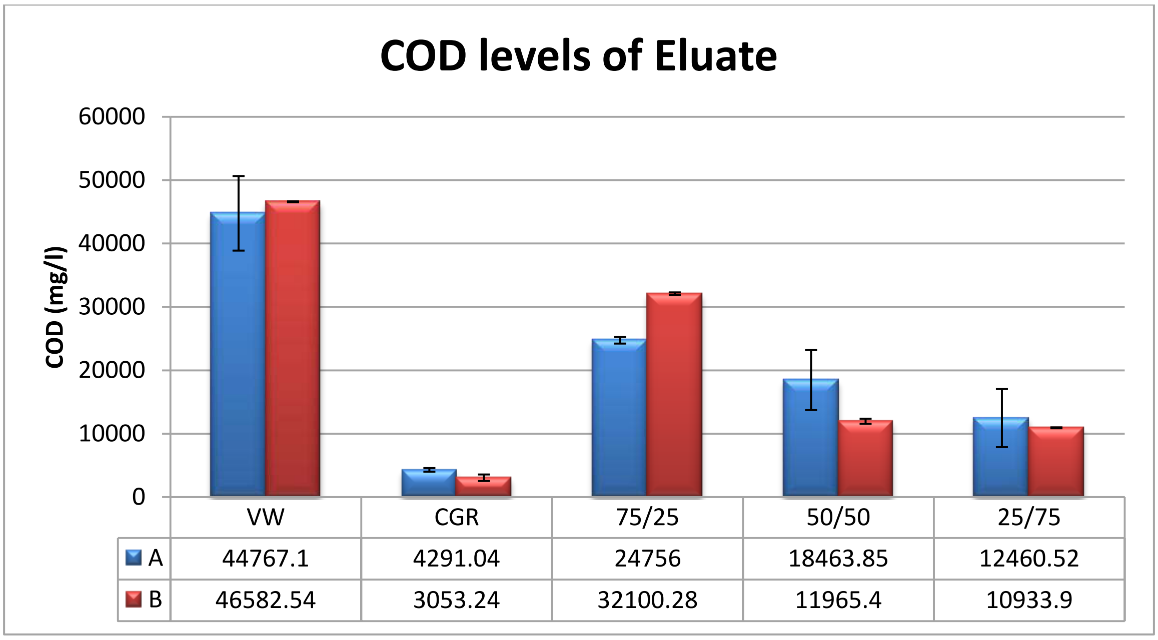
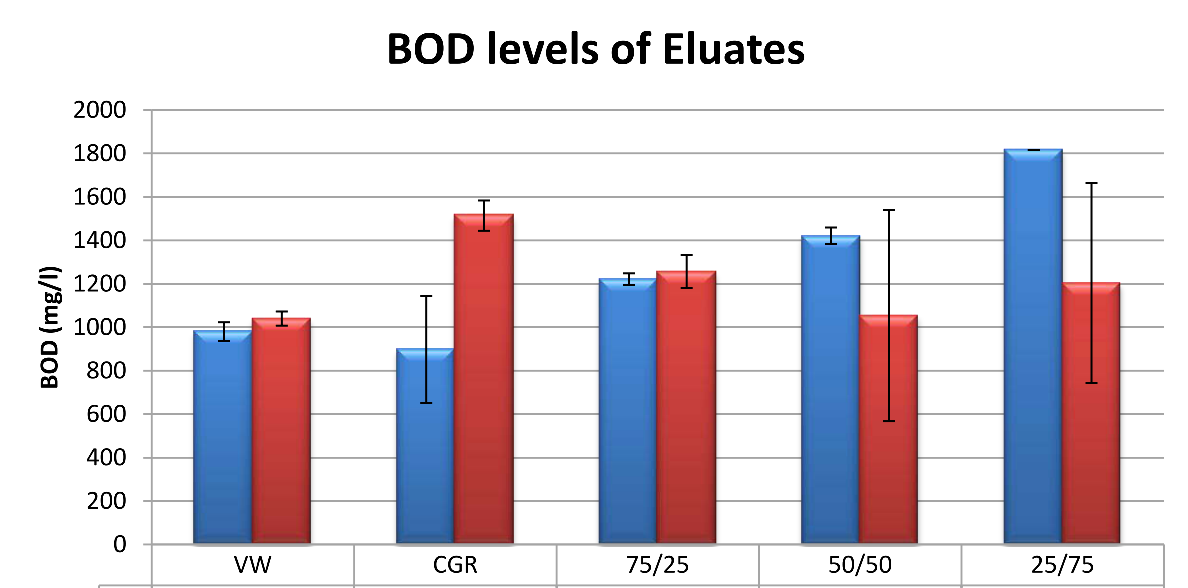


Figure 4-3 Graph of COD levels in substrate eluate

Chemical Oxygen Demand (COD) represents how much oxygen needs to be utilized in order to fully reduce the inorganic elements in the sample (react with oxygen to form a product). Once again, a similar pattern was prevalent in figure 4-3. The vegetable waste was the cause of much higher levels of COD. Even more noticeable was the levels of COD readings. The DWAF standard for COD was 75 mg/l as compared to the vegetable waste, which was roughly 45000 mg/l. All of the eluates of the various mixes have resulted in introducing high levels of COD.

These results give an indication that once the leachate was treated, the COD levels would not be at an acceptable level for discharge, according to DWAF (Department of Water Affairs, 2010). Vegetable waste has added a lot of COD to the eluate. This was expected as the vegetable waste easily breaks down and allowed large numbers of particles be transferred to the eluate.

4.4.3. BOD_5



	VW	CGR	75/25	50/50	25/75
A	979.67	897.67	1221.67	1421.33	1817
B	1040.33	1514.33	1257.33	1054.33	1204

Figure 4-4 Graph illustrating BOD characterisation results of eluates

The higher the Biological Oxygen Demand after five days (BOD_5) reading for the sample, the more o ygen used to decompose the samp e's organic e ements in five days. In Figure 4-4, experiment A has shown that combining the VW and CGR_{RAW} has increased the BOD levels. Substrates in experiment A have a pattern suggesting (with regards to mixes) the more CGR_{RAW} present in the mix, the higher the BOD level. However, this pattern was not adhered to either when the CGR_{RAW} or the experiment B results were taken into account. The inverse pattern was more plausible for experiment B. Perhaps when these substrates were mixed the resulted was high BOD levels. The BOD tests were done in triplicate and results were repeated if there was a discrepancy. There was no maximum BOD level for discharge in the DWAF standards.

4.4.4. Ammonia

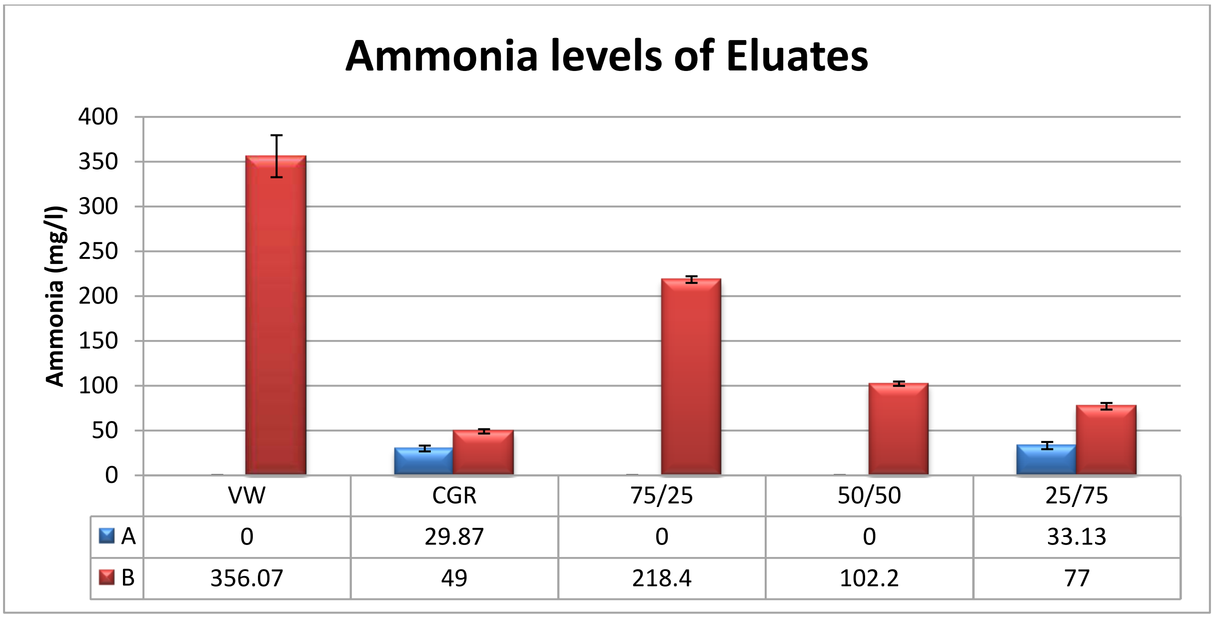


Figure 4-5 Graph of Ammonia levels from the substrate Eluate

Experiment A illustrates that the particular sample of vegetable waste does not cause ammonia levels to rise in the eluate. The ammonia content was attributed to the CGR_{RAW}, as the mixes with 50% of vegetable waste or more, in experiment A, had no concentrations of ammonia. VWA has caused nitrate levels to rise due to bioleaching. As NH_3 converts to NO_2 then the NO_2 was treated to N_2. This lowers how efficient the substrate would be in treating leachate.

Vegetable waste in experiment B (VWB) introduces very high amounts of ammonia to the Eluate. The mixes suggest a pattern, whereby the ammonia levels reduce, as the amount of vegetable waste in the mix reduces. The CGR_{RAW} also has a higher level of ammonia. Bioleaching should not occur in the VWB batch test as it does not convert the ammonia to nitrates (as seen in Figure 4-5). The ammonia results were completely different between experiment A and B.

4.4.5. NO_X

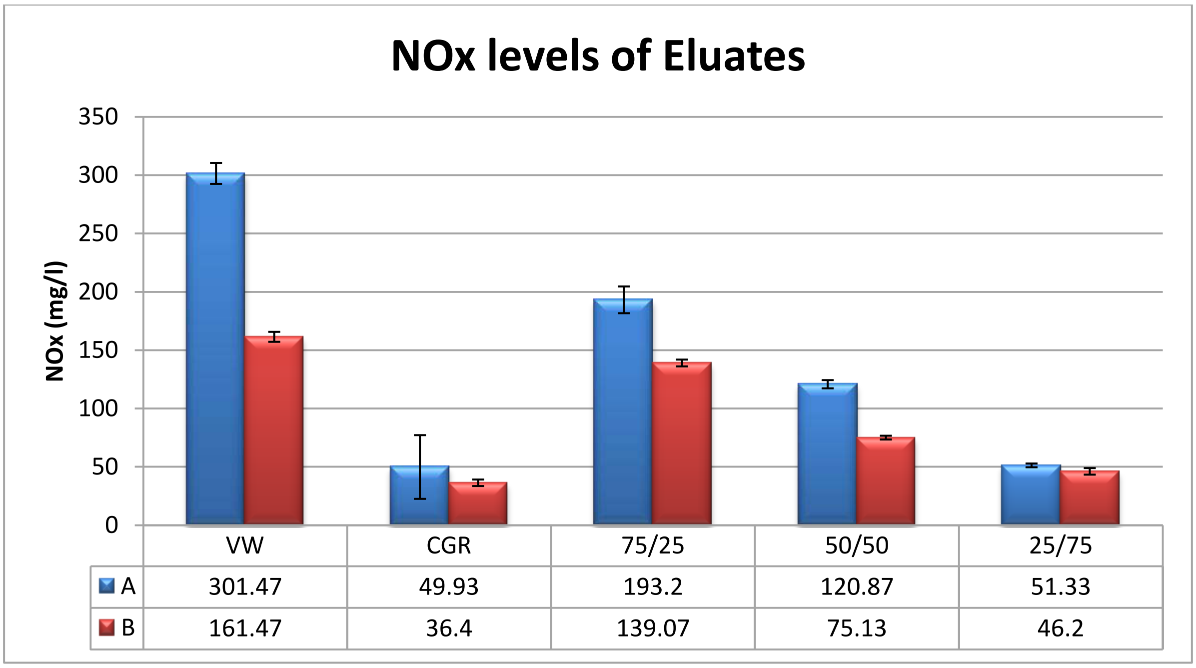


Figure 4-6 Graph of NO_X levels of substrate eluate

NO_X is the amount of total nitrogen products. The NO_X levels tested in eluate were an indication of the amount of nitrogen compounds which were introduced by the substrate in question to the liquid which it was testing. The above graph shows vegetable waste introduces more nitrogen compounds than CGR. VWA also introduced more NO_X than VWB. This was evident in the mixes. As the more vegetable waste was in the mix the higher the NO_X test readings were. All substrates cause NO_X levels to rise higher than the DWAF discharge standards of 15 mg/l. The best substrates in this regard were CGR and the 25/75 mix.

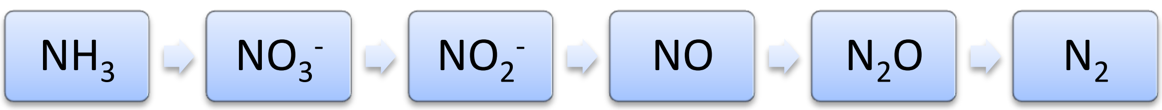


Figure 4-7 The process that occured in VWA batches (Nitrogen Cycle) (Zondi, 2011)

4.5. Batch Experiment results

4.5.1. Introduction

Nitrates levels were tested for batch tests, which were under anaerobic conditions. The results were recorded, plotted together with the respective mixes and the data was analysed to identify any patterns that emerged.

The kinetics of the denitrification processes were also shown below. The nitrate level of the Mariannhill Landfill Leachate (which was the input liquid) was approximately 4000mg/l (due to the testing method). Most readings, however, begin at less than 4000mg/l. This was due to the vegetable waste having a high percentage of moisture content. The leachate was then inadvertently diluted by the moisture which was amongst the substrate. It was also a combination of dilution and absorbance of the nitrates by the substrate, which was the case with the CGR_{RAW}. The leachate was monitored and even months after the experiments had concluded the nitrate reading remained the same.

Equations for the lines of best fit were derived by assuming a second order polynomial would be the best fit (this can be noticed visually).

The equation $y=ax^2+bx+c$ was used and then a, b and c where solved for, by using $x=0$ ($y=y_0$) and $y=0$ ($x=x_{end}$) and any other set of co-ordinates that make the graph fit the best (usua y in the midd e va ues and done by tria). This was done as the 'E ce best fit ine' was not fitting as required.

Experiment A and B were done with substrates, which where sampled at different times, thus the substrates were open to some variation. The nitrate removal results were plotted on the same set of axis to confirm results as well as to make it easier to identify any patterns that may emerge.

4.5.2. Vegetable waste

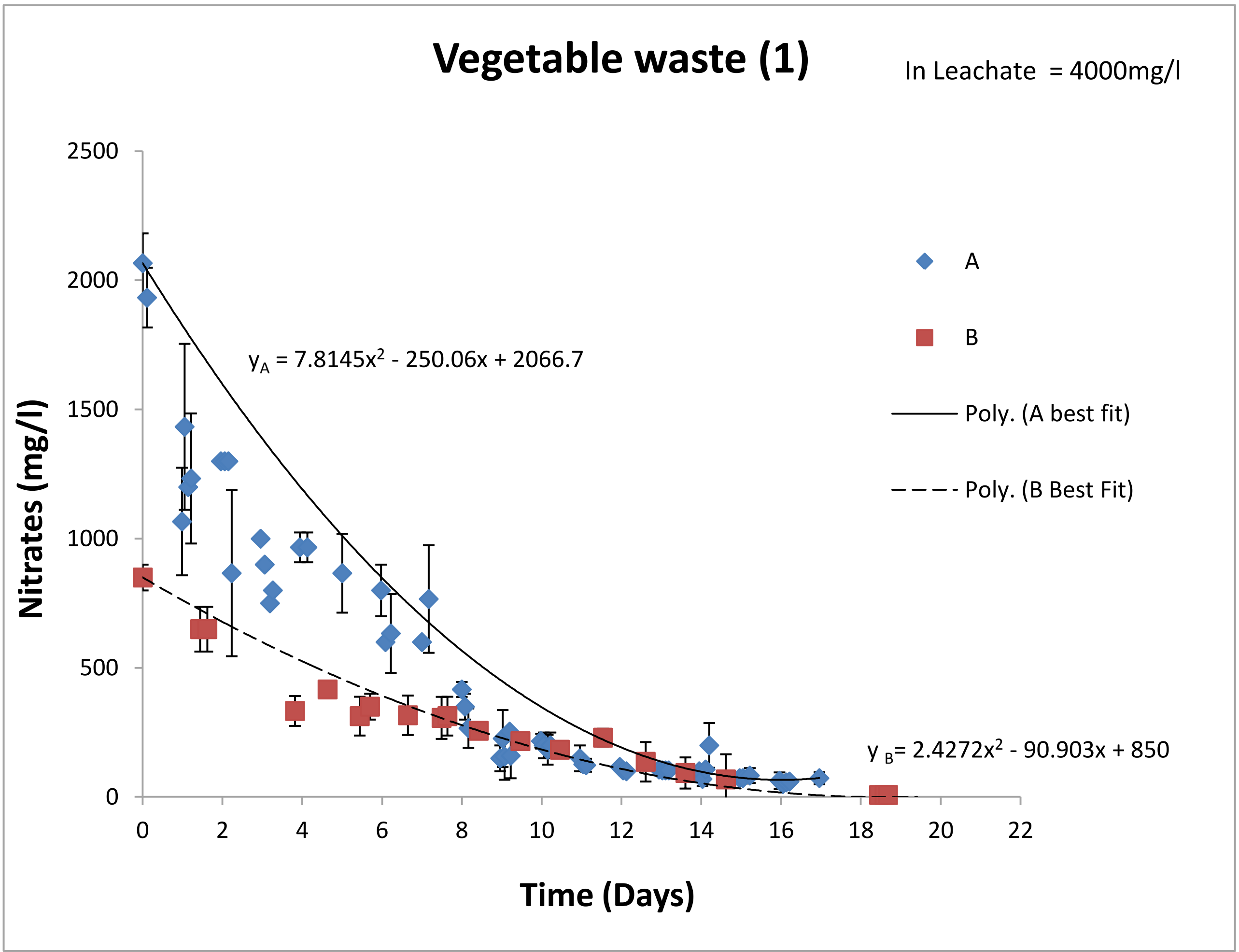


Figure 4-8 Graph of Vegetable waste performance as a substrate

Table 4-5 Output characterisation results of Vegetable waste Batch tests

Vegetable waste Eluate Batch tests					
Substrate/Test	pH	COD (mg/l)	BOD_5 (mg/l)	NH_3-N (mg/l)	NO_x-N (mg/l)
VW A	4.11	74568.85	445.33	0.00	628.60
VW B	4.39	56938.80	324.33	655.67	603.87

Experiment A was stopped before the nitrates were treaded completely. This was enforced as the lab had to be shut down for two weeks. It was decided not to leave the samples unsupervised for 2 weeks but to stop the experiment so that the necessary test could be done. The probable result of leaving the experiment running was the nitrate levels would be found to be 0 mg/l. However, the time at which the samples attained 0 mg/l nitrates would not be known.

The graph shows the nitrate level halved in the initial 4 days and the next 4 days it halved again. Thus the treatment process follows a second order polynomial. The values fluctuated as the system attempts to acclimatise. Acclimatisation in this sense refers to the system within the batch bottle attempting to find a balance to the rate of denitrification, as the ammonia was converting to nitrates; nitrates convert to nitrites which ultimately convert to nitrogen gas.

Thereafter, nitrate readings stabilise. Bioleaching contributed to the fluctuations (as seen in Appendix B), where the nitrate levels in the control increased from 0-1000mg/l. The substrate VWA was versatile enough to treat the nitrates. However, there was no ammonia from the eluate characterisation tests but if the ammonia results of the Mariannhill leachate were considered, then this leads to the deduction that VWA treated the ammonia (by converting it to nitrates) then concurrently treated nitrates. The ammonia concentration was fully eradicated where it was 10.73mg/l. This was acceptable according to the DWAF standards of 3mg/l of ammonia.

Total denitrification for VWA was not reached but was stopped at an average of 73.3mg/l, which had a higher rate of removal than VWB. This was contrary to the characterisation test results as VWB exemplified a better capacity as a carbon source, referring to a much higher RI_7 reading (754mg/l), carbon content (41.8%) and carbon to nitrogen ratio (82).

Experiment B was conducted with VWB which, at the time of setting up the experiment, seemed very moist. This reflects in the results as the time equal to zero reading was an average of 850mg/l as to the actual leachate reading of 4000mg/l. There was a similar acclimatisation but on a smaller scale. VWB does not treat ammonia. Rather, according to the eluate characterisation and batch results, VWB caused ammonia concentrations to rise to very high levels (10.73-655.67mg/l). VWB had not bioleached nitrates into the liquid as much as seen by the VWA (see in Appendix B), where the nitrates increased from a level of 0-18mg/l. Full denitrification of all three bottles was attained after 19.4 days.

The pH readings for both vegetable waste samples were very low. Denitrification had occurred but not at the optimal as the pH range of 6-8, thus the rate of denitrification would be much faster if using the vegetable waste as a substrate had not resulted in the batch becoming acidic to such an extent. (Plüg, 2008)

The Chemical oxygen demand (COD) results were very high. It has increased from 7468mg/l in the Mariannhill landfill leachate to more than 55000mg/l from the batches. This was beyond the acceptable discharge standards set by DAWF (75mg/l).

The NO_x results were also extremely high. Although all the nitrates have been removed, as well as all the ammonia for VWA, the NO_x results were very high for both samples of vegetable waste. The NO_x had decreased from 816.20mg/l to the region of 620mg/l. This was not an acceptable change as it was not close to being within the DWAF discharge standards of 15mg/l.

The batch eluate resulting from the batch experiment has fines from the vegetable waste suspended in the liquid. The fines were not easily removed by filtering. However, they do settle to the bottom easily, if left to be static overnight.

Vegetable waste does treat nitrates from Mariannhill landfill leachate. However, it was not as efficient as the known substrates. The other characteristics would mostly be governed by the sample taken, which can vary. The pH, COD, NH_3 and NO_x concentrations fall far from the DWAF standards. Furthermore, it has resulted in the leachate being more of a pollutant to the environment. The obvious conclusion was that 100% vegetable waste was not suitable to treat nitrates in leachate. It can be used if there is no better option but then it is essential that other polishing processes would be applied thereafter.

4.5.3. CGR_{RAW}

The batch tests have been done many times with CGR_{RAW} as substrate. In this experiment it was done once again to compare as the best substrate and to identify if the mixes were improvements on a substrate that has been considered a viable and feasible carbon source for treating nitrates.

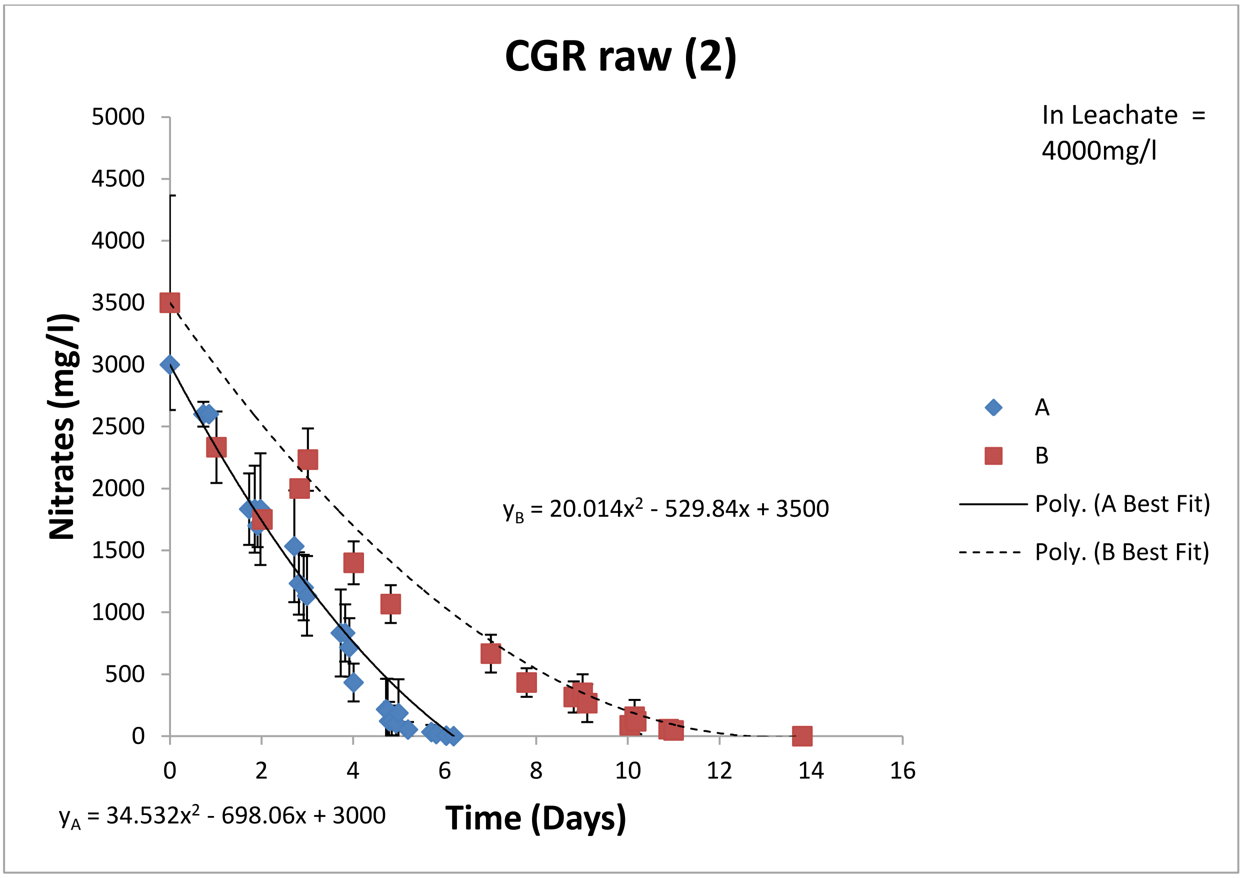


Figure 4-9 Graph of CGR_{RAW} performance as a substrate

Table 4-6 Output characterisation results of CGR_{RAW} Batch tests

CGR_{RAW} Eluate Batch tests					
Substrate/Test	pH	COD (mg/l)	BOD_5 (mg/l)	NH_3-N (mg/l)	NO_x-N (mg/l)
CGRA	8.07	8454.86	1036.67	49.47	45.73
CGRB	8.17	12408.95	416.67	141.87	118.53

The plots of CGRB show an acclimatisation period exhibited by the fluctuations in nitrate concentrations. The initial readings vary at the t=0. The best fit line was easily noticed to be a second order polynomial as both show patterns of starting with high rates of denitrification, thereafter the rate diminishes until there was no concentration of nitrate.

The rate of CGRA was much higher than CGRB resulting in it totally denitrified in less than half the time taken for CGRB. Yet CGRB has a higher RI_7, carbon content and carbon nitrogen ratio. This was because the BOD_5 in the batch was higher. This means that denitrifying bacteria were more prevalent in the CGRA experiment and that was the reason for A to fully denitrify before B.

Both samples had a pH closer to being within the optimal pH range for denitrification. The pH levels were also within the DWAF discharge standards, unlike the COD levels, which were not as high as the vegetable waste but not at an acceptable level. The ammonia and NO_x levels were lower for CGRA but both were not within the standards. The NO_x concentration had been reduced from the initial level of 816.20mg/l. This CGR_{RAW} had been tested thoroughly. These results were similar to previous experiments by Plüg (Plüg, 2008) and Zondi (Zondi, 2011).

These results, although showing improvements in most parameters, still enforce that further treatment could be required for the output to be acceptable according to the DWAF discharge standards.

4.5.4. 75% vegetable waste, 25% CGR_{RAW} mix substrate

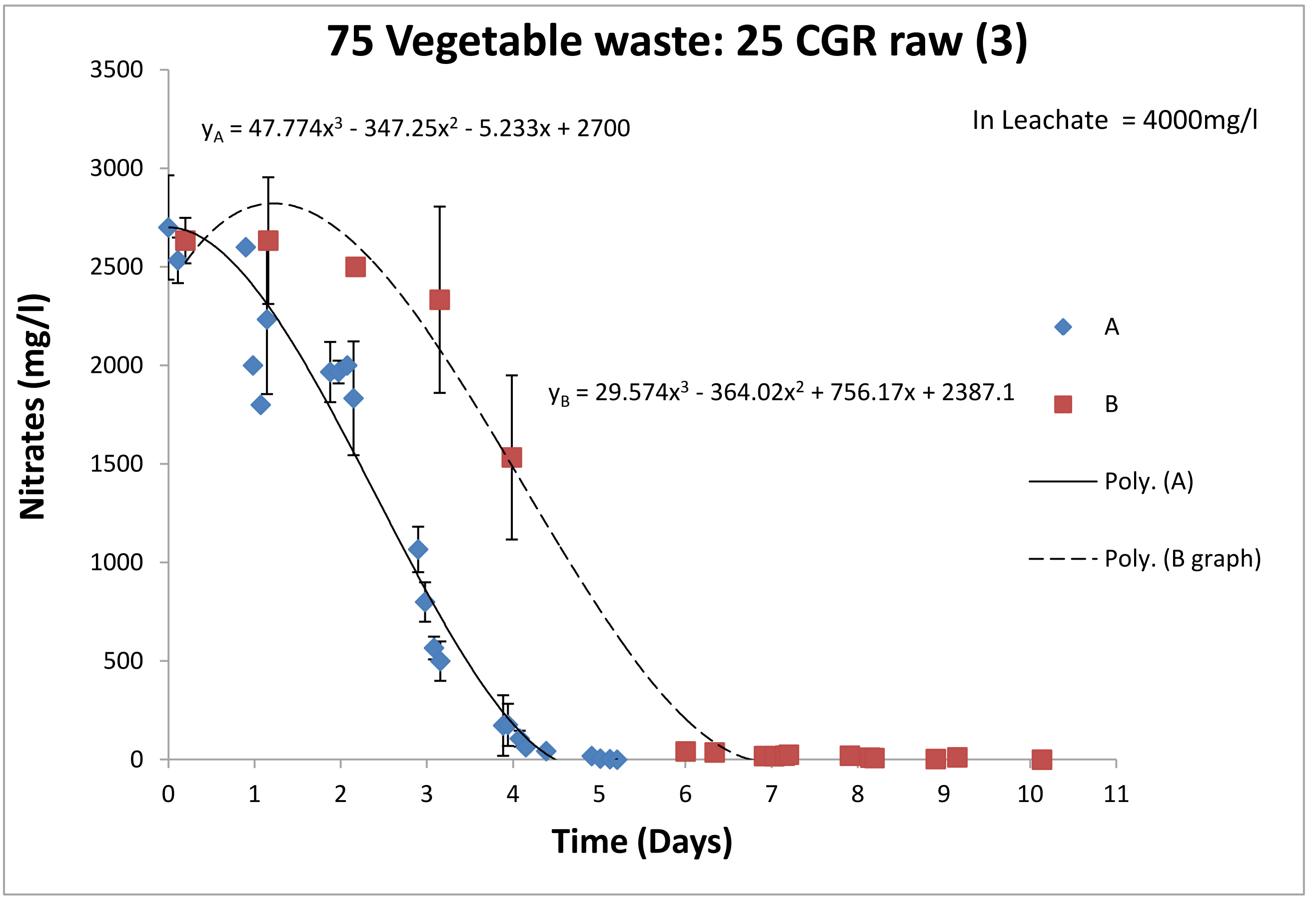


Figure 4-10 Graph of 75/25 performance as a substrate

Table 4-7 Output characterisation results of 75/25 mix Batch tests

75/25 mix Eluate Batch tests					
Substrate/Test	pH	COD (mg/l)	BOD_5 (mg/l)	NH_3-N (mg/l)	NO_x-N (mg/l)
75/25 A	6.44	24609.87	1617.33	406.00	555.33
75/25 B	6.12	26502.67	1467.67	99.40	597.33

The trends of these plots were different to the others in that the nitrate level does not change by much initially (within a day or two), thereafter, the rate of denitrification increased for around three days and subsequently began to asymptotically approach zero. This was a similar shape of a third order polynomial. The 75/25A plots rise and fall in the initial 2 days, which was indicative of acclimatisation. The best fit lines above were plotted by Microsoft Excel.

The only acceptable parameters according to DWAF were nitrate and pH.

The time taken for 75/25A to completely treat nitrates was 5.2 days where 75/25B takes twice as long. However, 75/25B tends to zero after 6 days. This was because the batch results show pH at a more conducive level for denitrification. Furthermore, a higher BOD_5 implies that more bacteria were available to treat nitrates. The COD readings were lower for 75/25B, which indicates that more carbon that was readily available in the batches was taken advantage of.

Ammonia levels were much lower for 75/25B. The nitrates levels remain parallel with the x-axis and took 4 more days to be treated. The readings for the last 4 were also positive for nitrites (NO_2^-). This usually indicates that the substrate was treating nitrate at a very fast rate, as nitrite was more easily converted into N_2. Thus if there was nitrites present, then nitrites (NO_2) were being produced from nitrates (NO_3) faster than it can be treated. This does not correspond with the asymptotic shape of the graph. Therefore the 75/25B substrate was treating nitrates as fast as it was emanating due to bioleaching and this was done at a fast rate due to the presence of nitrite.

When comparing COD, ammonia and NO_x results of experiments A and B, both sets of readings were similar, very high and not within DWAF standards for discharge.

4.5.5. 50% vegetable waste, 50% CGR_{RAW} mix substrate

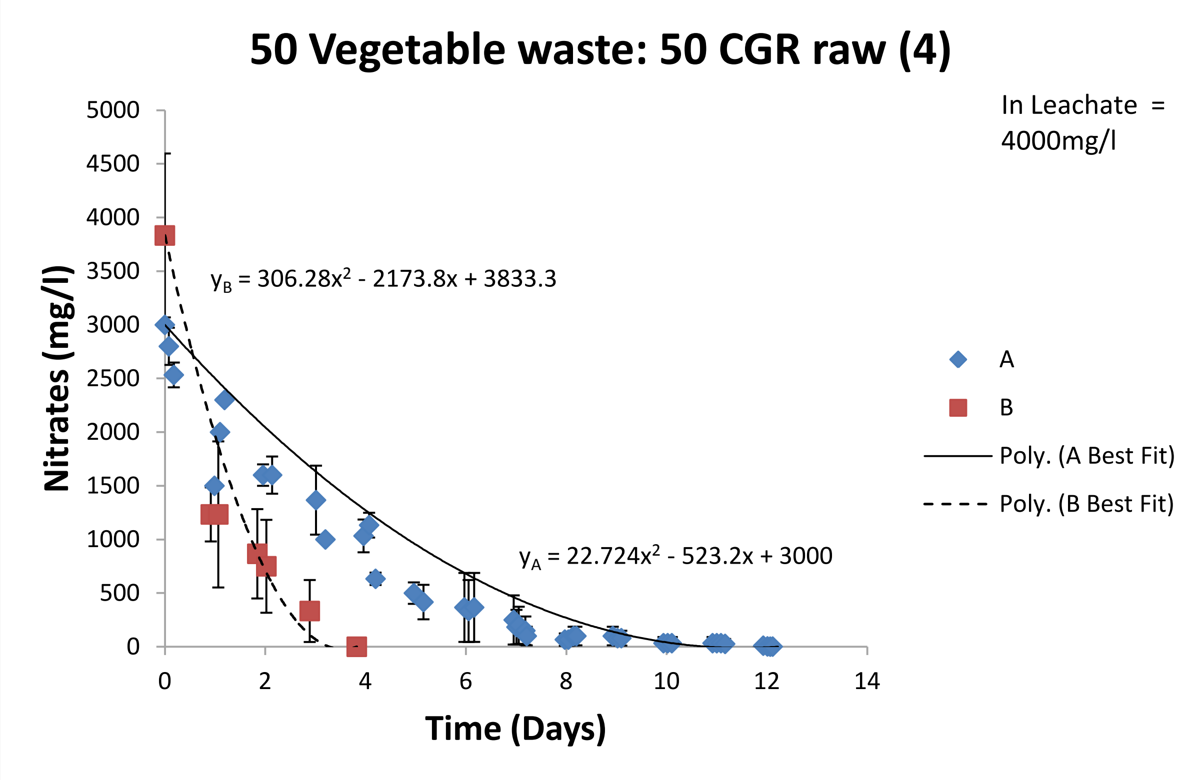


Figure 4-11 Graph of 50/50 performance as a substrate

Table 4-8 Output characterisation results of 50/50 mix Batch tests

50/50 mix Eluate Batch tests					
Substrate/Test	pH	COD (mg/l)	BOD_5 (mg/l)	NH_3-N (mg/l)	NO_x-N (mg/l)
50/50 A	6.71	26930.75	3598.67	400.87	475.53
50/50 B	7.80	10249.67	1475.00	146.07	164.73

The plots clearly suggest that a second order polynomial would be the line of best fit. Both experiments start with high levels of nitrate but 50/50B had an initial reading that was higher than the initial reading of 50/50A; thereafter, the nitrate readings for 50/50B plummet. Nitrites being present were symptomatic of the rate of denitrification being vigorous.

The nitrates were fully treated in less than 4 days for 50/50B and it took three times longer for 50/50A to be treated. It was noticed that the nitrate readings for 50/50B were straightforward, unlike the 50/50A readings where the nitrate readings fluctuate, at times to a difference of 500mg/l. This was due to acclimatisation in the batch.

The 50/50B substrate was so effective in treating nitrates as the RI_7 reading was higher than 50/50A (by 62mg/l). Although the BOD_5 was lower, the COD readings were also lower for 50/50B. This indicates that more carbon, that was readily available in the batches, was made use of.

The both pH measurements were within the optimum range and within the standards set out by the DWAF. However, COD, ammonia and NO_x did not conform to the DWAF discharge standards.

4.5.6. 25% vegetable waste, 75% CGR_{RAW} mix substrate

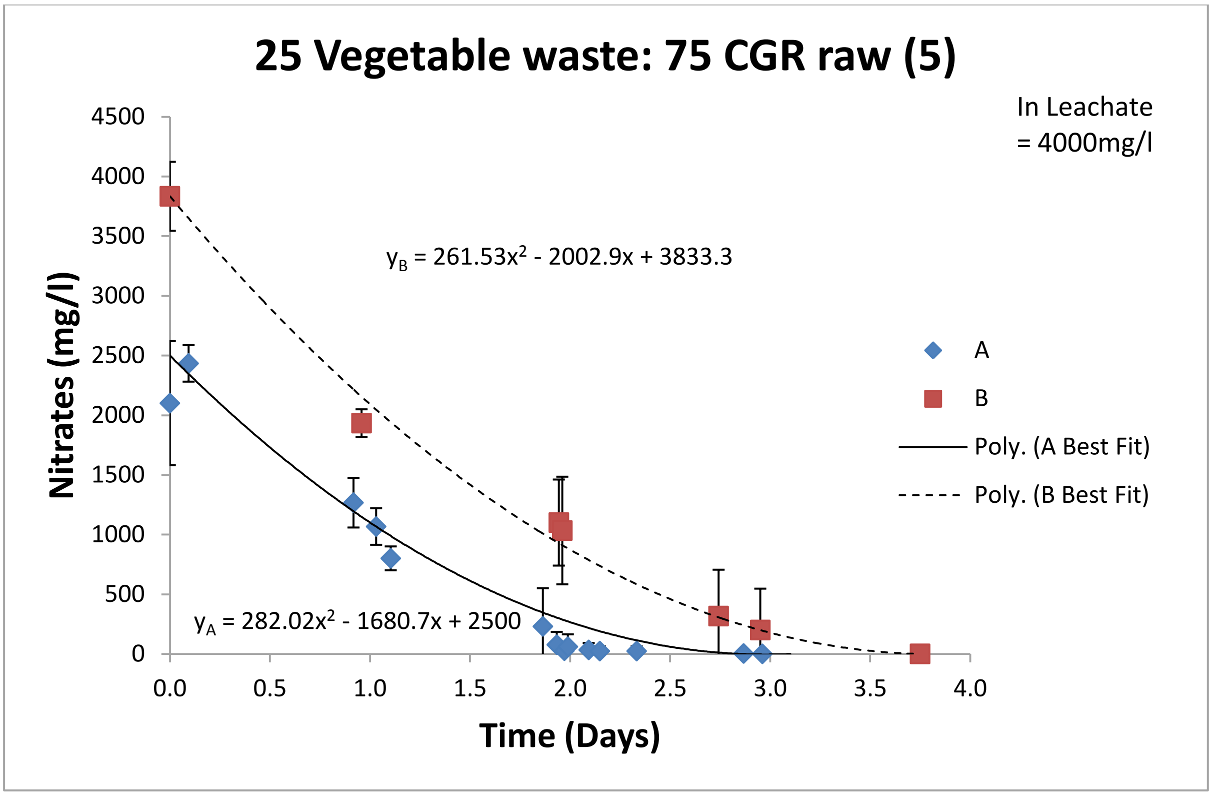


Figure 4-12 Graph of 25/75 performance as a substrate

Table 4-9 Output characterisation results of 25/75 mix Batch tests

25/75 mix Eluate Batch tests					
Substrate/Test	pH	COD (mg/l)	BOD5 (mg/l)	NH3-N (mg/l)	NOx-N (mg/l)
25/75 A	7.84	24085.53	1981.67	83.07	88.67
25/75 B	8.06	6409.05	965.33	76.53	99.40

The initial nitrate concentration of the batch with the substrate 25/75A was 2100 mg/l, which was less than 25/75B (T_0 = 3833mg/l). The plots were easily identified as second order polynomials.

It seems that readings were not taken regularly but the denitrification processes was taking place at such a high pace that the readings could not be taken fast enough to fill the spaces without readings. However, there was not more than a day that readings have not been taken and the time plotted was on a large scale. The time at which zero nitrates were achieved was accurately found as nitrate levels were watched very carefully to identify T_{end}.

Both sets of 25/75 batches have very fast denitrification rates as seen by the equations. Once again, at denitrification rates as high as these, nitrites were present. The nitrates were fully treated by 25/75A in 3.1 days and in 3.75 days by 25/75B. The experiment that ended first was using 25/75A but the 25/75B substrate treated faster as it had a steeper gradient.

Both substrates were very good denitrifying substrates. The 25/75A mix was effective as it had a high BOD_5 and high carbon content. The 25/75B was effective as it had a high RI_7 level and carbon content. The BOD_5 level was also low, which means it has been utilising readily available carbon.

Both batch eluates have acceptable pH values with regards to optimising denitrification and complying with the DWAF discharge standards. The other characteristics such as COD, ammonia and NO_x did not comply.

4.6. Total time to Denitrify

The following graph was plotted such that the best substrate can be identified, with respect to denitifying leachate.

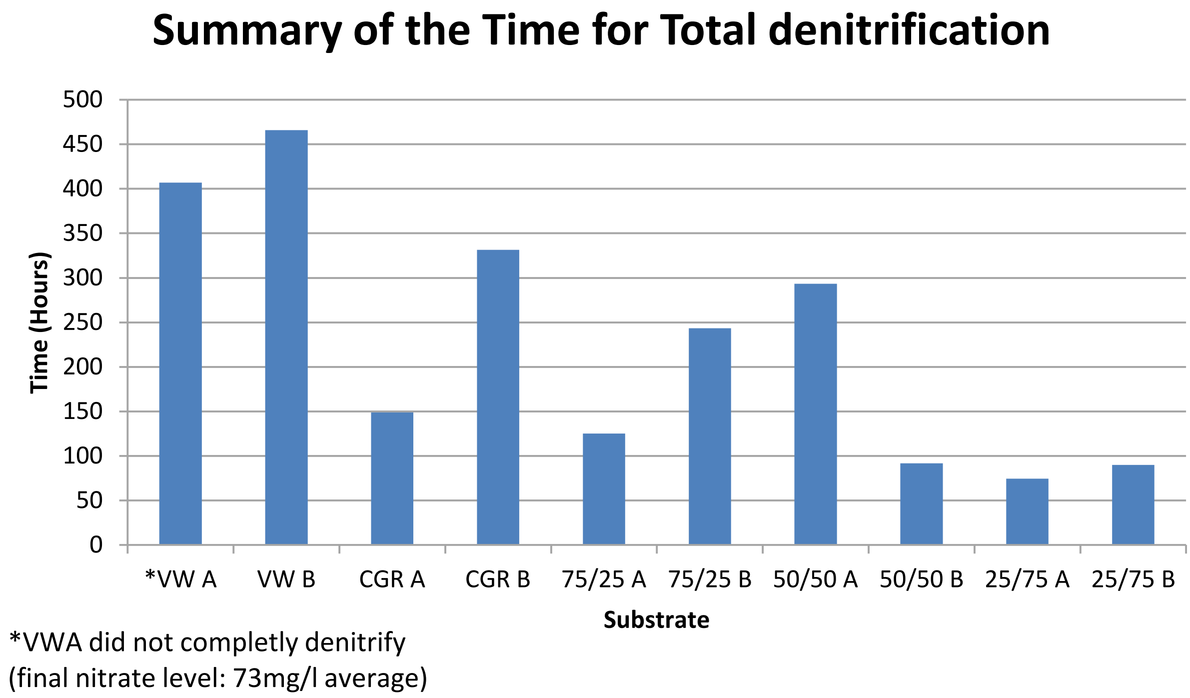


Figure 4-13 Graph of Total Time taken to denitrify

Vegetable waste took the most time to reach T_{end}. The carbon content and RI_7 were indicators that vegetable waste could be a good denitrifying substrate; however, the rate was not as expected due to the very low pH and BOD_5.

Raw Commercial Garden Refuse had shown to be a better substrate than vegetable was but was not as fast as the mixes. The denitrification was delayed due to the lack of readily available carbon.

All the mixes show improvements to both the 100% CGR_{RAW} and Vegetable waste. The one exception was 50/50A. The 50/50 mix was very unpredictable, as it had not complied with a result that would be expected, which would be a T_{end} in between 75/25 and 25/75. The 50/50A was not an improvement on CGRA.

The 75/25A took half the time of 75/25B. All of the characterisation tests done before and after batches show that there was very little difference in each case. However, 75/25A usually had slightly more suited results for a substrate. Small advantages accumulated and it resulted in halving the time to reach T_{end} of 75/25B. The fastest to totally denitrify was the 25/75 mix. Both A and B reached T_{end} under 100 hours. Only 50/50B was the other substrate achieved that.

4.7. Batch Characterisation Results

The following graphs in section 4.7 have been included to ascertain whether the substrates in question were suitable to be used to treat nitrates, with respect to the other parameters that need to be adhered to. Hence, the most feasible substrate mix can be identified.

4.7.1. Batch pH Results

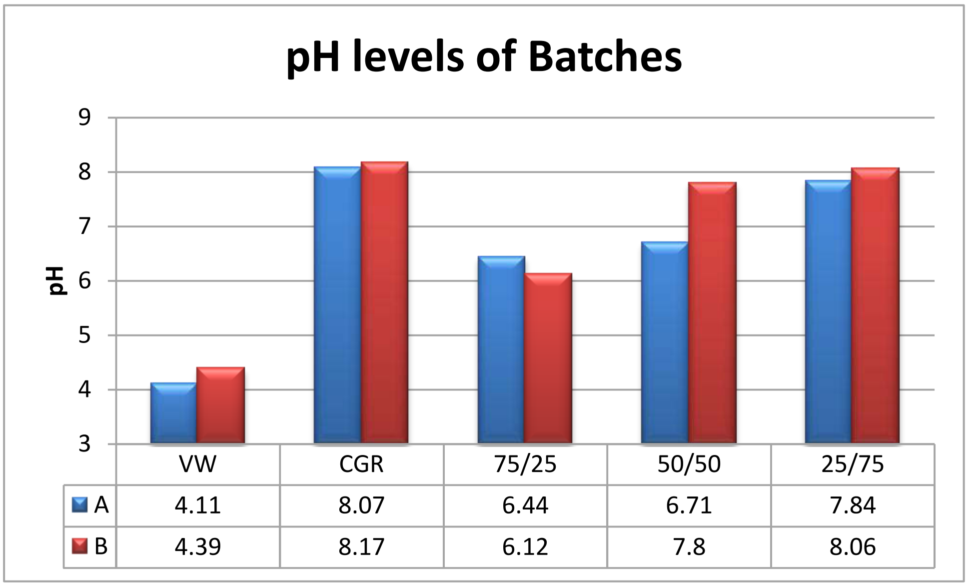


Figure 4-14 Graph plotted to compare pH levels in Batches

Vegetable waste (VW) pH readings were very low. This means the batch eluate was acidic. The pH levels for vegetable waste batch eluate were out of the optimal range for denitrification and the DWAF standards for discharge into a water body. All the other results were acceptable according to the DWAF discharge standards (5.5-9.5).

The correlation between pH and the rate of denitrification was affirmed as the batches with a pH within the 6-8 range treated nitrates more efficiently. The closer to the optimum range the pH was, the more the efficient the mix at treating nitrates. The only outlier was the 50/50A mix. The 50/50 mix, as stated before, was a very unpredictable substrate.

4.7.2. Batch BOD_5 Results

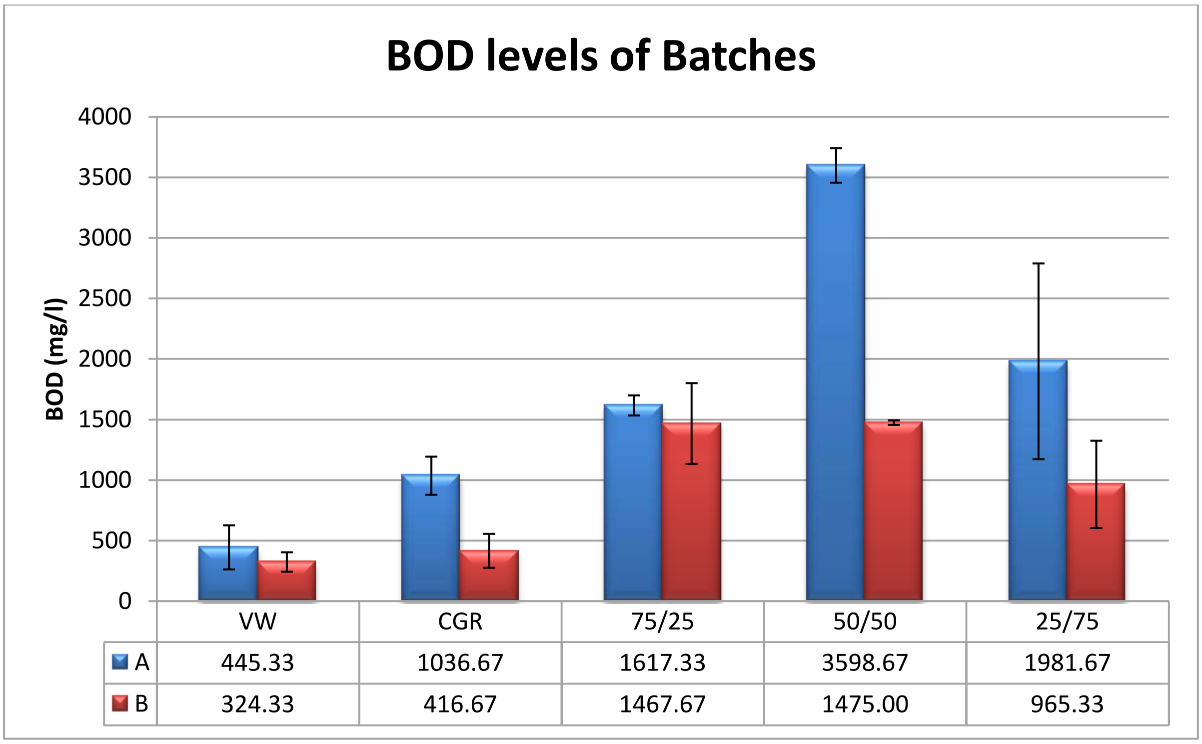


Figure 4-15 Graph plotted to compare BOD_5 levels in Batches

The Biological Oxygen Demand after 5 days (BOD_5) is a characterisation test that can be used to detect the amount of denitrifying bacteria in the sample. The higher the BOD reading the more denitrifying bacteria the more superior the substrate should be with regards to treating nitrates.

The vegetable waste had the least BOD, which was expected as it also took the longest to completely treat the nitrates. The 50/50A mix, which also took a long time to fully denitrify (12.2 days), had the highest BOD. The mix may have had an excess of bacteria. The mixes clearly had higher BOD_5 concentration levels. Each of the mixes had a higher level of BOD than its constituents, vegetable waste and CGR_{RAW} combined.

4.7.3. Batch COD Results

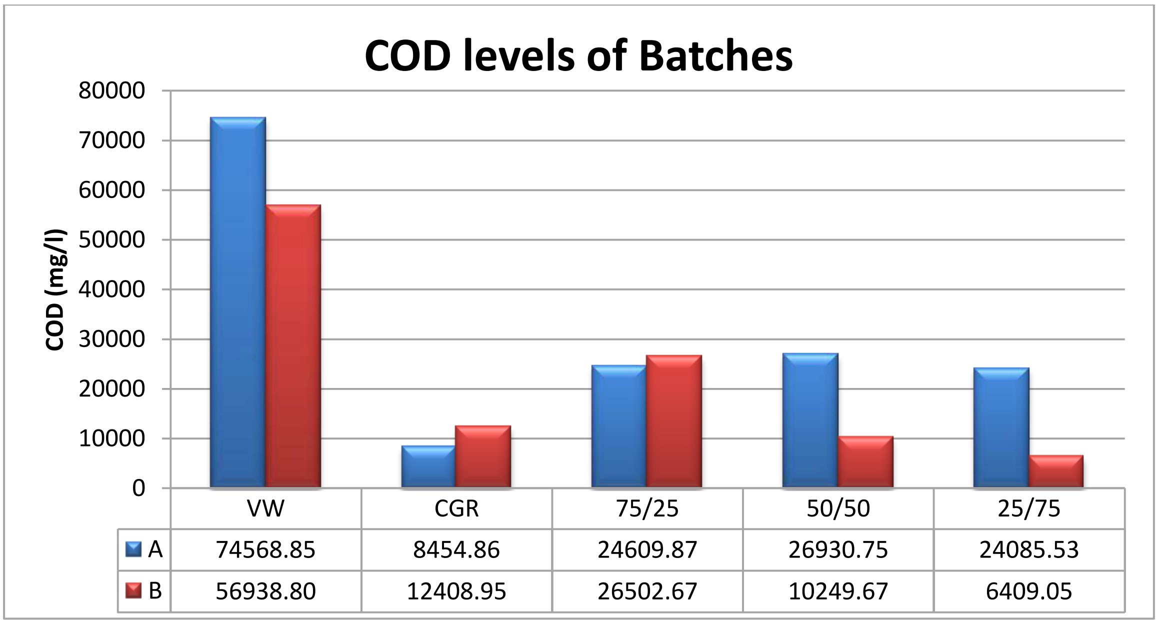


Figure 4-16 Graph plotted to compare COD levels in Batches

Chemical Oxygen Demand (COD) can be used as an indicator of the amount of easily available carbon. The higher the COD, the more the available carbon, the more potential the substrate has to treat nitrates but it is also an indicator that the available carbon is not being made full use of.

The perfect e amp e of a substrate's readi y avai ab e carbon not being made use of was vegetable waste. Vegetable waste had high levels of RI_7 and carbon content. Yet it still took a long period of time to treat nitrates. The reason was that it had low BOD readings thus there was a carbon source but no denitrifying bacteria to exploit it.

CGR_{RAW} had high carbon content and a regular BOD value but does not have the readily available carbon as the CGR_{RAW} was not easily degradable, as the RI_7 results were low. The low COD results for CGR_{RAW} support those findings. CGR_{RAW}, on average, had the lowest COD values compared to all the other mixes tested.

The 75/25 COD results point out that the substrate was not functioning at full capacity. The length of time taken to treat nitrates suggested the same (A 5.2 days and B 10.1 days).

An overall pattern emerged when comparing the substrates with the same constituents of experiments A and B (for example VWA to VWB). The substrate with the lower COD measurement always achieved T_{end} in a short amount of time.

None of the final COD results were acceptable to be discharged according to the DWAF (75mg/l). Therefore, the effluent will require further treatment.

4.7.4. Batch Ammonia Results

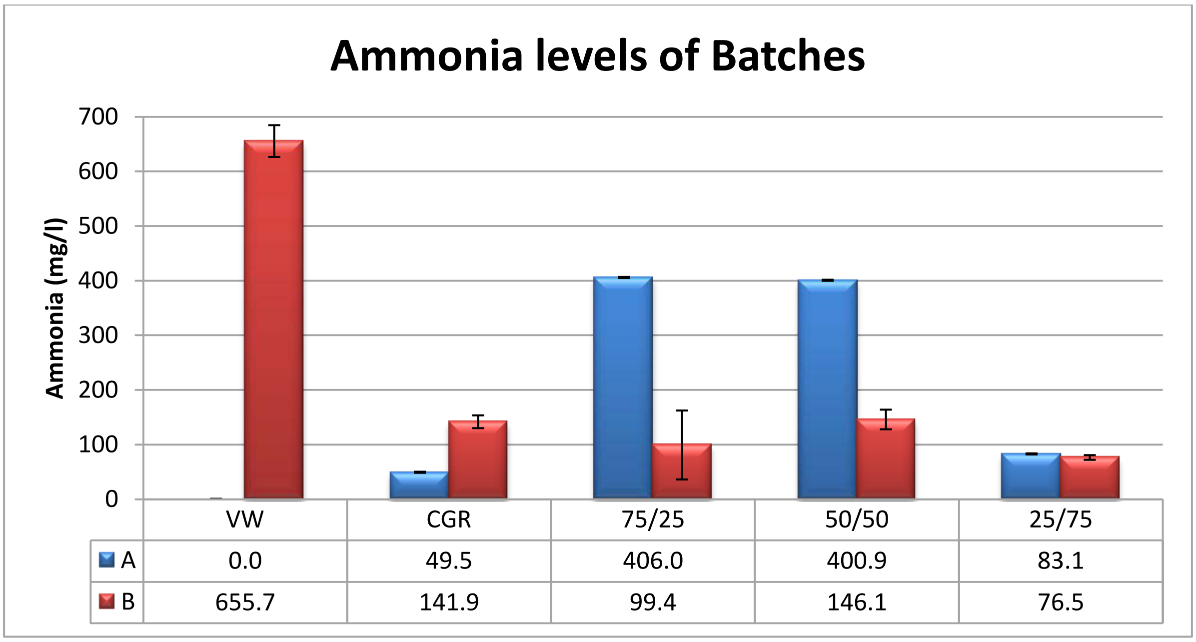


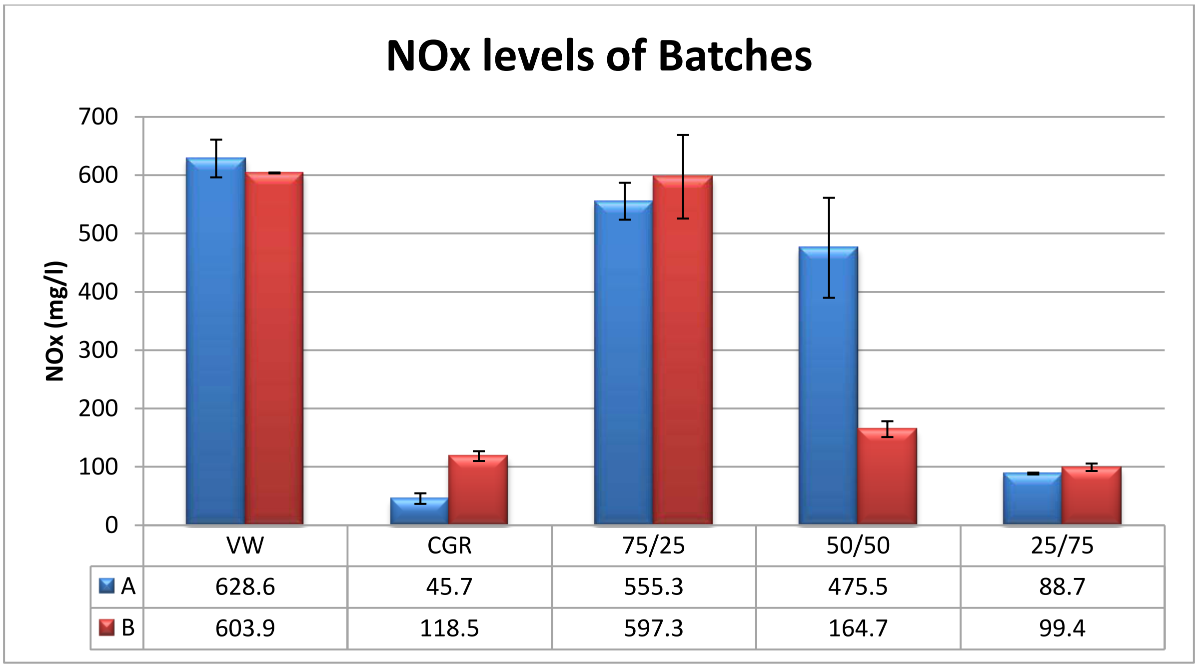
Figure 4-17 Graph plotted to compare Ammonia levels in Batches

The VWA removed all ammonia from the leachate which initially was 10.73mg/l. The other vegetable waste substrate reacted completely different. This was because the vegetable mix that made up VWA and VWB were not exactly the same. It should be mentioned that they were similar.

With the exception of VWA, all the batch experiments resulted in a higher concentration of ammonia than the leachate began with. The Mariannhill landfill leachate initially was not within the DWAF discharge standards for ammonia which was 3mg/l. The results do not conform to the DWAF standards, with the VWA being the only exception. If used to treat leachate, another treatment would be necessary to remove ammonia.

The next best substrates were 25/75 and CGR_{RAW}. These were the batches with the lowest ammonia concentrations on average.

4.7.5. Batch NO_X Results



	VW	CGR	75/25	50/50	25/75
A	628.6	45.7	555.3	475.5	88.7
B	603.9	118.5	597.3	164.7	99.4

Figure 4-18 Graph plotted to compare NO_x levels in Batches

NO_x is a measurement of the concentration of all nitrogenous products in a given sample, in this case batch eluate.

In the graph above, the NO_x concentrations were plotted for each substrate mix. From the plots above; the readings indicate that all NO_x concentrations have reduced from the original concentration of 816.2mg/l. However, the batch results still do not comply with the DWAF discharge standard of 15mg/l of NO_x.

The highest NO_x concentrations were the substrates that consist of more vegetable waste, which were the (100%) vegetable waste (VW) and the 75/25 mix. The substrates with the lowest NO_x concentrations were CGR_{RAW} and 25/75, which contained the least vegetable waste.

As can be seen from the graph, a pattern had emerged: the more vegetable waste in the substrate the higher the NO_x concentrations. The same applied to the NO_x concentrations of the characterisation eluates.

The best substrates with regards to NO_x readings were CGR_{RAW} and 25/75.

5. Application to a larger scale

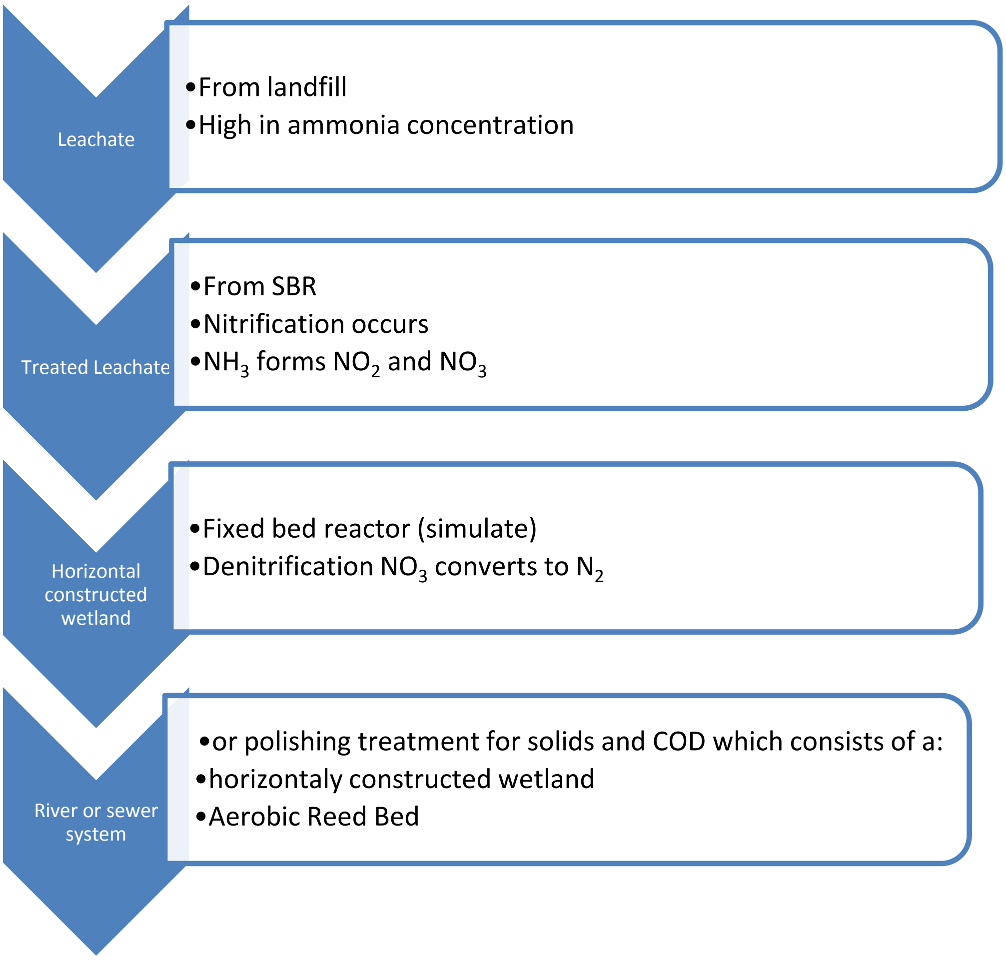


Figure 5-1 flow chart of the treatment process

The batch is a small scale simulation of what happens in a fixed bed reactor (FBR), which is anaerobic. Further test would have to be done to see if it is possible to apply the substrate suggested according to these results, but it so far looks promising. The sample flow rate for the FBR depends on the time it takes for the substrate to completely treat nitrates, thus flow is determined by time taken to replace the entire volume.

$$Flow\ (Q) = \frac{Volume\ of\ FBR}{Total\ Denitrification\ time} \text{..........................Equation 5.1}$$

The substrate could be supplied from the local garden waste collection contractors and the vegetable waste is already available from Dube Tradeport. There is an immense amount of garden refuse available locally as the Durban area has a sub-tropical climate and Dube Tradeport has daily wastage from the packaging facility.

The horizontal constructed wetland would be a large concrete bath filled with substrate and covered with aggregate to prevent the substrate from floating away and for the process to be kept anaerobic. (Plüg, 2008)

It would be more feasible to use the 25/75 mix with vegetable waste as this substrate has the most efficient denitrification process with similar adverse affects to the next best substrate. Any substrate chosen would still require a polishing treatment if the resulting liquid from the treatment is intended to be discharged into a freshwater body.

6. Conclusions

The aim of this dissertation was to investigate effectiveness of using vegetable waste (VW), Raw Commercial Garden Refuse (CGR_{RAW}) as a carbon source for denitrification of Mariannhill treated Landfill Leachate. This was achieved by testing the effectiveness of various mixes of vegetable waste and Raw Commercial Garden Refuse (75/25, 50/50 and 25/75) being used as a carbon source to remove nitrates from treated landfill leachate by doing lab experiments, then to ascertain if it was appropriate to use one of them as a substrate, based on feasibility, and how it would be applied to a larger scale, such as a leachate treatment facility.

An excess of nitrates can be harmful to the environment and can be harmful to people thus there was a need to remove these compounds from elements that would be discharged into the environment. Nitrate removal alternatives were researched. The experiment was performed according to the procedures from Standard Methods for Examination of Water and Wastewater. Tests and experiments were done to obtain results. These results were discussed to obtain conclusions to identify how effective the use of each substrate was as a carbon source to remove nitrates from treated landfill leachate.

There were five sets of batches for each of the different substrates which were being used to treat nitrates (VW, CGR_{RAW}, 75/25, 50/50 and 25/75). The liquid treated was treated Mariannhill Landfill Leachate, from the Treated effluent tank. The experiment was carried out twice.

The samples composite were different as it depends on what was disposed of, by Dube Tradeport, at the time of sampling. This accounts for the varying results. However, it was very apparent that the patterns remain the same for each of the kinetic plots of nitrogen removal (evident in the results – see figures 4-7 to 4-11). Random samples were taken as to show that, if required, any disposed vegetables that are available can be used to treat nitrate.

The nitrate level of the Mariannhill Landfill Leachate, which was the input liquid, was approximately 4000mg/l. Most readings however, began at less than 4000mg/l. This was due to the vegetable waste having a high percentage of moisture content. The leachate was inadvertently diluted. The reason for the initial nitrate readings to be low was a combination of dilution and absorbance of the nitrates by the substrate.

The vegetable waste seemed promising as a substrate seeing that the corresponding RI_7 was the highest compared to all the other substrates being tested. It had roughly the same carbon content as the rest but it did not perform as fast since the nitrate removal was inefficient. The nitrates would be fully treated but the process would take a long time to do so. The inefficiency was due to the acidic nature of the batch eluate, as it was out of the optimum range for denitrification which, consequently did not suit the denitrifying bacteria as illustrated by the low BOD_5 results. Furthermore, the vegetable waste introduced more nitrates to the liquid and at the same time treats the nitrates. This was noticed in the control results as there were no nitrates initially, thereafter, the nitrate level began to rise. On average the resulting vegetable waste batch eluate did not comply with any of the tested parameters of the DWAF standards of discharge (excluding VWA that did not have any ammonia). If the final nitrate levels were not taken into consideration, the vegetable waste substrate arguably made the leachate worse than it was initially, with regards to the DWAF discharge standard parameters. Hence, vegetable waste in this form was not a good substrate to be applied on the full scale (i.e. Applying all vegetables as disposed of, by Dube Tradeport, as a substrate to treat nitrates in a Fixed Bed Reactor) as different samples do have different results.

There have been previous experiments to determine if CGR_{RAW} would make a suitable nitrogen removal substrate. These have yielded results similar to the findings of the experiments conducted for this dissertation. The denitrification results were acceptable as there was full treatment and done within similar time frames to previous works. It would be expected that leachate would take one to two weeks to treat nitrates of high concentrations in landfill leachate. The rates of denitrification were inconsistent. The CGR_{RAW} substrate consists of a good portion of carbon content. However, there was not as much readily available carbon determined from the low RI_7 value. There was carbon but it was not readily available for the medium amount of denitrifying bacteria to use (from BOD_5, Figure 4-13). The pH conditions were near to being within the optimum range. The CGR_{RAW} batch effluents were not within the DWAF discharge standards, with the exception of the pH levels. The parameters were however closer to what was required than most of the substrates.

The mixes all had improved BOD_5 and IR_7 results which seemed to strike a balance between the vegetable waste lack of denitrifying bacteria and the CGR_{RAW} lack of readily available carbon. The carbon content and carbon to nitrogen ratio was maintained. The pH value was also balanced such that all the batch eluate pH values for the mixes were within the optimum range for denitrification. This resulted in the treatment of nitrates to become more efficient, with the exception of the 50/50A mix. However, all the characteristic parameters tested were not in compliance with DWAF discharge standards.

The 75/25 mix was the only substrate to show a pattern of a third order polynomial (all the other substrates demonstrated a second order polynomial pattern). The denitrification rate was improved but not the most effective seen in other results. The RI_7 reading would seem to be the reason for the rate not being as fast.

The 50/50 mix was very unpredictable as it did not perform as its characterisation suggested. It was unexpected that the results would not be a balance between the 75/25 and 25/75 mixes. (50/50A was slower than all the mixes and 50/50B was as fast as 25/75)

The 25/75 mix was the fasted to treat the nitrates completely and was done so consistently. The rate of denitrification was also the best. The 25/75 batch eluate was not with the DWAF discharge standards but was closer to complying compared with the other substrate results, similar to CGR_{RAW}.

In conclusion, the 25/75 mix was the best substrate that can be used on a larger scale to create a horizontal constructed wetland but would require further treatment to be discharged. This was due to 25/75 mix achieving a better rate of treatment of nitrates and has similar results with regards to DWAF discharge standards (pH, COD, NH_3 and NO_x). A random mix of vegetable waste, on its own, was not suitable to treat nitrates. Even though it was able to fully treat nitrates, it did not improve the leachate in terms of the other parameters of the DWAF discharge standards. The COD levels were of particular concern as they were consistently very high for all substrates. All objectives have been met and the aims have been achieved.

7. Recommendations

The recommend substrate was a mix of a random mix of 25% of vegetable waste sample (VW) and 75% of commercial garden refuse sample (CGR_{RAW}).

The experiment could be improved if samples are collected as fresh as possible so that it is known how long the substrate has been decomposing for.

If possible, conduct all tests on site as this prevents decomposition during transit. The results may not be as reliable and it does depend on the overnight courier service. The method of nitrate testing could be changed, ideally for it to be a device that records the nitrate (or all other tests parameters), while simultaneously, the batch test is being run and plots data points automatically. This would make results more accurate as well as allow more tests to be done simultaneously. Gas analysis can be done to determine if any useful products are released as a result of the process. There could be studies done to determine why a 50/50 mix is so unpredictable.

The solid samples should be cut as small as possible without allowing the substrate to become liquid. This allows the substrate to be more homogenous, thus, tests samples would be more of a representative of the sample.

More batch tests on a mix of vegetable waste is not necessary, unless there is a specific reason to use those particular constituents and the input to the mix is measured (each vegetable is weighed before being added to the mix).

There have been studies done where nitrate concentrations were being treated by using various carbon sources; however, there are not many treating leachate as compared to synthetic solutions and further studies should be done in order to find the properties of each vegetable, and if need be, which combination thereafter is most efficient, as it was noticed that VWA treated ammonia and nitrates completely. Further research should be done with regards to the uses of vegetable waste from Dube Tradeport for removal of ammonia as well as which vegetables introduce more ammonia when in contact with landfill leachate, as this would also improve the effectiveness of 25/75 mix.

Batch tests could be left beyond the time of full removal of nitrates as to identify if the substrates make a difference to other parameters especially nitrogen products like ammonia.

An experiment on a bigger scale or a simulation of how it will be applied (like column tests) will help understand if the substrate can be applied to a leachate treatment facility. A longevity test will also identify another aspect of the feasibility of using the substrates.

A polishing treatment should be researched for the effluent that will result from the outflow if one of the substrates tested in this dissertation is applied, especially for the removal COD, as all substrates tested showed high levels of COD. Thus the polishing treatment would treat the smaller amounts of adverse chemical compounds.

It was also noticed that there may be a correlation between sunlight versus nitrate removal. It could also be temperature versus nitrate removal but it was less likely as the laboratory was kept at a relatively constant temperature. Hence, further research should be conducted to investigate the effect of these parameters on nitrate removal (rates).

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9. Appendix

9.1. Appendix A (initial Characterisation)

COD

A

Sample	Date	Vol	Blank ave	1	2	3	Ave	Result	Std dev	Var	1	2	3	Std dev
Standard (KHP)	30/11/2013	1	-0.03100	0.03	0.027	0.03	0.029	**371.34**	0.002	0.000	**377.53**	**358.96**	**377.53**	**10.72**
Veg waste eluate		0.02	-0.03100	0.113	0.095	0.133	0.114	**44767.10**	0.019	0.000	**44560.80**	**38990.70**	**50749.80**	**5882.26**
CGR raw eluate 22/11/2013		0.05	-0.03100	0.001	0.005	0.005	0.004	**4291.04**	0.002	0.000	**3960.96**	**4456.08**	**4456.08**	**285.86**
75/25 eluate 29/11/2013		0.02	-0.03100	0.048	0.051	0.048	0.049	**24756.00**	0.002	0.000	**24446.55**	**25374.90**	**24446.55**	**535.98**
50/50 eluate 29/11/2013		0.02	-0.03100	0.011	0.037	0.038	0.029	**18463.85**	0.015	0.000	**12996.90**	**21042.60**	**21352.05**	**4737.05**
25/75 eluate 29/11/2013		0.05	-0.03100	0.027	0.089	0.093	0.070	**12460.52**	0.037	0.001	**7179.24**	**14853.60**	**15348.72**	**4580.42**
MLS 11/11/2013		0.05	-0.03100	0.03	0.027	0.031	0.029	**7468.06**	0.002	0.000	**7550.58**	**7179.24**	**7674.36**	**257.67**

B

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
Standard (KHP)	03/02/2014	1	0.00500	0.066	0.075	0.077	0.073	**418.79**	0.006	0.000	**377.53**	**433.23**	**445.61**	36.26
Veg waste eluate 28/01/2014		0.02	0.00500	0.196	0.161	0.158	0.172	**51575.00**	0.021	0.000	**59104.95**	**48274.20**	**47345.85**	6537.63
75/25 eluate 28/01/2014		0.05	0.00500	0.263	0.266	0.264	0.264	**32100.28**	0.002	0.000	**31935.24**	**32306.58**	**32059.02**	189.08
50/50 eluate 28/01/2014		0.05	0.00500	0.103	0.098	0.104	0.102	**11965.40**	0.003	0.000	**12130.44**	**11511.54**	**12254.22**	397.90
25/75 eluate 28/01/2014		0.05	0.00500	0.094	0.093	0.093	0.093	**10933.90**	0.001	0.000	**11016.42**	**10892.64**	**10892.64**	71.46
CGR raw eluate 28/01/2014		0.05	0.00500	0.033	0.025	0.031	0.030	**3053.24**	0.004	0.000	**3465.84**	**2475.60**	**3218.28**	515.34

pH

	pH				
A					
	R1	R2	R3	Average	Std Dev
Veg waste 23/11/2013	4.31	4.29	4.29	4.30	0.01
CGR raw 23/11/2013	6.53	6.66	6.73	6.64	0.10
Marian hill landfill leachate 25/11/2013	7.57	7.61	7.57	7.58	0.02
75/25 eluate 29/11/2013	4.36	4.36	4.36	4.36	0.00
50/50 eluate 29/11/2013	4.89	4.89	4.89	4.89	0.00
25/75 eluate 29/11/2013	6.12	6.13	6.14	6.13	0.01

	pH				
B					
	R1	R2	R3	Average	Std Dev
Veg waste eluate 28/01/2014	3.97	3.96	3.95	3.96	0.01
75/25 eluate 28/01/2014	3.85	3.84	3.85	3.85	0.01
50/50 eluate 28/01/2014	4.16	4.17	4.17	4.17	0.01
25/75 eluate 28/01/2014	4.76	4.76	4.77	4.76	0.01
CGR raw eluate 28/01/2014	6.17	6.27	6.26	6.23	0.06

Ammonia and NO_x

NH3 and NOx	NH_3							No_x					
	sample vol/mL	HCl Conc	HCl vol/mL	NH3-N (mg/L)	Ave	Std dev		sample vol/mL	HCl Conc	HCl vol/mL	Nox(mg/L)	Ave	Std dev
Eluates A	**10**	**0.1**						**10**	**0.10**				
Veg waste			0	**0**						2.08	**291.2**		
Veg waste			0	**0**						2.20	**308**		
Veg waste			0	**0**	**0.00**	**0.00**				2.18	**305.2**	301.47	9.00
CGR raw 1			0.24	**33.6**						0.58	**81.2**		
CGR raw 2			0.2	**28**						0.27	**37.8**		
CGR raw 3			0.2	**28**	**29.87**	**3.23**				0.22	**30.8**	49.93	27.30
MLS 1			0.08	**11.2**						4.96	**694.4**		
MLS 2			0.08	**11.2**						6.16	**862.4**		
MLS 3			0.07	**9.8**	**10.73**	**0.81**				6.37	**891.8**	816.20	106.50
75/25 Eluate 1			0	**0**						1.29	**180.6**		
75/25 Eluate 2			0	**0**						1.45	**203**		
75/25 Eluate 3			0	**0**	**0.00**	**0.00**				1.40	**196**	193.20	11.46
50/50 Eluate 1			0	**0**						0.86	**120.4**		
50/50 Eluate 2			0	**0**						0.84	**117.6**		
50/50 Eluate 3			0	**0**	**0.00**	**0.00**				0.89	**124.6**	120.87	3.52
25/75 Eluate 1			0.22	**30.8**						0.36	**50.4**		
25/75 Eluate 2			0.27	**37.8**						0.38	**53.2**		
25/75 Eluate 3			0.22	**30.8**	**33.13**	**4.04**				0.36	**50.4**	51.33	1.62

NH_3 and NOx	NH_3						Nox					
	sample vol/mL	HCl Conc	HCl vol/mL	NH3-N (mg/L)	Ave	Std dev	sample vol/mL	HCl Conc	HCl vol/mL	Nox(mg/L)	Ave	Std dev
Eluates B												
Veg waste eluate 28/01/2014			2.35	**329**					1.18	**165.2**		
Veg waste eluate 28/01/2014			2.64	**369.6**					1.16	**162.4**		
Veg waste eluate 28/01/2014			2.64	**369.6**	**356.07**	**23.44**			1.12	**156.8**	161.47	4.28
CGR raw eluate 28/01/2014			0.33	**46.2**					0.26	**36.4**		
CGR raw eluate 28/01/2015			0.36	**50.4**					0.28	**39.2**		
CGR raw eluate 28/01/2016			0.36	**50.4**	**49.00**	**2.42**			0.24	**33.6**	36.40	2.80
75/25 Eluate 28/01/2014			1.54	**215.6**					0.97	**135.8**		
75/25 Eluate 28/01/2015			1.59	**222.6**					1.00	**140**		
75/25 Eluate 28/01/2016			1.55	**217**	**218.40**	**3.70**			1.01	**141.4**	139.07	2.91
50/50 Eluate 28/01/2014			0.72	**100.8**					0.53	**74.2**		
50/50 Eluate 28/01/2015			0.75	**105**					0.55	**77**		
50/50 Eluate 28/01/2016			0.72	**100.8**	**102.20**	**2.42**			0.53	**74.2**	75.13	1.62
25/75 Eluate 28/01/2014			0.54	**75.6**					0.31	**43.4**		
25/75 Eluate 28/01/2015			0.53	**74.2**					0.33	**46.2**		
25/75 Eluate 28/01/2016			0.58	**81.2**	**77.00**	**3.70**			0.35	**49**	46.20	2.80

RI$_7$

Sample	Beaker Size	SG	Mass Sample	Volume Sample	Vol H2O	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
Example	1	0.5	0.013	0.026	0	0.974	79.01	21.27	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!
BATCH 2013 A																					
Veg Waste (12/11/2013)	1	0.5	0.025	0.05	0	0.95	79.01	21.27	0.0395	0.00830	0.0308	37.0	64.3	-14.71	0.01443	461.740	9.742	2.436	189.582	192.997	107.641
Veg Waste (12/11/2013)	1	0.5	0.025	0.05	0	0.95	79.01	21.27	0.0395	0.00830	0.0308	17.0	84.3	5.286	0.00663	212.151	9.742	2.436	87.105		
Veg Waste (12/11/2013)	1	0.5	0.025	0.05	0	0.95	79.01	21.27	0.0395	0.00830	0.0308	59.0	42.3	-36.71	0.02301	736.288	9.742	2.436	302.306		
CGR raw (28/01/2014)	1	0.5	0.025	0.05	0.006	0.944	79.01	21.27	0.0393	0.00824	0.0306	137.0	-35.7	-114.7	0.05309	1698.889	48.6	12.150	139.829	95.261	65.213
CGR raw (28/01/2014)	1	0.5	0.025	0.05	0.006	0.944	79.01	21.27	0.0393	0.00824	0.0306	20.0	81.3	2.286	0.00775	248.013	48.6	12.150	20.413		
CGR raw (28/01/2014)	1	0.5	0.025	0.05	0.006	0.944	79.01	21.27	0.0393	0.00824	0.0306	123.0	-21.7	-100.7	0.04766	1525.280	48.6	12.150	125.540		
75/25 mix (28/01/2014)	1	0.5	0.025	0.05	0	0.95	79.01	21.27	0.0395	0.00830	0.0308	158.0	-56.7	-135.7	0.06162	1971.755	20.06	5.015	393.149	350.848	36.949
75/25 mix (28/01/2014)	1	0.5	0.025	0.05	0	0.95	79.01	21.27	0.0395	0.00830	0.0308	137.0	-35.7	-114.7	0.05343	1709.687	20.06	5.015	340.895		
75/25 mix (28/01/2014)	1	0.5	0.025	0.05	0	0.95	79.01	21.27	0.0395	0.00830	0.0308	128.0	-26.7	-105.7	0.04992	1597.371	20.06	5.015	318.501		
50/50 mix	1	0.5	0.025	0.05	0.003	0.947	79.01	21.27	0.0394	0.00827	0.0307	153.0	-51.7	-130.7	0.05948	1903.328	23.08	5.770	329.841	298.222	7.622
50/50 mix	1	0.5	0.025	0.05	0.003	0.947	79.01	21.27	0.0394	0.00827	0.0307	148.0	-46.7	-125.7	0.05754	1841.128	23.08	5.770	319.062		
50/50 mix	1	0.5	0.025	0.05	0.003	0.947	79.01	21.27	0.0394	0.00827	0.0307	114.0	-12.7	-91.71	0.04432	1418.166	23.08	5.770	245.764		
25/75 mix	1	0.5	0.025	0.05	0.004	0.946	79.01	21.27	0.0393	0.00826	0.0307	147.0	-45.7	-124.7	0.05709	1826.757	32.03	8.008	228.110	234.835	13.167
25/75 mix	1	0.5	0.025	0.05	0.004	0.946	79.01	21.27	0.0393	0.00826	0.0307	135.0	-33.7	-112.7	0.05243	1677.634	32.03	8.008	209.489		
25/75 mix	1	0.5	0.025	0.05	0.004	0.946	79.01	21.27	0.0393	0.00826	0.0307	172.0	-70.7	-149.7	0.06679	2137.430	32.03	8.008	266.905		

Sample	Beaker Size	SG	Mass Sample	Volume Sample	Vol H2O	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
Example	1	0.5	0.013	0.026	0	0.974	79.01	21.27	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!
2014																					
B																					
Veg Waste (28/01/2014)	1.5	0.5	0.025	0.05	0	1.45	79.01	21.27	0.0603	0.01266	0.0470	97.0	4.3	-74.71	0.05774	1847.618	11.38	2.846	649.143	753.987	110.843
Veg Waste (28/01/2014)	1.5	0.5	0.025	0.05	0	1.45	79.01	21.27	0.0603	0.01266	0.0470	130.0	-28.7	-107.7	0.07738	2476.188	11.38	2.846	869.985		
Veg Waste (28/01/2014)	1.5	0.5	0.025	0.05	0	1.45	79.01	21.27	0.0603	0.01266	0.0470	111.0	-9.7	-88.71	0.06607	2114.284	11.38	2.846	742.834		
CGR raw (28/01/2014)	1.5	0.5	0.025	0.05	0.006	1.444	79.01	21.27	0.0600	0.01261	0.0468	23.0	78.3	-0.714	0.01363	436.282	39.7	9.925	43.956	135.052	79.359
CGR raw (28/01/2014)	1.5	0.5	0.025	0.05	0.006	1.444	79.01	21.27	0.0600	0.01261	0.0468	90.0	11.3	-67.71	0.05335	1707.191	39.7	9.925	172.001		
CGR raw (28/01/2014)	1.5	0.5	0.025	0.05	0.006	1.444	79.01	21.27	0.0600	0.01261	0.0468	99.0	2.3	-76.71	0.05868	1877.910	39.7	9.925	189.201		
75/25 mix (28/01/2014)	1.5	0.5	0.025	0.05	0	1.45	79.01	21.27	0.0603	0.01266	0.0470	42.0	59.3	-19.71	0.02500	799.999	19.89	4.973	160.873	338.343	170.631
75/25 mix (28/01/2014)	1.5	0.5	0.025	0.05	0	1.45	79.01	21.27	0.0603	0.01266	0.0470	105.0	-3.7	-82.71	0.06250	1999.998	19.89	4.973	402.182		
75/25 mix (28/01/2014)	1.5	0.5	0.025	0.05	0	1.45	79.01	21.27	0.0603	0.01266	0.0470	118.0	-16.7	-95.71	0.07024	2247.617	19.89	4.973	451.976		
50/50 mix	1.5	0.5	0.025	0.05	0.003	1.447	79.01	21.27	0.0602	0.01264	0.0469	123.0	-21.7	-100.7	0.07306	2338.008	23.72	5.931	394.198	361.081	65.719
50/50 mix	1.5	0.5	0.025	0.05	0.003	1.447	79.01	21.27	0.0602	0.01264	0.0469	94.0	7.3	-71.71	0.05584	1786.770	23.72	5.931	301.257		
50/50 mix	1.5	0.5	0.025	0.05	0.003	1.447	79.01	21.27	0.0602	0.01264	0.0469	121.0	-19.7	-98.71	0.07187	2299.992	23.72	5.931	387.788		
25/75 mix	1.5	0.5	0.025	0.05	0.004	1.446	79.01	21.27	0.0601	0.01263	0.0469	131.0	-29.7	-108.7	0.07776	2488.353	33.09	8.272	300.811	309.231	8.119
25/75 mix	1.5	0.5	0.025	0.05	0.004	1.446	79.01	21.27	0.0601	0.01263	0.0469	136.0	-34.7	-113.7	0.08073	2583.328	33.09	8.272	312.293		
25/75 mix	1.5	0.5	0.025	0.05	0.004	1.446	79.01	21.27	0.0601	0.01263	0.0469	137.0	-35.7	-114.7	0.08132	2602.323	33.09	8.272	314.589		

TS, VS solid

Date analysed	Sample	TS (%) Average	VS (%) Average	MC (%)	TS (%) Std Dev	VS (%) Std Dev
A						
18/11/2013	CGR raw	**48.5989**	**80.2125**	**51.4011**	2.8537	2.7897
18/11/2013	Vegetable Waste	**9.7423**	**90.6506**	**90.2577**	1.6826	1.3546
27/11/2013	Mix 75/25 Food waste to CGRraw	**20.0611**	**80.7550**	**79.9389**	1.1540	1.7642
27/11/2013	Mix 50/50 Food waste to CGRraw	**23.0818**	**77.6941**	**76.9182**	2.3222	2.6255
27/11/2013	Mix 25/75 Food waste to CGRraw	**32.0329**	**78.4579**	**67.9671**	3.2386	2.0537
B						
22/01/2014	Mix 75/25 Food waste to CGRraw	**19.8915**	**76.9133**	**80.1085**	2.8721	4.7216
22/01/2014	Mix 50/50 Food waste to CGRraw	**23.7242**	**67.1699**	**76.2758**	0.2214	8.9343
22/01/2014	Mix 25/75 Food waste to CGRraw	**33.0886**	**71.9417**	**66.9114**	7.6285	4.9063
23/01/2014	Vegetable waste	**11.3850**	**91.1592**	**88.6150**	0.4700	1.4537
23/01/2014	CGR raw	**39.7019**	**74.7537**	**60.2981**	1.2059	4.2562

TS, VS Eluate

Date analysed	Sample	TS (g/l) Average	VS (g/l) Average	TS (g/l) Std Dev	VS (g/l) Std Dev
A					
23/11/2013	CGR raw	7.077	4.151	0.037	0.005
23/11/2013	Veg waste	40.284	32.860	1.093	0.981
26/11/2013	MLS (11/11/13)	13.441	3.780	0.008	0.866
29/11/2013	75/25 eluate	30.229	25.588	6.465	3.536
29/11/2013	50/50 eluate	17.469	12.305	0.342	0.335
29/11/2013	25/75 eluate	9.637	5.777	0.023	0.019
-	-	-	-	-	-
B					
23/01/2014	Veg waste eluate	37.447	30.909	1.579	1.613
23/01/2014	75/25 eluate	28.800	21.968	0.477	0.287
23/01/2014	50/50 eluate	11.759	7.967	0.101	0.125
23/01/2014	25/75 eluate	13.784	8.044	0.036	0.037
23/01/2014	CGR Raw eluate	5.143	2.817	0.048	0.022

BOD_5

Sample	Date started				
		1	2	3	Average
A					
Veg Waste	23/11/2013	973	940	1026	979.6666667
CGR raw	23/11/2013	620	1090	983	897.6666667
75/25 H2O eluate	29/11/2013	1250	1197	1218	1221.666667
50/50 H2O eluate	29/11/2013	1379	1453	1432	1421.333333
25/75 H2O eluate	29/11/2013	1817	1817	1817	1817
MLS	26/11/2013	214	214	182	203.3333333
B					
Veg Waste	31/01/2014	1069	1047	1005	1040.333333
CGR raw	2014/06/02	1518	1582	1443	1514.333333
75/25 H2O eluate	31/01/2014	1186	1250	1336	1257.333333
50/50 H2O eluate	2014/05/02	1421	1240	502	1054.333333
25/75 H2O eluate	2014/05/02	1560	1368	684	1204

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Vat Reg. No. 4200161414

Report No.: **NR3970_a** (Supplement to Test Report No.: NR003970.DOC)
University of Kwazulu Natal
School of Civil Engineering, Survey
and Construction,
Howard College Campus, Durban
4000

Analyses Report

Date received: 25/11/2013
Date tested: 27/11/2013

Reference No.	Lab. No.	C %	N %	C:N Ratio
1 100% CGR Raw	3970	36.50	1.30	28.08
2 100% Food Waste	3971	41.10	2.62	15.69
3 75% Food Waste 25% CGR Raw	3972	39.20	1.83	21.42
4 50% Food Waste 50% CGR Raw	3973	35.20	1.43	24.62
5 25% Food Waste 25% CGR Raw	3974	35.50	1.42	25.00
Method#				

#Refer to BemLab work instructions
Order no.: U351737

Sample condition: Samples received in good condition.

Statement: The reported results may be applied only to samples received. Any recommendations included with this report are based on the assumption that the samples were representative of the bulk from which they were taken.

Dr. Pieter Raath for BemLab

Date Reported 28-11-2013

Report No.: **NR183_a** *(Supplement to Test Report No.: NR000183.DOC)*

Fatima Ali
University of Kwazulu Natal
School of Civil Engineering, Survey
and Construction,
Howard College Campus, Durban
4000

Analyses Report

Date received: 30/01/2014
Date tested: 07/02/2014

Reference	Lab.	N	C	C:N Ratio
No.	No.	%	%	
FW R1	183	2.78	56.50	20.32
75 R1	184	1.61	54.30	33.73
50 R1	185	1.35	61.00	45.19
25 R1	186	1.44	57.70	40.07
CGR R1	187	1.20	59.20	49.33
FW R2	188	0.51	41.80	81.96
75 R2	189	2.12	48.30	22.78
50 R2	190	1.63	42.20	25.89
25 R2	191	1.54	39.40	25.58
CGR R2	192	1.60	42.20	26.38
FW C	193	1.01	64.20	63.56
75 C	194	1.51	52.40	34.70
50 C	195	1.33	55.00	41.35
25 C	196	1.37	56.20	41.02
CGR C	197	1.03	54.40	52.82
Method[#]				

[#]Refer to BemLab work instructions
Order no.: U359152

Sample condition: Samples received in good condition.
Statement: The reported results may be applied only to samples received. Any recommendations included with this report are based on the assumption that the samples were representative of the bulk from which they were taken.

Dr. Pieter Raath 02-04-2014

on behalf of BemLab Date Reported

9.2. Appendix B (nitrate readings)

The highlighted blocks represent the presence of nitrites.

Vegetable waste

A

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
03/12 10:00	0.000	0.000	0	2200	2000	2000	2066.667	470	115.4701
03/12 12:35	0.108	2.583	155	2000	1800	2000	1933	450	115.4701
04/12 09:37	0.984	23.617	1417	1300	900	1000	1067	400	208.1666
04/12 11:10	1.049	25.167	1510	1200	1300	1800	1433	1000	321.455
04/12 13:20	1.139	27.333	1640	1200	1200	1200	1200	1000	0
04/12 15:05	1.212	29.083	1745	1500	1000	1200	1233	1000	251.6611
05/12 09:00	1.958	47.000	2820	1300	1300	1300	1300	900	0
05/12 11:20	2.056	49.333	2960	1300	1300	1300	1300	700	0
05/12 13:30	2.146	51.500	3090	1300	1300	1300	1300	1000	0
05/12 15:30	2.229	53.500	3210	1100	500	1000	867	1000	321.455
06/12 08:55	2.955	70.917	4255	1000	1000	1000	1000	1000	0
06/12 11:23	3.058	73.383	4403	900	900	900	900	900	0
06/12 14:30	3.188	76.500	4590	750	750	750	750	750	0
06/12 16:15	3.260	78.250	4695	800	800	800	800	800	0
07/12 08:30	3.938	94.500	5670	1000	900	1000	967	800	57.73503
07/12 13:00	4.125	99.000	5940	900	1000	1000	967	600	57.73503
08/12 10:00	5.000	120.000	7200	1000	900	700	867	500	152.7525
09/12 09:20	5.972	143.333	8600	800	900	700	800	500	100
09/12 12:00	6.083	146.000	8760	600	600	600	600	250	0
09/12 15:15	6.219	149.250	8955	800	600	500	633	500	152.7525
10/12 09:55	6.997	167.917	10075	600	600	600	600	250	0
10/12 14:00	7.167	172.000	10320	700	1000	600	767	350	208.1666
11/12 09:55	7.997	191.917	11515	400	400	450	417	250	28.86751
11/12 11:50	8.076	193.833	11630	300	400	350	350	200	50
11/12 13:53	8.162	195.883	11753	200	350	250	267	250	76.37626
12/12 09:00	8.958	215.000	12900	100	150	200	150	200	50
12/12 10:30	9.021	216.500	12990	300	280	100	227	30	110.1514
12/12 11:37	9.067	217.617	13057	260	110	100	157	30	89.62886
12/12 14:40	9.194	220.667	13240	260	250	250	253.3333	30	5.773503
12/12 15:20	9.222	221.333	13280	260	120	100	160	30	87.17798
13/12 09:30	9.979	239.500	14370	250	200	200	217	30	28.86751
13/12 11:10	10.049	241.167	14470	250	200	150	200	30	50
13/12 13:38	10.151	243.633	14618	250	150	150	183.3333	40	57.73503
13/12 15:15	10.219	245.250	14715	250	200	150	200	30	50
14/12 08:55	10.955	262.917	15775	200	150	100	150	40	50
14/12 10:57	11.040	264.950	15897	120	120	140	126.6667	30	11.54701
14/12 12:42	11.113	266.700	16002	100	150	120	123.3333	30	25.16611
15/12 08:55	11.955	286.917	17215	120	120	110	116.6667	30	5.773503

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
15/12 10:55	12.038	288.917	17335	100	110	100	103.3333	30	5.773503
15/12 12:55	12.122	290.917	17455	100	100	100	100	30	0
16/12 08:30	12.938	310.500	18630	120	100	100	106.6667	30	11.54701
16/12 10:30	13.021	312.500	18750	120	100	90	103.3333	30	15.27525
16/12 12:25	13.101	314.417	18865	110	100	100	103	25	5.773503
16/12 14:25	13.184	316.417	18985	100	100	110	103	30	5.773503
17/12 08:40	13.944	334.667	20080	100	100	100	100	30	0
17/12 10:40	14.028	336.667	20200	100	60	50	70	20	26.45751
17/12 12:30	14.104	338.500	20310	100	110	110	106.6667	25	5.773503
17/12 14:45	14.198	340.750	20445	250	250	100	200	10	86.60254
18/12 09:00	14.958	359.000	21540	90	80	50	73.33333	15	20.81666
18/12 11:00	15.042	361.000	21660	80	90	50	73.33333	15	20.81666
18/12 15:10	15.215	365.167	21910	50	100	100	83.33333	10	28.86751
19/12 09:00	15.958	383.000	22980	40	50	100	63.33333	5	32.1455
19/12 11:00	16.042	385.000	23100	40	50	60	50	0	10
19/12 13:00	16.125	387.000	23220	40	50	80	56.66667	0	20.81666
19/12 15:00	16.208	389.000	23340	60	60	60	60	0	0
20/12 09:00	16.958	407.000	24420	60	60	100	73.33333	0	23.09401

B

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
06/03 00:00	0.000	0.000	0	850	900	800	850	18	50
07/03 10:30	1.438	34.500	2070	700	550	700	650	2	86.60254
07/03 14:50	1.618	38.833	2330	700	550	700	650	0	86.60254
09/03 19:35	3.816	91.583	5495	400	300	300	333	0	57.73503
10/03 15:10	4.632	111.167	6670	400	450	400	417	0	28.86751
11/03 10:30	5.438	130.500	7830	400	270	270	313	0	75.05553
11/03 16:40	5.694	136.667	8200	300	400	350	350	0	50
12/03 15:30	6.646	159.500	9570	300	400	250	317	0	76.37626
13/03 11:45	7.490	179.750	10785	400	270	250	307	0	81.44528
13/03 15:15	7.635	183.250	10995	400	270	270	313	0	75.05553
14/03 10:05	8.420	202.083	12125	270	250	250	257	0	11.54701
15/03 11:10	9.465	227.167	13630	230	230	190	217	0	23.09401
16/03 10:55	10.455	250.917	15055	200	200	150	183	0	28.86751
17/03 12:50	11.535	276.833	16610	250	250	190	230	0	34.64102
18/03 14:30	12.604	302.500	18150	70	120	220	137	0	76.37626
19/03 14:24	13.600	326.400	19584	30	100	150	93	0	60.27714
20/03 14:45	14.615	350.750	21045	0	25	180	68	0	97.51068
24/03 10:55	18.455	442.917	26575	0	0	25	8	0	14.43376
24/03 14:10	18.590	446.167	26770	0	0	25	8	0	14.43376
24/03 16:15	18.677	448.250	26895	0	0	25	8	0	14.43376
25/03 09:45	19.406	465.750	27945	0	0	0	0	0	0

75/25

A

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
03/12 11:45	0.000	0.000	0	2600	2500	3000	2700	300	264.5751
03/12 14:25	0.111	2.667	160	2600	2400	2600	2533	300	115.4701
04/12 09:20	0.899	21.583	1295	2600	2600	2600	2600	100	0
04/12 11:20	0.983	23.583	1415	2000	2000	2000	2000	250	0
04/12 13:30	1.073	25.750	1545	1800	1800	1800	1800	100	0
04/12 15:13	1.144	27.467	1648	2500	2400	1800	2233	200	378.5939
05/12 08:50	1.878	45.083	2705	2000	2100	1800	1967	0	152.7525
05/12 11:10	1.976	47.417	2845	1900	2000	2000	1967	0	57.73503
05/12 13:35	2.076	49.833	2990	2000	2000	2000	2000	0	0
05/12 15:20	2.149	51.583	3095	1500	2000	2000	1833	150	288.6751
06/12 09:20	2.899	69.583	4175	1000	1200	1000	1067	0	115.4701
06/12 11:15	2.979	71.500	4290	700	900	800	800	0	100
06/12 13:45	3.083	74.000	4440	500	600	600	567	0	57.73503
06/12 15:30	3.156	75.750	4545	400	600	500	500	0	100
07/12 09:00	3.885	93.250	5595	100	350	70	173	0	153.7314
07/12 10:20	3.941	94.583	5675	120	300	110	177	0	106.9268
07/12 13:37	4.078	97.867	5872	100	150	70	107	10	40.41452
07/12 15:20	4.149	99.583	5975	70	80	40	63	0	20.81666
07/12 21:00	4.385	105.250	6315	50	50	30	43	0	11.54701
08/12 09:40	4.913	117.917	7075	10	40	5	18	0	18.92969
08/12 12:05	5.014	120.333	7220	1	15	0	5	0	8.386497
08/12 14:45	5.125	123.000	7380	0	5		3	0	3.535534
08/12 16:45	5.208	125.000	7500	0	0	0	0	0	0

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
10/03 11:10	0.000	0.000	0	2200	2000	1500	1900	0	360.5551
10/03 15:55	0.198	4.750	285	2700	2700	2500	2633	0	115.4701
11/03 15:00	1.160	27.833	1670	2400	2500	3000	2633	0	321.455
12/03 15:20	2.174	52.167	3130	2500	2500	2500	2500	0	0
13/03 14:45	3.149	75.583	4535	2700	2500	1800	2333	0	472.5816
14/03 10:50	3.986	95.667	5740	2000	1400	1200	1533	0	416.3332
16/03 11:15	6.003	144.083	8645	25	25	75	42	0	28.86751
16/03 19:20	6.340	152.167	9130	10	30	70	37	0	30.5505
17/03 09:05	6.913	165.917	9955	5	10	40	18	0	18.92969
17/03 12:00	7.035	168.833	10130	2	10	40	17	0	20.03331
17/03 14:50	7.153	171.667	10300	1	10	50	20	0	26.0832
17/03 16:00	7.201	172.833	10370	0	25	50	25	0	25
18/03 09:00	7.910	189.833	11390	0	10	50	20	0	26.45751
18/03 14:40	8.146	195.500	11730	0	1	30	10	0	17.03917
18/03 15:50	8.194	196.667	11800	0	0	25	8	0	14.43376
19/03 08:55	8.906	213.750	12825	0	0	10	3	0	5.773503
19/03 14:55	9.156	219.750	13185	0	0	35	12	0	20.20726
20/03 14:30	10.139	243.333	14600	0	0	0	0	0	0

50/50

A

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
05/12 10:10	0.000	0.000	0	3000	3000	3000	3000	30	0
05/12 12:05	0.080	1.917	115	3000	2700	2700	2800	25	173.2051
05/12 14:28	0.179	4.300	258	2600	2600	2400	2533	15	115.4701
06/12 09:55	0.990	23.750	1425	1500	1500	1500	1500	0	0
06/12 12:35	1.101	26.417	1585	2000	2000	2000	2000	0	0
06/12 14:44	1.190	28.567	1714	2300	2300	2300	2300	0	0
07/12 09:10	1.958	47.000	2820	1500	1700	1600	1600	0	100
07/12 13:30	2.139	51.333	3080	1500	1800	1500	1600	0	173.2051
08/12 10:30	3.014	72.333	4340	1500	1600	1000	1367	0	321.455
08/12 15:00	3.201	76.833	4610	1000	1000	1000	1000	0	0
09/12 09:15	3.962	95.083	5705	900	1000	1200	1033	0	152.7525
09/12 11:55	4.073	97.750	5865	1200	1200	1000	1133	0	115.4701
09/12 15:00	4.201	100.833	6050	600	700	600	633	0	57.73503
10/12 09:20	4.965	119.167	7150	400	600	500	500	0	100
10/12 13:55	5.156	123.750	7425	350	600	300	417	0	160.7275
11/12 09:30	5.972	143.333	8600	500	600	0	367	0	321.455
11/12 11:30	6.056	145.333	8720	500	500	0	333	0	288.6751
11/12 14:10	6.167	148.000	8880	500	600	0	367	0	321.455
12/12 09:05	6.955	166.917	10015	300	450	0	250	0	229.1288
12/12 10:25	7.010	168.250	10095	250	300	0	183	0	160.7275
12/12 11:30	7.056	169.333	10160	300	300	0	200	0	173.2051
12/12 14:40	7.188	172.500	10350	250	200	0	150	0	132.2876
12/12 15:20	7.215	173.167	10390	150	150	0	100	0	86.60254
13/12 09:33	7.974	191.383	11483	100	100	0	67	0	57.73503
13/12 11:15	8.045	193.083	11585	100	100	0	67	0	57.73503
13/12 13:45	8.149	195.583	11735	150	150	0	100	0	86.60254
13/12 15:05	8.205	196.917	11815	150	150	0	100	0	86.60254
14/12 08:30	8.931	214.333	12860	150	150	0	100	0	86.60254
14/12 10:46	9.025	216.600	12996	120	120	0	80	0	69.28203
14/12 12:35	9.101	218.417	13105	120	120	0	80	0	69.28203
15/12 08:45	9.941	238.583	14315	100	0	0	33	0	57.73503
15/12 10:45	10.024	240.583	14435	100	0	0	33	0	57.73503
15/12 12:45	10.108	242.583	14555	100	0	0	33	0	57.73503
16/12 08:15	10.920	262.083	15725	100	0	0	33	0	57.73503
16/12 10:15	11.003	264.083	15845	100	0	0	33	0	57.73503
16/12 12:15	11.087	266.083	15965	100	0	0	33	0	57.73503
16/12 14:15	11.170	268.083	16085	80	0	0	27	0	46.18802
17/12 08:30	11.931	286.333	17180	30	0	0	10	0	17.32051
17/12 10:30	12.014	288.333	17300	10	0	0	3	0	5.773503
17/12 11:50	12.069	289.667	17380	3	0	0	1	0	1.732051
17/12 13:00	12.118	290.833	17450	5	0	0	2	0	2.886751
17/12 14:00	12.160	291.833	17510	1	0	0	0	0	0.57735
17/12 15:30	12.222	293.333	17600	0	0	0	0	0	0

B									
Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
12/03 13:25	0.000	0.000	0	4000	4500	3000	3833.333	30	763.7626
13/03 11:25	0.917	22.000	1320	1500	1000	1200	1233	25	251.6611
13/03 15:00	1.066	25.583	1535	2000	1000	700	1233	15	680.6859
14/03 09:40	1.844	44.250	2655	1200	1000	400	867	0	416.3332
14/03 14:00	2.024	48.583	2915	1000	1000	250	750	0	433.0127
15/03 10:45	2.889	69.333	4160	500	500	0	333	0	288.6751
16/03 09:15	3.826	91.833	5510	0	0	0	0	0	0

25/75

2013 A

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
05/12 12:00	0.000	0.000	0	2400	1500	2400	2100	0	519.6152
05/12 14:15	0.094	2.250	135	2300	2400	2600	2433	0	152.7525
06/12 10:02	0.918	22.033	1322	1200	1500	1100	1267	0	208.1666
06/12 12:45	1.031	24.750	1485	900	1200	1100	1067	0	152.7525
06/12 14:30	1.104	26.500	1590	800	900	700	800	0	100
07/12 08:45	1.865	44.750	2685	40	600	50	230	0	320.4684
07/12 10:25	1.934	46.417	2785	0	200	30	77	0	107.8579
07/12 11:20	1.972	47.333	2840	0	70	8	26	0	38.31449
07/12 11:45	1.990	47.750	2865	0	180	0	60	0	103.923
07/12 14:15	2.094	50.250	3015	0	100	0	33	0	57.73503
07/12 15:35	2.149	51.583	3095	0	70	0	23	0	40.41452
07/12 20:00	2.333	56.000	3360	0	70	0	23	0	40.41452
08/12 08:50	2.868	68.833	4130	0	10	0	3	0	5.773503
08/12 11:05	2.962	71.083	4265	0	0	0	0	0	0
08/12 14:25	3.101	74.417	4465	0	0	0	0	0	0

B

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
24/03 15:20	0.000	0.000	0	3500	4000	4000	3833.333	0	288.6751
25/03 14:20	0.958	23.000	1380	2000	2000	1800	1933	0	115.4701
26/03 14:00	1.944	46.667	2800	1500	1000	800	1100	0	360.5551
26/03 14:25	1.962	47.083	2825	1500	1000	600	1033	0	450.925
27/03 09:10	2.743	65.833	3950	750	200	0	317	0	388.3727
27/03 14:10	2.951	70.833	4250	600	0	0	200	0	346.4102
28/03 09:20	3.750	90.000	5400	0	0	0	0	0	0

CGR_{RAW}

A

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
02/12 15:25	0.000	0.000	0	3000	3000	3000	3000	0	0
03/12 09:00	0.733	17.583	1055	2700	2500	2600	2600	25	100
03/12 11:56	0.855	20.517	1231	2600	2600	2600	2600	0	0
04/12 09:00	1.733	41.583	2495	1500	2000	2000	1833	25	288.6751
04/12 11:56	1.855	44.517	2671	2200	1500	1800	1833	0	351.1885
04/12 13:25	1.917	46.000	2760	1800	1500	1800	1700	0	173.2051
04/12 14:55	1.979	47.500	2850	2300	1400	1800	1833	10	450.925
05/12 08:40	2.719	65.250	3915	1500	1100	2000	1533	0	450.925
05/12 11:05	2.819	67.667	4060	1500	1000	1200	1233	0	251.6611
05/12 13:35	2.924	70.167	4210	1500	1000	1100	1200	0	264.5751
05/12 15:20	2.997	71.917	4315	1500	900	1000	1133	0	321.455
06/12 09:00	3.733	89.583	5375	1200	500	800	833	0	351.1885
06/12 11:19	3.829	91.900	5514	1100	700	700	833	0	230.9401
06/12 13:30	3.920	94.083	5645	900	450	800	717	0	236.2908
06/12 15:45	4.014	96.333	5780	600	300	400	433	0	152.7525
07/12 08:45	4.722	113.333	6800	500	50	100	217	0	246.6441
07/12 09:35	4.757	114.167	6850	500	25	100	208	0	255.3592
07/12 10:20	4.788	114.917	6895	300	15	50	122	0	155.4295
07/12 11:45	4.847	116.333	6980	250	10	120	127	0	120.1388
07/12 14:03	4.943	118.633	7118	250	0	60	103	0	130.5118
07/12 15:15	4.993	119.833	7190	500	0	60	187	0	273.0079
07/12 20:15	5.201	124.833	7490	120	0	40	53	0	61.10101
08/12 08:30	5.712	137.083	8225	100	0	0	33	0	57.73503
08/12 11:05	5.819	139.667	8380	50	0	0	17	0	28.86751
08/12 16:20	6.038	144.917	8695	12	0	0	4	0	6.928203
08/12 20:10	6.198	148.750	8925	0	0	0	0	0	0

B

Time	Days	Hours	Minutes	R 1	R 2	R 3	Avg	Control	STD
24/03 14:13	0.000	0.000	0	4000	4000	2500	3500	12	866.0254
25/03 14:40	1.019	24.450	1467	2000	2500	2500	2333	0	288.6751
26/03 14:45	2.022	48.533	2912	1750	1750	1750	1750	0	0
27/03 10:15	2.835	68.033	4082	2000	2000	2000	2000	0	0
27/03 14:35	3.015	72.367	4342	2000	2500	2200	2233	0	251.6611
28/03 14:35	4.015	96.367	5782	1500	1200	1500	1400	0	173.2051
29/03 10:00	4.824	115.783	6947	1100	900	1200	1067	0	152.7525
31/03 14:30	7.012	168.283	10097	800	700	500	667	0	152.7525
01/04 09:15	7.793	187.033	11222	500	500	300	433	0	115.4701
02/04 09:55	8.821	211.700	12702	300	450	200	317	0	125.8306
02/04 14:35	9.015	216.367	12982	350	500	200	350	0	150
02/04 17:00	9.116	218.783	13127	300	400	100	267	0	152.7525
03/04 15:15	10.043	241.033	14462	100	150	13	88	0	69.32772
03/04 17:50	10.151	243.617	14617	220	250	1	157	0	135.9301
03/04 18:40	10.185	244.450	14667	180	180	0	120	0	103.923
04/04 11:40	10.894	261.450	15687	40	130	0	57	0	66.58328
04/04 14:15	11.001	264.033	15842	40	100	0	47	0	50.33223
07/04 09:45	13.814	331.533	19892	0	0	0	0	0	0

9.3. Appendix C (Batch eluate characterisation)

COD A

For the COD results: Highlighted blocks signify the colour the contents in the test tube were after the COD test was complete (other than yellow). These samples had to be diluted and retested as the colour change indicates that the reading is not within the range of the test.

Sample	Date	Volume	Blank	Reading				Average	Result	Std	Var	Results			Std
Standard (KHP)	30/11/2013	1	0.00400	0.078	0.079	0.077		0.078	**457.99**	0.001	0.000	**457.99**	**464.18**	**451.80**	6.19
25/75 R1		0.02	0.00400	0.126	0.153	0.122		0.134	**40125.35**	0.017	0.000	**37752.90**	**46108.05**	**36515.10**	5218.00
Sample	Date	Volume	Blank	Reading				Average	Result	Std	Var	Results			Std
Standard (KHP)	12/11/2013	1	0.00375	0.069	0.069	0.072		0.070	**410.02**	0.002	0.000	**403.83**	**403.83**	**422.40**	10.72
25/75 R2		0.02	0.00375	0.058	0.056	0.041		0.052	**14827.81**	0.009	0.000	**16787.66**	**16168.76**	**11527.01**	2875.28
25/75 R3		0.02	0.00375	0.055	0.062	0.062		0.060	**17303.41**	0.004	0.000	**15859.31**	**18025.46**	**18025.46**	1250.63
25/75 C		0.02	0.00375	0.051	0.052	0.055		0.053	**15137.26**	0.002	0.000	**14621.51**	**14930.96**	**15859.31**	644.17
75/25 R1		0.02	0.00375	0.102	0.096	0.09		0.096	**28546.76**	0.006	0.000	**30403.46**	**28546.76**	**26690.06**	1856.70
75/25 R1		0.05	0.00375	0.262	0.0232	0.221		0.169	**20421.64**	0.128	0.016	**31966.19**	**2407.52**	**26891.21**	15805.70
75/25 R2		0.02	0.00375	0.068	0.063	0.054		0.062	**17922.31**	0.007	0.000	**19882.16**	**18334.91**	**15549.86**	2195.42

Sample	Date	Volume	Blank	Reading				Average	Result	Std	Var	Results			Std
Standard (KHP)	18/11/2013	1	0.00775	0.079	0.079	0.082		0.080	**447.16**	0.002	0.000	**440.97**	**440.97**	**459.53**	10.72
50 R1		0.05	0.00775	0.253	0.259	0.269		0.260	**31264.77**	0.008	0.000	**30357.05**	**31099.73**	**32337.53**	1000.50
50 R1		0.02	0.00775	0.114	0.107	0.103		0.108	**31022.36**	0.006	0.000	**32879.06**	**30712.91**	**29475.11**	1722.94
50 R2		0.02	0.00775	0.097	0.079	0.061		0.079	**22048.31**	0.018	0.000	**27618.41**	**22048.31**	**16478.21**	5570.10
50 R3		0.02	0.00775	0.107	0.095	0.09		0.097	**27721.56**	0.009	0.000	**30712.91**	**26999.51**	**25452.26**	2703.63
50 C		0.02	0.00775	0.103	0.112	0.116		0.110	**31744.41**	0.007	0.000	**29475.11**	**32260.16**	**33497.96**	2060.42
50 C		0.05	0.00775	0.259	0.268	0.272		0.266	**32007.45**	0.007	0.000	**31099.73**	**32213.75**	**32708.87**	824.17

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
Standard (KHP)	20/12/2013	1	0.00425	0.081	0.078	0.082	0.080	470.88	0.002	0.000	**475.01**	**456.44**	**481.19**	**12.88**
VW R1		0.05	0.00425	0.382	0.388	0.385	0.385	47129.24	0.003	0.000	**46757.90**	**47500.58**	**47129.24**	**371.34**
VW R1		0.02	0.00425	0.237	0.236	0.246	0.240	72849.69	0.006	0.000	**72024.49**	**71715.04**	**74809.54**	**1704.32**
VW R2		0.02	0.00425	0.242	0.208	0.257	0.236	71611.89	0.025	0.001	**73571.74**	**63050.44**	**78213.49**	**7769.19**
VW R3		0.02	0.00425	0.242	0.29	0.249	0.260	79244.99	0.026	0.001	**73571.74**	**88425.34**	**75737.89**	**8023.85**
VW C		0.02	0.00425	0.228	0.239	0.267	0.245	74396.94	0.020	0.000	**69239.44**	**72643.39**	**81307.99**	**6222.43**
VW C		0.05	0.00425	0.387	0.378	0.39	0.385	47129.24	0.006	0.000	**47376.80**	**46262.78**	**47748.14**	**773.01**
Sample	**Date**	**Volume**	**Blank**	**Reading**			**Average**	**Result**	**Std**	**Var**	**Results**			**Std**
Standard (KHP)	20/12/2013	1	-0.00575	0.064	0.067	0.07	0.067	450.25	0.003	0.000	**431.68**	**450.25**	**468.82**	**18.57**
75/25 R3		0.02	-0.00575	0.083	0.072	0.093	0.083	27360.54	0.011	0.000	**27463.69**	**24059.74**	**30558.19**	**3250.45**
75/25 C		0.02	-0.00575	0.089	0.094	0.094	0.092	30351.89	0.003	0.000	**29320.39**	**30867.64**	**30867.64**	**893.31**
CGR R1		0.05	-0.00575	0.053	0.058	0.063	0.058	7890.98	0.005	0.000	**7272.08**	**7890.98**	**8509.88**	**618.90**
CGR R2		0.05	-0.00575	0.074	0.077	0.072	0.074	9912.72	0.003	0.000	**9871.46**	**10242.80**	**9623.90**	**311.51**
CGR R3		0.05	-0.00575	0.053	0.063	0.05	0.055	7560.90	0.007	0.000	**7272.08**	**8509.88**	**6900.74**	**842.55**
CGR C		0.05	-0.00575	0.081	0.082	0.082	0.082	10820.44	0.001	0.000	**10737.92**	**10861.70**	**10861.70**	**71.46**

COD B

Sample	Date	Volume	Blank	Reading			Average	Result	Std	Var	Results			Std
Standard (KHP)	02/04/2014	1	0.00200	0.061	0.069	0.062	0.064	**383.72**	0.004	0.000	**365.15**	**414.66**	**371.34**	26.98
25 R1		0.05	0.00200	0.103	0.056	0.082	0.080	**9696.10**	0.024	0.001	**12501.78**	**6684.12**	**9902.40**	2914.31
25 R2		0.05	0.00200	0.044	0.04	0.05	0.045	**5281.28**	0.005	0.000	**5198.76**	**4703.64**	**5941.44**	623.01
25 R3		0.05	0.00200	0.032	0.037	0.04	0.036	**4249.78**	0.004	0.000	**3713.40**	**4332.30**	**4703.64**	500.25
25 C		0.05	0.00200	0.056	0.041	0.045	0.047	**5611.36**	0.008	0.000	**6684.12**	**4827.42**	**5322.54**	961.46
50 R1		0.05	0.00200	0.081	0.093	0.079	0.084	**10191.22**	0.008	0.000	**9778.62**	**11263.98**	**9531.06**	937.25
50 R2		0.05	0.00200	0.082	0.085	0.085	0.084	**10149.96**	0.002	0.000	**9902.40**	**10273.74**	**10273.74**	214.39
Sample	**Date**	**Volume**	**Blank**	**Reading**			**Average**	**Result**	**Std**	**Var**	**Results**			**Std**
Standard (KHP)	03/04/2014	1	0.00325	0.067	0.065	0.06	0.064	**375.98**	0.004	0.000	**394.55**	**382.17**	**351.23**	22.31
75 R1		0.05	0.00325	0.212	0.214	0.21	0.212	**25839.08**	0.002	0.000	**25839.08**	**26086.64**	**25591.52**	247.56
75 R2		0.05	0.00325	0.217	0.22	0.232	0.223	**27200.66**	0.008	0.000	**26457.98**	**26829.32**	**28314.68**	982.47
75 R3		0.05	0.00325	0.206	0.196	0.209	0.204	**24807.58**	0.007	0.000	**25096.40**	**23858.60**	**25467.74**	842.55
75 C		0.05	0.00325	0.204	0.219	0.202	0.208	**25385.22**	0.009	0.000	**24848.84**	**26705.54**	**24601.28**	1150.11
50 R3		0.05	0.00325	0.068	0.099	0.095	0.087	**10407.84**	0.017	0.000	**8014.76**	**11851.94**	**11356.82**	2087.20
50 C		0.05	0.00325	0.067	0.06	0.066	0.064	**7560.90**	0.004	0.000	**7890.98**	**7024.52**	**7767.20**	468.62
Sample	**Date**	**Volume**	**Blank**	**Reading**			**Average**	**Result**	**Std**	**Var**	**Results**			**Std**
Standard (KHP)	08/04/2014	1	0.00000	0.0067	0.071	0.081	0.053	**327.40**	0.040	0.002	**41.47**	**439.42**	**501.31**	249.55
75 R1		0.02	0.00000	0.088	0.083	0.089	0.087	**26819.00**	0.003	0.000	**27231.60**	**25684.35**	**27541.05**	994.74
75 R2		0.02	0.00000	0.075	0.083	0.0108	0.056	**17411.72**	0.040	0.002	**23208.75**	**25684.35**	**3342.06**	12247.39
75 R3		0.02	0.00000	0.101	0.116	0.125	0.114	**35277.30**	0.012	0.000	**31254.45**	**35896.20**	**38681.25**	3751.88
75 C		0.02	0.00000	0.078	0.083	0.114	0.092	**28366.25**	0.020	0.000	**24137.10**	**25684.35**	**35277.30**	6034.94
VW R1		0.02	0.00000	0.21	0.228	0.2	0.213	**65809.70**	0.014	0.000	**64984.50**	**70554.60**	**61890.00**	4390.85
VW R2		0.02	0.00000	0.186	0.181	0.235	0.201	**62096.30**	0.030	0.001	**57557.70**	**56010.45**	**72720.75**	9233.51
Sample	**Date**	**Volume**	**Blank**	**Reading**			**Average**	**Result**	**Std**	**Var**	**Results**			**Std**
Standard (KHP)	10/04/2014	1	0.00375	0.071	0.073	0.076	0.073	**430.65**	0.003	0.000	**416.21**	**428.59**	**447.16**	15.58
CGR R1		0.05	0.00375	0.108	0.099	0.107	0.105	**12491.47**	0.005	0.000	**12904.07**	**11790.05**	**12780.29**	610.59
CGR R2		0.05	0.00375	0.102	0.096	0.1	0.099	**11831.31**	0.003	0.000	**12161.39**	**11418.71**	**11913.83**	378.15
CGR R3		0.05	0.00375	0.109	0.108	0.107	0.108	**12904.07**	0.001	0.000	**13027.85**	**12904.07**	**12780.29**	123.78
CGR C		0.05	0.00375	0.107	0.104	0.112	0.108	**12862.81**	0.004	0.000	**12780.29**	**12408.95**	**13399.19**	500.25
VW R3		0.02	0.00375	0.199	0.253	0.187	0.213	**64752.41**	0.035	0.001	**60420.11**	**77130.41**	**56706.71**	10879.27
VW C		0.02	0.00375	0.189	0.186	0.213	0.196	**59491.76**	0.015	0.000	**57325.61**	**56397.26**	**64752.41**	4579.44

Sample	Date	Volume	Blank	Reading				Average	Result	Std	Var	Results			Std
Standard (KHP)	30/05/2014	1	0.00625	0.0058	0.065	0.064		0.045	**239.41**	0.034	0.001	**-2.79**	**363.60**	**357.41**	209.77
VW R1		0.02	0.00625	0.276	0.187	0.206		0.223	**67073.29**	0.047	0.002	**83474.14**	**55933.09**	**61812.64**	14504.59
VW R2		0.02	0.00625	0.276	0.276	0.265		0.272	**82339.49**	0.006	0.000	**83474.14**	**83474.14**	**80070.19**	1965.27
VW R3		0.02	0.00625	0.21	0.164	0.218		0.197	**59130.74**	0.029	0.001	**63050.44**	**48815.74**	**65526.04**	9018.40
VW C		0.02	0.00625	0.25	0.258	0.312		0.273	**82648.94**	0.034	0.001	**75428.44**	**77904.04**	**94614.34**	10436.01
75 R1		0.02	0.00625	0.125	0.1	0.085		0.103	**30042.44**	0.020	0.000	**36747.19**	**29010.94**	**24369.19**	6253.14
75 R2		0.02	0.00625	0.103	0.098	0.099		0.100	**29010.94**	0.003	0.000	**29939.29**	**28392.04**	**28701.49**	818.73
Sample	**Date**	**Volume**	**Blank**	**Reading**				**Average**	**Result**	**Std**	**Var**	**Results**			**Std**
Standard (KHP)	02/06/2014	1	0.00350	0.072	0.071	0.074		0.072	**426.01**	0.002	0.000	**423.95**	**417.76**	**436.32**	9.45
CGR R1		0.05	0.00350	0.095	0.096	0.098		0.096	**11490.91**	0.002	0.000	**11325.87**	**11449.65**	**11697.21**	189.08
CGR R2		0.05	0.00350	0.111	0.097	0.09		0.099	**11862.25**	0.011	0.000	**13306.35**	**11573.43**	**10706.97**	1323.54
CGR R3		0.05	0.00350	0.108	0.107	0.112		0.109	**13058.79**	0.003	0.000	**12935.01**	**12811.23**	**13430.13**	327.49
CGR C		0.05	0.00350	0.082	0.097	0.082		0.087	**10335.63**	0.009	0.000	**9716.73**	**11573.43**	**9716.73**	1071.97
VW R3		0.02	0.00350	0.097	0.082	0.111		0.097	**28830.43**	0.015	0.000	**28933.58**	**24291.83**	**33265.88**	4487.91
VW C		0.02	0.00350	0.09	0.08	0.079		0.083	**24601.28**	0.006	0.000	**26767.43**	**23672.93**	**23363.48**	1882.31

Sample	Date	Volume	Blank	Reading				Average	Result	Std	Var	Results			Std
Standard (KHP)	10/06/2014	1	0.00000	0.07	0.067	0.07		0.069	**427.04**	0.002	0.000	**433.23**	**414.66**	**433.23**	10.72
VW R1		0.01	0.00000	0.096	0.082	0.075		0.084	**52193.90**	0.011	0.000	**59414.40**	**50749.80**	**46417.50**	6617.70
VW R2		0.01	0.00000	0.09	0.107	0.101		0.099	**61477.40**	0.009	0.000	**55701.00**	**66222.30**	**62508.90**	5335.96
VW R3		0.01	0.00000	0.085	0.096	0.096		0.092	**57145.10**	0.006	0.000	**52606.50**	**59414.40**	**59414.40**	3930.54
VW C		0.01	0.00000	0.079	0.09	0.087		0.085	**52812.80**	0.006	0.000	**48893.10**	**55701.00**	**53844.30**	3519.21

pH

2013 A post batch	pH						Temperature (°C)				
	R1	R2	R3	Average	Control	Std Dev	R1	R2	R3	Average T	Control
CGR Raw	7.97	8.19	8.04	8.07	6.71	0.11	24	22	23	23	23
25/75	8.07	7.65	7.81	7.84	5.93	0.21	23	23	23	23	23
50/50	6.28	6.73	7.11	6.71	4.27	0.42	24	24	25	24.33333	24
75/25	6.44	6.46	6.42	6.44	4.38	0.02	23	23	23	23	23
Veg waste	4.08	4.16	4.08	4.11	4.10	0.05	25	25	25	25	25

2014 B post batch	pH						Temperature (°C)				
	R1	R2	R3	Average	Control	Std Dev	R1	R2	R3	Average T	Control
CGR Raw	8.19	8.03	8.28	8.17	7.06	0.13	20	22	23	21.66667	20
25/75	8.11	8.07	8.00	8.06	6.59	0.06	23	23	23	23	23
50/50	7.89	7.84	7.66	7.80	5.30	0.12	23	23	23	23	24
75/25	6.07	6.13	6.16	6.12	4.45	0.05	23	24	24	23.66667	23
Veg waste	4.48	4.38	4.31	4.39	3.97	0.09	24	23	20	22.33333	20

NH_3 and NOx	NH_3						Nox					
	sample vol/mL	HCl Conc	HCl vol/mL	NH3-N (mg/L)	Ave	Std dev	sample vol/mL	HCl Conc	HCl vol/mL	Nox(mg/L)	Ave	Std dev
Batches A												
Veg waste R1			0	**0**					4.71	**659.4**		
Veg waste R2			0	**0**					4.25	**595**		
Veg waste R3			0	**0**	**0.00**	**0.00**			4.51	**631.4**	628.60	32.29
Veg waste C			0	**0**					4.49	**628.6**		
CGR raw R1			0.29	**40.6**					0.26	**36.4**		
CGR raw R2			0.4	**56**					0.33	**46.2**		
CGR raw R3			0.37	**51.8**	**49.47**	**7.96**			0.39	**54.6**	45.73	9.11
CGR raw C			0.47	**65.8**					0.46	**64.4**		
75/25 R1			2.94	**411.6**					3.73	**522.2**		
75/25 R2			2.96	**414.4**					3.99	**558.6**		
75/25 R3			2.8	**392**	**406.00**	**12.20**			4.18	**585.2**	555.33	31.63
75/25 C			0	**0**					1.74	**243.6**		
50/50 R1			2.66	**372.4**					3.74	**523.6**		
50/50 R2			3.29	**460.6**					3.76	**526.4**		
50/50 R3			2.64	**369.6**	**400.87**	**51.75**			2.69	**376.6**	475.53	85.69
50/50 C			0	**0**					1.04	**145.6**		
25/75 R1			0.5	**70**					0.64	**89.6**		
25/75 R2			0.68	**95.2**					0.64	**89.6**		
25/75 R3			0.6	**84**	**83.07**	**12.63**			0.62	**86.8**	88.67	1.62
25/75 C			0.5	**70**					0.67	**93.8**		

NH3 and NOx	NH_3							Nox					
	sample vol/mL	HCl Conc	HCl vol/mL	NH3-N (mg/L)	Ave	Std dev		sample vol/mL	HCl Conc	HCl vol/mL	Nox(mg/L)	Ave	Std dev
Batches B													
Veg waste R1			4.92	**688.8**					0.01	4.31	**603.4**		
Veg waste R2			4.6	**644**						4.32	**604.8**		
Veg waste R3			4.53	**634.2**	**655.67**	**29.11**				4.31	**603.4**	603.87	0.81
Veg waste C			3.57	**499.8**						2.64	**369.6**		
CGR raw R1			0.97	**135.8**					0.10	0.91	**127.4**		
CGR raw R2			1.11	**155.4**						0.79	**110.6**		
CGR raw R3			0.96	**134.4**	**141.87**	**11.74**				0.84	**117.6**	118.53	8.44
CGR raw C			1.16	**162.4**						0.83	**116.2**		
75/25 R1			0.95	**133**					0.10	3.68	**515.2**		
75/25 R2			0.99	**138.6**						4.50	**630**		
75/25 R3			0.19	**26.6**	**99.40**	**63.11**				4.62	**646.8**	597.33	71.62
75/25 C			0.98	**137.2**						1.20	**168**		
50/50 R1			0.95	**133**					0.10	1.20	**168**		
50/50 R2			0.99	**138.6**						1.26	**176.4**		
50/50 R3			1.19	**166.6**	**146.07**	**18.00**				1.07	**149.8**	164.73	13.60
50/50 C			0.98	**137.2**					0.01	0.87	**121.8**		
25/75 R1			0.54	**75.6**					0.10	0.66	**92.4**		
25/75 R2			0.52	**72.8**						0.75	**105**		
25/75 R3			0.58	**81.2**	**76.53**	**4.28**				0.72	**100.8**	99.40	6.42
25/75 C			0.51	**71.4**						0.50	**70**		

BOD_5

Sample	Date started	Readings				
		1	2	3	C	Average
A						
Veg waste post batch	23/01/2014	631	267	438	299	445.3333333
CGR raw post batch	23/01/2014	1122	855	1133	1624	1036.666667
75/25 post batch	23/01/2014	1550	1710	1592	1186	1617.333333
50/50 post batch	23/01/2014	1742	7456	1598	1379	3598.666667
25/75 post batch	23/01/2014	2781	1999	1165	1646	1981.666667
B						
Veg waste post batch	25/03/2014	278	417	278	417	324.3333333
CGR raw post batch	2014/07/04	513	481	256	1090	416.6666667
75/25 post batch	25/03/2014	1721	1592	1090	374	1467.666667
50/50 post batch	17/03/2014	1486	1453	1486	481	1475
25/75 post batch	28/03/2014	1368	855	673	1860	965.3333333

9.4. Appendix D (equations used in Appendix)

Distiller equation:

Amount of NH_3 or NO_x (mg/l) = m * M * Vh *1000/Vs

m = atomic number of nitrogen= 14

M = molarity of HCL = 0.1

Vh = volume of HCL added (from Titrator)

Vs = volume of sample

Spectro-photometer (COD) equation:

COD (mg/l) = ($\underline{S}$ –$\underline{Sb}$) * abs/ Vs

$\underline{S}$ = average Spectro-photometer sample reading

$\underline{Sb}$= average Spectro-photometer blank reading

abs= absorption factor

Vs= volume of the sample

9.5. Appendix E (Summary of all Results)

Test/Substrate	VW A	VW B	CGR A	CGR B	75/25 A	75/25 B	50/50 A	50/50 B	25/75 A	25/75 B	MLS
Characterisation											
Solid											
MC (%)	90.26	88.62	51.40	60.30	79.94	80.11	76.92	76.28	67.97	66.91	
TS (%)	9.74±1.68	11.39±0.47	48.60 ±2.85	39.70±1.21	20.06±1.15	19.89±2.87	23.08±2.32	23.72±0.22	32.03 ±3.24	33.09±7.63	
VS (%)	90.65±1.35	91.16±1.45	80.21±2.79	74.75±4.26	80.75±1.76	76.91±4.72	77.69±2.63	67.17±8.93	78.46±2.05	71.94±4.91	
RI7 (mg O_2 /g DM)	193.00±107.64	753.99±110.84	95.26±65.21	135.05±79.36	350.85±36.95	338.34±170.63	298.22 ±7.62	361.08 ±65.72	234.84±13.17	309.23±8.12	
Total C (%)	41.10	41.80	36.50	42.20	39.20	48.30	35.20	42.20	35.50	39.40	
Total N (%)	2.62	0.51	1.30	1.60	1.83	2.12	1.43	1.63	1.42	1.54	
C/N Ratio	15.69	81.96	28.08	26.38	21.42	22.78	24.62	25.89	25.00	25.58	
Eluate											
TS (g/l)	40.28±1.09	50.23±5.36	7.08±0.04	5.14±0.05	30.23±6.47	28.80±0.48	17.47±0.34	11.85±0.10	9.64 ±0.02	13.78 ±0.04	13.44±0.01
VS (g/l)	32.86±0.98	36.30±5.76	4.15±0.01	2.82±0.02	25.59±3.35	21.97±0.29	12.305±0.335	7.97±0.13	5.78±0.02	8.04±0.04	3.78±0.87
pH	4.30	3.96	6.64	6.23	4.36	3.85	4.89	4.17	6.13	4.76	7.58
COD (mg/l)	44767.1±5882.26	46582.54±71.46	4291.04±285.86	3053.24±515.34	24756.00±535.98	32100.28±189.08	18463.85±4737.05	11965.40±397.90	12460.52±4580.42	10933.90±71.46	7468.06±257.67
BOD5 (mg/l)	979.67	1040.33	897.67	1514.33	1221.67	1257.33	1421.33	1054.33	1817.00	1204.00	203.33
NH3-N (mg/l)	0.00	356.07	29.87	49.00	0.00	218.40	0.00	102.20	33.13	77.00	10.73
NOx-N (mg/l)	301.47	161.47	49.93	36.40	193.20	139.07	120.87	75.13	51.33	46.20	816.20

Test/Substrate	*VW A	VW B	CGR A	CGR B	75/25 A	75/25 B	50/50 A	50/50 B	25/75 A	25/75 B
Post Batch tests										
Eluate										
pH	4.11	4.39	8.07	8.17	6.44	6.12	6.71	7.80	7.84	8.06
COD (mg/l)	74568.85	56938.80	8454.86	12408.95	24609.87	26502.67	26930.75	10249.67	24085.53	6409.05
BOD5 (mg/l)	445.33	324.33	1036.67	416.67	1617.33	1467.67	3598.67	1475.00	1981.67	965.33
NH3-N (mg/l)	0.00	655.67	49.47	141.87	406.00	99.40	400.87	146.07	83.07	76.53
NOx-N (mg/l)	628.60	603.87	45.73	118.53	555.33	597.33	475.53	164.73	88.67	99.40
Time for Total denitrification (hours)	407*	465.75	148.75	331.53	125.00	243.33	293.33	91.83	74.42	90.00
Equations (y=)	$7.8145x^2 - 250.06x + 2066.7$	$2.4272x^2 - 90.903x + 850$	$34.532x^2 - 698.06x + 3000$	$20.014x^2 - 529.84x + 3500$	$47.774x^3 - 347.25x^2 - 5.233x + 2700$	$12.004x^3 - 161.86x^2 + 171.04x + 2683.1$	$22.724x^2 - 523.2x + 3000$	$306.28x^2 - 2173.8x + 3833.3$	$282.02x^2 - 1680.7x + 2500$	$261.53x^2 - 2002.9x + 3833.3$

* did not reach full denitrification