

**'IMPROVING CONTAMINATED SEWAGE SLUDGE-
AN EXPERIMENT BASED ASSESSMENT OF SELECTED TREATMENT OPTIONS
FOR THE SASOL SEWAGE WORKS IN SASOLBURG (SOUTH AFRICA)'**

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ABSTRACT

Sasol Chemical Industries (SCI) located in Sasolburg, South Africa (SA), have since the early fifties produced fuels and waxes commercially, and recently diversified to produce a wider range of other chemicals. The Sasol One processes as with all industrial processes generate various waste streams. One such waste stream in the case of the Sasol One Site, which was the main theme of this study is the so-called poor quality sewage sludge generated during the treatment of domestic and industrial effluent in biological oxidation ponds at the sewage works. The poor quality of the sludge is related to the metals and pathogenic organisms present in the sludge. Furthermore, the stockpiling area where the sludge is stored, is running out of space thus creating an ongoing environmental and operational challenge to the management of the sewage works.

The primary objective of the study was therefore to identify suitable sludge treatment options by means of comparing three sludge treatment techniques, viz; Composting, ASP (Activated Sludge Pasteurisation) and SLASH (treatment of sludge with ash and / or lime). It was anticipated that one or a combination of these three techniques would improve the quality of the sludge in terms of its metal and pathogenic content and furthermore, as a more beneficial sludge, possibly support the humus requirements for the revegetation efforts during the rehabilitation activities on the Sasol One waste site.

In evaluating these possible treatment options the sludge was subjected to laboratory bench experiments and field plant trials. To arrive at an answer as to which treatment option was the best, a decision matrix was developed that compared and scored the treatment options using various weighted criteria. The criteria used considered (i) the present legal sludge treatment requirements in terms of the Water Research Commission guidelines;(ii) the sustainability of the option that would be the most likely one to succeed in the long term;(iii) the economic viability defined as a capital and operational expenditure required that would give an indication of the financial viability of the preferred option and; (iv) the technical feasibility being defined as the potential for the preferred option to achieve full scale operation and a measure of confidence to implement the option or not.

The experiments conducted and results achieved indicated that all three treatment options significantly improved the quality of the sludge in terms of metal and pathogenic content. However the composted sludge scored the highest points followed by SLASH and lastly ASP. Based on these experiments and the decision matrix used, Composting performed best by achieving a satisfactory score based on the WRC classification guidelines including cost and technical feasibility. With respect to this outcome the **Composting** was recommended as the preferred treatment option.

OPSOMMING

Sasol Chemiese Industrieë (SCI), geleë te Sasolburg, Suid-Afrika (SA), produseer sedert die vroeë vyftigs brandstowwe en wasse op 'n kommersiële basis, en het onlangs uitgebrei om 'n wyer reeks chemikalieë te lewer. Soos wat die geval is met alle industriële prosesse, genereer Sasol Een 'n verskeidenheid afvalprodukte. Die hooftema van hierdie studie is een van hierdie afvalprodukte, naamlik die sogenaamde swak gehalte rioolslyk wat gedurende die verwerking van huishoudelike en industriële rioolwater in biologiese oksidasiedamme by die rioolwerke geproduseer word. Die swak gehalte van die rioolslyk is te wyte aan die metale en patogeniese organismes wat in die slyk teenwoordig is. Die area waar die rioolslyk geberg word, is ook besig om vinnig vol te raak, en stel sodoende 'n deurlopende omgewings- en operasionele uitdaging aan die bestuur van die rioolwerke.

Die hoofdoel van die studie was dus om geskikte maniere van rioolslykbehandeling te identifiseer deur middel van die vergelyking van drie behandelingstegnieke, naamlik Kompostering, ASP (Pasteurisering van geaktiveerde rioolslyk) en SLASH (behandeling van rioolslyk met as en/of kalk). Dit is in die vooruitsig gestel dat een, of 'n kombinasie van hierdie drie tegnieke, die gehalte van die rioolslyk sou verbeter in terme van die metaal- en patogeniese inhoud daarvan. Die verbeterde rioolslyk kan moontlik ook bydra tot die humusvereistes vir die planthervestiging gedurende die rehabilitasieproses van die Sasol Een afvalterrein.

Gedurende die evaluering van hierdie moontlike behandelingsmetodes is die rioolslyk onderwerp aan laboratoriumeksperimente en veldtoetse. 'n Besluitnemingsmatriks is ontwikkel wat die behandelingsopsies met mekaar vergelyk en daaraan punte toeken – verskeie kriteria, waaraan verskillende gewigte toegeken is, is gebruik. Hierdie kriteria het die volgende aspekte in ag geneem:

- i) Die huidige wetlike vereistes vir rioolslykbehandeling in terme van die Waternavorsingskommissie se riglyne;
- ii) Die volhoubaarheid van die opsie wat op die lange duur die mees suksesvolle een sal wees;
- iii) Die ekonomiese lewensvatbaarheid, uitgedruk as 'n kapitale- en operasionele uitgawe, wat 'n aanduiding sal gee van die finansiële lewensvatbaarheid van die gekose opsie, en;

iv) Die tegniese uitvoerbaarheid, gedefinieer as die potensiaal van die gekose opsie om volskaalse werkverrigting te bereik, asook 'n mate van vertroue om die keuse te implementeer al dan nie.

Die eksperimente wat uitgevoer is en die resultate behaal dui daarop dat al drie die behandelingsopsies 'n beduidende verbetering in die gehalte van die rioolslyk teweeg gebring het ten opsigte van metaal- en patogeniese inhoud. Die gekomposteerde rioolslyk het die meeste punte behaal, gevolg deur SLASH, met ASP in die laaste plek. As hierdie eksperimente en die gevolgtrekkingsmatriks in ag geneem word, dan het Kompostering die beste presteer deurdat dit 'n bevredigende telling behaal het, gebaseer op die klassifikasie-riglyne van die WNK, koste en tegniese uitvoerbaarheid ingesluit. Met inagneming van hierdie resultaat word **Gekomposteerde rioolslyk** aanbeveel as die gekose behandelingsopsie.

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ABBREVIATIONS

BOD	: Biochemical oxygen demand (mg/l)
COD	: Chemical Oxygen Demand (mg/l)
T	: Temperature (°C)
CO₂	: Carbon Dioxide (mol % CO₂)
OA	: Oxygen Absorbed (mg/l)
ASP	: Activated Sludge Pasteurisation
CARA	: Conservation of Agricultural Resources Act
DEAT	: Department of Environmental Affairs and Tourism
DOH	: Department of Health
DL	: Detection limit of the instrument
DWAF	: Department of Water Affairs and Forestry
DS	: Dry Solids
ECA	: Environment Conservation Act
ERWAT	: East Rand Water Care Company
HA	: Health Act
MSW	: Municipal Solid Waste
NEMA	: National Environmental Management Act
NWA	: National Water Act
PETRO	: Pond enhanced treatment and operation
SASOL	: South African Gas and Oil Corporation
SLASH	: Sludge, lime and ash addition
SW	: Sewage Works
WSA	: Water Services Act
WRC	: Water Research Commission
WWTW	: Wastewater Treatment Works

Chapter 1

Introduction

1.1 Problem Statement and Research Motivation

Sasol Chemical Industries (SCI) located in Sasolburg, South Africa (SA), have since the early fifties produced fuels and waxes commercially, and recently diversified to produce a wider range of other chemicals (COLLINGS, 2002:9). These chemicals include ammonia, solvents and phenols. The dominant process over the historical existence of the site has been the gasification process and Fisher Tropsch conversion by which coal is essentially turned into fuel (such as petrol and diesel) and other hydrocarbon based products (COLLINGS, 2002:12). There are various Sasol Operations in Sasolburg, including the Sasol One Site, Sasol Midland Site and Natref, which is a 50% subsidiary of Sasol and Total. For the purpose of this dissertation the Sasol One Site with its waste disposal area and its Sewage Works (SW) will be covered in this study (Fig.1). During 2004 the Sasol One Site has changed over from coal to natural gas as a primary hydrocarbon feedstock. This change in feedstock has brought about many environmental improvements for the Site, such as improvements in air emissions, water use reduction and solid waste (ash) reduction.

The above described processes, as is the case with all industrial processes generate various waste streams. The main theme of this dissertation is sewage sludge generated by the treatment of a mixture of domestic and industrial effluent at the SW on the Sasol One Site in Sasolburg. Unfortunately, the change-over to natural gas did not bring about a reduction in the sewage sludge as it did with other solid and liquid wastes on site.

The SW treats wastewater not only from the Sasol production plants, but also from a range of non Sasol-related factories such as an oil refinery, a fertiliser factory and a rubber manufacturer, as well as domestic effluents from adjacent residential areas in Sasolburg as indicated in Figure1 (WATES *et al.*, 1995:4). Using mechanical filtering combined with biological oxidation, the SW produces approximately 30m³ of fresh sewage sludge per day (wet density). Next dewatering takes place in dedicated drying beds. After reducing the volume by approximately 50%, the sludge is stockpiled at a designated area (Fig.1) within the waste disposal site (SWART, 2007).

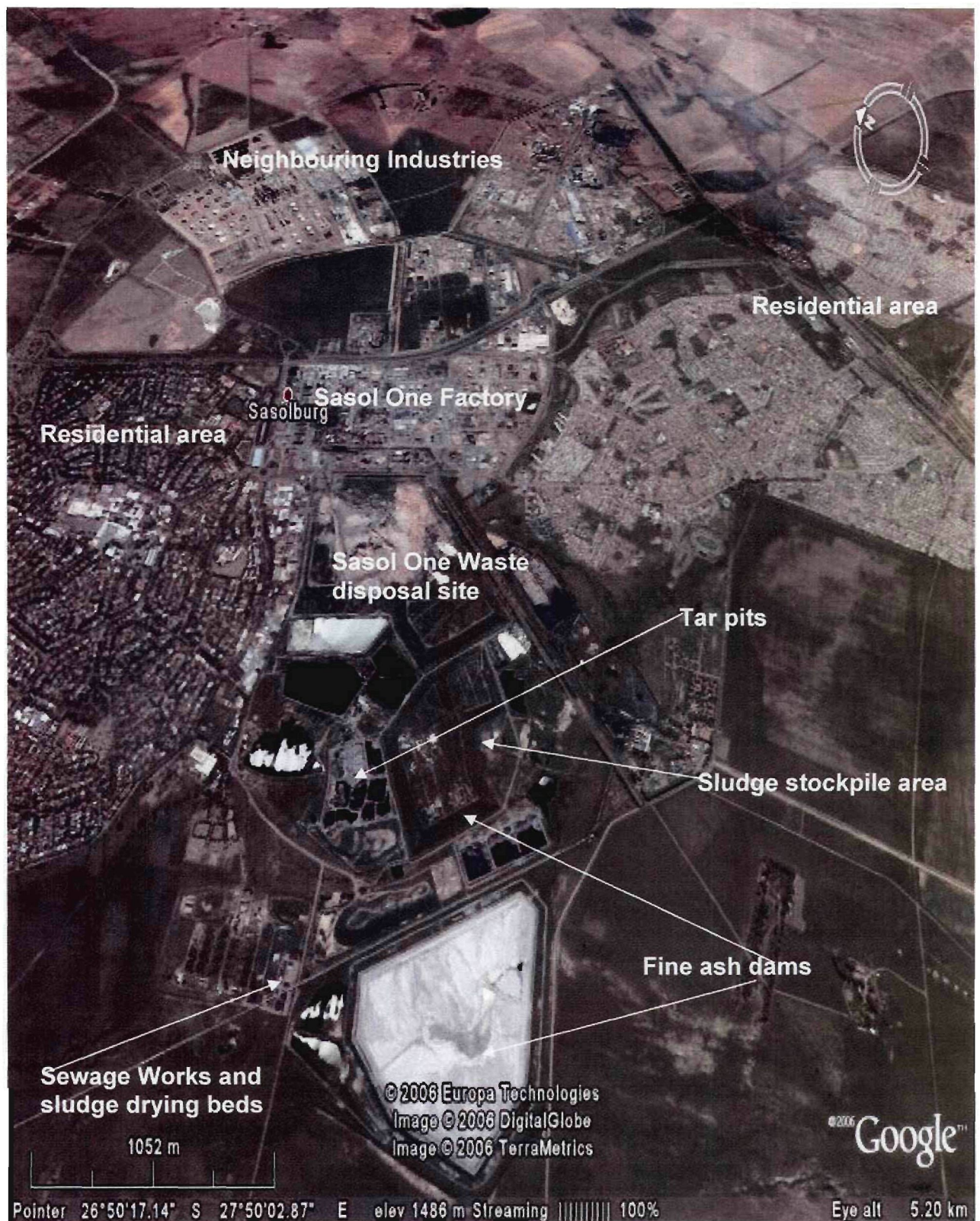


Figure 1: Layout and catchment area of the Sasol waste site and SW including residential areas and neighbouring industries (GOOGLE EARTH, 2006)

The stockpiling area is located on the Sasol One waste disposal site between an existing fine ash dam and an emergency dam (Fig.1). The waste disposal site contains various waste types together with their storage areas. These waste types range from tars and oils, spent catalyst, fine ash and coarse ash materials. This entire site is presently undergoing rehabilitation to deal with these legacy wastes that have originated from the gasification era (JONES & WAGENER, 2001:1-16).

As indicated, since the introduction of natural gas to the Sasol One Site, most of these wastes have been eliminated. As part of the rehabilitation efforts there will be an eventual requirement to re-vegetate these areas. How far treated sewage sludge could be used as a covering substrate necessary for vegetation to be established is currently under investigation.

The sewage sludge stockpile area covers approximately 4000m², and has no liner or any drainage system besides a natural drainage towards the toe drains of the adjacent fine ash dam. The run-off from this area is channelled along the toe drain system of the fine ash dam. It then runs into a collection dam from where it is finally pumped back to the SW. The total storage capacity of this area is estimated to be ca. 20000m³, of which 18000m³ has been taken up presently (SWART, 2007). Therefore there is a need to find alternative uses for the sewage sludge other than storage. Such alternative uses may include applications in agriculture (fertiliser, soil amelioration) and composting (gardening).

However, due to the high concentrations of certain heavy metals (largely originating from industrial sources) and pathogens (mainly of domestic origin) which exceed limits of SA guidelines (WRC & DWAF, 2006a:25) for such applications, methods of improving the sludge quality had to be found to allow for uses other than continued stockpiling.

It did not escape our attention that such treatment might be most efficient when applied to the differently contaminated sewage streams from industry and domestic areas before they mix. This could reduce the total volume of sludge polluted by both heavy metals and pathogens and allow for more specific and efficient treatment of each sludge type. This might even produce revenue by generating extractions of metals with commercial value such as copper commonly found at high concentrations in industrial wastewater. Owing to the need for more extensive investigations, this approach has been postponed in favour of finding options for improving the quality of the currently produced sludge to standards acceptable for

uses alternative to stockpiling. These improvement options will be the focus of this dissertation.

The research design thus comprises mainly of three major elements based on a literature survey, and communication with other persons, through which three potentially suitable treatment options were identified. After selecting by way of experiments and defining a set of criteria to evaluate the degree of suitability of each of the three identified options, a decision supporting matrix was developed to assist with the final treatment selection.

The evaluation criteria included **technology performance** (to what degree does each option achieve the desired reduction of pollution levels to acceptable standards, as determined by the WRC guidelines), **cost implications** (investment and running costs) as well as **sustainability or environmental friendliness** of the option. In order to assess the technology performance, a series of experiments was conducted in which each identified treatment option was applied to the sewage sludge. Based on these results, combined with the performance in respect to the other evaluation criteria, the most appropriate treatment option was chosen. Previous work, conducted by Sasol personnel on classifying the sludge quality according to the 1997 Permissible Utilisation and Disposal of Sewage sludge guidelines (WRC, 1997: 3), showed that the sludge Cu and Mo content posed a problem. However, the greatest concern with the sludge was its very high pathogen content indicated by the high prevalence of *Ascaris ova* and faecal coliforms in the sewage sludge (RAGOONANDAN, 2005:4).

At present, as indicated above, the sludge is stockpiled and not beneficially used due to its potentially dangerous and hazardous properties, subsequently posing a threat to workers and the receiving environment. In terms of the new Water Research Commission Guidelines (WRC) for the utilisation and disposal of wastewater sludge, the requirement has remained the same where the sludge is required to be either disposed of, or reused. From a legal perspective this also presents challenges (WRC & DWAF, 2006a:10).

Based on literature reviews three principally suitable treatment options for the sludge produced at the Sasol SW have been identified viz; **Composting, Activated Sludge Pasteurization and SLASH (treatment of sludge with ash and / or lime)**.

1.2 Objectives of the study

The primary objective of this study is thus to analyse the identified options and select the most suitable one. For this a **three-step** research design has been adopted namely:

- Application of the three pre-selected treatment options to Sasol sludge in pilot scale experiments to assess their performance regarding sludge improvement and associated costs (generation and evaluation of primary data).
- Selection and definition of criteria to assess the overall performance of the tested treatment options, including treatment efficiency (i.e. removal of pathogens, lowering heavy metal concentrations), associated operational costs and capital expenditure, environmental friendliness etc.
- Design of a decision support matrix in which above selected criteria are weighted to assist with the final selection of the most suitable treatment option for sewage sludge at the Sasolburg SW.

1.3 Methodological approach and scope of the study

Three different sludge treatment techniques, namely; ASP, SLASH and Composting, were investigated on a pilot scale at experimental level, to determine if they could remove pathogens and metals from the sewage sludge. Composting and SLASH were evaluated at pilot scale, while ASP could only be evaluated at a full scale commercial plant in Daspoort, Pretoria, SA. The experimental methods followed for each technique, evaluated with results, are outlined in Chapter Five of this dissertation.

A literature review was conducted on the three selected options for the sewage sludge treatment at the Sasol One Site SW. This literature review together with the relevant background theory is covered in Chapter Three.

The assessment of the selected options, using a decision matrix where defined criteria were used to assess and identify a preferred option or options, is covered in Chapter Four.

In summary, the study activities thus included:

- Classifying the untreated sludge by using the guidelines for the utilisation and disposal of wastewater sludge.
- Treat the sludge by using three different treatment options, namely: ASP, SLASH and Composting.
- Reclassify the sludge based on the efficiencies of the treatment options to assess whether there was an improvement in the sludge classification.
- Apply the decision matrix criteria and make a recommendation as to the preferred option and possible future research work.

Chapter 2

Overview of the Sasolburg Sewage Treatment Works

The Sasol One SW receives wastewater from three sources:

- (a) Domestic sewage from residential and industrial areas in Sasolburg town and the Sasol One factory
- (b) Industrial wastewater from neighbouring industries
- (c) Combined chemical wastewater streams from the Sasol One factory

The processes selected to treat the above mentioned sources is referred to as an integrated biological system where anaerobic biodegradation takes place in an aerobic-anaerobic pond reactor supplemented by aerobic biodegradation in biofilters. This process is known as the PETRO process, which is a propriety name and is an abridgement of the concept "Pond Enhanced Treatment and Operation" (WATES *et al.*, 1995:2).

According to WATES *et al.* (1995:2) the main reasons for selecting this process was largely due to the low operating and maintenance costs, ease of operation, low sludge production, and efficient pre-treating of the domestic wastewater stream to reduce chemical oxygen demand (COD) and ammonia loads going to the biofilters.

Processing of wastewater through the Sasol One SW starts with the effluent from the domestic sewer (A) that contains the domestic wastewater from the Sasolburg residential areas and neighbouring industries. This stream undergoes a physical process to remove floating solids. These solids (rags, plastic bags, etc) are disposed of at the municipal dumpsite. The stream then goes to the Petroponds where aerobic and anaerobic digestion of organics occurs. The sludge from the Petroponds goes to the drying beds (E) and the settled-out water to the mix box (D).

The chemical sewer (B) effluent goes to cooling ponds to settle. This effluent then moves to the mix box (D). From the industrial sewer (C) waste goes to the equalisation ponds to settle. The sludge is disposed onto the drying beds (E) and the settled-out water is returned to the flocculators. Flocculation is a bacterially aided process where particles in the water aggregate to flakes of size and density sufficient to settle and form sludge. The sludge goes to drying beds (E) and the water to the mix box (D).

From the mix box (D) water is pumped to the bio filters (F) (trickling filters) where organisms degrade (mineralise) the waste producing humus. The water then goes to the humus tanks. Sludge from here goes to the thickeners. After thickening the sludge goes to the drying beds (E). After drying out on the drying beds the sludge is stockpiled at the designated area on the waste disposal site (Fig. 1, 2 & 3).

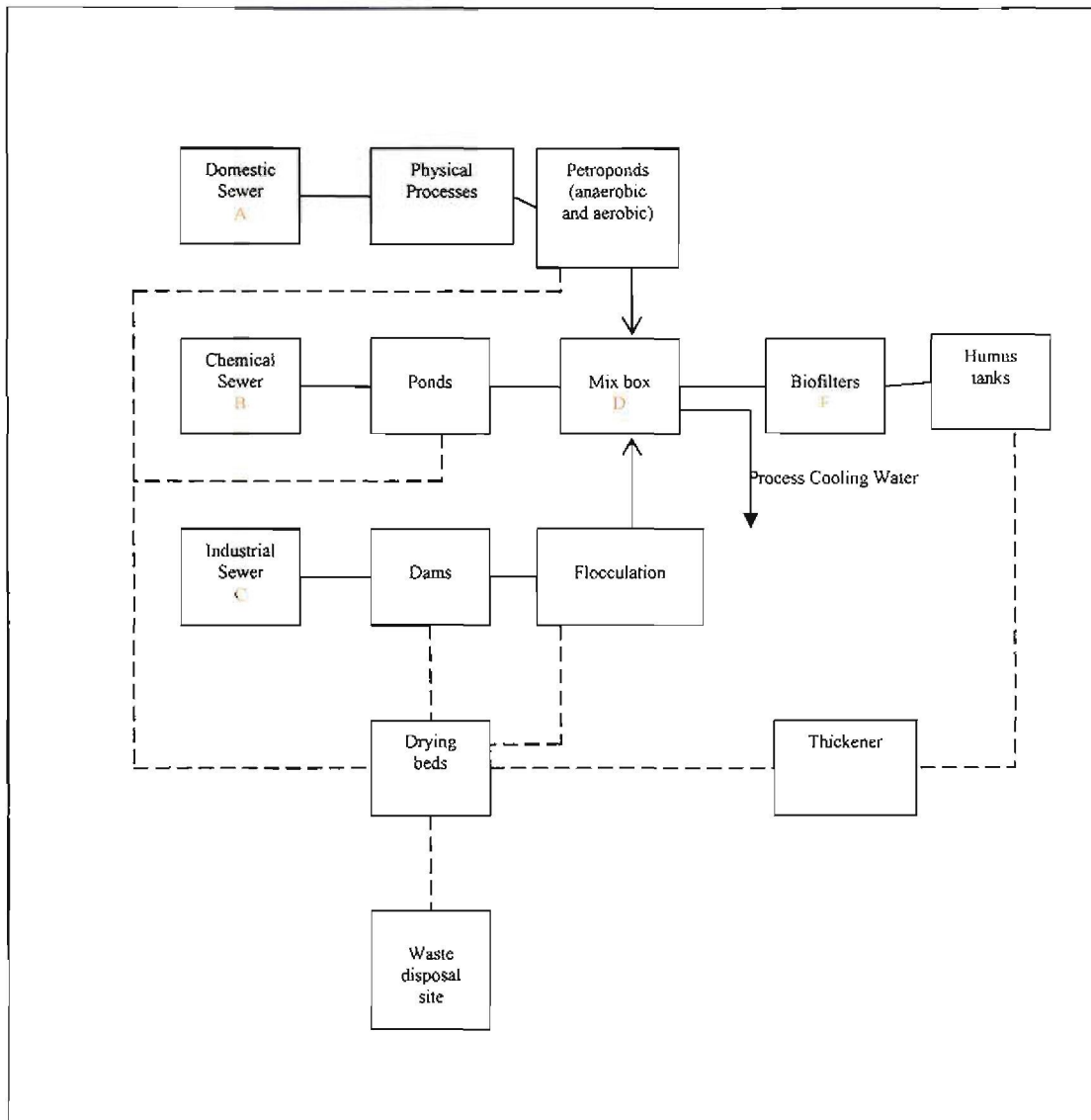


Figure 2: Schematic layout of the Sasol One wastewater treatment plant process flows (adapted from RAGOONANDAN, 2005)



Figure 3: Physical location of process equipment A, B, C, D, E and F as illustrated in Figure 2 (GOOGLE EARTH, 2006)

Chapter 3

Literature review and background theory

In this Chapter a brief introduction will be given on sewage sludge treatment options, *sewage treatment in SA*, and the regulatory environment governing sludge management practices in SA. Thereafter a focussed review will be done on the following three treatment options, viz. Composting, SLASH (ash – lime addition) and Activated Sludge Pasteurisation (ASP).

3.1 Overview of sewage sludge treatment options

In terms of identifying possible solutions to a sludge disposal problem, one would have to consider what beneficial uses there may be for the sludge generated, whether these uses are sustainable, and whether there are any feasible treatment options to deal with the hazardous properties of the sludge. METCALFE & EDDY (1991:12) have recommended the following possible treatment options to reduce the pathogen content of sewage sludge, these include:

- Composting
- Bio-piling
- Heat Drying
- Thermophylic aerobic digestion
- Beta –or gamma –ray irradiation
- Pasteurisation
- lime stabilisation
- land farming

In terms of the WRC, one can also consider finding a re-use option for the sludge or an appropriate disposal method. There could also be an opportunity to use the sludge as a soil ameliorant for the rehabilitation and re-vegetation requirements on waste disposal sites (WRC & DWAF, 2006a:12).

In terms of the rehabilitation requirements of the Sasol One waste sites, which largely include the rehabilitation of tar pit lagoons and other waste bodies left as legacies of the old gasification process, it will be eventually required to establish a sustainable land cover through re-vegetation with suitable grasses. The establishment of this

suitable land cover will require the amendment of the contaminated soil with rich organic material so as to assist with the re-grassing of the waste bodies (Fig.1).

According to the WRC guidelines, a type A and C sludge could be utilised as fertilisers for certain crop types, public gardens, parks, nurseries, the cultivation of instant lawns, animal grazing, or composting with other organic material (WRC & DWAF, 2006b:13).

In view of most sewage sludge's inherent organic and nutrient (Nitrogen and Phosphorus) content, the sewage sludge could also be regarded as a potential soil conditioner and fertiliser for agricultural and horticultural purposes (EKAMA, 1993:34).

Processing the sludge as an organic fertilizer could potentially add further value to an otherwise problematic sludge by converting it to an organic fertilizer via a process such as the Activated Sludge Pasteurization (ASP) process (FOURIE, 2006). Other possible solutions would be to treat the sewage sludge with lime or ash (SLASH), a procedure that has been demonstrated to be quite successful (REYNOLDS *et al.*, 1999:4).

As to the selection of suitable treatment options for the sludge problem and based on surveyed literature and the commercial success of the treatment options, this dissertation will only focus on Composting, SLASH and ASP. A more comprehensive literature survey will thus be done on these treatment options which are covered in section 3.6 of this Chapter.

3.2 Sewage treatment in South Africa

Man has used water as a carrier medium for household and industrial waste for many years. Technological advancements and an ever increasing population have led to increasing volumes of wastewater and their associated pollutants. Although natural environment has an inherent capacity to attenuate these pollutants, the volumes and concentrations have increased to such an extent that without the intervention of man nature can no longer cope (WATES *et al.*, 1995:1).

A SW can thus be considered as concentrated ecosystems by which natural attenuation mechanisms are enhanced in order to relieve the burden on natural systems. The function of a sewage treatment works is thus to decrease the polluted

level of the wastewater to such a level that acceptable quality standards are achieved (WATES *et al.*, 1995:2)

To achieve purification of typical domestic wastewater there are primarily 3 types of pollutants that need to be removed:

- Chemical oxygen demand (COD) - Organic compounds that cause biological consumption of dissolved oxygen in natural water systems. This term can also be expressed as oxygen absorbed (OA) or biochemical oxygen demand (BOD)
- Waste water nutrients which cause secondary pollution – eutrophication of natural waters.
- Faecal coliforms, Helminths and viruses which are health hazards (Pathogens).

According to MARX *et al.* (2004:5) there are approximately 900 wastewater treatment works registered in SA, with a registered cumulative treatment capacity of approximately 7200 Mℓ/d. An analysis of the registered treatment capacity is given in Figure 4 below. The chart shows that approximately 20% of the SW in SA treats 80% of the wastewater generated on a daily basis, while more than 82% have a registered capacity of 5 Mℓ/d or less. The Sasol SW thus falls within the 20% having a registered capacity of 45 Mℓ/d.

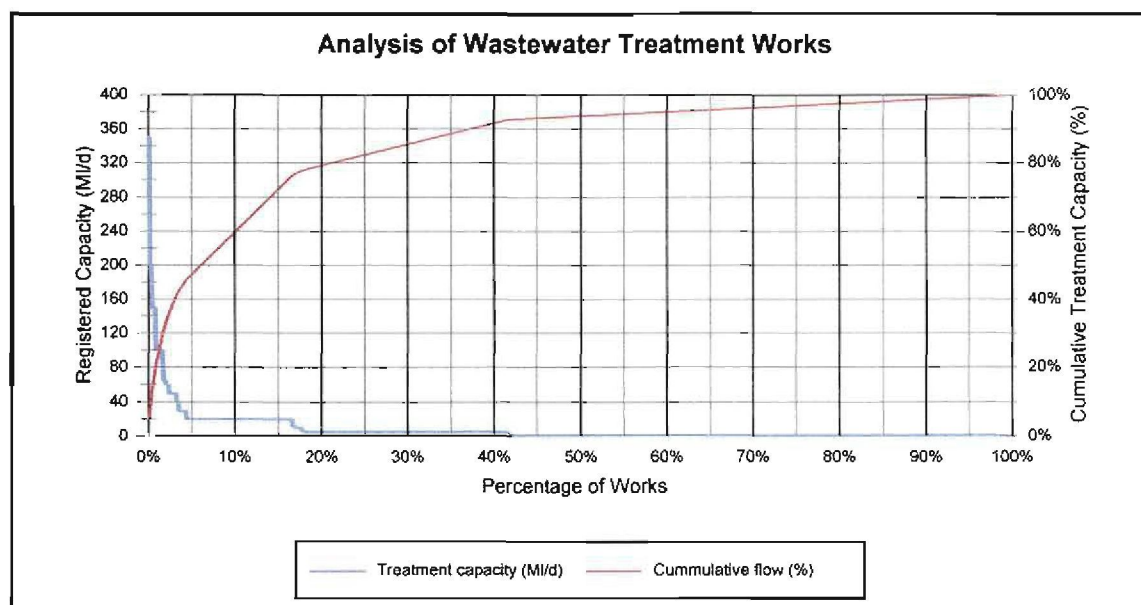


Figure 4: Registered wastewater treatment capacity in South Africa (MARX *et al.*, 2004)

The estimate of the daily sewage sludge production in SA is based on the assumption that all works with a capacity of less than 1.0 Mℓ/d are oxidation ponds, which do not produce any sludge. All other works generate sludge, but unfortunately no differentiation could be made between the treatment processes (MARX *et al.*, 2004:6). The estimate of the daily sludge production in SA is as follows: -

- Total flow treated in Wastewater Treatment Works (WWTW) 5 400 Mℓ/d
- Total flow treated in WWTW excluding oxidation ponds 4 970 Mℓ/d

Sludge Production:

- Primary sludge (@ 150 kg dry solids (DS) per Mℓ/d treated) 750 t DS/d
- Waste activated sludge (@ 200 kg DS per Mℓ/d treated) 1 000 t DS/d
- Digested primary sludge (30% reduction) 525 t DS/d
- Digested waste activated sludge(15% reduction) 850 t DS/d

The total mass of untreated sludge disposed of on a daily basis is estimated at 1 750 t DS/d for undigested and 1 375 t DS/d for digested sludge. The total mass of sludge may be equated to a population of approximately 21,2 million based on a solids production of 50 g per person per day, and an assumed component of 39% from industrial wastewater. MARX *et al.*, (2004:8) has quantified the sludge disposal methods applied in SA as illustrated in (Fig.5).

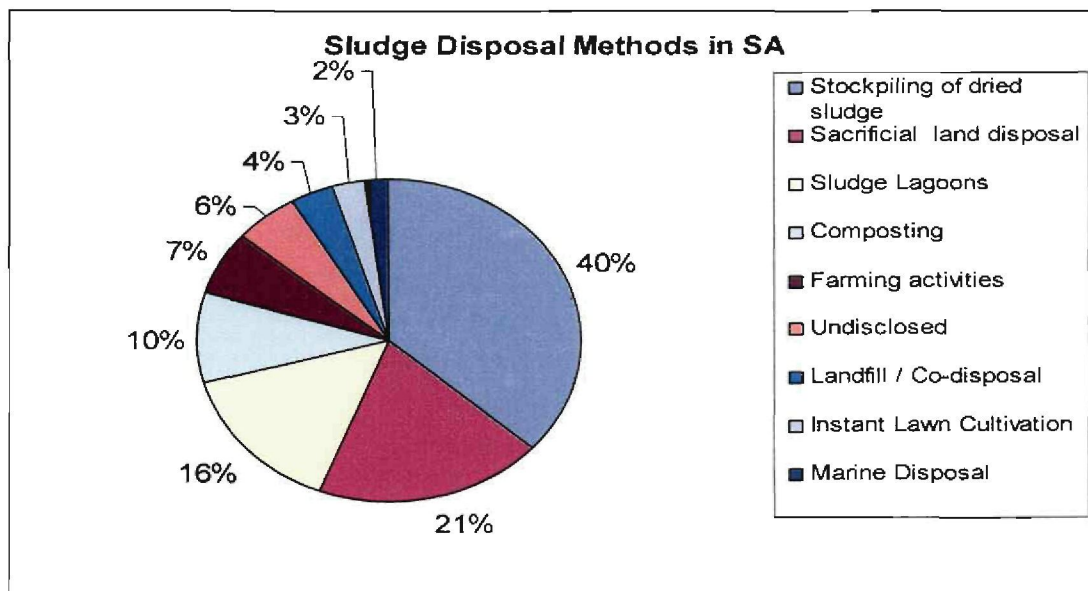


Figure 5: Sludge disposal methods used in SA (MARX *et al.*, 2004:8)

According to the investigations by MARX *et al.* (2004:6), the stockpiled sludge is typically used by municipalities and farmers, or disposed of in landfills, or further treated using processes such as composting. Disposal of sludge on sacrificial land is considered problematic due to the environmental impact thereof, especially on the ground water sources underlying such areas. The sacrificial areas were not necessarily selected in accordance with the latest environmental legislation, resulting in gross pollution in certain of these areas (MARX *et al.*, 2004:6).

The disposal of sludge in lagoons is regarded as a temporary measure, as the lagoons reach their saturation point at one stage or another. In recent years, serious spills have occurred, which caused public outcry and significant damage to the environment. This has made this option an unattractive solution, and all existing lagoons will sooner or later have to be replaced with a sustainable technology (MARX *et al.*, 2004:7).

There is international pressure to discontinue the disposal of sludge on landfills, mainly due to the landfill space it takes up. Even in an outstretched country such as South Africa, available landfill sites are limited. It is therefore important that all available space be utilised as efficiently as possible. Co-disposal of sludge with municipal solid waste (MSW) also requires that adequate volumes of MSW are available to maintain a workable mixture. Co-disposal should only be considered for those landfills having a deficient water balance so as to avoid the formation of leachate and the costly treatment thereof (MARX *et al.*, 2004:7).

Sod farming is the practice of cultivating instant lawn on land irrigated with sludge. When harvesting the lawn, the layer of sludge is also removed and transported to the land where the lawn sods are planted. As the sludge is generally not disinfected before irrigation on land, there is a real threat to public health as the pathogens in the soil are distributed to wherever the sods are planted. The areas utilised for the cultivation of the sods need to be carefully selected to avoid deterioration and eventual destruction of the soil through the increase in salinity, which is typically the case in clay soils. Irrigation of sludge may also result in the pollution of ground or surface water, due to the infiltration or run-off of water with a high nitrate concentration (MARX *et al.*, 2004:6).

The use of sludge by undisclosed users typically constitutes the use by the public in private residential gardens of sludge that has been dried on sludge drying beds. Although this use is "beneficial", it poses a general threat to public health as the

sludge is not disinfected, and no control exercised over the way the sludge is applied or used. The utilisation or disposal of sludge by means of composting is also widely practised and more detail is given in later sections of this dissertation.

According to MARX *et al.*, (2004:10) the City of Durban has been discharging sewage and selected industrial wastes through two deep-sea marine outfall sewers since the 1970's . The outfall sewers stretch between 3,2 km and 4,2 km into the deep sea, and the detritus and scum are removed from the wastewater before disposal. The disposal of sewage and wastewater sludge in the marine environment is still permissible in South Africa, although this practice has been prohibited by the European Union and no such sludge disposal has been permitted since 1994 (SAABYE *et al.*, 1994).

It is evident from the above that the methods presently used for the treatment and disposal of sewage sludge in SA are not ideal, and in some instances not in conformance with the present environmental and legal requirements. Similarly the same situation exists at the Sasol One Site sewage treatment works. It is therefore necessary in the Sasolburg case to investigate alternative disposal and, or treatment options so as to improve the current practices.

3.3 Guidelines for the Utilisation and disposal of wastewater sludge

This section of the dissertation will give an overview of the guidelines used in assessing the Sasolburg sludge, as well as the three tested treatment options. It is important to provide an understanding and background to the use of these guidelines in this project. Their resultant use will be reflected in the subsequent experimental chapters. These guidelines deal with the different options for managing sludge, and were used to select the most appropriate management options.

The term wastewater sludge or sewage sludge refers to the material removed from wastewater treatment plants designed to treat predominantly domestic wastewater. In this dissertation the wastewater includes specifically raw or primary sludge from a primary clarifier and/or oxidation pond sludge (WRC & DWAF, 2006a:4-5).

The guidelines used in this dissertation have replaced the following documents:

- Water Research Commission. Permissible Utilisation and Disposal of Sewage Sludge, 1st Edition, 1997 (WRC, 1997).

- Water Research Commission. Addendum to Permissible Utilisation and Disposal of Sewage Sludge, 1st Edition, 2002 (WRC, 2002).

There were several reasons cited why the previous guidelines had to be updated, the main reason being the significant change in the regulatory environment during the last decade. Other reasons for updating the sludge guidelines included the principle of sustainability that supports the appropriate and sustainable use of resources. Sludge management options should not harm the environment by either the inefficient use of non-renewable resources or the accumulation of a substance / compound in the environment to harmful levels (WRC & DWAF, 2006a:15).

3.4 Legal framework for sludge use and disposal

The use and disposal of wastewater sludge are influenced by, amongst others, the following acts and guidelines (WRC & DWAF, 2006a:17-18):

- The National Water Act (Act 36 of 1998) (NWA)
- The Environment Conservation Act (Act 73 of 1989) (ECA)
- The Fertilisers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947)
- The Conservation of Agricultural Resources Act (Act 43 of 1983) (CARA)
- The National Health Act (Act 61 of 2003) (HA)
- The Water Services Act (Act 108 of 1997) (WSA)
- The National Environmental Management Act (Act 107 of 1998) (NEMA)
- Minimum Requirement Guidelines: (Second edition) 1998
- Water Research Commission Guidelines on the utilisation and disposal of wastewater sludge

It is important to note that not all the Acts are relevant to all the uses. For example the minimum requirements need to be consulted for the disposal of sludge in a landfill, but don't have to be considered if sludge is to be used beneficially as a soil amendment (DWAF, 2005). Irrespective of the management option selected, the Department of Water Affairs and Forestry (DWAF) will remain the lead regulatory agent and will manage the sludge management options using the NWA.

In terms of the NWA waste is defined as *“any solid material, or material that is suspended, dissolved or transported in water and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted”* (SA, 1998).

Part 4 of the NWA deals with pollution prevention and in particular the situation where pollution of a water resource occurs or might occur as a result of activities on land. The person who owns, controls, occupies or uses the land in question is responsible for taking measures to prevent the pollution of water resources. If these measures are not taken, lead authorities may take whatever steps necessary to prevent the pollution or to remedy its effects, and to recover all reasonable costs from the persons responsible for the pollution (SA, 1998).

It is important to note that from the legal perspective the NWA and the guidelines for the utilisation and disposal of wastewater sludge are the two key legal focus areas.

3.5 Guidelines for classification and use of sludge

The new sludge guidelines (WRC & DWAF, 2006a, b) have replaced the 1997 guidelines (WRC, 1997) and its subsequent addendum (WRC, 2002). This revision process started in 2003, and since then most of South African laws and regulations pertaining to the environment, waste and water have either been replaced or updated.

The WRC 2006 sludge guidelines have been developed taking the updated regulatory framework into consideration. The guidelines adopt the principle of sustainability by offering different options for sludge handling. The agricultural use of sludge is presented as the preferred management option. However it has been recognised that not all sludge generated in SA is suitable for agricultural use. For this reason guidelines have also been developed for management options such as disposal in a landfill facility (WRC & DWAF, 2006b:5).

Because it became apparent that it would not be possible to develop a single guideline document that would adequately protect all receptors without unduly stringent requirements the WRC and DWAF agreed to develop a series of guidelines focused on specific sludge management options.

The following sludge guideline documents were then agreed upon:

- Volume 1: Selection of management options

- Volume 2: Requirements for the agricultural use of sludge
- Volume 3: Requirements for the on-site and off-site disposal of sludge
- Volume 4: Requirements for the beneficial use of sludge
- Volume 5: Requirements for the thermal sludge management practices and for commercial products containing sludge

In terms of the above guideline documents only Volumes one to three have been completed whilst four and five are still in the development stage. Thus, in terms of this dissertation, Volumes one and three were used most extensively. The next section will give an overview of the purpose and content of the sludge guideline volumes.

3.5.1 Volume One: Selection of management options

The main purpose of this guideline is to describe the initial comprehensive characterisation process to be followed for the sludge. Based on the results of the characterisation, appropriate management options can be selected. In this study the guideline was applied as prescribed in Volume One part 6 and thus what follows is only a summary of its application, therefore the guideline being more comprehensive should be consulted (WRC & DWAF, 2006a:23-31). The initial characterisation involves the collection of three sludge samples that are analysed for:

- Microbiological parameters such as *Faecal coliforms* and *Helminth ova*.
- Physical and stability indicators such as pH, total solids, volatile solids and volatile fatty acids.
- Chemical characteristics such as nutrients, metals and organic pollutants.

The above indicated parameters are then employed to determine the sludge's microbiological-, stability- and pollutant class. Each of these classes has preliminary classification criteria that is used to assess the specific sludge against (WRC & DWAF, 2006a:19-26). The public perception as to the use of a sludge is largely influenced by an odour that the sludge may have. If the sewage sludge did not smell the public would probably not complain, and thus the overall perception on the reuse of the sludge would improve. Therefore, a sludge with a high stability (low odour) would be more acceptable for general re-use.

In terms of the pollutant class it is important to have an indication of what the class is for planning purposes. In this classification the metal limits used for agricultural use is applied. These metals are Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn). There are other metals, not included in the above list, that also need to be determined and monitored. These metals are based on the benchmark values of typical SA sludges. They include; Antimony (Sb), Boron (B), Barium (Ba), Beryllium (Be), Cobalt (Co), Manganese (Mn), Molybdenum (Mo), Selenium (Se), Strontium (Sr), Thallium (Tl) and Vanadium (V). If the sludge has been assigned as a pollutant Class a, the sludge quality falls in the top 20% in terms of SA metal quality. Similarly if the sludge has been assigned as a pollutant Class c, the sludge quality falls in the bottom 20% in terms of metal content of typical SA sludges. The routine analysis of organic pollutants in sludge is not required for domestic sludge. Furthermore these analyses are very costly. However, in the interest of understanding whether there are organic pollutants in the sludge, the guidelines recommend that the poly-aromatic hydrocarbons be determined (WRC & DWAF, 2006a:26).

3.5.2 Volume Two: Requirements for agricultural use of wastewater sludge

Volume two describes the maximising of the beneficial use of sludge for agricultural practices, while also addressing aspects that could be of concern. This volume deals specifically with the agricultural use of the sludge, including the management, technical and legislative aspects as well as the sludge characterisation and monitoring requirements. It provides ceiling limits for metals and microbiological constituents in sludge intended for agricultural use.

In this volume agricultural use of sludge includes:

- The use of stabilised sludge as a nutrient source and/or soil conditioner at an application rate designed to supply a crop's nitrogen needs, while at the same time minimising the risk of nutrient leaching.
- The management of compost containing sludge that is not sold or distributed to the general public for use.
- Sludge used for municipal parks. If these parks are used by the public, additional pathogen management strategies will apply (WRC & DWAF, 2006b:1).

3.5.3 Volume Three: Requirements for the on-site and off-site disposal of sludge

Volume three describes the requirements and restrictions related to the on-site and off-site disposal of sludge. It gives guidance on managing the phasing out of uncontrolled stockpile facilities where DWAF will no longer accept the indefinite storage of sludge in uncontrolled stockpiles (WRC & DWAF, 2006a:10-11).

The essence of this volume is the following:

- Encourage the beneficial use of sludge.
- Land and marine disposal will be the last resort.
- Sludge producers will need to prove that beneficial use options were considered.
- Strict management and monitoring requirements will apply to protect receptors.

3.5.4 Volume 4: Requirements for the beneficial use of sludge

This volume describes the requirements and restrictions pertaining to the beneficial use of sludge. This volume gives guidance on:

- Rehabilitation of mining waste deposits
- Using sludge to aid remediation of contaminated soil
- Using sludge as a nursery medium
- Once-off high rate applications and covering of landfills

As mentioned above this Volume is presently being developed and is included in this section for completeness sake (WRC & DWAF, 2006a:12).

3.5.5 Volume 5: Requirements for the thermal sludge management practices and for commercial sludge products

The focus of this volume, which is also presently under development, is to firstly, address the use of thermal methods to manage sludge, and secondly to address the use of sludge to manufacture saleable products. These aspects were combined in one volume as many of the saleable products include a thermal process in their manufacturing process. For example, the use of sludge in brick manufacturing could be seen as both a thermal process and the production of a saleable product (WRC & DWAF, 2006a:13).

3.6 Selected sludge treatment options

3.6.1 Composting

According to HAUG (1993:1) "*composting is the biological decomposition and stabilisation of organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land*".

Composting as such is thus a form of waste stabilisation that requires specific conditions of moisture and aeration to produce thermophilic temperatures. These temperatures (generally above 45°C) are considered as the primary mechanism for pathogen inactivation. Aerobic composting is the decomposition of organic substrates in the presence of oxygen (air). The main products of biological metabolism are carbon dioxide, water and heat. The main objective of any composting is to convert putrescent organics biologically into a stabilised form and at the same time to destroy organisms that are pathogenic to humans (HAUG, 1993:2).

Sewage sludge is rich in nutrients such as nitrogen and phosphorus as well as trace amounts of heavy metals. However, the sludge has to be pretreated before land application, due to the presence of pathogenic compounds and heavy metals (TIQUIA *et al.*, 2002:152).

Organic composts can accomplish a number of beneficial purposes when applied to the land. Firstly, compost can serve as a source of organic matter that enhances the soil's condition. Compost has also been reported to improve the growth and vigour of crops in commercial agriculture. The literature generally agrees that compost is most useful as a soil conditioner, mulch, top dressing or organic base with fertiliser amendments (TIQUIA *et al.*, 2002:158).

As with the process of composting, there is no general rule of what converts something into compost. To this end HAUG (1993:2) puts forward that "Compost is an organic soil conditioner that has been stabilised to a humus-like product, that is free of viable human and plant pathogens, that does not attract insects or vectors, that can be handled and stored without nuisance, and that is beneficial to the growth of plants".

Composting has been used to degrade solid waste materials such as yard waste, sewage sludge, and food wastes. Composting conditions differ from other soil treatment processes in that bulking agents are added to the compost mixture to increase porosity and serve as sources of easily assimilated carbon for biomass growth (MARGESIN *et al.*, 2006:89).

The conventional aerobic compost process passes through four major microbiological phases, identified by temperature. They are mesophilic (30-45°C), thermophilic (45-75°C), cooling, and maturation. The greatest microbial diversity has been observed in the mesophilic stage. During aerobic metabolism heat is generated resulting in significant temperature increases that bring about changes in the microbial population and physiology in the compost mixture (POTTER *et al.*, 1999:1717).

The thermophilic stage has been characterized by spore forming bacteria such as *Bacillus* species and thermophilic fungi. Microbial re-colonisation during the cooling phase brings the appearance of mesophilic fungi whose spores have withstood the high temperatures of the thermophilic phase (FOGARTY & TUOVINEN, 1991:230).

In the final composting stage (maturation) most digestible organic material has been consumed by the microbial population and the compost material is considered stable (HAUG, 1993:10).

Sewage sludges are inevitable by-products of wastewater purification works. It has been reported by GASCO *et al.* (2005:310) that there has been globally a significant increase in sewage sludge production from wastewater treatment plants as a result of increases in the percentage of households connected to central treatment plants.

The conventional use of sewage sludges includes industrial utilisation, landfill, and more specific to this section - composting. It has been well documented that composted sewage sludge applied to agricultural land improves soil fertility. The compost supplies a high content of organic matter with favorable effects on the soils physical, chemical and microbiological properties (SANCHEZ *et al.*, 2004:328).

3.6.2 Types of composting processes

The composting process consists generally of the following basic steps: (1) mixing of dewatered sludge with a suitable bulking agent, such as wood chips, to create air voids in the sludge matrix; (2) aeration of the mixture for approximately 22 days; (3) screening of the bulking agent out of the mixture for reuse (if practicable); (4) further curing and storage; and (5) final disposal. The composted product can be sold for use in agriculture and horticulture (HAUG, 1993:48).

During the composting process, the mixture is heated to above 60°C by the biological activity, thereby causing pathogenic organisms to be inactivated. Aeration is required not only to supply oxygen, but to control the composting temperature and remove excess moisture (HAUG, 1993:49).

The composting process can be classified according to the techniques or processes used to keep the biological system aerobic, and by the method of constructing the compost pile. Aeration can be effected by forced aeration, mechanical mixing, or a combination of the two methods. Compost piles can be constructed in windrows, static piles or in silos or vessels. The method by which the piles are constructed has a great influence on the method of aeration applied. The next section will expand on this.

(a) Un-aerated windrows composting

In this composting process, the material is placed in long windrows (rows of composting material), and aeration is facilitated by mechanically overturning the windrows at regular intervals. In this way air is mixed into the composting material and the gaseous decomposition products and excess heat are vented into the atmosphere (MARX *et al.*, 2004:142).

A distinct disadvantage of the process is that it is not easily controlled due to aeration limitations. Malodorous smells are easily formed due to the anaerobic conditions created by the limited oxygen supply which also increase the duration of the composting process. Problems in attaining the required temperatures for disinfection are also foreseen in this process (METCALFE & EDDY, 1991:42).

(b) Aerated windrows composting

The process described by NELL and ROSS (1987:24) is similar to that applied for un-aerated windrows, but aeration is forced. This can be done by constructing the

windrows over aeration channels into which air can be blown, or through which air can be sucked, or by placing perforated pipes in the windrow as it is being constructed. The latter method would restrict any mechanical mixing of the windrow as this would damage the perforated pipes (MARX *et al.*, 2004:143).

Mechanical mixing of the windrows is recommended to ensure that all material is stabilised and disinfected. Alternatively, the windrows can be covered with mature compost to facilitate complete stabilisation and disinfection of the "raw" material, although this would complicate the construction of the windrows. A disadvantage of this process is that it requires a large area for the construction of the windrows (HAUG, 1993:64).

(c) Aerated static pile composting

In this process, the "raw" material is placed in one continuous pile. As the pile is constructed the material is aerated and the composting process starts. Due to the size of the pile, it is not possible to mix it during the composting period. Forced aeration is thus obligatory. For the purpose of blowing or sucking air through the pile, the system has to be covered or enclosed in a building with positive-forced ventilation. Air scrubbing has to be provided for odour control (HAUG, 1993:65).

The advantage of an enclosed system is that odours are also contained during placing of the "raw" material. A further advantage of enclosed static pile composting is that it requires less surface area as higher piles can be constructed, and space is therefore used more economically (HAUG, 1993:66).

(d) In-vessel composting

In-vessel composting is accomplished inside an enclosed container or vessel. The process is closely related to aerated windrows as both mixing and forced aeration is applied. The mixing can be done by means of moving mechanical equipment in static bins or by means of moving the (usually rotating cylindrically shaped) bins themselves. In-vessel composting, particularly if proprietary equipment and license agreements are involved, often turns out not to be a viable option when compared to the aforementioned alternatives (HAUG, 1993:79).

3.6.3 Main operating and design criteria

Various chemical and physical factors have a direct influence on the composting process and must therefore be controlled.

3.6.3.1 Chemical Factors

- **Moisture content:**

Moisture affects the rate of microbial activity as it acts as a transport media for microbiological metabolites, as a solvent in which chemical reactions can take place, and as a conductor of process heat. Excessively high moisture content will reduce the porosity of the composting material and thus restrict air circulation. The optimum moisture content lies between 50 and 60%.

- **Carbon: Nitrogen (C:N) ratio:**

The initial C:N ratio should be in the range of 25:1 to 35:1 by weight. High C:N ratios will have the effect that the organic material is not fully stabilised, whereas at low C:N ratios excess nitrogen may be liberated in the form of ammonia thus reducing the nitrogen content of the final product.

- **pH:**

The optimum pH lies between 6, 5 and 9, 5.

- **Oxygen requirements:**

Typical airflow requirements for a forced aeration system vary between 20 m³/h to 50 m³/h per ton of dry sludge. If aeration is affected by mixing, the piles have to be turned approximately twice per week. Under-aeration will result in anaerobic conditions whereas excessive aeration may result in cooling of the compost pile (HAUG, 1993:92).

3.6.3.2 Physical factors

- **Porosity:**

The porosity of the sludge-compost mixture is controlled by the bulking agent. Optimum particle size lies between 5 mm to 15 mm.

- **Temperature:**

To make compost acceptable for public use, an internal temperature of 65°C has to be maintained for at least 3 consecutive days.

- Bulking agent:

Bulking agent plays an important role in the composting process and its functions include moisture control, increase of air voids, C:N ratio adjustment and dilution of contaminant concentrations in the sludge (HAUG, 1993:101).

3.6.3.3 Advantages and disadvantages of composting

Advantages

- The nutrient value of the wastewater sludge is used beneficially.
- The process is relatively odour free due to the compulsory aerobic conditions required by the process, which limit the generation of odours and facilitate odour control.
- The process is capable of inactivating pathogenic organisms such as *Ascaris ova* very successfully if controlled properly. The product can thus meet health requirements fairly easily.
- The process has environmental appeal as it recycles natural nutrients and acts as a soil conditioner. The heavy metal content, however, has to be controlled.
- During use, the product is spread over a large area and therefore the risk of concentrating heavy metals is reduced. Thus special sites are not required for the disposal of the sludge in order to prevent pollution of the environment.
- Due to the soil-conditioning and nutrient value of the compost, the product has a market value. The possible revenue can be offset against the cost of the composting process.
- The technology required for the process is relatively simple and well known and the process is easily controlled (MARX *et al.*, 2004:144).

Disadvantages

- The concentration of heavy metals in the sludge may render the product unsuitable due to the possible pollution and increased health risk it creates.
- There is presently no formal market for compost and special efforts are required in this regard. Suitable outlet structures will have to be established and public relations efforts will be required to overcome possible public resistance to the use of the product.

- Strict process control is required to reduce the potential public health risk due to pathogens in the sludge, and to prevent the formation of obnoxious odours.
- The process poses a potential health risk to the operators due to the presence of fungi (*Aspergillus fumigatus*) and secondary bacterial pathogens (*Serratia marcescens*, *Pseudomonas* spp.) which may cause chronic bronchitis and other respiratory disorders. The extent of this potential risk is not known and is difficult to quantify due to the close resemblance with the common cold and other respiratory disorders (MARX *et al.*, 2004:144).

3.7 Ash and lime addition to sewage sludge (SLASH)

The combustion of coal in SA has been reported to produce in excess of 22 million tons of fly ash annually. This ash is usually stored on ash dumps where it has to be rehabilitated at a later stage. Ash is largely regarded as an untapped resource and currently being widely used in the cement- and brick-making industries. The use of ash in the cultivation of plants has been extensively investigated and its use in the forestry sector is well documented (OLBRICH, 1995).

Sewage sludge is well known to have heavy metals and many pathogenic organisms that classifies the sludge as hazardous and thus requires extensive treatment to ensure that it is safe for land disposal. Further, present legislation limits the methods available to the producers for the disposal of the sludge. The combination of these two by-products (Sludge and Ash) has been demonstrated to have beneficial synergistic actions in rendering the resultant product less harmful to the receiving environment (REYNOLDS *et al.*, 1999).

SLASH (acronym for **S**ludge, **L**ime, and **A**sh) is a technology that was developed over the past decade by Eskom, Ash Resources and the University of Pretoria to make a beneficial soil ameliorant from sewage sludge, lime and fly ash (REYNOLDS *et al.*, 2002:73).

The essence of the technology is:

Sewage sludge mixed with fly ash suitably augmented with quicklime (CaO) produces a heated pulse (exothermic hydrolysis reaction) to ensure pasteurisation (not sterilisation) of the sludge to make it free of disease-carrying organisms but still being biologically active. A suitably prepared mix of sludge, lime and fly ash (typically in a 6:3:1 ratio of sludge: fly ash: lime) is prepared that has a soil type texture and is

applied to low fertile and degraded soils to improve chemical (nutrient status, slow release liming potential) and physical (e.g. reduce erosion, improve soil water holding capacity) status of the growing medium (REYNOLDS *et al.*, 2002:73).

According to REYNOLDS *et al.* (2002:74) there are advantages when SLASH has been applied to soil. These include:

- Increases water retention in soil
- Improves physical characteristics of soil
- Decreases erosion potential
- Increases soil biological activity
- Acts as a substitute for agricultural liming
- Is a source of plant nutrients

An added advantage of the fly ash (and lime) is to bind heavy metals in the form of insoluble metal hydroxides in the SLASH. Effective odor control from the sewage sludge is achieved through the ash and lime. A fair amount of research has been done on SLASH, much of which has been published (REYNOLDS *et al.*, 2002:75).

It has been widely shown that SLASH is a viable technology that can improve a soil's physical property and fertility status resulting in better crop yields. It further has a long term residual effect and can be seen as a slow release source of elements required for plant growth (RETHMAN *et al.*, 1999:84).

3.7.1 Limitations of SLASH

The published research indicates that in many cases the crop responses to SLASH treatment has been limited with the benefit being dependent on a number of factors such as soil type and fertility status, climate, application rate, etc (RETHMAN *et al.*, 1999:85). There is also uncertainty as to the use of SLASH amended soils for growing edible crops (pathogen risk, although dramatically reduced, still exists). The transport costs restrict the use of SLASH to sites in close proximity to the waste raw materials used in its manufacture (RETHMAN *et al.*, 1999:86).

3.8 Activated sludge pasteurization process

The activated sludge pasteurisation process (ASP) sterilises the sewage sludge and at the same time enriches the sludge to render it fit for use in the environment as an organic fertiliser (FOURIE, 2006).

The ASP process has been patented by a company called Plateau ASP. This company has been acknowledged as an expert in the fields of sludge handling and manufacturing of organic fertilisers and applying it in agriculture. Its main business is to erect ASP plants and to manufacture organic fertiliser by using this patented technology to pasteurise and enrich sewage sludge by the ASP process, which is followed by drying and granulating the ASP product (FOURIE, 2006).

The claimed benefits cited include:

- Prevents air pollution by eliminating odorous gases before being emitted by the sewage sludge
- Reduces soil and water pollution by not having to dispose or stockpile the sludge
- Prevents groundwater pollution by preventing leaching from dumped sewage sludge
- Prevents heavy metal contamination of the soil due to the dilution effect of the sludge content in the application of enriched organic fertiliser
- The ASP product benefits the farmer as the chemicals used are nitrogen and phosphor which are both plant macro nutrients
- The organic matter component of the product serves as a biological pesticide against parasites and other pests
- The ASP organic fertiliser complies with all statutory regulations and laws
- DWAF, DEAT AND DOH have recognised the ASP product as an organic fertiliser; subsequently it is registered as a fertiliser in terms of the Farm Feeds, Agricultural Remedies and Stock Remedies Act 36 of 1947.

3.8.1 Process description

The ASP process involves the introduction of primary humus from a SW and reacting this with a poly-electrolyte to produce a sludge that is then dewatered with a belt press before it is introduced into the ASP reactor. Figure 6 provides a simplified diagram as to how the sludge is processed through a typical ASP plant.

Once the sludge has been introduced into the reactor with a peristaltic pump, ammonia and phosphoric acid is introduced to initiate the reaction (Figure 6). After the reaction time of approximately one and a half hours, it is then introduced into a rotary drum dryer. The resultant product after approximately 3 hours drying is a pelletised organic fertiliser (FOURIE, 2006).

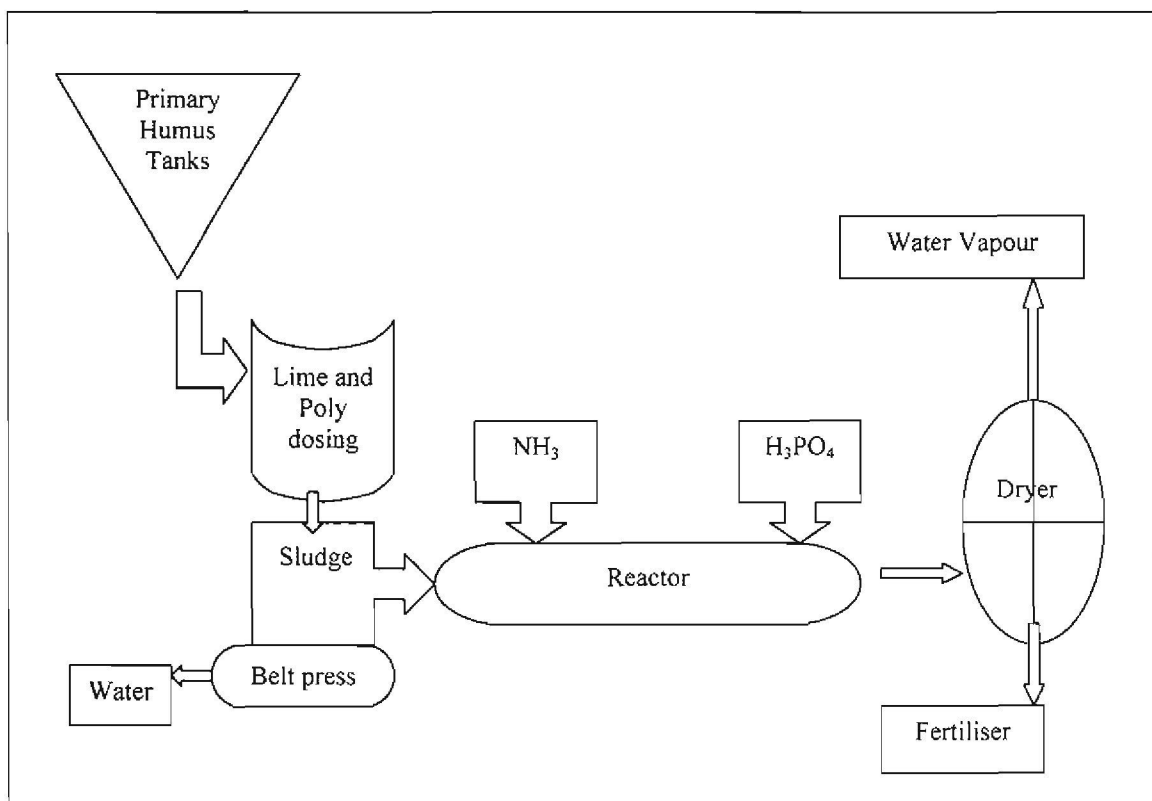


Figure 6: Simplified ASP sludge process flow diagram (Fourie, 2006)

Figure 7 below illustrates the introduction of the sludge into the reactor via a conveyer belt and also the injection point for ammonia dosing.

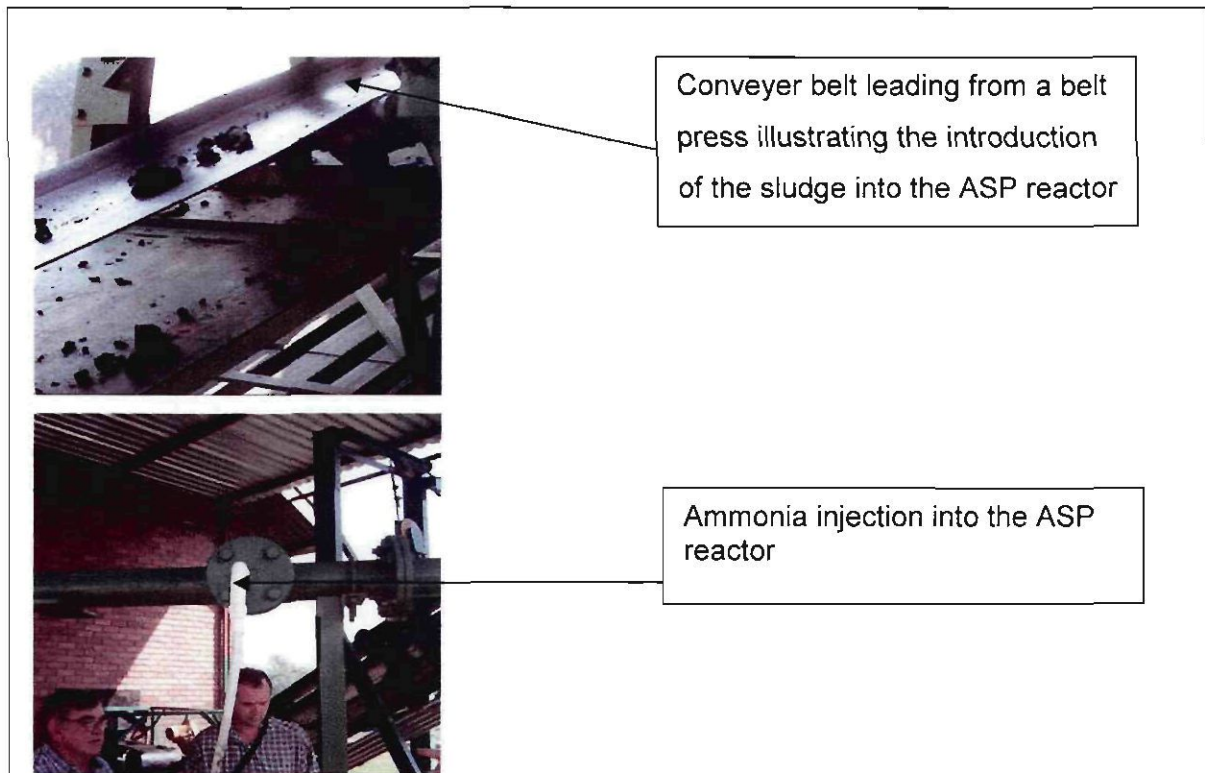


Figure 7: Introduction of sludge into ASP reactor with ammonia injection

Chapter 4

Assessment and selection of sludge treatment options

4.1 Development of the decision matrix

In order to assess which of the treatment options performed the best, a decision matrix had to be developed to compare the options against each other. In approaching the design of the matrix, criteria would have to be identified that are suitable to the components being assessed. It was decided that certain criteria would be of a quantitative and qualitative nature.

4.1.1 Quantitative and Qualitative criteria and ratings

The quantitative criteria included the WRC classification rating and the economic viability in terms of capital and operational cost of the various treatment options. The qualitative criteria included technical feasibility and sustainability of the treatment options.

Higher category weights were given to the quantitative criteria because they could be determined using established methods and techniques, whilst the qualitative criteria were given a lower category weighting due to their subjectivity.

4.1.2 Scoring

Given the assigned points to each of the criteria these were scored and summed for each option. The option with the highest score would be regarded as the preferred option.

4.1.2.1 WRC classification

The WRC classification, being quantitative criteria, was scored as follows:

A1c was given 10 points because it is considered a more stable sludge than a B2c and C2c sludge. As a result of this the B2c and C2c were given 5 and 1 points respectively.

4.1.2.2 Sustainability

The sustainability criterion being a qualitative criterion was defined as the option that would be the most likely one to succeed in the long term as a sustainable solution to an environmental problem, i.e. sustainability would encompass an ongoing solution in dealing with the sewage sludge problem and not reverting back to disposing or stockpiling the sludge. In this case, the criteria points were defined as High, Medium and Low sustainability solution, and were given points of 10, 5 and 1 respectively.

4.1.2.3 Economic viability

The economic viability criteria being a quantitative criterion were defined as a capital (CAPEX) and operational expenditure (OPEX) criterion. This would give an indication of the financial viability of the preferred option. The CAPEX and OPEX costs were determined by a separate assessment (PILLAY, 2007). The capital expenditure criterion was scored as either High, Medium and Low capital cost and were given assigned points of 1, 5 and 10 respectively. Here the rationale was used that the lower the capital input cost, the more economically viable the preferred option would be. Similarly the operational costs were treated in the same fashion.

4.1.2.4 Technical feasibility

Technical feasibility being a qualitative criterion was defined as the potential for the preferred option to achieve full scale operation and a measure of confidence to implement the option or not. The technical feasible criterion were consider as either Definite, Probable or Improbable and were assigned points of 10, 5 and 1 respectively.

Chapter 5

Experimental results of selected sludge treatment options

5.1 Composting

This section will introduce the materials and methods used to assess the composting of the sewage sludge, and the typical results achieved with these experiments.

5.1.1 Materials and Methods

Initial sludge samples were analysed for pathogens (*Ascaris ova* and faecal coliforms) and metals. The Guidelines for the Utilisation and Disposal of Wastewater Sludge (Vol 1 of 5) were used for the **preliminary classification** of the untreated sludge and compost product. The pollutant class was determined using an *Aqua Regia* extraction conducted by SGS Laboratories (WRC & DWAF, 2006a:53).

The microbiological class was determined at East Rand Water Care Company (ERWAT). The third parameter, stability, was determined by comparison to the nine stability options as outlined by the Guidelines for the Utilisation and Disposal of Wastewater Sludge (WRC & DWAF, 2006a:24). Poly-aromatic hydrocarbons analyses were done in previous studies and not repeated in this study (RAGOONANDAN, 2005).

Sewage works sludge was dried to approximately 14% solids on a drying bed. Municipal green waste (plant and tree cuttings) was shredded in a shredder to an approximate particle size of 20 cm. The sludge and shreddings were mixed in a 1:2 (sludge: shreddings) ratio with a Bobcat. The final pile volume was approximately 1 m³ (Fig. 8).

The porosity of this mixture was determined to be 50% by volume. This is measured by adding water to a known volume of the compost mixture in a bucket till all the pores are filled. The bucket is left to stand overnight and more water is added the next day if necessary. The contents are stirred to ensure there are no air bubbles and the volume of water added is equal to the pore volume. The porosity is the pore volume divided by the volume of the compost (HAUG, 1993:100).

The temperature was monitored using temperature probes connected to a data logger. The probes were inserted into the pile at various points. The pile was turned (un-aerated windrow composting technique, see section 3.6.2) with a Bobcat whenever the temperature exceeded 70°C.

The pile was also watered using buckets to maintain moisture content of not less than 30%. The moisture was determined on a sub-sample by using a moisture balance. The carbon dioxide (CO₂) emissions were measured using a hand held CO₂ meter (Gas Data-pro PCO₂, Gas Data Ltd. UK). The tube at the inlet of the meter was inserted into the pile at random sampling points.

Once the pile temperature dropped to 30°C the compost was allowed to cure for two weeks, i.e. by leaving it undisturbed. The pile was then sieved using a 10 mm screen sieve. The fine composted material was stored in drums while the oversize woodchips and green waste was kept aside for recycling and reusing.

The biochemical oxygen demand (BOD) tests were based on the modified method as outlined in HAUG, (1993:325). The nutrient solutions were made as per standard BOD Methods 5210D (CLESCERI *et al.*, 1998). The temperature profile results of the composting trials are presented in Figure 9.



Figure 8: Mixing of compost pile

5.1.2 Results and discussions

The following parameters; temperature, carbon dioxide emitted and biochemical oxygen demand are regarded significant to be discussed as these parameters give an indication of the efficacy and efficiency of the composting process.

5.1.2.1 Temperature profiles

Figure 9 shows a steady increase in the pile temperature from 20°C up to 70°C over a three week period. This was due to the activity of the mesophyllic and thermophyllic bacteria. According to HAUG (1993:2) exposure to a temperature of 55 to 60 °C for one or two days is sufficient to kill the pathogens present in sludge. Figure 9 and 10 clearly indicates the increased temperature and resultant steam from the pile. After two months of composting the temperature dropped. Curing was achieved over a period of one month.

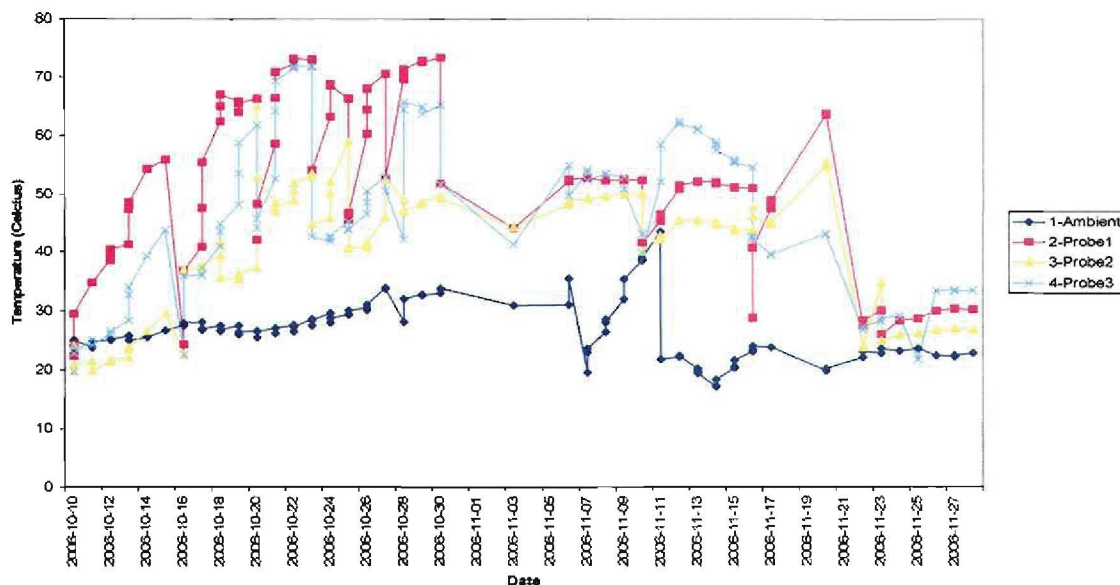


Figure 9: The temperature profile of the compost pile during composting



Figure 10: Steam generation during composting as an indication of exothermic reactions during composting of sludge material

5.1.2.2 Carbon dioxide emissions

The carbon dioxide (CO₂) emissions were indicative of microbiological activity. A consistent trend was not noticed with the CO₂ emissions. However, the emitted CO₂ was always higher than atmospheric CO₂, clearly indicating microbiological activity in the pile (Fig.11).

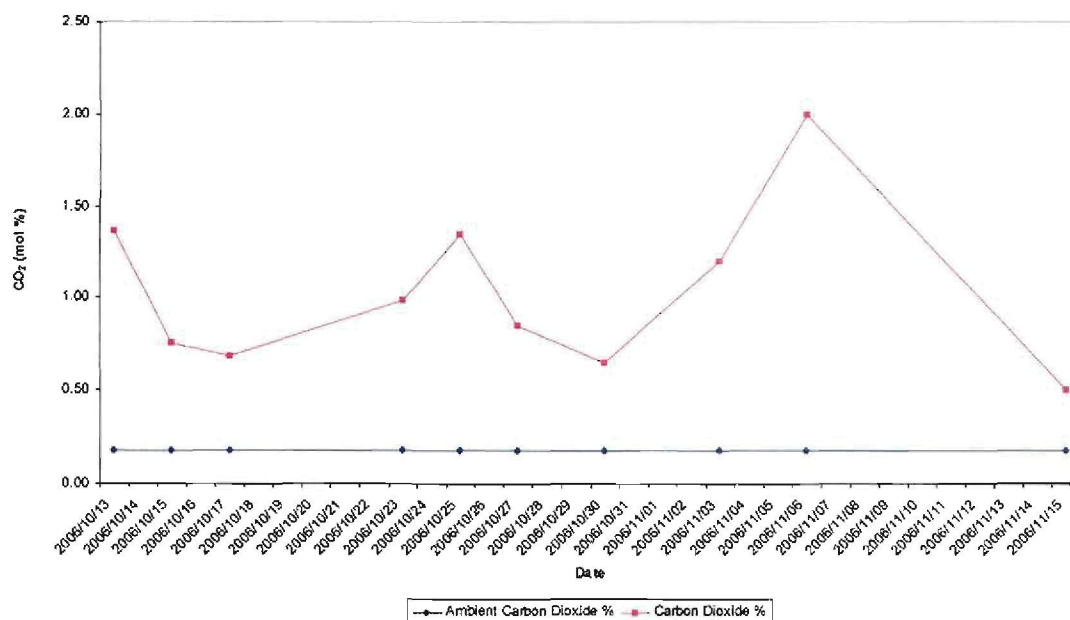


Figure 11: Plot of CO₂ emissions from the compost pile

5.1.2.3 Biochemical oxygen demand

The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) analysis of the sludge and compost are displayed in Table 1.

Table 1: BOD and COD analyses of Sewage works Sludge, Compost and Cured Compost

Sample	BOD ₅ (mg/L)	COD (mg/L)	BOD/COD Ratio
Sewage works Sludge 1	Too high (undefined)	95.8	Undefined
Sewage works Sludge 2	Too high (undefined)	95.8	Undefined
3 Week Compost 1	125	528	0.17
3 Week Compost 1	87.4	528	0.12
Curing Compost 1	93	522	0.18
Curing Compost 2	101	522	0.19
Cured Compost 1	30	132	0.23
Cured Compost 2	10	92	0.11

A BOD/COD ratio of less than 0.2 means the substrate is non-biodegradable. 0.2 – 0.6 mg/l indicates the substance is probably biodegradable and a ratio of greater than 0.6 indicates readily biodegradable. From Table 1, the BOD/COD ratio of the sewage works sludge was higher than the limit on the BOD instrument; this indicates the substrate was readily biodegradable.

After three weeks of composting until the cured material was obtained, the BOD/COD ratio of all the samples (except for Cured Compost 2) were less than 0.2 indicating non-biodegradability. This means that the degradable fractions from the materials were degraded and they had reached stability. Cured compost 1 was only just marginally over the 0.2 BOD/COD ratio at 0.23. The ratio of the duplicate, cured compost 2, was only 0.11, thus on average the cured compost had a BOD/COD ratio of less than 0.2 which indicates the biodegradation process had stopped.

Tables 2, 3 and 4 show the results obtained for the pollutant, microbiological and the stability class assessment of the untreated and treated materials. It was concluded from these tables that the composted material was classified as a type A1c sludge.

The composting of the sludge also brought about a reduction in most of the heavy metals including Copper and all of the pathogens. However, Molybdenum and Selenium still remained above the WRC limits (WRC & DWAF, 2006a:25). The stability class was determined to be class 1 where this treatment (Composting) could comply with a vector attraction option on a 90 percentile basis. In this case the option identified was option 5 (the use of an aerobic process at a temperature greater than 40°C).

5.2 Activated Sludge Pasteurisation

This section will introduce the materials and methods used to assess the activated sludge pasteurisation of the sewage sludge and the typical results achieved with this experiment.

5.2.1 Materials and methods

Initial sludge samples were analysed for pathogens (*Ascaris ova* and faecal coliforms) and metals. The guidelines for the Utilisation and Disposal of Wastewater Sludge (Vol 1 of 5) were used for the **preliminary classification** of the untreated sludge and ASP product. The pollutant class was determined using an Aqua Regia extraction method conducted by SGS Laboratories (WRC & DWAF, 2006a:53).

The microbiological class was determined at ERWAT. The third parameter, stability, was determined by comparison to the nine stability options as outlined by the WRC guidelines for the Utilisation and Disposal of Wastewater Sludge. Poly-aromatic hydrocarbons analyses were done in previous studies and are not repeated in this study.

The Sludge was dried to 14% solids content on a drying bed at the Sasolburg sewage works. The sludge (2m³) was then pumped into a road tanker equipped with discharge facilities and transported to the ASP Plateau facility in Daspoort Pretoria where it was processed through the ASP plant (Fig.6) by enriching through the addition of 35 kg anhydrous ammonia and 169 kg of a 53.51% phosphoric acid per 900 liter sludge. The treated sludge was transported back to the SW in Sasolburg where it was further allowed to dry in a dedicated drying bed. Figure 12 illustrates the consistency of the treated sludge as it was transferred to the drying beds in Sasolburg.



Figure 12: Treated ASP sludge in drying beds

5.2.2 Results and discussions

Tables 2, 3 and 4 show the results obtained for the pollutant, microbiological and the stability class assessment of the untreated and treated materials. It was concluded from these tables that the ASP product was classified as a type A1c. Applying the

ASP treatment to the sludge also brought about a reduction in all of the pathogens and in most of the heavy metals including Copper. However, Molybdenum and Selenium remained above the WRC limits. The stability class was determined to be class 1 where this treatment could comply with a vector attraction option on a 90-percentile basis. In this case the option was identified as option 6 (add alkaline material to raise the pH under specific conditions).

5.3 Sludge lime and ash addition

This section will introduce the materials and methods used to assess the lime and ash addition to the sewage sludge, and the typical results achieved with this experiment.

5.3.1 Materials and methods

Sludge preparation, ash and lime mixing and analysis

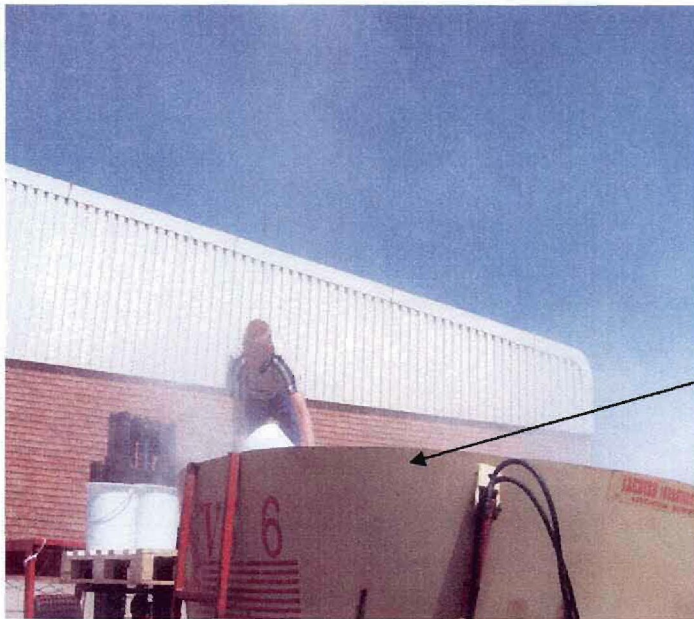
Initial sludge samples were analysed for pathogens (*Ascaris ova* and faecal coliforms) and metals. The guidelines for the Utilisation and Disposal of Wastewater Sludge (Vol. 1 of 5) were used for the **preliminary classification** of the untreated sludge and SLASH product. The pollutant class was determined using an Aqua Regia extraction conducted by SGS Laboratories.

The microbiological class was determined at ERWAT. The third parameter, stability, was determined by comparison to the nine stability options as outlined by the Guidelines for the Utilisation and Disposal of Wastewater Sludge. Poly-aromatic hydrocarbons analyses were done in previous studies and are not repeated in this study.

SW sludge was dried to 14% solids on a drying bed. Ash was obtained from the fine ash dams (Fig.1) on the Sasol waste disposal site in Sasolburg. Agricultural quality quicklime (CaO) was purchased from an external vendor (White Sands lime distributors) and contained in sealed buckets to prevent contact with moisture. Approximately 300 kg of dried sludge, 150 kg of fine ash and 50 kg lime were transported in drums and buckets to a farmer in Delmas, SA, where it was thoroughly mixed with ash and lime using a helical mixer (Diamond Implements, model VS6) (Fig. 13) in a 6:3:1 ratio (sludge: fine ash: lime).

The helical mixture required for this experiment was only available from the said farmer in Delmas. The treated sludge was then transported back to the SW in

Sasolburg and stored in sealed containers. After mixing and curing, the SLASH mixture was re-analysed for pathogens and metals as per WRC guidelines.



Sludge, ash and lime
being introduced into
helical mixer



The resultant slash
product once processed
through the helical mixer

Figure 13: Helical mixer and final SLASH product

5.3.2 Results and discussions

Tables 2, 3 and 4 show the results obtained for the pollutant-, microbiological- and the stability class assessment of the untreated and treated materials. It was concluded from these tables that the SLASH product was classified as a type A1c.

Applying the SLASH treatment to the sludge also brought about a reduction in all the pathogens and in most of the heavy metals including Copper. However, Molybdenum and Selenium again remained above the WRC limits.

The stability class using the SLASH treatment was determined to be class 1, where this treatment could comply with a vector attraction option on a 90-percentile basis. In this case, the option identified was option 6 (add alkaline material to raise the pH under specific conditions).

Table 2: Results of Aqua Regia Extraction (SGS Laboratories)

Pollutant Class	WRC Limits (mg/kg)			Classification of Treatment Options							
	Class a	Class b	Class c	Raw Sludge (mg/kg)	Class	Compost (mg/kg)	Class	SLASH (mg/kg)	Class	ASP (mg/kg)	Class
As	<40	40-75	>75	9.5	a	8.8	a	9.5	a	10.5	a
Cd	<40	40-85	>85	1.1	a	0.65	a	0.45	a	0.82	a
Cr	<1200	1200-3000	>3000	160	a	100	a	77	a	110	a
Cu	<1500	1500-4300	>4300	2800	b	1300	a	1300	a	1200	a
Zn	<2800	2800-7500	>7500	1200	a	840	a	510	a	1000	a
Pb	<300	300-840	>840	47	a	34	a	28	a	56	a
Hg	<15	15-55	>55	10.5	a	4.3	a	<DL	a	5.4	a
Ni	<420	420	>420	76	a	47	a	31	a	57	a
Sb*	<1.1	1.1-7	>7	<DL	a	<DL	a	<DL	a	<DL	a
Be*	<0.8	0.8-7	>7	1.1	b	1.3	b	0.65	a	1.1	b
Co*	<5	5-38	>38	15	b	8.5	b	6.6	b	9.7	b
Mo*	<4	4.0-12	>12	95	c	42	c	30	c	28	c
Se*	<5	5.0-15	>15	105	c	53	c	27	c	30	c
Ti*	<0.03	0.03-0.14	>0.14	<DL	a	<DL	a	<DL	a	<DL	a
B*	<23	23-72	>72	4.5	a	<DL	a	<DL	a	<DL	a
Ba*	<108	108-250	>250	0.80	a	<DL	a	<DL	a	<DL	a
Mn*	<260	260-1225	>1225	0.34	a	<DL	a	<DL	a	<DL	a
Sr*	<84	84-205	>205	0.31	a	<DL	a	<DL	a	<DL	a
V*	<85	85-430	>430	0.67	a	<DL	a	<DL	a	<DL	a

*Benchmark metals

DL : Detection Limit

Note: WRC Class changes are indicated in red and concentration changes in blue

Table 3: Results of Microbiological Analyses (ERWAT)

Microbiological Class	WRC Limits			Classification of the Treatment Options							
	Class A	Class B	Class C	Raw Sludge	Class	Compost	Class	SLASH	Class	ASP	Class
Faecal Coliforms (MPN/g dry sludge)	<1000	< 10 ⁶	> 10 ⁷	>2419	B	0	A	0	A	0	A
Helminth Ova (total viable ova/g dry sludge)	<0.25	<1	> 4	2	B	0	A	0	A	0	A

Note: WRC Class changes are indicated in red

Table 4: Stability Class Classification

Stability Class	ASP	Class	Compost	Class	SLASH	Class	Raw Sludge	Class
Options 1-9	6	1	5	1	6	1	8	2

5.4 Decision support matrix results

Table 5 presents the results from the assessments using the decision matrix for each of the treatment options and how each of the criteria were used to compare each of the treatment options with their resultant scores. Refer to Chapter 4 for the explanation and use of the decision support matrix.

In presenting the results, it is important to understand the rationale as to how the matrix was used. The first column of the table depicts the criteria category used as indicated in Chapter 4. As an example to illustrate how the matrix was applied, the WRC classifications will be used as a criteria.

The assessments of the WRC classifications are illustrated in Tables 2 to 4. Based on the results from these tables, classification ratings were assigned to the Composted sludge, SLASH and ASP product. The assigned points (10, 5 and 1) to A1c, B2c and C2c classifications, respectively were then applied to each of the WRC classifications; lastly the category criterion weight was multiplied by a weighting factor (10) to give a total criterion score in the last column of each criterion category.

Similarly, the other criteria identified were assessed in the same manner. In the final analysis, a total option score is given for each of the treatment options. This score is illustrated in the last line of the table. The treatment option with the highest score was chosen as the preferred option. In this instance, the **Composted Sludge** scored the highest points based on this assessment.

Table 5: Results from the assessment of treatment options using the decision support matrix

Decision Matrix	Treatment options		
Criteria Category (Quantitative)# (Qualitative)*	Composting	SLASH	ASP
WRC Classification (#) A1c = 10 B2c = 5 C2c = 1	A1c	A1c	A1c
Criterion category weight (X10)	10X10	10X10	10X10
Sustainability (*) High = 10 Medium = 5 Low = 1			
Criterion category weight (X 5)	10X5	10X5	10X5
CAPEX cost (#) High = 1 Medium = 5 Low = 10	R 600,000	R 500,000	R 26,000,000
Criterion category weight (X10)	5X10	10X10	1X10
OPEX cost (#) High = 1 Medium = 5 Low = 10	R 965,900	R 5,191,000	R 4,580,952
Criterion category weight (X10)	10X10	1X10	1X10
Technical feasible (*) Definite = 10 Probable = 5 Improbable = 1	Definite	Probable	Probable
Criterion category weight (X5)	10X5	5X5	5X5
Total option score	350	285	195

Chapter 6

Conclusions and Recommendations

The primary objective of this study was to identify a suitable sludge treatment option that would address the problematic metals and pathogens present in the sludge to render the sludge more usable in terms of its application. This was undertaken by means of comparing three selected sludge treatment techniques, viz; Composting, Activated Sludge Pasteurization and SLASH.

The experiments conducted and results achieved indicate that all three options significantly improved the quality of the sludge in terms of metal and pathogenic content. This was demonstrated by applying the WRC characterisation methodology to each of the selected treatment options. Tables 2, 3 and 4 present the results obtained in terms of the initial and final pollutant-, microbiological- and stability class of the sludge, and the subsequent treatment options applied.

In most instances there was an improvement in terms of metal concentration reduction (Table 2), pathogen reduction (Table 3) and the improvement of the stability class of the raw sludge (Table 4). Notwithstanding the fact that the results achieved suggested that any one of the treatment options applied could demonstrate an improvement in the sludge quality, they were not enough to provide an informed decision as to which option would be the ideal one.

As a result, a decision support matrix was developed and applied to identify the most preferred option. This decision support matrix set out to evaluate the sludge treatment options in terms of **1) technology performance** (to what degree did each option achieve the desired reduction of pollution levels by metals and pathogens to acceptable standards, as determined by the WRC guidelines); **2) cost implications** (investment and running costs); and **3) sustainability or environmental friendliness** of the option. The results from this assessment are presented in Chapter 5, Table 5. In this instance the composted sludge scored the highest points (350) followed by SLASH at 285 and lastly the ASP at 195. Based on this assessment, the **Composted Sludge** is recommended as the preferred option. Compared to the other two options, composting performed best by achieving a satisfactory score based on the WRC classification guidelines including cost and technical feasibility.

It is therefore recommended to the Sasol SW management to explore the implementation of a full scale composting plant further, in order to address the

current sewage sludge problem in terms of its quality and storage practices. The composted sludge of the quality as indicated in the WRC guidelines can be used for the re-vegetation requirements of the Sasol One waste sites. In-depth research could be done to confirm this. However, although the composting option was the most preferred option, the management of the SW is required to initiate an investigation to understand the origin of the metals identified in this study. If it is possible to reduce these metals at source, or to extract them in a commercially viable manner, the beneficial use of the composted sludge could be extended to public and commercial use, thus creating a long term sustainable option.

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