A TECHNICAL AND FINANCIAL REVIEW OF SEWAGE SLUDGE TREATMENT TECHNOLOGIES

CJ Marx · WV Alexander · WG Johannes · S Steinbach-Kane

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Water Research Commission

A TECHNICAL AND FINANCIAL REVIEW OF SEWAGE SLUDGE TREATMENT TECHNOLOGIES

Report to the
WATER RESEARCH COMMISSION

by

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Sludge Consult

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EXECUTIVE SUMMARY

The objectives of the study were to establish a reference document describing locally and internationally available sludge management technologies, their respective applicability under South African conditions, and first-order cost estimates of their possible implementation. The aim was to give a clear indication to metropolitan councils, municipalities and other sludge producers of the technologies available and applicable under local conditions, as well as an indication of the cost and economy of scale applicable to each process.

The study includes an overview of current sludge management practices in South Africa, as well as an estimate of sludge quantities and qualities and a brief description of commonly used sludge treatment and disposal methods.

A summary of the status quo of legislation in South Africa with regard to sludge management is also given. This is followed by a description of the possible utilisation and disposal routes available within this legal framework, using as a basis the *Sludge Utilisation or Disposal Decision Flow Diagram (SUDDFD)*, as presented in the Addendum No 1 to the *Permissible Utilisation and Disposal of Sewage Sludge (Edition 1)*, (Department of Agriculture *et al* 1997). The sludge treatment requirements and available technologies for each of the utilisation or disposal routes are listed in matrix form for easy reference and use.

Concise descriptions of the sludge treatment technologies mentioned in the matrix and other currently available techniques are given together with a first-order cost estimate for selected technologies.

First-order cost estimates are presented for the established processes that are considered appropriate for South African circumstances. The cost estimates include estimates of capital costs, annual costs of the capital expenditure, operating costs, and maintenance costs. These cost estimates serve as a guide in selecting appropriate sludge treatment technologies. Typical case studies are presented to illustrate the use of the Sludge Management Decision Matrix and the cost sheets.

The report concludes with the following recommendations for further research:

i. National survey of wastewater treatment plants, their treatment processes, sludge quantities and qualities as well as current sludge utilisation/disposal routes and related costs,

ii. Development of benchmark criteria for comparing the performance of different wastewater treatment plants and their sludge management.

iii. Monitoring of existing sludge reuse facilities and practices in order to establish the real effects and costs of the specific process involved.

iv. Future updating of this study on a regular basis in view of the dynamic nature of the aspect of sludge handling in the field of wastewater treatment.

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1 INTRODUCTION

1.1 BACKGROUND INFORMATION AND MOTIVATION OF THE STUDY

In 1997 the guide *Permissible Utilisation and Disposal of Sewage Sludge* (PUDSS 97) was co-published by the Departments of Agriculture (DOA), Health (DOH), and Water Affairs and Forestry (DWAF), the Water Institute of Southern Africa (WISA) and the Water Research Commission (WRC) (Department of Agriculture *et al.*, 1997). After publication, debate amongst stakeholders in the sludge disposal industry led to an agreement that a revised second edition of PUDSS 97 (Department of Agriculture *et al.*, 1997) was required. In the course of the debate a number of topics were identified requiring further research, and funding from the WRC research programme was approved for this purpose.

With reference to the specific focus of this project, it needs to be pointed out that sludge management has only recently been recognised as an integral part of wastewater treatment. This is illustrated by the fact that a number of sludge disposal strategies commonly used world-wide, such as disposal to sacrificial land, dumping in the sea, landfilling, lagooning and incineration, are considered to be undesirable due to their overall negative impact on the environment. This development has necessitated new technology for the treatment and disposal of sewage sludge.

The strategy for selecting appropriate sludge treatment and disposal techniques needs to satisfy the following important aspects in order to be successful:

- Sound economics;
- Reliable technology;
- Reduction of the environmental impact;
- Understanding of local needs;
- Understanding of local issues; and
- Public acceptance.

Sludge treatment technology is expensive and adds significantly to the overall cost of wastewater treatment. It is not uncommon that the cost for the treatment and disposal of sewage sludge can double the cost of wastewater treatment. The importance of sound economics and reliable technology therefore does not need further elaboration. High capital expenditure requires that reliable technology is implemented in order to ensure that the environmental impact is minimised as far as possible.

Very little work has been done on the assessment and costing of sludge treatment technologies globally, or specifically in South Africa. Consequently, local sludge handling agencies do not have access to a reference standard for making decisions regarding technical performance and relative costs of alternative sludge treatment and management options. The overall aim of the project is thus to redress this situation.

The understanding of the local needs and issues contributes to the public acceptance of a process that is also important to ensure its sustainability. It does not make sense to implement a process that is in direct conflict with any local needs or issues. On the contrary, the process to be implemented must be modified to such an extent that all the potential local issues are resolved or adequately addressed. It is thus also the aim of this study to make the reader sensitive towards possible impacts of the technologies discussed to enable him to make an informed decision.

It is clear from the above that there is no general solution for each and every installation and location. Each possible treatment alternative needs to be evaluated against the above criteria to establish the most suitable solution to the specific problem. Although economics play a major role in the decision process, it is not the only criterion anymore. Other criteria, such as local perceptions and public opinion, can easily overrule the economics of a process. It is therefore important that the decision-makers and evaluators are informed on the available technology as well as on the consequences of the technology so that they can make informed decisions. The purpose of this report is therefore also to provoke thought and discussion on the treatment and disposal of sewage sludge that should result in a better understanding of the problems that in turn should lead to better solutions.

1.2 OBJECTIVES OF THE STUDY

The overall objective of this study is to provide local sludge handling agencies with a reference standard to facilitate their decision-making process with regard to the technical and financial aspects of sludge treatment and management. To achieve this goal, the specific aims of this project were defined as follows:

- Review sludge treatment technologies available locally and internationally;
- Determine their applicability under South African conditions;
- Determine the costs of their implementation;
- Provide a comparison to sludge management technologies currently being used;
- Prepare a reference document that can serve as a tool for local authorities and other institutions involved in the treatment and disposal of wastewater sludge.

1.3 APPROACH AND METHODOLOGY

The review of sludge treatment technologies will be closely linked to the PUDSS 97 (Department of Agriculture *et al.*, 1997) document and its Addendum (Water Research Commission *et al.*, 2001), which was recently completed and will be published soon.

The Addendum was commissioned by the WRC to clarify the situation concerning the implementation of the sludge disposal guidelines.

This study uses the *Sludge Utilisation or Disposal Decision Flow Diagram (SUDDFD)* (Water Research Commission *et al*, 2001) set out in the Addendum as a starting point to identify the necessary sludge treatment steps that are required to implement the different options described in the diagram. Each treatment step is then discussed further in the form of processes and technologies available both locally and internationally. Strong reliance has been placed on research done by the Water Environment Research Foundation (WERF) in the USA, who are also linked to the Water Environment Federation (WEF). The research of WERF was summarised in the project report PROJECT 96-REM-1 (Pincince *et al.*, 1998). As this research was performed in the USA, it was necessary to adapt the findings to suit South African conditions.

In order to help the user of this report to read the information on sludge treatment technologies in the right context, an overview of current sludge management practices in South Africa and the legal requirements pertaining to sludge handling, utilisation and disposal is also given.

The review, together with the Addendum, then constitutes a useful, integrated tool to all sludge producers and managers to: -

(i) guide the sludge producer through the different disposal or utilisation options and to highlight relevant technical and legislative requirements associated with every decision;

(ii) outline which (technical) options are available to the sludge producer in order to implement the chosen disposal or utilisation option;

(iii) provide a first-order cost estimate on the selected technologies.

1.4 PRESENTATION OF INFORMATION

Chapter 2 gives an overview of current sludge management practices in South Africa. This includes an estimate of sludge quantities and qualities as well as a description of commonly used sludge treatment and disposal methods. These methods will be reviewed taking into consideration current legal requirements and possible future changes in legislation.

Existing legislation on sludge management in South Africa is also presented in this chapter. This is followed by a description of the possible utilisation and disposal routes available within this legal framework, using the *Sludge Utilisation or Disposal Decision Flow Diagram (SUDDFD)* (Water Research Commission *et al*, 2001) as a basis. The sludge treatment requirements and available technologies for each of the utilisation or disposal routes are listed in matrix form (Sludge Management Decision Matrix) for easy reference and use.

A concise description of the sludge treatment technologies mentioned in the matrix, as well as other currently available techniques, is given in **Chapter 3** together with a first-order cost estimate for selected technologies. In describing the state of development of the various processes, the following classification, as used in the WERF report (Pincince *et al*, 1998), has been employed:

Embryonic processes:	Processes that have been tested in a laboratory or on a bench-scale application only
Innovative processes:	Processes that have been tested on a demonstration scale or have had some degree of initial use
Established processes:	Processes that have been applied in several full-scale operations.

The known processes are classified in the above categories according to their South African application. Most embryonic and innovative processes are not considered for immediate implementation, as the risk involved in their application is considered to be too high. Some of the larger organisations involved in sludge management may use this information to plan their own research and development programmes.

Established processes are described in so-called technology sheets, with user-friendly references, and can be easily updated. The sheets give a short description of the process, assess the applicability of the process under South African conditions, list advantages and disadvantages as well as give references to existing installations in South Africa (where applicable) and typical literature references for further reading.

First-order cost estimates are presented for the established processes considered appropriate for South African circumstances. The cost estimates are presented in so-called cost sheets and include estimates of (1) capital costs, (2) annual costs of the capital expenditure, (3) operating costs, and (4) maintenance costs. These cost estimates are provided to serve as a guide in selecting appropriate sludge treatment technologies.

Typical case studies illustrating the use of the Sludge Management Decision Matrix and the cost sheets are presented in **Chapter 4**.

The report concludes with **Chapter 5** which contains recommendations for further research.

2 SLUDGE MANAGEMENT PRACTICES IN SOUTH AFRICA

2.1 SEWAGE TREATMENT IN SOUTH AFRICA

There are approximately 900 wastewater treatment works registered in South Africa, with a registered cumulative treatment capacity of approximately 7 200 Mℓ/d. If it is assumed that the spare capacity in the treatment works amounts to 25% of the registered treatment capacity, then the total flow treated on a daily basis amounts to 5 400 Mℓ/d.

An analysis of the registered treatment capacity is given in Figure 2.1 below. The chart shows that approximately 20% of the works treat 80% of the wastewater generated on a daily basis, while more than 82% have a registered capacity of 5 Mℓ/d or less.

Sophisticated sludge treatment processes should not be implemented for the latter group as basic processes, such as anaerobic or aerobic stabilisation and sludge-drying beds will generally be appropriate.

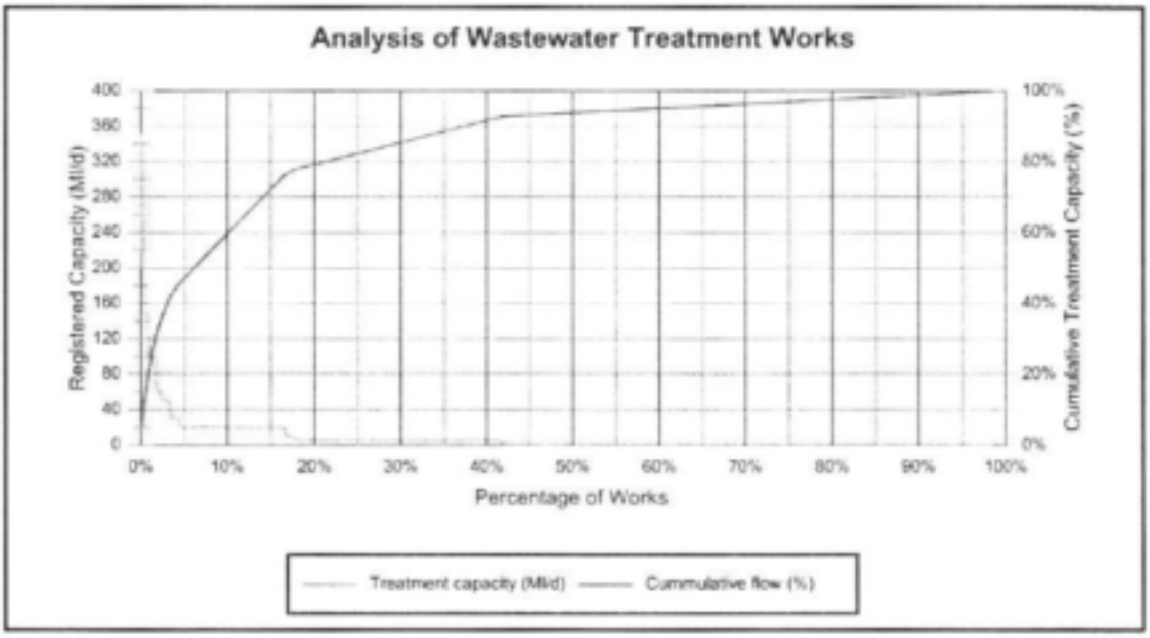

Figure 2.1: Registered wastewater treatment capacity in South Africa

The estimate of the daily sludge production in South Africa 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. The estimate of the daily sludge production in South Africa is thus 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 to be disposed of on a daily basis is thus 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.

Herselman has quantified the sludge disposal methods applied in South Africa as follows (Herselman, 2001):

- Stockpiling of dried sludge (40%);
- Sacrificial or Dedicated Land Disposal (21%);
- Sludge Lagoons (16%);
- Composting (10%);
- Farming activities (7%);
- Undisclosed (6%);
- Landfill/Co-disposal (4%);
- Instant lawn cultivation (3%);
- Marine disposal (2%).

According to the investigations by Herselman (Herselman, 2001), the stockpiled sludge is typically used by municipalities and farmers, or disposed of in landfills, or further treated using processes such as composting.

The disposal of sludge on sacrificial land has to be discontinued 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 areas. This situation is presently the topic being investigated by Herselman (Herselman, 2001).

The disposal of sludge in lagoons can only be seen 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 the existing lagoons will sooner or later have to be replaced with sustainable technology.

There is internationally 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.

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 clayey 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.

The use of sludge by undisclosed users typically constitutes the use of sludge that has been dried on sludge drying beds, by the public in private residential gardens. 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. This practice should therefore be ceased without delay.

The utilisation or disposal of sludge by means of composting is discussed in more detail in Sections 3.4 and 3.8 of this report.

The City of Durban has been discharging sewage and selected industrial wastes through two deep-sea marine outfall sewers since 1970 (Stevens, 2002). The outfall sewers stretch between 3,2 and 4,2 km into the deep sea, and the detritus and scum are removed from the wastewater before disposal. An intensive and stringent monitoring programme is carried out annually to ensure that the environment is not compromised. 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 (Saabye A. *et al*, 1994), and no such sludge disposal has been permitted since 1998.

It is evident from the above that the methods presently used for the treatment and disposal of sewage sludge in South Africa are not in conformance with the present environmental and legal requirements. In some cases there is a serious threat to public health. It is therefore necessary for alternative sludge disposal methods to be investigated and promoted to improve the current situation and to conserve our environment for future generations.

Technology is characterised by constant development – this also applies to the technology for the re-use or disposal of sludge. A document such as this one should therefore be regularly upgraded to keep pace with developments and so ensure that the best available technology is used in the treatment and disposal or re-use of wastewater sludge.

2.2 LEGAL REQUIREMENTS

The laws governing the disposal of wastewater sludge in South Africa are the following:

- National Environmental Management Act, 1998 (Act No. 107 of 1998);
- Environment Conservation Act, 1989 (Act No. 73 of 1989);
- National Water Act, 1998 (Act No. 36 of 1998);
- Hazardous Substances Act, 1973 (Act No. 15 of 1973);
- Fertiliser, Farm Feeds, Agricultural Remedies and Stock Remedies Act, 1947 (Act No. 36 of 1947);
- Conservation of Agricultural Resources Act, 1983 (Act No. 43 of 1983);
- Occupational Health and Safety Act, 1993 (Act No. 85 of 1993).

In addition, the following publications or procedures are also applicable and need to be consulted:

- Permissible Utilisation and Disposal of Sewage Sludge (Edition 1) 1997 (Department of Agriculture *et al*, 1997);
- Addendum No 1 to Permissible Utilisation and Disposal of Sewage Sludge (Edition 1) 1997, (to be published in 2002);
- Water Use Authorisation and Registration Management System (WARMS), (This is the registration system used by the Department of Water affairs and Forestry (DWAF) for water uses) (Department of Water Affairs and Forestry).
- Minimum Requirements: (Second Edition) 1998 or as revised thereafter (Department of Water Affairs and Forestry, 1998);

  The aforementioned document refers to the Waste Management Series published by DWAF, which establishes a reference framework of standards for waste management in South Africa in terms of section 20 of the Environment Conservation Act, 1989 (Act no. 73 of 1989). It is a trilogy consisting of:

  - Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste
  - Minimum Requirements for Waste Disposal by Landfill
  - Minimum Requirements for Water Monitoring at Waste Management Facilities

  Copies of these documents may be obtained from:

The Director: Water Quality Management
Department of Water Affairs and Forestry
P O Box X 313
PRETORIA
0001

2.3 SLUDGE UTILISATION AND DISPOSAL DECISION FLOW DIAGRAM

Within the current legislative framework in South Africa four main routes are available for the utilisation and disposal of wastewater sludge, namely:

- Sludge utilisation by the general public (only applicable to Class D sludge);
- Sludge utilisation in agriculture and industry;
- Sludge disposal off the site of the wastewater treatment works;
- Sludge disposal on the site of the wastewater treatment works.

These are also four of the five main alternatives followed in the *Sludge Utilisation and Disposal Decision Flow Diagram* (SUDDFD) as presented in the Addendum to the PUDSS 97 document (Department of Agriculture *et al.*, 1997). The SUDDFD is intended to guide the sludge producer or manager through the different utilisation and disposal options available and to highlight relevant technical and legislative requirements associated with each decision. The diagrams and a detailed description of all the steps and individual decision nodes can be found in the Annexure to this report.

The SUDDFD (Water Research Commission *et al*, 2001) starts off with an Initial Decision Diagram, which covers aspects such as the quality of sludge being produced on a plant and the legal status of current sludge disposal practices. The user is then led to the various reuse and disposal routes available. Sludge utilisation in agriculture is divided in two groups, namely, one for using Type D sludge and the other for using Types A, B or C sludge. The requirements for these two alternatives are significantly different - Type D sludge is the highest quality sludge that can be produced and has been classified for unrestricted use on land within certain limitations related to the application rate only.

According to PUDDS 97 (Department of Agriculture *et al*, 1997) the classification of wastewater sludge into Types A to D reflects the decreasing potential of the types to cause odour nuisance and fly-breeding as well as to transmit pathogenic organisms to man and his environment. The principles for differentiation between the sludge types are as follows:

- Type A sludge: Unstable with a high odour and fly nuisance potential; high content of pathogenic organisms
- Type B sludge: Stable with low odour and fly nuisance potential; reduced content of pathogenic organisms
- Type C sludge: Stable with insignificant odour and fly nuisance potential; containing insignificant numbers of pathogenic organisms
- Type D sludge: Of similar hygienic quality as Type C but with the metal and inorganic content limited to acceptable low levels. There is no restriction on the use of Type D sludge on land but the product must be registered in terms of Act 36 of 1947 if used for agricultural/ horticultural activities.

More information on the classification and composition of wastewater sludges and allowable concentrations can be found in PUDSS 97 (Department of Agriculture *et al.*, 1997), the Addendum (Water Research Commission *et al.*, 2001), WISA (Water Institute of Southern Africa, 1993) and Smith and Vasiloudis (1989).

In the SUDDFD (Water Research Commission *et al.*, 2001) each of the main utilisation and disposal routes lists a number of final end-use options such as fertiliser (for use of Type D sludge in agriculture), edible crops (for use of Types A, B or C sludge in agriculture), bricks (for sludge utilisation in industry) or land disposal (on-site sludge disposal). A list of possible end-use options, which are currently available, is given in the decision matrix presented in Section 2.4 of this report. A detailed description of the various end-use options can be found in Chapter 3.

2.4 SLUDGE MANAGEMENT DECISION MATRIX

The Sludge Management Decision Matrix (SMDM) consists of two parts. The first part (see Table 2.1) can be seen as a continuation of the SUDDFD (Water Research Commission *et al.*, 2001), in that it lists possible end-use options that are currently available under each of the main utilisation and disposal routes. The options listed are established ones, but in some cases also innovative processes that are considered potentially suitable for South African conditions. The restrictions and requirements listed in Table 2.1 are important factors to be kept in mind when considering a utilisation or disposal option.

The second part of the SMDM (see Table 2.2) relates established end-use options to required sludge treatment steps and the established technologies available under each treatment step. The various treatment steps and technologies are "rated" in terms of their applicability to the specific end-use options.

Table 2.1: Sludge Management Decision Matrix - Part 1

Utilisation / Disposal options	Restrictions	Requirements
ROUTE B: USE OF TYPE D SLUDGE IN AGRICULTURE		
i. Sale of processed sludge ii. Land application to: – Household vegetables and tobacco – Vineyards and fruit trees – Cereal culture and sugar cane – Public gardens and traffic islands – Public parks, recreation areas, lawns at schools, swimming pools, sports fields – Private gardens: Lawns, shrubs, trees, vegetables – Nurseries: Shrubs, trees and other plants – Instant lawn cultivation – Grazing for animals producing milk, meat and eggs – Crops not for grazing, but utilised as dry fodder – Natural veld and tree plantations	Maximum application rate of 8 dry t/(ha-year)	Requirements for Type D sludge: • Metal and inorganic content are limited to a certain level (see PUDSS 97 (Department of Agriculture *et al.*, 1997)) • Insignificant number of pathogenic organisms, i.e. sludge requires treatment such as alkaline stabilisation, composting, pasteurisation and thermal conversion that reduces pathogens

Utilisation / Disposal options	Restrictions	Requirements
ROUTE C: USE OF TYPE A, B OR C SLUDGE IN AGRICULTURE		
TYPE C (Use in agriculture):		
i. Sale of processed sludge	• Only as per special contract	Requirements for Type C sludge: Insignificant number of pathogenic organisms, i.e. sludge requires treatment such as alkaline stabilisation, composting, pasteurisation and thermal conversion that reduces pathogens.
ii. Land application to:		
– Vineyards and fruit trees	• All sludge must be mixed or covered with soil whenever possible.	
– Cereal culture and sugar cane	• All sludge must be mixed or covered with soil whenever possible.	
– Public gardens and traffic islands	• All sludge must be mixed or covered with soil whenever possible.	
– Public parks, recreation areas, lawns at schools, swimming pools, sports fields	• All sludge must be mixed or covered with soil whenever possible. • Application only during planting	
– Nurseries: Shrubs, trees and other plants	• No subsequent selling or alienation of sludge or any mixture containing such sludge is allowed by the user.	
– Instant lawn cultivation	• Application only with planting and during the period subsequent to harvesting prior to the next growing season. • No subsequent selling or alienation of sludge or any mixture containing such sludge is allowed by the user.	
– Grazing for animals producing milk, meat and eggs	• All sludge must be mixed or covered with soil whenever possible.	
– Crops not for grazing, but utilised as dry fodder	• All sludge must be mixed or covered with soil whenever possible.	
– Natural veld and tree plantations	• All sludge must be mixed or covered with soil whenever possible.	

Utilisation / Disposal options	Restrictions	Requirements
TYPE B (Use in agriculture):		
i. Sale of processed sludge	• Only as per special contract	Requirements for Type B sludge: Reduced content of pathogenic organisms i.e. sludge requires treatment such as anaerobic digestion (for primary sludge). Secondary sludges such as excess activated sludge and humus tank sludge are also classified as Type B
ii. Land application to: – Vineyards and fruit trees – Cereal culture and sugar cane	• Application only with planting and during the period subsequent to harvesting and prior to the next growing season. • All sludge must be mixed or covered with soil whenever possible.	
– Public gardens and traffic islands	• All sludge must be mixed or covered with soil whenever possible.	
– Public parks, recreation areas, lawns at schools, swimming pools, sports fields	• Application only during planting. • All sludge must be mixed or covered with soil whenever possible.	
– Nurseries: Shrubs, trees and other plants – Instant lawn cultivation	• Application only with planting and during the period subsequent to harvesting prior to the next growing season. • No subsequent selling or alienation of sludge or any mixture containing such sludge is allowed by the user.	
– Grazing for animals producing milk, meat and eggs	• Application only during planting. • All sludge must be mixed or covered with soil whenever possible.	
– Crops not for grazing, but utilised as dry fodder	• Application only with planting and during the period subsequent to harvesting prior to the next growing season.	
– Natural veld and tree plantations	• Application permissible only if area is effectively fenced to keep out unauthorised persons as well as animals producing milk, meat and eggs. • All sludge must be mixed or covered with soil whenever possible.	

Utilisation / Disposal options	Restrictions	Requirements
TYPE A (Use in agriculture):		
i. Sale of processed sludge	• Only as per special contract	Requirements for Type A sludge: No further treatment required. Type A sludge are sludges such as raw sludge, cold digested sludge, septic tank sludge, oxidation pond sludge
ii. Natural veld and tree plantations	• Application permissible only if area is effectively fenced to keep out unauthorised persons as well as animals producing milk, meat and eggs. • No subsequent selling or alienation of sludge or any mixture containing such sludge is allowed. • All sludge must be mixed or covered with soil whenever possible. • Application makes site unfit for any other purpose during such operation and for a minimum of two years afterwards. No nuisance or any other condition posing a potential health hazard or which may cause pollution of any water source is tolerated. • Utilisation of this site for any other purpose will only be permitted after necessary investigation has proved it to be safe.	
ROUTE D USE OF TYPE A, B, C OR D SLUDGE IN INDUSTRY		
i. Ash recycling	• Only innovative process at this stage	• Sludge has to be incinerated first.
ii. Brick production	• Only innovative process at this stage • Process has to be approved by the DWAF and the Department of Health.	
iii. Cement-kiln injection	• Only innovative process at this stage.	• Requires proximity of a cement factory with a suitable kiln.
iv. Light-weight aggregate production	• Only innovative process at this stage.	
v. Granular fertiliser (e g OCI Waste Conversion process)	• Only innovative process at this stage	• Requires addition of chemicals. • Process needs to be supported by a major fertiliser manufacturer to assure economic viability.

Utilisation / Disposal options	Restrictions	Requirements
vi. Pyrolysis (Sludge-to-oil)	• Only innovative process at this stage	• High-level technology requiring highly trained operators and maintenance crews • More than likely entire plant has to be imported
ROUTE E: USE OF TYPE A, B OR C SLUDGE OFF THE SITE OF WORKS		
i. Incineration		• Still requires solids (ash) disposal
ii. Combustion with solid waste		• Viability of incinerating solid waste (instead of recycling or other disposal methods) must be proven first
iii. Landfill (Co-disposal with domestic waste)	• DWAF has to agree to declassify sludge from hazardous to general waste	• Waste disposal site must have leachate collection system • Sludge solids content must be > 40% • Requires suitable landfill in close proximity
iv. Land reclamation: Stabilising mine dumps - grass or other plants	• All sludge must be mixed or covered with soil whenever possible. • Not allowed for Type A sludge	• Requires reclamation area in close proximity
ROUTE F: USE OF TYPE A, B OR C SLUDGE ON THE SITE OF WORKS		
i. Incineration		• Still requires solids (ash) disposal
ii. ATHOS process		• Still requires solids disposal
iii. Lagoons	• Only temporary measure	• Sludge disposal still required once lagoons are filled

Table 2.2: Sludge Management Decision Matrix - Part 2

TREATMENT PROCESS	RE-USE OR DISPOSAL OPTION						
	Alkaline stabilisation	**Composting**	**Land application**	**Co-disposal**	**Land reclamation**	**Incineration**	**Combustion with solid waste**
Conditioning	**Required**	**Required**	**Recommended**	**Required**	**Required**	**Required**	**Required**
Chemical conditioning	Required for dewatering	Required for dewatering	Required for dewatering	Required for dewatering	Required for dewatering	Required for dewatering	Required for dewatering
Heat conditioning	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not required	Not required
Thickening	**Recommended**	**Recommended**	**Recommended**	**Recommended**	**Recommended**	**Recommended**	**Recommended**
Centrifuges	Can be used if proven economical	Can be used if proven economical	Can be used if proven economical	Can be used if proven economical	Can be used if proven economical	Can be used if proven economical	Can be used if proven economical
Dissolved-air flotation	Recommended for WAS	Recommended for WAS	Recommended for WAS	Recommended for WAS	Recommended for WAS	Recommended for WAS	Recommended for WAS
Linear screens	In conjunction with belt filter press	In conjunction with belt filter press	In conjunction with belt filter press	In conjunction with belt filter press	In conjunction with belt filter press	In conjunction with belt filter press	In conjunction with belt filter press
Gravity	Recommended for primary and stabilised sludge	Recommended for primary and stabilised sludge	Recommended for primary and stabilised sludge	Recommended for primary and stabilised sludge	Recommended for primary and stabilised sludge	Recommended for primary and stabilised sludge	Recommended for primary and stabilised sludge
Vacuum filtration	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended
Stabilisation	**Recommended**	**Not required**	**Required, depending on application**	**Required**	**Required**	**Not required**	**Not required**
Anaerobic digestion	Recommended	Recommended but not required	Required, depending on application	Required	Required	Not required	Not required
Temperature-phased anaerobic digestion	Has to be proven viable	Not required	Has to be proven viable	Has to be proven viable	Has to be proven viable	Not required	Not required
Aerobic digestion	Recommended for WAS	Not required	Recommended for WAS depending on application	Recommended for WAS	Recommended for WAS	Not required	Not required
Autothermal thermophillic aerobic digestion	Has to be proven viable	Not recommended	Has to be proven viable	Has to be proven viable	Has to be proven viable	Not required	Not required
Dual digestion	Has to be proven viable	Not recommended	Has to be proven viable	Has to be proven viable	Has to be proven viable	Not required	Not required
Pasteurisation	Not required	Not recommended	Depending on application	Not required	Depending on application	Not required	Not required

TREATMENT PROCESS	RE-USE OR DISPOSAL OPTION						
	Alkaline stabilisation	**Composting**	**Land application**	**Co-disposal**	**Land reclamation**	**Incineration**	**Combustion with solid waste**
Dewatering	**Required**	**Required**	**Recommended**	**Required**	**Required**	**Required**	**Required**
Drying beds	Not recommended	Not recommended	Recommended if viable	Recommended if viable	Recommended if viable	Not recommended for unstabilised sludge	Not recommended for unstabilised sludge
Belt filter presses	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended
Chamber presses	Has to be proven viable	Has to be proven viable	Has to be proven viable	Has to be proven viable	Has to be proven viable	Has to be proven viable	Has to be proven viable
Centrifuges	Has to be proven viable	Has to be proven viable	Has to be proven viable	Has to be proven viable	Has to be proven viable	Has to be proven viable	Has to be proven viable
Vacuum filtration	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended
Vacuum-assisted drying beds	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended
Thermal conversion	**Not required**	**Not required**	**Required, depending on application**	**Not required**	**Not required**	**Not required**	**Not required**
Wet air oxidation	Not required	Not required	Not required	Not required	Not required	Not required	Not required
Drying	**Not recommended**	**Not recommended**	**Required, depending on application**	**Not required**	**Not required**	**Recommended**	**Recommended**
Carver Greenfield process	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended	Not recommended
Direct drying	Not recommended	Not recommended	If viable	If viable	If viable	If viable	If viable
Indirect drying	Not recommended	Not recommended	If viable	If viable	If viable	If viable	If viable
Flash drying	Not recommended	Not recommended	If viable	If viable	If viable	If viable	If viable

3 DESCRIPTION OF SLUDGE TREATMENT TECHNOLOGIES

3.1 INTRODUCTION

The study aims to provide a concise overview of the technologies available, both locally and internationally, for the processing and disposal of wastewater sludge. Strong reliance has been placed on research done by the Water Environment Research Foundation (WERF) in the USA, who have links with the Water Environment Federation (WEF). The research of WERF is summarised in the project report PROJECT 96-REM-1 (Pincince *et al.*, 1998). As this research has been performed in the USA, it was necessary to adapt the findings to suit South African conditions.

All technologies presented in this report are grouped according to the unit process (or sludge treatment step) they fall under, such as conditioning, stabilisation and dewatering. Each unit process is discussed under a separate heading.

The various technologies have been categorised as embryonic, innovative or established, in accordance with their level of development and application world-wide and their applicability to South Africa. The classification is based on the following definitions as used by WERF (Pincince *et al.*, 1998):

- Embryonic Processes: Processes that have been tested in a laboratory only.
- Innovative Processes: Processes that have been tested in a demonstration-scale application or have had some degree of initial use
- Established Processes: Processes that have been applied in several full-scale operations.

The classification of the technologies in these categories is not absolute. In this respect it is worthwhile to note that processes that may be classified as innovative or established in other parts of the world, may be considered embryonic in South Africa, owing to the fact that they have never been applied under local conditions. Most embryonic and innovative processes are not considered for immediate implementation, as the risk involved in their application is considered to be too high. Large sludge producers may include embryonic processes in their own research and development programmes.

The technical information is presented in two different formats: (1) all established processes are described in so-called technology sheets (see below), whereas (2) the innovative and embryonic processes are discussed in common text format due to the limited amount of information available on these technologies.

In addition to the technical information, cost estimates are presented in so-called cost sheets (see below) for those established processes considered most likely to be successful under South African conditions. The cost estimates allow these selected processes to be compared from a financial point of view, but as various site-specific factors may influence the final cost of a process, the outcome cannot be considered absolute.

3.1.1 Technology Sheets

The technology sheets aim to give a concise overview of a specific process and, at the same time to serve as an easy-to-use reference manual. Each established process is described on a separate technology sheet that comprises the following aspects:

- Process description:
  Short summary of how the process works
- Applicability to South Africa:
  This section indicates the suitability of the process under local conditions by taking into account the different sizes of sludge producers. The opinion given in this section needs to be evaluated for each specific application, and should only be viewed as a general comment and a guide based on the experience of the authors. Feasibility studies need to be performed before a final decision is taken.
- Requirements:
  A list of factors that have to be provided for, when utilising the specific process is given in this section. For example, many processes require sludge conditioning and/or thickening as a pre-treatment step. These processes also have to be taken into account when comparing various alternatives.
- Advantages / Disadvantages:
  Lists the benefits and shortcomings
- Main operating and design criteria:
  Lists (1) operating parameters that are vital to the process, (2) typical performance indicators, and (3) main design criteria (where available and applicable) for a first-order size estimate of the equipment required
- Typical reference installations:
  Lists typical reference installations in South Africa, so that interested parties can obtain first-hand information
- Typical literature references:
  For further and more detailed reading on the specific process

3.1.2 Cost Sheets

Cost estimates are presented in the so-called cost sheets for those established processes considered appropriate for South African circumstances.

The costs for the selected processes have been estimated on the basis described below:

- The base year of the costs given is July 1999.
- The rate of exchange of the major currencies applicable to the costs given is as follows:
  - US dollars $1,00 = R6.00
  - British pounds £1.00 = R10.00
  - German marks DM1.00 = R3.00
- Capital costs given as:
  - Civil construction costs
  - Mechanical equipment
  - Electrical and electronic equipment
- The annual costs of the capital expenditure have been calculated on the following basis:
  - Civil structures
    - Period 25 years
    - Interest rate 15% p.a.
  - Mechanical Equipment
    - Period 15 years
    - Interest rate 15% p.a.
  - Electrical and Electronic Equipment
    - Period 15 years
    - Interest rate 15% p.a.
  - Cost of operation
  - Cost of personnel
  - Cost of electricity
  - Cost of chemicals
- Annual maintenance costs have been estimated at the following percentages of the capital costs:
  - Civil structures 1,00%
  - Mechanical equipment 5,00%
  - Electrical equipment 5,00%
  - Electronic equipment 5,00%

It should be realised that the application cost of a specific process may differ from one wastewater treatment works to another because of site specific factors such as location, sludge composition and selected method of final disposal. As a result the cost estimates are to be seen as an indication of the relative cost of the processes compared with one another, and not as an accurate reflection of the cost of implementing such a process. Determining the actual implementation cost will require some further study and investigation, as the various site-specific factors, of which some have been mentioned above, need to be considered for each area, where the implementation of a specific process is considered. Although the cost estimates included in this report are presented with a high degree of confidence in their relative accuracy, and are considered suitable for use as benchmark costs, the true cost can only be established by inviting tenders for the implementation of the various processes.

3.2 PRE-TREATMENT AND CONDITIONING

In general, pre-treatment and conditioning processes are those that improve the efficiency of the subsequent processes. Generally the improvement concerns the thickening and dewatering properties of the sludge to be treated. Consequently only processes involving these treatment processes have been selected for discussion in this section. Processes that improve the efficiency of other sludge treatment processes are not discussed separately, but are seen to form part of the main treatment process.

3.2.1 Embryonic Processes

3.2.1.1 Acoustical Cavitation

Acoustical cavitation aims at increasing the solids content achievable during sludge dewatering, while simultaneously reducing the polyelectrolyte consumption (Pincince *et al.*, 1998). The process is based on the principle that acoustic devices attached to gravity belt sludge thickeners can break the surface tension of the sludge through the use of sound waves. Similarly, the mechanical agitation effected by the acoustic devices is expected to prevent clogging of the belt screen.

Acoustical cavitation has been tested only on a bench-scale application, using a batch process. Little is known about the efficiency of the process and the feasibility of its use in full-scale applications.

3.2.1.2 Electro-coagulation

The objective of electro-coagulation is to achieve sludge conditioning without the addition of chemicals (Pincince *et al.*, 1998). The process uses consumable metal electrodes made from scrap iron that release metallic ions when voltage is applied. The metallic ions facilitate coagulation, thereby concentrating the solid sludge particles and improving the solids content of dewatered sludge.

This process has been demonstrated in a bench-scale application only, and no information about its technical or financial viability is available.

3.2.1.3 Enzyme Conditioning

Enzyme conditioning involves the addition of enzymes to sludge in order to improve the dewatering characteristics of the sludge (Pincince *et al.*, 1998). It is believed that the dewatering characteristics of the sludge are improved because of the enzymes reducing the solid particles' affinity for water. The process requires incubation of the sludge for 16 hours after adding the enzymes, and laboratory tests have indicated an improvement of 2% to 4% in dewatered sludge solids content.

Although the process has been extensively tested in a laboratory-scale application, it was not developed or researched further.

3.2.1.4 Dual Polyelectrolyte conditioning

Dual polyelectrolyte conditioning has been investigated by the National Taiwan University of Science and Technology (Pincince *et al.*, 1998). In the tests, waste activated sludge was conditioned by adding a cationic and a non-ionic polyelectrolyte.

Experiments were carried out to establish the efficiency of the process, and to do this the capillary suction time, the specific resistance to filtration, the Zeta-potential and the settling rate were measured. It was found that the sludge conditioned with the cationic and the non-ionic polyelectrolyte performed better in the capture of fine particles, and that the flocs were more compact resulting in improved dewaterability. The process was also apparently less sensitive to polyelectrolyte overdosage.

This process has only been tested in a laboratory and, if found viable, may be worth investigating further, as implementation will not involve major capital expenditure. The process can be introduced for any current sludge dewatering operation in South Africa.

3.2.1.5 Mechanical disintegration

Müller (2001) of the Institute of Sanitary Engineering and the Institute of Mechanical Process Engineering at the Technical University of Braunschweig, Germany, investigated various mechanisms for disintegrating sewage sludge as a form of pre-treatment. The rationale behind the mechanical disintegration process is to physically rupture the cells to enable the release of the organic substances of the cells, which can then be treated easily by biological treatment processes.

The mechanisms he investigated included stirred ball mills, high-pressure homogenisers, ultrasonic homogenisers, the mechanical jet smash technique, the high performance pulse technique and the lysate centrifuge.

It appears that the process requires a relatively high energy input with the result that it may only be economically viable in highly loaded anaerobic digesters and situations where the disposal costs are high. It may also be applicable in cases, where sludge disposal is problematic as the process is claimed to reduce the amount of sludge by up to 65%.

Even though mechanical disintegration is still considered an embryonic process in South Africa, sludge pre-treatment has become very important in Europe where disposal costs are high. Currently, much research is being conducted in this field, and processes such as mechanical disintegration are no longer considered embryonic in the European marketplace.

3.2.1.6 Ozone Treatment

The enhancement of the dewaterability of waste activated sludge by ozone treatment has been tested in a laboratory-scale application only (Kwon *et al.*, 2001). Ozone doses were applied between 0 and 1.2 g O_3/g suspended solids (SS), and an apparent optimum of 0.4 g O_3/g SS was observed.

It was reported that although the ozone negatively affected the specific resistance to filtration, the dewaterability of the sludge was significantly improved. The sludge was dewatered by a filter press operated at 300 kPa. The moisture content decreased from 83% (non-treated sludge) to 60% (0.4 g O_3/g SS). It was also reported that the zone-settling velocity of the sludge increased by a factor of 15.

3.2.2 Innovative Processes

3.2.2.1 Carbon Dioxide Injection

During dewatering of sludge in centrifuges, conditions conducive to the formation of struvite could develop. Struvite, or magnesium ammonium phosphate hexahydrate, forms under specific conditions relating to the availability of its chemical components as well as pH levels, and is an insoluble crystal that can effectively cause permanent blockages in pipes. It also forms during co-digestion of waste activated sludge and primary sludge.

As the injection of carbon dioxide reduces the pH to a level, at which struvite does not readily form (Pincince *et al.*, 1998), it reduces maintenance requirements. The process involves vaporising liquid carbon dioxide and injecting it into the biosolids with the aid of a sparger that discharges in various directions. The efficiency of the process is primarily dependent on the size of bubbles formed during vaporisation (small bubbles are required) and on an adequate contact time.

3.2.2.2 Preheating

Preheating has the objective of increasing the solids content of dewatered sludge. Heat is applied prior to dewatering by using steam or heat exchangers (Pincince *et al.*, 1998). Pre-heating by steam involves injecting steam via a sparger into a sludge-holding tank, which should be sized for a minimum retention time of 30 minutes. The sludge is heated to a temperature of up to 60°C, which is believed to decrease the viscosity of sludge while enhancing the release of intracellular water. The improvement in the mass transfer rate of water is expected to result in an increase of 4% to 6% in dewatered sludge solids content. However, the use of heat exchangers has been found to destroy certain polymers used to enhance the dewatering characteristics of the sludge and alternative polymers should be selected in these cases. It has also been found that heating sludge with heat exchangers reduced the requirement for polymer addition in centrifuges. No information regarding the disinfection capabilities of the process could be found.

The process has been successfully demonstrated in full-scale applications, albeit on a very limited scale. It can only be considered if a source of waste heat is available.

3.2.2.3 Pulse-power conditioning

Pulse-power conditioning aims at increasing volatile solids reduction and methane production in anaerobic digesters (Pincince *et al.*, 1998). On its way to the digester, the sludge passes through an arc chamber, to which electrical discharges are applied. The energy field breaks down the sludge particles into soluble material, while at the same time promoting the formation of free radicals and ozone, and changing the electric charge of the particles.

Test results indicate that pulse-power conditioning reduces the retention time in the digester required to achieve similar volatile solids destruction and gas production, while the content of methane in the digester gas is increased. A further advantage is that the polymer requirement for dewatering of the digested sludge is reduced.

Very little is known about the state of development of this process, although it was tested on a full-scale basis in Orlando, Florida, during 1995/96.

3.2.3 Established Processes

3.2.3.1 Chemical Conditioning

Process:	**CHEMICAL CONDITIONING**
Unit process / Treatment category:	**Conditioning**

Process description

Chemical conditioning entails dosing sludge with chemicals such as ferric chloride, aluminium sulphate, lime or polyelectrolyte to enhance its thickening or dewatering characteristics. It is to be noted that the term polyelectrolyte is used in this report to describe long-chain organic molecules, also known as polymeric coagulants or polyacrylamites.

Dosing with polyelectrolyte is a requirement for the operation of most dewatering equipment and typical dosage rates vary between 2 kg to 6 kg polyelectrolyte per ton dry solids. Higher dosage rates may be required under abnormal conditions, and this would have a significant impact on the cost of the operation.

Ferric chloride, aluminium sulphate or lime, which are normally used in South Africa for the precipitation of phosphates, has the added advantage of producing sludge with improved settling characteristics. The dosage rates are, however, dictated by the phosphate content of the supernatant of the thickeners and not by the settling properties of the sludge, as the primary reason for their use is the chemical removal of phosphate, and not the improvement of the settling characteristics of the sludge.

Applicability to South Africa

Metro:	Well suitable
City:	Well suitable
Large municipality:	Well suitable
Medium size municipality:	Well suitable
Small municipality:	Well suitable

Requirements

- Chemicals
- Dosing equipment
- Polyelectrolyte make-up facilities
- Storage facilities
- Bulk handling facilities for large installations

Advantages

- Improves sludge settling and dewatering characteristics

Disadvantages

- Major contributor to operating cost of dewatering processes since polyelectrolyte is expensive

Main operating and design criteria

- Typical polyelectrolyte dosage rates for dewatering vary between 2 kg to 6 kg polyelectrolyte per ton dry solids.
- Many dewatering installations use polyelectrolyte in powder form to prepare their own solutions on site that usually have a strength of 0.1% – 0.5%. When preparing polyelectrolyte solution the wetting device is very important as the homogeneous mixing of the powder into a solution will be effective only if no "fish eyes" form.

Typical reference installations

Chemical conditioning with polyelectrolyte can be found at most dewatering installations that employ centrifuges or filter belt presses, such as:

- Olifantsvlei Regional Sludge Handling Facility (Johannesburg)
- Zandvliet WWTW (Cape Town)
- Paarl WWTW
- Olifantsfontein (Erwat)

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

[2] United States Environmental Protection Agency (EPA). 1979. *Process Design Manual: Sludge Treatment and Disposal.* EPA No. 625/1-79-011. Cincinnati: Centre for Environmental Research Information, U.S. Environmental Protection Agency.

Process: **CHEMICAL CONDITIONING**

Unit process / Treatment category: **Conditioning**

	Unit	Dry Polymers		Liquid Polymers		
		Capacity [kg Poly/h]				
		<10	10-60	<4	4-17	17-30
CAPITAL COST						
Civil works	R	87 000	102 000	72 000	87 000	102 000
Mechanical equipment	R	390 000	1 658 000	350 000	1 350 000	2 500 000
Electrical equipment	R	105 000	450 000	105 000	450 000	775 000
Total capital expenditure	**R**	**582 000**	**2 210 000**	**527 000**	**1 887 000**	**3 377 000**
Annual Capital Cost						
Civil works	R	13 459	15 779	11 138	13 459	15 779
Mechanical equipment	R	66 697	283 546	59 856	230 873	427 543
Electrical equipment	R	17 957	76 958	17 957	76 958	132 538
Total annual capital cost	**R**	**98 112**	**376 283**	**88 951**	**321 290**	**575 860**
Unit cost	**R/kg**	**3,36**	**2,15**	**7,62**	**6,47**	**6,57**
COST OF MAINTENANCE						
Civil works	R	870	1 020	720	870	1 020
Mechanical equipment	R	19 500	82 900	17 500	67 500	125 000
Electrical equipment	R	5 250	22 500	5 250	22 500	38 750
Total annual cost of maintenance	**R**	**25 620**	**106 420**	**23 470**	**90 870**	**164 770**
Unit cost	**R/kg**	**0,88**	**0,61**	**2,01**	**1,83**	**1,88**
COST OF OPERATION						
Personnel cost	R	35 000	35 000	35 000	35 000	35 000
Electricity cost	R	104	132	76	104	187
Cost of chemicals	R	876 000	5 256 000	350 400	1 489 200	2 628 000
Total annual cost of operation	**R**	**911 104**	**5 291 132**	**385 476**	**1 524 304**	**2 663 187**
Unit cost	**R/kg**	**31,20**	**30,20**	**33,00**	**30,71**	**30,40**
Total annual cost of O & M	**R**	**936 724**	**5 397 552**	**408 946**	**1 615 174**	**2 827 957**
Unit cost	**R/kg**	**32,08**	**30,81**	**35,01**	**32,54**	**32,28**
TOTAL ANNUAL COST	**R**	**1 034 836**	**5 773 835**	**497 897**	**1 936 464**	**3 403 817**
UNIT COST	**R/kg**	**35,44**	**32,96**	**42,63**	**39,01**	**38,86**

Note: The unit costs are in R/kg polymer. The unit costs are derived from the annual costs based on the upper value of the respective capacity range (e.g. 60 kg/h for the range 10 – 60 kg/h) and an operating time of 40 hours/week and 52 weeks/year. The cost of the polyelectrolyte was assumed to be R30/kg. Based on a typical dosage rate of 4 kg polymer/t DS, the following sludge amounts can be treated: -

	Dry Polymers		Liquid Polymers		
	Capacity [kg polymer/h]				
	<10	10 - 60	<4	4 - 17	17 - 30
Sludge treated [t DS/d]	20	120	8	34	60
Cost (R/t DS)	**141,76**	**131,84**	**170,52**	**156,04**	**155,44**

3.2.3.2 Heat Conditioning

Process:	**HEAT CONDITIONING**
Unit process / Treatment category:	**Conditioning**

Process description

The heating of sludge under pressure causes the cell structure of the organic constituents to break down so that the gel-like structure of the sludge disintegrates and bound water is released. Reduction of volatile solids is achieved together with the solubilisation of certain organic and inorganic constituents of the sludge and precipitation of others.

For municipal wastewater sludges the use of low-pressure oxidation systems (LPO) is normally adopted. These systems operate typically at temperatures of 170°C to 200°C and reactor pressures of 22 Bar to 25 Bar. Under these conditions approximately 25% to 30% of the volatile solids are oxidised or solubilised. Due to the high temperatures at which the sludge is treated, the process renders a sterile product. Patented processes, such as the ZIMPRO process, operate on this principle and produce a significant decrease in the specific resistance to filtration, with a corresponding increase in dewatering rates.

The typical arrangement of an LPO-conditioning plant is as follows: Sludge is withdrawn from a holding tank through macerators (to ensure solids size reduction to less than 5 mm) into a high-pressure sludge pump, which raises the system pressure to design level. The sludge passes through a heat exchanger into the reactor vessel where it is retained for a period of 20 minutes to 30 minutes depending on the sludge characteristics. The temperature inside the reactor is raised by direct steam injection. The thermally conditioned, sterile sludge leaves the reactor through another heat exchanger and is discharged into a holding tank. The sludge settles rapidly and the holding tank also serves as a thickener.

Applicability to South Africa

Thermal conditioning processes have been used in South Africa but are not popular due to negative aspects such as high operation and maintenance costs and the treatment requirements for the dewatering liquors.

Metro:	Possibly suitable
City:	Possibly suitable
Large municipality:	Depending on situation
Medium size municipality:	Not suitable
Small municipality:	Not suitable

Requirements

- Heat source
- Sophisticated pressurisation system

Advantages

- High process temperature renders a sterile product
- The conditioned sludge has very good dewatering characteristics and generally the use of supplementary flocculants is not required
- The conditioned sludge has very good settling characteristics and a relatively high solids concentration can be achieved in the thickener underflow, which reduces the capacity of the dewatering equipment.
- The dewatered sludge may be utilised for certain products such as compost or brick manufacturing without being a health hazard.

Disadvantages

- The equipment and operation of the plant are generally more sophisticated than that which is found on conventional wastewater treatment plants
- High level of maintenance
- Skilled operation and maintenance personnel required
- Corrosive and abrasive environment due to high temperatures which requires relatively expensive construction materials
- Scrubbing of vapours emanating from plant is required
- High energy requirements
- Treatment requirements for dewatering liquors
- High operation and maintenance costs
- Produces very high strength liquors which are difficult to treat and have a high ammonia, non-biodegradable COD and colour content
- Hazardous to health in that vapours and fumes emanating from the plant may adversely affect staff working on the installation

Main operating and design criteria

For LPO plant:

- Temperature: 170° C to 200°C
- Pressure: 22 bar to 25 bar
- Retention time in reactor: 20 minutes to 30 minutes

Typical reference installations

- Fishwater Flats (Port Elizabeth)
- Borcherds Quarry (Cape Town) (discontinued)

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse*. 3rd edition, Singapore: McGraw-Hill Book Co.

[2] United States Environmental Protection Agency (EPA). 1979. *Process Design Manual: Sludge Treatment and Disposal*. EPA No. 625/1-79-011. Cincinnati: Centre for Environmental Research Information, U.S. Environmental Protection Agency.

3.3 THICKENING

The purpose of thickening processes is to increase the solids concentration in the sludge by reducing its water content. As a result, the treatment capacity and efficiency of the downstream processes are increased by the higher solids content.

3.3.1 Embryonic Processes

3.3.1.1 Sirex Pulse-power Conditioning

The Sirex Pulse Power process involves applying frequency pulses to sludge solids. This is achieved by means of a special paddle system in a settling tank, and is said to allow the solids to agglomerate and settle at a higher than normal rate, without the addition of chemicals (Pincince *et al.*, 1998).

Very little is known about the technical feasibility and economic viability of this process, although it has reportedly been used in France and in Germany.

3.3.2 Innovative Processes

3.3.2.1 Anoxic Gas Flotation

Anoxic gas flotation involves thickening of anaerobically digested sludge in a flotation thickener as part of the digestion process (Pincince *et al.*, 1998). The mixed content of the anaerobic digester is withdrawn and conveyed to a flotation unit for thickening. In order to maintain anaerobic conditions, digester gas is used to induce the flotation process. The floated solids are then returned to the digester while the underflow is recycled to the wastewater treatment process, for instance the inlet works.

The advantage of this process is that a shorter hydraulic retention time can be maintained (due to an increase in the solids content of the sludge introduced to the digester) while normal or even increased solids retention time can be achieved.

The process has been tested in a pilot plant scale application with encouraging results. Solids contents in the digested sludge exceeding 6% could be achieved, compared to less than 3% for conventional sludge digestion. However, no information on the economic implications of the process is available at this time. Care should be exercised with this process if Struvite precipitation is likely to be a problem (see Section 3.2.2.1).

3.3.2.2 BIOFLOT Process

The BIOFLOT process is a variation of the dissolved-air flotation process. It uses the denitrifying capability of the organisms in the waste activated sludge as a source of gas to effect flotation (Pincince *et al.*, 1998).

The process involves the addition of calcium nitrate to waste activated sludge before the mixture is fed to a bioreactor tank. The calcium nitrate promotes denitrification in the sludge, i.e. the conversion of nitrate to nitrogen gas, and the nitrogen gas in turn leads to flotation of the sludge. The process requires no polymer addition and is said to require less space and energy than conventional dissolved-air flotation.

The process has been tested in a full-scale application and is marketed as being suitable for small treatment works treating up to approximately 2 Mℓ/d. Potential users should however take cognisance of the increased nitrate load, and the negative effect this could have on biological phosphate removal.

3.3.2.3 Recuperative Thickening

The recuperative thickening process is based on the same principle as the anoxic gas flotation process described above. It involves thickening of digested sludge and the subsequent return of the thickened sludge to the digester. In the recuperative thickening process, thickening is achieved by centrifugation, rather than flotation as in the case of anoxic gas flotation (Pincince *et al.*, 1998).

The increased solids content of the digester feed as a result of the thickening process, increases the mean cell residence time in the digesters. This allows a reduction in the hydraulic retention time and hence a reduction in digester volume at the same mean cell residence time as required for conventional digestion.

The process has been used in a full-scale application in at least one treatment facility, but no further information regarding its efficiency and financial viability is available.

3.3.2.4 Lysate-thickening Centrifuge Process

The Lysate-thickening centrifuge is a standard thickening centrifuge to which a mechanism is fitted that causes the cell walls of the micro-organisms in the sludge to be broken down (Otte-Witte *et al.*, 2000). The objective of the disintegration of the cells is to enhance the performance of the downstream biological processes, such as anaerobic digestion. It is maintained that the disintegration of the cells causes a rise in the concentration of the easily biodegradable COD as the organic substances of the cells are made available for digestion.

It is also maintained that the cell water, or lysate, contains enzymes that enhance the reaction rate of the subsequent biological processes. The overall advantages of this process are therefore seen to be as follows:

- Increased performance of anaerobic digesters;
- Accelerated disintegration of organic matter;
- Increased production of biogas by anaerobic digestion;
- Reduction in the specific sludge production;

- Improved dewaterability of the digested sludge;
- Reduction in the use of polyelectrolyte in the dewatering of the digested sludge.

Only two full-scale installations are known of to date (Cologne and Prague) with seemingly no reliable operational data available as yet.

3.3.3 Established Processes

3.3.3.1 Centrifuge thickening

Process:	**CENTRIFUGE THICKENING**
Unit process / Treatment category:	**Thickening**

Process description

Centrifugation is a method that enhances the solid/liquid phase separation by increasing the gravitational force on the medium processed. This increase is achieved by rotating at high speed a bowl containing the sludge.

Various types of centrifuge are available for a full range of liquid/solids separation requirements and it would not be practical to review all the alternatives within the scope of this report. The description under this section is limited to either the co-current or counter-current-flow solid bowl decanter centrifuges.

The centrifuges consist primarily of a cylindrical bowl or drum rotated at high speed, into which sludge is fed either at the end or in the middle by a positive displacement pump. The essential difference between co-current and counter-current machines is that with the former the sludge feed arrangement permits centrate and cake to move in the same direction whereas, with the latter, the cake and centrate move in opposite directions. A rotating scroll is installed in the centrifuge bowl which moves the cake deposited on the inner wall of the bowl to a conical section (beach) at the end of the machine where it is further dewatered or drained before discharge. Centrate moving in either direction discharges separately. Adjustable outlets on the bowl control the liquid level (pool depth) in the bowl. Polyelectrolyte is dosed into the sludge feed immediately before entry into the centrifuge.

The use of low-speed larger diameter machines is generally preferred as this avoids many of the wear problems experienced. However, the latest generation machines referred to above generally run at higher speeds and have been designed to be durable under these conditions. It therefore follows that the long-term mechanical performance considerations must be carefully assessed when specifying the machine type.

Applicability to South Africa

Extensive investigation by the equipment manufacturers has demonstrated the suitability of centrifuges for the dewatering and thickening activities required in the treatment of wastewater sludges and the equipment has been used extensively for many years. The latest generation of machines that use automatic differential speed control and durable materials, have obviated most of the problems experienced previously.

Metro:	Well suitable
City:	Well suitable
Large municipality:	Well suitable
Medium size municipality:	Possibly
Small municipality:	Not suitable

Requirements

- Sludge conditioning (chemical or thermal);
- The materials of construction of the centrifuge require careful selection due to the abrasive nature of the material. This is of particular consideration where high-speed machines are utilised. The use of stainless steel has predominated although this may not be warranted for wastewater sludge, as the abrasion resistance is the principal consideration. Scroll edges are normally 'Stellite' tipped and the inlet and other wear areas may require ceramic or tungsten carbide tile lining or coating.

Advantages

- Continuous process
- Compact installation
- Flexible automatic operation
- Enclosed equipment with no odour problems
- High solids capture
- Direct polyelectroloyte feed (no separate flocculation tank required)
- Effective thickener

Disadvantages

- Efficient grit removal required to prevent excessive wear
- Sensitive to variations in feed concentration and sludge characteristics for chemically conditioned sludge
- Specialised maintenance and repair
- High maintenance cost
- Requires chemical flocculants at all time to ensure effective solids capture

Main operating and design criteria

- Throughput: Depending on the size of the machine
- Low-speed machine: 1 600 to 1 800 rpm; centrifugal force of 750 g
- High-speed machine: > 2 500 rpm; centrifugal force of 1 100 to 1 200 g
- Polyelectrolyte consumption: 0 to 6 kg/tDS
- Solids content of thickened sludge: up to 8% DS, depending on type of sludge treated
- Solids capture: > 90%

Typical reference installations

- Cape Flats WWTW (Cape Town)

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **THICKENING CENTRIFUGE**

Unit process / Treatment category: **Thickening**

	Unit	WAS			WAS & Primary		
		Capacity [t DS/d]					
		5	10	20	5	10	20
CAPITAL COST							
Civil works	R	160 000	280 000	395 000	150 000	230 000	340 000
Mechanical & electrical equipment	R	1 950 000	2 850 000	3 450 000	1 500 000	1 950 000	2 750 000
Total capital expenditure	**R**	**2 110 000**	**3 130 000**	**3 845 000**	**1 650 000**	**2 180 000**	**3 090 000**
Annual capital cost							
Civil works	R	24 752	43 316	61 106	23 205	35 581	52 598
Mechanical & electrical equipment	R	333 483	487 399	590 009	256 526	333 483	470 297
Total annual capital cost	**R**	**358 235**	**530 714**	**651 115**	**279 730**	**369 064**	**522 895**
Unit cost	**R/t DS**	**196**	**145**	**89**	**153**	**101**	**72**
COST OF MAINTENANCE							
Civil works	R	1 600	2 800	3 950	1 500	2 300	3 400
Mechanical & electrical equipment	R	97 500	142 500	172 500	75 000	97 500	137 500
Total annual cost of maintenance	**R**	**99 100**	**145,300**	**176 450**	**76 500**	**99 800**	**140 900**
Unit cost	**R/t DS**	**54**	**40**	**24**	**42**	**27**	**19**
COST OF OPERATION							
Personnel cost	R	65 000	65 000	65 000	65 000	65 000	65 000
Electricity cost	R	20 904	28 704	37 440	11 544	28 704	37 440
Cost of chemicals	R						
Total annual cost of operation	**R**	**85 904**	**93 704**	**102 440**	**76 544**	**93 704**	**102 440**
Unit cost	**R/t DS**	**47**	**26**	**14**	**42**	**26**	**14**
Total annual cost of O & M	**R**	**185 004**	**239 004**	**278 890**	**153 044**	**193 504**	**243 340**
Unit cost	**R/t DS**	**101**	**65**	**38**	**84**	**53**	**33**
TOTAL ANNUAL COST	**R**	**543 239**	**769 718**	**930 005**	**432 774**	**562 568**	**766 235**
UNIT COST	**R/t DS**	**298**	**211**	**127**	**237**	**154**	**105**

3.3.3.2 Dissolved-air Flotation Thickening

Process:	**DISSOLVED-AIR FLOTATION (DAF)**
Unit process / Treatment category:	**Thickening**

Process description

Dissolved-air flotation (DAF) thickeners are used mainly for thickening secondary sludge, such as waste activated sludge, rather than for thickening primary sludge, the reason being that secondary sludge generally does not settle well.

The process of flotation reduces the specific gravity of the sludge particles, thereby forcing the particles to float rather than settle. It is thus obvious that the process will work better with a lighter sludge than with a heavy sludge such as primary sludge.

The method consists of attaching microscopic bubbles of air to the particles, thereby reducing the effective specific gravity of the particles. The air bubbles are generated by first dissolving air in water under an elevated pressure. When this saturated water is released into the DAF tank, the water becomes supersaturated and the dissolved gas in excess of the saturation concentration is released in the form of very fine bubbles that attach themselves to the sludge particles and drag them along to the surface.

Sludge particles are floated to the sludge blanket and then skimmed from the surface, while clarified effluent is withdrawn from below the float layer. The float from the units is scraped into a holding hopper from which it is pumped to disposal. Since the sludge contains a considerable amount of entrained air, positive displacement pumps, ejectors or centrifugal pumps that do not air-bind are used for this application. It may take several hours for the air to be released and the sludge to return to its normal density.

Due to the aerobic conditions created by the dissolved air, this thickening process is of great advantage in processes where the biosolids are required to remain aerobic, i.e. to prevent the release of phosphate. The aerobic conditions also reduce the odour potential of the sludge.

Applicability to South Africa

DAF thickeners have been installed since the early 1950s, but have only been generally accepted since about 1965. This process is well established in many areas of South Africa.

Metro:	Well suitable
City:	Well suitable
Large municipality:	Well suitable
Medium size municipality:	Suitable
Small municipality:	Possibly suitable, but not recommended

Requirements

- Compressor
- Air saturation system

Advantages	Disadvantages
• Provides better solids-liquid separation and often yields higher solids concentrations than gravity thickening.	• Higher operating and maintenance costs than gravity thickening due to pressurisation system
• Compact installation	• Little sludge storage capacity
• Can remove grit from sludge processing system	• Less efficient than centrifuge or linear screen
• Keeps sludge aerobic, i.e. prevents release of phosphate	• More difficult to operate than gravity systems

Main operating and design criteria

- Air requirements: 0,02 to 0,04 mg air/mg solids
- Solids concentration of thickened sludge: 3% to 4,5% (without conditioning)
- Solids loading (of flotation zone): 2 to 6 kg/(m^2h)
- Crossflow velocity (for flotation zone): 50 to 200 m/h
- Recycle ratio (of stream to be pressurised): 0,5 to 2,0
- Saturation pressure: 400 – 600 kPa

Typical reference installations

- Zeekoegat WWTW (Pretoria Tshwane)
- Athlone WWTW (Cape Town)
- Driefontein (Johannesburg Water)

Typical literature references

[1] Haarhoff J. & van Vuuren L. 1993. *A South African design guide for dissolved air flotation.* Water Research Commission Report No.332. Pretoria: Water Research Commission.

[2] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **DISSOLVED AIR FLOTATION (DAF)**

Unit process / Treatment category: **Thickening**

	Unit	WAS		
		Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	195 000	610 000	815 000
Mechanical & electrical equipment	R	900 000	1 550 000	2 250 000
Total capital expenditure	**R**	**1 095 000**	**2 160 000**	**3 065 000**
Annual capital cost				
Civil works	R	30 166	94 367	126 080
Mechanical & electrical equipment	R	153 915	265 076	384 788
Total annual capital cost	**R**	**184 082**	**359 443**	**510 868**
Unit cost	**R/t DS**	**101**	**98**	**70**
COST OF MAINTENANCE				
Civil works	R	1 950	6 100	8 150
Mechanical & electrical equipment	R	45 000	77 500	112 500
Total annual cost of maintenance	**R**	**46 950**	**83 600**	**120 650**
Unit cost	**R/t DS**	**26**	**23**	**17**
COST OF OPERATION				
Personnel cost	R	35 000	35 000	35 000
Electricity cost	R	11 544	17 160	23 400
Chemical cost	R			
Total annual cost of operation	**R**	**46 544**	**52 160**	**58 400**
Unit cost	**R/t DS**	**26**	**14**	**8**
Total annual cost of O & M	**R**	**93 494**	**135 760**	**179 050**
Unit cost	**R/t DS**	**51**	**37**	**25**
TOTAL ANNUAL COST	**R**	**277 576**	**495 203**	**689 918**
UNIT COST	**R/t DS**	**152**	**136**	**95**

3.3.3.3 Thickening by Linear Screens

Process:	**THICKENING BY LINEAR SCREENS**
Unit process / Treatment category:	**Thickening**

Process description

Gravity belt thickeners or linear screens are often used as a sludge pre-thickening step ahead of filter-belt-press dewatering equipment. The linear screens consist of a steel frame that supports rollers over which the screening cloth runs. There are various grades of filter cloth to change the quality of the filtrate and the solids concentration of the thickened sludge. Generally, the screen cloth is made of polyester.

The thickened sludge remains on the screen cloth and the liquid gravitates through the cloth to a collecting dish. The speed at which the screening cloth moves is adjustable that alters the loading rate of the equipment. The sludge load that can be thickened via this method is generally limited by the width of the screen cloth that is 2,2 m to 3,0 m.

Applicability to South Africa

Metro:	Well suitable
City:	Well suitable
Large municipality:	Well suitable
Medium size municipality:	Possibly
Small municipality:	Not recommended

Requirements

- Sludge conditioning system
- Washwater for rinsing filter cloth
- Sludge-cake conveyors
- Sludge-cake hoppers.

Advantages	Disadvantages
• Mechanical linear screens readily form part of the dewatering train and feed the thickened sludge directly onto the dewatering device. No pumping is required. • Only one dosage of polyelectrolyte is required and the thin sludge is readily	• Linear screens are relatively expensive • More maintenance intensive than gravity thickeners • More operator intensive than gravity thickeners • Chemical flocculation required to ensure solids capture

flocculated.

- There is a very short retention time of the sludge on the screen, no scum formation and hence a much lower risk of odour nuisance and/or phosphorus release from the WAS from biological nutrient removal plants.
- The quality of the filtrate is generally very high with a low concentration of suspended solids.
- Linear screens can readily meet the required sludge concentration of 6% to optimise the use of the dewatering device.

Main operating and design criteria

- Throughput: 20 to 150 m^3/h (depending on size of machine);
- Solids concentration of thickened sludge: 4% to 10% (depending on sludge type)
- Width of screening cloth: 0.8 to 3.0 m
- Solids capture: ~ 95%

Typical reference installations

- Olifantsvlei Regional Sludge Handling Facility (Johannesburg): Combined with dewatering belt filter presses
- Potsdam (Milnerton): Combined with dewatering belt filter presses

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **THICKENING BY LINEAR SCREENS**

Unit process / Treatment category: **Thickening**

	Unit	WAS			WAS & Primary		
		Capacity [t DS/d]					
		5	10	20	5	10	20
CAPITAL COST							
Civil works	R	600 000	890 000	1 315 000	600 000	890 000	1 315 000
Mechanical & Electrical equipment	R	1 250 000	1 950 000	3 015 000	1 250 000	1 950 000	3 015 000
Total capital expenditure	**R**	**1 850 000**	**2 840 000**	**4 330 000**	**1 850 000**	**2 840 000**	**4 330 000**
Annual Capital Cost							
Civil works	R	92 820	137 682	203 430	92 820	137 682	203 430
Mechanical & Electrical equipment	R	213 771	333 483	515 616	213 771	333 483	515 616
Total annual cost of capital	**R**	**306 591**	**471 166**	**719 046**	**306 591**	**471 166**	**719 046**
Unit cost	**R/t DS**	**168**	**129**	**99**	**168**	**129**	**99**
COST OF MAINTENANCE							
Civil works	R	6 000	8 900	13 150	6 000	8 900	13 150
Mechanical & Electrical equipment	R	62 500	97 500	150 750	62 500	97 500	150 750
Total annual cost of maintenance	**R**	**68 500**	**106 400**	**163 900**	**68 500**	**106 400**	**163 900**
Unit cost	**R/t DS**	**38**	**29**	**22**	**38**	**29**	**22**
COST OF OPERATION							
Personnel cost	R	65 000	65 000	65 000	65 000	65 000	65 000
Electricity cost	R	15 756	20 592	28 704	15 756	20 592	28 704
Cost of chemicals	R						
Total annual cost of operation	**R**	**80 756**	**85 592**	**93 704**	**80 756**	**85 592**	**93 704**
Unit cost	**R/t DS**	**44**	**23**	**13**	**44**	**23**	**13**
Total annual cost of O & M	**R**	**149 256**	**191 992**	**257 604**	**149 256**	**191 992**	**257 604**
Unit cost	**R/t DS**	**82**	**53**	**35**	**82**	**53**	**35**
TOTAL ANNUAL COST	**R**	**455 847**	**663 158**	**976 650**	**455 847**	**663 158**	**976 650**
UNIT COST	**R/t DS**	**250**	**182**	**134**	**250**	**182**	**134**

3.3.3.4 Gravity Thickening

Process:	**GRAVITY THICKENING**
Unit process / Treatment category:	**Thickening**

Process description

Continuously operating gravity thickeners have been the most common sludge thickening device on wastewater treatment plants until recent years. Gravity thickeners are generally circular with sloping bottoms. Sludge is discharged into a central stilling chamber at top water level, the solids settle to the bottom of the tank where they thicken and are scraped into a central collection hopper. The solids are then withdrawn by pumps or by gravity; the supernatant flows over a peripheral weir and is discharged from the thickener.

Thickener behaviour is affected by the sludge characteristics that are in turn affected by the sludge composition, type of pre-treatment process and presence of filamentous organisms. Primary sludge generally settles and thickens well provided that the sludge is reasonably fresh and biological solids such as waste activated sludge (WAS), are kept to a minimum. WAS can be thickened reasonably well by this method but is often plagued by bulking caused by filamentous organisms. Digested sludge thickens very well but is prone to a scum problem and fairly large quantities of fine particles are carried over the peripheral weirs.

Gravity thickeners can be used to produce short-chain volatile fatty acids (SCVFA) that enhance the biological phosphate removal. Care should be taken to ensure that this process does not produce odours, as some of the SCVFAs are extremely odorous. The SCVFAs have to be elutriated from the sludge in a separate process.

Applicability to South Africa

Metro:	Well suitable
City:	Well suitable
Large municipality:	Well suitable
Medium size municipality:	Well suitable
Small municipality:	Well suitable

Requirements

- Might require chemical conditioning, but generally not necessary

Advantages

- Relatively inexpensive
- Relatively easy to operate and maintain.
- Can readily meet the required 6% solids concentration for primary sludge to ensure optimum utilisation of the dewatering devices
- Provide sludge storage capabilities

Disadvantages

- The supernatant is generally not of a good quality and may contain high concentrations of suspended solids.
- The solids concentration achievable on WAS is usually less than 2,5%.
- Scum and floating sludge are normally present, particularly if the sludge has been vigorously aerated. This can lead to odour problems.
- Phosphorus is released from the sludge back into the supernatant.

Main operating and design criteria

- Solids loading rate: 0,5 to 5,5 kg solids/(m^2h) (depending on sludge type)
- Solids concentration of thickened sludge: 2% to 8% (depending on sludge type)

Typical reference installations

- This is the method of thickening sludge most commonly practised internationally.

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **GRAVITY THICKENING**

Unit process / Treatment category: **Thickening**

	Unit	WAS			WAS & Primary		
		Capacity [t DS/d]					
		5	10	20	5	10	20
CAPITAL COST							
Civil works	R	600 000	1 245 000	2 490 000	240 000	525 000	1 038 000
Mechanical equipment	R	365 000	400 000	800 000	300 000	355 000	390 000
Electrical equipment	R	110 000	135 000	178 000	105 000	110 000	132 000
Total capital expenditure	**R**	**1 075 000**	**1 780 000**	**3 468 000**	**645 000**	**990 000**	**1 560 000**
Annual capital cost							
Civil works	R	92 820	192 601	385 202	37 128	81 217	160 578
Mechanical equipment	R	62 421	68 407	136 814	51 305	60 711	66 697
Electrical equipment	R	18 812	23 087	30 441	17 957	18 812	22 574
Total annual capital cost	**R**	**174 053**	**284 095**	**552 456**	**106 390**	**160 740**	**249 849**
Unit cost	**R/t DS**	**95**	**78**	**76**	**58**	**44**	**34**
COST OF MAINTENANCE							
Civil works	R	6 000	12 450	24 900	2 400	5 250	10 380
Mechanical equipment	R	18 250	20 000	40 000	15 000	17 750	19 500
Electrical equipment	R	5 500	6 750	8 900	5 250	5 500	6 600
Total annual cost of maintenance	**R**	**29 750**	**39 200**	**73 800**	**22 650**	**28 500**	**36 480**
Unit cost	**R/t DS**	**16**	**11**	**10**	**12**	**8**	**5**
COST OF OPERATION							
Personnel cost	R	35 000	35 000	35 000	35 000	35 000	35 000
Electricity cost	R	15 768	23 126	47 304	12 614	15 768	38 894
Total annual cost of operation	**R**	**50 768**	**58 126**	**82 304**	**47 614**	**50 768**	**73 894**
Unit cost	**R/t DS**	**28**	**16**	**11**	**26**	**14**	**10**
Total annual cost of O & M	**R**	**80 518**	**97 326**	**156 104**	**70 264**	**79 268**	**110 374**
Unit cost	**R/t DS**	**44**	**27**	**21**	**39**	**22**	**15**
TOTAL ANNUAL COST	R	254 571	381 421	708 560	176 654	240 008	360 223
UNIT COST	R/t DS	139	104	97	97	66	49

3.3.3.5 Vacuum Filtration

Process:	**VACUUM FILTRATION**
Unit process / Treatment category:	**Thickening**

Process description

The vacuum filter consists primarily of an internally partitioned stiffened cylindrical drum rotating partially submerged in a bath of conditioned sludge. The surface of the drum is covered with a porous filter medium that is selected based on the dewatering properties of the sludge. The rotating drum is divided into separate, sealed segments that are connected to a rotary valve on the axis of the drum. As the drum rotates in the sludge bath, the rotary valve causes each separate segment to operate in sequence as a cake formation, cake dewatering and cake discharge zone.

A vacuum is applied through 330° of rotation whilst the drum is partially immersed in the sludge bath. Air pressure is applied for the remaining 30° of rotation to assist with separation of the sludge cake from the filter cloth prior to removal by a scraper blade.

Applicability to South Africa

Rotary drum vacuum filters have been utilised for sludge and other slurry dewatering applications for over fifty years and the detailed design, equipment, selection and construction is well defined. It has recently fallen out of favour as a result of improvements in alternative mechanical thickening systems, as well as the fact that it uses complex technology, requires conditioning chemicals and suffers from high operation and maintenance costs.

Vacuum filtration has not been used in the South African wastewater treatment industry for thickening of sludge. Even though it is extensively used in the industry for dewatering sludges of various types, it is not expected to be implemented for municipal sludge treatment due to the improvements in alternative mechanical thickening systems that offer improved efficiency.

Metro:	Not recommended
City:	Not recommended
Large municipality:	Not recommended
Medium size municipality:	Not recommended
Small municipality:	Not recommended

Requirements

- Sludge conditioning
- Washwater system (to clean filter cloth)

- Vacuum system

Advantages

- Continuous process
- Good solids capture

Disadvantages

- Complex technology
- Requires sludge conditioning
- High operation and maintenance costs

Main operating and design criteria

- Not recommended for South African conditions

Typical reference installations

- No known installations in South Africa

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

3.4 STABILISATION

Sludge stabilisation is aimed at reducing the microbiological activity in the organic fraction of the sludge. If the micro-organisms are allowed to flourish, they will cause nuisance conditions such as: -

- Survival of pathogens that can pose a threat to public health;
- Putrefaction of the sludge;
- Release of obnoxious odours.

In order to prevent the above conditions, sludge can be stabilised by means of: -

- Reducing the volatile content of the sludge, either biologically or chemically: This reduction will also result in a smaller amount (mass) of sludge to be disposed of.
- Adding chemicals to the sludge to render it unsuitable for the survival of micro-organisms;
- Using heat treatment to disinfect or sterilise the sludge.

It has to be noted that sterilisation or disinfection is not the same as stabilisation. A sterilised product that has been treated with the aim of destroying or inactivating its pathogens, might still rot, i.e. sterilisation does not necessarily mean that the product is also stable.

3.4.1 Embryonic Processes

3.4.1.1 Brinecell Process

The Brinecell process that has so far been proposed as a concept only (Pincince *et al.*, 1998) aims at reducing pathogens in the sludge by exposure to ozone and chlorine. The brine cells may be installed either directly in a sludge-holding tank or externally, with the sludge passing through the cells via a circulation loop. The sludge itself is seeded with sodium chloride (approximately 3% by weight) and an electric current is applied to the brine cells that cause ozone and chlorine to be released, which then destroy the pathogens.

The process has not been demonstrated and no further information is available.

3.4.1.2 High-pressure Anaerobic Digestion

High-pressure anaerobic digestion means operating the anaerobic digester under pressures of between 200 kPa and 500 kPa (Pincince *et al.*, 1998). Due to the elevated pressure, more carbon dioxide remains in solution in the digester liquid, and consequently the calorific value of the digester gas is increased. The already pressurised digester gas obviates the need for gas compressors to feed subsequent gas-fired units, boilers, etc.

The process has been tested on a small scale, but no information on its practical and financial viability is available.

3.4.1.3 Simultaneous Digestion and Metal Leaching

The process of simultaneous digestion and metal leaching aims at achieving higher reduction in pathogens while also increasing the solubility of metals during the aerobic digestion process (Pincince *et al.*, 1998).

It involves the addition of elemental sulphur to the sludge that is then mixed and aerated. The process requires a retention period of approximately 9 days to decrease the pH of the mixture to approximately 2, at which level the metals in the sludge will be in solution.

The process has as yet only been tested in a laboratory-scale application using shaker flasks, but destruction of pathogens was reportedly more effective than in the case of conventional aerobic digestion.

3.4.2 Innovative Processes

3.4.2.1 Aerobic-Anoxic Digestion

The objective of aerobic-anoxic digestion is to decrease the power use of aerobic digesters while simultaneously improving their performance (Pincince *et al.*, 1998). The process involves cyclic operation of the aerators of an aerobic digester in response to the concentration of nitrogen species in the sludge. Anoxic conditions are allowed to develop when the aerators are switched off that promotes denitrification. In this way the oxygen requirements of the process are reduced, and it is also possible to control the pH of the digester more easily and maintain it at a near neutral level. The transfer rate of oxygen to the sludge is also expected to be higher, particularly when the aerobic phase is started, due to the low dissolved oxygen level in the sludge at that stage. This should therefore improve the efficiency of the aerators.

The process is used at a 19 Mℓ/d wastewater treatment facility in the USA, but no other references or information is available.

3.4.2.2 BIOSET Process

The patented BIOSET process was developed to produce liquid fertiliser and to disinfect the sludge (Pincince *et al.*, 1998). The process is based on the addition of alkaline and acidic reagents, such as lime and sulfamic acid, to the sludge in a closed reactor. The mixture has to be retained in the reactor for about 4 minutes at elevated temperatures (20° C to 90° C) and pressures (40 kPa to 350 kPa). The addition of the chemicals to the sludge results in an exothermic reaction that generates the heat required for the process. At the end of the retention period, the pressure is relieved to atmospheric pressure and any steam and ammonia released from the process can be used to produce liquid ammonium phosphate fertiliser. The treated sludge solids comply with the microbiological classification requirements for Class D sludge and have a very high pH, at around 11.5 to 12.5.

The process has been used in a full-scale application since 1996 but is not widely used, probably due to cost implications and complexity of the operation.

3.4.2.3 Carbon Dioxide Injection to Alkaline Stabilisation

Alkaline stabilisation involves the addition of alkaline material to dewatered sludge, whereafter the mixture is retained in a closed vessel for a period sufficient to achieve pathogen reduction through the increase in temperature resulting from the exothermic reaction of the sludge with the alkaline material.

In a modification to the alkaline stabilisation process, carbon dioxide is injected into the blender, where the dewatered sludge is mixed with the alkaline material (Pincince *et al.*, 1998). This results in a greater temperature increase, and the mixture is discharged to a retention vessel where it is kept for 30 minutes in order to achieve sufficient pathogen reduction.

The process has been tested in full-scale pilot plants, and the average temperature increase reported with CO_2 injection was approximately 20% greater than without CO_2 injection. No information on the cost of the process is available.

3.4.2.4 Irradiation

Irradiation has been internationally accepted for the disinfection of medical products and instruments as well as food products. The process utilises gamma rays or electron beams, with cobalt 60 generally being used as the source for gamma rays and an electron beam accelerator for generating the electron beams. The latter technology is sophisticated and requires high technology equipment. It is also only effective if the substance to be irradiated is in the form of thin layers, as the penetration depth of the electron beams is limited. This technology would therefore be impractical for the disinfection of sludge.

The gamma ray irradiation could be used due to the high penetration ability of gamma rays (Du Plessis, 1996). The dewatered sludge has to be in contact with the radiation source for approximately 20 minutes for total sterilisation. At present, the cobalt "pencils" are being imported from Canada that makes the cost of this process vulnerable to variations in the rate of exchange. There is the further risk that the use of cobalt 60 may be boycotted as it is a radioactive material, against which there is a resistance worldwide.

Although irradiation is proclaimed to be safe, the risks involved presently outweigh the advantages of the process. It is therefore not recommended at this stage.

3.4.2.5 Liquid A Process

The Liquid A process is so named as it aims to produce a liquid sludge that complies with the requirements of a Class A sludge according to American regulations (Pincince *et al.*, 1998) which, in terms of microbiological quality, compares to a Class D sludge in South Africa. The sludge will, however, not necessarily comply with the requirements for a Class D sludge where metal content is concerned, as this depends on the quality of the feed solids.

The process involves the mixing of thickened sludge and granular lime in a reactor in which the mixture is then heated to approximately 65°C and held at this temperature for one hour that is sufficient to reduce the pathogens to the required level. Mixing in the reactor is achieved by the injection of air, which can also be circulated to improve the energy efficiency of the process.

The process is intended for use at small facilities since it is a batch process. It has been applied in a full-scale installation.

3.4.2.6 Micronair Process

The Micronair process combines dissolved-air flotation with aerobic digestion (Pincince *et al.*, 1998). Underflow from an aerobic digester is fed through a compressed-air system that results in very small bubbles being formed in the stream after pressure release. When the thus "aerated" stream is recycled back to the aerobic digester, it tends to lift the sludge solids to the surface, thus creating a sludge blanket at the top of the tank. It is claimed that the solids retention time is thereby increased, resulting in a lower sludge production.

The process requires significant pre-treatment of sludge prior to digestion. All solid objects must be removed by screening, whereafter the sludge must be degritted. The pre-treatment processes are of utter importance to avoid damage to the compressed-air system.

The process has been tested in full-scale applications.

3.4.2.7 Ozone Treatment

Ozone treatment is used to decrease pathogen levels in the sludge to acceptable standards for further processing. Proprietary processes such as Oxyozone and Synox are used for this purpose (Pincince *et al.*, 1998).

Acidified thickened sludge is mixed with ozone gas in a pressurised vessel and allowed a contact time of 60 minutes. Thereafter the sludge is degassed to remove excess ozone and is then transferred to the subsequent treatment process. This can be a typical process such as conditioning with polymers, dewatering and lime stabilisation, or a specialised process like dewatering and pelletisation to create a product that can be used as a fertiliser or fuel.

The process is still under development and has been tested on a pilot-plant scale only. The treatment of metal-containing side-streams from the ozone process still requires attention.

3.4.2.8 Thermo Tech Process

The Thermo Tech process involves the processing of sludge and municipal organic waste in a hydro-pulper to produce slurry with a 10% to 12% solids content (Pincince *et al.*, 1998). This slurry is subsequently pumped into aerated tanks with a retention capacity of 24 hours for pasteurisation.

Although solids reduction achieved in the process is limited to less than 10%, the objective is to create a stable product from organic waste that can be sold as a fertiliser. Nutrient conservation is therefore of the essence. The material removed from the aeration tanks is subsequently dewatered, dried and pelletised, and the final product is said to contain 6% to 8% nitrogen.

3.4.2.9 Two-Phase Anaerobic Digestion

Two-phase anaerobic digestion is very similar to temperature-phased anaerobic digestion, which is discussed under "Established Processes" below. In the case of two-phase anaerobic digestion, the process is separated based on acid and methane-forming bacterial phases rather than on a temperature basis (Pincince *et al.*, 1998). This enables the optimisation of each phase.

However, in some cases these bacterial phases are separated by temperature as acid-forming bacteria proliferate at higher temperatures than methane-forming bacteria that makes it essentially similar to the temperature-phased anaerobic digestion process.

The process has been used on a limited basis, and a greater destruction of volatile solids and pathogens compared to conventional anaerobic digestion is claimed.

3.4.2.10 Vertad Process

The Vertad process aims at producing a digested sludge that conforms to microbiological content requirements and at the same time uses as small a plan area as possible (Pincince *et al.*, 1998).

The process provides for autothermal thermophilic aerobic digestion in a vertical shaft-type reactor. The reactor is typically 100 m long and 3 m in diameter, with the greater part of it being located below ground. The reactor is divided into three zones based on temperature - the upper zone having a temperature of about 15°C and the lower zone of about 65°C. Digested sludge is withdrawn from the lower part of the shaft. The disinfected sludge is discharged for further processing, and a liquid side-stream is withdrawn for treatment.

Current knowledge indicates that the process was intended to be demonstrated in mid-1997, but no results of this demonstration are known.

3.4.2.11 Thermal Hydrolysis

Thermal hydrolysis is a process similar to the Zimpro process. Primary and waste activated sludge are heated to between 140°C and 160°C by injecting steam directly into the dewatered sludge in a batch reactor (Weisz *et al.*, 2001). This process has been patented and is called the Cambi THP. The temperature in the reactor is maintained for a period of 30 minutes, whereafter the sludge is digested in an anaerobic digester. In the Cambi THP, the sludge is sterilised and the cells are broken down, resulting in a residue that can be easily dewatered. It is reported that the problems previously experienced with the thermal treatment of sludge have been resolved in developments since 1990.

Apparently an energy surplus of about 100% over conventional digestion is achieved, and the mass of stabilised sludge is claimed to be reduced by more than 60%. There are four full-scale plants already in operation in Scandinavia and the United Kingdom.

3.4.2.12 Vermiculture Process

Vermiculture is a relatively simple process in which a soil conditioner with a wide range of applications is produced (Van Oorschot *et al.*, 1999). The sewage sludge is fed to a variety of worm species that convert the organic material into more worm biomass and vermicast. Vermicast is the excreta from the worms and can be used as a plant growth medium and soil conditioner. The worms themselves can be sold for bait, animal feed and small composting systems.

The largest vermiculture facility operating on sewage sludge is apparently located in Australia and has a treatment capacity of 400 m^3/week. The plant was commissioned in 1998 and there is still a lack of widespread experience in operating plants of this scale. In South Africa, vermiculture or vermicomposting is used at several small-scale installations.

3.4.3 Established Processes

3.4.3.1 Anaerobic Digestion

Process:	**ANAEROBIC DIGESTION**
Unit process / Treatment category:	**Stabilisation**

Process description

Anaerobic digestion is one of the oldest processes used for the stabilisation of sludge. It involves the decomposition of organic and inorganic material in the absence of molecular oxygen. The organic material in mixtures of primary and biological sludge is converted biologically to a variety of products, but predominantly methane and carbon dioxide. The process is normally carried out in airtight reactors to enable the capture of the gas being produced. Sludge, in a solids concentration of 3% to 6%, is fed to the reactor either continuously or intermittently and retained in the reactor for varying periods of time (usually 15 to 60 days). The stabilised sludge, withdrawn from the reactor continuously or intermittently, is reduced in organic and pathogen content and is non-putrescible.

The content of the reactor (digester) is mixed and heated in high-rate digesters, resulting in higher efficiencies in the reaction rate, thereby allowing shorter retention of the sludge in the reactor.

The anaerobic digestion process results in the conversion of some of the organic material to methane and carbon dioxide, thereby reducing the solids content of the sludge being fed to the digester. The methane gas is usually used for heating the digesters, and excess gas can be used as a source of energy.

Applicability to South Africa

Metro:	Well suitable
City:	Well suitable
Large municipality:	Well suitable
Medium size municipality:	Well suitable
Small municipality:	Well suitable

Requirements

- Sludge thickening
- Heat source
- Mixing of the digester

Advantages

- Reduces the total sludge mass, i.e. typically 20% to 50 % of the volatile solids are destroyed.
- Reduces the costs of sludge disposal as a smaller sludge mass is produced after digestion.
- Produces a stable product that is generally odour free.
- Provides a product suitable for use as a soil conditioner. Digested sludge is relatively rich in free nitrogen and phosphorus.
- Inactivates certain pathogens. Many pathogens die off during the digester retention time. High operating temperatures also destroy some harmful bacteria.
- Anaerobic digestion is one of the least expensive methods of obtaining a substantial degree of solids stabilisation.
- No outside energy required apart from mixing.

Disadvantages

- A high initial capital outlay is required to provide closed digesters, heating and mixing equipment.
- The micro-organisms are susceptible to small changes in their environment. Close monitoring is therefore essential to ensure successful digestion.
- It produces a poor quality supernatant rich in ammonia, phosphorus and suspended solids.
- The growth rate of the methanogens is slow and therefore long sludge ages are required for digestion. This increases the required digester volumes.
- Depending on the nature of the sludge, the pipework may be susceptible to magnesium ammonium phosphate hexahydrate (struvite) deposits when the digested sludge comes into contact with air. The possibility of struvite formation also influences the selection of the dewatering equipment in that belt presses are more suitable than centrifuges to cope with this problem.

Main operating and design criteria

- Solids loading rate: 0,5 to 1,6 kg volatile solids added/day per m^3 of digester capacity for low-rate digesters (not heated)
  1.6 to 4.8 kg volatile solids added/day per m^3 of digester capacity for high-rate digesters (heated; T ~ 35°C and mixed)
- Retention time: 20 to 30 days (low rate)
  10 to 20 days (high rate)
- Typical volatile solids destruction: 45% to 60%
- Typical biogas production: 0,75 to 1,1 m^3/kg volatile solids destroyed
- Biogas composition: ~ 65% to 70% methane (by volume); 25% to 30% CO_2

Typical reference installations

- Anaerobic digestion is one of the treatment processes most often applied nationally and internationally.

Typical literature references

[1] Ross W.R., Novella P.H., Pitt A.J., Lund P., Thomson B.A., King P.B. & Fawcett K.S. 1992. *Anaerobic Digestion of Wastewater Sludge: Operating Guide.* Water Research Commission Report No. TT55/92. Pretoria: Water Research Commission.

[2] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **ANAEROBIC DIGESTION**

Unit process / Treatment category: **Stabilisation**

Unthickened feed (3% DS)

	Unit	Primary	WAS & Primary		
		Capacity [t DS/d]			
		5	5	10	20
CAPITAL COST					
Civil works	R	2 000 000	2 520 000	4 450 000	9 280 000
Mechanical & electrical equipment	R	1 200 000	1 725 000	3 350 000	6 215 000
Total capital expenditure	**R**	**3 200 000**	**4 245 000**	**7 800 000**	**15 495 000**
Annual capital cost					
Civil works	R	309 399	389 842	688 412	1 435 610
Mechanical & electrical equipment	R	205 220	295 004	572 907	1 062 871
Total annual capital cost	**R**	**514 619**	**684 847**	**1 261 319**	**2 498 481**
Unit cost	**R/t DS**	**282**	**375**	**346**	**342**
COST OF MAINTENANCE					
Civil works	R	20 000	25 200	44 500	92 800
Mechanical & electrical equipment	R	60 000	86 250	167 500	310 750
Total annual cost of maintenance	**R**	**80 000**	**111 450**	**212 000**	**403 550**
Unit cost	**R/t DS**	**44**	**61**	**58**	**55**
COST OF OPERATION					
Personnel cost	R	65 000	65 000	65 000	65 000
Electricity cost	R	17 160	17 160	23 400	34 320
Total annual cost of operation	**R**	**82 160**	**82 160**	**88 400**	**99 320**
Unit cost	**R/t DS**	**45**	**45**	**24**	**14**
Total annual cost of O & M	**R**	**162 160**	**193 610**	**300 400**	**502 870**
Unit cost	**R/t DS**	**89**	**106**	**82**	**69**
TOTAL ANNUAL COST	R	676 779	878 457	1 561 719	3 001 351
UNIT COST	R/t DS	371	481	428	411

Process: **ANAEROBIC DIGESTION**

Unit process / Treatment category: **Stabilisation**

Thickened feed (5% DS)

	Unit	Primary	WAS & Primary		
		Capacity [t DS/d]			
		5	5	10	20
CAPITAL COST					
Civil works	R	1 125 000	1 515 000	2 520 000	3 450 000
Mechanical & electrical equipment	R	585 000	875 000	1 725 000	2 125 000
Total capital expenditure	**R**	**1 710 000**	**2 390 000**	**4 245 000**	**5 575 000**
Annual capital cost					
Civil works	R	174 037	234 370	389 842	533 713
Mechanical & electrical equipment	R	100 045	149 640	295 004	363 411
Total annual capital cost	**R**	**274 082**	**384 010**	**684 847**	**897 124**
Unit cost	**R/t DS**	**150**	**210**	**188**	**123**
COST OF MAINTENANCE					
Civil works	R	11 250	15 150	25 200	34 500
Mechanical & electrical equipment	R	29 250	43 750	86 250	106 250
Total annual cost of maintenance	**R**	**40 500**	**58 900**	**111 450**	**140 750**
Unit cost	**R/t DS**	**22**	**32**	**31**	**19**
COST OF OPERATION					
Personnel cost	R	65 000	65 000	65 000	65 000
Electricity cost	R	17 160	17 160	23 400	28 080
Total annual cost of operation	**R**	**82 160**	**82 160**	**88 400**	**93 080**
Unit cost	**R/t DS**	**45**	**45**	**24**	**13**
Total annual cost of O & M	**R**	**122 660**	**141 060**	**199 850**	**233 830**
Unit cost	**R/t DS**	**67 21**	**77 29**	**54 75**	**32 03**
TOTAL ANNUAL COST	**R**	**396 742**	**525 070**	**884 697**	**1 130 954**
UNIT COST	**R/t DS**	**217**	**288**	**242**	**155**

3.4.3.2 Temperature-phased Anaerobic Digestion

Process:	**TEMPERATURE-PHASED ANAEROBIC DIGESTION**
Unit process / Treatment category:	**Stabilisation**

Process description

Temperature-phased anaerobic digestion combines thermophilic and mesophilic digestion and pathogen reduction. The aim is to improve digestion performance in terms of solids reduction and gas production as compared to the conventional one-stage mesophilic anaerobic digestion process. In the thermophilic phase, digestion rates are significantly increased due to increased biological activity. (Biochemical reaction rates double with every 10°C temperature rise until a limiting rate is reached). This means that shorter retention times or increased degradation of volatile solids can be achieved. At mesophilic temperatures reaction rates are lower, but a less odorous sludge is produced. A number of different process configurations have been developed and implemented in full-scale applications.

- Anaerobic Stabilisation Thermophilic / Mesophilic (ASTM)

The ASTM technology is applied in Europe and uses a thermophilic pre-digestion step followed by a mesophilic post-digestion step. A typical process scheme is as follows: The incoming raw sludge is preheated by heat recovery from the heat-treated thermophilic sludge and is then fed into the anaerobic thermophilic reactor. The thermophilic reactor is heated to about 60°C by heating the recirculated sludge via an external heat exchanger, which in turn is heated with hot water from the boiler system or cooling water from the biogas engines. The thermophilic pre-treated sludge is discharged to an equalising tank to guarantee the minimum retention time of 2 hours for pasteurisation at a temperature of 55°C - 60°C. From the equalisation tank the sludge is then transferred via an additional pumping station and through the heat recovery heat exchanger to the mesophilic digester. The recirculation system of the mesophilic digester is equipped with an emergency cooler to keep the temperature below 36°C under unfavourable hot summer conditions. The biogas of both reactors and also from the equalisation tank is collected in a gas holder and usually utilised in boilers or in a co-generation plant.

- Temperature-Phased Anaerobic Digestion Process

A similar process to the ASTM has been developed and patented in the United States by the Iowa State University under the name of TPAD (Temperature-phased anaerobic digestion process). The technology is licensed to the Anaerobic Biosystems Corporation of Ames.

- Schwarting/Uhde process

The Schwarting/Uhde process uses mesophilic and thermophilic treatment steps to optimise the performance and operation of the digestion process. Raw sludge (primary and WAS) is fed to the process at a dry-solids (DS) content of about 4% to 10%. After macerating, the sludge is preheated by the digested sludge from the second stage and finally heated up to 37°C before being fed into the first digester that operates in the mesophilic temperature range. The retention time in the first digester is about 5 to 6 days, during which the organic solids content is reduced by about 40%. Before entering the second digester the sludge is heated to 55°C. The second digester operates in the thermophilic temperature range and the retention time of the sludge is again 5 to 6 days, during which an overall organic solids reduction of 55% is achieved. The overall retention time is thus 10 to 12 days, compared to 20 days for conventional mesophilic digestion.

The Schwarting/Uhde process uses two cylindrical tanks in series that are both operated in upflow mode. Contrary to conventional anaerobic digestion, the digester contents are not completely mixed but the objective is to achieve a defined plug flow. Perforated plates in the cylindrical digesters are used to obtain an even flow distribution and to realise plug flow conditions. The mixing of the digester content is achieved by periodically raising and lowering the column of liquid in the tank, thus creating turbulence at the perforated plates. This patented pulse-mixing system also enables the separation of the biogas from the liquid. Biogas is collected at the top of the digesters, whereas settled solids that accumulate at the bottom of the tanks, are frequently removed via screw pumps. Heat loss from the digester tanks is compensated for by temperature-controlled heat insulation.

The Schwarting/Uhde process was originally developed for the treatment of manure and biowaste and was applied in sewage sludge treatment in a full-scale application for the first time in 1994.

Applicability to South Africa

The ASTM process has been applied to about ten WWTWs in Germany so far, either in the design of new wastewater treatment facilities or for the upgrading of existing plants. The full-scale applications range in capacity from 14 000 to 1,6 million population equivalents. Eight full-scale TPAD systems are reported to be operating now in the U.S. There are four WWTWs using the Schwarting/Uhde process, all of them in Germany. The capacities range from 47 000 to 120 000 population equivalents. So far, there are no known applications of any of these processes in South Africa.

Metro:	Suitable
City:	Suitable
Large municipality:	Not suitable
Medium size municipality:	Not suitable
Small municipality:	Not suitable

Requirements

- Sludge thickening (when digesting waste activated sludge)
- Heat source
- Specialised insulation of digesters

Advantages	**Disadvantages**
As compared to single-stage, mesophilic anaerobic digestion:	
• Increased destruction of volatile solids	• Higher energy requirements
• Shorter overall retention times	• Poorer quality of supernatant
• Increased gas production	• Odour problems
	• Occasional foaming of digester
	• Less process stability

Main operating and design criteria

- ASTM
- 2 to 3 day's retention time in the thermophilic stage at 55°C to 60°C.
- 12 to 15 day's retention time in the thermophilic stage at 35°C to 37°C.
- The degradation of organic solids is more than 50% and values of up to 60% have been reported.
- The basic design is almost independent of solids load as long as a raw sludge concentration of 6% DS is not exceeded.
- The reactors/digesters can be made of steel or concrete. Special care has to be taken in the civil design of the thermophilic stage to allow temperatures of up to 60°C.
- At high sludge concentrations special attention has to be paid to an effective mixing of the reactors. In large reactors (> 1 500 m^3) the best results have been achieved with draft tube mixers. Friction losses in the pumping of high solids sludge can increase exponentially due to the non-Newtonian behaviour of the sludge.
- There is a special tendency of thermophilic sludge to foaming. Special equipment, for instance overfall weirs inside the reactor and foam traps in the gas line, should be provided. It is generally not recommended to use gas injection for reactor mixing.
- To optimise the energy efficiency of the two-stage process, the heat of the thermophilic sludge should be recovered to heat up the incoming raw sludge. This can be done in sludge/sludge heat exchangers or in two-coupled high-rate sludge/water heat exchangers. For large treatment plants the latter system is recommended.

- Schwarting/Uhde process
- Retention times in the mesophilic digester (37°C) and the thermophilic digester (55°C) are 5 to 6 days each.
- The high loading rate in combination with plug flow conditions results in a reduction of the required digester volume by 40% to 60%. So far, digester size has been limited in full-scale applications to about 700 m^3.
- Within 10 to 12 day's retention time, organic solids reductions of more than 55% can be achieved as compared to 40% by conventional anaerobic digestion with retention times

of 20 to 30 days.

- The thermophilic operation reduces the content of pathogenic and thus pasteurises the sludge.
- The dewaterability of the digested sludge is claimed to improve.
- The defined plug flow is supposed to guarantee a reliable operation with varying loads. Sludge foaming is claimed not to be a problem due to the plug flow conditions.

Typical reference installations

- Waterval WCW (Erwat)

Typical literature references

[1] Oles J., Dichtl N. & Niehoff H.H. 1997. Full scale experience of two-stage thermophilic/mesophilic sludge digestion, *Water Science and Technology*, Vol. 36, No. 6-7, pp.449-456.

[2] Schafer P.L. & Farrell J.B. 2000. Turning up the heat, *Water Environment & Technology*, November 2000, pp.27-32.

3.4.3.3 Aerobic Digestion

Process:	**AEROBIC DIGESTION**
Unit process / Treatment category:	**Stabilisation**

Process description

Aerobic digestion is similar to the activated sludge process. It involves the direct oxidation of any biodegradable matter and the oxidation of microbial cellular material by organisms (endogenous respiration) that occurs as the supply of available substrate is depleted. The latter step is the predominant reaction in aerobic digestion.

Aerobic digestion may be used to treat (1) only waste activated sludge (WAS), (2) mixtures of WAS or trickling filter sludge and primary sludge, (3) WAS from extended aeration plants, or (4) activated sludge from treatment plants designed without primary settling. Aerobic digestion is specifically used for treating secondary sludge that has a lower oxygen demand than the primary sludge.

Aerobic digestion is usually conducted in open, unheated tanks. Sludge is fed to the reactor at a dry solids concentration of 2% to 4%. The overflow from the reactor goes to a solid-liquid separator, from where the thickened and stabilised solids are either recycled back to the digester or removed for further processing.

Aerobic digestion is most commonly used to stabilise WAS from small activated sludge plants (< 20 Mℓ/d).

Applicability to South Africa

	Primary sludge	WAS
Metro:	Not suitable	Suitable
City:	Not suitable	Suitable
Large municipality:	Not suitable	Suitable
Medium size municipality:	Not suitable	Suitable
Small municipality:	Not suitable	Suitable

Requirements

- Sludge thickening
- Aeration

Advantages

For small activated sludge plants and as compared to anaerobic digestion:

- The operation is relatively easy
- Capital costs are lower than for anaerobic digestion
- It produces an odourless, humuslike, stable end product
- Lower COD concentrations are produced in the supernatant liquor than in the case of anaerobic digestion

Disadvantages

- Digested sludge has very poor mechanical dewatering characteristics
- Operating (power) costs are high
- Temperature, location and type of tank material influence performance significantly
- There is no useful by-product such as methane
- It produces potential odour problems

Main operating and design criteria

- Hydraulic retention time: 10 to 20 days
- Solids loading: 1,6 to 4,8 kg volatile solids / (m^3d)
- Oxygen requirements: ~ 2,0 kg oxygen / kg volatile solids destroyed
- Energy requirements for mixing: 20 to 40 kW/ Mℓ (for mechanical surface aerators)
  1,2 to 2,4 m^3/(m^3min) (for diffused air)
- Volatile solids reduction: 40% to 50%

Typical reference installations

- Zandvliet WWTW (Cape Town)
- Zeekoegat WWTW (Pretoria)
- Rooiwal WWTW (Pretoria)

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **AEROBIC DIGESTION**

Unit process / Treatment category: **Stabilisation**

Unthickened feed (1%DS)

	Unit	WAS		
		Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	805 000	1 625 000	3 350 000
Mechanical & electrical equipment	R	600 000	845 000	1 355 000
Total capital expenditure	**R**	**1 405 000**	**2 470 000**	**4 705 000**
Annual capital cost				
Civil works	R	124 533	251 387	518 243
Mechanical & electrical equipment	R	102 610	144 509	231 728
Total annual capital cost	**R**	**227 143**	**395 896**	**749 971**
Unit cost	**R/t DS**	**124**	**108**	**103**
COST OF MAINTENANCE				
Civil works	R	8 050	16 250	33 500
Mechanical & electrical equipment	R	30 000	42 250	67 750
Total annual cost of maintenance	**R**	**38 050**	**58 500**	**101 250**
Unit cost	**R/t DS**	**21**	**16**	**14**
COST OF OPERATION				
Personnel cost	R	65 000	65 000	65 000
Electricity cost	R	34 320	92 040	168 480
Total annual cost of operation	**R**	**99 320**	**157 040**	**233 480**
Unit cost	**R/t DS**	**54**	**43**	**32**
Total annual cost of O & M	**R**	**137 370**	**215 540**	**334 730**
Unit cost	**R/t DS**	**75**	**59**	**46**
TOTAL ANNUAL COST	**R**	**364 513**	**611 436**	**1 084 701**
UNIT COST	**R/t DS**	**200**	**168**	**149**

Process: **AEROBIC DIGESTION**

Unit process / Treatment category: **Stabilisation**

Thickened feed (2.5 %DS)

	Unit	WAS		
		Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	605 000	950 000	2 150 000
Mechanical & electrical equipment	R	345 000	715 000	1 250 000
Total capital expenditure	**R**	**950 000**	**1 665 000**	**3 400 000**
Annual capital cost				
Civil works	R	93 593	146 964	332 604
Mechanical & electrical equipment	R	59 001	122 277	213 771
Total annual capital cost	**R**	**152 594**	**269 242**	**546 375**
Unit cost	**R/t DS**	**84**	**74**	**75**
COST OF MAINTENANCE				
Civil works	R	6 050	9 500	21 500
Mechanical & electrical equipment	R	17 250	35 750	62 500
Total annual cost of maintenance	**R**	**23 300**	**45 250**	**84 000**
Unit cost	**R/t DS**	**13**	**12**	**12**
COST OF OPERATION				
Personnel cost	R	65 000	65 000	65 000
Electricity cost	R	34 320	92 040	168 480
Total annual cost of operation	**R**	**99 320**	**157 040**	**233 480**
Unit cost	**R/t DS**	**54**	**43**	**32**
Total annual cost of O & M	**R**	**122 620**	**202 290**	**317 480**
Unit cost	**R/t DS**	**67**	**55**	**43**
TOTAL ANNUAL COST	**R**	**275 214**	**471 532**	**863 855**
UNIT COST	**R/t DS**	**151**	**129**	**118**

3.4.3.4 Autothermal Thermophilic Aerobic Digestion

Process:	**AUTOTHERMAL THERMOPHILIC AEROBIC DIGESTION**
Unit process / Treatment category:	**Stabilisation**

Process description

Autothermal Thermophilic Aerobic Digestion (ATAD) represents a refinement of both conventional and high-purity oxygen aerobic digestion. As the name implies, the process operates in the thermophilic temperature range of 45 to 60°C. Thermophilic digestion can be used to achieve removal rates of up to 70% of the biodegradable organics at very short retention times of 3 to 4 days. The process can operate without external heat input by using the heat released during microbial oxidation of organic matter. It has been demonstrated that this quantity is sufficient to heat wet slurries containing from 95% to 97% of water to the thermophilic range of 45°C if sufficiently high oxygen transfer efficiencies can be obtained so that air or oxygen stripping of the heat does not occur. Insulated reactors are required to achieve this. The feed sludge should also contain more than 3% solids to support optimal thermophilic digestion.

The thermophilic aerobic digestion process is self-regulating with respect to temperature. The decrease in biological activity (digestion rate) at elevated temperatures reduces the quantity if heat released during the exothermic reaction with a resultant decrease in the process operating temperature.

Applicability to South Africa

The process has been studied in South Africa and it has been found not to be feasible due to the costs involved and the fact that the process produces a sludge that cannot readily be dewatered. The costs of the process are high as pure oxygen has to be used for the aeration of the sludge to ensure that the thermophilic temperatures are reached.

Metro:	Not recommended
City:	Not recommended
Large municipality:	Not recommended
Medium size municipality:	Not recommended
Small municipality:	Not recommended

Requirements

- Supply of pure oxygen
- Insulation of reactor(s)
- Sludge thickening

Advantages	Disadvantages
• Shorter retention times to achieve a given solids reduction • Improved volatile solids reduction • Greater reduction of bacteria and viruses as compared to mesophilic digestion • Process is relatively stable and recovers quickly from minor upsets • It is not affected by relatively wide variations in outside air temperature	• The digested sludge cannot readily be dewatered • High operating and capital cost • Operation of the process is fairly complex • Potential for odour problems

Main operating and design criteria

- Temperature range: 45°C to 60°C
- Retention time: 3 to 4 days to achieve volatile solids reduction of up to 70%
- Dry solids concentration in sludge feed: > 3%

Typical reference installations

- None known in South Africa

Typical literature references

[1] Metcalf & Eddy Inc. (1991) *"Wastewater Engineering: Treatment, Disposal and Reuse"*. 3rd edition, McGraw-Hill Book Co, Singapore.

[2] Trim B.C. 1984. *Sludge stabilisation and disinfection by means of autothermal aerobic digestion using oxygen.* Water Research Commission Report No 87/1/84, Pretoria: Water Research Commission.

3.4.3.5 Dual Digestion

Process:	**DUAL DIGESTION**
Unit process / Treatment category:	**Stabilisation**

Process description

The dual digestion process consists of a thermophilic aerobic digestion stage followed by a mesophilic anaerobic digestion stage. The first stage is similar to the ATAD process and brings about pasteurisation and a small amount of stabilisation. Extensive stabilisation in the aerobic stage is not desired due to the high energy requirements, and the retention time in this stage is therefore kept to less than one day. The majority of stabilisation takes place in the second stage where shorter retention times are experienced as compared to single-stage, mesophilic anaerobic digestion where metabolic rates are increased.

Dual digestion does not use all the reduced volatile solids to create methane gas, as a fraction of the volatile solids is reduced in the aerobic digester. The dual digestion system produces approximately 35% less methane than a conventional, single-stage anaerobic digester. However, this gas is not required for heating purposes as is the normal practice in anaerobic digestion.

Applicability to South Africa

The dual digestion process has been researched extensively at the Milnerton WWTW and Athlone WWTW of the Cape Metropolitan Council. The Milnerton installation was operated on pure oxygen, whereas the Athlone installation was operated on air, and pure oxygen supplemented air for the supply of oxygen. The plant at Milnerton operated very satisfactorily, but the process was not continued as, in the opinion of the Council, the benefit did not warrant the expense. Although sludge disinfection is required in terms of legislation, it is not strictly enforced, with the result that the pasteurisation and disinfection processes are neglected. The cost of the pure oxygen made the process relatively expensive.

Apparently the operation of the Athlone installation apparently was more problematic and difficult to control due to foaming with air. The process was prone to temperature fluctuations, which is one of the reasons why the Council discontinued the operation.

Metro:	To be considered when sludge disinfection is required
City:	To be considered when sludge disinfection is required
Large municipality:	To be considered when sludge disinfection is required
Medium size municipality:	Not recommended (technical considerations)
Small municipality:	Not recommended

Requirements

- Sludge thickening
- Aeration

Advantages

- Sludge pasteurisation can be achieved simply and effectively.
- No external heating of the anaerobic digester is required as heat is transferred from the aerobic digester.
- The aerobic digester "stabilises" the sludge for the anaerobic digester with regard to temperature, alkalinity and pH that results in a more stable operation of the anaerobic digester.
- Overall capital cost might be reduced due to smaller anaerobic digester volume and there being no need for heat transfer equipment.
- Existing anaerobic digestion plants can be easily converted to treat 2 to 3 times more sludge.
- Final sludge is less prone to odour problems.

Disadvantages

- Odour scrubbing units may be required for aerobic digester.
- Aeration equipment can clog due to excessive grit.
- The cost of pure oxygen is high. Pure oxygen appears to be required for maintaining sufficiently high operating temperatures and limiting heat losses.
- If excessive heat losses occur, external heat sources will be needed to supplement the aerobic autothermal process.
- Process control with pure oxygen is simple but with air is difficult due to foaming.
- Sludge may be more difficult to dewater.
- Dual digestion is a patented process.

Main operating and design criteria

- Temperature: 50°C to 60°C (aerobic stage)
  20°C to 40°C (anaerobic stage)
- Solids loading rate: 3,4 to 7,4 kg volatile suspended solids/m^3 per day
- Retention time: < 1 day (aerobic stage)
  8 to 10 days (anaerobic stage)
- Volatile solids reduction: < 20% in aerobic stage
  e.g. 40% for a retention time of 7,5 days in the anaerobic stage
- Dry solids concentration in sludge feed: ~ 3%

Typical reference installations

- None known in South Africa.

Typical literature references

[1] Messenger J.R., de Villiers H.A., Laubscher S.J.A., Kenmuir K. & Ekama G.A. 1993. Evaluation of the dual digestion system: Part 1 – Overview of the Milnerton experience, *Water SA*. Vol. 19, No. 3, pp.185-191.

[2] Messenger J.R., de Villiers H.A. & Ekama G.A. 1993. Evaluation of the dual digestion system: Part 2 – Operation and performance of the pure oxygen aerobic reactor, *Water SA*. Vol. 19, No. 3, pp.193-200.

[3] Messenger J.R. & Ekama G.A. 1993 a. Evaluation of the dual digestion system: Part 3 – Considerations in the process design of the aerobic reactor, *Water SA*, Vol. 19, No. 3, pp.201-208.

[4] Messenger J.R. & Ekama G.A. 1993 b. Evaluation of the dual digestion system: Part 4 – Simulation of the temperature profile in the batch fed aerobic reactor, *Water SA*, Vol. 19, No. 3, pp.209-215.

[5] Water Research Commission. 1992. *Evaluation and optimisation of dual digestion of sewage sludge*. Water Research Commission Report No. 189/1/92 (Executive Summary), No. 189/2/92 (Part 1: Overall system performance), No. 189/3/92 (Part 2: Aerobic reactor performance), No. 189/4/92 (Part 3: Evaluation of the technology for practical implementation). Pretoria: Water Research Commission.

[6] Pitt AJ & Ekama G.A. 1995. *Dual digestion of sewage sludge using air and pure oxygen.* Research Report W87, Dept of Civil Eng., University of Cape Town. Cape Town: University of Cape Town.

3.4.3.6 Pasteurisation

Process:	**PASTEURISATION**
Unit process / Treatment category:	**Stabilisation**

Process description

Pasteurisation involves heating wet sludge to 70°C and holding it at this temperature for a minimum period of 30 minutes that will inactivate the pathogenic organisms. The two methods that are used for sludge pasteurisation comprise (1) the direct injection of steam, and (2) indirect heat exchange. As heat exchangers tend to scale or foul up with organic matter, it appears that direct steam injection is the most feasible method.

Principal system components include steam boiler, pre-heater, sludge heater, high-temperature holding tank, blow-off tank and storage basins for the untreated and treated sludge. Heat recovery must be implemented for the system to be viable.

Pasteurisation can be applied to either untreated or digested sludge with minimal pre-treatment. Digester gas is an ideal fuel and is usually produced in sufficient quantities to disinfect locally produced sludge.

Even though the pasteurisation process inactivates pathogenic organisms, re-growth can occur whenever the process is not effective.

Applicability to South Africa

A pasteurisation plant was constructed at the Cape Flats WWTW of the Cape Metropolitan Council. The plant was discontinued due to the introduction of a thermal treatment conditioning plant that changed the sludge treatment process.

Metro:	Not recommended
City:	Not recommended
Large municipality:	Not recommended
Medium size municipality:	Not recommended
Small municipality:	Not recommended

Requirements

- Sludge thickening
- Heat source

Advantages

- Process renders a pathogen-free (disinfected) product

Disadvantages

- Odour problems
- Process requires skills such as operating the boiler and understanding high-temperature and pressure processes
- Potential re-growth of pathogens in treated sludge

Main operating and design criteria

- Temperature: 70°C
- Retention time: > 30 minutes
- Batch process preferable to avoid re-inoculation if short-circuiting occurs
- Equipment must be corrosion-resistant

Typical reference installations

- Cape Flats WWTW (Cape Town): Discontinued

Typical literature references

[1] Morrison I.R. 1986. *The pasteurisation of sludge*. Water Research Commission Report No. 86/1/86, Pretoria: Water Research Commission.

3.4.3.7 Methyl-Bromide Fumigation

In the methyl-bromide process dewatered sludge with a solids content of about 60% is built up into a small stockpile and then covered with a tarpaulin membrane. Methyl-bromide gas is introduced, for example via perforated pipes, from the bottom of the pile and the mixture is left under the tarpaulin for one day. After that the treated sludge can be readily used as fertiliser or soil conditioner, as it is disinfected.

Methyl bromide was defined under the Montreal Protocol of 1991 as a chemical that contributes to the depletion of the earth's ozone layer. Accordingly, the manufacture and importation of methyl bromide will be phased out in developed countries up to 2005, and in developing countries up to 2015. South Africa was classified initially as a developed country, but was later reclassified as a developing country with the proviso that the use of methyl bromide has to cease by 2010. The use of methyl bromide will be phased out according to a set programme. As the fumigation of sewage sludge is not a critical use of methyl bromide, this process should not be used, and most probably will not be tolerated anymore.

3.4.3.8 Alkaline Stabilisation

Alkaline stabilisation is a process where quicklime (CaO) is added to the dewatered sludge to raise the pH of the sludge to above 11. In this process, the quicklime is hydrated causing the mixture to heat up as a result of the exothermal hydration reaction. Temperatures of up to 70°C can be reached, causing the pathogenic organisms to be inactivated.

The product of the process can be applied on cultivated land as a replacement for lime that is required to neutralise the acidity of the fertilisers applied by the farmers. This process will be described in more detail in Section 3.8 "Product Uses and Disposal Options".

3.4.3.9 Composting

The composting process consists of mixing dewatered sludge with a suitable bulking agent, such as wood chips, to create air voids in the sludge matrix. The mixture is then aerated for approximately 22 days, whereafter the bulking agent is screened out of the mixture for re-use. The composted product can be sold for use in agriculture and horticulture. During the composting process, the mixture is heated to above 60°C by the biological activity, thereby causing pathogenic organisms to be inactivated. This process is discussed in more detail in Section 3.8 "Product Uses and Disposal Options".

3.5 DEWATERING

3.5.1 Embryonic Processes

3.5.1.1 Electro-acoustic Dewatering

Electro-acoustic dewatering is aimed at improving the efficiency of conventional mechanical sludge dewatering processes (Pincince *et al.*, 1998). An electric field is applied to a belt filter press (rollers are positively charged and the belt is negatively charged) that accelerates the separation of the water from the sludge particles. In addition to the electric field, ultrasound is applied to the sludge from beneath the belt that also enhances the dewatering process by "dislocating" the water from pores and capillaries.

The process has been tested on prototype units only.

3.5.1.2 Electro Dewatering

Electro dewatering is a process applied to recessed-plate filter presses in order to increase solids concentration in the dewatered sludge cake. It involves the application of an electric field to the filter press that improves the separation efficiency of the process (Pincince *et al.*, 1998).

The process has been tested on a bench-scale filter press, and filter cake solids concentration increased from 23% to 47%. No further information regarding development of the process was available.

3.5.1.3 Mechanical Freeze-thawing

Alternate freezing and thawing of sludge promotes the solid-liquid separation process through an increase in the porosity of the sludge after thawing that is used to achieve dewatering of the sludge without the addition of conditioning chemicals.

The process is reported to achieve a dewatered sludge cake with a solids content of approximately 40%, from an initial 4% to 6% solids content (Pincince *et al.*, 1998).

It is reported that the process is applicable to any type of sludge, at any solids concentration, but is particularly effective with chemical and biochemical sludges that do not drain readily. Energy costs for artificial freeze-thawing are prohibitive, and the concept must depend on natural freezing and thawing to be cost-effective. This rules the process out for application under South African conditions.

3.5.1.4 Membrane Belt Press Dewatering

The membrane belt press is a modified belt filter press that uses a membrane belt with a pore size from 0.01 to 16 μm. It is claimed that this process uses less washwater than the conventional belt filter press (Pincince *et al.*, 1998).

The process has been used in a laboratory-scale application only, and no known installations could be found.

3.5.1.5 Simon Moos Process

The Simon Moos technology aims at providing mobile sludge dewatering units for small wastewater treatment facilities (Pincince *et al.*, 1998). The system consists of polymer addition and flocculation, followed by dewatering under gravity. The dewatering unit is a rectangular tank containing longitudinal screens that separate solids and liquids.

The process was developed in Denmark where it is applied for dewatering of municipal sludge. It has found very limited application elsewhere.

3.5.1.6 Tubular Filter Press Process

The University of Natal researched the tubular filter press in South Africa in 1992 (Pincince *et al.*, 1998). The process consists of a tubular configured filter press, where sludge is fed under pressure into a self-supporting array of horizontally collapsible fabric tubes. The dewatered sludge is removed by pumping through the tube array at high velocity. A roller-cleaning device that traverses the length of the tube array then dislodges cake from the tube walls. The dislodged cake, in the form of flakes, is simultaneously transported out of the tubes, drained and conveyed to a collection hopper.

A prototype of this device was constructed at a potable water treatment plant in South Africa and subsequently the process has been applied at several other potable water facilities.

The tubular filter press is not recommended for use on biological sludge as the solids content achieved is very low. It could possibly be used on a small scale as a thickening rather than a dewatering device.

3.5.1.7 Two-stage Dewatering with Additives

The process basically involves the pelletisation of dewatered sludge, whereafter the pellets are coated with either diatomaceous earth or gypsum, calcium carbonate, coal dust etc. (Pincince *et al.*, 1998). The coated pellets are then compressed to increase the solids content to between 40% and 55%.

It is reported that, although the process was successfully demonstrated on a small scale, it failed when it was tried on a large-scale basis. No operating full-scale installations have been reported.

3.5.1.8 Verti-press Process

In the past, the Verti-press has been primarily applied for dewatering mineral concentrates in sulphur refineries and pigmenting or dyeing processes. It is also believed to be applicable to wastewater sludge (Pincince *et al.*, 1998).

The process uses a filter press that is a modified standard recessed plate filter press, and includes horizontal filter chambers and diaphragms. The filter chambers are stationary and have inflatable end seals that are inflated before sludge is injected into the chambers. The sludge in the chambers is located on a horizontal filter belt, and the pressurised diaphragms squeeze liquid out of the sludge on the belt. At the end of the process the seals are deflated and the filter belt moved to allow removal of the filter cake and the start of a new cycle.

No applications of this process involving municipal sludge have been reported, although testing has been done.

3.5.1.9 Deep-frying of Sludge in Waste Oil

The process of deep frying sludge in waste oil was developed in Japan (Okuno *et al.*, 1999 b). Sludge is heated to 90°C under reduced atmospheric pressure to produce solids with a moisture content of less than 5%, an oil content of 30% and a calorific value of 21 to 23 kJ/kg. It is reported that the odour of the product "is much less as compared with the feed sludge".

The waste oil is mostly edible oil obtained from restaurants, hotels and the food industry. The product could possibly be used in the manufacture of Portland cement or even in the manufacture of fertiliser.

3.5.2 Innovative Processes

3.5.2.1 Electro-osmotic Dewatering

Electro-osmotic dewatering is similar to the electro-acoustic dewatering process described earlier, but does not employ ultrasound.

The process requires two belt filter presses operating in series (Smollen and Kafaar, 1995; Snyman *et al.*, 1999). The second press was electronically charged, the top and bottom belts having opposite charges. The belts thus attracted either sludge solids or water, depending on their charge, in this way aiding the dewatering process.

In South African tests, cake solids of up to 45% were achieved using aerobically digested sludge, and of 17% to19% using waste activated sludge. The process could be manipulated by increasing or decreasing the voltage applied; higher voltages increased the rate of dewatering, while lower voltages led to an increase in the time required to achieve the desired results.

ERWAT, in conjunction with Steinmüller Africa and the CSIR, have been testing the process on a pilot scale. The following findings have been published thus far:

- Applying voltage of between 15V and 25V increased the dewatering significantly in waste activated sludge and anaerobically digested sludge;
- Applying voltage on sludge thickened by dissolved-air flotation did not enhance the efficiency of dewatering, unless the sludge was stored to de-air;
- The technology is as sensitive to polyelectrolyte dosages as is the case with conventional belt filter presses;
- The technology is sensitive to the feed rate;
- The technology functioned well with non-thickened waste activated sludge, resulting in cake solids above 20%.

A full-scale application is to be installed shortly at the Vlakplaas WWTW.

3.5.2.2 DAB System

The DAB system is aimed at small wastewater treatment facilities for which it claims to provide a low-cost and low-maintenance dewatering system (Pincince *et al.*, 1998).

The process is operated on a batch principle and is designed to thicken and dewater sludge in a vertical, fixed drum filter in a vat. The process can apparently dewater secondary sludge to approximately 15% to 20% solids and septic tank wastes to about 22% to 25% solids. A complete dewatering cycle requires 12 hours, and because it is a batch process, it is most suited to small installations.

The DAB system has been applied at several small wastewater treatment facilities in Canada and Sweden.

3.5.2.3 Quick-Dry Filter Bed Process

The Quick-Dry Filter Bed process is a patented process designed to increase the rate at which sludge dries on conventional sludge-drying beds (Pincince *et al.*, 1998). It involves the addition of a proprietary flocculator to effect inline flocculation. The solids and liquid are separated by installing a proprietary filter medium approximately 150 mm below the surface of the sand bed in the drying beds. This medium consists of vertical cells which, while providing structural strength, also allow the sludge to drain more rapidly thereby reducing the time required for drying of the sludge. The system also includes a specially designed mechanism that removes dried sludge from the drying beds without damaging the sand bed.

It is claimed that dried sludge with a solids content of 35% to 45% is obtained with a cycle time of 5 to 7 days, compared to the norm of 14 to 21 days. The process is apparently used at approximately 60 wastewater treatment plants, probably in the United States.

3.5.2.4 Dewatering by Rotary Press

The rotary press aims at providing a simple and enclosed dewatering process that produces a sludge cake with a high solids content (Pincince *et al.*, 1998). Sludge is first conditioned in an enclosed flocculation tank equipped with a variable speed mixer, and then fed into a channel containing rotating filter elements. The liquid passes through the filters, while solids are retained and compressed to form a filter cake. The complete system is enclosed that minimises odour problems.

It is claimed that the process achieves a cake solids level of approximately 32% when applied to mixed primary and waste activated sludge. It does, however, require substantially more polymer addition than a belt filter press, although the equipment is said to be smaller, simpler and easier to operate than a belt filter press. Furthermore it is claimed that the energy requirements are less than 10% of the energy requirements for centrifuges.

The process has been used at a number of wastewater treatment works in Canada, England, France and Japan.

3.5.2.5 Dewatering by Screw Press

This process, which has traditionally been used in the pulp and petrochemical industries, is starting to find application in the wastewater sludge treatment field (Pincince *et al.*, 1998).

The system consists of a screw that rotates inside a mobile drum lined with screens. As the sludge is transported by the screw, it is squeezed between the screw and the screens that forces the water out of the sludge. The water drains through the screens and is collected for treatment, while the screw discharges the dewatered sludge. The efficiency of the process can be increased by the injection of steam into the screw shaft. The process has been successfully implemented at various wastewater treatment works, mostly in Japan, and is starting to find application in the United States.

3.5.2.6 Second-stage Dewatering

Very little information is available with respect to the equipment used in second-stage dewatering. The process involves a further dewatering step after initial dewatering by conventional methods (for instance the belt filter press and centrifuge). The equipment used in the second dewatering step is said to operate essentially similar to belt filter presses (Pincince *et al.*, 1998).

The process has been used in Italy and France, and was tested on a bench-scale model in the USA. No further information is available.

3.5.3 Established Processes

3.5.3.1 Dewatering by Drying Beds

Process:	**DRYING BEDS**
Unit process / Treatment category:	**Dewatering**

Process description

In many countries drying beds are the most widely used method of sludge dewatering. The drying area is partitioned into individual beds of convenient size, so that one or two beds will be filled in a normal loading cycle. Sludge drying beds are typically used to dewater digested sludge.

In a conventional drying bed, sludge is placed on the bed in a layer of 200 mm to 300 mm and allowed to dry. Sludge dewaters by drainage through the sludge mass and support media and by evaporation from the surface exposed to the air. Most of the water leaves the sludge by drainage, thus the provision of an adequate underdrainage system is essential. Alternatively, thickened sludge can be spread on a concrete slab where it is left to dry in the sun. Sludge can be removed from the drying beds after it has drained and dried sufficiently to be spadable. Sludge removal is accomplished by manual shovelling into wheelbarrows or trucks or by a scraper or front-end loader.

Sludge drying beds have a significant environmental impact due to the large area required, and the fact that even digested sludge emits an odour. Sludge has to be well stabilised to reduce the odour potential of the drying beds. The area required is determined by the application depth (typically 200 mm to 300 mm) and drying period (typically ~ 21 days), which may be adjusted depending on the nature of the sludge and preconditioning applied. Local precipitation and evaporation play a significant role in determining the size of the drying area, as any rainwater that falls on a drying bed must also be removed along with the water that present in the sludge. Sludge drying beds are best applied in a relatively warm and dry climate. The long wet winters in the Cape region, for example, may necessitate a reduction in the depth of application and an extension of the drying time.

The effectiveness of the drying process can be increased by turning the sludge on the beds in order to bring the lower, wetter layers of sludge to the top where they dry faster. The Greater Johannesburg Metropolitan Council (now Johannesburg Water) has installed an auger-turned drying bed at the Goudkoppies WWTW to achieve a solids content of the dewatered sludge in excess of 35% to enable co-disposal at the Goudkoppies Landfill. The system consists of a concrete slab onto which the dewatered sludge is placed by means of trucks and front-end loaders. The sludge is periodically turned by a special purpose machine running on tracks fitted with a front-mounted auger. The drying time of the dewatered sludge can be reduced by up to 50% by frequent turning of the sludge. The costs have not yet been analysed to determine the financial benefits, and consequently no comments can be made in this regard.

The system would, however, only be viable at larger installations, as the cost of the auger-turning is significant. A simpler method of turning the sludge could be employed at smaller facilities.

Attention may be drawn here to the *"Guidelines for the Design and Operation of Sewage Sludge Drying Beds"* published by the Water Research Commission.

Applicability to South Africa

Sludge drying beds are the most widely used sludge drying technology in South Africa and is hence well known.

The capital cost for the construction of sludge drying beds is generally high and depends on the specific conditions, such as soil and climatic conditions. The drying beds are therefore considered appropriate only for small installations with a capacity of up to about 5 t DS/d.

Metro:	Generally not suitable - too expensive
City:	Generally not suitable - too expensive
Large municipality:	Generally not suitable - too expensive
Medium size municipality:	Suitability depending on specific circumstances
Small municipality:	Suitable

Requirements

- Sludge stabilisation
- Sludge thickening
- Turning machine can be considered for large installations

Advantages

- Low maintenance
- Low energy consumption
- Less sensitive to sludge variability
- Higher solids content than mechanical methods

Disadvantages

- Large area requirements
- High capital cost for construction
- Sludge has to be manually removed from the sludge drying beds
- Possible odour problems
- Requires (well) stabilised sludge
- Should only be considered for small installations

Main operating and design criteria

- Sludge loading: 70 to 150 kg dry solids/(m^2year) (depending on sludge type and climate)
  0,07 to 0,09 m^3/capita
- Retention time: 2 to 4 weeks (depending on climate and frequency of sludge turning)
- Solids content of dried sludge: 40% to 60%

Typical reference installations

Drying beds are installed at almost every single WWTW, for instance:

- Goudkoppies WWTW (Johannesburg) with mechanical turning;
- Daspoort WWTW (Tshwane)

Typical literature references

[1] Ceronio A.D., van Vuuren L.R.J., & Warner A.P.C. 1999. *Guidelines for the Design and Operation of Wastewater Sludge Drying Beds.* Water Research Commission Report No TT107/99, Pretoria: Water Research Commission.

[2] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **Dewatering by Sludge Drying Beds**

Unit process / Treatment category: **Dewatering**

Conventional without mechanical turning

Drying to 30% dry solids

	Unit	WAS or Digested		
		Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	6 600 000	13 200 000	26 400 000
Mechanical & electrical equipment	R	0	0	0
Total capital expenditure	**R**	**6 600 000**	**13 200 000**	**26 400 000**
Annual capital cost				
Civil works	R	1 021 016	2 042 032	4 084 064
Mechanical & electrical equipment	R	0	0	0
Total annual capital cost	**R**	**1 021 016**	**2 042 032**	**4 084 064**
Unit cost	**R/t DS**	**559**	**559**	**559**
COST OF MAINTENANCE				
Civil works	R	66 000	132 000	264 000
Mechanical & electrical equipment	R	-	-	-
Total annual cost of maintenance	**R**	**66 000**	**132 000**	**264 000**
Unit cost	**R/t DS**	**36**	**36**	**36**
COST OF OPERATION				
Personnel cost	R	40 000	60 000	80 000
Electricity cost	R	0	0	0
Cost of chemicals	R			
Total annual cost of operation	**R**	**40 000**	**60 000**	**80 000**
Unit cost	**R/t DS**	**22**	**16**	**11**
Total annual cost of O & M	**R**	**106 000**	**192 000**	**344 000**
Unit cost	**R/t DS**	**58**	**53**	**47**
TOTAL ANNUAL COST	**R**	**1 127 016**	**2 234 032**	**4 428 064**
UNIT COST	**R/t DS**	**618**	**612**	**607**

3.5.3.2 Dewatering by Belt Filter Press

Process:	**DEWATERING BY BELT FILTER PRESS**
Unit process / Treatment category:	**Dewatering**

Process description

Belt filter presses are continuous-feed sludge dewatering devices that involve the application of chemical conditioning, gravity drainage and mechanically applied pressure to dewater the sludge. The belt press utilises two endless belts of multi-weave or monofilament, simple-weave polyester material. Each belt fulfils a separate function with the upper belt generally acting as a press that bears against the lower that is the filter.

The configuration of the press and roller arrangement normally permits three separate zones that provide gravity drainage, compression and shear. The latter two are influenced by the confluence of the two belts and the mechanical pressure applied by the rollers and tensioning system.

A sludge feed arrangement is provided at the front of the gravity drainage zone that distributes sludge across the full effective width of the belt. Redistribution of sludge to permit leaching of free water is accomplished by ploughs placed in echelon formation over the free drainage area. Belt tension is maintained by synchronised pneumatic or hydraulic belt tensioning systems that control the mechanical pressure in the compression and shear zones, while belt speed is controlled by a variable speed drive either of the mechanical or A/C frequency inverter type. A tracking system is required to permit continuous belt alignment using pneumatic or hydraulic cylinders.

Sludge removal is effected by self-aligning tilting scrapers that discharge onto a chute for conveyance to the materials handling system. Filtrate and washwater pans are incorporated into the frame under the filter belt.

Applicability to South Africa

Filter belt presses have been utilised in sludge and slurry systems for approximately 25 years and the detailed design and equipment selection are well defined.

Metro:	Well suitable
City:	Well suitable
Large municipality:	Well suitable
Medium size municipality:	Possibly depending on specific situation
Small municipality:	Generally not suitable

Requirements

- Sludge conditioning
- Washwater system

Advantages

- Dewatering system does not require supplementary aid such as a vacuum
- Continuous process
- Good solids capture
- High cake solids with thermally conditioned sludge
- Visible gravity drainage zone
- Low mechanical maintenance cost
- Low energy requirements
- Relatively low flocculant requirements

Disadvantages

- Often requires linear screens or thickeners to provide optimum performance
- High belt replacement cost
- High washwater requirements (particularly on chemically conditioned sludge)
- High suspended solids in washwater

Main operating and design criteria

- Solids loading rates: 100 kg to 300 kg per meter belt width per hr)
- Solids content of dewatered sludge: 12% to 25% (for chemically conditioned sludge)
  25% to 40% (for thermally conditioned sludge)
- Width of screening cloth: 0,5 m to 3,0 m
  Commonly used for municipal applications: 1,5 m to 2,2 m
- Solids capture: > 96%
- Polyelectrolyte consumption: 2 kg/t DS to 6 kg/t DS

Typical reference installations

Numerous, for instance:

- Olifantsvlei Regional Sludge Handling Facility (Johannesburg)
- Goudkoppies WWTW (Johannesburg)
- Milnerton WWTW (Cape Town)
- Paarl WWTW

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

[2] Slim J.A., Devey D.G. & Vail J.W. 1984. *Sludge dewatering and the treatment of sludge liquors.* Water Research Commission Report No. 82/1/84, Pretoria: Water Research Commission.

[3] Smollen M., Fourie J.M. & Ross W.R. 1985. *Sludge characterisation and dewatering.* Water Research Commission Report No 89/1/85, Pretoria: Water Research Commission.

Process: **DEWATERING BY BELT FILTER PRESS**

Unit process / Treatment category: **Dewatering**

Sludge cake < 18%
Excludes pre-thickening

	Unit	WAS or Digested		
		Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	1 250 000	1 750 000	3 450 000
Mechanical & electrical equipment	R	2 050 000	4 150 000	7 650 000
Total capital expenditure	**R**	**3 300 000**	**5 900 000**	**11 100 000**
Annual capital cost				
Civil works	R	193 374	270 724	533 713
Mechanical & electrical equipment	R	350 585	709 721	1 308 280
Total annual capital cost	**R**	**543 959**	**980 445**	**1 841 993**
Unit cost	**R/t DS**	**298**	**269**	**252**
COST OF MAINTENANCE				
Civil works	R	12 500	17 500	34 500
Mechanical & electrical equipment	R	102 500	207 500	382 500
Total annual cost of maintenance	**R**	**115 000**	**225 000**	**417 000**
Unit cost	**R/t DS**	**63**	**62**	**57**
COST OF OPERATION				
Personnel cost	R	110 000	110 000	145 000
Electricity cost	R	39 000	78 000	129 480
Cost of chemicals	R			
Total annual cost of operation	**R**	**85 904**	**93 704**	**102 440**
Unit cost	**R/t DS**	**47**	**26**	**14**
Total annual cost of O & M	**R**	**200 904**	**318 704**	**519 440**
Unit cost	**R/t DS**	**110**	**87**	**71**
TOTAL ANNUAL COST	**R**	**744 863**	**1 299 149**	**2 361 433**
UNIT COST	**R/t DS**	**408**	**356**	**323**

Process: **BELT FILTER PRESS**

Unit process / Treatment category: **Dewatering**

Sludge cake > 20%
Excludes pre-thickening

	Unit	WAS or Digested Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	1 250 000	1 750 000	3 450 000
Mechanical & Electrical equipment	R	2 350 000	4 850 000	8 955 000
Total capital expenditure	**R**	**3 600 000**	**6 600 000**	**12 405 000**
Annual Capital Cost				
Civil works	R	193 374	270 724	533 713
Mechanical & Electrical equipment	R	401 890	829 433	1 531 458
Total annual cost of capital	**R**	**595 264**	**1 100 157**	**2 065 171**
Unit cost	**R/t DS**	**326**	**301**	**283**
COST OF MAINTENANCE				
Civil works	R	12 500	17 500	34 500
Mechanical & Electrical equipment	R	117 500	242 500	447 750
Total annual cost of maintenance	**R**	**130 000**	**260 000**	**482 250**
Unit cost	**R/t DS**	**71**	**71**	**66**
COST OF OPERATION				
Personnel cost	R	110 000	110 000	145 000
Electricity cost	R	39 000	78 000	129 480
Cost of chemicals	R			
Total annual cost of operation	**R**	**149 000**	**188 000**	**274 480**
Unit cost	**R/t DS**	**82**	**52**	**38**
Total annual cost of O & M	**R**	**279 000**	**448 000**	**756 730**
Unit cost	**R/t DS**	**153**	**123**	**104**
TOTAL ANNUAL COST	**R**	**874 264**	**1 548 157**	**2 821 901**
UNIT COST	**R/t DS**	**479**	**424**	**387**

Process: **MOBILE BELT FILTER PRESS DEWATERING**

Unit process / Treatment category: **Dewatering**

As a number of wastewater treatment facilities are small and therefore do not warrant the permanent installation of mechanical dewatering equipment, the costs of a mobile unit have been calculated to enable evaluation of this alternative.

Continuous belt filter press
Sludge cake > 20%
Includes thickening

	Unit	WAS	Digested
		Capacity [t DS/d]	
		8	10
CAPITAL COST			
Mechanical & electrical equipment	R	2 950 000	2 950 000
Total capital expenditure	**R**	**2 950 000**	**2 950 000**
Annual capital cost			
Mechanical & electrical equipment	R	504 500	504 500
Total annual capital cost	**R**	**504 500**	**504 500**
Unit cost	**R/t DS**	**173**	**138**
COST OF MAINTENANCE			
Mechanical & electrical equipment	R	147 500	147 500
Total annual cost of maintenance	**R**	**147 500**	**147 500**
Unit cost	**R/t DS**	**51**	**40**
COST OF OPERATION			
Personnel cost	R	165 000	165 000
Electricity cost	R	179 712	179 712
Cost of chemicals	R		
Total annual cost of operation	**R**	**344 712**	**344 712**
Unit cost	**R/t DS**	**118**	**94**
Total annual cost of O & M	**R**	**492 212**	**492 212**
Unit cost	**R/t DS**	**169**	**135**
TOTAL ANNUAL COST	R	996 712	996 712
UNIT COST	R/t DS	341	273

3.5.3.3 Chamber Press Dewatering

Process:	**CHAMBER PRESS DEWATERING**
Unit process / Treatment category:	**Dewatering**

Process description

Although the chamber or filter press is defined as a batch process, the use of multiple filter presses and the automation of the press equipment permit continuous feed and discharge.

The filter presses used for wastewater sludge consist of a number of rectangular recessed plates between 500 mm^2 and 1500 mm^2 in size, normally manufactured from reinforced polypropylene or rubber and provided with filter cloths or media of monofilament or multiweave polyester or similar synthetic or natural fibre materials. The plates are either supported on their sides or hung from the top.

During the pressing cycle, sludge is pumped into the chambers formed by the recessed plates that for wastewater sludge are normally between 25 mm and 50 mm in depth. Filtrate passes through the filter cloth and is collected in grooves on the plate and directed to drainage ports. As the sludge volume decreases more sludge enters the pressing zone and further filtration occurs through the cake deposited onto the filter cloth. The pressure required on the feed system gradually increases as the sludge is dewatered and is generally in the range of 500 kPa to 1 500 kPa.

During the pressing cycle the plates are retained by hydraulic rams, the number being dependent upon the configuration of the press. Rams are also utilised for opening and closing of the press at the beginning and end of the cycle.

A basic filter press system utilises manual systems for initiation of operation, plate separation, and discharge. These systems are not acceptable on larger installations due to the number and size of the plates and the rapid cycle time required to reduce the installation size. The presses normally used for wastewater sludge dewatering are therefore provided with automatic opening and closing cycles, plate separation systems, automatic drip tray operation and auxiliary systems to assist with cake release.

As the cake is released vertically from the filter press the installation is normally mounted at a high level to permit direct discharge into skips or onto a conveyor system.

The press feed system may be either through direct feed using hydraulic ram or pumps or through a receiver fed by positive displacement pumps and with system pressure maintained by an air compressor.

Filter presses are of robust construction designed to accommodate the filtration pressures with end plates manufactured from cast iron or steel, support beams of deep channel or beam section and robust operating equipment. A hydraulic power pack is required for operation of the rams for opening and closure.

Periodic cloth washing is required and replacement becomes necessary particularly if damage occurs during the cake clearance cycle. Mechanical maintenance is required primarily on the press feed system.

Applicability to South Africa

Although filter presses produce very high solids concentration in the sludge cake, their use has not been established in the South African wastewater treatment industry. This is mainly attributed to the high costs that are not outweighed by the advantages of the high operating solids concentration achieved. The use of chamber presses in the wastewater industry is therefore not recommended in general. The technology may be applicable for specialised industrial applications.

Metro:	Not recommended
City:	Not recommended
Large municipality:	Not recommended
Medium size municipality:	Not recommended
Small municipality:	Not recommended

Requirements

- Sludge conditioning
- Pressurisation system
- Washwater system

Advantages

- High cake solids concentration

Disadvantages

- High capital and operating costs
- Special support structure requirements
- Large area requirements

Main operating and design criteria

- Operating pressure: 500 kPa to 1 500 kPa
- Throughput: Depending on size of machine
- Cake solids concentration: up to 50% (depending on sludge type)

Typical reference installations

- None in South Africa at Wastewater Treatment works

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse*. 3rd edition, Singapore: McGraw-Hill Book Co.

[2] Slim J.A., Devey D.G. & Vail J.W. 1984. *Sludge dewatering and the treatment of sludge liquors*. Water Research Commission Report No. 82/1/84. Pretoria:Water Research Commission.

[3] Smollen M., Fourie J.M. & Ross W.R. 1985. *Sludge characterisation and dewatering*. Water Research Commission Report No 89/1/85. Pretoria: Water Research Commission.

3.5.3.4 Dewatering by Centrifugation

Process:	**CENTRIFUGATION**
Unit process / Treatment category:	**Dewatering**

Process description

Centrifugation enhances the solid/liquid phase separation by increasing the gravitational force on the medium processed. This increase is achieved by rotating a bowl containing the sludge at high speed.

Various types of centrifuge are available for a full range of liquid/solids separation requirements and it would not be practical to review all the alternatives within the scope of this report. The description under this section is limited to either the co-current-flow or counter-current-flow solid bowl decanter centrifuges.

The centrifuges consist primarily of a cylindrical bowl or drum driven at high speed into which sludge is fed either at the end or in the middle by a positive displacement pump. The essential difference between co-current and counter-current machines is that with the former the sludge feed arrangement permits centrate and cake to move in the same direction whereas in the latter the cake and centrate move in opposite directions. A rotating scroll is installed within the centrifuge bowl which moves the cake deposited on the inner wall of the bowl to a conical section (beach) at the end of the machine where it is further dewatered or drained before discharge. Centrate moving in either direction discharges separately. Adjustable outlets on the bowl control the liquid level (pool depth) in the bowl. Polyelectrolyte is dosed into the sludge feed immediately before entry into the centrifuge.

The use of low-speed larger diameter machines is generally preferred as this avoids many of the wear problems experienced. However, the latest generation machines referred to above generally run at a higher speed and have been designed to give durability under these conditions. It therefore follows that the long-term mechanical performance considerations must be carefully assessed when specifying the machine type.

Applicability to South Africa

Extensive investigation by the equipment manufacturers has demonstrated the suitability of centrifuges for the dewatering and thickening activities required in the treatment of wastewater sludges, and the equipment has been used extensively for many years. The latest generation of machines, which uses automatic differential speed control and durable materials, does not give many of the problems experienced previously.

Metro:	Well suitable
City:	Well suitable
Large municipality:	Well suitable

Medium size municipality: Not recommended
Small municipality: Not recommended

Requirements

- Sludge conditioning (chemical or thermal);
- The construction materials for the centrifuge require careful selection due to the abrasion resistance required of the material. This is of particular importance in high-speed machines. The use of stainless steel has predominated although this may not be warranted for wastewater sludge, as the abrasion resistance is the principal consideration. Scroll edges are normally 'Stellite' tipped and the inlet and other wear areas may require ceramic tile, or tungsten carbite tile lining or coating.

Advantages

- Continuous process
- Compact installation
- Flexible automatic operation
- Enclosed equipment with no odour problems
- High solids capture
- Direct polyelectroloyte feed (no separate flocculation tank required)

Disadvantages

- Efficient grit removal required to prevent excessive wear
- Sensitive to variations in feed concentration and sludge characteristics for chemically conditioned sludge
- Specialised maintenance and repair required
- High maintenance cost
- Relatively high flocculant requirement

Main operating and design criteria

- Throughput: Depending on the size and design of the machine
- Low speed machine: 1 600 rpm to 1 800 rpm; centrifugal force of 750 g
- High speed machine: > 2 500 rpm; centrifugal force of 1 100 g to 1 200 g
- Polyelectrolyte consumption: 3 kg/t DS to 8 kg/t DS
- Solids content of dewatered sludge: 12% to 25% (for chemically conditioned sludge)
  25% to 40% (for thermally conditioned sludge)
- Solids capture: > 96%

Typical reference installations

- Fishwater Flats WRW (Port Elizabeth)
- Mitchells Plain WWTW (Cape Town)
- Cape Flats WWTW (Cape Town)

- Borcherd's Quarry (Cape Town)

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse*. 3rd edition, Singapore: McGraw-Hill Book Co.

[2] Slim J.A., Devey D.G. & Vail J.W. 1984. *Sludge dewatering and the treatment of sludge liquors*. Water Research Commission Report No. 82/1/84. Pretoria: Water Research Commission.

[3] Smollen M., Fourie J.M. & Ross W.R. 1985. *Sludge characterisation and dewatering*". Water Research Commission Report No 89/1/85, Pretoria: Water Research Commission.

Process: **CENTRIFUGATION**

Unit process / Treatment category: **Dewatering**

Sludge cake < 18%
Excludes pre-thickening

	Unit	WAS or Digested		
		Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	325 000	735 000	1 650 000
Mechanical & electrical equipment	R	1 850 000	3 450 000	6 550 000
Total capital expenditure	**R**	**2 175 000**	**4 185 000**	**8 200 000**
Annual capital cost				
Civil works	R	50 277	113 704	255 254
Mechanical & electrical equipment	R	316 382	590 009	1 120 162
Total annual capital cost	**R**	**366 659**	**703 713**	**1 375 416**
Unit cost	**R/t DS**	**201**	**193**	**188**
COST OF MAINTENANCE				
Civil works	R	3 250	7 350	16 500
Mechanical & electrical equipment	R	92 500	172 500	327 500
Total annual cost of maintenance	**R**	**95 750**	**179 850**	**344 000**
Unit cost	**R/t DS**	**52**	**49**	**47**
COST OF OPERATION				
Personnel cost	R	110 000	110 000	145 000
Electricity cost	R	45 240	90 480	145 080
Cost of chemicals	R			
Total annual cost of operation	**R**	**155 240**	**200 480**	**290 080**
Unit cost	**R/t DS**	**85**	**55**	**40**
Total annual cost of O & M	**R**	**250 990**	**380 330**	**643 080**
Unit cost	**R/t DS**	**138**	**104**	**87**
TOTAL ANNUAL COST	R	617 649	1 084 043	2 009 496
UNIT COST	R/t DS	338	297	275

3.5.3.5 Dewatering by Vacuum Filters

Process:	**VACUUM FILTRATION**
Unit process / Treatment category:	**Dewatering**

Process description

The vacuum filter consists primarily of an internally partitioned, stiffened cylindrical drum rotating partially submerged in a bath of conditioned sludge. The surface of the drum is covered with a porous filter medium that is selected based on the dewatering properties of the sludge. The rotating drum is divided into separate sealed segments that are connected to a rotary valve on the axis of the drum. As the drum rotates in the sludge bath, the rotary valve causes each separate segment to operate in sequence as a cake formation, cake dewatering and cake discharge zone.

A vacuum is applied whilst the drum is immersed in the sludge bath and normally through 330 degrees of rotation at which stage air pressure is applied to assist with separation of the sludge cake from the filter cloth prior to removal by a scraper blade. Approximately 25% to 30% of the vacuum filter drum is immersed in the sludge bath that is fed continuously. The applied vacuum causes the formation of a sludge layer on the filter cloth and encourages filtrate to pass through the cloth media into the drum segment. As the evacuated section of the drum passes through the sludge, the cake increases in thickness. When the section of the drum, on which the cake is formed, emerges from the sludge bath, the vacuum continues to be applied, causing air and additional filtrate to be removed from the sludge.

A number of factors affect the performance of vacuum filters, such as immersion depth of the drum, rotation speed, filter cloth type, solids concentration of the sludge feed and sludge filtration characteristics.

Applicability to South Africa

Rotary drum vacuum filters have been utilised for sludge and other slurry dewatering applications for over fifty years, and detailed design, equipment, selection and construction have been well defined. It has recently fallen out of favour as a result of improvements to alternative mechanical dewatering systems, as well as the fact that it uses complex technology, requires conditioning chemicals and suffers from high operation and maintenance costs. It is not expected that this process will be considered for treatment of wastewater sludges in South Africa.

Metro:	Not recommended
City:	Not recommended
Large municipality:	Not recommended
Medium size municipality:	Not recommended
Small municipality:	Not recommended

Requirements

- Sludge conditioning
- Washwater system (to clean filter cloth)
- Vacuum and pressurisation system

Advantages

- Continuous process
- Good solids capture
- Cake solids content similar to mechanical dewatering equipment

Disadvantages

- Complex technology
- Requires sludge conditioning
- High operation and maintenance costs
- High washwater requirements

Main operating and design criteria

- Chemically conditioned sludge:

  From previous investigations it appears that the optimum performance of a vacuum filter can be defined approximately as follows: -
  - Cake solids content: ~ 20%
  - Solids capture: ~ 98%
  - Filter loading rate: ~ 15 kg dry solids/(m^2h)
  - Rotational speed: ~ 52 m/h
  - Polyelectrolyte consumption: ~ 6 kg/t DS
- Thermally conditioned sludge:

  From previous investigations it appears that the optimum performance of a vacuum filter can be defined approximately as follows: -
  - Cake solids content: ~ 40%
  - Solids capture: ~ 98%
  - Filter loading rate: ~ 75 kg dry solids/(m^2h)
  - Rotational speed: ~ 70 m/h

Typical reference installations

- None known in South Africa

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

[2] Slim J.A., Devey D.G. & Vail J.W. 1984. *Sludge dewatering and the treatment of sludge liquors.* Water Research Commission Report No. 82/1/84. Pretoria: Water Research Commission.

[3] Smollen M., Fourie J.M. & Ross W.R. 1985. *Sludge characterisation and dewatering.* Water Research Commission Report No 89/1/85. Pretoria: Water Research Commission.

3.5.3.6 Dewatering by Vacuum-assisted Drying Beds

Process:	**DEWATERING BY VACUUM-ASSISTED DRYING BEDS**
Unit process / Treatment category:	**Dewatering**

Process description

The vacuum-assisted drying bed method accelerates sludge dewatering and drying by applying a vacuum to the underside of porous filter plates. The process usually includes the following steps: (1) conditioning the sludge with a polymer, (2) filling the beds with sludge, (3) dewatering the sludge initially by gravity drainage followed by applying a vacuum, (4) allowing the sludge to air-dry for approximately 24 to 48 hours, (5) removing the dewatered sludge, and (6) washing the surface of the porous plate with a high-pressure hose to remove the remaining sludge residue.

The vacuum-assisted drying bed process was advertised in South Africa as the Rapid Sludge Dewatering System (RSDS) in the late 1980s. The RSDS consists of a porous floor onto which thickened sludge is poured. A vacuum is created below the floor to increase the driving force for the drainage of water through the sludge and the floor.

Applicability to South Africa

Upon advertisement of the RSDS process in South Africa, some installations were constructed, but it was found that the system did not meet expectations. Problems experienced were blinding and cleaning of the porous floor, with the result that the efficiency of the system dropped. As a consequence the system is not advocated in South Africa anymore.

Metro:	Not recommended
City:	Not recommended
Large municipality:	Not recommended
Medium size municipality:	Not recommended
Small municipality:	Not recommended
	Not recommended

Requirements

- Sludge conditioning
- Sludge thickening
- Vacuum system

Advantages

- Reduced cycle time required for sludge dewatering (as compared to conventional drying beds)
- Reducing the effect of weather on sludge drying
- Smaller area requirements

Disadvantages

- Further processing required for additional moisture reduction
- Problems with the blinding of the porous floor
- High maintenance requirements
- Energy intensive

Main operating and design criteria

- Cake solids content: 8% to 23%
- Cycle time: 1 to 3 days

Typical reference installations

- George WWTW

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

3.6 DRYING PROCESSES

The process of drying sludge involves the reduction of water content by vaporisation of water to the atmosphere. The processes discussed below all involve the provision of auxiliary heat to increase the vapour-holding capacity of the ambient air and to provide the latent heat necessary for evaporation.

3.6.1 Embryonic Processes

3.6.1.1 DHV Drying

The objective of the DHV drying process, developed by DHV Water and Environment BV of the Netherlands, is to provide an economical method for drying sludge (Pincince *et al.*, 1998). The process consists of two spiral conveyors, in which sludge transport and heat transfer are boosted by the addition of heated steel ball bearings. The first conveyor transports the sludge and the heated ball bearings that cause the water contained in the sludge to evaporate. At the end of the drying process the ball bearings are separated from the sludge that is then dried and cooled. The second conveyor returns the ball bearings that are heated up again.

A patent has been obtained for this process and DHV is searching for equipment manufacturers to support the product development. Due to the state of development of this process, it is not recommended for consideration at this stage.

3.6.1.2 Fluidised Bed Drying

The objective of the fluidised bed drying process is to dry the sludge prior to incineration or melting (Pincince *et al.*, 1998). Dewatered sludge is distributed over a hot sand bed that has a temperature of approximately 800°C. The rapid evaporation of water causes the sludge particles to be reduced to micro-sized particles. The particles are dried further in the upper heating zone of the fluidised bed. Due to the energy requirements of this process it is likely to be very expensive.

3.6.1.3 Kinetic Drying

The objective of the kinetic drying process is to generate a product for agricultural use. The process produces powdered biosolids with a solids content of about 90% to 95% (Pincince *et al.*, 1998). The drying unit is operated at a temperature of 200°C and weir plates in the unit agitate the sludge. A constant flow of air through the dryer removes the dried, powdered material and conveys the product to an air classifier and cyclone. About half of the air is returned to the drying unit, while the remainder is treated by carbon filters.

Two pilot demonstrations were conducted in 1996 on units processing one to two dried tons per hour at 20% and 30% solids respectively. As this process is still in the experimental stage it is not considered to be viable for selection at this time.

3.6.1.4 Microwave Drying

The objective of the microwave drying process is to dewater and/or dry liquid sludge. Microwaves are used to heat the sludge to enable evaporation of the water. This process has been tested in a bench-scale application only and is therefore not recommended at this stage (Pincince *et al.*, 1998).

3.6.1.5 Multi-pass Drying

In the multi-pass dryer, dewatered sludge is dried by subjecting it to direct and indirect heat (Pincince *et al.*, 1998). The unit consists of a horizontal vessel through which the sludge is transported by a series of stainless steel belts. As the solids move along, they are dried by exposure to direct and indirect heat. Limited data is available on this process and it is therefore not recommended at this stage.

3.6.1.6 Thin-film Drying

The thin-film dryer consists of a vertical drying unit that is equipped with a distributor at the top and horizontally rotating blades along the shaft in the centre of the drying unit (Pincince *et al.*, 1998). Sludge at a solids content of 10% is fed into the top of the dryer and then evenly spread over the heated shell. As the sludge descends in the unit, it is in continuous contact with the shell, thus drying gradually. The dried sludge is abstracted from the bottom of the dryer.

Due to the limited information available this process can only be considered to be embryonic and is therefore not recommended at this stage.

3.6.2 Innovative Processes

3.6.2.1 Centridry Process

The objective of the centridry process is to dewater and thermally dry liquid sludge to generate a product with a solids content in the range of 50% to 90% (Pincince *et al.*, 1998; Fawcett, 2001).

The liquid sludge is first dewatered in a centrifuge, from which it is discharged with a solids content of about 28% to 30%. It then enters an air contactor that surrounds the centrifuge, and in which the solids are suspended by hot air. As the solids are dried, they are conveyed by the hot air to a cyclone for gas-solid separation. The size of the dried material varies between 1 mm to 1.5 mm in diameter.

The major advantage of this process lies in the fact that the volume of the sludge to be disposed of is reduced by orders of magnitude, thus significantly reducing the cost for the disposal. The heat also disinfects the product, and, depending on the content of heavy metals, it could be used as a source of nutrients in agriculture.

3.6.2.2 EcoTechnology

In the EcoTechnology process, the sludge is gradually dried by passing through the following six distinctive process steps (Pincince *et al.*, 1998):

i. dewatering with polymer addition;

ii. mechanical separation and direct thermal drying;

iii. preheating and indirect thermal drying;

iv. vacuum/compression and heat recovery;

v. final drying;

vi. pelletisation.

A pilot programme has been started in the USA, however, no results are available as yet. This process can therefore not be recommended at this stage.

3.6.2.3 Extractive Process

The objective of extractive processes is to reduce the sludge volume and to recover fats and oils (Pincince *et al.*, 1998).

Sludge is mixed with a chilled solvent such as triethylamine or tetrachloroethylene prior to dewatering in a centrifuge. The dewatered sludge is then fed to a thermal dryer, with the vapour from the dryer being condensed and mixed with the centrate. This liquid mixture is treated by decanting and distillation, thereby yielding the solvent to be recycled back to the process, and the fats and oils, which have been extracted from the sludge, can be recovered.

Extractive processes cannot be recommended at this stage due to the high risk involved when working with the solvents mentioned above.

3.6.2.4 Filter Press/Drying

The objective of the filter press/dryer is to increase the solids content of liquid sludge to up to 95% by dewatering and drying (Pincince *et al.*, 1998). This is achieved in a single unit, a recessed plate filter press, into which thickened sludge is pumped that has been pre-treated with a polymer. As a first step, normal mechanical dewatering takes place, after which the drying phase commences. The plates are heated with steam or hot water and a vacuum is applied to the filtrate line. When the dried material reaches about 92% to 95% solids content, the product is discharged from the filter press.

This process has been installed and used at various treatment works in Europe. Due to the high requirement for manual labour, this process is not recommended at this stage.

3.6.2.5 Infrared Drying

The infrared drying unit consists of a number of augers that convey the sludge through the dryer and over infrared heating elements that are located above the augers (Pincince *et al.*, 1998). Sludge is discharged into the augers, and as it passes through the dryer, the water from the sludge evaporates due to the heat, emitted by the infrared elements. It is alleged that a solids content of 80% to 85% can be achieved with this system.

Infrared dryers have been installed at several facilities in the USA, however, expansion of the equipment as a result of the heat proved to be a problem at some of the plants. Due to the state of development of this process, it is not recommended at this stage.

3.6.2.6 Sludge MASTER IRC Process

The Sludge MASTER IRC represents an indirect dryer that uses hot oil, pumping it through a hollow-flight auger (Pincince *et al.*, 1998). In addition, gas-fired burners heat the outside shell of the dryer. The steam generated during the drying process is withdrawn and condensed. It is claimed that one of the advantages of the unit is that it does not require recycling of the dried material to be mixed with the feed sludge, as might be necessary in other drying systems.

Full-scale units with a capacity of up to 50 wet tons per day have been installed in the USA. However, before this technology can be installed or recommended for use in South Africa, it is necessary to obtain more information on the operation and maintenance requirements of this process.

3.6.2.7 Freeze-thaw Drying

Freeze-thaw drying involves the repeated freezing and thawing of sludge converting the sludge to a granular material that drains more readily than the original more gelatinous material (Pincince *et al.*, 1998). Although this process has been proved to achieve solids contents in excess of 70% when additional drying time is allowed after thawing, the energy input required to achieve artificial freezing and thawing is prohibitive, and the process can only be used in climates where freezing occurs naturally. For this reason the process is not recommended for South African conditions.

3.6.3 Established Processes

3.6.3.1 Carver-Greenfield Process

Process:	**CARVER-GREENFIELD PROCESS**
Unit process / Treatment category:	**Drying**

Process description

The proprietary Carver-Greenfield process is a multiple-effect evaporation process for drying of sludge. The major steps involve oil mixing, multiple-effect evaporation, oil-solids separation and condensate-oil separation. The oil-sludge mixture is passed through falling film evaporators where water is removed on the principle that it has a lower boiling point than the oil carrier medium. After evaporation an oil-solids mixture remains, and the solids are separated from the oil in a centrifuge. The dry solids can be further processed or suitably disposed of, for example by landfilling, while the oil is recovered for re-use.

Applicability to South Africa

The Carver-Greenfield process has actually become obsolete, even though at least one plant is known to still operate in the USA (Los Angeles). The process is reportedly expensive, very complex and difficult to control. It has not been used in South Africa.

Metro:	Not suitable
City:	Not suitable
Large municipality:	Not suitable
Medium size municipality:	Not suitable
Small municipality:	Not suitable

Requirements

- Sludge dewatering
- Heat source (steam)

Advantages

- Process yields re-usable products

Disadvantages

- Expensive and very complex
- Difficult to control

Main operating and design criteria

- Heat and energy recovery from the dried sludge by means of an incinerator-pyrolysis reactor or gasifier should be investigated when evaluating the Carver-Greenfield process.

Typical reference installations

- None in South Africa

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

3.6.3.2 Direct Drying

Process:	**DIRECT DRYING**
Unit process / Treatment category:	**Drying**

Process description

Direct drying can be accomplished in a rotary dryer in which the sludge is in contact with hot gases. Mechanically dewatered sludge is mixed with previously dried sludge to provide a low-moisture dryer-feed. Hot gas at temperatures of ~ 650°C is introduced into the dryer, usually in a co-current flow pattern. The drum containing the sludge and hot gas is rotated in order to bring all the sludge into contact with the gases to improve the mass transfer of moisture from the sludge to the gases. The drum often has ploughs or louvres to agitate the sludge as the drum revolves. After the sludge has been held in the dryer for 20 to 60 minutes, the dried sludge is discharged at a temperature of 80 to 90°C. A portion of the dried product is recycled, and the balance is processed further or disposed of.

The exhaust gases from the drum are conveyed to a cyclone, where entrained solids are separated from the gas. If required, the gas is then treated further (air pollution control and deodorisation) before being discharged.

Various materials, including dried sludge, may be used as a fuel for the heating process.

Applicability to South Africa

Metro:	Suitable
City:	Suitable
Large municipality:	Possibly
Medium size municipality:	Not recommended
Small municipality:	Not recommended

Requirements

- Sludge dewatering
- Heat / Fuel source

Advantages

- Process renders usable product, e.g. as soil conditioner or for the manufacture of fertiliser
- Sludge volume and weight is greatly reduced (moisture content of dried product < 10%)

Disadvantages

- Expensive process
- Could cause odour problems
- The energy balance of the process has to be examined carefully to determine viability

Main operating and design criteria

- Retention time of sludge: ~ 20 to 60 minutes
- Rotational speed of drum: 5 to 8 rpm
- Gas velocities: 1,2 m/s to 3,7 m/s (otherwise dust entrainment with exhaust gas)

Typical reference installations

- Cape Flats WWTW (Cape Town)

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

3.6.3.3 Indirect Drying

Process:	***INDIRECT DRYING***
Unit process / Treatment category:	**Drying**

Process description

Indirect drying is similar to direct drying in the sense that a rotary dryer is used. In indirect dryers, the sludge is contained in a central cell (for instance a drum) that is surrounded by a steam jacket. The steam provides the heat to effect the mass transfer of moisture from the sludge to the air in the drum.

Applicability to South Africa

Metro:	Suitable
City:	Suitable
Large municipality:	Possible
Medium size municipality:	Not recommended
Small municipality:	Not recommended

Requirements

- Sludge dewatering
- Heat / Steam source

Advantages

- Process renders usable product, e.g. as soil conditioner or for the manufacture of fertiliser
- Sludge volume and weight is greatly reduced

Disadvantages

- Expensive process
- Odour problems. Requires treatment of exhaust gases

Main operating and design criteria

- Supplier-specific.

Typical reference installations

- There are no known installations in South Africa.

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

3.6.3.4 Flash Drying

Process:	**FLASH DRYING**
Unit process / Treatment category:	**Drying**

Process description

Flash drying is the rapid removal of moisture by spraying or injecting the solids into a hot gas stream. The process involves pulverising the sludge in the presence of hot gases. The equipment is designed such that the sludge particles remain in contact with the turbulent hot gases long enough to accomplish mass transfer of moisture from the sludge to the gases.

One operation uses a cage mill that receives a mixture of wet sludge and recycled dried sludge. The hot gases and sludge are forced up a duct in which most of the drying takes place. A cyclone then separates the vapour and solids. The dried sludge can be used as a soil conditioner or may be disposed of in other ways, such as incineration.

Applicability to South Africa

Metro:	Suitable
City:	Suitable
Large municipality:	Possibly
Medium size municipality:	Not recommended
Small municipality:	Not recommended

Requirements

- Sludge dewatering
- Heat / Fuel source

Advantages

- Process renders usable product, e.g. as soil conditioner or for the manufacture of fertiliser.
- Sludge volume and weight is greatly reduced. A moisture content of less than 10% in the dried product can be achieved.

Disadvantages

- Expensive process
- Odour problems
- Requires treatment of exhaust gases

Main operating and design criteria

- Supplier-specific
- Gas velocities: 20 to 30 m/s

Typical reference installations

- None in South Africa

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

3.7 THERMAL CONVERSION

Thermal conversion processes utilise high temperatures to stabilise sludge and to change its physical characteristics.

3.7.1 Embryonic Processes

3.7.1.1 Catalytic Extraction Process

The objective of the catalytic extraction process is to transform wastes into products such as gases, ceramics and metals (Pincince *et al.*, 1998).

The process involves adding waste products and chemical reactants to molten metals such as iron. The molten metal reduces the waste products to the elemental constituents by dissolving their molecular bonds. Adjusting the process parameters, such as the temperature, pressure or the chemical reactants added can vary the products of the process.

The technology is presently applied to industrial wastes only, and research on treating hazardous wastes with this process is still in progress.

3.7.1.2 Co-gasification

The objective of co-gasification is to reduce the volume of waste and to bind the heavy metals in the sludge (Pincince *et al.*, 1998).

Dewatered sludge is mixed with coal into a slurry and then pumped into the gasification reactor that requires pure oxygen for the partial combustion of the slurry. The reactor is operated at a temperature of around 1 350°C at which the ash melts and the metals are bound in the ash. The gas produced by the process is cooled and scrubbed, and can be used for industrial purposes or for power generation.

Research done in the USA has indicated that this process is not economically viable.

3.7.1.3 Electric-arc Gasification

The objective of electric-arc gasification is to produce useable gas from waste materials. This process has apparently not been tested with municipal wastewater sludge yet (Pincince *et al.*, 1998).

The organic material in the sludge is gasified using heat from an electric arc generator rather than from partial oxidation of the feed material. Some tars and oils are also generated in the process and are abstracted from the system as condensate. The temperatures in the reactor are such that carbon dioxide is reduced to carbon monoxide and high molecular weight compounds are cracked.

3.7.1.4 Gasification of Char from Sludge Pyrolysis

The objective of gasification of char from sludge pyrolysis is to generate gas from the char produced in the sludge-to-oil process that is described later in this report. Gas is formed by the reaction of steam and char at temperatures of 800°C to 1 000°C (Pincince *et al.*, 1998).

The process has been tested on a laboratory-scale application only.

3.7.1.5 Gasification: Syngass-Thermanetic and Renugas Processes

The objective of the Syngass-Thermanetic and Renugas processes is to produce gas from sludge or from a mixture of sludge and municipal solid waste or any other organic waste (Pincince *et al.*, 1998).

The Syngass-Thermanetic process uses a mixture of sludge and shredded solid waste that is gasified to yield a gas with a low energy value. In the Renugas process, biomass is converted to gas in a fluidised bed reactor. The bed consists of inert solids and is fluidised by steam and oxygen. In order to control the water content in the process, the feed biomass must be fairly dry (minimum dry solids content of 75%) as water is already supplied by the steam. The Renugas process has mainly been used on alfalfa and sugarcane wastes.

These gasification processes generally yield gases with a low energy level that can be increased by purification.

3.7.1.6 Microwave Gasification

Microwave gasification aims at sludge volume reduction and energy recovery in the form of heat and gas (Pincince *et al.*, 1998).

Sludge with a solids content of 50% to 60% first undergoes a pyrolysis step at approximately 545°C to reduce its water and volatile organic content. The gases and entrained organics from the pyrolysis step are then treated in a combined microwave and gasifier to reduce the water and tar content to less than 1%. The gas is subsequently separated from the solids, cooled and cleaned for further use, whereas the solids are incinerated to provide heat for the pyrolysis process.

This process has been tested in the laboratory only.

3.7.1.7 Sludge Pyrolysis

Sludge pyrolysis reduces dried sewage sludge to ash by heating it in a kiln-type pyrolyser (Pincince *et al.*, 1998). The gas produced in the process is used for firing the kiln, with any excess heat being recovered for drying of the incoming sludge. The solid residue from the pyrolysis process reportedly has the appearance of ash from a furnace and contains substantial amounts of carbon. The limited air supply to the kiln causes pyrolytic loss of much of the organic material in the sludge but still leaves significant amounts of carbon in the residue. It is claimed that the heavy metal content of the residue is generally acceptable in terms of American legislation, i.e. that it will pass the Toxic Components Leaching Procedure (TCLP) tests. It is, however, thought that the heavy metal content of the ash will be directly influenced by the original quantities of heavy metals present in the sludge, and this statement may therefore not apply to all sludges.

A company, Waste Distillation Technology Inc., has referred to pilot developments, but no specific information is available.

3.7.1.8 Supercritical Water Oxidation

The objective of supercritical water oxidation is to transform liquid wastes into inert solids, water and carbon dioxide (Pincince *et al.*, 1998).

Under super critical conditions for water i.e. at temperatures of 350°C to 650°C and pressures of 220 bar to 250 bar, salts in water become insoluble, whereas normally insoluble organic liquids and gases become soluble and break down to water and carbon dioxide. It has been reported that problems are experienced with wastes containing high solids content and/or high concentrations of caustic, chloride and sulphide.

The process appears to be mainly intended for the treatment of industrial and possibly hazardous wastes. Limited experimentation has been done with sewage sludge.

3.7.1.9 Total Bio-combustion

Total Bio-combustion aims at reducing the sludge volume by using a four-stage process that consists of alternating thermophilic (70°C tot 90°C) and mesophilic (30°C to 40°C) anaerobic digesters (Pincince *et al.*, 1998). The process operates on the principle that the organisms produced by the one stage are inactivated by the temperature shift during the following stage, thus serving as substrate for the organisms of that particular stage. At the end of the cycle, the solids are separated and recycled to the first stage of the process.

It is reported that 96% of the volatile solids are removed, and that the remaining 4% appear as soluble material in the liquid phase that can be treated by normal biological processes such as activated sludge.

Reportedly, this process had been operated in London on a laboratory-scale application for 5 years. No further information was available.

3.7.2 Innovative Processes

3.7.2.1 Deep-shaft Wet Air Oxidation

The objective of the deep-shaft wet air oxidation process is to reduce pathogens and the volume of sludge (Pincince *et al.*, 1998).

The system consists of a tube-and-shell reactor that is suspended in a well of 1 500 m to 3 000 m deep and provides a temperature and pressure-controlled environment. Concentric tubes divide the reactor into a downflow and an upflow section. Air or oxygen is injected into the sludge at the top of the reactor and the mixture then flows down in one tube and back up to the surface in the other tube, thereby subjecting all sludge to pressures of up to 10 MPa and temperatures of up to 250°C. Under these conditions, the organic material is oxidised to water, carbon dioxide and ash.

It is alleged that volatile solids destruction of greater than 75% is achieved by the process, and that the settling and dewatering characteristics of the product are comparable to those of ash. The heat generated in the process can be recovered if economically viable.

The advantages of the process include small space requirements, low energy requirements (because of the use of natural hydrostatic pressure and exothermal heating), high COD and suspended solids removal efficiencies and low odour emissions. A distinct disadvantage is that a deep well has to be drilled that will be very expensive, and skilled operators are needed for process control. It is thought that the process is more likely to find application in the Witwatersrand area where old mine shafts might be used in the construction of the reactors.

3.7.2.2 Oxygen Injection (Incineration)

The objective of injecting oxygen into an incinerator is to increase the capacity of the incinerator and to decrease air emissions as well as to reduce the fuel consumption of the incinerator (Pincince *et al.*, 1998).

The process was used in a demonstration project where oxygen was added to the combustion zone of a multiple-hearth furnace. This allowed the solids throughput to be increased by 35% to 55% or, alternatively, wetter sludge could be incinerated. The process also lowered the emissions of total hydrocarbons, nitrogen oxides and carbon monoxides and the natural gas consumption declined by approximately 33%.

The process may present an alternative when otherwise additional incinerators would have to be constructed or additional pollution control equipment would have to be installed.

3.7.2.3 RHOX Process

The objective of the RHOX process is to decrease the use of fuel and the emissions of metals in multiple-hearth incinerators (Pincince *et al.*, 1998). The multiple-hearth furnace is operated in such a manner that the temperature at the top of the hearth is maintained at less than 550°C. At this temperature no additional fuel is required for the combustion of dewatered sludge with a solids content in excess of 25%. The operating temperature of the furnace is such that no metals are volatised, albeit at the sacrifice of incomplete combustion of the organic matter. The exhaust gas is cooled and cleaned and moisture is removed in a scrubbing system.

The process is in full-scale operation at six wastewater treatment plants in the USA. This process can be considered for use if it is found that the sludge has to be incinerated for it to be disposed of. The process has the advantage of reportedly reducing the amount of fuel required in the incineration process and also reducing the requirement for extensive scrubbing of the off-gases from the reactor as the metals are not volatised.

3.7.2.4 ATHOS Process

The ATHOS process was developed in France, where a large-scale demonstration plant was constructed treating 150 kg DS/h (50 000 population equivalents) (Djafer *et al.*, 2001).

In the process, the sludge is heated to 235°C at a pressure of 50 bar for the wet-air oxidation process. At this temperature and pressure, 75% of the COD and 70% of the ammonia are removed. It is claimed that almost total ash mineralisation is achieved leaving a residue that can be landfilled without any further treatment. Leaching tests have apparently confirmed the safety of the product.

After the oxidation, the residual organic matter consists mainly of volatile fatty acids that are not toxic to the biological processes. The effluent could therefore enhance denitrification.

3.7.3 Established Processes

3.7.3.1 Incineration

Process:	**INCINERATION**
Unit process / Treatment category:	**Thermal conversion**

Process description

Incineration is complete combustion, converting organic solids to oxidised end products. Incineration is a high-temperature process in which the carbonaceous material in the sludge feed is ignited and burnt to produce CO_2, water vapour and an ash residue.

Before the fuel cost increase in the early 1970s, the cost of incineration was competitive with other sludge disposal methods. However, the increase in the cost of fuels resulted in a re-evaluation of the process and in many cases in a move away from incineration. In the last five to ten years, however, there has been renewed interest in the incineration process as a result of process developments to improve efficiency by making more use of the heat produced.

There are a few types of incinerator, but the two most common types are the multiple-hearth and the fluidised-bed types. There are many variations in the process configuration to recover heat, among other things, but essentially the process may be described as follows: -

- Dewatered wastewater sludge at a solids concentration of approximately 20% enters a sludge drying section. The composition of the sludge feed may vary from waste activated sludge only to a combination of primary sludge, digested sludge and waste activated sludge.
- The hot smoke gases exiting the incinerator (at approximately 900°C depending upon the incinerator type) are cooled immediately in a steam boiler to around 250°C and cooled further in a hot water heat exchanger to around 170°C. The removal of solids from the gas usually follows next producing a clean gas that can exit the system through a stack without violating any environmental emission control regulations.
- The steam that is produced in the boiler can be used for heating the incoming sludge in a dryer and increasing its solids concentration to up to 50% by driving off moisture from the sludge. Depending upon the initial composition of the sludge it should now contain a sufficiently high concentration of volatile solids to enable it to burn without additional fuel in the incinerator, i.e. the incinerator operates in the autothermic mode.
- Auxiliary fuel is required to start the incinerator and may also be required on occasions when the load to the incinerator is particularly low. The fuel may be a fuel oil or digester gas.
- The ash produced in the incineration process will be about 35% to 45% of the dry solid mass fed to the unit. It will contain less than 5% free carbon and is biologically inert. It could be disposed of in a brick-making operation, for example.

Applicability to South Africa

Metro:	Possibly suitable
City:	Possibly suitable
Large municipality:	Not recommended
Medium size municipality:	Not suitable
Small municipality:	Not suitable

Requirements

- Sludge dewatering
- Fuel source
- Air scrubbing system

Advantages

- With the incorporation of suitable gas cleaning equipment the air pollution potential of the stack gas can be eliminated
- The sludge mass is reduced by about 50% which significantly reduces the final mass of solids requiring disposal.
- The plant can be constructed on site to avoid the high operating costs associated with transportation of sludge to distant disposal sites.
- The ash produced is pathogen free.
- Screenings from the inlet works can also be disposed of in the incinerator.
- Toxins present in the feed to the process, such as PCBs and pesticides, will be destroyed.
- In the autothermic mode, the operating costs of the process are significantly reduced.

Disadvantages

- In order to reduce the operating costs of the process it must operate as far as possible without auxiliary fuels. To ensure autothermic operation of the incinerator, the sludge must be dewatered to a volatile solids concentration of >60% that implies that dewatering is a prerequisite.
- It is envisaged that the process will require highly skilled operators.
- Disposal of the ash is still necessary and could represent additional costs.
- The capital and operating costs of this process are high.
- Sophisticated equipment is required to reduce air pollution.

Main operating and design criteria

- Multiple-hearth furnace:
  - Solids content of sludge feed: > 15% (auxiliary fuels required) or > 30% (no auxiliary fuels required)
  - Average loading rates: 25 to 75 kg/(m^2h)
  - Ash residue: ~ 25% to 35% of dry solids feed
- Fluidised bed incineration:
  - Operating temperature: 760°C to 820°C
  - Average loading rates: 30 to 60 kg/(m^2h)
  - Ash residue: ~ 20% to 30% of dry solids feed;

Typical reference installations

- Durban Kwa Mashu

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

3.7.3.2 Combustion with Solid Waste

Process:	**COMBUSTION WITH SOLID WASTE (CO-INCINERATION)**
Unit process / Treatment category:	**Thermal conversion**

Process description

Co-incineration is the process of incinerating wastewater sludge with municipal solid waste. Mixing the sludge with solid waste increases the concentration of volatile solids in the mixture and produces an incinerator feed with autothermic properties. Another objective of this process is to reduce the combined costs of incinerating sludge and solid wastes.

Applicability to South Africa

In the South African context, very little is presently being done to make use of the energy content of municipal solid waste or even to recycle components of this waste. There are a number of process routes for recovering usable fuels from municipal solid waste that are cheaper than incineration. For this reason it is doubtful that the incineration of municipal solid waste would be considered in the medium to long term. Consequently, the co-disposal of wastewater sludge and municipal solid waste by incineration is considered to be an uneconomical system for this country at present.

Metro:	Possibly suitable
City:	Possibly suitable
Large municipality:	Not recommended
Medium size municipality:	Not suitable
Small municipality:	Not suitable

Requirements

- Sludge dewatering
- Air scrubbing system

Advantages

- Process produces the heat energy necessary to evaporate water from the sludge and support the combustion of solid wastes and sludge.
- Process provides an excess of heat for steam generation without the use of auxiliary fuels.

Disadvantages

- Uniform mixing of sludge and solid waste is very important and often proves to be difficult.
- Poor temperature control
- Air pollution problems

Main operating and design criteria

- Criteria depending on the incinerator used and possibly on the composition of the sludge-solid waste mixture.

Typical reference installations

- None known in South Africa

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse*. 3rd edition, Singapore: McGraw-Hill Book Co.

3.7.3.3 Wet Air Oxidation

Process:	**WET AIR OXIDATION**
Unit process / Treatment category:	**Thermal conversion**

Process description

Wet air oxidation involves the treatment of sludge at an elevated temperature and pressure. In the proprietary Zimpro process, untreated sludge is macerated and mixed with a specified quantity of compressed air before being pumped through a series of heat exchangers. The mixture then enters a reactor that is operated at a temperature of 175°C to 315°C. The reactor is pressurised in order to keep the water in the liquid phase and pressures of up to 20 MPa are attainable. This process is essentially the same as the one discussed in Section 3.2 under "Heat Conditioning", with the exception that higher temperatures and pressures are applied to oxidise the volatile solids more completely.

Leaving the reactor after treatment are gases, liquid and ash. Before the liquid and ash are removed from the system via a pressure-reducing valve, they pass through the heat exchangers to heat up the incoming sludge. Gases released in the process are separated in a cyclone and then discharged to the atmosphere. Liquid and stabilised solids are separated in a lagoon or settling tank or on sand beds. The liquid is returned to the primary settling tank of the treatment works, while the solids are disposed of by landfilling or other means.

The wet air oxidation process has been further developed, as is evident when compared to earlier descriptions of the process. The success of the developments needs to be prove before this technology is recommended for use in South Africa.

Applicability to South Africa

Many wet air oxidation installations have been taken out of commission due to corrosion, high energy costs, excessive maintenance requirements and odour problems. Even though suppliers are now claiming to have overcome these problems, their claims still have to be verified in a full-scale application over an extended period of time. The process can therefore not be recommended for South African conditions at this stage.

Metro:	Possibly
City:	Possibly
Large municipality:	Not suitable
Medium size municipality:	Not suitable
Small municipality:	Not suitable

Requirements

- Sludge thickening / dewatering
- High pressure steam system
- Sludge liquor treatment

Advantages

- Process can be designed to be thermally self-sufficient when untreated sludge is used.

Disadvantages

- Process produces high strength recycle liquor that typically has a COD of 10 000 to 15 000 mg/ℓ and is difficult to accommodate in the treatment process of the works.
- Many wet air oxidation installations have been taken out of commission due to corrosion, high energy costs, excessive maintenance requirements and odour problems.

Main operating and design criteria

- Operating temperature: 175°C to 315°C
- Operating pressure: up to 20 Mpa

Typical reference installations

- Fishwater Flats WWTW (Port Elisabeth)
- Milnerton WWTW (Cape Town): Decommissioned

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

3.8 PRODUCT USES AND DISPOSAL OPTIONS

Final disposal of wastewater sludge involves the removal of the final product from the works and its application elsewhere, whereafter it is considered not to be a problem anymore. This can be done in various ways that include the further processing of stabilised and dewatered sludge in order to extract a useful product before the remainder is being disposed of. Examples are the application of the sludge in a beneficial manner, for instance in brick-making or agriculture, or the disposal of the sludge in a location where it serves a useful purpose, for instance in capping landfill sites or in reclaiming of open-cast mines. Some final disposal options and product uses are discussed below.

3.8.1 Embryonic Processes

3.8.1.1 Adsorbent Production

Adsorbent production aims at producing suitable material for removing hydrogen sulphide from odorous air (Pincince *et al.*, 1998). The process has been tested in a laboratory-scale application only, where dried wastewater sludge was pyrolysed in an oven to generate a product with an adsorptive capability. It was found, however, that the adsorption capacity for hydrogen sulphide was only 25% compared to that of commercially available activated carbon. It is therefore doubtful whether this process will be economically viable.

As the process has only been tested in a laboratory-scale application and no pilot or full-scale facilities are known of, this process cannot be recommended at this stage.

3.8.1.2 Ethanol Production

The cellulose contained in the sewage sludge can be converted to ethanol by hydrolysis and fermentation (Pincince *et al.*, 1998). It was found that of the 10% to 25% of cellulose present in sewage sludge, approximately 20% to 60% could be converted to ethanol. This process has apparently only been tested in a laboratory.

3.8.1.3 Protein Extraction for Animal Food

Prof. WA Pretorius from the University of Pretoria is investigating the production of proteins from wastewater. The process is still in the laboratory-scale stage, and the yield of proteins appears to be adequate to make the process feasible.

There are, however, still issues that need to be clarified in relation to heavy metals that apparently precipitate on the micro-organisms and hence pollute the proteins produced. Further research is thus needed in terms of the reduction of the concentration of heavy metals in the product (Pretorius, 2002).

3.8.2 Innovative Processes

3.8.2.1 Ash Recycling

Ash recycling aims at utilising the ash from sewage sludge incineration in a beneficial manner. Recycling options include using the ash as select fill or in cement manufacture, and producing artificial lightweight aggregate, slag or bricks.

The latter option is also known as thermal solidification and is apparently practised in some full-scale installations in Japan (Okuno and Yamada, 1999a). For the production of artificial lightweight aggregate, ash from sludge incineration is blended with water and small amounts of alcohol distillation waste. The mixture is pelletised and dried and then heated in a fluidised bed kiln to harden the pellets. The end product is a porous sphere that has a lower specific gravity and less compressive strength than traditional lightweight aggregates. Possible uses of the aggregate are as fill material, addition to planting soil, substitute for the anthracite media in a rapid sand filter or for paving walkways.

The main objective of the production of slag is to reduce the sludge volume and to immobilise the heavy metals contained in the sludge (Okuno and Yamada, 1999a). It is claimed that the initial volume of dewatered sludge cake can be reduced by 96% with the slag process. After incineration of the sludge, the ash is mixed with a small amount of lime (to assist the melting process) and then heated in a furnace to 1 500°C. At these temperatures the inorganic material melts and turns to slag when cooled down. If cooled rapidly with water, granulated slag will be obtained that can then be disposed of or used as landfill material. Due to the high temperatures in the furnace, most heavy metals will have escaped in the off-gas that thus will have to be scrubbed before it can be discharged to the atmosphere.

As the granulated slag is too brittle for further beneficial reuse, additional treatment in the form of "annealing" is required. If the slag is re-heated at 1 400°C for 30 minutes and then gradually cooled down, it will crystallise and a marble-like mineral will be obtained. It is claimed that this marble-like material has a high strength and acid resistance. Possible uses are as concrete aggregate, interlocking and water permeable tiles.

Ash from sludge incineration can furthermore be used to manufacture bricks by high-pressure moulding and heat treatment (Okuno and Yamada, 1999a). By gradually increasing the temperature in the furnace, the sludge ash is formed into bricks that reportedly are of superior quality to commercially available bricks. However, the brick process requires very good temperature control, long detention times in the furnace, specific ash characteristics and the handling of large amounts of off-gas.

At this stage, the energy costs alone for the lightweight aggregate, slag and brick process (including the sludge incineration) are still higher than the selling value of the end product and the processes are therefore not recommended for South African conditions at this stage.

Ash could also be mixed with lime sludges from water treatment facilities to generate an agricultural liming agent. The process offers the means to dispose of ashes from the incineration process and of water treatment sludge though it presupposes that the sewage sludge will first be incinerated that will often not be considered due to high-energy cost. *For this reason the process cannot be recommended at this stage.*

3.8.2.2 Melting Furnace Process

The objective of the melting furnace process is to produce from heat dried sludge an inert material with low metal leaching characteristic (Pincince *et al.*, 1998).

Various types of furnace can be used to produce inert materials with low leaching characteristics. Due to the high temperatures in the furnace, the organic material in the sludge is burnt off, while the remaining inorganic matter "melts" and forms into clinker or glassy material, in which the metals are trapped. However, some of the metals and organic material are still volatised and the off-gas of the process has to be scrubbed before it can be discharged into the atmosphere.

Some full-scale plants are in operation in Japan. A test plant was set up in New York but had to be decommissioned and dismantled in the mid-90s because of its unfavourable economics.

3.8.2.3 Brick Production

Building bricks can be produced from sludge by mixing the sludge with clay (WISA, 1993). The resulting slurry is formed into bricks and then fired in a kiln that will destroy all pathogens in the sludge. As the organic material in the slurry ignites, it contributes to the energy required in the brick-making process. An advantage of incorporating sludge in the production is that less water and energy are required, thus yielding savings in the manufacturing process. The bricks produced are not as strong as conventional bricks, but testing in America indicated that they nevertheless meet all ASTM standards for strength and other properties.

All the sludge from the Fishwater Flats Works in Port Elisabeth has gone into the manufacture of bricks since 1983. The following advantages have been experienced (WISA, 1993):

- The fuel consumption in the firing process of the bricks reduced by some 70%.
- A brick containing 30% sewage sludge weighs 21% lighter than a conventional brick. This reduces transport costs as more bricks can be carried per load.
- The kiln throughput has increased by almost 100% due to the fuel value of the sewage sludge.

- The water consumption has reduced, as the water contained in the sludge cake is usually sufficient for the extrusion process.
- The sludge can also be used as a fuel to provide heat for the brick drying chamber.

3.8.2.4 Cement-kiln Injection

Cement-kiln injection of dewatered sludge destroys the pathogens in the sludge and reportedly reduces the smog-producing nitrogen oxides that are formed in the cement-manufacturing process (Pincince *et al.*, 1998). The process consists in dewatered sludge being added to the pre-heating zone of a pre-calciner cement plant. Due to the high temperatures, the organic matter is destroyed with the sludge ash residue being incorporated into the cement product. It is claimed that this binding also effectively contains the heavy metals from the sludge in the cement matrix that makes them unavailable to the environment. Another advantage of the process is that the sludge does not need to be incinerated first as is the case if it is used in cement manufacture as a substitute for silica sand, for example (see Ash Recycling in Section 3.8.2.1).

Cement-kiln injection has been in use at a cement factory in Los Angeles since May 1996, but no further information was provided. It has also been demonstrated and implemented in Switzerland. The process is thought to be suitable for use in South Africa, but its success and economical application depend on the proximity of a cement factory with a kiln suitable for the purpose.

3.8.2.5 Light-weight Aggregate Production

Lightweight aggregates can be produced either from sewage sludge ash (see Ash Recycling in Section 3.8.2.1) or directly from dewatered sludge by mixing it with fly ash and bentonite (clay) (Pincince *et al.*, 1998). The mixture is then pelletised and dried and the resulting product could be used in lightweight structural concrete and masonry units. The size of the aggregates can be adjusted to suit the intended purpose. It is possible to recover some thermal energy from the process that can be used to dry the pellets.

A full-scale plant is apparently operating successfully in the United States.

3.8.2.6 OCI Waste Conversion

The OCI Waste Conversion system aims at converting sewage sludge into a fertiliser product (Pincince *et al.*, 1998).

Sludge is mixed with nutrients and reagents, the latter one with the purpose to turn the organic matter contained in the sludge into water-soluble compounds. The mixture is then dried in an indirect thermal dryer which comprises a number of contact plates that size the solid particles as they move along. The ultimate product consists of semi-spherical granules with a solids content of 90% to 95%.

The nutrients added to the process are selected depending on the requirements of the final product – during a demonstration in California in 1996 anhydrous ammonia and sulphuric acid were used to produce an ammonium sulphate fertiliser.

The OCI Waste Conversion process is similar to the ASP process (discussed later in this section) about which some doubt exists in terms of its viability. For this reason the OCI process cannot be recommended at this stage. Before the economic viability of a fertiliser-from-sludge project can be assured, the process will need to be supported by a major fertiliser manufacturer.

3.8.2.7 Oil-from-Sludge Conversion

Oil-from-sludge conversion comprises patented processes, such as the Enersludge™ and various pyrolysis processes, in which the organic content of the sludge is converted to oil with properties similar to fuel (Van Oorschot *et al.*, 1999; Steger and Meißner, 1999, Pincince *et al.*, 1998). The conversion is achieved by pyrolysis, a highly endothermic process, where the sludge is heated in an oxygen-free atmosphere. As most organic material is thermally unstable, it is split into gaseous, liquid and solids fractions through a combination of thermal cracking and condensation reactions.

The oil-from-sludge processes are usually operated at atmospheric pressure and temperatures between 350°C to 500°C to favour the production of solid and liquid products rather than gases. All sludge has to be dewatered and then dried to a solids content of about 95% before it can be used as feed for the pyrolysis (or oil-from-sludge conversion) process.

The liquid fraction (or pyrolysis oil) from the conversion process can be used as a substitute for standard low-sulphur heavy fuel oil. Except for the ignition point, the pyrolysis oil is within the specification of standardised low-sulphur heavy fuel oil. The solid fraction (or char) can be used to provide some of the energy needs of the process. It is claimed that by burning the char in a hot-gas generator that is similar to a fluidised bed incinerator, most if not all the energy for the sludge drying and reactor heating can be produced. Steger and Meißner (1999) reported that their process produces a net output of energy even at solids concentrations of the feed sludge of approximately 17%. Other utilisation options for the char are in the manufacture of bricks, as a reducing agent in the steel industry or as fuel for power plants.

Presently there are two plants in operation in Germany with capacities of 10 000 and 60 000 tons per year. A 30 tons/day Enersludge™ plant is currently being constructed and commissioned in Australia.

The oil-from-sludge processes constitute a high level of technology that inevitably would require highly trained operators and maintenance crews. It is also expected that most or all parts of the plant would have to be imported from overseas. The viability of these processes under South African conditions will therefore have to be carefully analysed.

3.8.2.8 Krepro Process

The Krepro process aims at recovering valuable products such as phosphate, precipitants (used for chemical phosphorus removal) and energy from wastewater sludge (Hansen *et al.*, 1999). The process was developed in Sweden and was run on a pilot scale (500 kg DS/h) at the Helsingborg WWTP for about four years. Apparently the plant is now being re-designed to a fully automated facility with higher capacity.

The process consists of six different treatment stages:

i. Thickening:
Digested or raw sludge is thickened in a centrifuge to about 5% DS.

ii. Acidification:
The thickened sludge is mixed with sulphuric acid to reach a pH below 2. Inorganic salts like heavy metals, precipitants and phosphate become almost completely dissolved while the organic matter remains in solid form.

iii. Hydrolysis:
The sludge is hydrolysed for about one hour at 140°C and 3,6 bar that dissolves the previously undissolved inorganic salts as well as 40% of the organic particles. After hydrolysis the sludge is cooled down and enters a flush tank where the pressure is released.

iv. Organic separation:
The pH is raised to ~3 by adding sodium hydroxide causing heavy metals to precipitate as metal sulphides. The solid matter is then separated in a centrifuge, producing an organic sludge with a DS content of 45% to 50% and an energy content comparable to wood chips. The sludge contains almost no phosphorus.

v. Precipitation of phosphorus:
The phosphorus contained in the reject water from the centrifuge (~90% of the original amount of phosphorus) is precipitated as ferric phosphate at a low pH by adding a ferric salt. By keeping the pH below 2,8, heavy metals and precipitation chemicals will remain in the liquid phase.

vi. Phosphorus separation:
The ferric phosphate is separated in a centrifuge with a DS of ~35%. The reject water contains dissolved COD and precipitants and is pumped back to the inlet of the wastewater treatment works to improve nitrogen and phosphate removal.

The following operational experiences were published:

- High temperature and low pH make the sludge a highly corrosive and erosive liquid. Transfer pumps had to be manufactured from a special steel or ceramic and Teflon-coated pipes had to be used. The hydrolysis reactors were glass-lined to prevent corrosion.

- Sludge (DS content >6%), as well as fibres and rags, caused the heat exchangers to clog.
- Thermal hydrolysis at a low pH caused odours. Covered equipment is therefore essential and a comprehensive odour control system is required to reduce the environmental impact.

The various products from the Krepro process can be utilised as follows:

- Organic sludge:
  The energy content of the sludge is claimed to be higher than the amount of energy required to run the Krepro process. The sludge, however, contains heavy metals and therefore can only be used in those energy plants that are equipped with cleaning devices for exhaust fumes. The sludge can be easily pelletised and dried, up to a DS content of 90%.
- Ferric phosphate:
  The phosphorus concentration in the ferric phosphate can reach values of up to 15% P/kg DS. The ferric phosphate can be used as a fertiliser in agriculture but the product requires further treatment before spreading due to its syrup-like consistency.
- Precipitant:
  The recycling of precipitant decreases the dosage of external precipitant for chemical P-removal.
- Carbon:
  The carbon improves the nitrogen removal (denitrification) at the wastewater treatment works.

The process still has to prove its viability and cannot be recommended for South African conditions at this stage due to the complex technology and high capital and operating costs. Even the developers recommend that this technology should only be used in the of case conventionally treated sludge not being permitted to be used on farmland.

3.8.2.9 Noell Conversion Process

A pilot plant using the Noell conversion process and treating 500 kg/h of sewage sludge was constructed at Freiberg (Germany). The process entails the gasification of dried sludge at temperatures of 1 400°C to 1 700°C, at which all hazardous organic substances, such as dioxins and furans, are destroyed (Jaeger and Mayer, 1999). The lack of oxygen in the gases, as well as the technology applied, prevents the formation of dioxins and furans in the gas cooling process. It is thus expected that the gases released to the atmosphere will comply with the strictest of the laws being enforced at present.

The process consists of the following steps:

- Dewatered sludge is dried and ground to a grain size < 500 µm
- Sludge dust is mixed with technically pure oxygen and burnt in the gasification reactor. Gasification takes place at a pressure of 2,6 MPa. Oxygen is fed to the process in sub-stoichiometrical quantities to ensure a reducing environment in the reactor that yields a raw gas rich in CO and H_2.
- The hot gases and the liquid slag flow to a quenching reactor where the gases are cooled to temperatures of about 200°C by water injection while the slag falls into a quenching bath. The temperature shock on the slag causes it to form a glass-like granulate that, after washing and dewatering, can be used as a high quality substance due to its chemical and mechanical stability.
- The water-saturated gases are scrubbed and the solids are removed. The water is recycled to the process.
- The gases are further treated in the desulphurisation process consisting of a fixed-bed hydrolysis reactor where any COS traces are converted to H_2S. Furthermore, any nitrogen present in the gases is converted to ammonia.
- The hydrogen sulphide is oxidised to form elementary sulphur that is then filtrated to yield a high quality product.
- Metals, heavy metals, cyanide and ammonia can be found in the quenching and scrubbing water, all of which need to be treated in a special treatment step. The precipitates are filtered out and the filter cake is disposed of at a hazardous landfill site.
- The gas produced at the plant is of high purity allowing its use in power plants, gas motors and gas turbines without restriction.

3.8.2.10 Active Sludge Pasteurisation (ASP)

The ASP process is a South African development that negates the need for sludge stabilisation whilst pasteurising and enriching the sludge with the nutrients N and P (Van Oorschot *et al.*, 1999; Nell *et al.*, 1990). Anhydrous ammonia is added to dewatered sludge which raises the temperature to about 60°C and the pH to approximately 11,5 to 12. Due to the high temperature, pH and ammonia toxicity, the sludge is pasteurised, i.e. the pathogens in the sludge are inactivated. The sludge mixture is then neutralised by adding phosphoric acid that causes the temperature to rise further to 70°C as the reaction taking place is of exothermic nature. The resultant product is a fertiliser that can be applied in agriculture depending on the nutrient requirements of the crops. Due to the high concentrations of nitrogen and phosphate the application rate is such that the heavy metals in the sludge are claimed to be considered as micronutrients for the crops.

As an alternative to the liquid fertiliser, it has been suggested to dry the sludge-nutrient mixture after the neutralisation step to obtain a granular or pelletised product with a moisture content of about 15%.

To date, however, the process has been used in demonstrations only, and no full-scale unit has been constructed.

3.8.2.11 Granular Fertiliser Manufacture

The manufacture of granular fertiliser from wastewater sludge is being investigated, particularly as the requirements for organic fertilisers in the agricultural sector are being realised.

The existing installations are all on a small scale and no real full-size installations have been constructed as yet. Extensive research is also required before this process can be implemented.

3.8.3 Established Processes

3.8.3.1 Alkaline stabilisation

Process:	**ALKALINE STABILISATION**
Unit process / Treatment category:	**Product Uses and Disposal Options / Stabilisation**

Process description

Alkaline stabilisation, or lime stabilisation, is a process in which lime (CaO) is added to wastewater sludge in order to produce a soil-like product that is pathogen free. The product can be applied on cultivated land as a replacement for lime that is required to neutralise the acidity of the fertilisers applied by the farmers.

Dewatered sludge with a solids content of 18% to 40% is mixed with the lime-containing substance (such as kiln dust and/or unslaked lime) in a pug mill or a screw blender. It is important that the lime substance contains sufficient CaO to produce the correct pH conditions. The resultant granular soil-like product is processed further by one of two methods:

- The stabilised dewatered sludge is air dried while the pH is maintained above pH 12,0 for a period of at least 12 days. The sludge is retained for at least 30 days to ensure that the solids content levels reach and maintain a minimum value of 65%. This method is suitable for climates where the air temperature is above 5°C.
- The stabilised dewatered sludge is heated at a pH greater than 12, using the exothermic reactions of the added lime, to a minimum temperature of 52°C. This temperature is then maintained for a minimum period of 12 hours throughout the sludge mass. Following the heat treatment the sludge is air dried (for instance by intermittent turning of windrows) until the solids content reaches a minimum of 50%. During this drying period the pH must be maintained above pH 12 for at least 3 days.

The resultant product is unlike either of its constituent materials. Instead, a well-aggregated material is produced as a result of the chemical reactions which occur during the stabilisation process. This results in a material with the following physical properties:

- excellent physical handling
- low odour and low odour potential
- stable under storage
- aesthetically acceptable appearance
- easy to apply to land

Applicability to South Africa

The alkaline stabilisation process is suitable for treating large volumes of sludge where an adequate supply of a cheap lime-containing chemical is available.

ESKOM TSI and Ash Resources (Pty) Ltd have developed a process called SLASH that uses fly ash in lieu of the lime. The process looks very promising but it can only be classified as innovative at this stage. Contact details for more information are given below:

ESKOM TSI	Kelly Reynolds
Private Bag 40175	(Tel) 011-629 5028
Cleveland	(Fax) 011 629 5528
2022	
or:	
Ash Resources (Pty) Ltd	(Tel) 011 8866200
P O Box 3017	
Randburg	
2125	

Metro:	Suitable
City:	Suitable
Large municipality:	Suitable
Medium size municipality:	Suitable
Small municipality:	Suitable

Requirements

- Lime-containing material
- Sludge dewatering

Advantages

- Apart from the advantages associated with the physical properties of the soil-like final product, the high pH achieved during the processing of the sludge precipitates the heavy metals present.
- The product is marketable in the agricultural sector for the following reasons:
  - It contains a significant quantity of lime and gives a long-term liming reaction that is similar to that achieved with agricultural limestone.

Disadvantages

- The maintenance of temperature (minimum 52°C) and pH (minimum 12) throughout the sludge mixture for the specified period is critical to the destruction of pathogens, particularly *Ascaris lumbricoides*.
- A market for the lime-stabilised sludge has to be guaranteed to ensure that the process is economically viable. Such a market does not yet exist in South Africa.
- The cost of the lime-containing material may be prohibitive.

- The initial high pH of the product is rapidly reduced in soil because the strong alkaline component of the lime is small and is quickly neutralised.
- The majority of the lime in the product exists as calcium carbonate, the same ingredient as in agricultural limestone.
- The soil-like properties of the product make it suitable for use in the land reclamation and forestry industry as well as for use as a daily landfill cover material and a final cover material for closing landfills.
- The process is simple to operate and does not require sophisticated control equipment.

- The nutrient content of the soil-like product is low (approximately 1% N, P and K) and the nutrient levels will thus have to be supplemented if used in agriculture.
- Dewatering of the sludge is a prerequisite for this process, which increases the overall costs.
- If raw primary sludge is treated, ammonia will be released to the atmosphere.

Main operating and design criteria

- pH: > 12
- Retention time: 30 days (not heated)
  3 days (T > 52°C)
- Dry solids content after stabilisation: 50% to 65%;
- Possible sources of lime-containing material:

  To make lime stabilisation more attractive from an environmental point of view it would be ideal to make use of a waste product from another industry as a source of raw material for the process. This would solve two waste disposal problems at once. Naturally, the suitability of various lime-containing by-products from industry depends upon their calcium oxide (CaO) content as well as their cost. The following have been identified as possible sources for calcium oxide:
  - Cement kiln dust, a fine-grained alkaline by-product of cement manufacture. It contains primarily CaO and smaller amounts of MgO and K_2O. The available CaO in cement kiln dust amounts to approximately 335 g/kg.
  - Slagment essentially a cement that has different curing properties to typical Portland cement: It contains approximately 5 g available CaO per kilogram slagment.
  - Commercial slaked and unslaked lime, mined in the Northern Cape: The available CaO content of slaked lime is approximately 690 g/kg, while the corresponding figure for unslaked lime amounts to approximately 840 g/kg.

Typical reference installations

- None in South Africa

Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse*. 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **ALKALINE STABILISATION***

Unit process / Treatment category: **Product Uses and Disposal Options / Conditioning**

	Unit	Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	750 000	1 350 000	2 250 000
Mechanical & electrical equipment	R	1 250 000	2 250 000	4 150 000
Total capital expenditure	**R**	**2 000 000**	**3 600 000**	**6 400 000**
Annual capital cost				
Civil works	R	116 025	208 844	348 074
Mechanical & electrical equipment	R	213 771	384 788	709 721
Total annual capital cost	**R**	**329 796**	**593 633**	**1 057 794**
Unit cost	**R/t DS**	**181**	**163**	**145**
COST OF MAINTENANCE				
Civil works	R	7 500	13 500	22 500
Mechanical & electrical equipment	R	62 500	112 500	207 500
Total annual cost of maintenance	**R**	**70 000**	**126 000**	**230 000**
Unit cost	**R/t DS**	**38**	**35**	**32**
COST OF OPERATION				
Personnel cost	R	140 000	140 000	170 000
Electricity cost	R	54 600	101 400	140 400
Cost of alkaline material	R			
Retailing income	R			
Total annual cost of operation	**R**	**194 600**	**241 400**	**310 400**
Unit cost	**R/t DS**	**107**	**66**	**43**
Total annual cost of O & M	**R**	**264 600**	**367 400**	**540 400**
Unit cost	**R/t DS**	**145**	**101**	**74**
TOTAL ANNUAL COST	**R**	**594 396**	**961 033**	**1 598 194**
UNIT COST	**R/t DS**	**326**	**263**	**219**

* – excludes pre-treatment costs for instance uses conditioned and dewatered sludge cake as input product at DS > 20%
– excludes retail of alkaline sludge cake and cost of alkaline material

3.8.3.2 Composting

Process:	**COMPOSTING**
Unit process / Treatment category:	**Product Uses and Disposal Options / Stabilisation**

Process description

Composting is an aerobic thermophilic biological process involving the decomposition of putrescible organic material into a relatively stable humus-like end product. When properly managed, the process decreases the weight, volume, and water content of the sludge and kills pathogenic organisms. Factors affecting the process include oxygen, nutrients, moisture, pH, and the presence of toxic chemicals.

The composting process consists 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 re-use (if practicable); (4) further curing and storage; and (5) final disposal. The composted product can be sold for use in agriculture and horticulture.

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.

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.

- Unaerated windrows composting

In this composting process, the material is placed in long windrows, 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 to the atmosphere.

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.

- <u>Aerated windrows composting</u>

The process is similar to that applied for unaerated 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.

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.

- <u>Aerated static pile composting</u>

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.

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.

- <u>In-vessel composting</u>

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 are 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 licence agreements are involved, often turns out not to be a viable option when compared to the aforementioned alternatives.

Applicability to South Africa

Metro:	Well suitable
City:	Well suitable
Large municipality:	Well suitable
Medium size municipality:	Suitable, but not on sophisticated scale
Small municipality:	Suitable, but not on sophisticated scale

Requirements

- Sludge dewatering
- Bulking agent
- Aeration (for certain composting processes)

Advantages

- The sludge is stabilised to such an extent that the product can be stored for long periods. Fluctuating demands for the product therefore do not cause problems.
- As a result of the stabilising effect, alternative processes such as anaerobic digestion may be omitted that can reduce the cost of stabilising primary sludge.
- 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

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. Care should thus be taken to select and employ operators who are not sensitive to the environment at the composting site. Regular health checks should be compulsory.

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.

Main operating and design criteria

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

- 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. An excessively high moisture content will reduce the porosity of the composting material and thus restrict air circulation. The optimum moisture content lies between 50% to 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 m^3/h to 50 m^3/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.

- 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.

Typical reference installations

- Olifantsvlei Regional Sludge Handling Facility (Johannesburg)
- Northern Works (Johannesburg)
- Paarl WWTW

Typical literature references

[1] Haug R.T. 1993. *The Practical Handbook of Compost Engineering.* Lewis Publishers: London

[2] La Trobe and Associates 1994. *Forced aeration composting of sewage sludge for rural communities.* Water Research Commission Report No. 341/1/94, Pretoria: Water Research Commission.

[3] Nell J.H. & Ross W.R. 1987. *Forced aeration composting of sewage sludge: Prototype study.* Water Research Commission Report No. 101/1/87, Pretoria: Water Research Commission.

[4] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse.* 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **COMPOSTING***

Unit process / Treatment category: **Product Uses and Disposal Options / Stabilisation**

	Unit	Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	2 250 000	4 250 000	8 500 000
Mechanical & electrical equipment	R	1 325 000	2 500 000	4 750 000
Total capital expenditure	**R**	**3 575 000**	**6 750 000**	**13 250 000**
Annual capital cost				
Civil works	R	348 074	657 472	1 314 945
Mechanical & electrical equipment	R	226 598	427 543	812 331
Total annual cost of capital	**R**	**574 671**	**1 085 015**	**2 127 276**
Unit cost	**R/t DS**	**315**	**297**	**291**
COST OF MAINTENANCE				
Civil works	R	22 500	42 500	85 000
Mechanical & electrical equipment	R	66 250	125 000	237 500
Total annual cost of maintenance	**R**	**88 750**	**167 500**	**322 500**
Unit cost	**R/t DS**	**49**	**46**	**44**
COST OF OPERATION				
Personnel cost	R	360 000	465 000	585 000
Electricity cost	R	23 400	54 600	109 200
Cost of Bulking agent	R	1 072 500	2 145 000	4 290 000
Retailing of compost	R			
Total annual cost of operation	**R**	**1 455 900**	**2 664 600**	**4 984 200**
Unit cost	**R/t DS**	**797**	**730**	**683**
Total annual cost of O & M	**R**	**1 544 650**	**2 832 100**	**5 306 700**
Unit cost	**R/t DS**	**846**	**776**	**727**
TOTAL ANNUAL COST	**R**	**2 119 321**	**3 917 115**	**7 433 976**
UNIT COST	**R/t DS**	**1 161**	**1 073**	**1 018**

*
- < 10 t DS/d = low tech approach
- excludes pre-treatment costs for instance takes conditioned and dewatered sludge cake as input product at DS > 20%
- excludes retailing of compost that is estimated at approximately R400 to R500 per ton DS
- Note: Large-scale operations become more complex and require a certain degree of automation that will impact negatively on the economy of scale.

3.8.3.3 Land Application

Process:	**LAND APPLICATION**
Unit process / Treatment category:	**Product Uses and Disposal Options**

Process description

The land application of wastewater sludge in agriculture is the oldest known form of sludge disposal. It is permissible in terms of the *Guidelines for the Disposal of Wastewater Sludge*, subject to certain conditions (Department of Agriculture *et al.*, 1997). Sludge can be applied as liquid, dewatered sludge or processed sludge, as discussed below.

(i) Disposal of liquid sludge

Disposal of liquid sludge is practised, for example, in the USA by transporting thickened sludge to the farmers with tankers. At the farms, the sludge is injected into the soil by means of specialised equipment. In South Africa, disposal of liquid sludge is apparently practised by ERWAT and Pietermaritzburg. ERWAT uses the sludge on their own land for fodder production.

(ii) Disposal of dewatered sludge

Dewatered sludge is disposed of by spreading on land with suitable manure spreaders. This option has been implemented by ERWAT on the East Rand in association with the Bapsfontein Farmers Association, and it has been in operation for approximately the past five years.

One of the most important factors to be taken into account is the seasonal demand for sludge used in agriculture. This requires the storage of sludge for long periods of up to 9 months. The storage of sludge creates the potential for soil and surface water pollution, and could create an odour problem.

The biggest advantage of utilising sludge in agriculture lies in the addition of organic material to the soil. However, farmers may be reluctant to utilise the sewage sludge since they are concerned about the reliability of the N-content in it. Furthermore, there is generally a tendency amongst consumers to oppose products that have been grown on sewage sludge. The farmers will thus have to be convinced of the agricultural and economic benefits of this solution, as this will determine the price they are willing to pay. A measure of success has been achieved in the Bapsfontein area, due to the fact that ERWAT deliver the sludge free of charge.

Although the land application of dewatered sludge appears attractive, it cannot be seen as a short-term solution. With the seasonal demand necessitating long storage periods, this option might also not be seen as a stand-alone solution. Independent research will be required to establish possible negative effects of this practice and an extensive marketing exercise will be needed to create a demand for the use of sludge and to overcome possible resistance on the side of the consumers.

(iii) Disposal of processed sludge

The disposal of processed sludge in agriculture dictates that the sludge is treated either by composting or by lime stabilisation.

As for the use of dewatered sludge, the farmers will have to be convinced of the economic and agricultural benefits of applying sludge to the lands. This will take some years as crops are only produced annually.

The advantage of this utilisation option is that the sludge can be stored indefinitely without creating odours or smells. The sludge is also disinfected that reduces the risk to the farmers and their labourers, and it facilitates easy handling of the product. As the sludge is dried in the composting process, its application is relatively simple. However, the initial processing of the sludge through processes such as composting, lime treatment and pelletising adds to the cost of this utilisation method.

Applicability to South Africa

i. Disposal of liquid sludge: This form of sludge disposal is not practised in South Africa and is not considered suitable in the local context.
ii. Disposal of dewatered sludge: Based on the experience of ERWAT this is an option for South Africa but it might take considerable time to establish.
iii. Disposal of processed sludge: Although it is considered a feasible method, the associated cost may be prohibitive unless some cost recovery can be achieved by selling the processed product for use in agriculture.

	Disposal of liquid sludge	Disposal of dewatered sludge	Disposal of processed sludge
Metro:	Depending on	Depending on	Suitable
City:	demand	demand	Suitable
Large municipality:			Suitable
Medium size municipality:			Suitable
Small municipality:			Suitable

Requirements

- Sludge dewatering (for disposal of dewatered sludge)
- Sludge stabilisation (for disposal of processed sludge)

Advantages	Disadvantages
• Adds organic material to the soil • Low cost if application areas are in close vicinity (for disposal of liquid and dewatered sludge)	• Seasonal demand; long storage periods • Demand and market have first to be created • Possible objections from consumers • Disposal of processed sludge not viable if product cannot be sold • If the farms are not in close vicinity to the works, high transport costs from works to farms, especially in the case of liquid sludge

Main operating and design criteria

- Refer to PUDSS 97 (Department of Agriculture *et al.*, 1997) for limitations on land application

Typical reference installations

- ERWAT

Typical literature references

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3.8.3.4 Landfilling (Co-disposal with domestic waste)

Process:	**LANDFILLING (CO-DISPOSAL)**
Unit process / Treatment category:	**Product Uses and Disposal Options**

Process description

Landfilling or co-disposal is the disposal of treated sludge on a landfill together with domestic waste. This method requires declassification of the sludge from a hazardous to a general waste, in order to allow its disposal on a landfill site not designed specifically for hazardous waste. Should the Department of Water Affairs and Forestry agree to such a declassification, then the waste disposal site used must have a leachate collection system to prevent the pollution of groundwater. Sludge disposed of in this manner must have a solids content of more than 40% as the DWAF regards sludge with less than 40% solids as leachate-forming and will not allow its disposal by landfilling.

If a landfill site with a leachate collection system is not available, a so-called piggy-back operation can be considered. This involves the capping of an existing landfill site and the subsequent creation of a new landfill site with the required lining and leachate collection system on top of it. A feasibility study and an environmental impact assessment will be required before co-disposal of sludge with domestic waste in a landfilling operation will be allowed.

Applicability to South Africa

The co-disposal of dewatered sludge with domestic waste at a landfill site is considered a viable option for ultimate disposal.

Metro:	Suitable, but not recommended
City:	Suitable, but not recommended
Large municipality:	Suitable, but not recommended
Medium size municipality:	Suitable
Small municipality:	Suitable

Requirements

- Sludge dewatering and partial drying (up to 40% DS)

Advantages

- Low cost (if landfill site is relatively close to the works)

Disadvantages

- Requires suitable landfill site in near vicinity to reduce transport cost
- Takes up landfill space

- Forms leachate

Main operating and design criteria

- Refer to PUDSS 97 (Department of Agriculture *et al.*, 1997) for limitations on land application.

Typical reference installations

- Cape Metropolitan Council
- Johannesburg Water Goudkoppies WWTW

Typical literature references

[1] Department of Agriculture, Department of Health, Department of Water Affairs and Forestry, Water Institute of Southern Africa, Water Research Commission. 1997. *Permissible Utilisation and Disposal of Sewage Sludge.* Water Research Commission Report No. TT 85/97, Edition 1. Pretoria: Water Research Commission.

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3.8.3.5 Land Reclamation

Process:	**LAND RECLAMATION**
Unit process / Treatment category:	**Product Uses and Disposal Options**

Process description

Processed sludge is mixed with soil or other organic waste products and co-composted, whereafter it can be used as a land reclamation fill material. The composting process required can be a low technology process, depending on the application of the fill material. Successful co-composting of waste paper pulp and wastewater sludge has been carried out in the past.

This kind of land reclamation can be carried out in the abandoned parts of open-cast or strip mines. The original land profile can be restored by filling the mined areas with the composted material. Nutrients in the organic material will be beneficial for plant growth in the reclaimed areas.

Use of such a material in the capping of landfill sites or restoration of areas damaged by erosion could also be considered.

Applicability to South Africa

The use of sludge in land reclamation is entirely feasible.

Metro:	Suitable
City:	Suitable
Large municipality:	Suitable
Medium size municipality:	Suitable
Small municipality:	Suitable

Requirements

- Sludge processing, i.e. stabilisation
- Other "waste" products have to be available to mix with the sludge

Advantages	Disadvantages
• Low cost (if site is relatively close to the works)	• Requires mines etc. to be in the vicinity to reduce transport cost

Main operating and design criteria

- Refer to PUDSS 97 (Department of Agriculture *et al.*, 1997) for limitations on land application.

Typical reference installations

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Typical literature references

[1] Metcalf & Eddy Inc. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse*. 3rd edition, Singapore: McGraw-Hill Book Co.

Process: **LAND RECLAMATION***

Unit process / Treatment category: **Product Uses and Disposal Options**

	Unit	Capacity [t DS/d]		
		5	10	20
CAPITAL COST				
Civil works	R	250 000	375 000	750 000
Mechanical & electrical equipment	R	750 000	1 350 000	2 550 000
Total capital expenditure	**R**	**1 000 000**	**1 725 000**	**3 300 000**
Annual capital cost				
Civil works	R	38 675	58 012	116 025
Mechanical & electrical equipment	R	128 263	230 873	436 093
Total annual capital cost	**R**	**166 938**	**288 885**	**552 118**
Unit cost	**R/t DS**	**91**	**79**	**76**
COST OF MAINTENANCE				
Civil works	R	2 500	3 750	7 500
Mechanical & electrical equipment	R	37 500	67 500	127 500
Total annual cost of maintenance	**R**	**40 000**	**71 250**	**135 000**
Unit cost	**R/t DS**	**22**	**20**	**18**
COST OF OPERATION				
Personnel cost	R	95 000	95 000	95 000
Electricity cost	R	14 040	17 160	23 400
Road transport (ave. 100km)	R	227 500	455 000	910 000
Total annual cost of operation	**R**	**336 540**	**567 160**	**1 028 400**
Unit cost	**R/t DS**	**184**	**155**	**141**
Total annual cost of O & M	**R**	**376 540**	**638 410**	**1 163 400**
Unit cost	**R/t DS**	**206**	**175**	**159**
TOTAL ANNUAL COST	**R**	**543 478**	**927 295**	**1 715 518**
UNIT COST	**R/t DS**	**298**	**254**	**235**

* – Excludes pre-treatment costs for instance takes conditioned and dewatered sludge cake as input product at DS > 20%.

3.8.3.6 Disposal to Sea

Process:	**DISPOSAL TO SEA**
Unit process / Treatment category:	**Product Uses and Disposal Options**

Process description

Due to the extended coastline of South Africa, the disposal of sewage to sea is practised by some of the coastal cities and towns. The process cannot strictly be classified as a process for the disposal of sludge, as the sewage is not treated, and hence no sludge is formed.

In the case of Durban, sewage and selected industrial wastewater is pre-treated by the removal of detritus and scum prior to being pumped some 4,2 km into the sea, into the Benguela current.

The process is monitored stringently and comprehensively to ensure the ecological integrity of the environment. The monitoring program includes microbiological, chemical and ecological measurements.

Applicability to South Africa

Metro:	Suitable
City:	Suitable
Large municipality:	Suitable
Medium size municipality:	Suitable
Small municipality:	Suitable

Requirements:

- Head of works
- Sea outfall with pump station

Advantages

- Cheap process

Disadvantages

- Risk to environment

Main operating and design criteria

- Strong sea currents are required

Typical reference installations

- Durban Central Wastewater Treatment Works
- Durban Southern Wastewater Treatment Works

Typical literature references

4 TYPICAL CASE STUDIES

Two typical case studies are presented to illustrate the use of the Sludge Management Decision Matrix and the Cost Sheets.

4.1 CASE STUDY 1: USE OF TYPE D SLUDGE IN AGRICULTURE

SLUDGE DATA

Sludge producer:	Plant A
Sludge quantity:	10 t DS/d
Sludge quality:	
– Inorganic:	Metal content < Type D
– Organic:	• No primary sludge • WAS from extended aeration plant

UTILISATION AND DISPOSAL

Utilisation / Disposal goal:	Use in agriculture
Typical options for above:	1) Composting 2) Alkaline stabilisation

TREATMENT STEPS REQUIRED

Composting:	Conditioning Thickening Dewatering Composting
Alkaline stabilisation:	Conditioning Thickening Dewatering Alkaline stabilisation

SELECTION OF TECHNOLOGIES

Composting:	Conditioning	• Chemical conditioning with dry polymers
	Thickening	• DAF • Linear screens
	Dewatering	• Belt filter press (assume sludge cake <18%) • Centrifuge (assume sludge cake <18%)
	Composting	• Aerated windrows or aerated static pile
Alkaline stabilisation:	Conditioning	• Chemical conditioning with dry polymers
	Thickening	• DAF • Linear screens
	Dewatering	• Belt filter press (assume sludge cake <18%) • Centrifuge (assume sludge cake <18%)

Alkaline stabilisation • Unslaked lime

COSTING OF TECHNOLOGIES

Total annual costs (in SA rands):

	Chemical condition.	DAF	Linear screens	Belt filter press	Centrifuge	Com-posting	Alkaline stabil.
Capital	98 112	359 443	471 166	980 445	703 713	1 085 015	593 633
Operating	473 104	52 160	85 592	93 704	200 480	2 664 600	241 400
Maintenance	25 620	83 600	106 400	225 000	179 850	167 500	126 000
Total	596 836	495 203	663 158	1 299 149	1 084 043	3 917 115	961 033

Note:
- Operating costs for chemical conditioning include the cost of chemicals at a dosing rate of 4kg/t DS and a cost of R 30 per kg of Polyelectrolyte.
- Operating costs for linear screen and Belt filter press exclude cost of chemicals.
- Operating costs for centrifuge exclude cost of chemicals (poly).
- Cost of lime is not included in the operating costs of alkaline stabilisation.
- Retailing cost for compost and lime stabilised sludge are not included.
- The dewatered sludge cake has been specified as DS < 18% since only WAS is dewatered.

COST COMPARISON OF DIFFERENT OPTIONS

Option 1A: Chemical conditioning -> Linear Screen -> Belt Press -> Composting

Option 1B: Chemical conditioning -> Linear Screen -> Belt Press -> Alkaline stabilisation

Option 1C: DAF -> Chemical conditioning -> Centrifuge -> Composting

Option 1D: DAF -> Chemical conditioning -> Centrifuge -> Alkaline stabilisation

Option 1E: DAF -> Chemical conditioning -> Belt Press -> Composting

Option 1F: DAF -> Chemical conditioning -> Belt Press -> Alkaline stabilisation

Total annual costs (in Rand):

	Option 1A	Option 1B	Option 1C	Option 1D	Option 1E	Option 1F
Capital	2 634 738	2 143 355	2 246 283	1 754 901	2 523 015	2 031 632
Operating	3 317 000	893 800	3 390 344	967 144	3 283 568	860 368
Maintenance	524 520	483 020	456 570	415 070	501 720	460 220
Total	6 476 258	3 520 175	6 093 197	3 137 115	6 308 303	3 352 220

CONCLUSIONS

- All options using composting cost around R7 million per annum while all options using alkaline stabilisation are roughly R3 million cheaper. However, the cost of lime has not been taken into account for alkaline stabilisation. Furthermore, some of the costs for all options will be offset by the retail value of the final product (i.e. compost or lime-stabilised sludge).
- All options with composting have high operating costs due to the cost of bulking agent.

4.2 CASE STUDY 2: DISPOSAL OF TYPE B SLUDGE OFF THE SITE OF THE WORKS

SLUDGE DATA

Sludge producer: Plant B

Sludge quantity: 30 t DS/d => 10 t DS/d primary; 20 t DS/d WAS

Sludge quality:

- Inorganic: Metal content > Type D
- Organic:
  - Primary sludge, anaerobically digested
  - WAS, not digested

UTILISATION AND DISPOSAL

Utilisation / Disposal goal: Disposal off the site of the Works

Typical options for above: 1) Landfill (Co-disposal)
2) Land reclamation

TREATMENT STEPS REQUIRED

Landfill: Stabilisation of WAS
Conditioning
Thickening
Dewatering

Land reclamation: Stabilisation of WAS
Conditioning
Thickening
Dewatering

SELECTION OF TECHNOLOGIES

Landfill:	Stabilisation of WAS	• Aerobic digestion • Anaerobic digestion
	Conditioning	• Chemical conditioning with dry polymers
	Thickening	• Linear screens
	Dewatering	• Belt filter press (assume sludge cake >18%) • Centrifuge (assume sludge cake <18%)
Land reclamation:	Stabilisation of WAS	• Aerobic digestion • Anaerobic digestion
	Conditioning	• Chemical conditioning with dry polymers
	Thickening	• Linear screens
	Dewatering	• Belt filter press (assume sludge cake >18%) • Centrifuge (assume sludge cake <18%)

COSTING OF TECHNOLOGIES

Total annual costs (in SA rands):

	Aerobic digestion	Anaerobic digestion	Chemical condition.	Linear screens	Belt filter press	Centri-fuge	Landfill cost	Land reclam.
Capacity [tDS/d]	20	20	30	30	30	30	30	30
Capital	749 971	2 498 481	202 426	1 078 569	3 097 756	2 063 124	n/d	828 177
Operating	233 480	99 320	1 677 632	140 556	411 720	435 120	n/d	1 542 600
Maintenance	101 250	403 550	55 920	245 850	723 375	516 000	n/d	202 500
Total	1 084 701	3 001 351	1 935 978	1 464 975	4 232 851	3 014 244		2 573 277

Note:
- Cost for landfill have not been determined (n/d).
- Where required, cost estimates are extrapolated from unit costs for 20 t DS/d capacity.
- Cost estimate for aerobic and anaerobic digestion is based on unthickened feed.
- Operating costs for chemical conditioning exclude cost of chemicals.
- Operating costs for linear screen exclude cost of chemicals (poly), as these costs have been included in the chemical conditioning of the sludge to be treated.
- Operating costs for centrifuge exclude cost of chemicals (poly), as these costs have been included in the chemical conditioning of the sludge to be treated.
- Centrifuge will not reach same DS content as belt press.

COST COMPARISON OF DIFFERENT OPTIONS

Option 2A: Aerobic digestion -> Chemical conditioning -> Linear Screen -> Belt Press -> Landfill

Option 2B: Anaerobic digestion -> Chemical conditioning -> Linear Screen -> Belt Press -> Landfill

Option 2C: Aerobic digestion -> Chemical conditioning -> Centrifuge -> Landfill

Option 2D: Anaerobic digestion -> Chemical conditioning -> Centrifuge -> Landfill

Option 2E: Aerobic digestion -> Chemical conditioning -> Linear Screen -> Belt Press -> Land reclamation

Option 2F: Anaerobic digestion -> Chemical conditioning -> Linear Screen -> Belt Press -> Land reclamation

Option 2G: Aerobic digestion -> Chemical conditioning -> Centrifuge -> Land reclamation

Option 2H: Anaerobic digestion -> Chemical conditioning -> Centrifuge -> Land reclamation

Total annual costs (in SA rands):

	Option 2A	Option 2B	Option 2C	Option 2D	Option 2E	Option 2F	Option 2G	Option 2H
Capital	5 128 723	6 877 233	3 015 521	4 764 031	5 956 900	7 705 410	3 843 698	5 592 208
Operating	2 463 388	2 329 228	2 346 232	2 212 072	4 005 988	3 871 828	3 888 832	3 754 672
Maintenance	1 126 395	1 428 695	673 170	975 470	1 328 895	1 631 195	875 670	1 177 970
Total	8 718 506	10 635 156	6 034 923	7 951 573	11 291 783	13 208 433	8 608 200	10 524 850

CONCLUSIONS

- As no cost for landfill per se could be determined, the various options that include landfilling are about R2,5 million cheaper than the respective options that include land reclamation.
- All options using anaerobic digestion are almost R2 million more expensive than the respective options using aerobic digestion.
- The dewatering option of the linear screen plus belt press process is about R2,5 million more expensive than the centrifuge process. However, the dry solids content that can be achieved with the former is higher, thus reducing the total volume of the dewatered sludge that will then bring down transport costs. The trade-off between dry solids content and transport costs has to be determined in more detail by the project team before a final decision is taken.

5 RECOMMENDATIONS

During the study it became apparent that certain information that is required for conducting a comprehensive assessment of sludge management options, was either lacking or not readily available. The following research needs have therefore been identified: -

vii. A national survey of wastewater treatment plants, their treatment processes, sludge quantities and qualities as well as current sludge utilisation/disposal routes and related costs

viii. The development of benchmark criteria to enable a performance comparison of different wastewater treatment plants and their sludge management: The most difficult part will be to define the parameters that take local conditions into account.

ix. The monitoring of existing sludge reuse facilities and practices for establishing the real effects and costs of the specific process involved.

x. The regular updating of research (this study in particular), due to the dynamic nature of the aspect of sludge handling in the field of wastewater treatment. This is of particular importance to ensure that the correct economic figures are presented, and that developments in the field are reflected in and incorporated into the updated documentation.

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APPENDIX A: SLUDGE UTILIZATION OR DISPOSAL DECISION FLOW DIAGRAM (SDUDFD)

FIGURE 1 **ROUTE A : INITIAL DECISION DIAGRAM**

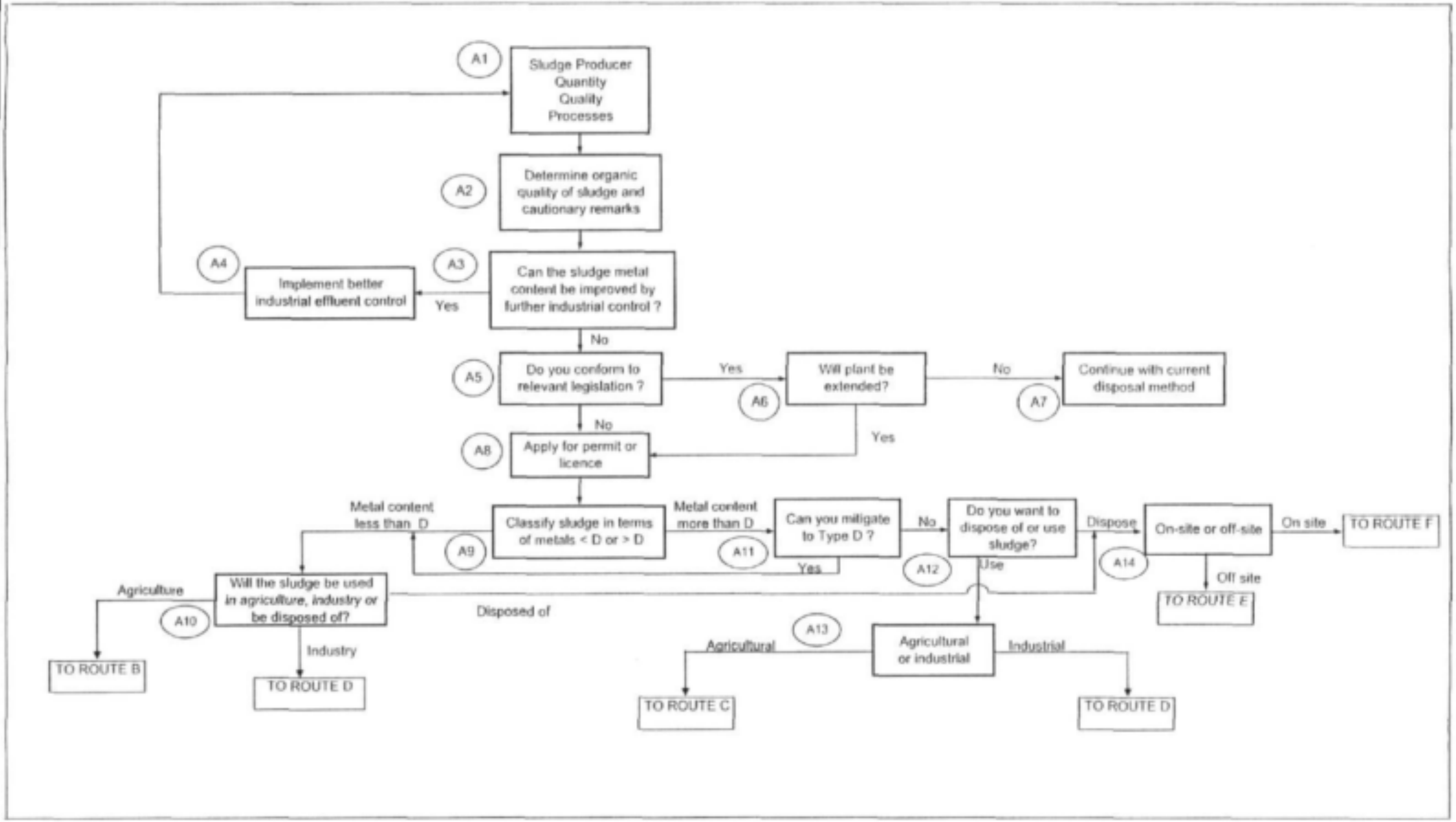


FIGURE 2 **ROUTE B : USE OF A TYPE D SLUDGE IN AGRICULTURE**

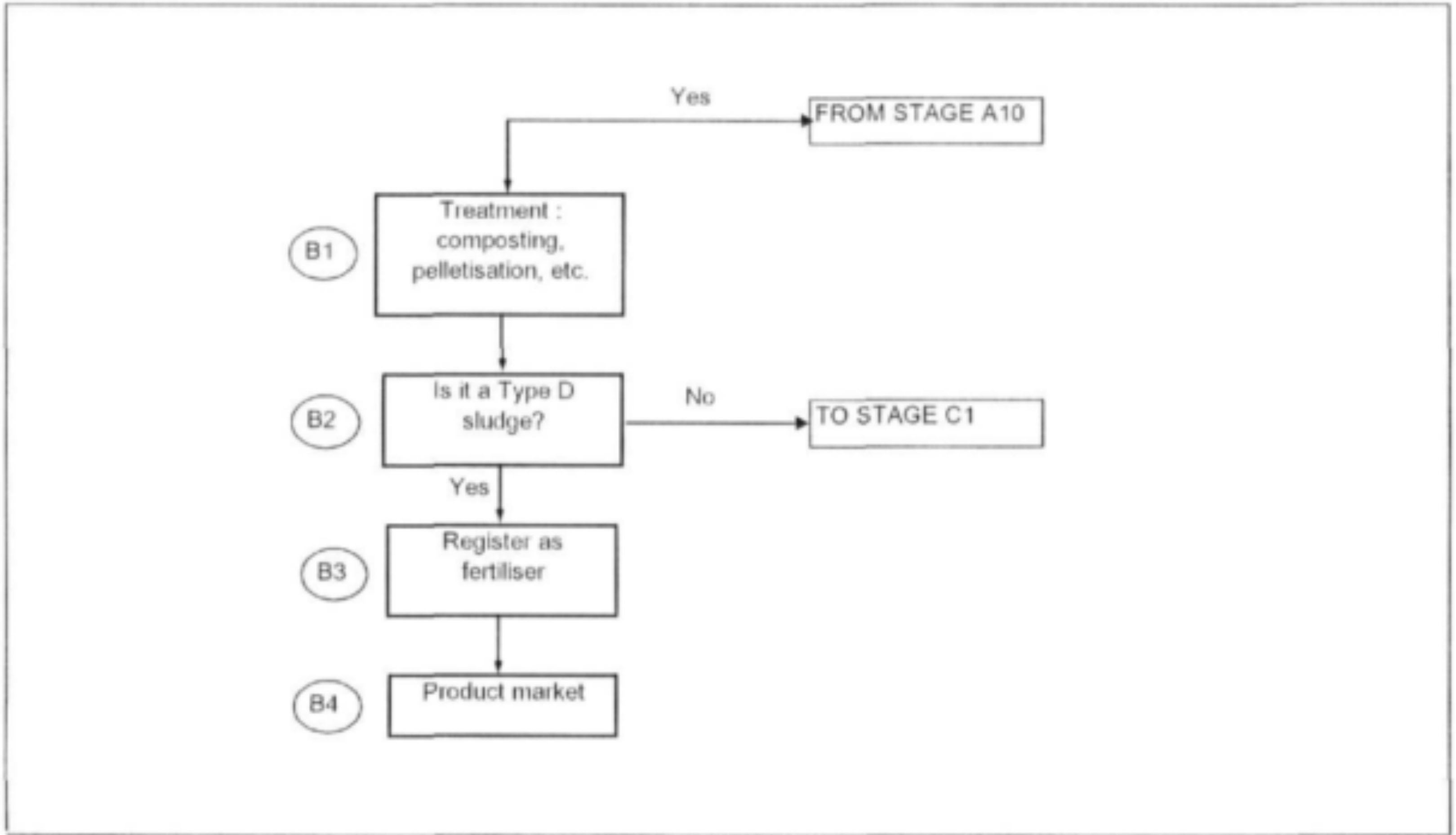


FIGURE 3 **ROUTE C : USE OF A TYPE A, B OR C SLUDGE IN AGRICULTURE**

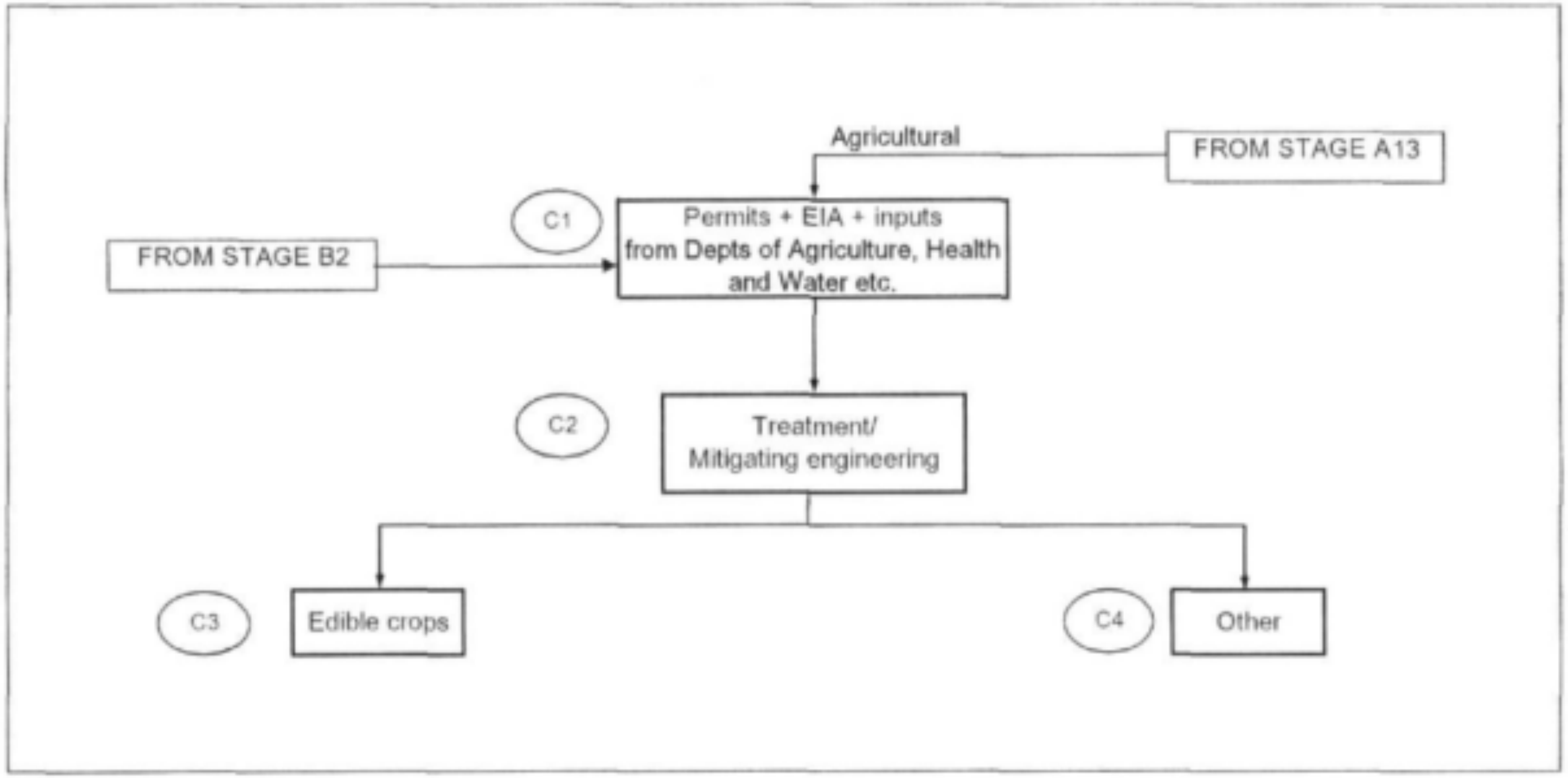


Figure 4

ROUTE D : USE OF TYPE A, B, C OR D SLUDGE IN INDUSTRY

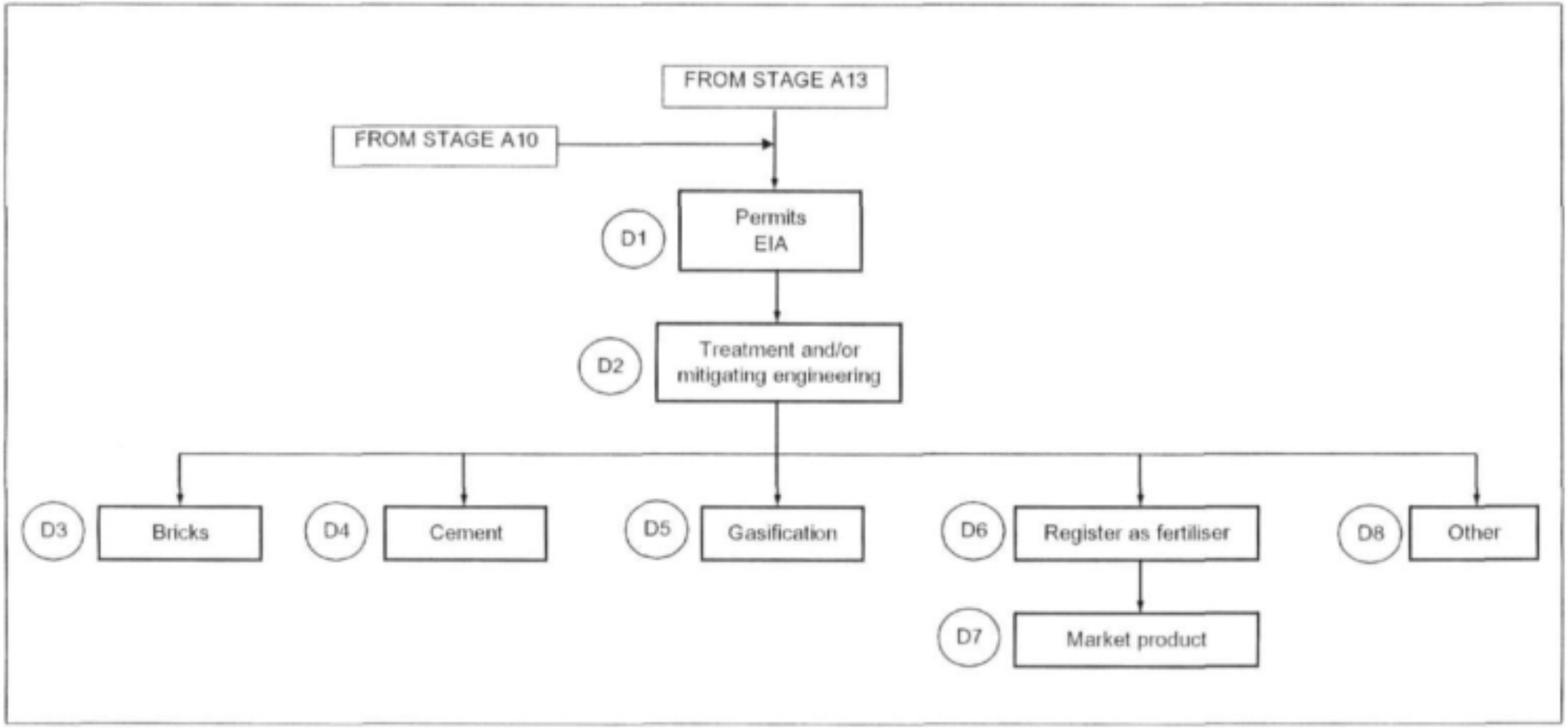


Figure 5 **ROUTE E : DISPOSAL OF TYPE A, B OR C SLUDGE OFF THE SITE OF WORKS**

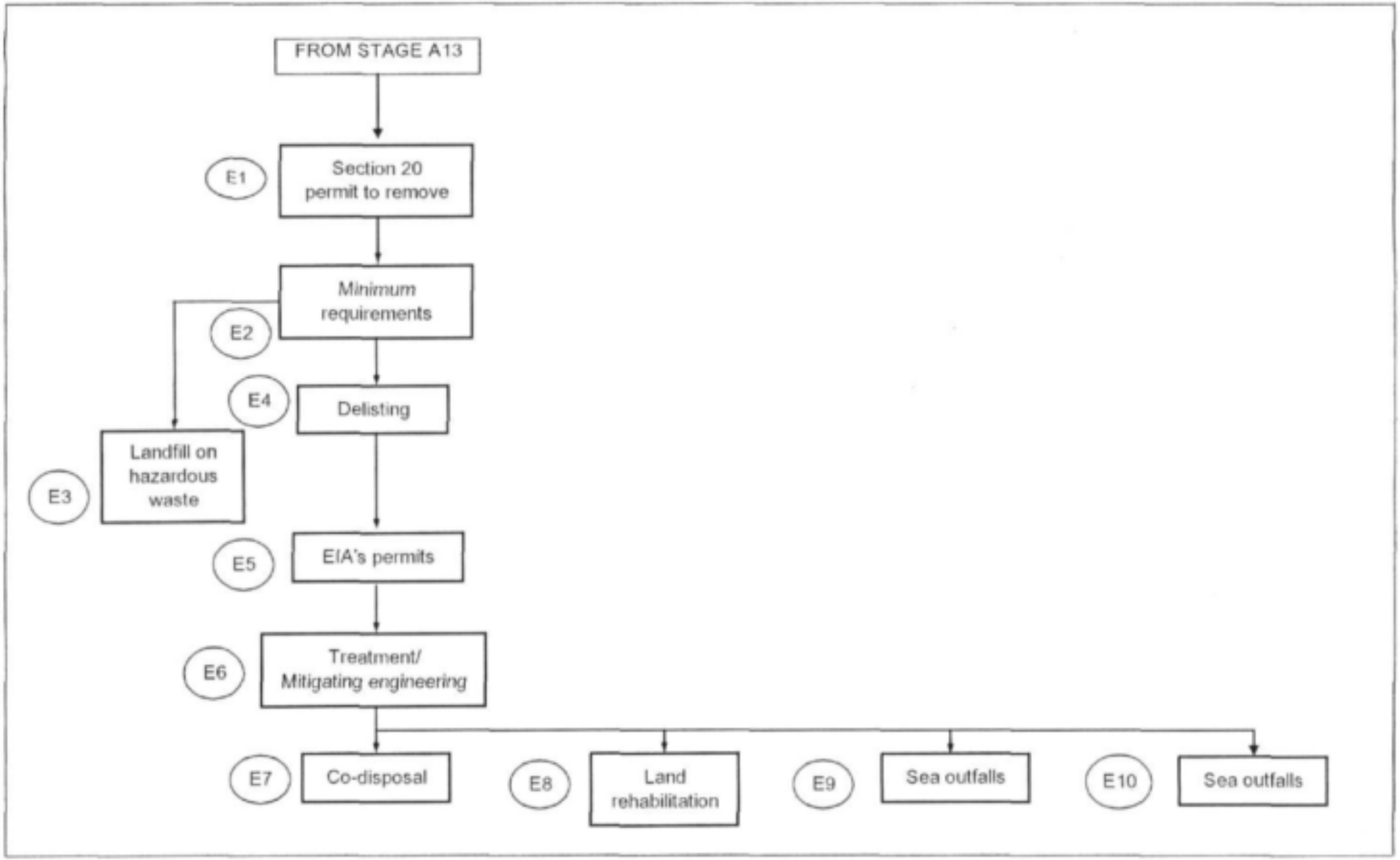
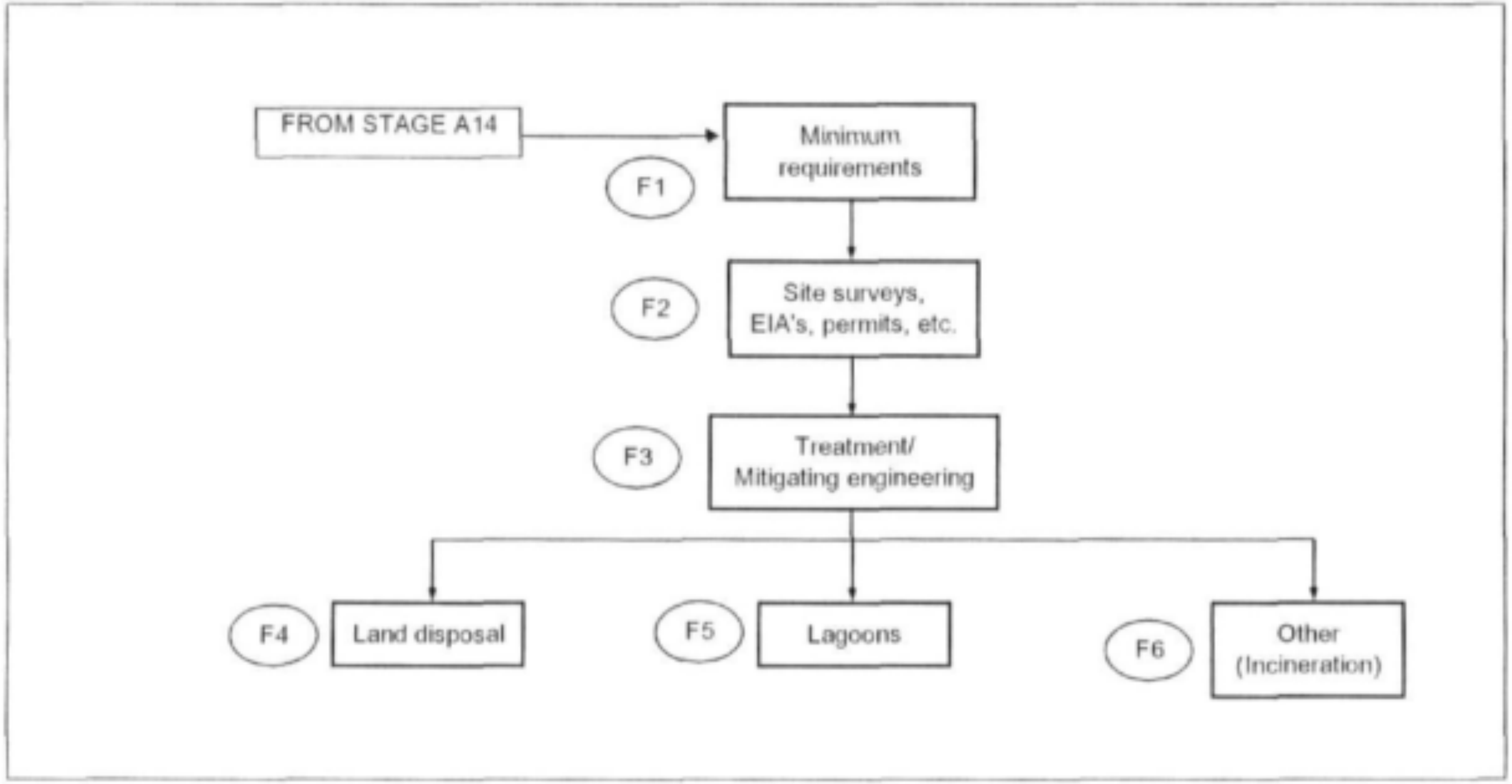


FIGURE 6 **ROUTE F : DISPOSAL OF TYPE A, B OR C SLUDGE ON THE SITE OF WORKS**



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