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THE CO-DISPOSAL OF WASTE-WATER SLUDGE WITH REFUSE IN SANITARY LANDFILLS

REPORT TO THE
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FOREWORD

From time immemorial the disposal of man's waste products has been an indicator of the standard of civilisation he has attained. The more sophisticated and developed a country is, the more advanced is it's methods of waste disposal.

Alongside advances in development and sophistication of mankind, has been the growth in population and the resultant metropolitan conurbations. This has resulted in a concomitant increase in waste, in both of its forms, namely waste-water and solid waste. In order to prevent the spread of disease and allied health problems it has become necessary to research every possibility for more efficient and safe ways of disposing of waste-water sludge as well as refuse.

Waste managers in South Africa have in the past considered landfill as a hole in the ground where waste is buried and forgotten (tomb concept). However, more recently the importance of proper landfill management including leachate and biogas management is becoming more of a reality (bioreactor concept). The importance of controlled landfill management, incorporating sludge co-disposal, in which leachate is contained, recycled and treated, thereby, accelerating the stabilisation process must not be underestimated.

It is, therefore, encouraging to find through this research project that by the co-disposal of waste-water sludge with refuse in a sanitary landfill, both waste streams can be beneficially disposed, and that their decompositions can satisfactorily take place, in certain circumstances, and within defined limits.

The objectives of this research project have been to show that by combining waste-water sludge with refuse in a practical "hands on" manner, effective landfilling treatment takes place without negatively influencing the environment.

P E Odendaal
Executive Director, Water Research Commission

EXECUTIVE SUMMARY

INTRODUCTION

Waste-water and refuse represent the major sources of polluted wastes generated in urban areas. These wastes have undesirable characteristics necessitating further processing and transformation into end-products to render them environmentally acceptable. South Africa currently produces about 40 million tons of domestic refuse per annum and about 12 million tons per annum of waste-water sludge from biological treatment processes. Roughly 95 percent of domestic refuse generated in South Africa is still disposed of on land, in landfills.

Sanitary landfilling, whereby the waste is compacted and covered each day with a soil layer, offers the most versatile method for the disposal of solid wastes in an economical and environmentally sound manner. Co-disposal (or joint disposal) in its widest sense, is understood to be the calculated and monitored interaction of waste-water sludge (or selected difficult industrial and commercial wastes) with municipal refuse in a properly controlled landfill site.

The co-disposal of waste-water sludge and refuse in sanitary landfills is not a new concept and is being practised in many parts of the world, especially in drier areas which have a perennial water deficit. Over the last two decades, much progress has been made towards ensuring that the co-disposal practice is carried out in an environmentally sound way. However, different approaches to co-disposal have led to quite different experiences and attitudes, with the result that different perceptions of the values and dangers of the co-disposal practice have developed.

In comparison, the co-disposal of waste-water sludge with refuse in sanitary landfills in South Africa has not been widely implemented to date, due to various reasons. One such reason is that waste-water sludge has always been accepted as a good soil conditioner and has been widely used by farmers as a fertiliser. However, the continued land application of waste-water sludge could decrease if the Department of Health's Draft Guide (1991) relating to sludge disposal is implemented in South Africa. An acceptable alternative to land application as disposal method will then have to be found for those waste-water sludges that contain pollutants (such as heavy metals) which could cause food chain contamination. The controlled co-disposal of waste-water sludge with refuse in a landfill is such a disposal option.

As a result of the foregoing, a three-year research project was negotiated between the Cape Town City Council and the Water Research Commission with the objective of developing practical operational criteria for the landfill co-disposal of domestic refuse and anaerobically digested waste-water sludge liquor.

MATERIALS AND METHODS

The research was carried out at the Coastal Park landfill site which is adjacent to the Cape Flats waste-water treatment plant. This area experiences a Mediterranean climate (hot dry summers and cool wet winters) with the average evaporation exceeding the rainfall by some 600 mm per year. This type of climate necessitated the co-disposal process to be optimised for both winter and summer periods.

Construction of Experimental Landfill Lines

Two refuse lines were utilised; one in which the sludge liquor was co-disposed with refuse and one with no sludge addition (which acted as a control). Both lines received the same amount of refuse (some 30 tons per day) and were treated in the same manner during each run. The two lines were each 2,5 m high and 6 m wide and were separated by a rubble berm.

Landfilling proceeded in a top to bottom method with the refuse collection vehicles discharging their loads on the top of the working face of the experimental lines. The landfill compactor (CAT 9592 kg) then spread the refuse down the 4:1 slope of the face in layers some 300 to 400 mm thick. Once this was completed, the waste-water sludge liquor containing some 2,2% total solids (m/v) was applied to the refuse in predetermined volume ratios by means of two 50 mm flexible hand-held hosepipes attached to a sludge tanker. As soon as the predetermined volumes of refuse and sludge had been applied, the refuse/sludge mixture was compacted using the steel wheeled landfill compactor. The compacting procedure was standardised and each section of the line received four passes (down and up represent one pass) with the compactor wheels. The identical procedure was carried out on the control line containing refuse only. Both lines were covered with a 100 to 150 mm sand layer after each daily run.

Optimisation of the refuse/sludge co-disposal ratios as well as operation at the optimum ratios was carried out for each seasonal period over some 18 months and involved 50 experimental runs.

Landfill Monitoring Programme

Because of the heterogeneous nature of the unsorted and unmilled domestic refuse used in the experiments there were certain constraints in the collection and interpretation of the data from the landfilling procedures. The following tests were carried out on the co-disposal and control lines in order to compare and evaluate the two operations:

- Operational parameters - the workability of the refuse and sludge mixtures by means of the landfill compactor and the manoeuvrability of the machine in the mixtures were selected as important practical operational criteria;
- Moisture content of the landfilled waste;
- Density and compaction of the landfilled waste;
- Landfill biogas constituents;
- Leachate generation and selected quality parameters;
- Meteorological considerations.

Associated Studies

Various peripheral studies were also carried out during the contract period (or which formed part of other research projects) which provided supplemental information of a co-disposal operation and which broadened the scope of the project:

- Box Tests to establish interrelationships between moisture content, field capacity, bulk density, compaction and leachate generation;
- Water balance calculations for the Coastal Park landfill;
- Lysimeter studies on sludge co-disposal.

EXPERIMENTAL RESULTS

Optimum Refuse to Sludge co-disposal ratios for Successful Workability of the Landfill Compactor

Landfill compactors are generally required to work for extended periods, and excessive downtime should be avoided as a result of cleaning of the machine or for other damage as a result of the sludge co-disposal operation. The experimental runs established that excessive addition of sludge liquor caused the belly plate of the landfill compactor to sink too deep into the refuse/sludge mixture, thus retarding the manoeuvrability of the machine.

The following terminology was developed to describe the workability of the landfill compactor machine:

- **Critical Working Ratio** - was that ratio of refuse to sludge at which the landfill compactor machine was just able to work successfully in the mixture;
- **Safe Working Ratio** - was that ratio of refuse to sludge at which the landfill compactor machine was able to work successfully for extended periods without getting damaged or stuck. The Safe Working Ratio was developed to ensure that the landfill compactor would not labour unnecessarily during full-scale operation. A practical safety margin of 33 percent was added to the Critical Working Ratio to achieve this.

Table 1 summarises the results of the experimental runs on workability of the landfill compactor machine in relation to the co-disposal ratios (by volume and mass) of the refuse to sludge liquor for the winter (wet) and summer (dry) periods in the Western Cape.

The Safe Working Ratio of refuse to sludge liquor (by volume) for the winter and summer seasons was determined to be 6 : 1 and 4 : 1 respectively.

TABLE 1: RESULTS OF THE CO-DISPOSAL EXPERIMENTAL RUNS FOR WINTER AND SUMMER PERIODS

SEASON	CRITICAL WORKING RATIO		SAFE WORKING RATIO	
	By Volume	By Mass	By volume	By Mass
WINTER	4,5 : 1	1,5 : 1	6 : 1	2 : 1
SUMMER	3 : 1	1 : 1	4 : 1	1,3 : 1

NOTE: All ratios are "refuse-to-sludge liquor"
Average density of refuse : 335 kg/m^3
Average solids concentration of sludge: 2,2% (m/v)

Compaction and Bulk Density of Landfilled Waste

Ten *in situ* bulk density determinations were carried out to compare the degree of compaction of the landfilled refuse in the co-disposal and control experimental lines. The median density in the co-disposal line (1368 kg/m^3) was determined to be only some 5,6% higher than that of the control line (1295 kg/m^3). An explanation for the small difference between the *in situ* densities of the co-disposal and control lines was possibly the fact that their moisture content were very similar (some 30%).

The influence of sludge co-disposal on the compaction of refuse was studied in more detail in the Box Tests. A major benefit accruing from the wetting of the incoming refuse by addition of sludge liquor was the change in physical transition from a highly bulky solid waste to that of a semi-solid state. The wetted refuse became less rigid and softer which enabled it to be better compacted. The Box Tests indicated that the compaction effect was greatly influenced by the placement moisture content of the waste. Increase of the moisture content in the range 35 to 55% (achieved by a refuse/sludge volume ratio of 6 : 1) resulted in a 25% improvement in the compaction.

Moisture Content of Landfilled Waste

Ten moisture determinations (at a depth of 1 m) was determined in order to compare the moisture content of the landfilled refuse in the co-disposal and control lines. Analyses indicated that the moisture content of the refuse/sludge mixtures within the co-disposal line (in the range 22 to 46%) were significantly less than the theoretically calculated value (in the range 37 to 62%). It was evident that less moisture was being held in the refuse than was expected. The lower moisture content was probably due to a combination of factors such as evaporation, leachate migration and methodology of the moisture determinations.

Three depth profile sampling runs were also carried out at various places in both experimental lines in order to ascertain the variation in the moisture content of samples taken at 0,5 m intervals down from the surface. The results indicated no significant differences in the moisture content at depths down to 2,5 m.

Leachate Generation

A leachate collection system (7 m x 7 m HDPE liner) was installed during week 20 in a section of each of the co-disposal and control lines. The volumes of leachate from the experimental lines were monitored over two winter periods and two summer periods. The results indicated that leachate production only followed the rainfall pattern during the first winter rainfall period (1992) and far less leachate was produced during the second winter period (1993). In comparison, no significant volumes of leachate were collected from the control line during the same monitoring periods.

An explanation for these results could be the high annual evaporation rate at Coastal Park which exceeds that for rainfall by some 600 mm. The results indicated that the Coastal Park landfill has a capacity to hold increased amounts of moisture during most of the year. However, in order to minimise the production of excess leachate it is suggested that co-disposal be practised in the Western Cape only during the months when evaporation exceeds rainfall. If all-year co-disposal is to be practised then leachate collection as well as recycling and treatment should be considered.

Landfill Gas Constituents

It is widely accepted that co-disposal of an anaerobically digested waste-water sludge with domestic refuse could speed up the onset of the methanogenic phase in a landfill and thus hasten the stabilisation of the waste.

Three gas extraction wells were inserted into each of the experimental lines in order to monitor the concentration (not gas volumes) of the landfill gas components (such as CH_4, CO_2, N_2 and O_2). The analyses indicated that the formation of methane gas was initially delayed in the co-disposal line. This phenomenon could be due to increased concentration of volatile acids in the co-disposal line as a result of accelerated acido/acetogenesis.

Pressure and temperature measurements were subsequently carried out on the gas extraction wells in order to quantify the production of biogas from the two experimental lines. The results indicated insignificant differences between the co-disposal and control lines. The low temperatures and low pressures recorded, indicated a landfill of low microbial activity.

Water Balance Calculation for Coastal Park Landfill

According to the Minimum Requirements for waste disposal by landfill (DWAF, 1994a), a water balance calculation is required to establish whether the site falls into the leachate producing (B^+), hence leachate management category. A water balance was calculated for the Coastal Park landfill site to indicate the role that co-disposal of refuse and waste-water sludge liquor could play in the overall management of these two waste streams.

The water balance calculation indicated that liquid in the form of waste-water sludge moisture, equivalent to 1244 mm per annum, could be added to the refuse landfilled at Coastal Park. The added water would, theoretically, increase the moisture content of the incoming refuse from 30%, to its field capacity moisture content of about 60%, without increasing the potential to generate leachate.

On the basis of the simplistic water balance carried out in this study, a measure of co-disposal with waste-water sludge would be permissible especially during the drier months of the year (October to May). Calculations showed that the following degree of co-disposal of waste-water sludge from the Cape Flats waste-water treatment plant would be permissible:

a) Addition of 16,6% of the total volume of digested sludge liquor (at 2,3% total solids).

or

b) Addition of the total volume of a mechanically dewatered digested sludge cake (at 12,4% total solids).

Box Tests

Box Tests were developed to establish interrelationships between landfill parameters such as moisture content, field capacity, bulk density, degree of compaction and leachate generation. The experimental procedures entailed weighing known mixtures of domestic refuse and anaerobically digested sludge liquor in a 0,5 m^3 standard box (1 m x 1 m x 0,5 m high). The various refuse to sludge volume ratios were initially well mixed and then compacted in the box in a standard manner. The bottom of the box was perforated to allow leachate to drain out and be collected in a tray for measurement.

The results obtained in the Box Tests illustrated the importance of maintaining the correct moisture concentration of the refuse being landfilled i.e. to satisfy the physical requirements for compaction and the biological requirements for accelerated stabilisation. It seems fortuitous that both these physical and biological requirements are largely satisfied at a moisture concentration of some 55%. The moisture content at the field capacity was also determined in the Box Tests to be some 55% of the mass of the refuse. This moisture concentration of the wetted refuse should, theoretically, not result in production of excessive amounts of leachate from the landfill.

Lysimeter Studies on Co-disposal

Column lysimeters containing approximately 500 kg of a standard refuse matrix at a density of some 700 kg/m^3 as well as 200ℓ of digested sludge liquor (5% total solids) were used to ascertain the effect of sludge addition on leachate production, the refuse stabilisation process as well as phosphate and nitrogen (TKN) release in the leachate. One of the lysimeters contained only refuse (i.e. no sludge) in order to act as a control.

The addition of waste-water sludge liquors to refuse in landfills was found to increase the chance of leachate generation and release, if the moisture content within the site is allowed to increase above that equivalent to the field capacity.

Anaerobically digested waste-water sludge was found to contribute, along with various liquid replacement strategies, to the stimulation of methanogenic conditions within the landfill. The extent of the contribution by the sludge addition alone, could however, not be quantified.

The leachate collected from the lysimeters containing waste-water sludge was found to have higher concentrations of both total phosphate and TKN. Therefore, water balance management which would include leachate collection, recycling and treatment would be required should waste-water sludge co-disposal be practised, especially in water surplus areas.

CONCLUSIONS

The results of this research have provided practical operational criteria for the landfill co-disposal of domestic refuse and anaerobically digested waste-water sludge liquor. The main conclusions to be derived from this research are summarised as follows:

- The application of sludge to land as a fertiliser or soil conditioner is generally regarded as the most sensible sludge disposal option. However, the impact of pending sludge legislation policies in South Africa may prohibit the agricultural utilisation of sludges that contain high concentrations of pollutants such as heavy metals and pathogenic bacteria. In such instances, and also where there is no agricultural demand for the sludge, it is likely that much greater use will be made of landfill co-disposal as an alternative sludge disposal option.

- The controlled co-disposal of waste-water sludge with refuse is a landfill strategy which can play an important beneficial role in the overall management of these two waste streams.

- The importance of moisture in solid-state anaerobic decomposition has been highlighted for optimising the physical, chemical and biological conditions for accelerated stabilisation of the landfilled waste. This reduces the long-term care requirements of the landfill and allows earlier productive final usage of the site surface.

- Additional moisture is added to a landfill during a sludge co-disposal practice. As a result, proper water balance management must be practised so as not to exceed the field capacity of the landfill, especially during wet seasonal periods. Consideration should thus be given to the provision of containment liners so as to facilitate the collection, treatment and disposal of the leachate as an essential part of the overall landfill management.

- Landfill co-disposal technology needs to be recognised by the policy and regulation community and managed by the waste management industry to the prescribed Minimum Requirements (DWAF, 1994a).

- Landfills should be sited adjacent to waste-water treatment plants so as to enable various options to be exercised for the treatment and utilisation of the sludge, leachate and biogas end-products. Such an integrated waste management strategy would be advantageous in terms of improved pollution control.

- Local authorities or companies wishing to co-dispose waste-water sludge with refuse must apply for a permit within the framework of the Minimum Requirements of the Department of Water Affairs and Forestry (DWAF, 1994a) as well as of Section 20 of the Environment Conservation Act, No. 73 of 1989.

- It is recommended that should the details of this report be utilised elsewhere, cognizance be taken of the local conditions in the Western Cape to assist in the adoption of the technology.

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Mr H G J Beekman (Chairman)	Cape Town City Council
Dr S A Mitchell	Water Research Commission
Mr K A Kaveney	Cape Town City Council
Mr G E Lord	Cape Town City Council
Mr J G Stow	Cape Town City Council
Mr K S Fawcett	Cape Town City Council
Mr P H Novella	Cape Town City Council
Dr W R Ross	Ross Consultancy

- The project was implemented and controlled by a Co-ordinating Committee, namely:-

Mr G E Lord (Chairman)	Cape Town City Council
Mr P H Novella	Cape Town City Council
Mr K S Fawcett	Cape Town City Council
Mr J G Stow	Cape Town City Council
Mr M A Greenhalgh	Cape Town City Council
Dr W R Ross	Ross Consultancy

- This final report was written and edited by an Editorial Committee, made up as follows:-

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CHAPTER 1
INTRODUCTION

South Africa's population is expected to grow from 29,1 million in 1985 to 59,7 million by the year 2010. This rapid population growth accompanied by urbanisation and industrialisation has resulted in a dramatic increase in the mass of waste being generated. South Africa currently produces some 40 million tons of domestic refuse per annum and 12 million tons per annum of waste-water sludge from biological waste-water treatment processes (Ninham Shand Inc., 1993).

Roughly 95 percent of domestic refuse (consisting largely of paper products, plastics, glass, metal, organic matter and industrial waste that is not regarded as hazardous) generated in South Africa is disposed of on land in landfills, which is still the easiest and cheapest method of disposing of solid waste in this part of the world. Sanitary landfilling, if properly controlled, is generally neat, safe, inexpensive and offers the most versatile method for the disposal of solid waste in an economical and environmentally sound manner (Ninham Shand Inc., 1993).

Co-disposal (or joint disposal) in its widest sense, is understood to be the calculated and monitored interaction of waste-water sludge or selected difficult industrial and commercial wastes with municipal refuse in a properly controlled landfill site (Department of the Environment - UK, 1993). The co-disposal of waste-water sludge and refuse in sanitary landfills is being practised in many parts of the world, especially in drier areas which have a perennial water deficit. For example, in the United Kingdom, some 15 percent of waste-water sludge is currently co-disposed with domestic wastes and it is likely that much greater use will be made of this disposal option as sea disposal is being phased out. The major perceived problems with the disposal of waste-water sludge on a landfill are the controlled admixture thereof with the refuse and the possible generation of increased leachate volumes (Craft and Blakey, 1988; Hall, 1990).

Over the last two or three decades much progress has been made in several countries - particularly USA, UK and Germany towards ensuring that the co-disposal practice is carried out in an environmentally sound way. However, different approaches have led to quite different experiences and attitudes, with the result that different perceptions of the values and dangers of the practice have developed (Department of the Environment - UK, 1993).

This research project was negotiated with the objective of developing practical operational criteria and to investigate the possible role that landfill co-disposal of domestic refuse and anaerobically waste-water sludge liquor could play in the overall management of these two waste streams in South Africa.

CHAPTER 2
OBJECTIVE AND TASKS OF THE PROJECT AND CONTRACT AGREEMENT

2.1 INTRODUCTION

Prior to the commencement of all research projects, the problem facing the researchers must be defined and aims set out on how the solutions are to be found. Quite often the aims are modified during the research as more information becomes available.

This chapter sets out the main objective and the subsequent tasks of this project. The contract entered into between the Cape Town City Council and the Water Research Commission is described briefly.

2.2 MAIN OBJECTIVE OF THE PROJECT

To develop practical operational criteria for the landfill co-disposal of domestic refuse and anaerobically digested waste-water sludge liquor.

2.3 TASKS OF THE PROJECT

- To undertake a literature search on local and overseas practice;
- to establish the correct ratios of refuse to waste-water sludge liquor for both the summer and winter periods in the Western Cape with respect to compactor workability;
- to establish the effect of sludge addition on landfill parameters such as moisture content, compaction, biogas formation and leachate generation;
- to develop test procedures in order to quantify such parameters as field capacity, saturation moisture content, compaction and the amount of leachate produced;
- to investigate the effect of co-disposal on the water balance equation;

- lysimeter studies;
- to propose site specific guidelines for waste-water sludge co-disposal practice.

This report contains the procedures followed, results obtained as well as conclusions associated with the main objective.

It was decided by the Steering Committee that investigations to establish the best full-scale methods of spreading and the transport of sludge should not form part of this project. This project should only try to assess the viability of the waste-water sludge co-disposal concept and not delve into full-scale applications.

Furthermore, it was considered that the treatment of leachate, including recycling, should form the basis of further projects.

2.4 CONTRACT AGREEMENT

The agreement between the Water Research Commission and the Cape Town City Council stipulated that the Water Research Commission would make funds available on request to the Cape Town City Council who would in turn provide the necessary personnel, facilities and equipment in order to carry out the approved working programmes. At the end of the project the Cape Town City Council would prepare a final report on the research.

Although the contract did not call for the appointment of a Steering Committee, one was established which met twice yearly. A Co-disposal Co-ordinating Committee was also formed in order to control the project on a day to day basis.

The duration of the practical aspects and monitoring phases of the project was initially two years (1991 and 1992) but this was subsequently extended by a further year (1993) by mutual agreement.

CHAPTER 3
LEGISLATION RELATING TO LANDFILL PRACTICES

3.1 INTRODUCTION

The current international (first world) landfill design concepts have generally led to the dismissal of the "attenuate and disperse" concept with the emphasis, more recently, on "engineered containment and operational safeguards". This is generally achieved by the installation of either an engineered clay liner or a polymeric membrane (HDPE). Using these materials emphasis is placed on preventing the release of leachate into the geologic environment.

Improvements in the standards of landfill engineering preparation were necessary and the risk of groundwater pollution should now be significantly reduced. However, the introduction of these new methods has probably been advocated and adopted without the full implications being realised (Harris *et al.*, 1994). The main problem concerns the period for which the sites engineered to the new standards, will pose an environmental risk. Although short-term pollution risks may have been reduced, the residual risk will remain for a much longer period.

The "dry tomb landfill" concept and the "bioreactor landfill" concept, illustrate the dilemma concerning current landfill practices and legislation (Ham, 1988; Knox, 1988; Pohland *et al.*, 1983). While the "dry tomb" concept advocates reducing the moisture content of the landfill, so as to minimise leachate formation, the "bioreactor" concept advocates optimising the moisture content in order to accelerate the *in situ* stabilisation of the wastes.

This section considers the current legislation regarding waste management in South Africa and abroad, in the context of the legal status of waste-water sludge co-disposal with refuse in landfills.

3.2 SOUTH AFRICAN LEGISLATION PERTAINING TO LANDFILL PRACTICES

A survey of current waste disposal practices in South Africa submitted to the President's Council in 1991 concluded that the position of solid waste management was highly unsatisfactory and presented a serious threat to human health and the environment (President's Council, 1991). South Africa at present (1995) does not have a comprehensive national statute covering waste management. Provisions for dealing with waste are scattered among 37 national statutes, 16 provincial ordinances and numerous by-laws (Department of Environment Affairs, 1992; Ninham Shand Inc., 1993). The most important Acts are:

- Environment Conservation Act, No. 73 (1989)
- Water Act, No. 54 (1956)
- Health Act, No. 63 (1977)

The current status of waste-water sludge disposal in South Africa is given in a recent Water Institute of Southern Africa (WISA) publication entitled "Sewage Sludge: Utilization and Disposal: Information Document" edited by G A Ekama (WISA, 1993). This document is available from WISA, P O Box 6011, Halfway House, 1685 South Africa.

3.3 ENVIRONMENT CONSERVATION ACT, NO. 73 OF 1989

The Environment Conservation Act (Sections 20, 21, 22, 24, 24a, 26, 29 and 30), including the amendments of 1992, is the only Act that deals specifically with waste management. The Act empowers the Minister to determine what will and will not constitute waste. This power has been exercised and, in terms of Government Gazette No 12703 (Notice 1986) dated 24 August 1990, "waste" is classified as:

> "an undesirable or superfluous by-product, emission, residue or remainder of any process or activity, any matter, gaseous, liquid or solid or any combination thereof, originating from any residential, commercial-industrial area,
>
> Excluding, amongst other substances,
>
> (i) water used for industrial purposes or any effluent produced by or resulting from such use which is discharged in compliance with the provisions of Section 21(1) of the Water Act No 54, 1956 or on the authority of an exemption granted under Section 21(4) of the said Act;
>
> (ii) any matter discharged into a septic tank or french drain sewage system and any water or effluent contemplated by Section 21(2) of the Water Act, 1956.

1 The provision of a classification of waste made it possible to enforce the Environment Conservation Act, No. 73 of 1989 and makes it mandatory to comply with Section 20 of the Act.

2 Sludges from effluent treatment plants are now considered as waste and no longer as effluent controlled by the Water Act, No. 54 of 1956 (Bredenhann *et al.*, 1991)

3.3.1 PERMIT SYSTEM FOR DISPOSAL SITES

The siting and management of waste disposal sites is covered by Section 20 of the Environment Conservation Act which notes that,

1 No person shall establish, provide or operate any disposal site without a permit issued by the Minister of Water Affairs and Forestry and that the Minister may -

   a) issue a permit subject to such condition as he may deem fit;
   b) alter or cancel any permit or condition in a permit;
   c) refuse to issue a permit:

   Provided that such Minister may exempt any person or category of person from obtaining a permit, subject to such conditions as he may deem fit.

2 Any application for a permit referred to in Sub-Section (1) shall be in the form and be accompanied by such information as the Minister may prescribe.

3 If the Minister should require any further information to enable him to make a decision on an application for a permit referred to in Sub-Section (1) he may demand such information from the applicant.

4 The Minister shall maintain a register in which details of every disposal site for which a permit has been issued shall be recorded.

5 The Minister may from time to time in the Gazette issue directions with regard to:

   a) the control and management of disposal sites in general;
   b) the control and management of certain disposal sites or disposal sites handling particular types of waste; and
   c) the procedure to be followed before any disposal site may be withdrawn from use or utilized for another purpose.

6 Subject to the provisions of any other law no person shall discard waste or dispose of it in any other manner, except -

   a) at a disposal site for which a permit has been issued in terms of subsection (1); or
   b) in a manner or by means of a facility or method subject to such conditions as the Minister may prescribe.

   Any person who contravenes a provision of Sub-Sections 1, 5 or 6 of Section 20 of The Act shall be guilty of an offence and liable, on conviction, to certain penalties.

The Department of Water Affairs and Forestry is entrusted with the legislation and regulation of waste disposal sites. Notice of the intended regulations regarding the application of a waste disposal site permit were published for comment in the Government Gazette No. 13330 (No. R1481) dated 28 June 1991. Although these regulations have not yet been officially ratified, the Department of Water Affairs and Forestry has introduced a permit system. Persons currently operating disposal sites, or wishing to open a disposal site, now require a permit.

3.3.2 PERMIT APPLICATIONS AND PERMIT ISSUE

Applications for a waste disposal permit must be submitted on a form available from the Director-General, Directorate of Water Quality, Private Bag X313, Pretoria, 0001, or any of the Regional Offices of the Department of Water Affairs and Forestry (DWAF). The applicant may also be required to furnish additional supportive information before the site is approved, depending on the amount and type of waste earmarked for disposal and the environmental characteristics of the site.

Copies of the completed application form and plans are then sent by DWAF to the local office of the Department of Environment Affairs (DEA) and the Department of National Health and Populations Development (DNHPD) for comment. Following a site visit with representatives from DWAF, DEA and DNHPD the applicant receives written notification of the suitability of the site. The permit application procedure as outlined in the Minimum Requirements (DWAF, 1994a) is summarised in Figure 3.1 (Ninham Shand Inc., 1993).

An important part of the permitting process involves a public participation process which consults with affected and interested parties. This process has to be satisfactorily completed prior to the issuing of a permit.

Once all relevant documentation has been processed by DWAF, one of two types of permits is issued. Permits for Hazardous Waste Containment Sites e.g. H:H or H:h (previously Class 1 sites) are issued by the Director: Water Pollution Control, in Pretoria, while permits for General Urban Solid Waste Sites e.g. GMB$^+$, GLB$^-$, etc. (previously Class 2 sites) are issued by the relevant regional directors of DWAF. On receipt of the permit, the applicant may proceed with the construction of the disposal site, notifying DWAF in writing on completion. This is followed by an inspection by departmental officials of the Regional Director to ensure that permit conditions have been met. Should any discrepancies occur, the applicant may be required to alter the construction works to meet the permit conditions.

Once the Regional Director is satisfied, written permission is then granted for disposal of waste to proceed on the permitted site (Figure 3.1).

Where an applicant does not agree with the permit conditions, the matter may be taken up with the regional office in question or, in the case of a Class H:H or H:h site, with the Director: Water Pollution Control (Pretoria).

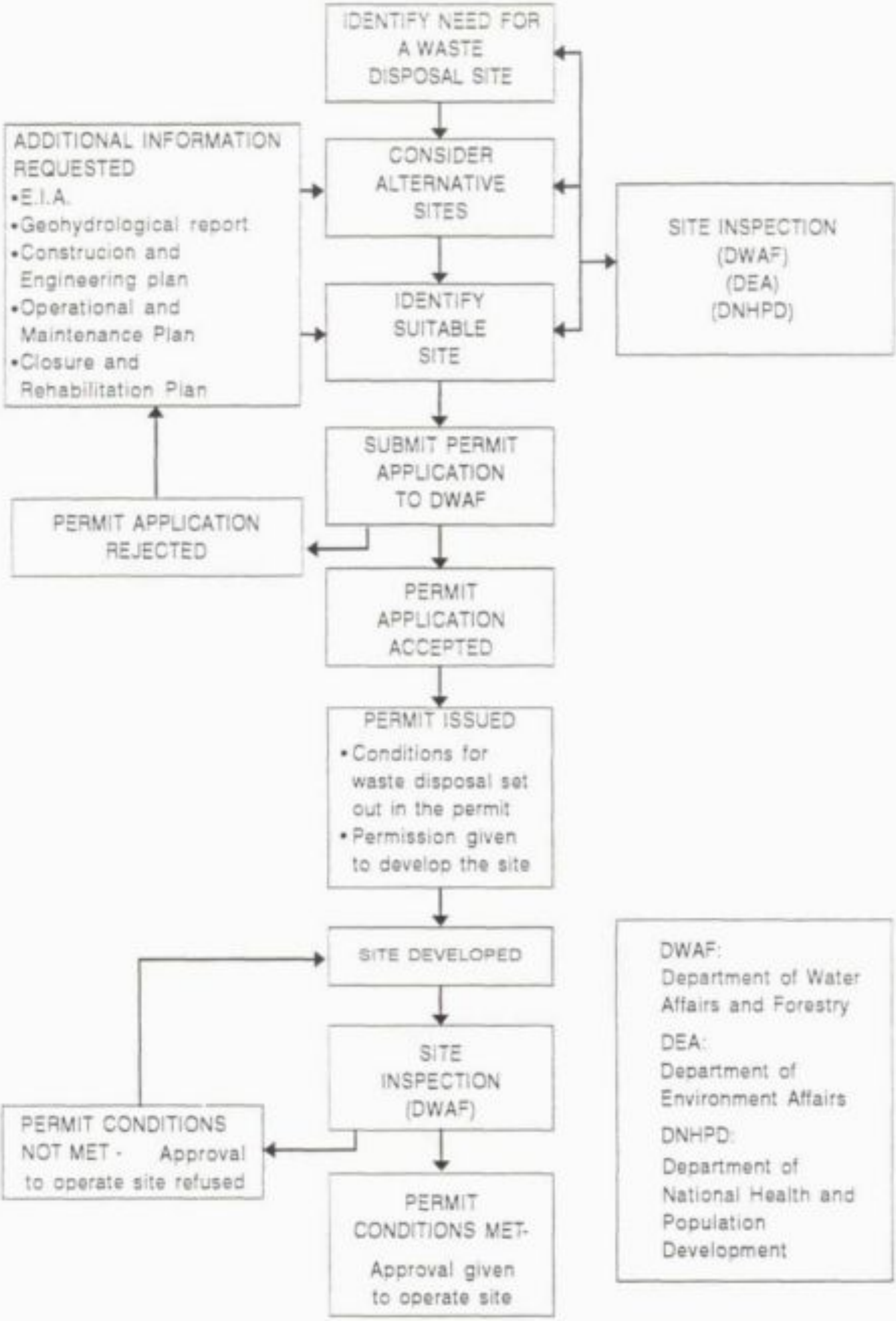


Figure 3.1 Process of approval for a waste disposal site in South Africa (Ninham Shand Inc., 1993).

3.3.3 RESPONSIBILITIES OF THE PERMIT HOLDER

The permit holder is subject to the conditions laid down in the permit. The objective of the permit is to ensure that the disposal site is operated and maintained without causing a public nuisance or health hazard and with a view to protecting the surface and groundwater from leachate contamination.

All liquids that arise from the disposal site, including leachate and runoff, must be collected and either retained in evaporation ponds, treated to a quality in terms of Section 21(1)(a) of the Water Act, 1956, and discharged into a municipal sewer, or recycled on the disposal site. The permit holder must also take sufficient precautions to ensure that the site is protected from 1 in 50 year flood events.

Should the disposal site cause pollution to the surface and groundwater, an official of the DWAF may be appointed to investigate the site in terms of Sections 23 and 24 of the Water Act, 1956. The permit holder may be asked to take remedial measures to prevent further pollution. Should the permit holder fail to comply with the directives, the DWAF may take temporary possession of the site, amend the permit, or close the site and recover any expenses incurred.

The permit holder must notify the DWAF should a change in operational procedures take place or before operation commences on virgin ground so that the relevant engineering and protection can be approved.

Permit holders are obliged to inform the DWAF in writing 180 days prior to leasing, selling or closing a disposal site. Appropriate measures (as specified in Minimum Requirements) must be taken to cover and rehabilitate the site on closure. A maintenance and monitoring programme should also be implemented to ensure that even subsidence takes place and that groundwater contamination does not occur.

3.3.4 LEGAL STATUS OF WASTE-WATER SLUDGE CO-DISPOSAL IN LANDFILLS IN TERMS OF THE ENVIRONMENTAL CONSERVATION ACT

Areas where sludges from effluent treatment plants are to be stored or disposed of require a permit in terms of Section 20(1) of the Environment Conservation Act (Bredenhann *et al.*, 1991). The act will apply in the case where waste-water sludge (either cake or liquor) is removed from the waste-water treatment plant to be disposed of on a waste disposal site. The permit issued under this act will stipulate the hazard rating of the sludge and the co-disposal ratios to be employed.

Currently, where liquids are co-disposed with solids, the liquid:solid ratio may not exceed 1:20. The hazardous rating will dictate whether the sludge must be disposed of on a hazardous waste disposal site or whether it can be disposed of on a general waste disposal site. In the latter case gas management will be a condition of the permit; depending on circumstances, it might also be addressed on specific hazardous waste disposal sites (Crawford, 1993).

3.4 WATER ACT, NO. 54 OF 1956

While the Water Act of 1956, including the amendments of 1991, deals primarily with the utilisation of water, it does contain important provisions (Sections 21, 22, 23, 24 and 26 of the Act) with regard to the prevention of water pollution, which, in the context of waste disposal, can be a potential pollution threat (Ninham Shand Inc., 1993).

In terms of Section 22 of the Act:

Prevention of water pollution:

> "Any person who has control over land on which anything was or is done which involved or involves a substance capable of causing water pollution, whether such a substance is a solid, liquid, vapour or gas or a combination thereof, shall take such steps as may be prescribed by regulation under Section 26 in order to prevent:
>
> a) any public or private water on or under that land, including rain water which falls on or flows over or penetrates such land, from being polluted by that substance, or if that water has already been polluted, from being further polluted by that substance."

In terms of Section 23 of the Act:

Pollution of water to be an offence:

> "Any person who wilfully or negligently does any act which could pollute public or private water, including underground, or sea water in such a way as to render it less fit...shall be guilty of an offence".

In terms of Section 24 of the Act:

(Directions by Director-General in connection with Water):

> The Director-General of Water Affairs and Forestry can authorise investigations of land threatened by pollution and issue directions to counter the threat. In this regard the Minister does not require the co-operation of the owner or occupier of the land and can also recover the costs incurred.

3.4.1 MINIMUM REQUIREMENTS FOR WASTE DISPOSAL SITES

Minimum Requirements may be defined as norms used to distinguish between acceptable and non-acceptable waste management practices. The formulation of such Minimum Requirements are essential to create uniformity in the application of legislation (Bredenhann *et al.*, 1991; Ball *et al.*, 1993).

Minimum Requirements for waste disposal by landfill (DWAF, 1994a), for the handling and disposal of hazardous waste (DWAF, 1994b) and for monitoring at waste management

facilities (DWAF, 1994c) have been formulated by the Department of Water Affairs and Forestry. The Minimum Requirements will be developed on an ongoing basis to promote compliance with environmental policy and legislation. Table 3.1 shows the typical format used in tabulating Minimum Requirements, based on the landfill site classifcation system. The Minimum Requirements that will apply to any particular landfill will depend on its classification which in turn will be a function of the waste type, the size of the landfill operations, the potential for leachate generation and the need for leachate management (DWAF, 1994a).

Copies of the three Documents which comprise the Minimum Requirements are obtainable from the Department of Water Affairs and Forestry.

3.4.2 LEGAL STATUS OF WASTE-WATER SLUDGE CO-DISPOSAL IN LAND FILLS IN TERMS OF THE WATER ACT (1956)

According to the Department of Water Affairs and Forestry it is not possible at this stage to stipulate hard and fast rules for the co-disposal of waste-water sludge with domestic refuse but only to consider waste-water sludge as another waste product which must be dealt with in a manner consistent with overall waste disposal criteria (Crawford, 1993).

TABLE 3.1 MINIMUM REQUIREMENTS (DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1994a)

LEGEND B^- = No significant leachate produced B^+ = Significant leachate produced R = Requirement N = Not a requirement F = Flag: special consideration to be given by expert or Departmental representative	CLASSIFICATION SYSTEM									
	G General Waste								H Hazardous Waste	
	C Communal Landfill		S Small Landfill		M Medium Landfill		L Large Landfill		h Hazard Ratings 3 & 4	H Hazard Ratings 1-4
MINIMUM REQUIREMENTS	B^-	B^+	B^-	B^+	B^-	B^+	B^-	B^+		
Post-Closure Surface Water Monitoring	N	N	N	F	F	R	R	R	R	R

3.5 HEALTH ACT, NO. 63 OF 1977

Since waste disposal can under certain circumstances constitute a health hazard, certain provisions of the Health Act, including the amendments of 1992, do have an important bearing on the subject (Ninham Shand Inc., 1993). The objective of the Health Act is, "to provide for measures for the promotion of the health of the inhabitants of the Republic".

In terms of Section 34, the Minister of Health, can make regulations relating to - "any condition which is likely to constitute a danger to health, or to remedying or removing any such condition".

In terms of Section 35, regulations relating to rubbish, night-soil, sewage or other waste and reclaimed products, the Minister of Health, "may in consultation with the Ministers of Water Affairs and Forestry, and Environmental Affairs make regulations relating to the regulation, control, restriction or prohibition of, or providing for, any or all of the following matters,

or any other matter deemed necessary, in respect of rubbish, night-soil, sewage or other waste originating from residential, industrial or commercial premises or any other premises".

In terms of Section 20: Duties and Powers of Local Authorities:

> "Every local authority shall take all lawful, necessary and reasonably practicable measures -
>
> a) to maintain its district at all times in a hygienic and clean condition;
>
> b) to prevent the occurrence within the district of -
> (i) any nuisance;
> (ii) any unhygienic condition;
> (iii) any offensive condition; or
> (iv) any other condition which will or could be harmful or dangerous to the health of any person within its district or the district of any other local authority.
>
> c) to prevent the pollution of any water intended for the use of the inhabitants of its district, irrespective of whether such water is obtained from sources within or outside its district, or to purify such water which has become so polluted.

The Health Act, therefore, imposes a positive obligation on local health authorities to ensure that hygienic conditions are maintained and to take steps to rectify any conditions, including waste disposal, which may constitute a threat to public health.

3.5.1 LEGAL STATUS OF WASTE-WATER SLUDGE CO-DISPOSAL IN LANDFILLS IN TERMS OF THE HEALTH ACT (1977)

The Department of National Health and Population Development have published a draft guide for the processing, storage, transportation, utilization or disposal of waste-water sludge and other solid wastes, for instance screenings, detritus and digested sludge (DNHPD, 1991; WISA, 1993).

In these guidelines sludge is classified into types A, B, C and D in decreasing order of its potential to cause odour nuisances and fly breeding, as well as to transmit pathogenic organisms to man and his environment.

The principles on which the classification of the sludge types should be differentiated are summarised as follows (DNHPD, 1991; WISA, 1993):

Type A:	Unstable, with a high odour and fly nuisance potential; high content of pathogenic organisms.
Type B:	Stable, with low odour and fly nuisance potential; reduced content of pathogenic organisms.
Type C:	Stable, with insignificant odour and fly nuisance potential; containing insignificant numbers of pathogenic organisms.
Type D:	Sludge included in this type is of similar hygienic quality as Type C, but since it is produced for unrestricted use on land at a maximum application rate of 8 dry t/ha/annum, the heavy metal and inorganic content is limited to acceptable low levels.

The Guidelines permit the unrestricted co-disposal of Type D sludge on a landfill. Sludge types A, B and C can be co-disposed but are however subject to certain restrictions (refer Table 5.4).

Davis (1989) reports that future expansions in the agricultural utilisation of waste-water sludge in the United Kingdom will depend on it's cost and accessibility relative to other outlets such as co-disposal in sanitary landfills and incineration.

The draft guide also list the most common horticultural and agricultural uses of waste-water sludge and permissible methods of disposal as well as the conditions and restrictive measures under which the various types of sludge may be applied or disposed of. According to the draft guide, it is permissible to co-dispose types A, B, C and D sludges with domestic waste on landfill sites under certain conditions. However, permit requirements in terms of the Environmental Protection Act, No. 73 of 1989 (which is administered by the Department of Water Affairs and Forestry) must be met.

The main concern of the Department of National Health and Population Development is the necessary precautionary measures to prevent groundwater pollution by increased volumes of leachate containing heavy metals and pathogenic organisms (Van der Merwe, 1993).

The possible inclusion of limits for arsenic (73 mg/kg), chromium (600 mg/kg) and nickel (420 mg/kg) in waste-water sludge to be disposed/co-disposed in landfill/disposal sites without liner and leachate collection is being recommended for amendment.

3.6 DEVELOPMENTS IN OVERSEAS LEGISLATION PERTAINING TO LANDFILL PRACTICES

3.6.1 CURRENT OVERSEAS PRACTICE

Current landfill practice in the United Kingdom and Europe have evolved to an international standard designed to provide engineered containment of waste breakdown products and operation standards to prevent pollution of water. This approach conforms with implementation of Directives issued by the Council of the European Communities (1980, 1991, 1993).

In the U S A, the engineering requirements have been taken a stage further with the necessity, from October 1993, to prevent rainfall infiltration into household waste sites by the use of capping layers with permeability no greater than the bottom liners, the so-called "Dry Tomb" approach (RCRA Subtitle 'D') (US EPA, 1991).

3.6.2 IMPLICATIONS OF CURRENT OVERSEAS PRACTICE

Harris *et al.* (1994) state that the introduction of the current methods of landfill engineering and new standards probably has been advocated and adopted without the full implications being realised. The main problem concerns the period (after closure) for which the landfill site will pose an environmental risk. Although short-term pollution risks may have been reduced, the residual risk of storage of undegraded wastes in dry containment sites will remain for a much longer period. For this risk to be eliminated, the polluting components of the waste, which could later become mobilised, have to be transposed into the liquid or gaseous phases and removed. With the required moisture content and movement of water (or leachate) in the wastes being reduced to negligible amounts by the engineering measures, this process will be very protracted unless additional measures are taken.

Regardless of the risks of membrane liner failure, a system which continues to impose management and regulation costs for possibly hundreds of years, because of its environmental risk, cannot be regarded as sustainable. It is argued by Harris *et al.* (1994) that no regulatory system, or indeed political system can be guaranteed to provide adequate control for this length of time.

3.6.3 INTERNATIONAL CONCERNS ON SUSTAINABLE DEVELOPMENT

The widely accepted definition of sustainable development (Munro and Holdgate, 1991) is:

> "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The current approach to landfill design and operation with its potential long term environmental risk cannot be considered compatible with this definition (Belevi and Baccini, 1987; Knox, 1990; The Environmental Monitoring Group: Western Cape, 1992; Walker, 1993).

The concept of sustainable development was central to the United Nations Conference on Environment and Development (UNCED), the "Earth Summit", held in Rio de Janeiro in June 1992. Agenda 21 of UNCED required a comprehensive and forward looking action plan for the next century. The European Community member states in June 1992 made a commitment to produce national action plans for the implementation of Agenda 21 by the end of 1993. The Department of the Environment (1993) produced a Consultation Paper on the UK Strategy for Sustainable Development intended to meet these requirements.

The requirements of sustainable development have very clear implications for the objectives of landfill and have already formed the basis of specific waste management policy in some countries. For instance, an objective of the Swiss waste management policy since 1986 has been that each generation manages its waste to a status of final stage quality (Eka, 1986). This is defined as the stage when any emissions to the environment are acceptable without further treatment. The duration of one generation has been interpreted in Switzerland as being approximately 30 years (Belevi and Baccini, 1989), consistent with the 30 year post-closure monitoring period required by the proposed EC Landfill Directive and by RCRA Subtitle 'D' in the USA (US EPA, 1991). A Certificate of Completion will not be issued until it can be shown that the landfill is unlikely to cause pollution of the environment.

3.7 A NEW APPROACH TO LANDFILL NEEDED

Current landfill practices generally cannot be regarded as the best practicable environmental option or compatible with sustainable development because they pass on a large proportion of the environmental burden to future generations. Changes are needed to ensure that each generation deals with its own problems (Belevi and Baccini, 1987; Knox, 1990; Walker, 1993).

Two broad strategies to achieving this are suggested (Harris *et al.*, 1994):

- pre-treatment of wastes to final storage quality, before landfilling, by a combination of pre-sorting, recycling and waste minimisation, incineration, anaerobic digestion and composting or;
- development of highly efficient bioreactor landfills for mixed wastes with extensive recirculation and treatment of leachate to achieve final storage quality within a generation.

Neither approach has yet been technically proven. Research and development are considered essential to determine whether landfill practices can become sustainable.

The co-disposal of waste-water sludge with refuse in a landfill is a typical management strategy which can play a role in the development of a bioreactor landfill. This technology would need to be recognised by the policy and regulation community and managed by the waste management industry to prescribed minimum standards. Furthermore such sludges need to be viewed as a sustainable and valuable resource and not just as a waste product.

CHAPTER 4
LITERATURE SURVEY OF CO-DISPOSAL PRACTICES

4.1 INTRODUCTION

The disposal of waste-water sludges in sanitary landfills is by no means a new concept. In the United Kingdom where about 1.2 million tons (dry weight) of sludge is produced annually (Hill, 1991), approximately 24% is disposed of in landfills (Watson-Craik *et al.*, 1992). In the United States, where landfilling of waste-water sludge is viewed primarily as a disposal method, about 25% of the generated municipal waste-water sludge is landfilled (EPA, 1984). In the former Federal Republic of Germany most waste-water sludge was deposited in sanitary landfills (Koehlhoff, undated).

The disposal of waste-water sludge in sanitary landfills in South Africa has not been widely implemented due to various reasons, including the dry climate which improves the operation of sludge drying beds. In the Western Cape, waste-water sludge from virtually any source has always been accepted as a good, cheap soil conditioner and it is currently widely used, by vegetable farmers as a fertiliser (Novella and Fawcett, 1992). These practices are likely to decrease when the Draft Guide relating to sludge disposal (Department of National Health and Population Development, 1991) are implemented.

Reference has been made (Ekama, 1992) to three fears regarding the continued use of sludge as a fertiliser, namely, ground water pollution, aerosol production (odours) and most important, food chain contamination. In the latter case excessive heavy metal concentrations seem to be the major contaminant in the sludge. These heavy metals cannot be removed from waste-water sludges by means of conventional sludge treatment processes. Therefore, if they are not prevented from entering the sewerage system, an acceptable alternative to land application as disposal method must be found. Controlled co-disposal of waste-water sludge with refuse in a landfill is such as method.

4.2 FULL-SCALE APPLICATIONS

(a) **Sludge-Only Landfilling** (EPA, 1984) - Most sludge-only landfills consist of a series of trenches dug into the ground, into which predominantly dewatered waste-water sludge is deposited and then covered with soil. Other sludge-only landfill designs exist (area fill mounds, area fill layers and diked containment) in which sludge is deposited on the ground surface, but these are not common. Further information on these methods can be obtained in the EPA (1978) document.

(b) **Sludge Co-disposal with Refuse** (method 1) (EPA, 1984; Hill, 1991)- A slight modification to the normal landfilling method is required when dewatered waste-water sludge is added to the refuse. In this method thin layers of sludge are applied between layers of refuse. The thin layers of the sludge are achieved by spreading the deposited sludge using the landfill compactor blade. Thin layers of refuse are then added and the two layers become mixed during the compaction process. Dewatered sludge with solids concentrations greater than 15% should be used in this method. The main operational disadvantage here is that the landfill compactor tends to become fouled with sludge.

(c) **Sludge Co-disposal with Refuse** (method 2) (Hill, 1991; West Yorkshire Waste Management Authority, 1990) - In this method the sludge is deposited at the toe of the landfill and is spread out carefully using the blade of the landfill compactor. The loose refuse is disposed of at the top of the landfill slope and compacted down the slope to cover the sludge. The sludge remains in a horizontal layer under the lift and is not mixed in with the refuse as in the previous method. The utilisation of this method requires a number of truck loads of refuse to successfully cover a load of sludge.

(d) **Sludge Disposal in trenches in a landfill** - Trenches are usually about 3 to 4 m deep and some 1½ m wide, with varying lengths, dug into previously landfilled waste. It is however recommended that if this method is used, trenches of not more than 15 to 20 m long be excavated. This results in confined cells within the landfill mass into which waste-water sludge is deposited. These cells can be achieved in long trenches if a 1 to 1,5 m wide wall is left unexcavated every 20 m. The trenches should not be filled more than two thirds of the way with sludge; once this is achieved the trench is back-filled with the excavated refuse and compacted using the landfill compactor. The excess excavated refuse should be transported to the working face of the site and landfilled in the conventional manner.

(e) **Sludge Co-disposal with baled refuse** (Hill, 1991; West Yorkshire Waste Management Authority, 1990) - The bales, either of high density (some 1600 kg/m^3) or medium density (some 1000 kg/m^3), are stacked in a landfill usually 2 or 3 high. It is not recommended that bales be placed onto sludge as this operation could become messy and the wheeled loader (with fork attachments) could become contaminated with sludge. It is usually much better to form a series of bays into which the sludge delivery vehicle can reverse and tip its load. The size of the bay can be varied according to sludge volumes. It is recommended that the floor area per cell should not exceed 3 m x 3 m for ease of operation. Once filled, the open end of the cell can be closed off with bales which are manoeuvred towards the rear of the bay. In this manner the sludge is squeezed until its upper surface is level with the top of the adjacent bales. The cell can then be covered by pushing whole or broken bales onto the surface of the sludge which can be spread and lightly compacted using a bulldozer. In this method, some 20 tons of wet sludge cake (dewatered) can be disposed with some 80 tons of baled waste (4:1 refuse to sludge volume ratio).

(f) **Mixing sludge with soil for use as cover** (EPA, 1984) - In this method, soil or cover material can be mixed with sludge. The resulting mixture can be used as intermediate or final cover of landfills. When used as final cover in the rehabilitation process of the landfill, the sludge in the soil can promote the revegetation of the site. One must be cautious, however, to prevent any run off, which may contain elevated levels of nitrogen, phosphorus, heavy metals or other pollutants from reaching water bodies.

4.3 POSSIBLE SLUDGE TYPES FOR CO-DISPOSAL

a) Primary sludge - The chief component of primary sludge is human faeces. This material is withdrawn from the bottom of primary settling tanks and is mainly of an organic nature. In its raw state primary sludge is putrescible and rapidly develops strong and offensive odours. The average percentage dry solids of primary sludge is in the range of 2 to 5% TS (Ross *et al.*, 1992).

b) Anaerobic digested sludge - This sludge type is considered the most suitable for co-disposal purposes because it is stabilised and furthermore is claimed to inoculate the landfill with methanogenic bacteria which are necessary for the stabilisation of the organic component of refuse with resultant biogas production.

c) Humus tank/trickling filter sludge - In biological filtration (aerobic trickling filter) processes most of the dissolved organic matter as well as the non-settleable solids passing through the primary settling tank are converted into settleable solids. These solids undergo biological breakdown and are periodically washed off the stationary media (stone or plastic) by the effluent. This effluent passes through the secondary settling tank in which the settleable solids are removed from the bottom as humus/trickling filter sludge. The average percentage dry solids of humus tank sludge is in the range of 1 to 3% TS (Ross *et al.*, 1992).

d) Waste activated sludge - In the activated sludge process, bacteria and other micro-organisms feed on incoming organic matter and produce additional cell mass (ie increased sludge solids). A certain quantity of the sludge is removed periodically as waste activated sludge in order to control the activated sludge process. The waste activated sludge solids concentration can vary from 0,3 to 0,7% TS, depending on the concentration of activated sludge in the reactor (Ross *et al.*, 1992).

e) Chemical sludge - This sludge can be obtained as a waste sludge from water treatment plants as well as from waste-water treatment works. More and more inland waste-water works are including chemical treatment together with biological treatment in their process line up in order to reduce phosphate levels in the effluent, in accordance with the requirements of the Department of Water Affairs. Concentrations of chemical sludge vary widely but generally 1 mg/ℓ ferric chloride dosed will produce 0,66 mg/ℓ ferric hydroxide in the sludge (Ross *et al.*, 1992).

TABLE 4.1 COMBINATIONS OF DIFFERENT SLUDGES GENERALLY FOUND IN A WASTE-WATER TREATMENT WORKS

	TYPE OF WORKS	TYPE OF SLUDGE
i)	Biological filtration with primary sedimentation	Mixture of primary and humus sludge
ii)	Activated sludge with primary sedimentation	Mixture of primary and waste activated sludge
iii)	Biological filtration as well as activated sludge with primary sedimentation	Mixture of primary, humus and waste activated sludge
iv)	Activated sludge including chemical phosphate removal with primary sedimentation	Mixture of primary, chemical and waste activated sludge
v)	Anaerobic digestion with primary sedimentation	Primary sludge

f) Mixtures of sludge - In reality, waste-water treatment works rarely produce only one type of sludge but rather mixtures of the above-mentioned sludges. Table 4.1 (Ross *et al.*, 1992) gives a few common combinations of sludges which may be found in waste-water treatment works in Southern Africa.

4.4 SLUDGE DISPOSAL OPTIONS

After the anaerobic digestion process, various options are available for stabilised sludge disposal. Although the utilisation of sludge to improve soils for agricultural purposes provides an attractive means of disposing of the sludge, there are many factors to be considered to avoid creating a secondary pollution problem that may be ultimately costly and time consuming to rectify.

Sludge disposal options include:

- utilisation as a soil conditioner or low grade fertilizer
- co-disposal along with refuse in a landfill (various options available)
- composting
- incineration
- brick manufacture
- heat treatment
- etc.

CHAPTER 5
MATERIALS AND METHODS

5.1 INTRODUCTION

This Chapter describes the location of the research site at Coastal Park and gives the background to the science of landfilling, landfill techniques and introduces the concept of a landfill as a bioreactor. The characteristics of the waste-water sludge and municipal refuse utilised in the research are also discussed as well as the methods of constructing the two research lines.

5.2 LOCATION OF RESEARCH FACILITIES

5.2.1 INTRODUCTION

It is recommended that should the details of this report be utilised elsewhere, cognizance be taken of the local conditions in the Western Cape to assist in the adaption of the technology for other locations with different climatic conditions.

5.2.2 LOCATION

The Coastal Park landfill is located in the south western portion of the Cape Flats, adjacent to the Cape Flats waste-water treatment works. The landfill is situated some 300 m from the False Bay Coast line. The siting of the two waste handling facilities, namely the Coastal Park landfill and the Cape Flats waste-water treatment works, adjacent to each other enables various treatment options to be exercised and has advantages in terms of improved pollution control.

The Cape Town central business district is situated some 30 km to the north of the landfill with the suburban area extending to some 3 km from the site. Figure 5.1 illustrates the location of Coastal Park in relation to the surrounding area.

The siting of waste management facilities are usually subject to public outcries as they are not wanted by the community which they serve (NIMBY - not in my back yard - syndrome). Therefore, it makes sense to site various waste disposal facilities close to each other in order to minimize public opposition, as well as to integrate waste disposal management.

Figure 5.1 Locality plan of the Coastal Park landfill.

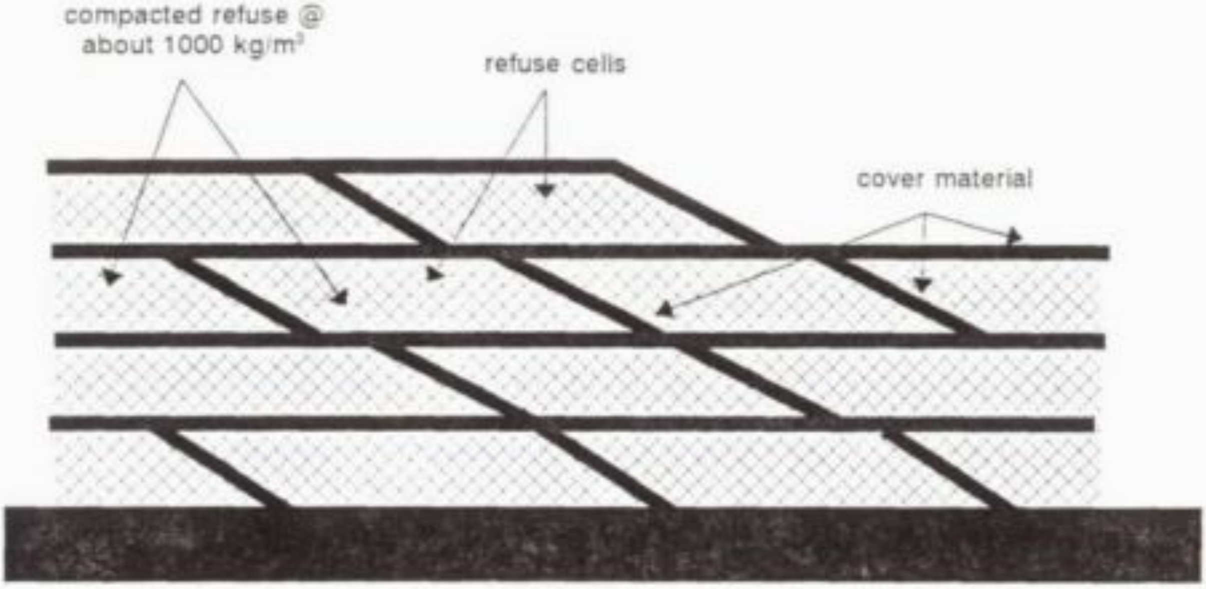


Figure 5.2 Cell method of landfill operation.

5.2.3 CLIMATE

The research facilities are situated in an area which enjoys a mediterranean climate with hot dry summers and cool wet winters. It is in a winter rainfall area but subject to an annual water deficit. The 30 year average evaporation exceeds rainfall by some 600 mm per year (Blight *et al.*, 1990). Wind direction during the summer months is predominantly from the south-east. Gale force south-easterly winds are common during the summer period. During the winter months the direction changes to the north-west and north westerly storms are common. Temperatures are generally moderate.

Meterological Data is given in Section 6.7.

5.3 SANITARY LANDFILLING METHODS

5.3.1 INTRODUCTION

It is not the intention in this section to give a detailed description of landfill construction, layout or management. It is, however, necessary to outline the changes in philosophy which have occurred in the development of this technology. Further information regarding the principles of landfill management may be obtained from the Institute of Waste Management, (Southern Africa), P O Box 1378, Pinegowrie, 2123 South Africa or in the Minimum Requirements (DWAF, 1994a).

5.3.2 TRADITIONAL PHILOSOPHY OF LANDFILLING

For many decades mankind has sought for a suitable place in which to deposit waste. Moving away from the concept of "finding a hole to fill" into the later "engineered design of landfilling" the shortage of suitable landfill sites has resulted in the need to compress or compact refuse into the smallest possible volume, thereby lengthening the life of existing landfill sites. The ever increasing quantities of waste have necessitated a further change, namely from small local disposal sites to large regional disposal areas, further complicating the problem of finding suitable places for waste disposal.

The philosophy of sanitary landfilling, wherein the waste is compacted to the smallest volume by excluding as many voids as possible and covering each day's waste with a soil cover to exclude rats, flies and other health problems has been successfully applied throughout the world. Unusable waste lands contaminated through landfilling have been transformed into city parks, sportfields and recreation areas. This method of disposal has resulted in the development of leachate treatment plants and biogas utilisation techniques.

5.3.3 NEW PHILOSOPHY OF LANDFILLING

Investigations which have been carried out by excavating into landfills, which have been built on the principles enumerated in the previous paragraph, have shown that decomposition of the waste does not always take place due to lack of sufficient moisture or higher than normal densities which amongst others can cause a retardation of the decomposition process. Recent disposal philosophy has begun to consider the landfill as a bioreactor and has a tendency to optimise the conditions wherein maximum anaerobic decomposition can take place, thereby, reducing the organic fraction of the waste to an inert or at least environmentally acceptable substance. This would allow for the recycling of landfills (for plastic, glass, etc.) once the decomposition process has been completed, thereby, providing additional space for waste disposal. If optimal decomposition could be encouraged, the deleterious effect of unstabilised leachate migrating from the waste would be minimised, while methane generation could be utilised to a maximum.

5.3.4 METHODS OF CELL CONSTRUCTION

Two basic methods are utilised, namely, the trench and the area methods. The method utilised is to some degree site specific as well as waste type specific.

In the **trench method** waste is spread and compacted into an excavated trench. Cover material which is taken from the excavation is spread over the waste in a relatively thin layer to form the cell. The **area method** is generally used when waste is spread and compacted on the natural surface of the ground and cover material is spread and compacted over it.

A sanitary landfill does not need to be operated in only one or the other method. Combinations of the two are possible and flexibility depending on the nature of the site and the waste is one of the greatest advantages of sanitary landfilling.

In both methods, mentioned above, the cell is utilised as the basic building mechanism. In the cell system the waste is spread and compacted in layers in a confined area. At the end of the working day or more frequently if warranted, it is covered with a 100 - 150 mm continuous layer of cover material (usually soil). The compacted waste and soil layer constitute a cell. A series of adjoining cells make up a lift whilst the completed landfill consists of one or more lifts. Figure 5.2 illustrates the cell method of sanitary landfilling.

The dimensions of a cell are usually not fixed but are determined by the volume of the incoming waste and the *in situ* density of the compacted waste. The height of the cell is usually some 2.5 m and compaction of the waste into the cell occurs on 4:1 gradient using a landfill compactor or similar machine which has steel wheels. The direction can either be up the slope from the toe of the lift (Figure 5.3) or down the slope from the top of the lift.

Cover material volume requirements are not fixed and are dependant on the surface area of the waste to be covered and the required thickness of the layer. The recommended thickness in order to provide a continuous cover is about 150 mm. The final layer would have to be substantially thicker and would incorporate methods of capping and rehabilitation of the site to standards specified in Minimum Requirements (DWAF, 1994a) to prevent the ingress of water, production of leachate and the uncontrolled escape of landfill gas.

Figure 5.4 shows schematically a containment landfill which incorporates all the necessary safety and environmental protection methods. Readers are referred to the Minimum Requirements for further details (DWAF, 1994a).

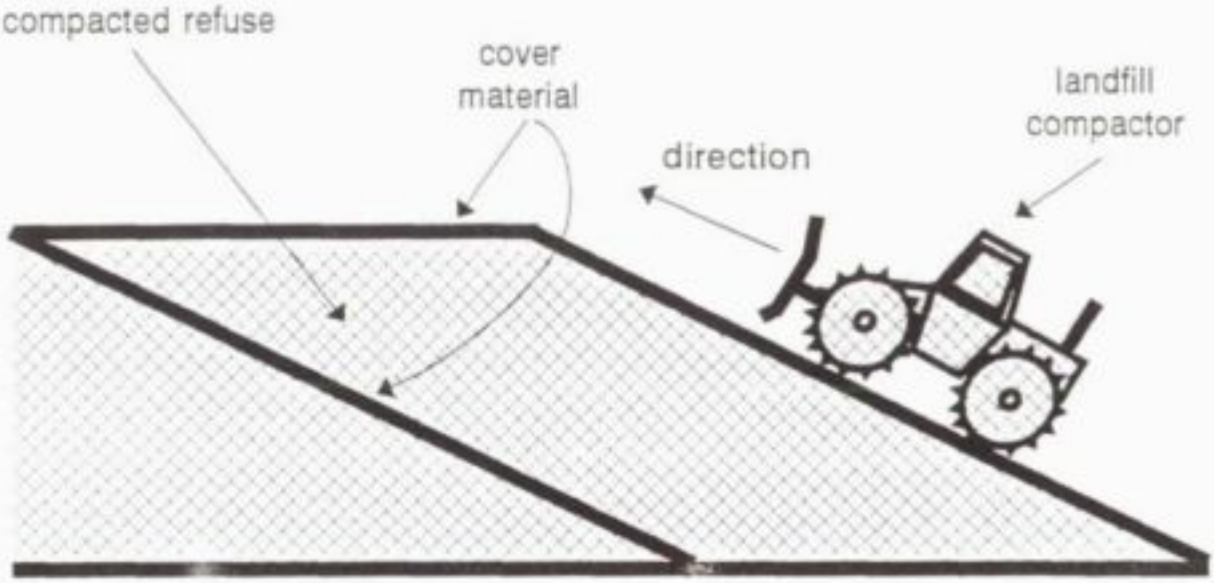


Figure 5.3 Landfill compactor operating up the slope.

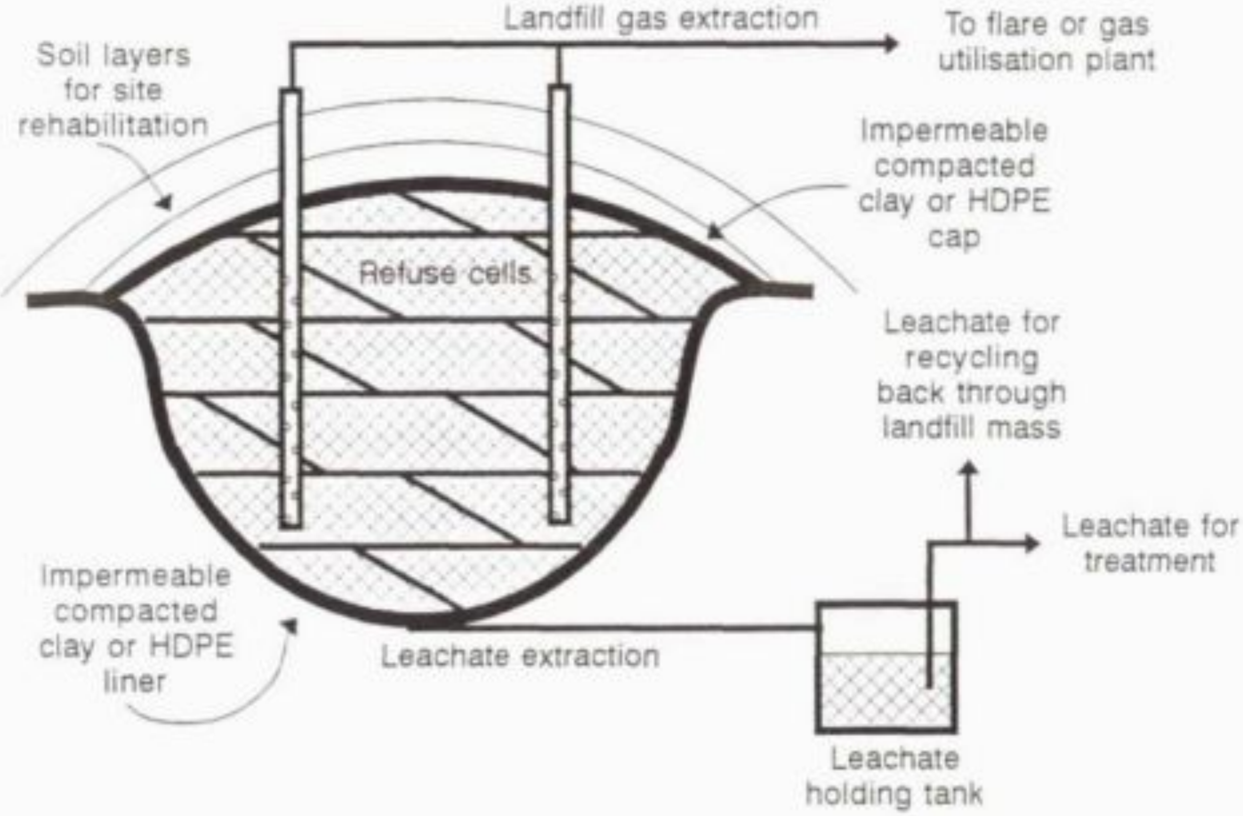


Figure 5.4 Typical containment landfill with the necessary environmental protection.

5.3.5 LANDFILL DECOMPOSITION PROCESSES

The anaerobic digestion metabolic process taking place in a waste-water sludge anaerobic digester and in a sanitary landfill are similar, except for the degree of moisture present in the two processes and the temperature. Digestion of waste-water sludge can be achieved in some 30 days at a moisture content of about 96% (4% total solids) and mesophilic temperatures (about 30 to 35°C) while stabilisation of refuse in a landfill could take longer than 100 years at ambient temperature, if the moisture content is as low as 30% (70% total solids).

The anaerobic decomposition process in each case can be described adequately and simply as occurring in the absence of oxygen in two stages involving two different types of bacteria. Figure 5.5 gives a simplistic illustration in 2 stages of the 5 phase theory of anaerobic digestion (Ross *et al.*, 1992):

First stage: The organic material present in the feed sludge or refuse is converted into organic acids (also called volatile fatty acids) by acid forming bacteria.

Second stage: These organic acids serve as the substrate (food) for the strictly anaerobic methane-producing bacteria, which convert the acids into methane and carbon dioxide.

The end result of each process is (Ross *et al.*, 1992):

(a) A well stabilised sludge or refuse in which 40 to 60% of the volatile solids have been destroyed;

(b) A combustible gas consisting of 60 to 70% methane with the remainder largely being carbon dioxide.

Figure 5.6 illustrates the solids breakdown path during the anaerobic digestion of a waste-water sludge.

5.4 WASTE-WATER SLUDGE CHARACTERISTICS FOR CO-DISPOSAL

5.4.1 INTRODUCTION

In waste-water treatment, waste sludges are derived from different processes. Each type of sludge has its own characteristics which in turn can vary from one treatment works to another (refer Item 4.3).

One of the major problems associated with waste-water sludge handling is the ultimate safe disposal of the treated sludge.

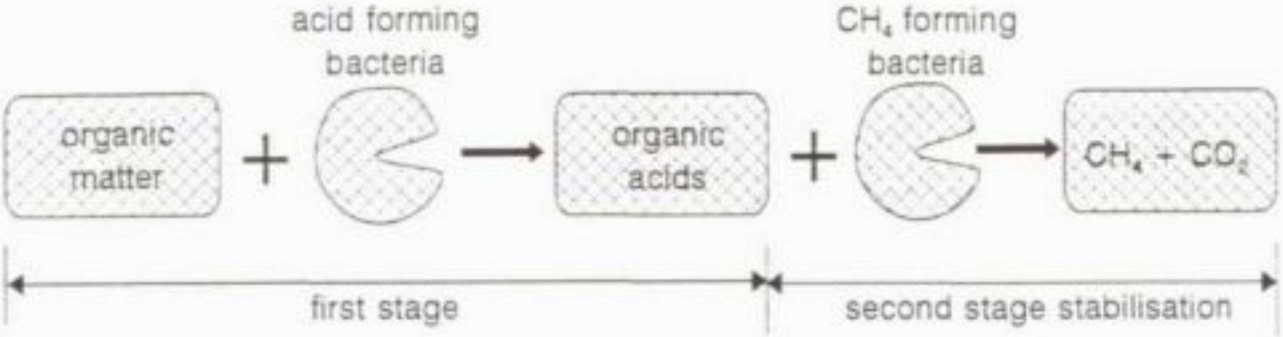


Figure 5.5 Two stages of anaerobic stabilisation (simplified version of 5 phase theory).

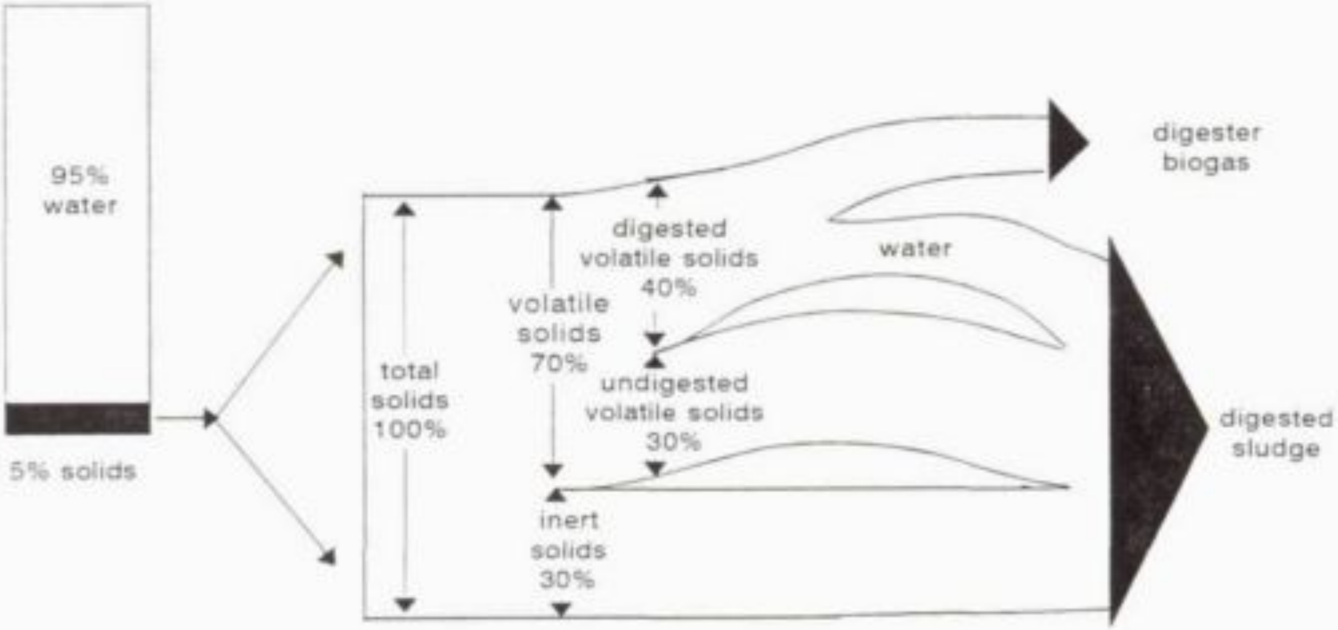


Figure 5.6 Sludge solids breakdown path during the anaerobic digestion process.

5.4.2 CITY OF CAPE TOWN WASTE-WATER SLUDGE SCENARIO

The sludges produced at the Cape Town Municipality's three waste-water treatment works are all anaerobically digested and land-dried, prior to disposal. Both the Cape Flats and Mitchell's Plain works produce an anaerobically digested mixture of thickened primary and waste-activated sludge, while the Athlone works produces an anaerobically digested thickened primary sludge only. The thickened waste-activated sludge component at the Athlone works is disposed of directly into the gravity sewer feeding the Cape Flats works, where it is withdrawn ultimately from the primary sedimentation tanks for conventional sludge treatment.

Currently, most of the dried digested sludge produced at the three treatment works is utilised by the Parks & Forests and Cleansing Branches of the Municipality for soil additive and composting purposes, respectively. The remainder of the sludge is used by local farmers and the general public. However, once the principles of the draft guide (DNHPD, 1991) become a requirement, current disposal options would have to be revised. Table 5.2 (Novella and Fawcett, 1992) indicates the possible classification of the various sludges, together with most feasible disposal options.

The sludge produced at the Cape Flats works is classified presently as a Type B sludge, but with full pasteurisation anticipated for 1995/96, the sludge will have unrestricted disposal options (i.e. Type D). It is envisaged, therefore, that a portion of the wet pasteurised and anaerobically digested sludge could be co-disposed at the Coastal Park landfill and that excess dried sludge could be utilised as a landfill cover.

5.4.3 SLUDGE TYPE USED FOR CO-DISPOSAL STUDIES AT COASTAL PARK

The sludge which was utilised in the co-disposal research was an anaerobically digested mixture of primary and waste activated sludge obtained from the 150 Ml/d Cape Flats waste-water treatment works situated adjacent to Coastal Park. Table 5.1 gives the average analysis as well as maximum and minimum values for selected parameters of the Cape Flats sludge.

TABLE 5.1 ANALYSES OF THE WASTE-WATER SLUDGE FROM CAPE FLATS WASTE-WATER TREATMENT WORKS, USED IN THE CO-DISPOSAL RUNS

		MIN	MAX	AVE
Total solids	%	1,8	2,6	2,2
Volatile solids	%	70,3	76,6	73,3
Total alkalinity	mg/ℓ $CaCO_3$	2140	3131	2558
Volatile acid alkalinity	mg/ℓ $CaCO_3$	87	205	153
pH		7,1	7,5	7,3

TABLE 5.2: SLUDGE DISPOSAL OPTIONS (Selected from Tables 2 & 3 of Draft Guide; Department of National Health and Population Development, 1991)

	OPTION	CF (existing)	CF (future)	ATH	MP
	TYPE OF SLUDGE	Type B	Type D	Type B	Type B
2	Household vegetables consumed raw or cooked	N/P	P (2)	N/P	N/P
5	Public gardens & traffic islands only for beautifying with minimum human contact	P (6)	P (6)	P (6)	P (6)
6	Public parks, recreation areas, lawns at schools, swimming pools, sportfields	P (2,6)	P (6)	P (2,6)	P (2,6)
7	Private gardens - lawns, shrubs, trees, vegetables	N/P	P (6)	N/P	N/P
13	Composting with other organic material	P	P	P	P
15	Land application - ploughed in repeatedly, landfill (co-disposal on landfill site)	P (4.5.6.8.9)	P	P (4.5.6.8.9)	P (4.5.6.8.9)

NOTE:
a) P = permissible
b) N/P = not permissible
c) figure in brackets = restriction (see ** below)
d) CF future = full pasteurisation
e) CF = Cape Flats Waste-water Treatment Works
f) ATH = Athlone Waste-water Treatment Works
g) MP = Mitchell's Plain Waste-water Treatment Works

**** RESTRICTION:**

2. Application only during planting.
4. Application permissible, only if the area is effectively fenced to keep out unauthorised persons as well as milk, meat and egg producing animals.
5. No subsequent selling or alienating of sludge or any mixture containing such sludge is allowed by the user.
6. All sludge must be covered with soil whenever possible.
8. Application of excessive quantities of waste-water sludge to land cause that site to be unfit for any other purpose during such operation and for a minimum period of two years after termination thereof.
   No nuisance or any other condition posing a potential health hazard or which may cause pollution of any water source will be tolerated on such site.
   Utilisation of this site for any other purpose will only be permitted after the necessary investigation has proved this to be safe.
9. Co-disposal with domestic waste in Class 2 disposal sites. Permit requirements in terms of the Environment Conservation Act, No. 73 of 1989, must be met. Limits can be set for As, Cr and Ni for sludge to be disposed of.

5.5 REFUSE CHARACTERISTICS FOR CO-DISPOSAL

5.5.1 CITY OF CAPE TOWN REFUSE SCENARIO

The Cape Town City Council is a Grade 15 municipality and has a population of some 1,3 million people (City Engineer, 1993). The City operates 14 cleansing districts and services some 200 000 domestic dwellings and commercial collection points. The current mode of collection, twice weekly using black bags, will be phased out over the next five years and is being replaced by the 240 litre 'once a week' container system.

Presently the municipal waste generated per capita in the Western Cape ranges from around 0,3 kg/d to some 1,5 kg/d. This averages out at between 0,8 to 1,0 kg/cap/d. The Cape Town Municipality is not involved in large scale recycling. However, recycling initiatives by private enterprise or other community based organisations (e.g. schools), are encouraged.

A portion of the waste is composted aerobically, then screened in a compost plant which has a capacity to produce some 8000 m^3 per annum (6200 ton wet mass) (Lord, 1991) of high grade municipal compost which is sold back to the community for use in gardens.

The Cape Town Municipality provides a regional waste disposal service and disposes of some 675 000 ton of municipal refuse at the city's three landfill sites (City Engineer, 1993). The City operates two class GLB$^+$ landfills (general waste, large landfill, leachate producing) one of which is Coastal Park and one class H:H (hazardous waste-hazard rating 1 & 2) landfill site.

5.5.2 REFUSE COMPOSITION USED FOR CO-DISPOSAL STUDIES AT COASTAL PARK

A project carried out during 1985 and 1986 was aimed at keeping a record of waste composition from all the Cleansing districts falling within the Cape Town Municipal area (Futre, 1986).

The refuse utilised for this co-disposal research project was primarily of domestic origin and originated from the Muizenberg and Mitchells Plain collection areas. These Cleansing Depots were therefore utilised as refuse feeder areas.

Table 5.3 gives the composition of municipal refuse from the Eastridge and Westridge Cleansing Depots in Mitchells Plain and the Muizenberg Cleansing Depot as well as average values for the whole City (Futre, 1986).

5.5.3 REFUSE MOISTURE CONTENT

The moisture content of the incoming refuse is of vital importance if the landfill site is utilised for a co-disposal practice in which a waste-water sludge liquor is added to the refuse. The refuse moisture content determines the amount of water in the form of the waste-water sludge which can be added so that the field capacity of the landfill is not exceeded. The determination of the water balance for a landfill site co-disposal operation is complex (Hojem, 1989a) and these aspects are discussed in more detail in Section 7.3.

TABLE 5.3 COMPOSITION OF REFUSE USED IN THE EXPERIMENTAL RUNS

CONSTITUENTS	EASTRIDGE	WESTRIDGE	MUIZENBERG	AVERAGE
Kitchen	21.8	25.4	25.2	24.1
Garden	7.7	6.4	3.6	5.9
Cardboard	2.2	2.8	2.8	2.6
Paper	24.7	24.9	27.6	25.7
Glass	7.1	7.2	10.1	8.1
Plastics	12.0	9.9	9.2	10.4
Textiles	5.9	5.1	5.7	5.6
Beverage (Cans)	0.6	0.8	0.5	0.6
Other Metals	5.2	5.7	5.8	5.6
Fines	3.7	3.3	3.2	3.4
Unclassified	9.1	8.5	6.1	7.9
	100	100	100	

* All values are % by wet or dry mass

Table 5.4 gives the average monthly moisture contents of refuse disposed of at Coastal Park for the period 1992 to 1993. From these figures and the mass of incoming refuse, the mass of moisture added to the landfill, due to the moisture content of the waste, can be calculated.

5.6 CONSTRUCTION OF CO-DISPOSAL LINES AND MACHINERY USED

5.6.1 INTRODUCTION

One of the major problems encountered with most forms of research is how to conduct the investigation so as to facilitate full-scale application of the results. Size of the experiment is often dependent on cost and how accurate and concise one requires the results, and in which manner the results are to be interpreted.

Size of experimentation varies from small in laboratory scale, followed by pilot-scale and prototype then to full-scale. Usually one builds on the conclusions of small scale units and carries out further research and development progressively to a larger scale.

The concept of co-disposal of waste-water sludge with refuse is not new and has been well researched: Pohland *et al.*, 1983; Pohland and Gould, 1986; Cossu and Serra, 1987; Blakey, 1991; Pohland, 1991; Chapman and Ekama, 1991; Watson-Craik *et al.*, 1992. Most of this research has been carried out in the laboratory or on pilot-scale. It was thus decided to research the application and subsequent monitoring as close to full-scale as possible in order to investigate the unknowns as set out in the objective and tasks of the project (Chapter 2) as well as to confirm some of the claims of other researchers.

TABLE 5.4 AVERAGE MONTHLY MOISTURE CONTENT OF DOMESTIC REFUSE DISPOSED OF AT COASTAL PARK

YEAR	MONTH	% MOISTURE (wet basis)
1991	August	35.7
	September	48.7
	October	29.2
	November	-
	December	38.4
1992	January	57.6
	February	30.1
	March	45.2
	April	-
	May	39.9
	June	42.0
	July	48.7
	August	52.6
	September	-
	October	-
	November	-
	December	-
1993	January	44.0
	February	44.5
	March	-
	April	50.3
	AVERAGE	43.4 %

5.6.2 CONSTRUCTION OF EXPERIMENTAL LINES

A major question which required answering was how to apply the sludge in a full-scale application and how this application would affect the operation of the landfill machinery. It was decided to construct refuse lines with size scaled down from that used in full-scale operation, but retaining the same operational methods and machinery used in full-scale landfilling procedures. Table 5.5 gives a comparison of the full-scale daily operation at the Coastal Park landfill with that utilised in the size-reduced research lines.

Two refuse lines were utilised in the research, one in which the co-disposal research was carried out and the other, with no sludge addition, which acted as a control. Both lines received the same amount of refuse and were treated in the same manner during each run (Figure 5.7).

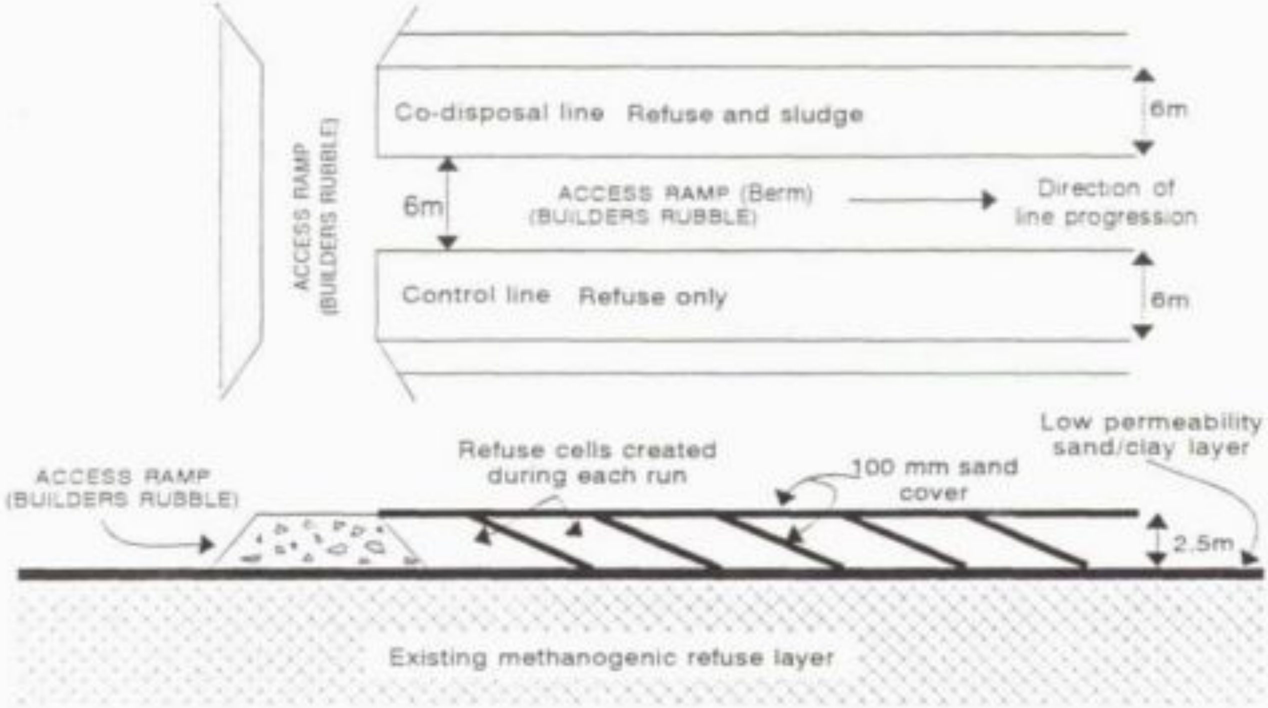


Figure 5.7 Layout of the experimental lines with specific reference to construction.

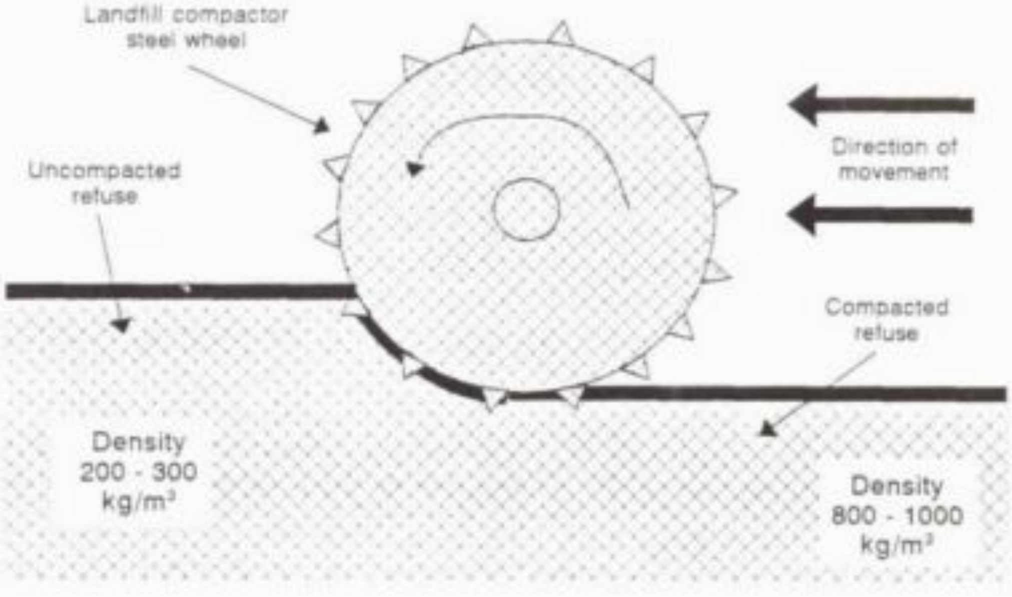


Figure 5.8 Effect of compaction with the steel wheel of the landfill compactor.

TABLE 5.5 **COMPARISON BETWEEN FULL-SCALE AND EXPERIMENTAL OPERATIONAL CRITERIA AT COASTAL PARK**

	EXPERIMENTAL RUNS	FULL-SCALE
Mass of refuse per day	± 30 ton	± 600 ton
Height of lift	2,5 m	2,5 m
Width of line	6.0 m	30 m
Gradient of slope	4:1	4:1
Distance moved per day	± 2 m	± 18 m
Number of loads per day	8	± 160

The two lines, which were 2,5 m high and 6 m wide, were separated by a rubble berm. This 2,5 m high rubble berm was constructed in a "T" shape and provided a ramp which enabled the refuse collection vehicles to drive up onto the lines in order to discharge the refuse. The central separating berm also provided access for the sludge tanker from which the sludge liquor was spread. The construction of the central berm progressed ahead of the two research lines.

Landfilling proceeded in a top to bottom method with the refuse collection vehicles discharging their loads on the top of the working face of the experimental lines. The landfill compactor then spread the refuse down the 4:1 slope of the working face in refuse layers some 300 to 400 mm thick. Once this was completed, the waste-water sludge containing some 2,2% total solids(m/v) was spread over the refuse in pre-determined ratios by means of two 50 mm flexible hosepipes attached to the sludge tanker.

As soon as the pre-determined quantities of refuse and sludge had been applied the refuse/sludge mixture was compacted using the steel wheeled landfill compactor. The compacting procedure was standardised and each section of the line received four passes with the compactor wheels (down and up represents one pass). The identical procedure was carried out on the control line containing refuse only. Both lines were covered with a 100 to 150 mm sand layer after each daily run.

Figure 5.8 shows schematically the effect of compaction with the steel wheeled landfill compactor whilst Figure 5.7 shows the layout of the experimental lines with special reference to their construction.

The lines were constructed on top of a previously landfilled layer of refuse which was in the methanogenic stage. This was intended to prevent any possible pollution resulting from the addition of the waste-water sludge from reaching the ground water without passing through a methanogenic layer. The interface between the bottom of the experimental lines and the top of the previously landfilled layer comprised of a 300 to 400 mm compacted layer of a low permeability clay / soil mixture. The rubble berm was constructed of waste builders rubble which comprised mainly of old bricks, mortar and sand/soil. A bulldozer was used to build and shape the berm. Figure 5.7 gives the dimensions of the berm.

5.6.3 MACHINERY USED

The following machinery and vehicles were used in the research project in order to carry out the experimental landfilling:

(a) **Landfill Compactor**

Type:	CAT
Gross Mass:	9592 kg
Compressing Force:	45.25 kg/cm

This machine was used to spread and compact the refuse in approximately 300 to 400 mm layers. An average of four compaction passes were made per layer.

(b) **Bulldozer with Towed Scraper**

Bulldozer Type:	CAT D6
Scraper Capacity:	$15m^3$

The bulldozer was used as a solo machine to build and shape the rubble berm.
The bulldozer/scraper combination was used to collect and spread the cover material over the exposed refuse to a depth of approximately 100 to 150 mm after each test run.

(c) **$8m^3$ Sludge Tanker**

This vehicle was used to collect the digested waste-water sludge liquor from the adjacent Cape Flats Waste-water Treatment Works and transport it to the landfill site. The sludge was applied directly from the tanker by means of two 50 mm flexible hand-held hoses. The sludge was applied after the refuse was spread out and prior to the compaction process.

(d) **$12m^3$ Refuse Collection Vehicles**

Average Payload:	± 4300 kg
Density of Full Payload:	300 to 370 kg/m^3

These rear loading refuse collection vehicles, of the compacting variety, were used to collect household refuse and their contents were discharged onto the experimental lines as required.

CHAPTER 6
EXPERIMENTAL RESULTS

6.1 INTRODUCTION

Before embarking on the actual data collection it was necessary to identify the constraints in the system. Projects of this nature have certain monitoring limitations, with problems arising out of the scale of the project and the physical aspects of the material, in which the processes to be monitored are occurring. In this project, the refuse was deposited straight from the collection truck and, being unsorted, consisted of the most heterogeneous assortments possible. Unlike smaller scale investigations which have been carried out elsewhere, where specially prepared refuse (either shredded, milled or simulated) has been used, it was considered of little benefit to carry out analysis of small isolated portions of the refuse mass. These would be unlikely to be representative of the mass as a whole and any chemical or biological test results could be very misleading. Better conclusions could be drawn from results obtained on the large and more homogeneous end-products such as the landfill gas and the leachate. Where it was necessary to sample the landfill itself, the largest sample practicable was taken. The results of the moisture determinations which had to be carried out on manageable samples proved to be problematical with a low level of confidence, attributed to the heterogeneity of the sample and waste in the landfill.

Taking cognisance of the above, it was therefore decided that the following parameters would give adequate and meaningful results within the constraints of the project:

- Operational parameters - the workability of the refuse and sludge mixtures by means of the landfill compactor and the manoeuvrability of the machine in the mixtures were selected as important practical operational criteria;
- Moisture content of the landfilled waste;
- Density and compaction of the landfilled waste;
- Landfill biogas constituents;
- Leachate generation and selected quality parameters; and
- Meteorological considerations.

6.2 OPERATIONAL CO-DISPOSAL RATIOS

6.2.1 INTRODUCTION

Optimisation of the co-disposal ratios as well as operation at the optimum ratios involved some 50 experimental runs spanning a period of some 18 months. In dealing with optimising the co-disposal of waste-water sludge with refuse two important questions had to be answered:

a) How much sludge could be added to ensure that the field capacity of the landfill is not exceeded?

b) How much sludge could be added to ensure that the landfill machinery was still able to operate successfully in the waste?

Cape Town experiences a mediterranean climate with wet winter months and dry summer months (refer Section 5.2) which necessitated the process to be optimised for both the winter and summer periods.

Once the optimisation was completed for each seasonal period, operation at the optimum ratio for an extended period took place, during which time the long term effects of operating at those specific ratios were determined.

6.2.2 OPERATIONAL OPTIMISATION PROCEDURES (refer also to Section 5.6)

Once the pre-determined number of refuse truck loads and the correct volume of sludge had been applied to the experimental lines at Coastal Park, the refuse and sludge mixture was compacted using the steel wheels of the landfill compactor.

The workability of the mixture of refuse and sludge by means of the landfill compactor and the manoeuvrability of the machine in the mixture, were highlighted as extremely important practical operational criteria. Landfill compactor machines are required to work for extended periods in order to ensure that all waste which is deposited each day is spread, compacted and covered.

The addition of waste-water sludge (liquor or cake) should not prejudice the landfilling operation, especially with regards to the operation of the landfill compactor. The following terminology was developed in order to describe the workability and manoeuvrability of the compacting machine.

- **Critical Working Ratio** - is that ratio at which the landfill compactor machine is just able to work successfully in the mixture.

- **Safe Working Ratio** - is that ratio at which the landfill compactor machine is able to work successfully for unlimited periods without getting damaged or stuck. The Safe Working Ratio was developed to ensure that the landfill compactor would not labour unnecessarily during full-scale operation. A practical safety margin of 33 per cent was added to the Critical Working Ratio to achieve this.

6.2.3 RESULTS OF OPTIMISATION EXPERIMENTAL RUNS

Table 6.1 gives a summary of the comments made during the optimisation runs on the workability and manoeuvrability of the landfill compactor in relation to the ratio (by volume) of refuse to sludge. These comments relate to the first optimisation period in which both the critical and safe working ratios were obtained for the wet winter period, during May 1991, in the Western Cape.

It must be noted that the ratios are generally given in volume of refuse to volume of sludge. The volume of refuse is that as measured in a full refuse collection vehicle (rear loading compactor) with densities of some 300 to 370 kg/m^3 (average 335 kg/m^3).

TABLE 6.1 OBSERVATIONS DURING THE WINTER OPTIMISATION RUNS

CO-DISPOSAL RATIO BY VOLUME (REFUSE TO SLUDGE)	COMMENTS ON LANDFILL COMPACTOR MACHINE WORKABILITY AND MANOEUVRABILITY
12:1	No noticeable difference existed between the co-disposal and control lines.
6:1	The compacting machine tended to sink lower into the refuse/sludge mixture, resulting in slightly more difficult movement.
4,5:1	The compacting machine sank deep into the mixture, with the belly plate under the machine occasionally touching the mixture. Manoeuvrability of the machine was still possible although it was more difficult than the 6:1 ratio.
3:1	This ratio was found to be too wet as the compacting machine sank deep into the mixture and the belly plate of the machine was dragged over the wet surface. The manoeuvrability was retarded at this ratio.

From the observations as listed in Table 6.1 it was deduced that the ratio (by volume) of 4,5:1 refuse to sludge (by mass 1,5:1; i.e. 1500 kg refuse added to 1000 kg sludge) was the Critical Working Ratio and that ratios below this value would be too wet. The Safe Working Ratio of 6:1 by volume (by mass 2:1; i.e. 2000 kg refuse added to 1000 kg sludge) of refuse to sludge was obtained by simply adding the margin of safety (33%) to the Critical Working Ratio.

Similarly, Table 6.2 gives a summary of the observations obtained during the second optimisation period which was carried out during the dry summer months, during December 1991, in the Western Cape.

From the observations listed in Table 6.2 it was deduced that the following ratios (by volume) would be applicable to the dry summer months:

Critical Working Ratio : 3:1
Safe Working Ratio : 4:1

Figure 6.1 shows all the refuse/sludge volume ratios which were utilised during the optimisation runs. The optimisation runs for the Winter and Summer months are highlighted on the figure.

Table 6.3 gives the results as obtained during the optimisation periods, by volume and mass for the critical and safe working ratios.

TABLE 6.2 OBSERVATIONS DURING THE SUMMER OPTIMISATION RUNS

CO-DISPOSAL RATIO BY VOLUME (REFUSE TO SLUDGE)	COMMENTS ON LANDFILL COMPACTOR MACHINE WORKABILITY AND MANOEUVRABILITY
6:1	Very little difference was noticed between the co-disposal and control lines. The mixture appeared dry.
4,5:1	The landfill compactor tended to sink deeper into the refuse/sludge mixture. Operation was successful.
3:1	The machine sank deep into the refuse/sludge mixture; operation appeared to be at the limit but still possible; belly plate did not touch the waste.

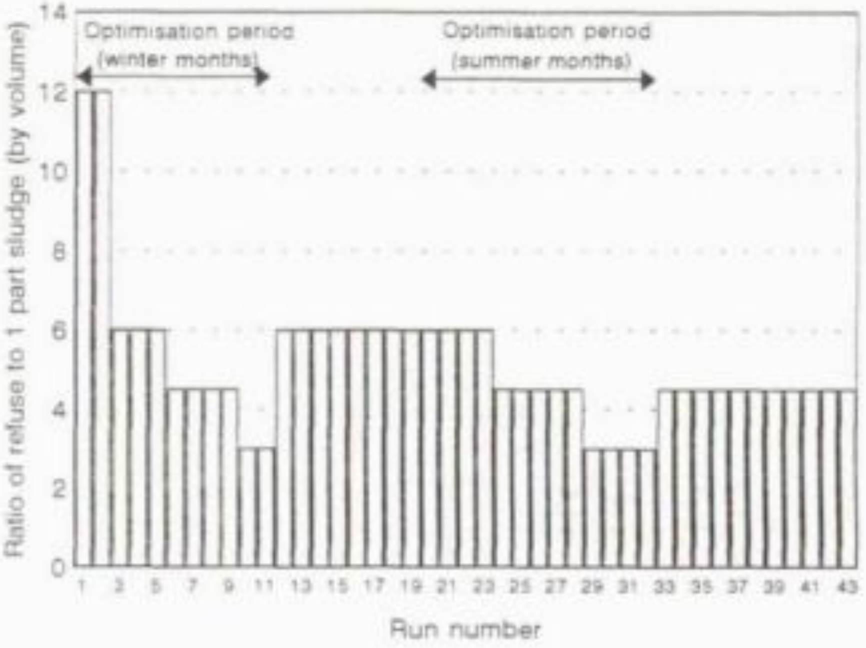


Figure 6.1 Refuse / sludge ratios utilised during the optimisation periods.

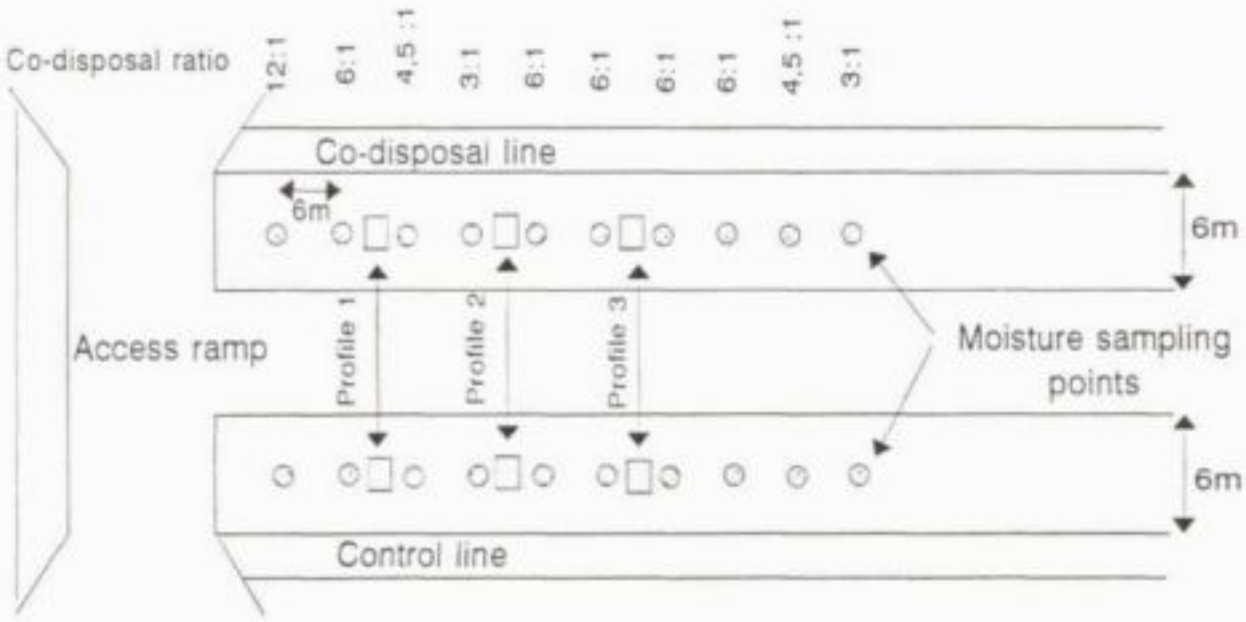


Figure 6.2 Location of the moisture sampling points and moisture profile holes on the experimental lines.

TABLE 6.3 RESULTS OF THE CO-DISPOSAL EXPERIMENTAL RUNS FOR WINTER AND SUMMER PERIODS

SEASON	CRITICAL WORKING RATIO		SAFE WORKING RATIO	
	By Volume	By Mass	By Volume	By Mass
WINTER	4,5 : 1	1,5 : 1	6 : 1	2 : 1
SUMMER	3 : 1	1 : 1	4 : 1	1,3 : 1

NOTE : All ratios are "refuse-to-sludge liquor"
Average density of refuse: 335 kg/m^3
Average solids concentration of sludge : 2,2% (m/v)

6.3 MOISTURE CONTENT OF THE LANDFILLED WASTE

6.3.1 INTRODUCTION

Various factors affect the rate of bacterial degradation of the organic fraction of municipal refuse in a landfill. These include amongst others:

- Type of bacteria present
- Availability of food (substrate)
- Type of food (substrate) present
- Availability of nutrients
- Presence of toxic materials
- pH
- Temperature
- Moisture content
- Degree of anaerobic conditions (absence of oxygen)

Moisture content has been highlighted as one of the major factors determining the rate of anaerobic breakdown of refuse in a landfill bioreactor (Ross, 1990a; Senior *et al.*, 1991; Pohland, 1991). In controlled co-disposal, the solid waste absorbs excess moisture from the waste-water sludge and reduces leachate migration.

Moisture is of prime importance in solid-state anaerobic decomposition, for transporting microbial metabolites and acting as solvent in which chemical reactions can take place. Lema *et al.* (1988) report that anaerobic biodegradation of organic material is usually stimulated when a landfill has a water content of 50 - 70% - a figure unlikely to be reached in dry areas or during dry periods elsewhere. In comparison, Parr *et al.* (1982) report the optimum moisture for rapid decomposition in aerobic composting as being 50-60%.

The movement of moisture has also been shown to be a factor in stimulating gas production (Hartz and Ham, 1983; Klink and Ham, 1982). The movement of moisture is only significant when the moisture content of the refuse in the landfill is equal to or greater than the field capacity (Barlaz *et al.*, 1987). The main effect of increased moisture content is probably the facilitated exchange of substrate, nutrients, buffer, dilution of inhibitors and spreading of microorganisms between the waste micro-environments (Christenson and Kjeldsen, 1989).

The monitoring of moisture content of the landfilled waste in the control as well as the co-disposal lines was, therefore, considered to be of vital importance.

6.3.2 MOISTURE DETERMINATIONS

The taking of representative samples of landfilled waste is not an easy task, nor is the subsequent laboratory analysis. The methodology followed in these moisture determinations can be obtained from the Scientific Services Branch, Cape Town City Council.

6.3.3 RESULTS OF MOISTURE DETERMINATIONS

The location of the moisture sampling points are indicated in Figure 6.2. The analytical results of these samples, taken at a depth of 1 m into landfilled waste in the experimental lines, are shown in Table 6.4 and graphically represented in Figure 6.3.

TABLE 6.4 MOISTURE CONTENT OF SAMPLES FROM THE CONTROL AND CO-DISPOSAL LINES

DATE		CONTROL LINE	CO-DISPOSAL LINE		
Placement	Sampling time after placement (months)	Moisture (%)	Co-disposal Volume Ratio (Refuse to Sludge)	Moisture (%)	
				Theor.	Actual
91-06-01	4	24,9	12:1	37	22,6
91-06-28	4	32.7	6:1	46	29,6
91-07-18	4	29,9	4,5:1	51	38,4
91-08-15	5	24.8	3:1	62	26,7
91-09-19	4	33.8	6:1	46	34,1
91-10-04	8	29,5	6:1	46	40,6
91-11-07	7	29,9	6:1	46	46.3
91-12-05	8	31,5	6:1	46	32,7
92-01-23	12	18,9	4,5:1	46	22,1
92-03-05	19	30,6	3:1	51	40,0

Figure 6.3 gives a plot of all the moisture values as tabulated in Table 6.4. It can be seen that the actual moisture content of the refuse to sludge mixture within the co-disposal line (in the range 22 to 46 %) was significantly less than that of the theoretically calculated value (in the range 37 to 62 %). This indicates that less moisture was being held in the refuse than was expected. The lower moisture content was possibly due to a combination of factors such as evaporation and leachate migration. According to the literature (Lema *et al.*, 1988) the determined moisture contents of both the control and co-disposal lines (22 to 46 %) was likely to be below the optimum moisture requirements for solid-state anaerobic decomposition.

Three profile sampling runs were also carried out at certain points in both lines in order to ascertain whether any variation with depth existed in the moisture content of samples taken at 0,5 m intervals from the surface. The three profile sampling points are indicated on Figure 6.2 and the results obtained are tabulated in Table 6.5 and plotted in Figures 6.4, 6.5 and 6.6.

Interpretation of this data indicates that no significant difference in moisture content between the control and co-disposal lines has resulted from the addition of the waste-water sludge liquor. In two of the three determinations the moisture content of the co-disposal line was less than that of the control line. This ambiguity can possibly be ascribed to channelling and to the methodology of sampling for the moisture content.

TABLE 6.5 RESULTS OF PROFILE MOISTURE DETERMINATIONS

DEPTH (DOWN FROM SURFACE)	MOISTURE (%)					
	PROFILE 1		PROFILE 2		PROFILE 3	
	CONTROL	CO-DISPOSAL	CONTROL	CO-DISPOSAL	CONTROL	CO-DISPOSAL
0,5 m	37,9	24,5	27,4	38,9	36,4	34,8
1,0 m	38,2	22,6	20,9	32,9	35,4	21,2
1,5 m	38,8	21,1	33,6	34,2	44,6	19,1
2,0 m	40,1	44,5	24,8	40,7	39,2	21,5
2,5 m	32,1	32,3	15,5	31,6	34,0	20,2
Co-disposal volume ratio	-	4,5:1 to 6:1	-	3:1 to 6:1	-	6:1
Months after refuse placement	14	14	16	16	24	24

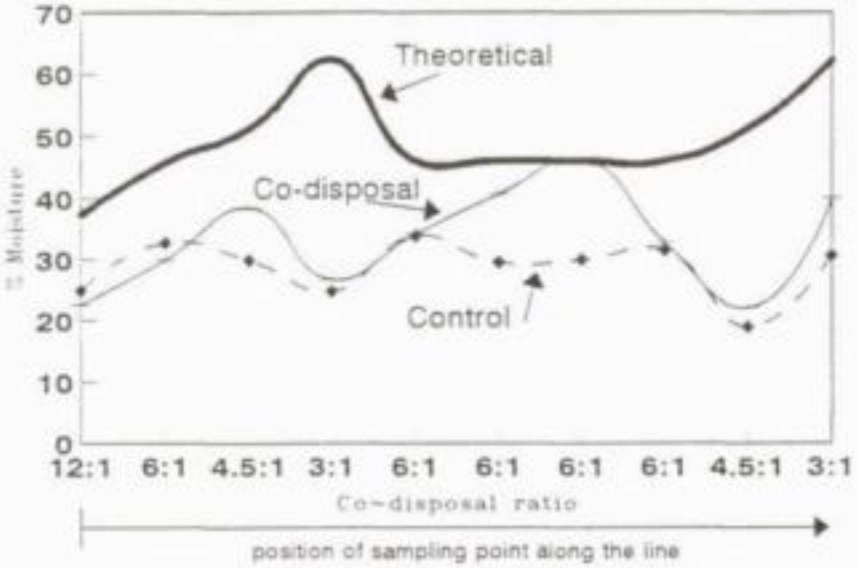


Figure 6.3 Moisture content on samples from the experimental lines including the theoretical values for the co-disposal line.

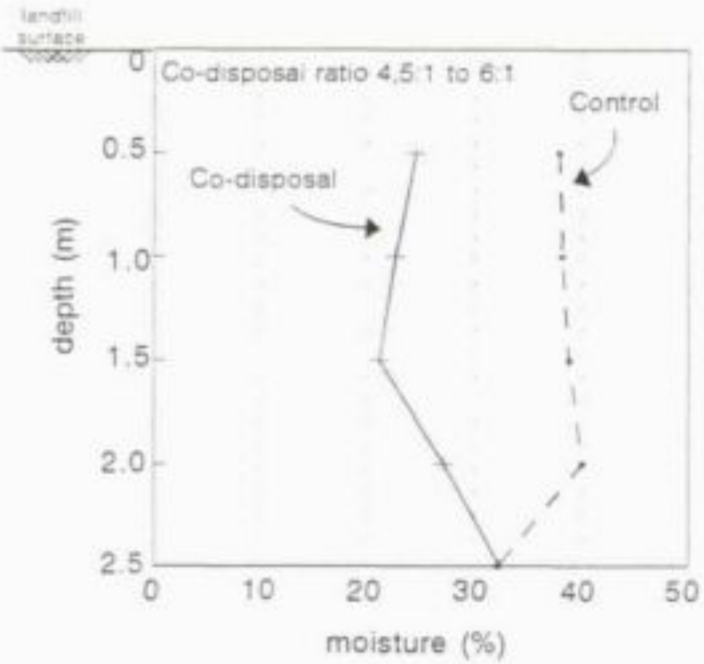


Figure 6.4 Moisture content for Profile 1 sampling point.

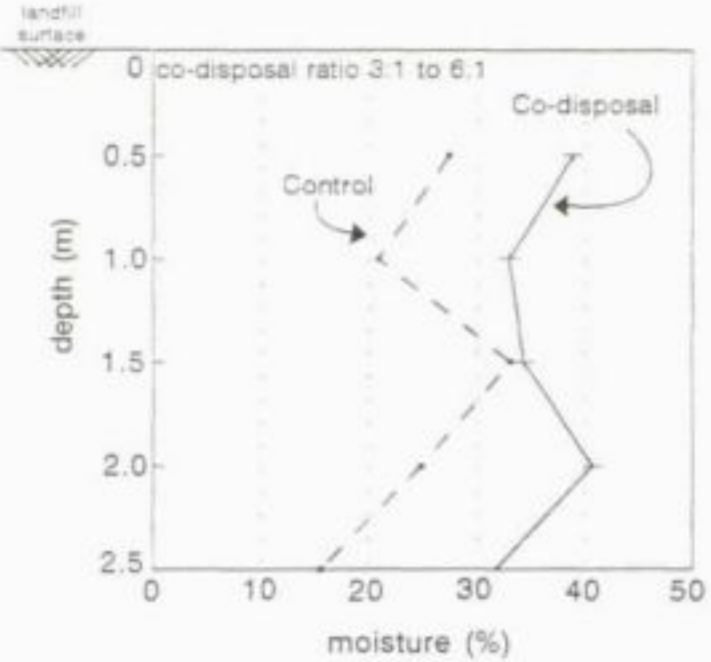


Figure 6.5 Moisture content for Profile 2 sampling point.

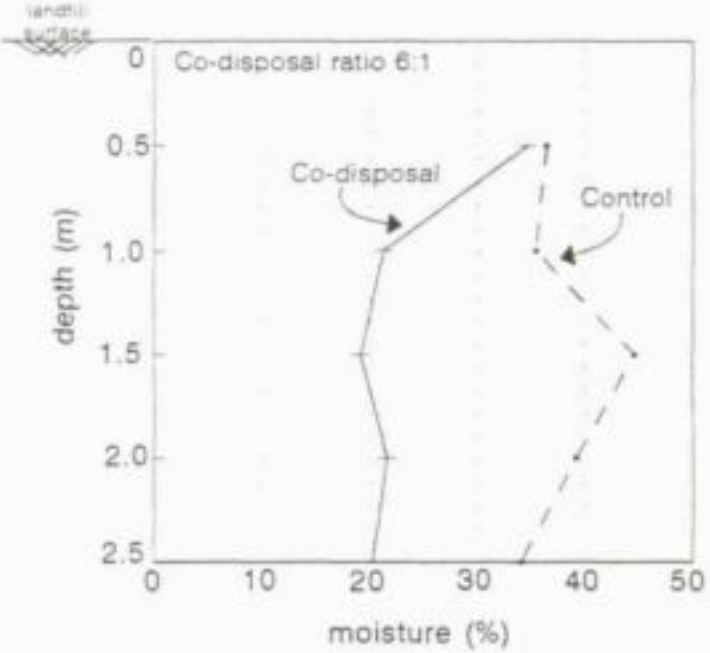


Figure 6.6 Moisture content for Profile 3 sampling point.

6.4 COMPACTION (BULK DENSITY)

6.4.1 INTRODUCTION

The absence of free oxygen is an absolute requirement for the anaerobic stabilisation process occurring within the landfill. Presence of oxygen in the landfill is usually limited to the top 1 m of the compacted waste. The compaction process reduces the aerobic phase of refuse stabilisation by displacing air caught up in voids within the refuse. The remaining oxygen is subsequently used up immediately after landfilling in aerobic decomposition of the easily biodegradable organic matter (Christensen and Kjeldsen, 1989).

Compaction is utilised in sanitary landfilling as a method of volume reduction or densification in the landfilling process. The overall success of the landfilling operation depends to a large extent on this compaction process. The efficiency of landfill compaction may be judged directly by the densities which are achieved whilst the optimum use of landfill volume dictates whether a site is economically competitive (Pavoni *et al.*, 1975).

Although benefits from high densities in a landfill are evident, there is possibly a point beyond which the biological processes slow down. It has been shown that at moisture contents of some 65%, methanogenesis is promoted in low density refuse (200 kg/m^3) compared to high density refuse (800 kg/m^3) (Verstraete *et al.*, 1984). Contrasting results have, however, also been obtained where a density increase from 320 to 470 kg/m^3, at constant moisture content (21%) effected a doubling of gas production rate (Rees, 1982).

6.4.2 *IN SITU* DENSITY DETERMINATIONS

The methodology followed in ascertaining the *in situ* density of previously landfilled refuse in the control and co-disposal lines can be obtained from the Cleansing Branch, Cape Town City Council.

6.4.3 RESULTS OF DENSITY DETERMINATIONS

Figure 6.7 shows the location of the sampling points for density determinations on the experimental lines as well as the co-disposal volume ratios (refuse to sludge). Table 6.6 gives the results of all the density determinations on both the control and co-disposal lines. This data is presented graphically in Figure 6.8.

The densities obtained (Table 6.6) for the control and the co-disposal lines have been statistically evaluated and the results are given in Table 6.7.

From the above statistical results it can be seen that there is very little difference between the two sets of data. From Table 6.6 and Figure 6.7 it can be seen that the density in the co-disposal line was found to be higher than that of the control line for 70% of the samples tested. If only these results are considered, then the density in the co-disposal line was some 8% higher than that of the control line.

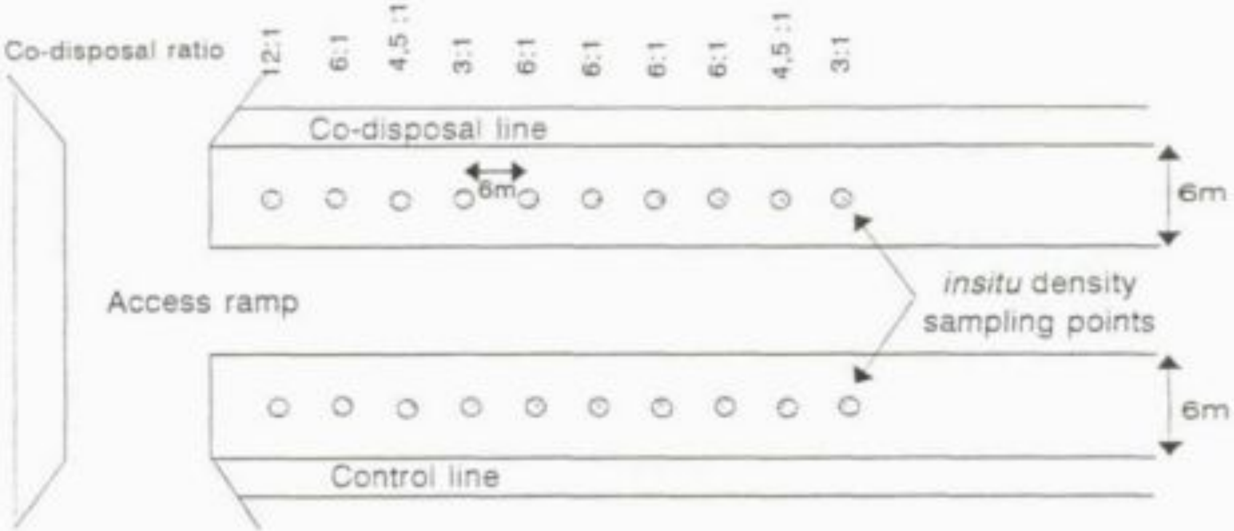


Figure 6.7 Location of the density determinations on the experimental lines.

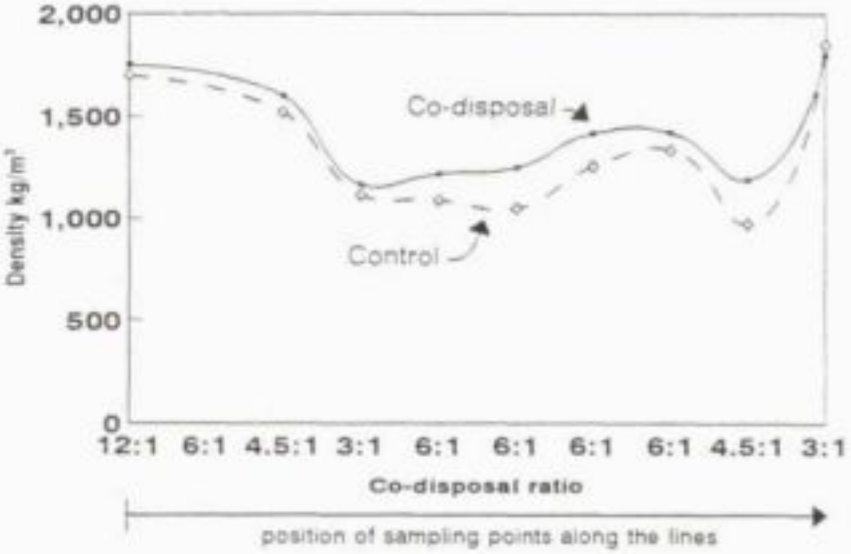


Figure 6.8 Density results from sampling points on the experimental lines.

The use of sand as cover material in sanitary landfilling is discussed briefly in Chapter 5. Sand was used in both the co-disposal and control lines as cover. However, because the daily cell was considerably smaller in volume, than in a full-scale application, the ratio of sand to refuse in the compacted waste was found to be much higher.

TABLE 6.6 DENSITY OF LANDFILLED REFUSE IN THE CONTROL AND CO-DISPOSAL LINES

		CONTROL LINE	CO-DISPOSAL LINE	
DATE OF PLACEMENT	TIME AFTER PLACEMENT (MONTHS)	DENSITY (kg/m^3)	CO-DISPOSAL VOLUME RATIO	DENSITY (kg/m^3)
1991-06-01	4	1 700	12:1	1 750
1991-06-28	4	1 730	6:1	1 320
1991-07-18	4	1 520	4.5:1	1 600
1991-08-15	5	1 115	3:1	1 165
1991-09-19	4	1 090	6:1	1 220
1991-10-04	8	1 050	6:1	1 250
1991-11-07	7	1 255	6:1	1 417
1991-12-05	8	1 335	6:1	1 421
1992-01-23	12	1 192	4.5:1	974
1992-03-05	19	1 850	3:1	1 800

TABLE 6.7 STATISTICAL COMPARISON BETWEEN DENSITIES OBTAINED IN THE CONTROL AND CO-DISPOSAL LINES

	CONTROL	CO-DISPOSAL
n	10	10
MIN	1050	974
MAX	1850	1800
MEAN	1384	1392
MEDIAN	1295	1368
STD.DEV(S)	279	249

Table 6.8 gives the percentage sand in both the control and co-disposal lines for two different positions in the lines sampled at different times. As a comparison the percentage sand at Coastal Park on the full-scale landfill ranges from some 10 to 20 per cent.

TABLE 6.8 QUANTITY OF COVER MATERIAL (SAND) IN THE CO-DISPOSAL AND CONTROL LINES

		%SAND	
DATE OF PLACEMENT	TIME AFTER PLACEMENT (months)	CONTROL	CO-DISPOSAL
1991-07-18	4	38,4	38,1
1992-03-05	7	34,2	30,3

Table 6.9 gives results for the routine *in situ* density measurements carried out on the full-scale landfill at Coastal Park. These results, which give densities 3 months after refuse placement for the period 1991 to 1993, have been included to facilitate comparison with the refuse landfilled in the control and co-disposal lines.

TABLE 6.9 DENSITY MEASUREMENTS FROM THE FULL-SCALE COASTAL PARK LANDFILL (3 MONTHS AFTER REFUSE PLACEMENT)

SAMPLING DATE		DENSITY (kg/m^3)
1991	MARCH	920
	JULY	952
	SEPTEMBER	1463
	DECEMBER	1078
1992	MARCH	991
	JUNE	1010
	SEPTEMBER	1144
	DECEMBER	1044
1993	MARCH	1258
	JUNE	884
	OCTOBER	1060
	DECEMBER	1332

6.5 LANDFILL GAS

6.5.1 INTRODUCTION

The anaerobic biological stabilisation process occurring within a landfill involves the transformation of complex biodegradable organic material to mainly methane and carbon dioxide. This mixture of gases is generally referred to as biogas or more specifically in this context as landfill gas.

Landfill gas is produced in fairly large volumes from landfilled municipal refuse. One ton of biologically degradable material produces 416 m^3 of methane gas; therefore, 1 ton of municipal refuse will produce 208 m^3 of methane gas (Letcher, 1990) - this assumes that about 50% of municipal refuse is biodegradable.

Landfill gas is classified as hazardous because of its explosive nature and inflammable methane content (45 to 65%). Poor control measures have resulted in several dangerous situations (Lombard and Jewaskiewitz, 1990). Methane is now recognised as a contributory factor in global warning and is one of the so-called greenhouse gases (Penkett, 1989).

Landfill gas is, however, very useful and can be used in many different ways, some more financially viable than others. In the UK, in 1992, there were no fewer than 40 schemes utilising landfill gas. Of these, some 15 were classified as direct use with the balance being for power generation (Aitchison, 1992). In South Africa, biogas from landfill is being used by AECI for cyanide production (Hill, 1990). There is, however, a large range of applications including electricity generation, household hot water systems, office heating, clay drying, lighting, cooking and brick-firing which could be considered (Letcher, 1992). More recently the viability of utilising purified methane gas as an alternative fuel for petrol powered vehicles has been investigated by the Atomic Energy Corporation (Coetzer *et al.*, 1993).

It is widely accepted that co-disposal of an anaerobically digested waste-water sludge with domestic refuse could speed up the onset of the methanogenic phase in a landfill. This in turn could shorten the length of the acidogenic/acetogenic phases (Ross, 1990b; Hojem, 1989b; Watson-Craik *et al.*, 1992) and thus hasten the stabilisation of the landfill and lessen the pollution potential.

6.5.2 EXPERIMENTAL SET-UP

In order to effectively monitor concentrations of the main components (CH_4, CO_2, N_2 and O_2) of landfill gas produced in the two experimental lines, six gas extraction wells were inserted into the refuse. Three wells were inserted in the control line and three in the co-disposal line.

Figure 6.9 shows schematically the positions of the gas sampling wells in both the control and co-disposal lines in relation to the co-disposal ratio applied in the co-disposal line. An existing well placed in methanogenic refuse some distance away from the experimental lines was used as an overall control well, against which all gas results obtained in the co-disposal research could be compared.

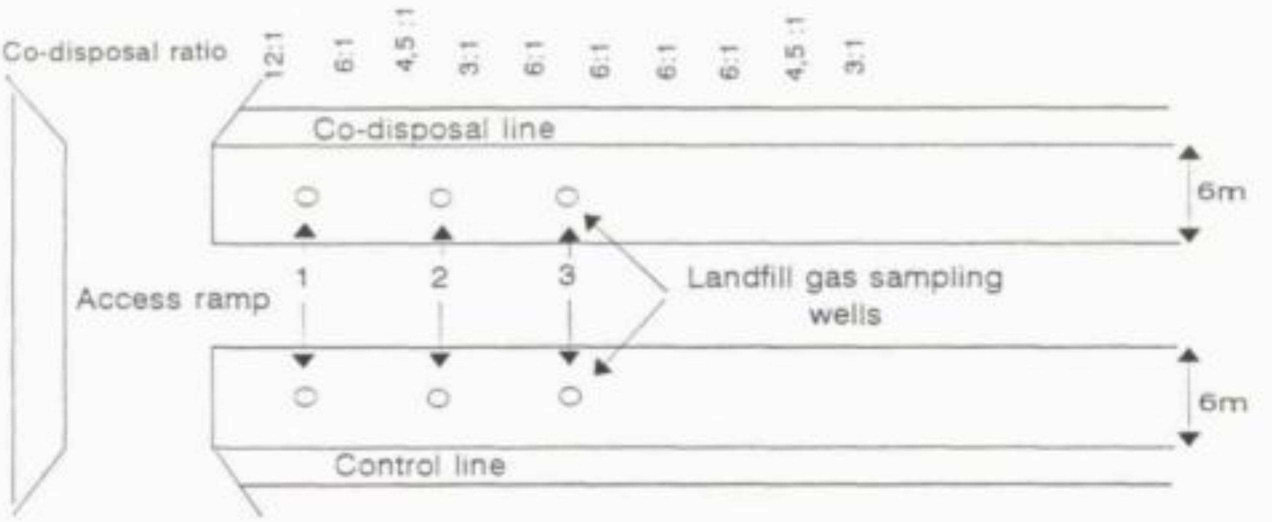


Figure 6.9 Location of the landfill gas sampling wells on the control and co-disposal lines.

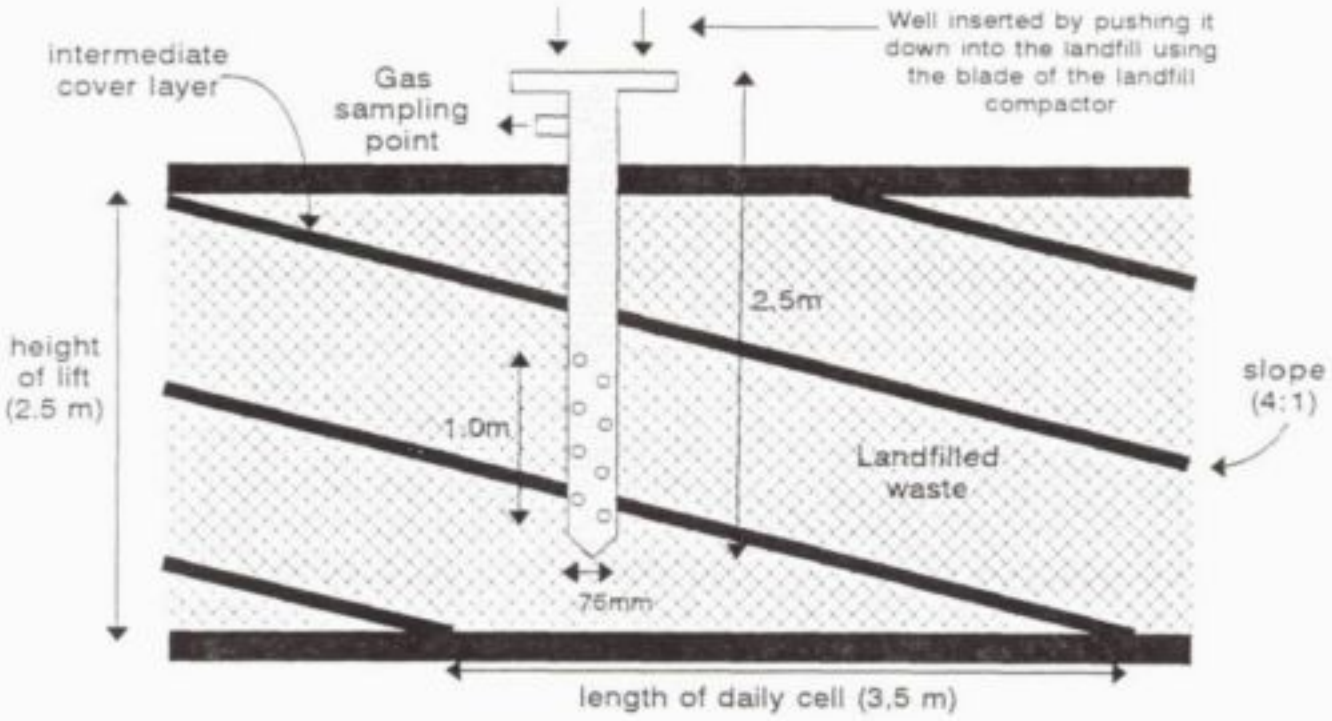


Figure 6.10 Details of the landfill gas sampling wells inserted in the experimental lines.

The gas wells utilised in this experiment were custom made using mild steel. The shape included a sharp point on the lower end and a flat heavy plate on the upper end. This design enabled the wells to be easily pushed down into the landfilled waste using the blade of a landfill compactor as a hammer. The details of the gas well and its installation is given in Figure 6.10.

Details of the gas sampling and analysis methods utilised in the research can be obtained from the Scientific Services Branch, Cape Town City Council.

6.5.3 RESULTS OF GAS MONITORING PROGRAMME

Landfill gas contains essentially methane and carbon dioxide. However, small quantities of nitrogen and oxygen are also found. The other constituents which are found are usually classified as impurities and their concentrations are generally very low. A full assay of landfill gas composition is difficult and costly to carry out. Therefore, it was decided only to determine the main components; methane, carbon dioxide, nitrogen and oxygen.

Table 6.10 gives the results for these gases for the first set of two wells whilst Tables 6.11 and 6.12 gives the results for the second and third sets respectively.

Table 6.13 gives the results which were obtained for methane, carbon dioxide, oxygen and nitrogen on samples taken from the overall control well situated some 250 m away from the co-disposal research site, in refuse which was landfilled about 9 years previously and is presently in the methanogenic phase. This well, which is of the same design and dimensions as the wells used in the co-disposal studies (Figure 6.10) was originally placed some 5 years ago as part of another research project which investigated the quantity and quality of landfill gas for possible use in a purified form as a fuel for vehicles.

Figure 6.11 gives a graphical presentation of the results given in Table 6.10 for the first set of gas wells in the control and co-disposal lines. Similarly Figures 6.12 and 6.13 give plots for the results of the second and third sets of gas wells as tabulated in Tables 6.11 and 6.12 respectively. Figure 6.14 gives the plot of the results which were obtained for the overall control well. As a comparison, Figure 6.15 gives plots of the methane results from all six experimental wells.

The analyses as illustrated in Figure 6.15 indicates that methanogenesis may have been delayed in the earlier samples, due to the addition of the waste-water sludge. This phenomenon is thought to be due to increased concentrations of volatile acids in the co-disposal line as a result of possible accelerated acido/acetogenesis. Similar conditions were detected in pilot lysimeter co-disposal studies (Chapman and Ekama, 1991).

However, it must be noted that gas concentration and not gas volumes were measured. Therefore, it is difficult to say with confidence whether methanogenesis was inhibited or not, as it is possible to have enhancement of biogas production along with lower concentrations of some of the product gases.

TABLE 6.10 LANDFILL GAS ANALYSES FOR THE FIRST SET OF WELLS IN THE CONTROL AND CO-DISPOSAL LINES

MONTHS AFTER PLACEMENT	GAS CONCENTRATION (%)							
	WELL 1 (CONTROL)				WELL 1 (CO-DISPOSAL)			
	CH_4	CO_2	O_2	N_2	CH_4	CO_2	O_2	N_2
4	16.2	12.2	20.1	51.5	12.6	10.1	19.9	57.4
5	18.0	14.3	18.9	48.9	0.5	0	28.0	71.5
6	18.3	14.3	18.8	48.7	2.2	1.0	27.1	69.7
7	20.2	14.3	18.1	47.3	2.6	1.5	26.6	69.3
8	46.5	39.4	3.1	11.0	43.5	36.8	3.7	16.0
9	51.9	42.5	1.1	4.5	49.9	42.2	0.9	7.0
10	56.5	42.9	0.2	0.4	58.8	40.6	0.2	0.4
11	57.6	40.8	0.5	1.1	42.9	26.6	8.5	22.0
12	58.7	40.2	0.3	0.8	60.3	38.8	0.2	0.7
13	61.1	38.1	0.3	0.5	59.1	39.9	0.4	0.6
14	59.6	40.1	0.1	0.2	61.5	38.0	0.1	0.4
15	59.6	40.2	0.1	0.1	61.5	37.9	0.2	0.4
16	59.9	38.1	0.6	1.4	61.5	38.3	0.1	0.1
17	57.0	41.5	0.3	1.2	57.8	39.2	0.3	2.7
18	55.8	43.3	0.1	0.8	56.0	40.4	0.1	3.5
20	57.9	41.4	0.3	0.4	58.6	38.1	0.7	2.3
21	59.5	38.6	0.5	1.4	61.5	37.1	0.2	1.2
22	63.2	36.1	0.4	0.3	63.9	34.4	0.5	1.2
23	50.0	-	-	-	52.0	-	-	-
25	62.8	37.0	0.1	0.1	60.7	35.4	0.7	3.2
26	63.4	35.4	0.2	1.0	57.3	34.6	0.8	7.3
27	55.8	33.6	1.3	9.3	23.3	19.8	8.2	48.7
28	58.7	38.2	0.3	2.8	30.4	25.2	5.8	38.6
29	57.8	39.6	0.2	2.4	49.6	35.5	1.4	13.5

TABLE 6.11 LANDFILL GAS ANALYSES FOR THE SECOND SET OF WELLS IN THE CONTROL AND CO-DISPOSAL LINES

MONTHS AFTER PLACEMENT	GAS CONCENTRATION (%) WELL 2 (CONTROL) CH_4	 CO_2	 O_2	 N_2	 WELL 2 (CO-DISPOSAL)* CH_4	 CO_2	 O_2	 N_2
6	2.5	1.3	26.8	69.6	0.3	15.2	23.4	61.1
7	26.1	21.4	14.2	38.3	7.2	5.1	24.2	63.5
8	23.4	18.3	15.8	42.5	8.7	7.0	23.0	61.3
9	1.0	2.7	26.9	69.4	0.3	0	27.8	71.9
10	0.6	0	27.2	71.9	1.1	0	27.1	71.8
12	2.0	0	27.4	70.6	0.2	0.2	27.1	72.5
13	39.4	23.8	10.0	26.8	0.7	0.9	27.0	71.4
14	36.7	22.4	10.8	30.1	0.5	0.9	26.9	71.7
15	28.8	22.8	9.2	39.2	0.1	2.2	20.8	76.9
16	30.4	22.2	9.2	38.2	0.3	2.4	20.3	77.0
17	8.9	13.8	12.4	64.9	9.1	8.2	16.6	66.1
18	16.9	20.4	8.0	54.7	7.4	7.4	16.1	69.1
20	33.7	31.6	2.5	32.2	21.2	18.0	11.7	49.1
21	46.3	28.7	5.0	20.0	33.5	20.0	9.9	36.6
22	59.1	33.4	1.7	5.8	42.8	20.8	8.1	28.3
23	50.0	-	-	-	15.0	-	-	-
25	62.5	37.3	0.1	0.1	35.0	18.7	10.2	36.1
26	38.7	27.9	6.3	27.1	31.2	19.6	9.7	39.5
27	18.1	16.7	11.8	53.4	14.2	21.6	7.5	56.7
28	19.8	20.9	8.8	50.5	16.7	23.7	5.5	54.1
29	20.3	21.4	8.5	49.8	30.6	31.8	1.9	35.8

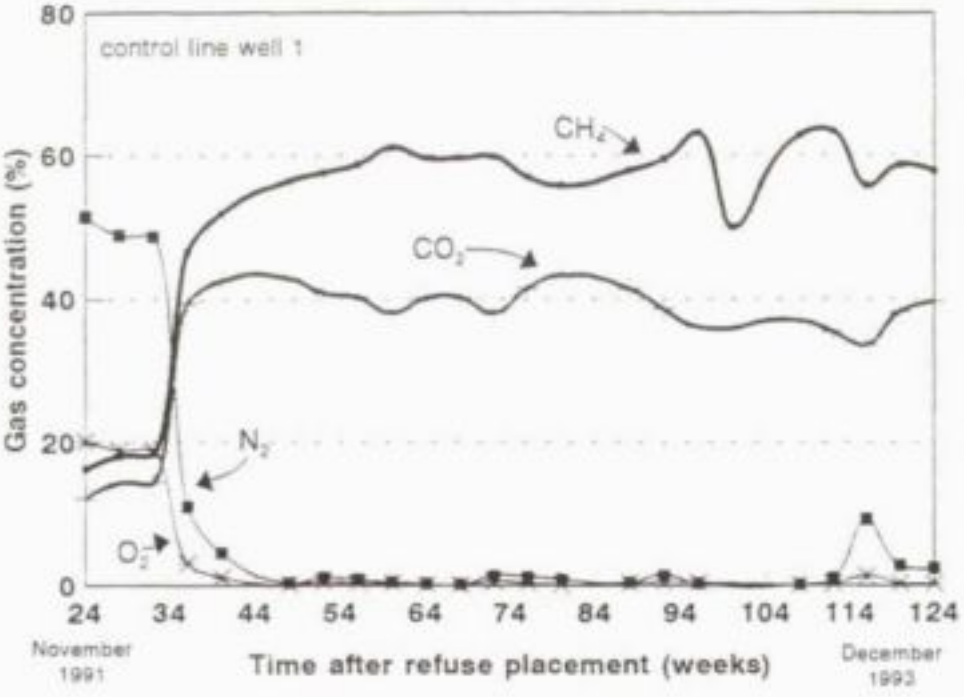
Note:* The results for Well number 2 (co-disposal line) are unreliable as that well was found to be faulty i.e. it filled up with water during the wet season. The well was subsequently replaced but continued to fill up with water (this was assumed to be due to pathways formed by the landfilling of plastic and other such-like constituents which encouraged the flow of liquid towards the well).

TABLE 6.12 LANDFILL GAS ANALYSES FOR THE THIRD SET OF WELLS IN THE CONTROL AND CO-DISPOSAL LINES

MONTHS	GAS CONCENTRATION (%)							
AFTER	WELL 3 (CONTROL)				WELL 3 (CO-DISPOSAL)			
PLACEMENT		CH_4	CO_2	O_2	N_2	CH_4	CO_2	O_2N_2
6	57.9	40.9	0.3	0.9	56.5	38.5	0.7	4.3
7	58.6	38.1	0.3	3.0	62.1	36.9	0.3	0.7
8	60.1	35.1	1.1	3.7	62.9	35.1	0.6	1.3
9	50.0	-	-	-	49.0	-	-	-
11	65.3	34.1	0.2	0.4	63.2	29.2	1.6	6.0
12	60.5	37.6	0.4	1.5	54.5	33.9	2.6	9.0
13	54.9	39.7	0.2	5.2	56.3	38.7	0.2	5.2
14	55.1	39.9	0.7	4.3	55.9	37.4	1.4	5.3
15	55.0	41.6	0.1	3.3	56.9	39.7	0.5	2.9

TABLE 6.13 LANDFILL GAS ANALYSES ON SAMPLES TAKEN MONTHLY FROM THE OVERALL CONTROL WELL

DATE OF SAMPLING	GAS CONCENTRATION (%)			
	CH_4	CO_2	O_2	N_2
92-02-26	57.1	42.5	0.2	0.2
92-03-11	57.0	42.8	0.1	0.1
92-05-29	59.5	39.7	0.3	0.5
92-07-07	60.0	36.1	0.9	3.0
92-08-04	61.1	36.9	0.7	1.3
92-09-02	59.4	38.8	0.6	1.2
92-10-06	60.5	39.2	0.2	0.1
92-11-03	59.6	40.2	0.1	0.1
92-12-15	59.6	40.2	0.1	0.1
93-01-20	58.6	41.2	0.1	0.1
93-03-15	59.4	40.2	0.3	0.1
93-04-23	59.4	39.8	0.3	0.5
93-05-17	61.7	37.4	0.7	0.2
93-06-07	47.0	-	-	-
93-08-03	65.2	33.6	0.1	1.1
93-09-14	62.3	37.5	0.1	0.1
93-10-20	61.4	38.4	0.1	0.1
93-11-29	56.1	36.7	1.7	5.5
93-12-17	58.9	40.8	0.1	0.2



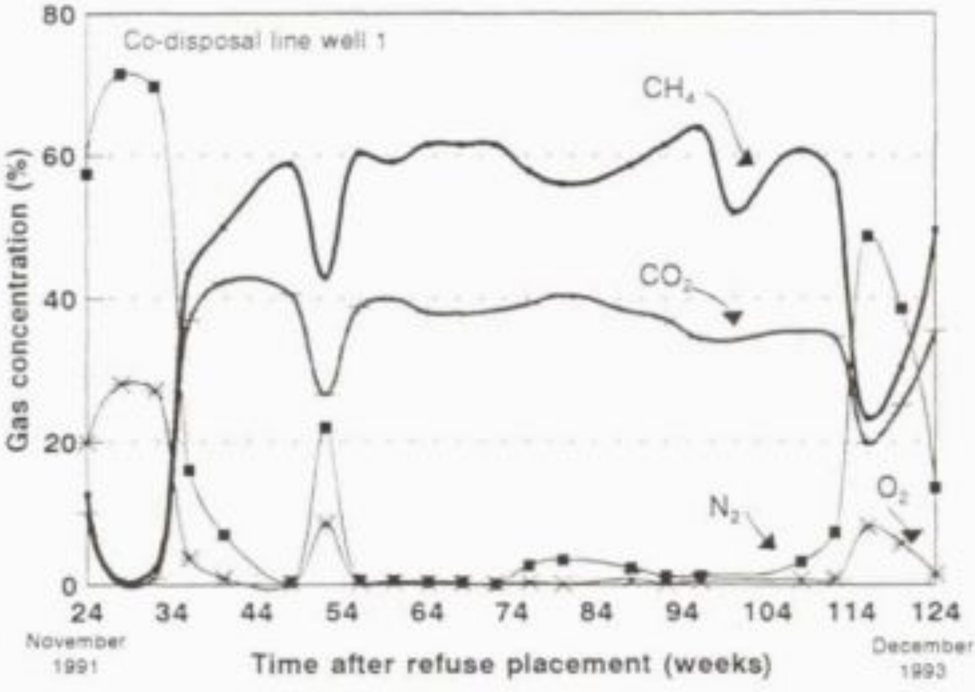
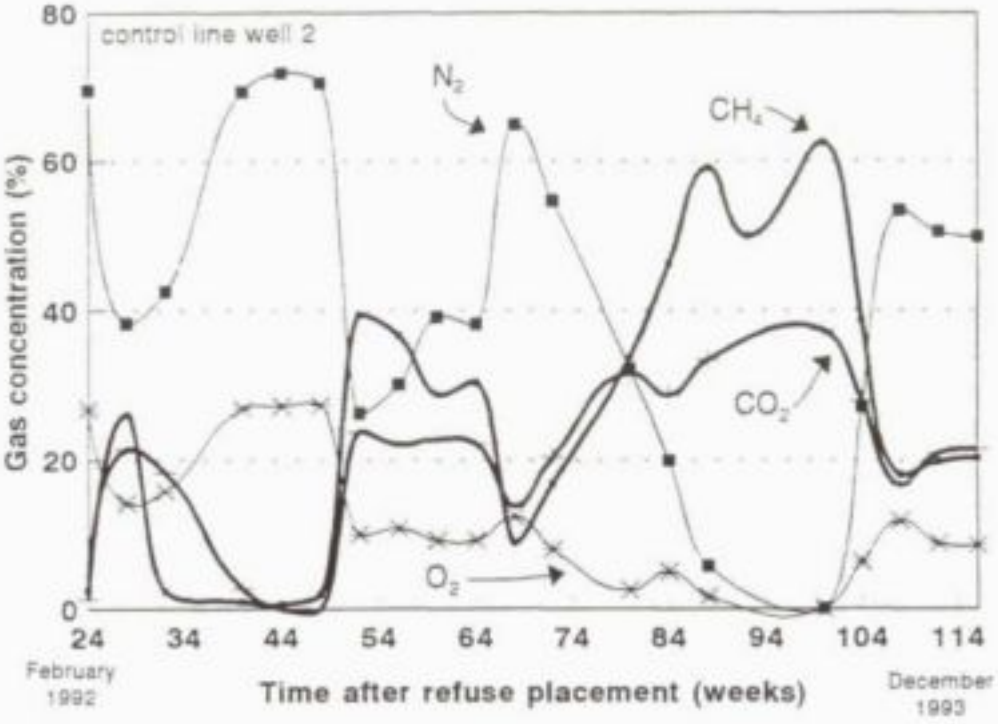


Figure 6.11 Landfill gas concentrations for the first set of gas wells in the control and co-disposal lines.



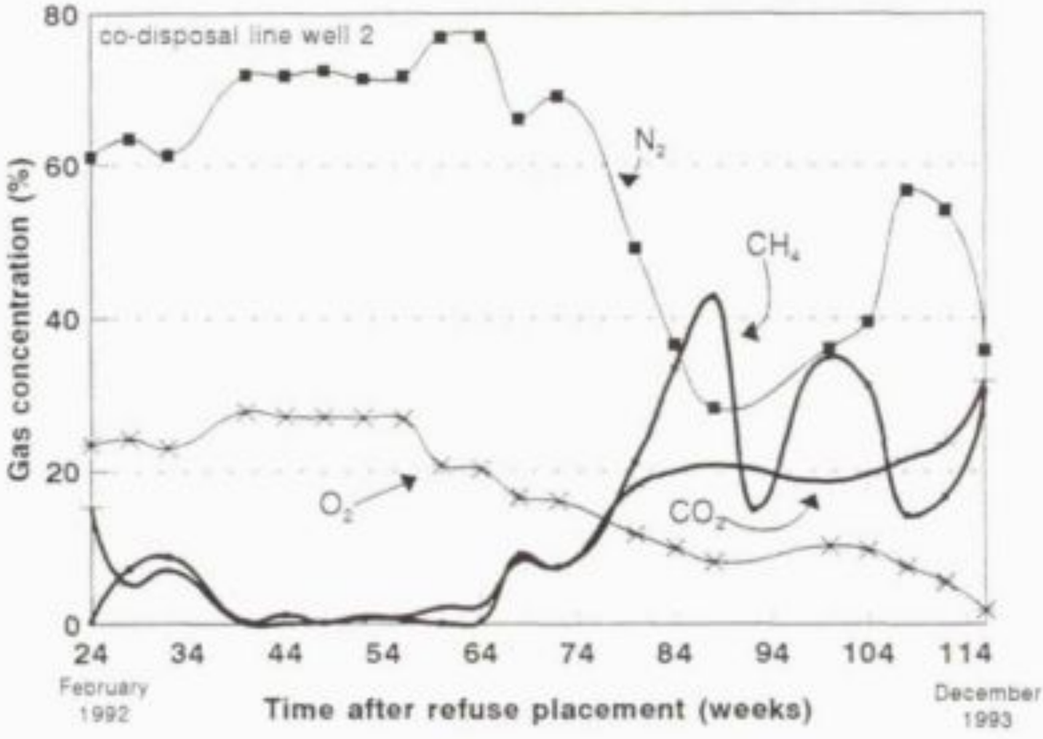


Figure 6.12 Landfill gas concentrations for the second set of gas wells in the control and co-disposal lines.

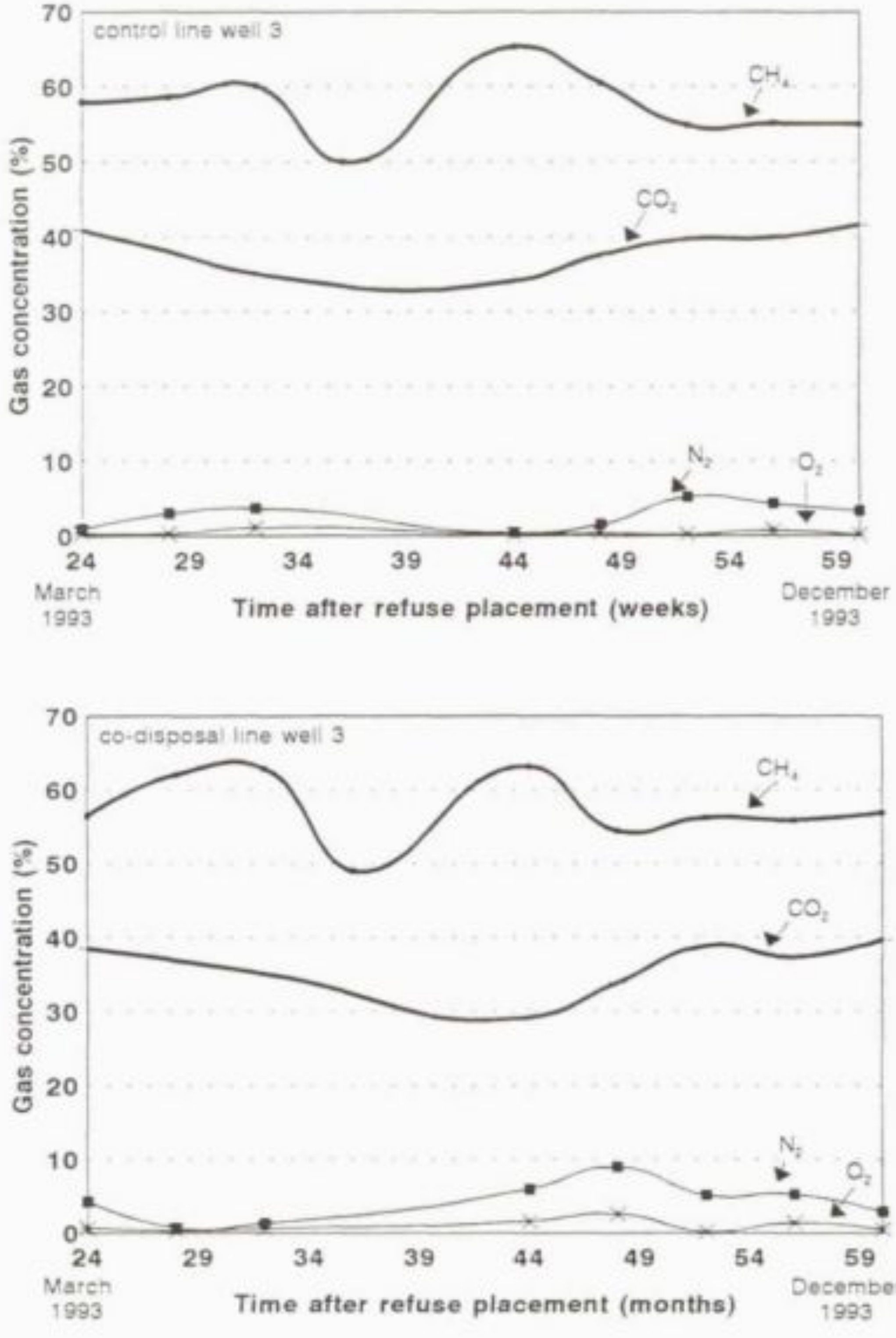


Figure 6.13 Landfill gas concentrations for the third set of gas wells in the control and co-disposal lines.

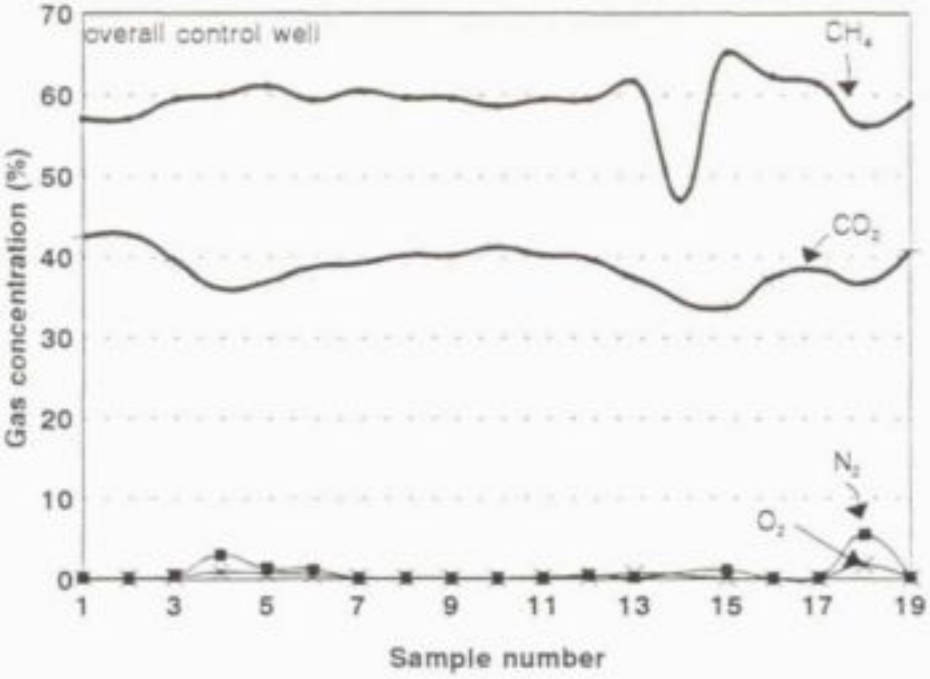


Figure 6.14 Landfill gas concentrations for the overall control well.

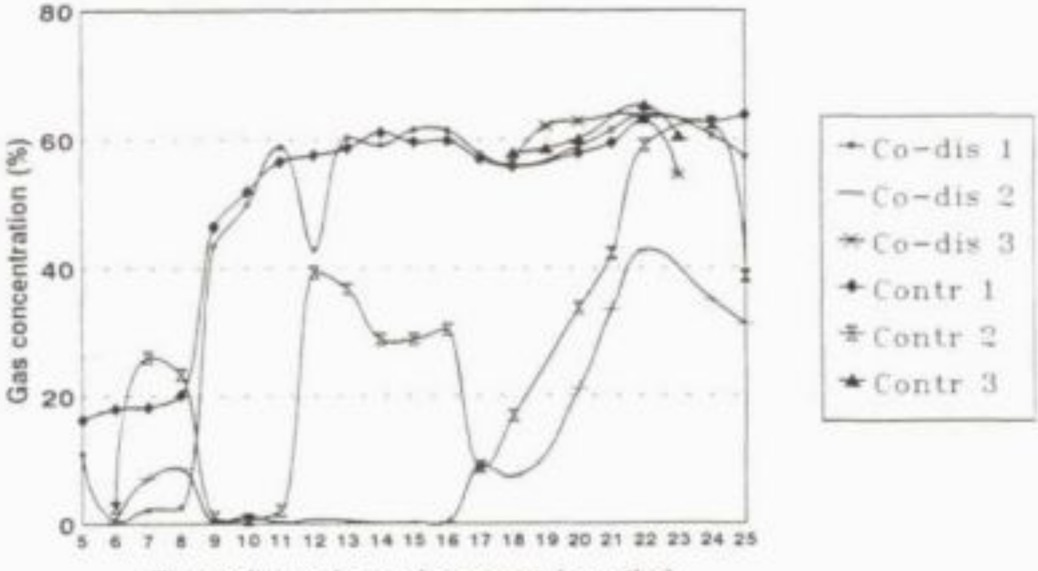


Figure 6.15 Methane concentrations for all monitoring wells in the control and co-disposal lines.

The co-disposal ratio is reported to be an important factor in determining whether the addition of waste-water sludge to refuse will enhance or inhibit methanogenesis. Research using column lysimeters operated in a leachate discard mode (i.e. no recycling) indicated that at a high sludge to refuse loading rate, methane release was higher by a factor of approximately two. However, at medium sludge loading rates, co-disposal increased methane release rates by a factor of 20 (Watson-Craik *et al.*, 1992).

In order to confirm the biogas production at the test site, the University of Natal (Prof Letcher) was approached for assistance. In June 1993 (during winter in the Western Cape) methane, oxygen, pressure and temperature measurements were carried out. It was concluded that the addition of waste-water sludge, at those concentrations used, had little or no effect on landfill gas production and that the relatively small biodegradable content of the sludge was probably insufficient to appreciably increase methane production. The low temperatures (17 to 24°C recorded and low pressures (< 10 Pa) indicated a landfill of low microbial activity; this was confirmed by the overall control well which also recorded low temperature and pressure at the time of sampling.

6.6 LEACHATE

6.6.1 INTRODUCTION

Landfill leachate is the liquid which percolates through a landfill site and is usually lost or collected from the bottom of the fill. Leachate is regarded as highly polluting and is a consequence of the landfilling and decomposition of putrescible wastes. It is made up of the percolation of rainfall into and through the landfill, moisture contained in the waste at the time of landfilling, and liquid produced in the biological process.

Until relatively recently it has been considered good practice to try and exclude water from landfilled wastes by cellular operation using low permeability cover, graded caps, etc. However, the need for moisture in the landfill to ensure controlled landfill stabilisation within a greatly reduced timescale has lately been recognised (Robinson and Gronow, 1993; Pohland and Al-Yousfi, 1994).

The co-disposal of waste-water sludge liquors with refuse in a landfill introduces an extra factor into the water balance. A major problem perceived by regulatory authorities such as the Department of Water Affairs and Forestry is that the co-disposal practice could result in the possible generation and release of more leachate with high concentrations of pollutants.

It was, therefore, decided to implement leachate monitoring as part of the project monitoring programme in order to assess the effect of the co-disposal operation on leachate quality and quantity.

6.6.2 LEACHATE COLLECTION SYSTEM

A leachate collection system was installed during week 20 (May 1992) in a section of each of the co-disposal and control lines. The collection system comprised a 7 m x 7 m HDPE liner (1,5 mm thick) which was covered by a 300 mm layer of permeable sand for protection, over which landfilling was carried out. The outlet was from the centre of the liner and comprised a 50 mm diameter PVC pipe which drained to a collection sump. A valve was fitted to the end of the pipe to facilitate sampling. Figure 6.16 gives a schematic diagram of the leachate collection system whilst the general layout of the lines incorporating the liners is given in Figure 6.17.

6.6.3 EFFECT OF CO-DISPOSAL ON LEACHATE QUANTITY

Figure 6.18 indicates the volume of leachate per week which was collected from the co-disposal line between May 1992 and December 1993. This period covers two winter periods and two summer periods. The Western Cape is in a winter rainfall area (see Sections 5.2 and 6.7) and hence the data collected during the winter months should give an indication of what could be expected as far as leachate production is concerned in a full-scale application.

Figure 6.19 gives the weekly rainfall measured at Coastal Park during this period. From the two figures it can be seen that leachate production only followed the rainfall pattern during the first winter rainfall period (1992) and far less leachate was produced during the second winter period (1993); the latter volumes produced could be assumed as being low. No significant volumes of leachate were collected from the control line during the same periods. The results indicated that although the co-disposal practices influenced leachate production, the effect thereof was minimal and less than theoretically expected. This confirms the results reported in Section 6.3 where no significant differences were found in the moisture content of the landfilled waste in the control and co-disposal lines.

It is difficult to explain these observations. However, it can be stated with confidence that during the winter period experienced shortly after the liner was installed, an increase in leachate from the co-disposal line occurred (week 22 - 30, 1992).

One possible explanation, if one considers the good quality of the leachate collected, is that the waste-water sludge liquor after being applied to the refuse at its time of placement was absorbed into the refuse which resulted in a higher moisture content and a blinding layer of sludge mass on the surface of the refuse. The water entering the co-disposal line during the first winter rains was not easily absorbed into the already wet refuse. This process was further inhibited by the waste-water sludge layer on the surface of the refuse. Any excess rainfall was lost from the co-disposal line as leachate. During the following warmer summer period, moisture was lost from the line due to evaporation and the organic layer was degraded diminishing any possible blinding characteristics. Therefore, when the second wet winter period arrived (weeks 13-36, 1993), the rainfall which penetrated the refuse was absorbed into the dry waste. The blinding characteristics of the Cape Flats sludge has been detected in the laboratory (Smollen *et al.*, 1984) and on site when sludge liquor has been applied to sand drying beds.

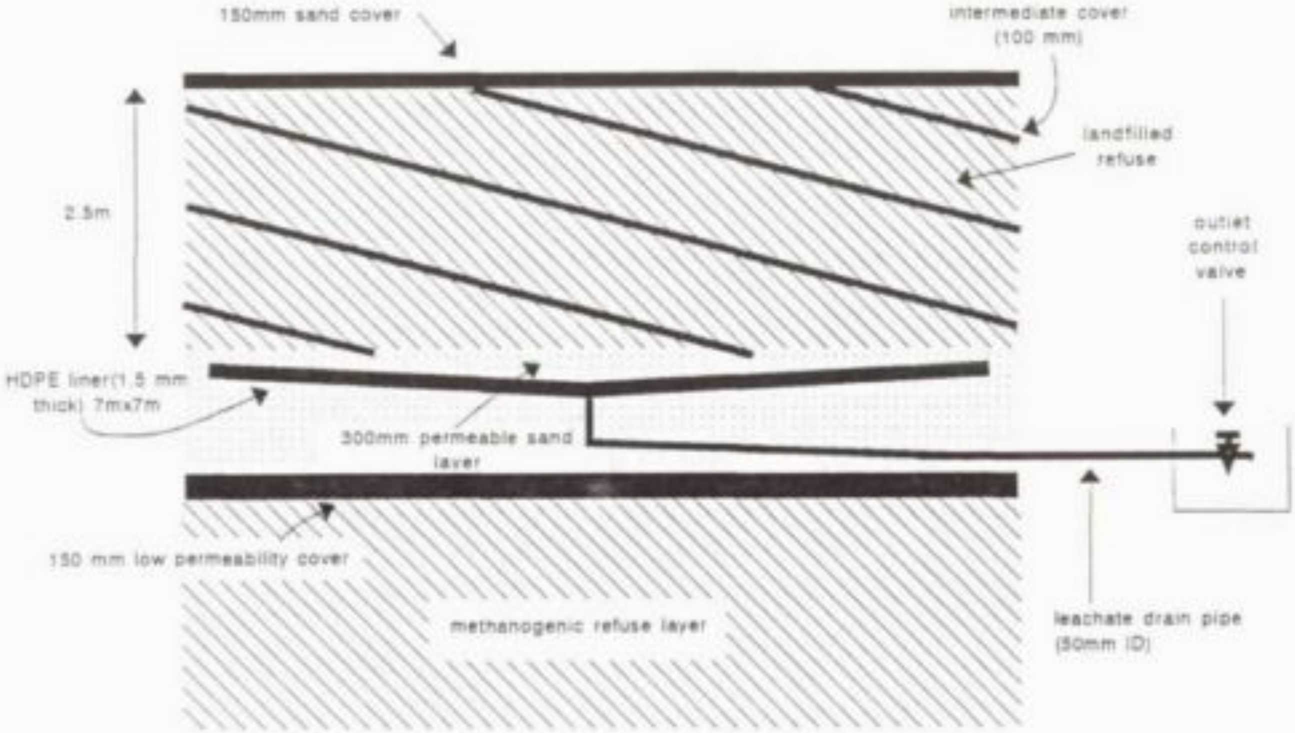


Figure 6.16 Schematic diagram of the leachate collection system installed within a section of each line.

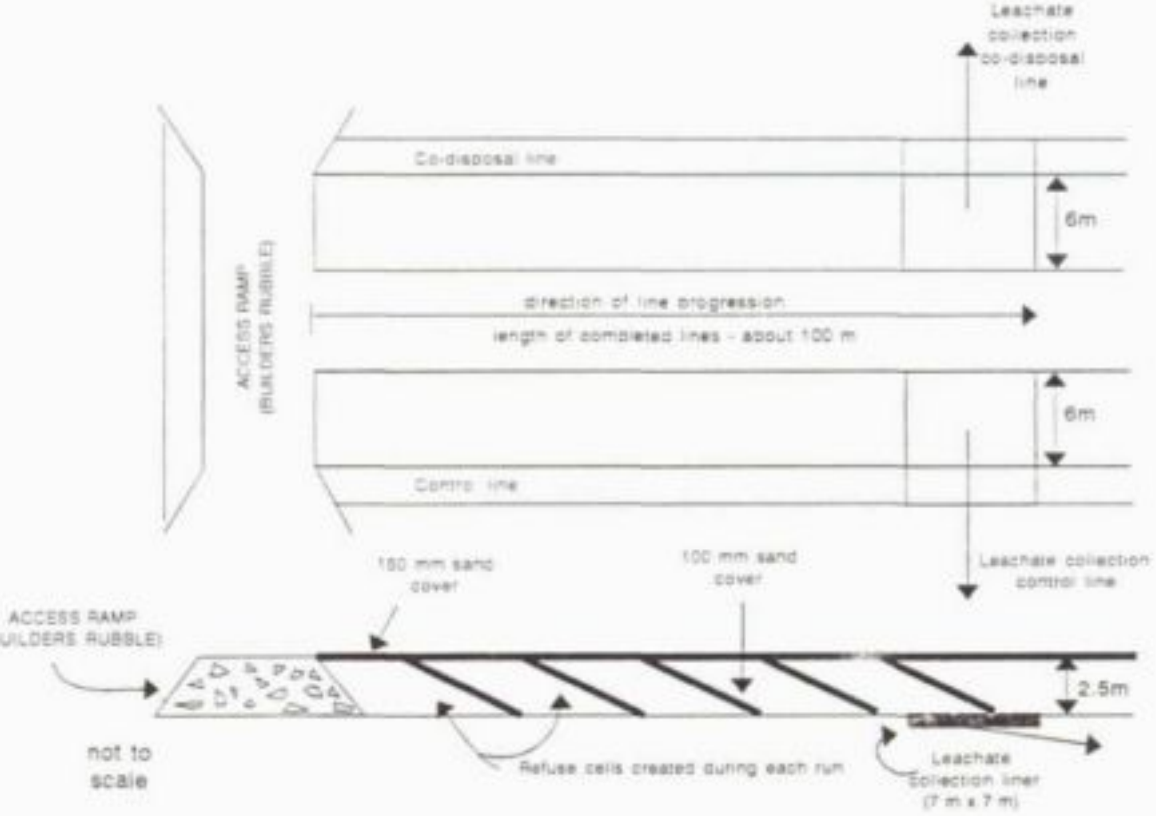


Figure 6.17 General layout of the experimental lines incorporating leachate collection.

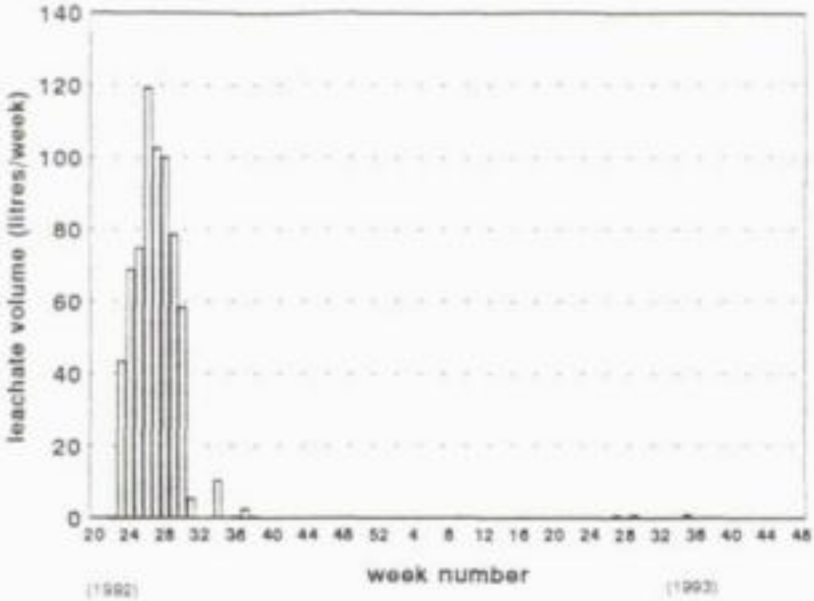


Figure 6.18 Volume of leachate collected per week from the co-disposal line (no leachate was collected from the control line).

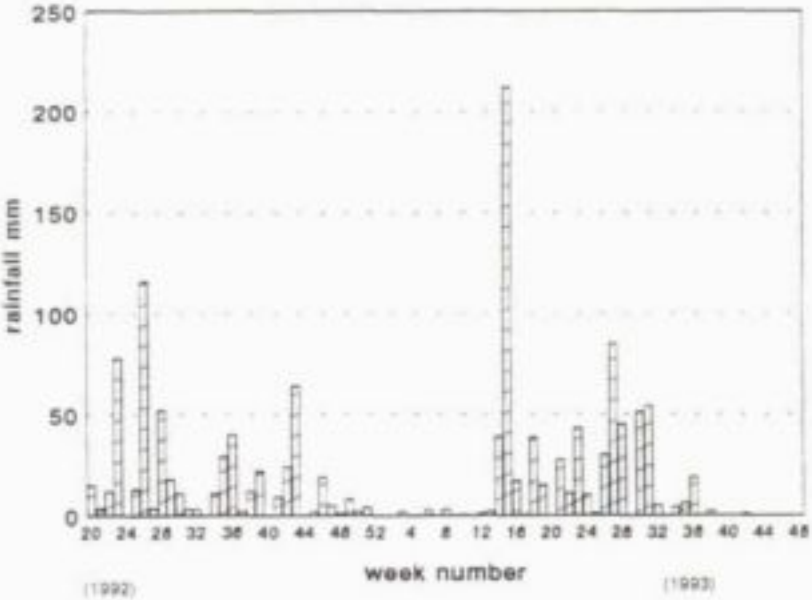


Figure 6.19 Weekly rainfall measured at Coastal Park during the investigation period.

Another explanation, which could be more feasible, is that evaporation was so high during the summer months that the subsequent winter rains could not achieve the field capacity; this explains why no leachate was collected. Blight *et al.* (1990) has pointed out that Coastal Park lies within a water deficit area with rainfall only exceeding evaporation during the few wet winter months. The thirty year average annual figure for evaporation exceeds that for rainfall by about 600 mm. This shows that a significant amount of moisture is lost from the landfill during most of the year. This ensures that the landfill has an overall capacity to hold moisture, even during the wet winter months.

It is recommended, therefore, as a safeguard, that the co-disposal operation of adding extra moisture should not be practised all year round but should terminate at least one month prior to the winter rainfall period and recommenced four months later. If all year co-disposal is to be practised then leachate collection and recycling/treatment should be considered.

It, therefore, becomes apparent that should additional moisture be added to a landfill by way of co-disposal operations, and such practices are all year round, then leachate management must become an essential part of the landfill management strategy.

6.6.4 EFFECT OF CO-DISPOSAL ON LEACHATE QUALITY

Table 6.14 records the results of chemical analyses carried out on eight samples of leachate collected from the co-disposal line. Seven of the samples were taken during the first winter period (May to September 1992) whilst only one sample was possible after the second winter period (August 1993). During the rest of the investigation period no leachate was collected from the co-disposal line.

During the same sampling period virtually no leachate was collected from the control line, hence, it was only possible to sample and analyze on one occasion. Table 6.15 gives the results for this sample taken some 15 months after placement (August, 1993).

In comparing the average results of the leachate from the co-disposal line (Table 6.14) with the results for the single sample from the control line (Table 6.15), it was found that there was no significant difference between the two sets of data. The results obtained from the co-disposal line were similar to that of the filtered anaerobically digested waste-water sludge liquor. No effect of sludge solids or any influence from the decomposing refuse was detected.

Leachate produced from refuse in a landfill generally contains very high concentrations of COD and TKN. Typical COD concentrations during the acid phase is very high and can be greater than about 50 000 mg/ℓ (as O) whilst during the methanogenic and later phases, COD's of some 3 000 mg/ℓ reducing to some 1 000 mg/ℓ can be expected.

CHAPTER 7
ASSOCIATED STUDIES

7.1 INTRODUCTION

The main objective of the Project was to develop practical operational criteria for the landfill co-disposal of domestic refuse and anaerobically digested waste-water sludge liquor. This objective was achieved by carrying out full-scale studies at the Coastal Park landfill site using two experimental lines. The results of these studies have been presented in Chapter 6 of this report.

Other important peripheral studies were also carried out during the contract period which provided supplemental information of a co-disposal operation and which broadened the scope of the Project. The following sections reflect the results from the associated studies.

7.2 BOX TESTS TO QUANTIFY LANDFILL PARAMETERS SUCH AS FIELD CAPACITY, COMPACTION, MOISTURE CONTENT AND BULK-DENSITY

7.2.1 PURPOSE OF BOX TESTS

Box Tests were developed to establish the interrelationships between landfill parameters such as moisture content, field capacity, bulk density, degree of compaction and leachate generation. The above parameters also needed to be quantified so as to enable a water balance to be calculated for a refuse/sludge co-disposal operation (as described in Section 7.3). The detailed results of the Box Tests are presented in Chapter 13, Appendices 1 and 2.

7.2.2 MATERIALS AND METHODS

The experimental procedures entailed weighing known mixtures of domestic refuse and anaerobically digested sludge liquor in a 0.5 m^3 standard box (1 m x 1 m x 0.5 m high). This enabled the bulk density of various refuse/sludge volume ratios (in the range 20:1 to 2:1) to be determined. The various refuse/sludge volume ratios were initially well mixed on a plastic sheet and then compacted in the box in a standard manner. The bottom of the box was perforated to allow leachate to drain out and be collected in a tray for measurement.

The Box Tests were repeated (Appendix 2) which confirmed the results of the initial studies (Appendix 1).

7.2.3 RESULTS OF BOX TESTS

The following range of values were typical of those obtained in the Box Tests:

Moisture content of incoming refuse	= 30 - 35%
Field capacity of compacted refuse	= 50 - 55%
Saturation moisture content of refuse	= 70 - 75%
Compaction increase (by increasing the moisture content from 35% to 55%)	= 20 - 25%
Refuse/Sludge liquor volume ratio suitable for co-disposal	= 6:1

7.2.4 CONCLUSIONS

The results obtained in the Box Test studies illustrated the importance of maintaining the correct moisture concentration of the refuse being landfilled i.e. to satisfy the physical requirements for compaction and the biological requirements for accelerated stabilisation. It is fortuitous that both the physical and biological requirements are largely satisfied at a moisture concentration of some 55%. The moisture content at the field capacity was also determined in the Box Tests to be some 55% of the mass of the refuse. This moisture concentration of the wetted refuse should theoretically not result in the production of excessive amounts of leachate from the landfill.

The Box Tests indicated that at placement of the refuse, moisture content had a significant effect on the compacted density. The compacted bulk density of incoming refuse was typically 350 kg/m^3 at a moisture content of 35%. Increase of the moisture content from 35 to 55% resulted in a 25% improvement in the compaction at a refuse/sludge volume ratio of 6:1. The resultant density of some 680 kg/m^3, using a flat compacting device, was lower than the density achieved at operational landfills using steel wheeled compactors. The results of this research established that no significant incremental improvement in the compaction of the refuse was obtained at moisture values greater than 55% or with heavier compaction equipment.

7.3 CALCULATION OF A SIMPLISTIC WATER BALANCE AT THE COASTAL PARK LANDFILL SITE FOR A REFUSE / SLUDGE CO-DISPOSAL OPERATION

According to the Minimum Requirements for waste disposal by landfill (DWAF, 1994a) a Climatic Water Balance calculation is required to establish whether the site falls into the leachate producing (B^+), hence leachate management category. A water balance was calculated for Coastal Park landfill site to indicate the role that co-disposal of refuse and waste-water sludge liquor could play in the overall management of these two waste streams. The detailed results of the water balance calculation are presented in Chapter 13, Appendix 3.

7.3.1 GENERAL WATER BALANCE EQUATION FOR A LANDFILL SITE

A typical example of a water balance equation is set out below:

$$J = [A + B + C + D + E] - [F + G + H + I]$$

Where, annually:

J = water retained by landfill to achieve its field capacity
A = water added by incoming refuse
B = precipitation on landfill
C = biochemical and biological water production
D = water added by co-disposal of waste-water sludge
E = surface and groundwater flow into landfill
F = evaporation losses from landfill
G = water vapour loss associated with biogas escape from landfill
H = water loss in leachate from landfill
I = water loss in surface run-off from landfill

a) Variables C, E, G and I

These factors offer the greatest degree of uncertainty in the water balance calculation on full-scale sites. For simplistic purposes, the values of these variables will be eliminated from the water balance equation as they are not known but are at present understood to be small in comparison with other items.

b) Variable H

For simplistic purposes, the value of the variable H will be assigned a value of zero i.e. no leachate production if the landfill is just maintained at its field capacity.

c) Variable J

This variable was assigned a value typical of the field capacity of the compacted landfilled wastes, i.e. 60% moisture at a landfill bulk density of 1000 kg/m^3.

7.3.2 SIMPLISTIC WATER BALANCE EQUATION

The water balance equation, therefore, was reduced to the functions that could reasonably accurately be quantified at the Coastal Park landfill site:

$$\begin{array}{ccccc} J & = & [A + B + D] & - & [F] \\ \text{Water Retained} & = & \text{Water Input} & - & \text{Water Output} \end{array}$$

The determined values of the variables were as follows:

J = 54 120 ton/annum
A = 27 060 ton/annum
B = 18 400 ton/annum
D = 48 348 ton/annum
F = 39 688 ton/annum

7.3.3 PERMISSIBLE SLUDGE CO-DISPOSAL QUANTITIES

The calculation above implies that a mass of 48 348 ton of liquid per annum (equivalent to 1 344 mm per annum) in the form of waste-water sludge moisture could be added to the refuse landfilled at Coastal Park. This mass of water would theoretically increase the moisture content of the incoming refuse from 30% to its field capacity moisture content of about 60% without the generation of leachate. The moisture of the incoming waste was found to be about 43% during the investigation period; however, the moisture content of previously landfilled waste was found to be some 30% on excavation.

On the basis of the simplistic water balance carried out in this study, a measure of co-disposal with waste-water sludge would be permissible, especially during the drier months of the year (October to May). The following degree of co-disposal with waste-water sludge from the Cape Flats waste-water treatment plant would be permissible to maintain a field capacity of 60% moisture content and density of 1000 kg/m^3 at the Coastal Park landfill site:

a) Addition of digested sludge liquor (2,3% total solids) = 16,6% of total current annual available volume at Cape Flats

OR

b) Addition of dewatered digested sludge cake (12,4% total solids) = 100% of total current annual available volume at Cape Flats

7.3.4 CONCLUSIONS

The simplistic water balance predictions made in this report need to be verified, because of the variable properties of refuse and the uncertainties in the estimation of many of the parameters (especially evaporation) that influence the water balance equation.

The co-disposal of refuse and waste-water sludge is not without its side effects. Whether these are beneficial or detrimental, a balanced view must be taken in assessing the overall suitability of the process as a disposal option.

7.4 LYSIMETER STUDIES

7.4.1 INTRODUCTION

The use of column lysimeters for refuse stabilisation and waste-water sludge co-disposal studies is well documented (Pohland *et al.*, 1992, amongst others). The volume of the units used, however, has varied considerably. Pohland and Gould (1986) used columns which were 2,84 m^3 whilst the reactors used by Blakey (1991) were 0,14 m^3 and those of Watson-Craik *et al.* (1992) were 0,0095 m^3.

This section reviews the waste-water sludge co-disposal studies carried out by Chapman and Ekama (1991) as well as by Novella *et al.* (1995) in column lysimeters situated at the University of Cape Town.

7.4.2 DESCRIPTION OF COLUMN LYSIMETERS

Six identical column lysimeters were constructed, each was 4,25 m high with 0,6 m internal diameter. The lysimeters were fabricated out of 2 mm gauge steel 210 ℓ drums. The units were hot dipped galvanised and the insides were coated with epoxy paint. The base of each lysimeter comprised an inverted mild steel cone with a 25 mm outlet at the base in order to facilitate leachate collection and withdrawal. A brass gate valve was fitted to the leachate drain pipe in order to control leachate withdrawal. The tops of the lysimeters were sealed using oil drum lids which had been modified to allow for water make-up/leachate recycling and biogas extraction. The outsides of the units as well as the lid was insulated with glass fibre insulation in order to minimise temperature fluctuations. The insulation was covered with plastic sheeting to protect the insulation material from the elements. A schematic drawing with dimensions of a lysimeter is given in Figure 7.1.

7.4.3 LYSIMETER CONTENTS

(a) Refuse - each lysimeter was filled with approximately 500 kg of a standard refuse matrix made up from selected constituents. Table 7.1 lists the constituents of the standard refuse matrix. In making up the standard refuse, it was assumed that future landfills would contain less recyclable material; therefore, the quantities of paper/cardboard were reduced whilst glass and metals were left out. The putrescible (organic) fraction was increased to make up the difference. The ash content was set at 2%, equivalent to that for the first world communities in Cape Town, as it is essentially inorganic and inert.

The previously mixed refuse was added to the lysimeters in 25 kg portions and compacted until the required density was achieved. Volumes of water and sludge liquor were added to each lysimeter during the refuse placement in order to elevate the moisture content of the mixed refuse to some 65%; that originally estimated to be equivalent to the field capacity of compacted refuse within a landfill.

After refuse placement and moisture addition, the density of the contents of the lysimeters were calculated to be some 700 kg/m^3.

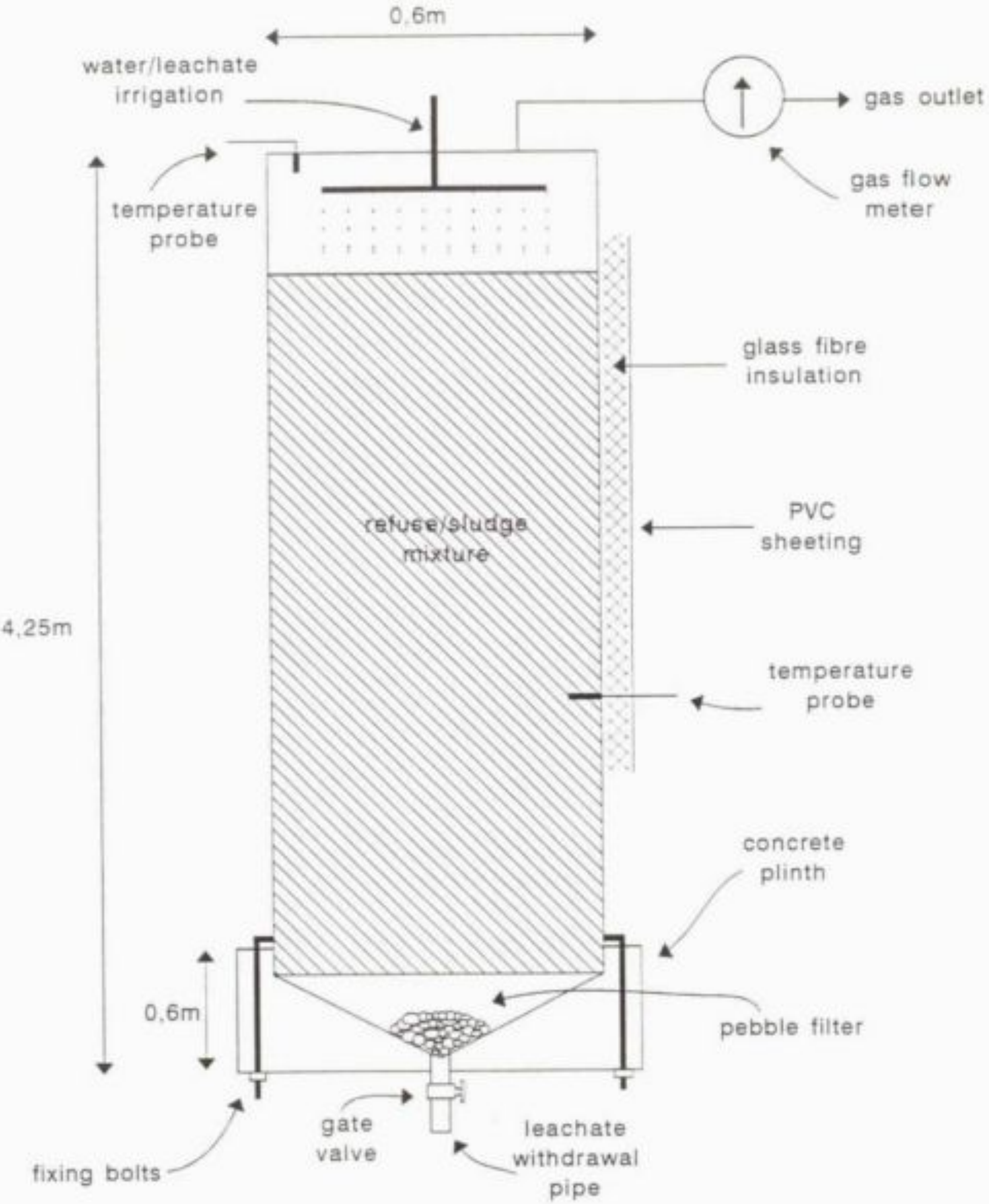


Figure 7.1 Schematic diagram of the lysimeters utilised in the lysimeter research.

TABLE 7.1 COMPOSITION OF THE STANDARD REFUSE MATRIX

CONSTITUENT	% (BY MASS)
putrescible	60
paper/cardboard	15
cloth	20
plastic	3
ash	2

(b) Sludge - the waste-water sludge utilised in the lysimeter co-disposal studies was obtained from an anaerobic digester at the Mitchell's Plain waste-water treatment works. This treatment works receives waste-water from a domestic area and thus contains a negligible industrial component. The sludge was withdrawn from the outlet of the anaerobic digester and, therefore, can be considered as well stabilised (40 to 60% of VS destroyed). The sludge at time of placement contained 5% total solids of which about 70% was volatile solids.

Approximately 200 ℓ of the sludge liquor was added to each co-disposal lysimeter whilst Unit 1 received no sludge and was considered the control lysimeter.

Table 7.2 gives the mass of refuse which was placed in the four lysimeters which were used for the co-disposal evaluation as well as the volumes of waste-water sludge liquor and water added to each in order to increase the moisture content to the required 65%. The resultant calculated density of the contents of the lysimeters is also given in Table 7.2.

TABLE 7.2 MASS OF REFUSE, VOLUMES OF SLUDGE AND WATER AND CALCULATED DENSITY IN EACH LYSIMETER

PARAMETER		LYSIMETER			
		1 no sludge	2 sludge	5 sludge	6 sludge
Refuse	kg	495	462	528	445
Water	ℓ	240	29	61	21
Waste-water sludge liquor		ℓ	-	200	200200
Moisture content	%	65	65	65	65
Density (calculated)	kg/m³	714	691	789	666

7.4.4 OVERVIEW OF LYSIMETER OPERATION

An overview of the lysimeter research project with regard to lysimeter contents, operation and performance of the six lysimeters over the 1 200 day investigation is given in Table 7.3 (Novella *et al.*, 1995). From this table it can be seen that two lysimeters (Units 1 and 2) did not become methanogenic during the 1 200 day investigation period. Unit 1 did not receive sludge at placement but did receive liquid replacement (water). Unit 2 did receive sludge but did not receive liquid replacement during its operation. The other four lysimeters (Units 3, 4, 5 and 6) received both sludge and liquid replacement during the course of their operation. From the foregoing it seems that both waste-water sludge addition at placement and liquid replacement (in some form or another) is required to stimulate the onset of methanogenesis.

While this seems an obvious conclusion, the issue is not so simple, because in three of the four lysimeters (Units 3, 4 and 5) that became methanogenic, the onset of methanogenesis was primarily stimulated by the nature of liquid replacement strategy. Unit 3 became methanogenic as a result of the recirculation of stabilised leachate, Unit 4 by buffer addition followed by flush out with a high water flux and Unit 5 by an increased water flux after the first signs of methanogenesis was noticed. Only Unit 6 became methanogenic of its own accord after some 900 days even though the methanogenic process was retarded by the acid leachate recycling operation. Therefore, only Units 1, 5 and 6 whose performance can be attributed partially or fully to waste-water sludge co-disposal are discussed in this section. The results for Unit 2 has also been included for the discussion on leachate production.

TABLE 7.3 CONTENTS, OPERATION AND PERFORMANCE OF THE SIX LYSIMETERS USED IN THIS INVESTIGATION (Novella *et al.*, 1995)

UNIT	CONTENTS	OPERATION	METHANOGENESIS COMMENCED (DAY)	COMMENT
1	refuse	liquid (water)	acid to end	
2	refuse/ sludge	no liquid	acid to end	
3	refuse/ sludge	liquid (water/leachate)	methanogenic (d 820)	recirculation methanogenic leachate
4	refuse/ sludge	liquid (water/leachate)	methanogenic (d 50)	buffer/water flush
5	refuse/ sludge	liquid (water/leachate)	methanogenic (d 350)	water flush
6	refuse/ sludge	liquid (leachate)	methanogenic (d 1000)	leachate recycling

Note: Water and/or waste-water sludge was added to all six lysimeters to raise the moisture content to the initially assumed filed capacity of 65%. The measured field capacity was found to be 48%.

7.4.5 EFFECT OF WASTE-WATER SLUDGE CO-DISPOSAL ON LEACHATE PRODUCTION

Field capacities of landfilled refuse are generally considered to be in the order of 60 to 65%. Values in this range are often quoted in the literature; however, it seems that these values are generally estimates and not measured values (refer Chapter 13, Appendix 1 for discussion). At time of placement, the moisture content in all lysimeters was increased to a value of 65% by the addition of only water to Unit 1 and varying volumes of a mixture of water and waste-water sludge liquor (5% solids) to the rest. Table 7.2 gives the mass of refuse which was added to each lysimeter. The initial moisture content of the refuse at placement before moisture addition was measured to be 48%. The amount of water, therefore, in Units 1, 2, 5 and 6 at the time of placement was made up as follows.

	Unit 1	Unit 2	Unit 5	Unit 6
Refuse (48% mixture)	237,6ℓ	221,8ℓ	253,4ℓ	213,6ℓ
Sludge (95% moisture)	-	190 ℓ	190 ℓ	190 ℓ
Water	240 ℓ	29 ℓ	61 ℓ	21 ℓ
TOTAL	477,6ℓ	440,8ℓ	504,4ℓ	424,6ℓ

After placement of the contents, Unit 2 was sealed and monitored for 1 200 days. Leachate was removed from the lysimeter every 2 weeks. The volume of leachate was recorded and the leachate was discarded. No liquid makeup or leachate recycling was used to replenish lost moisture i.e. the moisture content of the refuse was allowed to decrease unhindered.

Figure 7.2 gives a plot of water loss as leachate, water retained, moisture content and estimated field capacity for Unit 2. From Figure 7.2 it can be seen that after placement, moisture was lost as leachate from Unit 2 at a rate of about 1 500 mℓ per day for some 140 days. A sudden change in the rate of moisture loss occurred on about day 140 when the rate reduced to about 60 mℓ per day and remained at this lower rate for the remainder of the test period. The moisture content remaining in Unit 2 at this point of change was calculated to be about 47%.

The field capacity is defined as the maximum moisture content held in landfilled refuse. Therefore, if the field capacity is exceeded then the excess moisture will be released until the moisture content drops to or below that of the field capacity. The abrupt change of moisture release from Unit 2 must have occurred at the moisture content equivalent to the field capacity, in this case 47%.

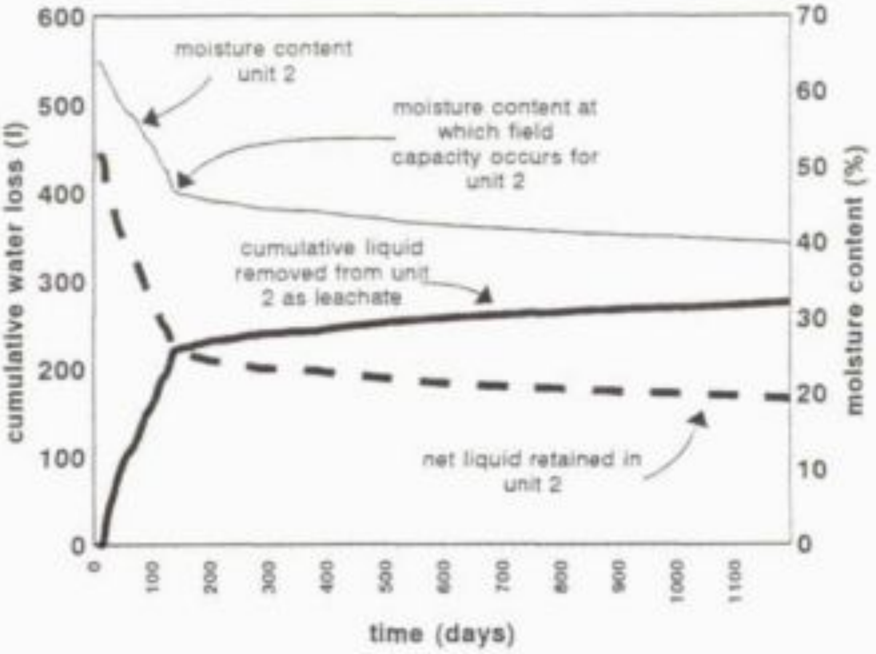


Figure 7.2 Liquid lost as leachate, water retained, moisture content and field capacity for unit 2 - lysimeter studies.

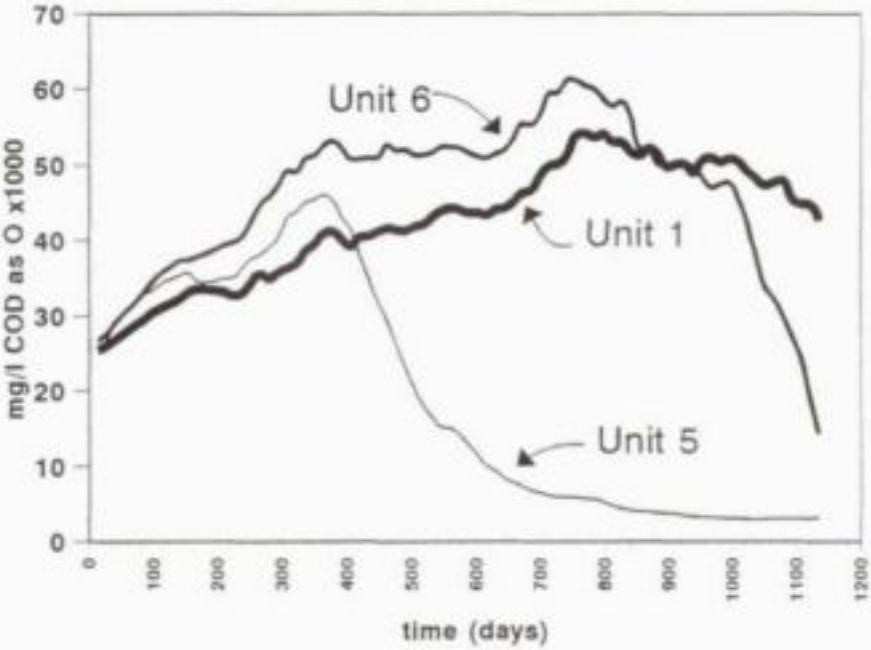


Figure 7.3 COD concentration (smoothed data) for Units 1 (no sludge), 5 (sludge) and 6 (sludge) - lysimeter studies.

Therefore, it can be seen that should sludge co-disposal be practised in such a way as to elevate the moisture content of the refuse and sludge mixture to above that of the field capacity, some 3 ℓ per day of leachate could be produced per ton of refuse co-disposed with sludge in the landfill. This was calculated from the volume of leachate (1500 mℓ) released by the lysimeter contents (500 kg) per day whilst the moisture content of the refuse/sludge mixture was above the field capacity moisture content (47%). Conversely, if water balance management was properly practised, and the amount of sludge added is calculated using the simple water balance equation (refer Section 7.3), in which the total moisture content within the landfill is limited to a maximum equal to that of the field capacity, then only about 120 mℓ per day of leachate per ton of refuse in the landfill could be produced (60 mℓ of leachate released per day).

7.4.6 EFFECT OF ANAEROBIC WASTE-WATER SLUDGE ADDITION ON THE STABILISATION PROCESS

The moisture content of refuse is reported to have a profound effect on the rate of stabilisation of the refuse within a landfill (Ross, 1990a; Pohland and Al-Yousfi, 1994). The moisture content, therefore, of Units 1, 5 and 6 was set at the same value. In Unit 1, water alone was used to elevate the moisture content whilst in Units 5 and 6 waste-water sludge along with a small amount of water was used. Furthermore, water make up (Unit 1 and 5) and leachate recycling (Unit 6) was practised to maintain a high moisture content within the refuse.

In order to discuss the effect of sludge addition on the stabilisation process, only leachate COD concentration and leachate pH will be discussed. Figure 7.3 gives leachate COD concentration (smoothed data) for Units 1, 5 and 6 whilst Figure 7.4 gives leachate pH values for the same units.

From Figure 7.3 it can be seen that the leachate COD concentration from Unit 5 decreased rapidly from about day 380; at the same time the pH of the leachate (Figure 7.10) increased rapidly. It was assumed, therefore, that at day 380 methanogenesis commenced.

The leachate COD concentration from Unit 6 (Figure 7.3) started decreasing at about day 800 and the leachate pH (Figure 7.4) started increasing shortly afterwards as methanogenesis commenced. It must be noted that throughout the period, acid leachate was recycled back onto Unit 6. The short chain fatty acids which were recycled to Unit 6 resulted in higher leachate COD concentrations and lower leachate pH values.

Conversely, the leachate from Unit 1, did not exhibit any of the typical signs of refuse starting methanogenesis (rapid decrease in leachate COD concentration, increase in leachate pH) during this period.

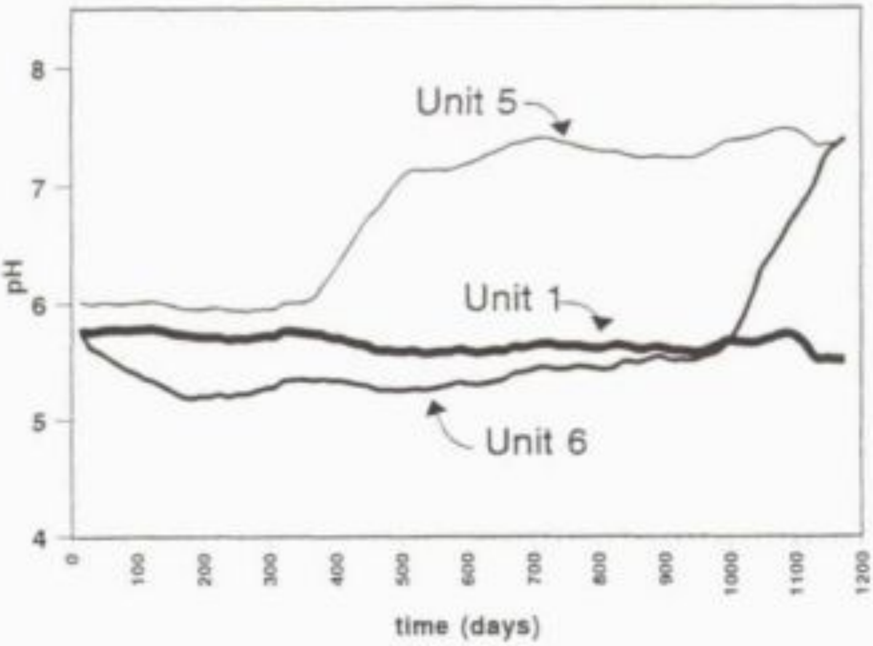


Figure 7.4 pH measurements (smoothed data) for Units 1 (no sludge), 5 (sludge) and 6 (sludge) - lysimeter studies.

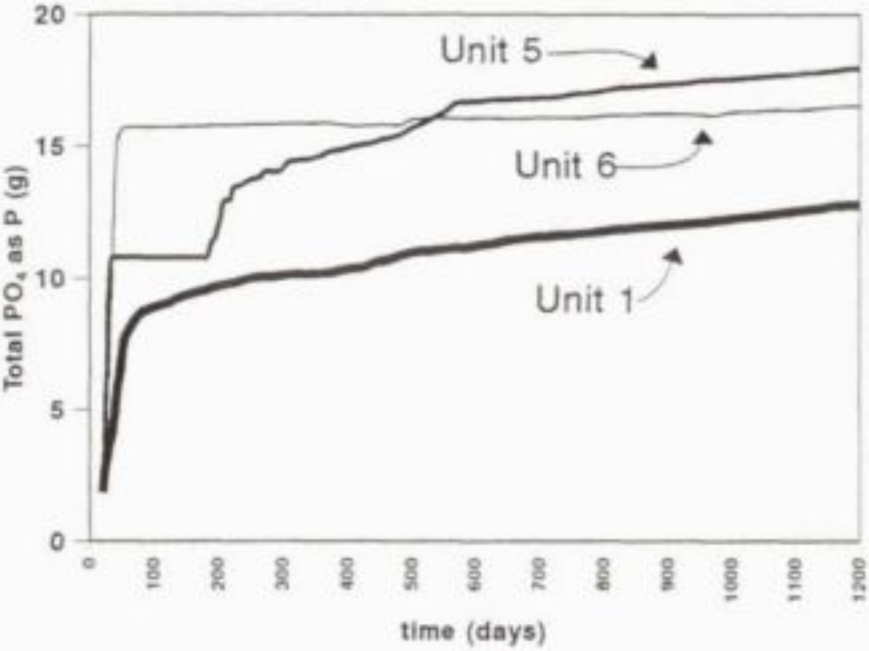


Figure 7.5 Cumulative total phosphate released from Units 1 (no sludge), 5 (sludge) and 6 (sludge) - lysimeter studies.

The addition of the anaerobically digested waste-water sludge to both Units 5 and 6 along with the liquid replacement strategy, must have contributed to the onset and progress of methanogenesis in these two lysimeters. From the COD concentrations alone it can be seen that a reduced period was required for the onset of methanogenesis and greatly reduced leachate COD concentrations were observed after methanogenesis commenced. The contribution of the sludge to the start of methanogenesis could not be quantified; however, it could have been by providing initial alkalinity to the system as well as a seed for the start of methanogenic activity, once the conditions were such that methanogenic activity could proceed.

7.4.7 EFFECT OF ANAEROBIC WASTE-WATER SLUDGE CO-DISPOSAL ON THE PHOSPHATE CONCENTRATION OF THE LEACHATE

Waste-water treatment sludges contain varying concentrations of total phosphate. Smith and Vasiloudis (1989), report that for samples of sludges from 77 different waste-water treatment works of different process configurations, a range in total phosphate from 4,1 to 41,0 g/kg (dry basis) as P was obtained. They furthermore report an average value for total phosphate of 6,8 g/kg (dry basis) for sludge from the Mitchell's Plain works and an average value of 18,9 g/kg (dry basis) for sludge from the Cape Flats works. The higher sludge total phosphate from Cape Flats can be expected as that works is of a biological nitrogen and phosphorus (full nutrient) removal design whilst Mitchells Plain is only designed for biological nitrogen removal.

Therefore, about 68 g of total phosphate was added to the co-disposal units by way of sludge addition. In addition, each lysimeter contained a significant unquantified amount of total phosphate from the selected refuse.

Figure 7.5 gives the total cumulative mass of total phosphate leaving Units 1,5 and 6 in the leachate. From this Figure it can easily be seen that more total phosphate was released from the co-disposal lysimeters (Units 5 & 6) than from the lysimeter containing no sludge (Unit 1). Unit 5 released 40% more and Unit 6, 30% more total phosphate than Unit 1 by the end of the 1200 day investigation period.

It must be noted that leachate recycling was practised on Unit 6 and only the excess leachate was discarded which resulted in the net loss of phosphate being considerably lower than that actually produced.

Therefore, it can be clearly seen that waste-water sludge co-disposal could increase the mass of total phosphate released from the landfill should leachate collection not be practised.

7.4.8 EFFECT OF ANAEROBIC WASTE-WATER SLUDGE CO-DISPOSAL ON THE TKN CONCENTRATION OF THE LEACHATE

Waste-water sludge contains varying concentrations of TKN. Smith and Vasiloudis (1989), report a range in TKN from 16,7 to 58,4 g/kg (dry basis) as N, for samples of sludges from 77 different works of different process configurations. The sludge from the Mitchells Plain works was found to contain a TKN concentration of 22,2 g/kg (dry basis). Therefore, 220 g of TKN was added to each co-disposal lysimeter by way of sludge addition. In addition the selected refuse contribute a significant unquantified amount of TKN to each lysimeter.

Figure 7.6 gives the total cumulative mass of TKN leaving Units 1, 5 and 6 in the leachate. From this Figure it can be seen that about 30% more TKN was released from Unit 5 than from Unit 1 (no sludge). However, the amount of TKN released from Unit 6 (containing sludge) was 28% lower than that from Unit 1 (no sludge). It must be noted that leachate recycling was carried out on Unit 6 and only the excess leachate containing a portion of the TKN was discarded.

If one, therefore, ignores the TKN mass released from Unit 6 as not being representative, because of the complicating nature of leachate recycling and compares only Unit 1 (no sludge) to Unit 5 (containing sludge) significantly more nitrogen in the leachate in the form of TKN was released from Unit 5 than from Unit 1. Therefore, during waste-water sludge co-disposal practises a higher mass of TKN could be released in the leachate.

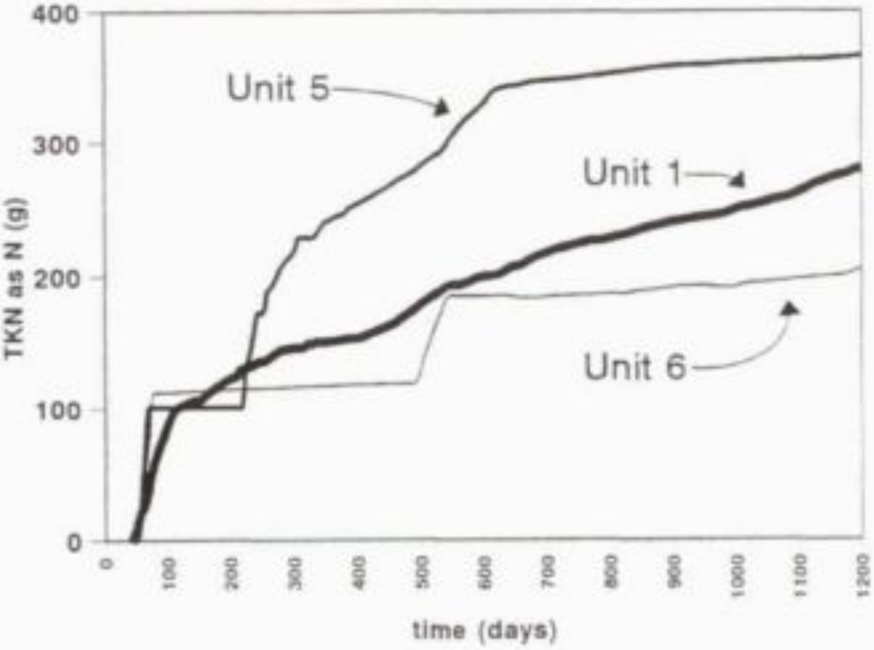


Figure 7.6 Cumulative TKN (as N) released from Units 1 (no sludge), 5 (sludge) and 6 (sludge) - lysimeter studies.

CHAPTER 8
FRAMEWORK FOR THE DRAWING UP OF SITE SPECIFIC GUIDELINES FOR WASTE-WATER SLUDGE CO-DISPOSAL PRACTICES

8.1 INTRODUCTION

In the absence of any established Code of Practice for the co-disposal of waste-water sludge with refuse in landfills in South Africa, local authorities must operate within the framework of the Minimum Requirements (DWAF, 1994a) as well as of Section 20 (1) of the Environmental Conservation Act, No. 73 of 1989. Local authorities or companies wishing to co-dispose waste-water sludge with refuse on an unlicensed landfill should carry out the following procedures (Bredenhann and Airey, 1990; Bredenhann *et al.*, 1991; Ball *et al.*, 1993) which would result in the landfill site being permitted for inter alia waste-water sludge co-disposal:

- An application for a permit to establish, construct and operate a waste disposal site must be submitted on a permit application form prescribed by, and available from, the Department of Water Affairs and Forestry (DWAF). Procedures and guidelines to assist perspective applicants in preparing and submitting permit applications have been formulated and are available from any offices of the DWAF.

- The permit application form must be accompanied by various reports and plans (see Figure 3.1). The number and extent of these reports will vary depending on the amount and types of wastes to be disposed, of as well as the characteristics of the environment in which the site is located.

  The following reports and plans might have to be submitted with the permit application:

  (a) motivation report
  (b) environment impact assessment (EIA) report
  (c) geohydrological report
  (d) water balance report
  (e) construction and engineering plan
  (f) operation and maintenance plan (including the co-disposal operation)
  (g) water quality monitoring plan
  (h) closure and rehabilitation plan

- Should the process of waste-water sludge co-disposal be introduced to a licensed landfill, the permit conditions may have to be amended. Hence, the landfill owner/operator must contact the Department of Water Affairs and Forestry in order to obtain the relevant permission before proceeding.

8.2 WATER BALANCE CALCULATIONS FOR CO-DISPOSAL

The possibility that a landfill will generate leachate at a significant rate is assessed by means of a Climatic Water Balance that uses published, easily available figures from the weather station closest to the landfill site;

$B = R - E$ ....(1)
where:
B = climatic water balance in mm of water
R = rainfall in mm
E = evaporation from the landfill cover surface in mm (taken as 0,7 x A-pan or 0,88 x S-pan evaporation).

If B is positive, the site may at least have a seasonal water surplus and there will be a possibility that leachate may be generated seasonally. In such a case, leachate management will be required by containment measures i.e. sealing of the base of the landfill and provision for collecting and disposing of the leachate. In situations of doubt, a full, detailed water balance calculation using a programme such as HELP (1992) is required to establish whether a site fall into the leachate management category or not. If it is intended to co-dispose of liquid or high moisture waste (such as sludge liquor or dewatered sludge), this additional moisture loading must be assessed in terms of mm of water per half year and added to the term R in question (1) above (Ball *et al.*, 1993).

8.3 CODE OF PRACTICE

The West Yorkshire Waste Management Authority (1990) in the United Kingdom carried out trials on the co-disposal of waste-water sludge with loose and baled waste and their Draft Code of Practice will prove useful to other local authorities in the formulation of landfill co-disposal strategies.

It is suggested that a Code of Practice for co-disposal should include the following type of information:

a) Objectives and scope of the Code of Practice.

b) Background information on the waste types (also chemical and physical characteristics), size/class of the landfill and the seasonal application ratios of refuse and waste-water sludge.

c) Operational planning and liaison with other governmental and private organisations who have an interest in the co-disposal operation.

d) Working procedures and instructions to operatives for:

   i) sludge transportation to the landfill site;
   ii) site mobile equipment;
   iii) controlled application of the sludge at the working face;
   iv) waste compaction and daily covering according to accepted sanitary landfill procedures;
   v) health and safety aspects in the sludge co-disposal operation.

e) Control of the landfill site with respect to sludge, leachate and gas monitoring.

f) Periodic review and modification of the Code of Practice in the light of experience, research, legislative requirements and investigation of complaints by the general public.

8.4 PERMIT ISSUED

On receiving the permit the applicant may proceed with the development and operation of the landfill site according to any conditions which may be stipulated by the permit and to the procedures described in Figure 3.1 and in Chapter 3 (Section 3.3.2).

CHAPTER 9
DISCUSSION

9.1 REFUSE CHARACTERISTICS INFLUENCING CO-DISPOSAL

Municipal refuse is generated from both domestic and commercial sources and its composition is extremely heterogeneous. Furthermore, refuse has various physical characteristics which significantly influence a sludge co-disposal operation. For example, the moisture content of the incoming refuse would determine the mass of water in the form of sludge which could be added on a seasonal basis so that the field capacity of the landfill was not exceeded.

Other physical characteristics of the refuse, such as it being sorted/unsorted, shredded/unshredded or baled/unbaled would all influence the strategy that needs to be devised to suitably mix the refuse and the sludge. The nature of the refuse therefore plays an important role in the formulation of a Code of Practice for the co-disposal operation.

9.2 SUITABLE SLUDGE TYPES FOR CO-DISPOSAL

In waste-water treatment, waste sludges are derived from different processes. Each type of sludge has its own physical, chemical and biological characteristics which in turn can vary from one treatment works to another. Waste-water treatment works rarely produce only one type of sludge but rather mixtures of primary, secondary aerobic and secondary anaerobic sludges.

The main criteria governing the suitability of a sludge for co-disposal are its degree of moisture (which influences the water balance), its degree of stabilisation (which influences the health aspects of the operation) and whether the sludge is aerobic or anaerobic (the presence of methanogenic bacteria is very advantageous). From the foregoing, the most suitable sludge type for the co-disposal operation would be an anaerobically digested primary sludge which had been dewatered, but not pasteurised. However, site specific circumstances together with the cost aspects generally determine the sludge type of choice for co-disposal.

The co-disposal of anaerobically digested sludge liquor (as carried out in this project) instead of dewatered sludge cake requires a strict control of the landfill water balance. However, use of sludge liquor instead of sludge cake also has various advantages, such as:

a) savings on mechanical sludge dewatering costs;

b) savings on vehicle transportation as the sludge liquor can be more economically pumped to the landfill site via a pipeline;

c) no special mechanical mixing procedures have to be carried out as the sludge liquor can be uniformly spread on the refuse at the tipping face by means of flexible hosepipes. The moisture in the sludge liquor is readily absorbed by the drier refuse at its time of placement which is beneficial to the waste compaction process.

The South African Department of National Health and Population Development (1991) has produced a set of Guidelines indicating permissible utilisation and disposal routes for waste-water sludge. In these Guidelines, sludge is classified into types A, B, C and D in decreasing order of its potential to cause odour nuisances and fly breeding, as well as to transmit pathogenic organisms to man and his environment. The Guidelines permit the unrestricted co-disposal of Type D sludge on a landfill. Sludge types A, B and C however can be co-disposed with domestic waste in Class 2 disposal sites but the permit requirements in terms of the Environment Conservation Act, No. 73 of 1989 and the Minimum Requirements of the DWAF must be met.

9.3 IMPORTANT ROLE OF MOISTURE IN LANDFILLING

All living organisms require moisture for survival. The anaerobic digestion metabolic processes taking place in a sewage sludge digester and in a landfill bioreactor are basically similar, except for the degree of moisture present in the two processes. Digestion of sewage sludge can be achieved in some 30 days at a moisture content of 96% while stabilisation of refuse could take as long as 100 years if the moisture content is as low as 30%.

The moisture content and the resulting microbial interactions are thus interrelated. This has serious implications for the effective stabilisation of landfilled refuse in "so-called dry landfills" (Britz, 1990). Reduction of leachate volume by limitation of site water entry is not necessarily a desirable strategy since high moisture contents maximise refuse decomposition processes (Diaz *et al.*, 1982; Robinson and Maris, 1985).

Similarly until relatively recently it has been considered good practice to try and exclude water from landfilled wastes by cellular operation using low permeability cover, graded caps, etc. However, the need for moisture in the landfill to ensure controlled landfill stabilisation with a greatly reduced timescale has lately been recognised (Robinson and Gronow, 1993; Pohland and Al-Yousfi, 1994).

Various basic factors affect the rate of bacterial degradation of municipal refuse in a landfill. These include biological factors such as type of bacteria, availability of food and nutrients, presence of toxic materials and environmental factors such as moisture content, pH and degree of anaerobic conditions (absence of oxygen).

The main effect of increased moisture content is probably to facilitate the spreading of microorganisms between the waste micro-environments, for transporting microbial metabolites, for exchange of nutrients and buffers, for dilution of inhibitors and for acting as solvent in which chemical reactions can take place (Christenson and Kjeldsen, 1989). Lema *et al.*, (1988) report that anaerobic biodegradation of organic material is usually stimulated when a landfill has a water content of 50 to 70% - a figure unlikely to be reached in dry areas or during dry periods. Similarly, Barlaz (1988) reported that moisture contents of 55% or higher could lead to more rapid production of methane from the landfill, while methane production was not observed from the refuse in which the moisture contents were less than 35%.

The movement of moisture has also been shown to be a factor in stimulating gas production (Hartz and Ham, 1983; Klink and Ham, 1982). The movement of moisture is only significant when the moisture content of the refuse in the landfill is equal to or greater than the field capacity (Barlaz *et al*., 1987).

It is apparent from the foregoing that moisture is of prime importance in solid-state anaerobic decomposition. However, the "dry tomb landfill" and "bioreactor landfill" concepts illustrate the dilemma concerning current landfill practices and legislation (Ham, 1988; Knox, 1988; Pohland *et al*., 1983). While the "dry tomb" concept advocates reducing the moisture content of the landfill so as to minimise leachate formation, the "bioreactor" concept advocates optimising the moisture content in order to accelerate the *in situ* stabilisation of the wastes.

9.4 CLAY OR PLASTIC LINERS FOR LEACHATE CONTAINMENT

Landfill leachate can constitute a serious pollution hazard during certain phases of the stabilisation process. The possibility that a landfill will generate leachate at a significant rate is assessed by means of a Climatic Water Balance. If the site has a seasonal water surplus, leachate management may be required by containment measures i.e. sealing of the base of the landfill and provision for collecting and deposing of the leachate. In situations of doubt, a full detailed water balance calculation using a programme such as HELP (1992) is required to establish whether a site falls into the leachate management category or not. If it is intended to co-dispose sludge liquor or dewatered sludge cake then this additional moisture loading must be incorporated in the Climatic Water Balance.

Engineered containment is generally achieved by the installation of either a clay liner or a polymeric geomembrane, such as high density polyethylene (HDPE), under the landfill. Using these materials, emphasis is placed on preventing the release of leachate into the geological environment. Improvements in the standards of landfill engineering preparations were necessary and the risk of groundwater pollution should be significantly reduced by the provision of containment liners.

9.5 ADVANTAGES / DISADVANTAGES OF SLUDGE CO-DISPOSAL

The co-disposal of refuse and waste-water sludge is not without its side effects. Whether these are beneficial or detrimental, a balanced view must be taken in assessing the overall suitability of the process as a sludge disposal option.

9.5.1 Advantages of Co-disposal (Buivid et al., 1981; Barlaz et al., 1987; Craft and Blakey, 1988; Ham, 1988; Knox 1988)

- The added moisture (from the sludge) is claimed to accelerate the microbiological, physical and chemical attenuation mechanisms responsible for the decomposition of the refuse and the leachate, thereby reducing the time necessary for stabilisation of the landfill. This reduces the long-term care requirements of the landfill and allows earlier productive final usage of the site surface.

- Addition of anaerobically digested waste-water sludge is claimed to have the beneficial effects of inoculating the refuse with some of the necessary methanogenic bacteria (together with nutrients and trace elements) for enhancing the formation of biogas. Complete stabilisation can only be achieved once the biodegradable fraction of the waste has been anaerobically decomposed and converted into biogas. Biogas is a valuable by-product for utilisation as an energy resource.

- The additional moisture from the waste-water sludge significantly improves the compaction and subsequent rate of settlement of the generally too dry refuse. This can extend the life-span of the landfill by reducing airspace requirements which is financially quantifiable.

9.5.2 Disadvantages of Co-disposal

- The major perceived problem with the co-disposal of waste-water sludge with refuse on a landfill is the possible generation and release of more leachate with high concentrations of pollutants. This problem can be overcome by the installation of an engineered containment liner.

- Another perceived problem is the controlled admixture of dewatered sludge cake with the refuse. There are various ways in which this can be overcome so that the normal landfilling procedures are not prejudiced by the co-disposal operation.

9.6 CO-DISPOSAL INTEGRATES WASTE MANAGEMENT

The siting of a landfill adjacent to a waste-water treatment plant not only enables various treatment options to be exercised but furthermore has advantages in terms of improved pollution control. Figure 9.1 illustrates the complimentary nature of such an integrated waste management strategy. Excess leachate from the landfill site can, after recycling or treatment in its raw state, be transferred to the waste-water plant for treatment whilst sludge form the waste-water plant can be directed to the landfill site for co-disposal.

Biogas which is rich in methane is generated in both the anaerobic sludge digestion process on the waste-water plant as well as in the anaerobic stabilisation processes occurring within the landfill bioreactor. This increased biogas volume can be utilised in various ways as a renewable energy source. In this context it would be advantageous to utilise the biogas; a) to generate electricity in order to run a portion of the waste-water treatment works; b) to provide heating in order to promote the mesophilic process in the anaerobic sludge digesters; c) to use the methane component in the biogas as a fuel for landfill machinery.

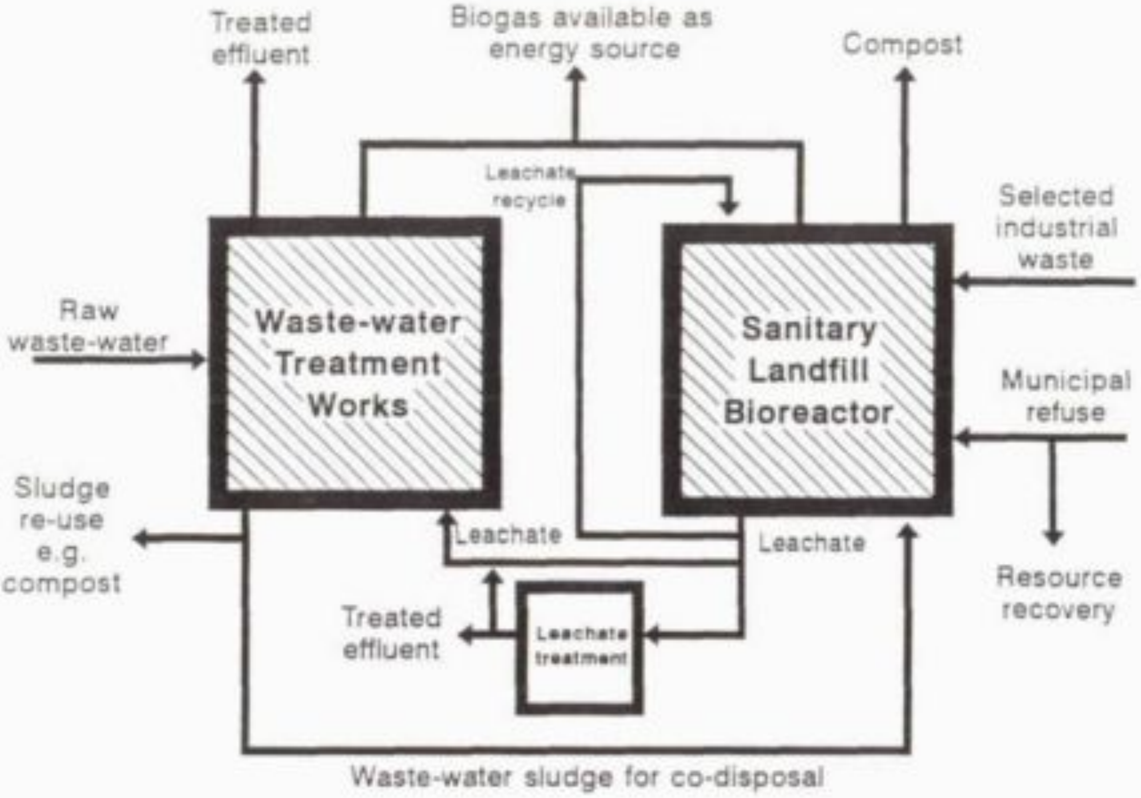


Figure 9.1 Complimentary nature of integrated waste disposal management.

9.7 SHORTCOMINGS OF WASTE MANAGEMENT LEGISLATION IN SOUTH AFRICA

South Africa at present does not have a comprehensive national statute covering waste management. Provisions for dealing with waste are scattered among 37 national statutes, 16 provincial ordinances and numerous by-laws. According to the Department of Water Affairs and Forestry it was not possible in 1993 to stipulate hard and fast rules for the co-disposal of waste-water sludge with domestic refuse but only to consider waste-water sludge as another waste product which must be dealt with in a manner consistent with overall waste disposal criteria (Crawford, 1993).

In the absence of any established Code of Practice for the co-disposal of waste-water sludge with refuse in landfills in South Africa, local authorities must operate within the framework of the Minimum Requirements of the DWAF as well as of Section 20 (1) of the Environment Conservation Act, No. 73 of 1989. Local authorities or companies wishing to co-dispose waste-water sludge with refuse on an unlicensed or licensed landfill should contact the DWAF for application of the necessary permit (as discussed in Section 3.3.2).

9.8 OVERSEAS DEVELOPMENTS ON SUSTAINABLE LANDFILL PRACTICES

Current landfill practice have evolved to provide engineered containment of waste breakdown products and operation standards to prevent pollution of water. The main outstanding problem concerns the period for which the landfill site (after closure) will pose an environmental risk (Harris *et al.*, 1993). Although short-term pollution risks may have been reduced, the residual risk of storage of wastes, especially in dry containment sites ("dry tomb" approach), will remain for a much longer period.

Regardless of the risks of membrane liner failure, a system which continues to impose management and regulation costs for possibly hundreds of years, because of its environmental risk, cannot be regarded as sustainable i.e. because it passes on a large proportion of the environmental burden to future generations. No regulatory system, or indeed political system can be guaranteed to provide adequate control for this length of time.

The requirements of sustainable development have very clear implications for the objectives of landfill and have already formed the basis of specific waste management policy in some countries. For instance, an objective of some European waste management policies since 1986 have been that each generation manages its waste to a status of final stage quality. This is defined as the stage when any emissions to the environment are acceptable without further treatment. The duration of one generation has been interpreted as being approximately 30 years, consistent with the 30 year post-closure monitoring period required by the proposed EC Landfill Directive and by RCRA Subtitle 'D' in the USA. A Certificate of Completion will not be issued until it can be shown that the landfill is unlikely to cause pollution of the environment.

Changes in the landfill legislation are therefore needed to ensure that each generation deals with its own problems. Two broad strategies to achieving this are:

- pre-treatment of wastes to final storage quality, before landfilling, by a combination of pre-sorting, recycling and waste minimisation, incineration, anaerobic digestion and composting; or
- development of highly efficient bioreactor landfills incorporating sludge co-disposal and with extensive recirculation and treatment of leachate to achieve final storage quality within a generation.

Neither approach has yet been technically proven. Research and development are considered essential to determine whether landfill practices can become sustainable.

CHAPTER 10
CONCLUSIONS

The results of this research have provided practical operational criteria for the landfill co-disposal of domestic refuse and anaerobically digested waste-water sludge liquor. The main conclusions to be derived from this research are summarised as follows:

- The application of sludge to land as a fertiliser or soil conditioner is generally regarded as the most sensible sludge disposal option. However, the impact of pending sludge legislation policies in South Africa may prohibit the agricultural utilisation of sludges that contain high concentrations of pollutants such as heavy metals and pathogenic bacteria. In such instances, and also where there is no agricultural demand for the sludge, it is likely that much greater use will be made of landfill co-disposal as an alternative sludge disposal option.

- The controlled co-disposal of waste-water sludge with refuse is a landfill strategy which can play an important beneficial role in the overall management of these two waste streams.

- The importance of moisture in solid-state anaerobic decomposition has been highlighted for optimising the physical, chemical and biological conditions for accelerated stabilisation of the landfilled waste. This reduces the long-term care requirements of the landfill and allows earlier productive final usage of the site surface.

- Additional moisture is added to a landfill during a sludge co-disposal practice. As a result, proper water balance management must be practised so as not to exceed the field capacity of the landfill, especially during wet seasonal periods. Consideration should thus be given to the provision of containment liners so as to facilitate the collection, treatment and disposal of the leachate as an essential part of the overall landfill management.

- Landfill co-disposal technology needs to be recognised by the policy and regulation community and managed by the waste management industry to the prescribed Minimum Requirements (DWAF, 1994a).

- Landfills should be sited adjacent to waste-water treatment plants so as to enable various options to be exercised for the treatment and utilisation of the sludge, leachate and biogas end-products. Such an integrated waste management strategy would be advantageous in terms of improved pollution control.

- Local authorities or companies wishing to co-dispose waste-water sludge with refuse must apply for a permit within the framework of the Minimum Requirements of the Department of Water Affairs and Forestry (DWAF, 1994a) as well as of Section 20 of the Environment Conservation Act, No. 73 of 1989.

- It is recommended that should the details of this report be utilised elsewhere, cognizance be taken of the local conditions in the Western Cape to assist in the adoption of the technology

CHAPTER 11
RECOMMENDATIONS FOR FUTURE RESEARCH

There is a need for further complementary studies either on full-scale or using more manageable pilot-scale studies. The following recommendations for future research are highlighted:

- Landfill gas management in South Africa :
    - beneficial utilisation of landfill gas
    - optimisation of landfill gas generation
    - detailed characterisation of landfill gas components
    - control of potential hazards of landfill gas;
- The effect of various types of waste sludges on landfill operation and stabilisation:
    - water treatment sludge (Alum/Ferric salts)
    - waste activated sludge
    - primary sludge (untreated)
    - industrial sludges;
- The characterisation and treatment of landfill leachates in South Africa with specific reference to:
    - leachate recycling and recirculation processes
    - anaerobic treatment
    - acid digestion (to promote the formation of short chain fatty acids for use in nutrient removal systems)
    - aerobic lagoon treatment
    - blending with raw waste-water in activated sludge works;
- Development of practical methods to effectively apply dewatered sewage sludge (greater than 10% solids) to the refuse (baled or loose) without negatively affecting the workability of the landfill compactor;
- Viability of multiple co-disposal e.g. co-disposal of oil and waste-water sludge with refuse;

- Establishment of interrelationships between the optimum moisture requirement for biological degradation and compaction, and the field capacity of a landfill which governs the physical production of leachate;

- Landfill hydraulics research:

  - design of sub-cap leachate re-injection systems
  - avoidance of hydraulic barriers within landfills;

- Requirements for sustainable landfill practices i.e. optimisation of landfill bio-stabilisation so as to meet the criteria for final-stage quality within 30 years.

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CHAPTER 13
APPENDIX 1

BOX TEST REPORT NO. 1

USE OF BOX TESTS TO QUANTIFY LANDFILL PARAMETERS SUCH AS BULK DENSITY, MOISTURE CONTENT, COMPACTABILITY AND FIELD CAPACITY OF REFUSE/SLUDGE MIXTURES

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1. INTRODUCTION

The co-disposal of refuse and sewage sludge in sanitary landfills is being practised in many parts of the world, especially in drier areas which have a perennial water deficit. For example, in the United Kingdom, some 15% of sewage sludge is currently co-disposed with domestic wastes and it is likely that much greater use will be made of this disposal option as sea disposal is being phased out. The major perceived problems with the disposal of sewage sludge on a landfill are the controlled admixture thereof with the refuse and the possible generation of excess leachate (Craft and Blakey, 1988; Hall, 1990).

The Coast Park landfill site, Cape town, is in a water deficit area with potential evaporation exceeding precipitation by some 600 mm per annum (Blight *et al.*, 1990). Precipitation exceeds evaporation only during the four winter months of June to September. This research project was negotiated to investigate the possible role that co-disposal of refuse and sewage sludge could play in the overall management of these two waste streams. The main research objective of the project was to develop practical operational criteria for the integrated treatment and co-disposal of a combination of refuse and sewage sludge in a landfill bioreactor in order to optimise both the physical and biological factors (such as compaction and stabilisation).

The research was divided into two phases, namely:

i) Practical co-disposal experiments at Coastal Park to determine the most suitable volume ratio of refuse and anaerobically digested sewage sludge liquor for compactor workability.

ii) Box Tests to quantify important interrelated parameters (such as field capacity, bulk density, moisture content and compaction) which influence the water balance during the co-disposal operation.

This reports describes the results of the Box Tests carried out during July - October 1991 and their relevance to the implementation of the Coastal Park co-disposal project.

2. EXPLANATION OF CO-DISPOSAL TERMINOLOGY (WITH TYPICAL VALUES)

2.1 Bulk density (wet in-situ)

The density is better described as a bulk mass density as it takes the entire refuse/sludge mixture into consideration. Bulk density is the wet mass per unit volume of refuse, usually expressed in kg per m^3. The bulk wet *in-situ* density is a difficult parameter to measure because of the heterogeneity of the landfilled refuse and the wide variation in density that occurs with differing degrees of compaction.

Typical values of bulk density:

The following bulk density values appear representative (Blight, 1990):

Uncompacted refuse : 150 to 350 $kg.m^{-3}$
Heavily compacted refuse : greater than 1 000 $kg.m^{-3}$

Density determinations up to 1 500 $kg.m^{-3}$ can occur when the cover material consists of fine sand which infiltrates the refuse, partly filling the voids.

2.2 Moisture content of refuse

The moisture content of refuse is expressed as a mass percentage i.e. the mass of water contained in a unit mass of dry refuse. Water may be held in emplaced refuse in three forms: gravitational, capillary and hygroscopic. Gravitational water, which is characteristically present in macrovoids between refuse components, may facilitate the development of perched water tables even when the moisture content is below the field moisture capacity. Conversely, capillary and hygroscopic water is held in micropores and microvoid spaces (Ehrig, 1983).

The moisture content of the incoming refuse is generally much less than its saturation moisture content i.e. the maximum mass of water that it could absorb.

Typical values of refuse moisture content at Coastal Park:

Only limited data is available on the moisture content of incoming refuse at Coastal Park but it is assumed to be considerably less than the moisture content of Durban refuse which varies in the range 58 - 62% (Lombard, 1991). The distribution of moisture content at various depths of the landfill was determined by direct sampling at Coastal Park at the end of the wet and dry seasons (Blight *et al.*, 1990). The results of the analyses showed that the water content was mostly below the field capacity (estimated as 60% moisture) at the end of the wet season but there was a zone of material at a depth of 4 m that was above the field capacity and one at 2 m that was at field capacity. The end of the dry season water content profile was well below the field capacity.

Samples of landfilled waste were taken and analysed from Coastal Park during 1991 and these all recorded moisture contents below 30%.

In Thailand, for example, the characteristic low moisture content of landfilled refuse of less than 5% recorded during the dry season increases to more than 65% in the wet months and is accompanied by leachate generation (Lohani, 1984).

2.3 Moisture absorptive capacity of a landfill

The moisture absorptive capacity of (35%) a landfill approximates the field capacity of the emplaced waste (55 - 65%) minus the moisture content of the incoming refuse (20 - 30%) (Lombard, 1990). The absorptive capacity changes with refuse particle size (by provision of additional void spaces) and emplaced refuse density increase (due to compaction). The saturation moisture content of the incoming refuse can be considerably higher than the in-situ moisture absorptive capacity of the landfilled waste.

2.4 Field capacity of a landfill

The field capacity of landfilled refuse is the water content, expressed as a percentage of the dry mass of refuse, that will be held in the refuse by capillarity when allowed to drain by gravity i.e. the water content of refuse subject to wetting will increase up to the field capacity. Once the field capacity has been reached, additional water will not be retained by the refuse but will drain through it as leachate. This description is known to be an over-simplification, as no quantitative information being available in the literature on variation of field capacity with refuse density. Landfills are heterogeneous in composition and certain zones may have considerably lower and higher field capacities than the overall average value (Blight, 1990).

The field capacity of a landfill is thus the maximum amount of water that can be retained under compaction without percolation and is normally less than the saturation moisture content of the incoming refuse (Mayet, 1991). As decomposition and compaction of refuse occurs in a landfill, the field capacity progressively decreases. However, leachate is often emitted from a refuse mass before the field capacity has been reached due to channelling, etc.

Typical values of field capacity:

The literature records values for field capacity of refuse that vary from 80% for fresh refuse (Campbell, 1983) to between 63% and 74% for refuse more than four years old (Holmes, 1980). The field capacity for Coastal Park was approximated by Blight *et al.* (1990) to be 60%. Lombard (1990) reports that the field capacity of refuse in a landfill site approximates 55 - 60% of the mass deposited.

2.5 Compaction of refuse

A major benefit accruing from the wetting of the incoming refuse is the change in physical transition from a highly bulky solid waste to that of a semi-solid state. The added moisture does not increase the volume of the refuse/sludge mixture, as it fills the voids between the individual particles. The wetted refuse becomes less rigid and softer which enables it to be better compacted.

In general terms, effective compaction of municipal solid waste implies obtaining maximum in-place density under a given set of operation conditions. These conditions include amount and type of waste handled, topography and layout of landfill site, number and types of compactors, rate of waste arrival, nature of compaction in-transit, level of competence of operators, type of cover material and prevailing climatic conditions. One must also distinguish between density of waste on placement, after initial settlement and during various stages of maturity. The latter two tend to be higher (in the same landfill) because of the combined effects of heavier cover material and compression and subsequent settlement due to overburden, selfweight and repeated vehicle traffic (Mayet, 1991).

Typical values of refuse compaction:

A recent detailed compaction test on urban waste conducted by the Richards Bay municipality achieved an in-place density of 1 400 kg.m-^{3} using the area method with a 22,3 ton steel wheel compactor. About half the waste was municipal (i.e. compactable), some 22% builders rubble, 11% industrial, 15% soil and the balance was bark and wood shards. A similar test was conducted in Durban on domestic and some commercial waste using a 31,3 ton steel wheel compactor. An in-place density of 800 kg.m^{-3} was achieved with less waste and fewer passes, and without prior bed preparation or cover material (Mayet, 1991).

The potential benefits of effective compaction arise from the increased availability of airspace and its associated implications, viz. revenue from private contractors and extended use of existing infrastructure. This is best illustrated by example where a municipal site expects to landfill 200 000 tons per annum and has a total available airspace of 15 million m^{3}. Based on predicted landfill densities of say 500, 750 and 1000 kg.m^{-3}, the projected lifespan would be 37,5, 56,3 and 75 years respectively, assuming no annual growth in waste to be landfilled (Mayet, 1991).

2.6 Optimum moisture requirements for solid-state anaerobic metabolism in a landfill

All living organisms require moisture for survival. The anaerobic digestion metabolic processes taking place in a sewage sludge digester and in a landfill bioreactor are basically similar, except for the degree of moisture present in the two processes. Digestion of sewage sludge can be achieved in some 30 days at a moisture content of 96% while stabilisation of refuse could take as long as 100 years if the moisture content is as low as 30%.

The moisture content and the resulting microbial interactions are thus interrelated. This has serious implications for the effective stabilisation of refuse in dry landfills (Britz, 1990). Reduction of leachate volume by limitation of site water entry is not necessarily a desirable strategy since high moisture contents maximise refuse decomposition processes (Diaz *et al.*, 1982; Robinson and Maris, 1985).

Various basic factors affect the level of biological activity in the decomposition of refuse: biological factors such as bacteria, food, nutrients, presence of toxic materials and environmental factors such as moisture, temperature, pH and degree of anaerobic conditions (absence of oxygen). Moisture is of prime importance in solid-state anaerobic decomposition, for transporting microbial metabolites and acting as solvent in which chemical reactions can take place. Lema *et al.* (1988) report that anaerobic biodegradation of organic material is usually stimulated when a landfill has a water content of 50 - 70%; a figure unlikely to be reached in dry areas or during dry periods. Similarly, Parr *et al.* (1982) report the optimum moisture content for rapid decomposition in aerobic composting as being 50 - 60%. Further research needs to be carried out to establish the interrelationship between the optimum moisture requirement for biological degradation and the field capacity of a landfill which governs the physical production of leachate.

Studies by Pohland *et al.* (1983) have led to a convenient description of the component phases of landfill stabilisation and the associated indicator parameters. These are illustrated in Figure 13.1 for selected leachate and gas characteristics. Landfill activity may be regarded as commencing with an initial lag or adjustment Phase 1 which continues until sufficient moisture has accumulated to stimulate reaction. Field capacity moisture is reached in Phase 2 and leachate and gas formation reflects a transition from aerobic to anoxic or anaerobic conditions.

3. MATERIALS AND METHODS USED IN THE BOX TESTS

These experiments were carried out at the Athlone transfer station of the Cleansing Branch of the Cape Town Municipality during July to October 1991.

3.1 Standard Box

A 1,0 m^3 volume box was initially used but the experiments were time-consuming and labour-intensive. A 0,5 m^3 volume box (1m x 1m x 0,5m high) was thereafter used for the determination of the bulk density of various refuse/sludge volume ratios. The box had perforations in the bottom to allow leachate to drain out and be collected in a tray.

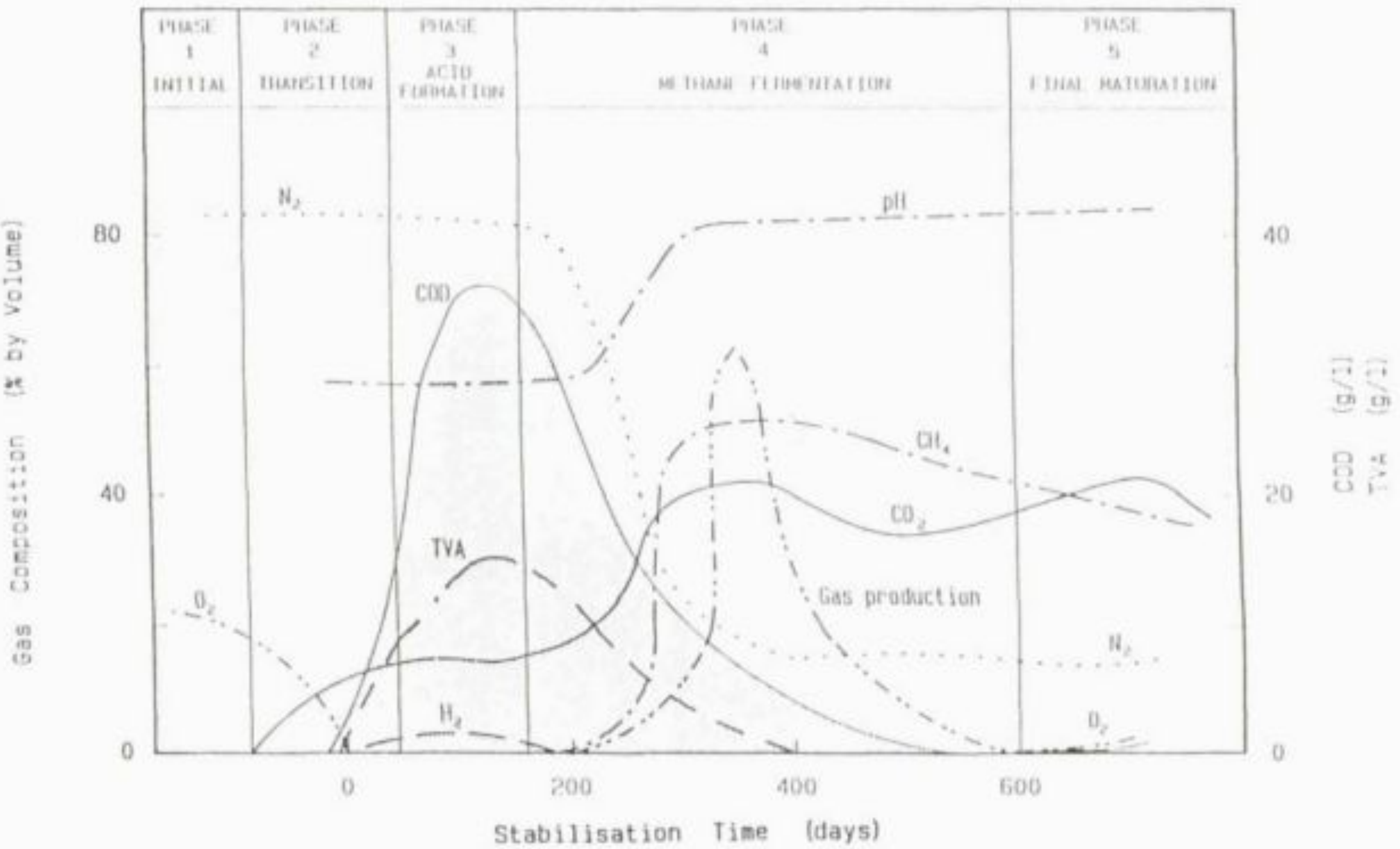


Figure 13.1 Changes in the selected indicator parameters during the phases of landfill stabilisation (Pohland *et al.*, 1983).

3.2 Scale and pulley system

The scale and pulley system was connected to a hoist which enabled the mass of the box and its contents to be weighed.

3.3 Compaction masses

It is difficult to simulate the action of a landfill compactor in a box test. Three different masses were used during the box experiments for compaction of the refuse/sludge mixtures, namely 475 kg, 600 kg and 1 615 kg. These masses had a standard size base, namely 0,8m x 0.8m which permitted the pressures exerted by the compactors to be calculated by the formula:

$$\text{Pressure: } (kg.m^{-1}.s^{-2}) \text{ or (Pascals - Pa)} = \frac{\text{FORCE (kg)} \times 9{,}8\ m.s^{-2}}{\text{Area } (m^2)}$$

Pressure of compactor 1: 475 kg = 7,27 kPa
Pressure of compactor 2: 600 kg = 9,18 kPa
Pressure of compactor 3: 1615 kg = 24,5 kPa

The point load pressures exerted by landfill compactors are unknown.

3.4 Concrete mixer

A concrete mixer was used to provide optimum contacting of the refuse and the digested sewage sludge liquor for determination of the saturation moisture content of refuse. After mixing, the excess moisture was allowed to drain for volume measurement.

3.5 Refuse

Fresh refuse was used for these experiments and only large items (such as cardboard boxes and plastic sheets) were excluded from the Box Tests. Duplicate samples were taken for moisture analyses due to the heterogeneous nature of the refuse.

3.6 Digested sewage sludge liquor

The digested sewage sludge used in these experiments had a solids content of some 20 $g.l^{-1}$ (i.e. a moisture content of 98% and a solids content of 2%).

3.7 Box Test experimental procedures for determination of bulk density, compactability and field capacity of various refuse/sludge mixtures.

The following procedures (with slight variations) were followed for carrying out the Box Tests:

a) The empty box was weighed.

b) The compactor mass was weighed.

c) The box was filled with 10 cm layers of refuse and compacted after each layer in a standardised manner until the box was filled to the 500 mm height. Samples were taken of the incoming refuse for initial moisture content.

d) The filled box was weighed again and the bulk density determined as a function of the compactor mass used and the moisture content of the refuse.

e) The known volume of the compacted box contents was emptied on a plastic sheet and a known volume of digested sewage sludge liquor was added and mixed into the refuse to increase the moisture level. This allowed the refuse/sludge volume ratio to be determined. Samples were taken of the mixture for moisture analyses but these were included in the subsequent weighings.

f) The box contents was reconstituted as before (see item c) by filling with 10 cm layers and compacting after each layer in the standard manner until all the mixture had been transferred back into the box. The degree of compaction was measured and expressed as a percentage reduction in the initial height of the refuse in the box. The volume of any leachate that drained from the box into the tray was also measured. The refilled box was weighed again and the bulk density determined at the new moisture content.

g) The procedure was repeated for different refuse/sludge volume ratios in the range 20/1 to 2/1.

3.8 Experimental procedures to determine the saturation moisture content of refuse

The saturation moisture content of incoming refuse is easy to determine and as such is a useful index. Its value will be higher than the field capacity of the landfilled waste which in turn is generally higher than the moisture content of the incoming refuse. Determination of the saturation moisture content enables the range in these parameters to be assessed for different types of refuse constituents.

Known volumes of refuse were placed in the concrete mixer to which was also added known volumes of digested sewage sludge liquor until it was apparent that the saturation point had been reached. Different components of refuse were also selected for this test so as to obtain the range in values for high absorbance (dry paper) and low absorbance (wet kitchen waste). The refuse was sampled for moisture content determinations before and after admixture with the sewage sludge liquor.

4. RESULTS AND DISCUSSION OF BOX TEST 1

This test was of an exploratory nature to get acquainted with the apparatus and procedures. The result are presented in Table 13.1 and summarised below:

i) The bulk density of the refuse increased from 345 to 493 kg.m^{-3} (28,7% increase), equivalent to a 20% increase in compaction, at a refuse/sludge volume ratio of 20/1.

ii) The moisture content of the incoming refuse was 34,5% and was increased to 42,5% by addition of the sludge liquor.

TABLE 13.1: RESULTS OF BOX TEST 1

Procedure No.	Volume Ratio Refuse/ Sludge	Compacted Bulk Density ($kg.m^{-3}$)	Moisture Content (%)	Volume Leachate Produced (litre)	Compaction (based on % of original height in box)
1	-	345	34,5	-	-
2	20/1	493	42,5	0	20%

Conditions of Test 1:

Compactor mass = 600 kg
Box volume = 1,0 m^3
Sludge solids = 2,6%

5. RESULTS AND DISCUSSION OF BOX TEST 2

The results are presented in Table 13.2 and Figure 13.2 and summarised below:

i) A decrease in the volume ratio of refuse/sludge in the range 20/1 to 3,5/1 increased the bulk density of the mixture from 350 to 800 $kg.m^{-3}$.

ii) Addition of increasing ratios of digested sewage sludge liquor to the refuse increased the moisture from an initial value of 37,4% to a saturation value of some 56% under the exerted test compaction pressure.

iii) A leachate was produced between the refuse/sludge volume ratios of 7,7/1 and 4,8/1 (refer Fig. 13.2d). This situation corresponds to the field capacity which occurred at a moisture level of 56%.

iv) No measurable compaction of the refuse could be obtained at moisture levels below 51%. This is to be compared with a 26% increase in compaction at a moisture content of 56% which was achieved by a refuse/sludge volume ratio of 4,8/1 (refer Fig 13.2c).

TABLE 13.2: RESULTS OF BOX TEST 2

Procedure No.	Volume Ratio Refuse/ Sludge	Compacted Bulk Density ($kg.m^{-3}$)	Moisture Content (%)	Volume Leachate Produced (litre)	Compaction (based on % of original height in box)
1	-	350	37,4	0	-
2	20/1	360	51,3	0	0
3	7,7/1	563	55,4	0	20
4	4,8/1	689	56,5	0,74	26
5	3,5/1	800	55,8	2,86	30

Conditions of Test 2:

Compactor mass = 445 kg
Box volume = 0,5 m^3
Sludge solids = 1,16%

6. RESULTS AND DISCUSSION OF BOX TEST 3

The results are presented in Table 13.3 and Figure 13.3 and summarised below:

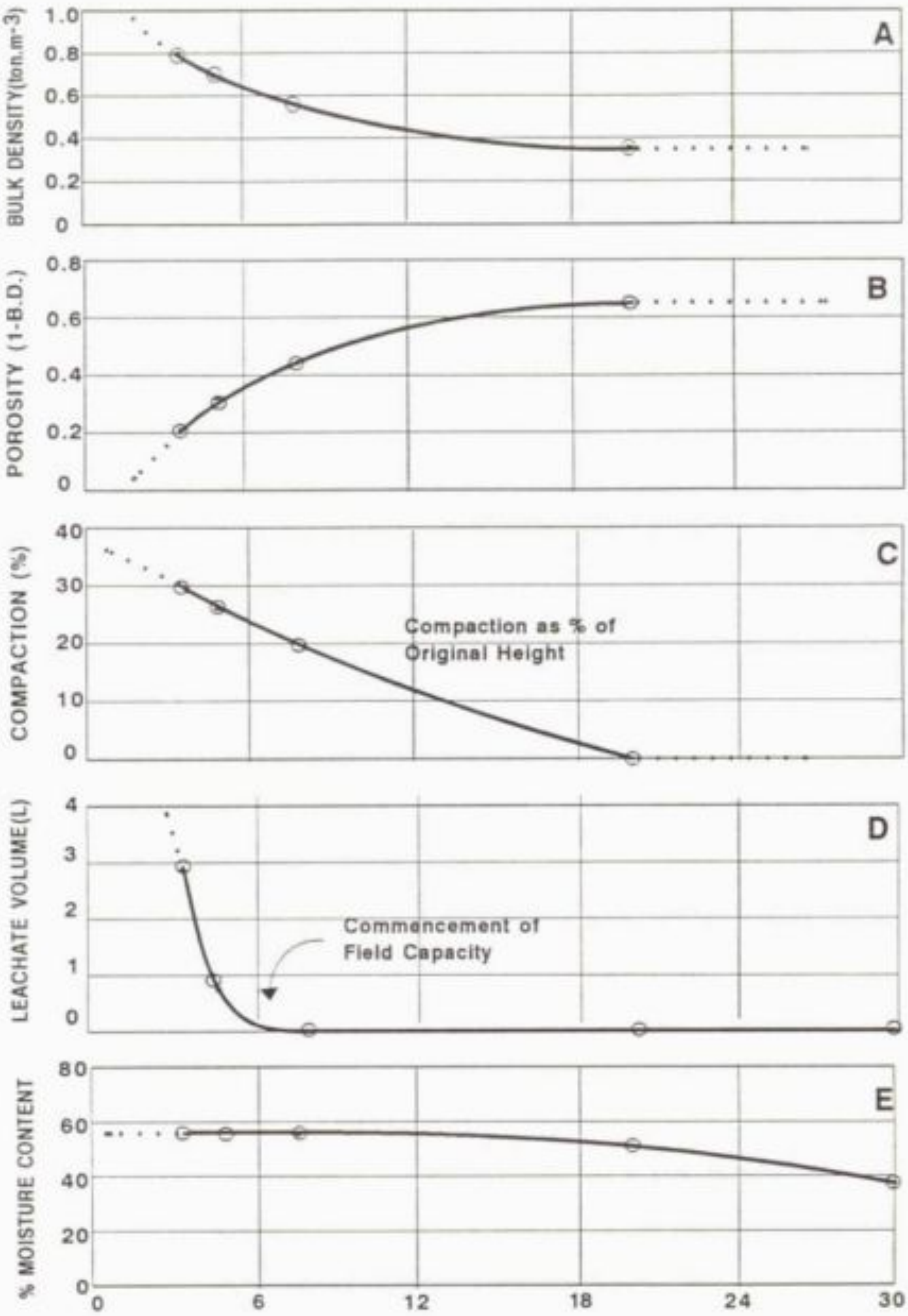
i) The incoming refuse on this occasion was much wetter (49% moisture) than for Box Test 1 (35%) and Box Test 2 (37%) due to the rainy weather conditions.

ii) A decrease in the volume ratio of refuse/sludge in the range 12,5/1 to 3,1/1 increased the density of the mixture from 500 to 800 $kg.m^{-3}$.

iii) Addition of increasing ratios of digested sludge liquor to the refuse resulted in a field capacity value between a moisture content of 60 and 70%.

iv) A leachate was produced between the refuse/sludge volume ratios of 6,25/1 and 3,1/1.

v) No significant compaction was obtained during Box Test 3. The reason for this phenomenon was thought to be due to the higher initial moisture content of the incoming refuse. Comparison between Box Test 2 and 3 (using the same compactor masses) indicates that the degree of compaction was relatively more significant when the moisture was 50% and the bulk density was 600 $kg.m^{-3}$. Higher moisture (60%) and density (800 $kg.m^{-3}$) levels produced a relatively insignificant incremental compaction due to the fact that water is not compressible.



Volume ratio of Refuse/Sludge

Figure 13.2 Results of Box Test No.2

TABLE 13.3: RESULTS OF BOX TEST 3

Procedure No.	Volume Ratio Refuse/ Sludge	Compacted Bulk Density (kg.m^{-3})	Moisture Content (%)	Volume Leachate Produced (litre)	Compaction (based on % of original height in box)
1	-	500	48,7 50,0	0	0
2	12,5/1	580	not done	0	0
3	6,3/1	620	60,0	0	20
4	3,1/1	800	70,8	0,84	6

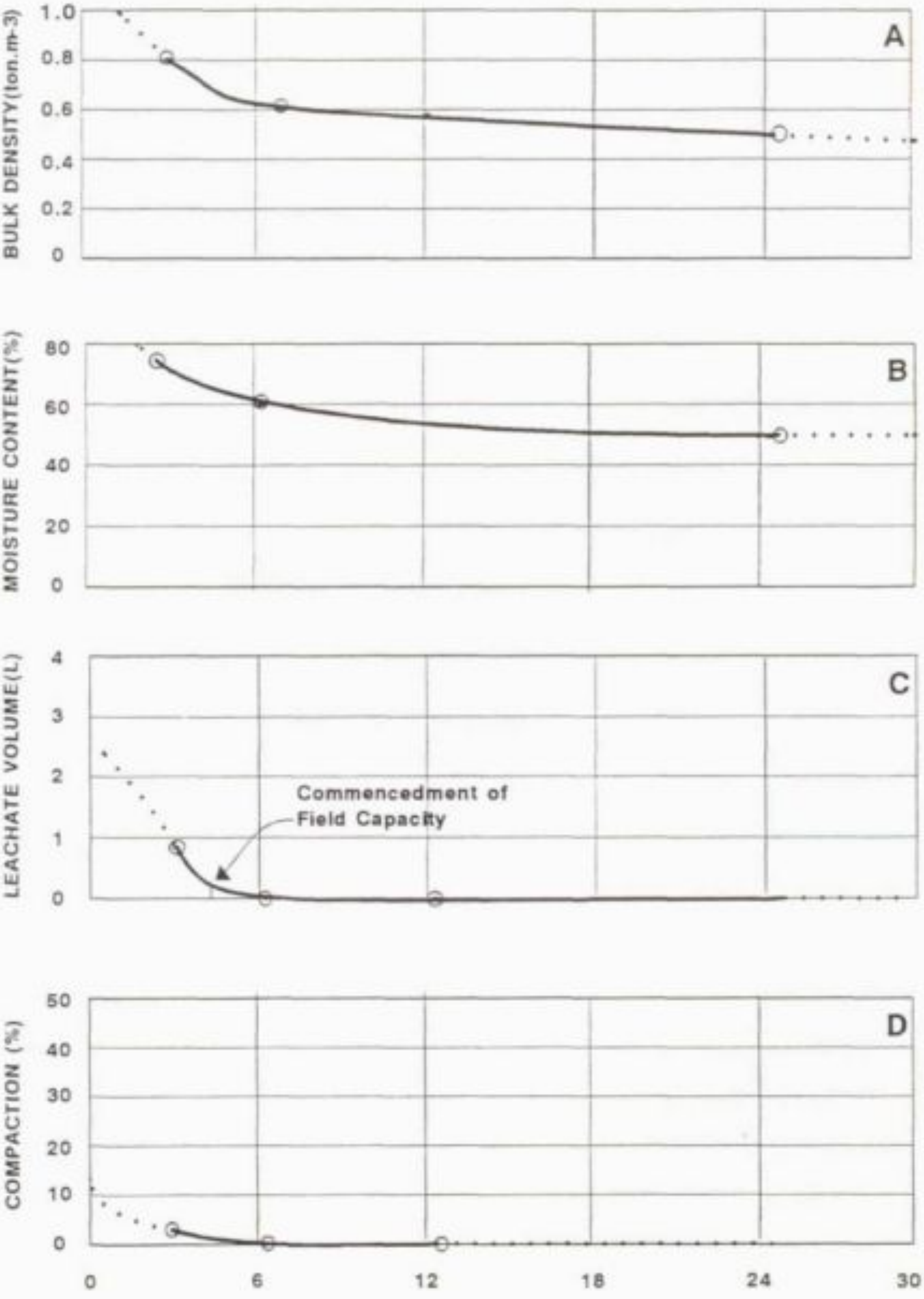
Conditions of Test 3:
Compactor mass = 445 kg
Box volume = 0,5 m^3

7. RESULTS AND DISCUSSION OF BOX TEST 4

The results are presented in Table 13.4 and summarised below:

i) Increase in moisture content from 47% to 65% resulted in a significant increase in the bulk density (from 370 to 622 kg.m^{-3}) with a concomitant 16.4% increase in compaction of the refuse.

ii) A three-fold increase in the compactor mass (from 460 kg to 1 615 kg) increased the bulk density to a value of 716 kg.m^{-3} and a 27% increase in compaction (based on the initial height of the refuse in the box).



Volume ratio of Refuse/Sludge.

Figure 13.3 Results of Box Test No.3.

TABLE 13.4: RESULTS OF BOX TEST 4

Procedure No.	Mass of Compactor	Volume Ratio Refuse/ Sludge	Compacted Bulk Denisty (kg.m^{-3})	Moisture Content (%)	Volume Leachate Produced (litre)	Compaction (based on % of original height in box)
1	460	-	370	40,0 54,2	-	-
2	460	6/1	622	64,6	0,6	16,4
3	1615	6/1	716	60,8	0,6	27,4

Conditions of Test 4: Box volume = 0,5 m^3

8. RESULTS AND DISCUSSION OF TESTS TO DETERMINE THE SATURATION MOISTURE CONTENT OF REFUSE

These tests were carried out on three occasions (refer procedures 1-5; 6-7; 8-9 in Table 13.5).

i) Procedures 1-5

The moisture content of the incoming refuse increased from 37,5% to a saturation value of some 70% which was equivalent to a refuse/sludge volume ratio in the range 2,5/1 to 1,0/1.

ii) Procedures 6-7

This refuse sample constituted wet kitchen waste with an initial moisture content of 59,8%. The saturation moisture content increased to 75,4% at a refuse/sludge volume ratio of 2,0/1.

iii) Procedures 8-9

This refuse sample constituted dry paper waste with an initial moisture content of 25,3%. The saturation moisture content increased to 83,6% at a refuse/sludge volume ratio of 1,3/1.

TABLE 13.5: SATURATION MOISTURE CONTENTS OF REFUSE

PROCEDURE NO.	VOLUME RATIO REFUSE/ SLUDGE	EXCESS VOLUME OF LEACHATE PRODUCED (litre)	SATURATION MOSITURE CONTENT (%)
1	(initial)	-	37.5
2	2,2/1	0*	72,1
3	2,4/1	0	65,7
4	2,5/1	0	70,5
5	2,0/1	12,3	70,9
6	(initial)	-	(59,8) (kitchen waste)
7	2,0/1	0	75,4
8	(initial)	-	(25,3) (paper waste)
9	1,3/1	8,0	83,6

*__Note__: This indicated conditions just below the saturation moisture content.

9. GENERAL DISCUSSION AND CONCLUSIONS

The experiments described in this report achieved their objective of establishing the interrelationships between the parameters that influence the water balance of a landfill site. These interrelationships have provided operational criteria to optimise both the physical and biological factors (such as compaction and waste stabilisation) influencing the co-disposal operation. The established inter-relationships between moisture content, degree of compaction, generation of leachate and field capacity, as determined in the Box Tests is illustrated in Figure 13.4.

9.1 Recommended moisture content of refuse for landfilling

Recent analyses of the landfilled refuse at Coastal Park have indicated a moisture content of some 30% which is below the value of 50% needed to sustain biological activity. Addition of sewage sludge liquor would allow better moisture control during the drier months of the year (October - May) so as to optimise the biological activity in the landfill.

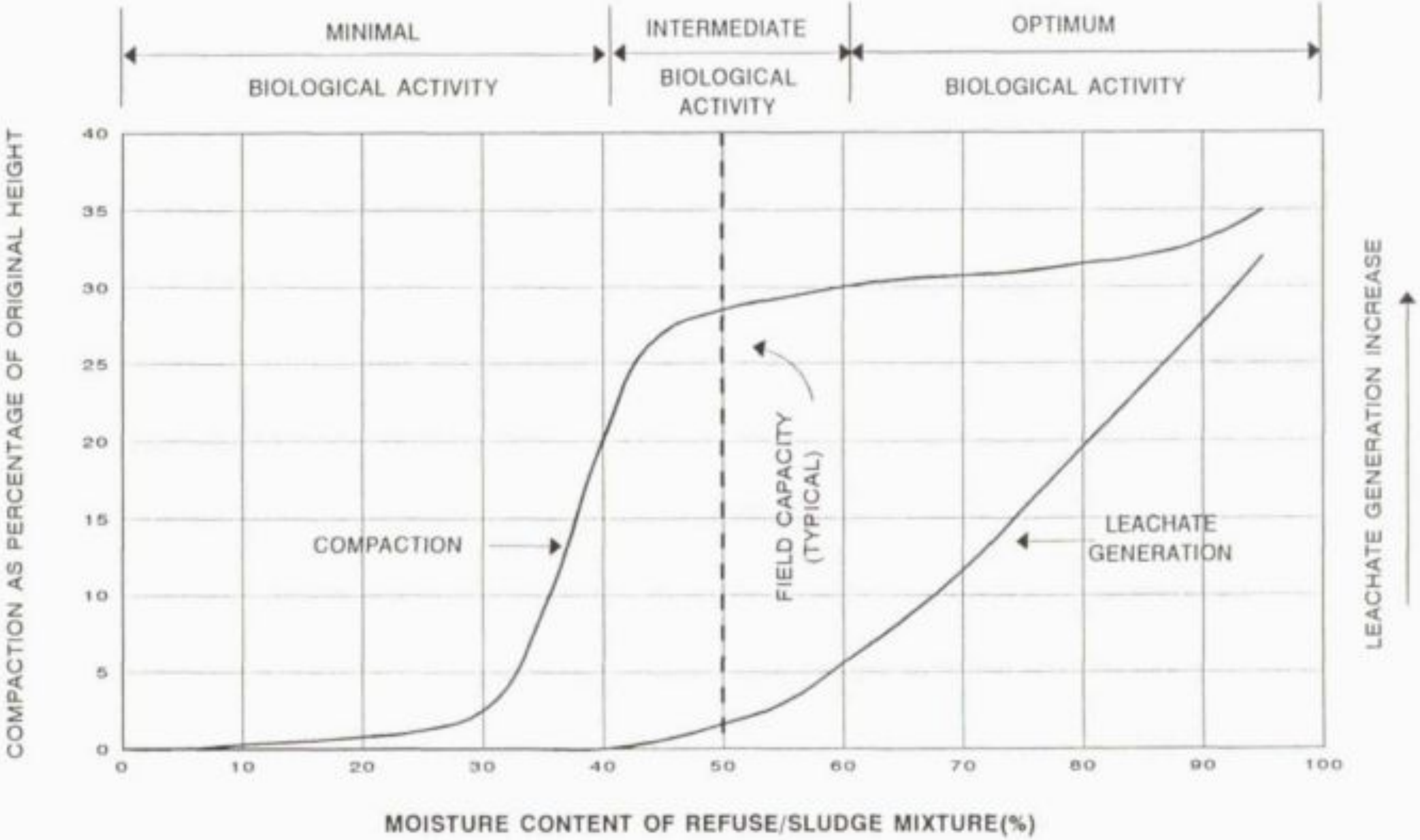


Figure 13.4 Established inter-relationships between moisture content, field capacity, degree of compaction and generation of leachate-From Box Tests.

The following values were typical of those obtained in the Box Test experiments:

Saturation moisture content of income refuse = 70 - 75%
Field capacity of compacted refuse/sludge mixture = 50 - 55%
Moisture content of incoming refuse = 30 - 35%

The results obtained in this study have illustrated the importance of maintaining the correct moisture concentration of the refuse being landfilled i.e. to satisfy the physical requirements for compaction and the biological requirements for stabilisation. It is fortuitous that both the physical and biological requirements are largely satisfied at a moisture concentration of some 55%. The moisture content at the field capacity was also determined in the Box Tests to be some 55% of the mass of the refuse. This moisture concentration of the wetted refuse should therefore not result in an excess production of leachate from the landfill.

9.2 Optimisation of refuse compaction

The Box Tests indicated that the compaction effect was greatly influenced by the placement moisture content of the combined refuse/sludge mixture. The compacted density of incoming refuse was typically 350 $kg.m^{-3}$ at a moisture content of 35%. Increase of the moisture content from 35 to 55% resulted in a 25% improvement in the compaction at a refuse/sludge volume ratio of 6/1. The resultant density of some 680 $kg.m^{-3}$ was slightly lower than the density achieved at operational landfills using steel wheeled compactors.

The results of the Box Test research established that no significant incremental improvement in the compaction of the refuse was obtained at moisture values greater than 55% or with heavier compaction equipment.

9.3 Practical implementation of co-disposal

The concept of co-disposal of refuse and sewage sludge is sound but the practical implementation needs to be investigated in more detail. Probably the most serious difficulty is that of the simultaneous mixing of the sludge cake with the refuse in a manner that promotes the optimum compaction at the tip face. A refuse/sludge volume ratio of 6/1 appears to be a suitable value of co-disposal.

9.4 Recommended sludge type for co-disposal

The co-disposal of digested sewage sludge liquor is the recommended sludge type as it contains the necessary methanogenic bacteria for seeding of the anaerobic landfill. Application of sludge liquor would significantly minimise the costs of sludge dewatering and transportation. However, proper water balance management must be practised so as not to exceed the field capacity of the landfill.

9.5 Biogas extraction from the landfill

Biogas abstraction would promote the more rapid stabilisation of the waste and also enhance the settlement of the landfill. The added moisture would promote the formation of biogas which is a valuable by-product for utilisation as an energy source.

9.6 Data collection and processing

More measurements need to be made of the parameters that influence the water balance equation so as to provide more reliable data for decision-making purposes. A Code of Practice also needs to be formulated for the co-disposal of refuse and sludge (refer Chapter 8.3).

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CHAPTER 13
APPENDIX 2

BOX TEST REPORT NO. 2

REPEAT OF BOX TESTS TO QUANTIFY LANDFILL PARAMETERS SUCH AS BULK DENSITY, MOISTURE CONTENT, COMPACTABILITY AND FIELD CAPACITY OF REFUSE/SLUDGE MIXTURES

by

M GREENHALGH

W R ROSS

P NOVELLA

1. INTRODUCTION

Box Tests were carried out during July - October 1991 to quantify important inter-related parameters (such as moisture content, bulk density, field capacity and compaction) which influence the water balance during a refuse/sludge co-disposal operation. The results were submitted as Box Test Report No. 1 to the Second Meeting of the Steering Committee. It was decided that some of the experiments should be repeated to confirm the results. This report describes the results of the repeat Box Tests carried out during June 1992.

2. EXPERIMENTAL APPARATUS AND PROCEDURES

The materials and methods used in the repeat Box Tests were essentially the same as that recorded in Box Test Report No. 1, except for the use of a heavier compactor. Emphasis was given to refuse/sludge volume ratios in the range 6,25/1 to 4,17/1 as the previous experiments had indicated the commencement of field capacity at these ratios. Three repeat Box Tests were carried out at the Athlone Transfer Station of the Cleansing Branch of the Cape Town Municipality during the period 8 - 9 June 1992.

3. RESULTS AND DISCUSSION OF REPEAT BOX TESTS

The results of the repeat Box Tests are presented in Table 13.6 and discussed below.

3.1 Moisture Content of Incoming Refuse

The moisture content of incoming refuse had been carried out on a routine basis (weekly) since June 1992. The following values were recorded during the period of the repeat Box Tests:

Date	Moisture content (%)
1992-06-09	36,8
1992-06-09	44,7
1992-06-11	53,7
1992-06-18	29,1
1992-07-09	47,4
1992-07-16	50,0
1992-08-12	52,6

The above moisture analyses were in the range 29% - 53% and were generally higher than the values recorded for the previous Box Tests (30% - 35%). The moisture content of the incoming refuse would be expected to be higher during the rainy winter months than during the drier summer months.

3.2 Compacted Bulk Densities

The compacted bulk density of incoming refuse was typically 450 $kg.m^{-3}$ at a moisture content of 40 % (Table 13.6). Increase of the moisture content from 40% to 55% resulted in an increase of the compacted bulk density from 450 $kg.m^{-3}$ to 760 $kg.m^{-3}$.

3.3 Degree of Compaction

According to Table 13.6, a 22% increase in compaction (expressed as a percentage reduction in the initial height of the refuse in the box) was achieved by increasing the placement moisture to a value of some 55% (equivalent to a refuse/sludge volume ratio of 6,25/1).

Only a small incremental improvement (from 22% to 25%) in the compaction was obtained by reducing the refuse/sludge volume ratio from 6,25/1 to 4,17/1.

The results established that only a marginal improvement in the compaction of the refuse/sludge mixture was obtained with a compactor mass of 1 625 kg as compared with the compactor mass of 445 kg used during the previous Box Tests.

3.4 Field Capacity

The first signs of leachate production were generally evident at a refuse/sludge volume ratio of 6,25/1 and a moisture content in the range 55 - 58% (Table 13.6). These criteria corresponded to the field capacity of the compacted refuse/sludge mixtures.

3.5 Comparison betweem the two series of Box Tests

The results of the repeat Box Tests were essentially similar to the previous tests, as indicated in Table 13.7. This confirms the conclusions derived in Box Test Report No. 1 (Appendix 2, Chapter 13).

4. CONCLUSIONS

The Box Tests achieved the objective of establishing inter-relationships between parameters that influence the water balance of a landfill site. These inter-relationships have provided operational criteria to optimise both the physical and biological factors influencing the co-disposal operation without causing excessive production of leachate. Both the degree of compaction and the biological requirements for accelerated stabilisation of the wetted refuse would be optimised at a moisture content of some 55 % which is equivalent to the field capacity of the landfill.

TABLE 13.6: SUMMARY OF REPEAT BOX TESTS (8 - 9 JUNE 1992)

Procedure No.	Volume Ratio Refuse/ Sludge	Compacted Bulk Density ($kg.m^{-3}$)	Moisture Content %	Volume Leachate Produced (litre)	Compaction (based on % of original height in box)
1	Refuse alone	380	n.d.	0	-
2	6,25/1	794	55,5	0,33	22
3	4,17/1	853	57,5	0,45	25
4	Refuse alone	500	36,8	0	-
5	6,25/1	787	58,8	0,35	20
6	4,17/1	920	53,4	0,21	25
7	Refuse alone	480	44,7	0	-
8	6,25/1	692	56,4	0,05	22
9	4,17/1	819	55,0	0,14	28

TABLE 13.7: COMPARISON BETWEEN THE TWO SERIES OF BOX TESTS

Parameters	Box Tests carried out in July - October 1991	Repeat Box Tests carried out in June 1992
Mass of compactor used	445 kg	1 625 kg
Box volume	0,5 m^3	0,5 m^3
Moisture content of incoming refuse	30 - 35 %	40 - 50 %
Compacted bulk density of incoming refuse	390 $kg.m^{-3}$	450 $kg.m^{-3}$
Compacted bulk density at refuse/sludge volume ratio of 6,25/1	620 $kg.m^{-3}$	760 $kg.m^{-3}$
Degree of compaction (% decrease of initial height) at refuse/sludge volume ratio 6,25/1	17 - 21 %	22 - 25 %
Field capacity moisture content of compacted refuse/sludge mixtures	50 - 55 %	54 - 58 %
Approximate refuse/sludge volume ratio to achieve field capacity	6/1	6/1

CHAPTER 13
APPENDIX 3

CALCULATION OF A SIMPLISTIC WATER BALANCE AT THE COASTAL PARK LANDFILL SITE FOR A REFUSE / SLUDGE CO-DISPOSAL OPERATION

by

W R ROSS

1. INTRODUCTION

The main objective of this research project was to develop practical operational criteria for the co-disposal of a combination of refuse and sewage sludge in a landfill bioreactor in order to optimise both the physical and biological factors (such as compaction and stabilisation).

The research has been divided into various phases, namely:

a) Routine collection of data such as rainfall, evaporation, mass of incoming refuse, water content of incoming refuse, determination of actual water content at various depths of the landfill, cell leachate volumes, compacted refuse density, methane concentration of extracted biogas, etc.

b) Practical co-disposal experiments at Coastal Park to determine the most suitable volume ratio of refuse and anaerobically digested sewage sludge liquor for compactor workability.

c) Box Tests at Athlone transfer station to quantify important interrelated parameters (such as field capacity, bulk density, moisture content and compaction) which influence the water balance during the co-disposal operation.

Approval was given at the 2nd meeting of the Steering Committee for this project to apply the results obtained in the Box Tests for calculation of the water balance at the Coastal Park landfill for a refuse/sludge co-disposal operation.

This report gives the tentative results of a simplistic water balance to indicate the role that co-disposal of refuse (from Coastal Park) and sewage sludge (from Cape Flats) could play in the overall management of these two waste streams.

2. GENERAL WATER BALANCE EQUATION OF A LANDFILL SITE

Hojem (1989) has shown the complexity of water balance determinations. The water balance equations all have a similar form (Ehrig, 1983; Department of Environment - United Kingdom, 1986; Lombard, 1990; Blight *et al.*, 1990; Chapman and Ekama, 1990) and a typical example is set out below:

$$J = [A + B + C + D + E] - [F + G + H + I]$$

$$\text{WATER RETAINED} = \text{WATER INPUT} - \text{WATER OUTPUT}$$

Where, annually:

J = water retained by landfill to achieve its field capacity
A = water added by incoming refuse
B = precipitation on landfill
C = biochemical and biological water production
D = water added by co-disposal of sewage sludge
E = surface and groundwater flow into landfill
F = evaporation losses from landfill
G = water vapour loss associated with biogas escape from landfill
H = water loss in leachate from landfill
I = water loss in surface run-off from landfill

2.1 Variables C, E, G and I

These factors offer the greatest degree of uncertainty in the water balance calculation on full-scale sites. For simplistic purposes, the values of these variables were eliminated from the water balance equation as they are not known but are understood to be small in comparison with other items (Blight *et al.*, 1990).

2.2 Variable H

For simplistic purposes, the variable H was assigned a value of zero i.e. no leachate production if the landfill is just maintained at its field capacity. Theoretically, the field capacity of a landfill is the maximum amount of water that can be retained by capillarity under compaction without percolation (Mayet, 1991). Once the field capacity has been reached, additional water will not be retained by the refuse but will drain through it as leachate. This description is known to be an over-simplification; no quantitative information being available in the literature on variation of field capacity with refuse density. Landfills are heterogeneous in composition and certain zones may have considerably lower and higher field capacities than the overall average value (Blight, 1990).

2.3 Variable J

This variable was assigned a value typical of the field capacity of the compacted landfilled wastes. i.e. 60% moisture at a landfill bulk density of 1 000 $kg.m^{-3}$. The literature records values for field capacity of refuse that vary from 80% for fresh refuse (Campbell, 1983) to between 63% and 74% for refuse more than four years old (Holmes, 1980). The field capacity for Coastal Park was approximated by Blight *et al.* (1990) to be 60%. Lombard (1990) reports that the field capacity of refuse in a landfill site approximates 55 - 60% of the mass deposited. In comparison, Box Tests carried out during this project recorded field capacity values in the range 50 - 55% (Ross *et al.*, 1991).

2.4 Simplistic water balance equation

The water balance equation therefore was reduced to the functions that could be reasonably accurately quantified at the Coastal Park landfill site:

$$\begin{array}{cccccc} J & = & [A + B + D] & - & [F] \\ \text{Water Retained} & = & \text{Water Input} & - & \text{Water Output} \end{array}$$

3. WATER ADDED BY INCOMING REFUSE

3.1 Mass of incoming domestic refuse per annum

According to extrapolated weigh-bridge data, the current (1991) mass of domestic refuse landfilled at Coastal Park amounts to some 90 200 ton per annum (Novella, 1991).

3.2 Calculation of area of refuse landfilled per annum

Assume height of landfill = 2,5 m

Assume compacted bulk density of landfill = 1 000 $kg.m^{-3}$

Assume the peripheral area of landfilled refuse = a square

$$\text{Area of refuse landfilled per annum} = \frac{90\ 200\ m^3}{2{,}5\ m} = 36\ 080\ m^2$$

3.3 Moisture content of incoming refuse

Based on the Box Tests and other typical data (Ross *et al.*, 1991; Walmer Bulletin, 1991; Chapman and Ekama, 1990; Novella, 1991) the moisture content of incoming refuse was assumed to be 30% i.e. 0,3 ton water per ton refuse.

3.4 Water added by incoming refuse landfilled per annum (function A)

The mass of water added by the incoming refuse per annum can be calculated using the data in items 3.1 and 3.3.

Mass of water added by moist incoming refuse per annum = Mass of incoming domestic refuse per annum x Moisture content of refuse

= 90 200 ton.annum $^{-1}$ x 0,3

A = 27 060 ton.annum $^{-1}$

4. PRECIPITATION AND EVAPORATION AT COASTAL PARK LANDFILL SITE

Blight *et al*. (1990) have summarised the climatic parameters at the Coastal Park landfill (Figure 13.5) based on 30 year average annual figures for precipitation and evaporation. They constructed a corresponding annual water balance (Figure 13.6) calculated by Fenn *et al.*'s (1975) adaptation of the method of Thornthwaite and Mather (1957) and based on a weekly calculation interval.

The following conclusions were made by Blight *et al*. (1990) based on the above-mentioned information:

a) Annual precipitation at Coastal Park = 510 mm = 0,51 m
Annual pan evaporation at Coastal Park = 1 110 mm = 1,11 m.

b) The landfill site (winter rainfall area) is nominally in a water deficit area with the annual potential evaporation exceeding precipitation by some 600 mm.

c) Figure 13.6 indicates that moisture is gained by the refuse for 3 months from mid June to mid September.

d) On the basis of the water balance, a time for the Coastal Park landfill to reach field capacity was calculated, as well as the ensuing rate of generation of leachate. The calculations showed that the Coastal Park landfill could be expected to reach overall field capacity in 1993 whereafter the predicted rate of leachate production was 200 mm per year.

e) Blight *et al*. (1990 state however that the results of such water balance calculations are liable to uncertainty because of the highly variable nature of the weather and to variable properties of the refuse and cover material. Uncertainties in the estimation of run-off and evaporation add to the uncertainty of the prediction.

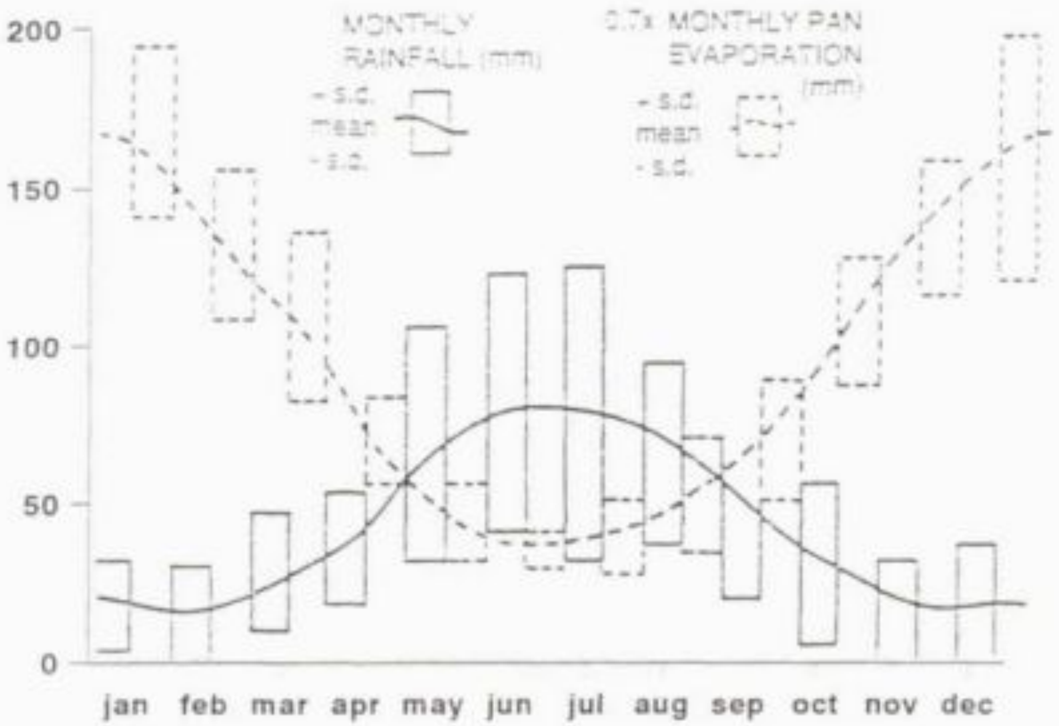

Figure 13.5 Summary of climatic parameters at Coastal Park landfill (Blight *et al.*, 1990).

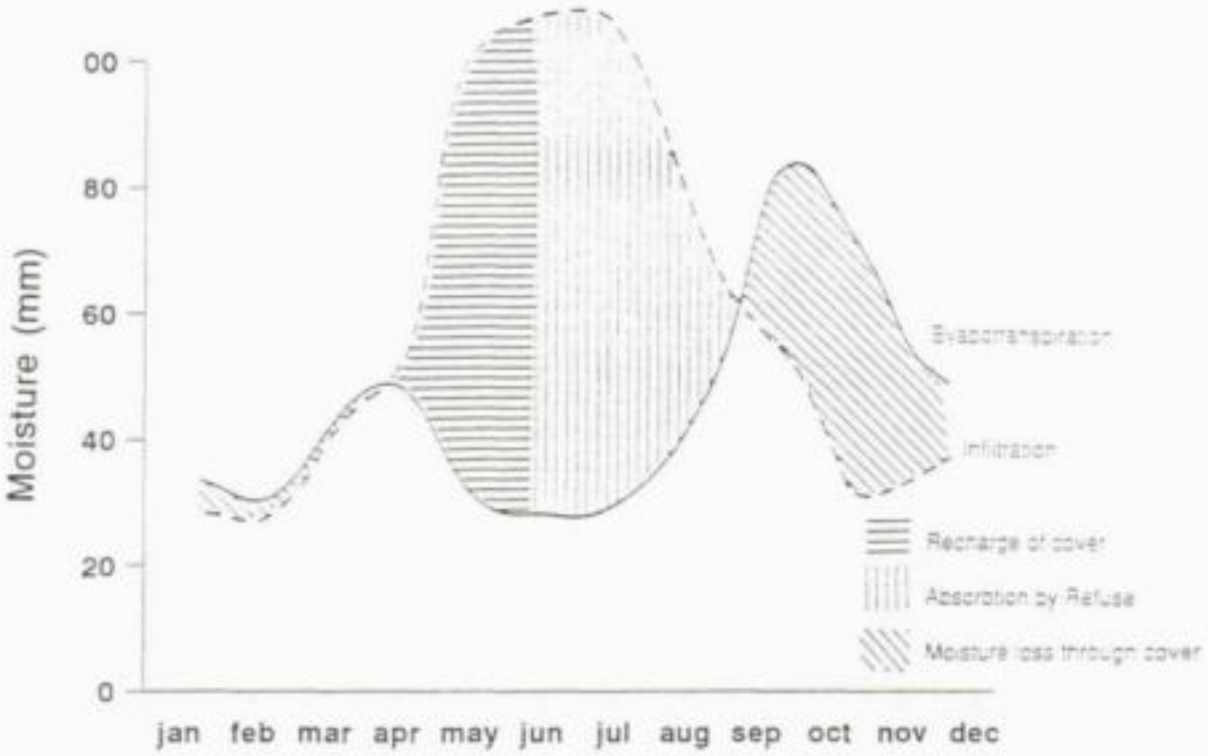

Figure 13.6 Water balance at Coastal Park (Blight *et al.*, 1990).

4.1 Mass of water input due to precipitation on landfill per annum (function B)

Precipitation on landfill per annum = Annual precipitation (m.annum^{-1}) x Area of refuse landfilled per annum (m^2)

= 0,51 m.annum^{-1} x 36 080 m^2

= 18 400 m^3. annum^{-1}

B = 18 400 ton.annum^{-1}

4.2 Mass of water lost due to evaporation from landfill per annum (function F)

The calculation of the evaporation from a landfill site is a controversial factor affected by many variables. The value used by Blight *et al.* (1990) was: 0,7 (mean pan evaporation - 1 standard deviation). In comparison, Benster (1991) used a value of 0,4 times the evaporation pan reading for evaporation from soil in the Western Cape.

Water loss by evaporation per annum = Annual evaporation (m.annum^{-1}) x Area of refuse landfilled per annum (m^2)

= 1,10 m.annum^{-1} x 36 080 m^2

= 30 688 m^3.annum^{-1}

F = 39 688 ton.annum^{-1}

5. ANNUAL WATER RETAINED BY LANDFILL TO ACHIEVE ITS FIELD CAPACITY (FUNCTION J)

For the purpose of the water balance equation, the annual mass of water that can be retained by the landfilled refuse (without producing leachate) is assigned a value equal to the moisture content of the landfill at its compacted field capacity (60% moisture at a bulk density of 1 000 kg.m^{-3}).

Annual mass of water retained by landfilled refuse = Annual mass of water in landfill at its field capacity

= 90 200 ton.annum^{-1} x 0,6

J = 54 120 ton.annum^{-1}

Most authors use the function (J - B) to quantify the "mean storage change" over the landfill site (Ehrig, 1983) or the "gain in landfill moisture" (Blight, 1990).

6. PERMISSIBLE MASS OF WATER TO BE ADDED AS SEWAGE SLUDGE (FUNCTION D) TO BALANCE WATER EQUATION

The permissible amount of sludge to be co-disposed with refuse can be calculated by solving the simplistic water balance equation. The determined values of the variables (refer items 3.4, 4.1, 4.2, 5) were assigned to the equation as follows:

$$\mathbf{J = [A + B + D] - [F]}$$

where:

$J = 54\ 120\ \text{ton.annum}^{-1}$

$A = 27\ 060\ \text{ton.annum}^{-1}$

$B = 18\ 400\ \text{ton.annum}^{-1}$

$D =$ unknown variable

$F = 39\ 688\ \text{ton.annum}^{-1}$

Rearranging the equation gives:

$$\begin{aligned} \mathbf{D} &= \mathbf{F + J - A - B} \\ &= 39\ 688 + 54\ 120 - 27\ 060 - 18\ 400 \\ &= 48\ 348\ \text{ton.annum}^{-1} \end{aligned}$$

This implies that a mass of 48 348 ton of water per annum (equivalent to 1 344 mm per annum) in the form of sewage sludge moisture could be added to the refuse landfilled at Coastal Park. This mass of water would theoretically increase the moisture content of the incoming refuse from 30% to its field capacity moisture content of 60% without the generation of leachate. The relative values of the variables in the simplistic water balance equation are illustrated in Figure 13.7.

7. CHARACTERISTICS OF SEWAGE SLUDGE FOR POTENTIAL CO-DISPOSAL WITH REFUSE AT THE COASTAL PARK LANDFILL SITE

Digested sewage sludge is the recommended sludge type for co-disposal as it is stabilised and contains the necessary methanogenic bacteria for seeding of the anaerobic landfill. A survey of sludge types at the Cape Flats waste-water treatment plant was carried out by Fawcett (1991) and is illustrated in Figure 13.8.

Although the use of liquid sludge increases the likelihood of leachate being produced it has the advantage of being readily available and pipe flowable. Dewatered sludges, on the other hand have a higher concentration of solids but are costly to produce and also to transport.

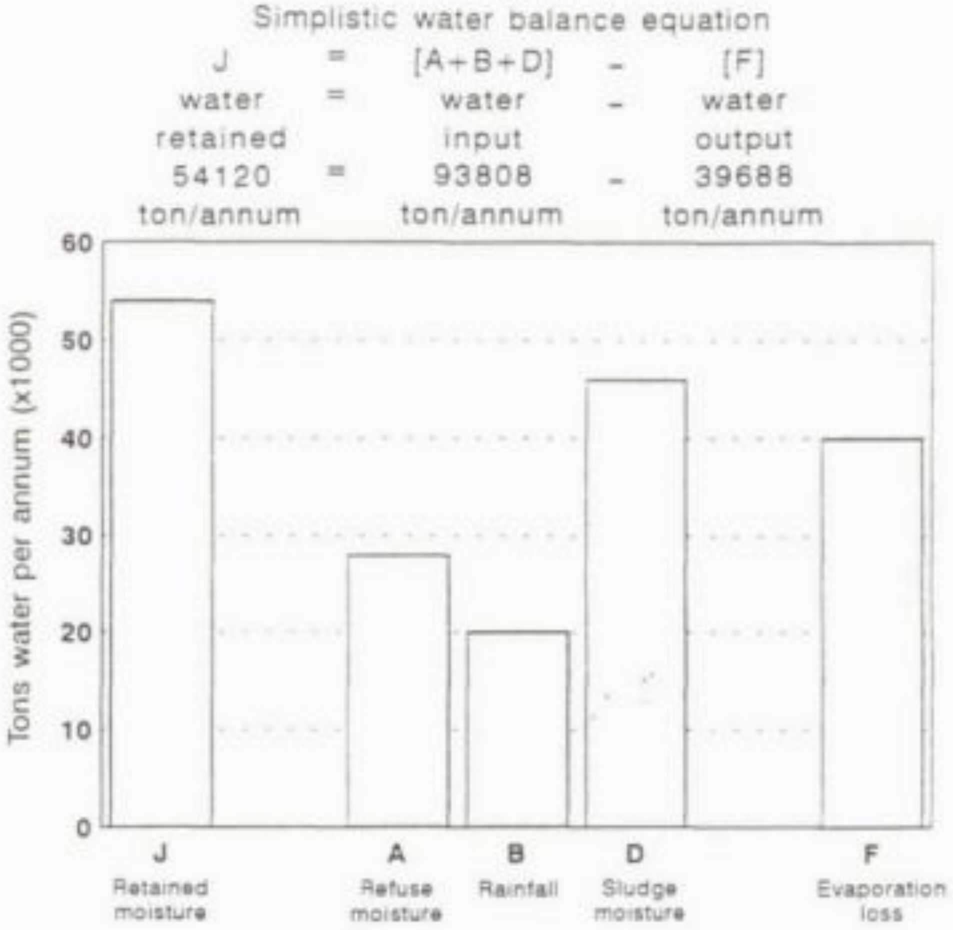

Figure 13.7 Components of Coastal Park water balance equation to retain landfill at field capacity (60 % moisture).

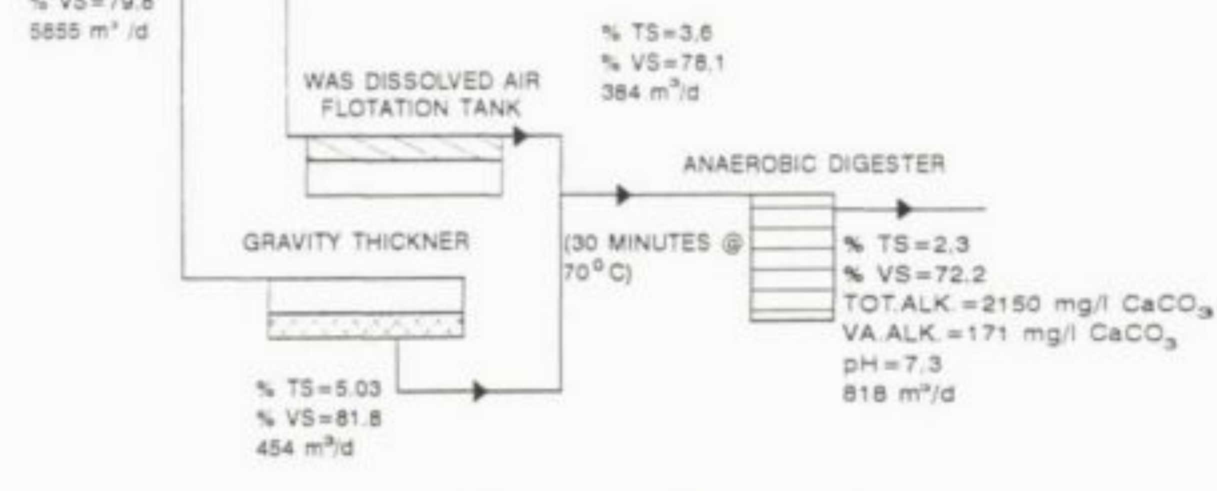

Figure 13.8 Survey of sludge types at Cape Flats waste-water treatment plant (Fawcett, 1991).

The permissible volume of Cape Flats sewage sludge which could be used for co-disposal purposes is calculated as follows:

Average daily flow of digested sludge liquor = 818 $m^3.d^{-1}$
= 298 570 m^3.annum $^{-1}$

Average total solids concentration = 2,3% TS
(i.e. 97,7% H_2O)

Mass of water in digested sludge liquor at Cape Flats (2,3% TS) = 298 570 x 0,977
= 291 702 ton.annum^{-1}

But permissible mass of water to be added as sewage sludge (D - refer item 6) = 48 348 ton.annum^{-1}

Digested sludge liquor at 2,3% TS which can be used for co-disposal purposes = $\frac{48\ 348 \times 100}{291\ 702}$

= 16,6% of total annual available volume at Cape Flats

The high water content (97,7% of digested sludge liquor at Cape Flats would only permit some 16,6% of the total available volume to be used for co-disposal purposes at Coastal Park.

A reduction in the water content of the sludge liquor would have a significant effect on the volume occupied by the sludge. A measure of thickening and dewatering of the sludge liquor would enable a greater percentage of the total available volume to be used for co-disposal purposes.

8. EFFECT OF SLUDGE DEWATERING ON THE CO-DISPOSAL OPERATION

8.1 Relationship between volume change of sludge relative to change in solids content

The volume reduction of sludge during a thickening or dewatering process can be calculated as follows (Dillar, 1981):

$$\text{Volume reduction of the sludge} = 1 - \frac{100 - \text{Initial weight \% water}}{100 - \text{Final weight \% water}}$$

The relationship between volume change of sludge relative to change in solids content is illustrated in Figure 13.9. The graph indicates an example where a 81,5% sludge volume decrease can be achieved for an increase in total solids content from 2,3 to 12,4%.

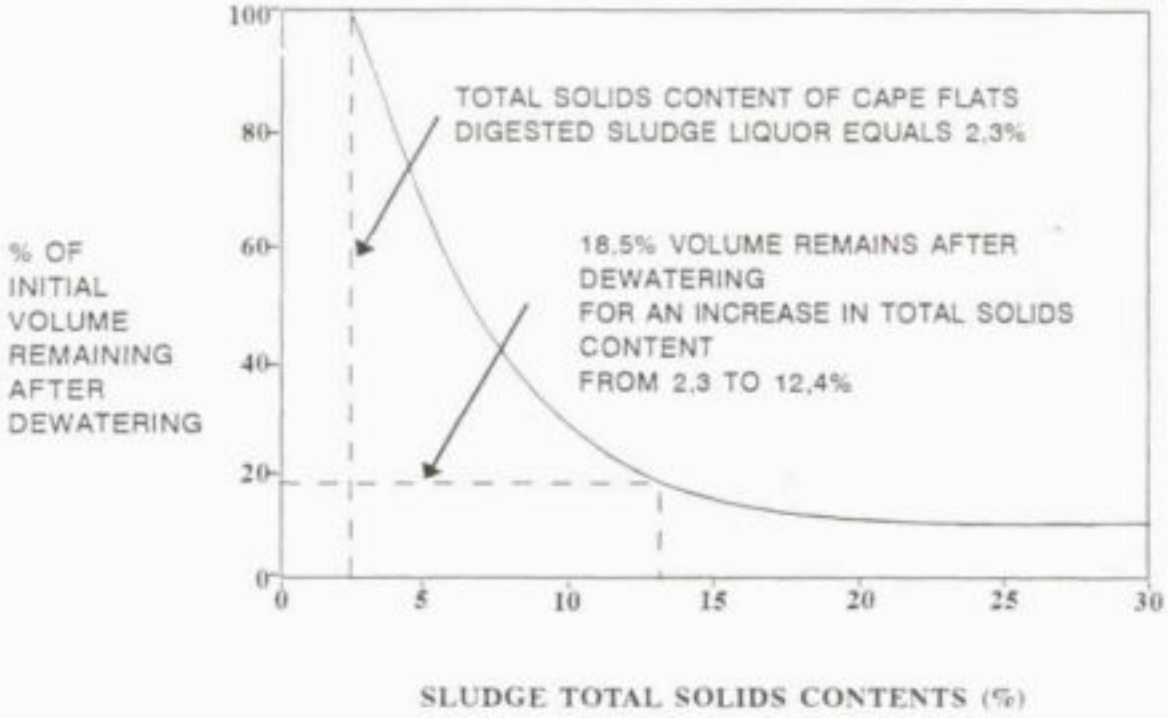

Figure 13.9 Relationship between volume change of sludge relative to change in solids content during thickening and dewatering processes.

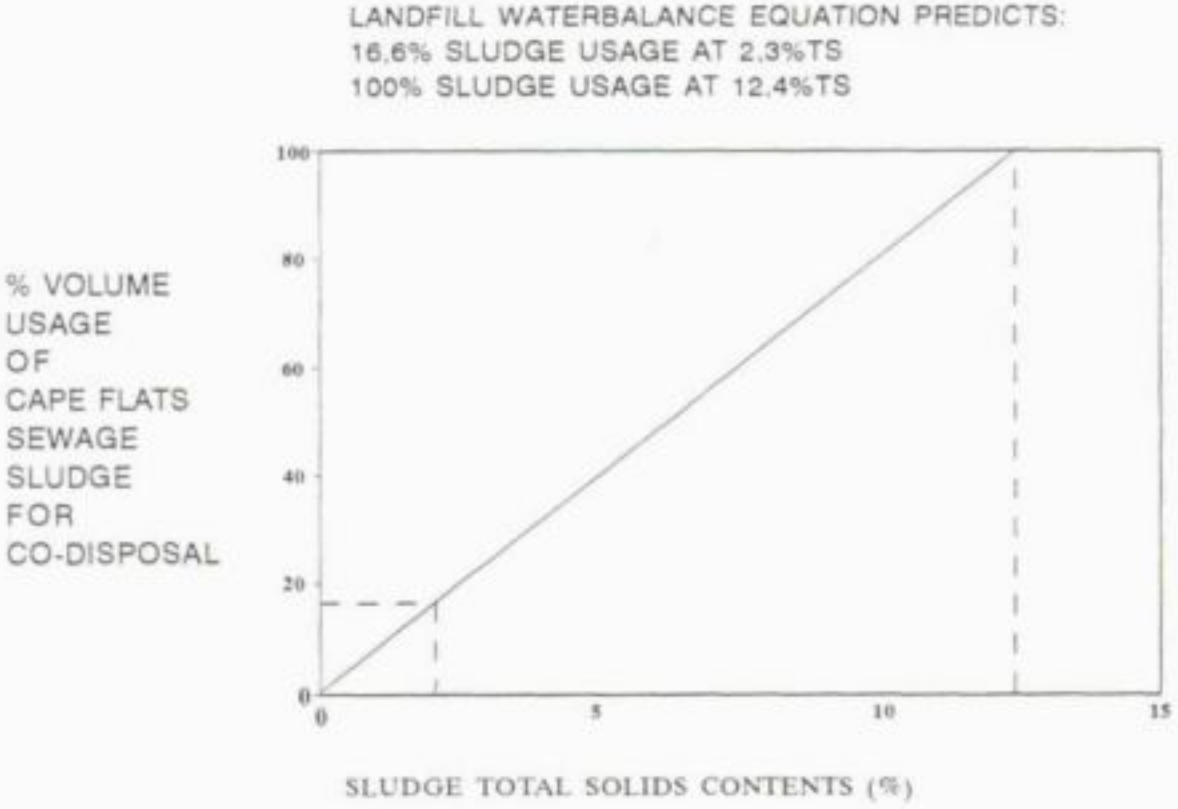

Figure 13.10 Volume usage of available Cape Flats digested sludge for co-diposal with refuse at Coastal Park as a function of the degree of dewatering of the sludge.

8.2 Use of dewatered Cape Flats digested sludge for co-disposal purposes

Total volume digested sludge liquor = 298 570 $m^3.annum^{-1}$

Total solids of digested sludge liquor = 2,3%

Assume total solids of digested sludge cake after dewatering = 12,4% (i.e. 87,6% water)

Volume of dewatered sludge cake = $\frac{298\ 570}{12,4 \div 2,3}$

= 55 383 $m^3.annum^{-1}$

Mass of water in sludge cake = 55 383 x 0,876

= 48 515 $ton.annum^{-1}$

But permissible mass of water to be added as sewage sludge (refer item 6) = 48 348 $ton.annum^{-1}$

Digested sludge cake at 12,4% TS which can be used for co-disposal purposes = $\frac{48\ 348 \times 100}{48\ 515}$

= approximately 100% of total annual available volume at Cape Flats

The relationship between the volume usage of available Cape Flats digested sludge for co-disposal with refuse, as a function of the degree of dewatering of the sludge is illustrated in Figure 13.10.

The formula of the graph in Figure 13.10 is as follows:

$$Y = \frac{48\ 348}{298\ 570 \times \frac{2,3}{X} \times 1 - \frac{X}{100}} \times 100$$

8.3 Resultant refuse : dewatered sludge mass ratio

The following assumptions are made for this determination:

mass of refuse landfilled = 90 200 ton.annum^{-1}

mass of co-disposal dewatered sludge at 12,4% TS and Density = 1 (refer item 8.2) = 55 383 ton.annum^{-1}

$$\frac{\text{Refuse}}{\text{Dewatered sludge}} \quad \text{Mass Ratio} = \frac{90\ 200}{55\ 383}$$

$$= 1{,}63:1$$

8.4 Resultant refuse : dewatered sludge volume ratio

The volume of refuse changes with its degree of compaction which is a function of its resultant density. During the landfilling operation, the refuse occupies various volumes i.e compaction in refuse truck, uncompaction during tipping, wetting with sewage sludge, compaction with steel wheel compactors and final settlement and compression due to decomposition, biogas extraction and effect of overburden.

During co-disposal of refuse and sludge, the added moisture does not increase the volume of the refuse/sludge mixture as it fills the voids between the individual particles. The wetted refuse becomes less rigid and softer which enables it to be better compacted.

Calculation of the refuse to dewatered sludge volume ratio must therefore stipulate the density of the resultant refuse in question i.e. compacted or uncompacted refuse before or after landfilling.

The following example for the Coastal Park landfill suffices:

Mass of refuse landfilled = 90 200 ton.annum^{-1}

Bulk density of compacted refuse in refuse truck = 350 kg.m^{-3}

Volume of compacted refuse (Density = 0,35) = 257 714 m^3.annum^{-1}

Volume of co-disposed dewatered sludge cake (12,4% TS and Density = 1) (refer item 8.2) = 55 383 m^3.annum^{-1}

$$\frac{\text{Compacted refuse}}{\text{Dewatered sludge}} \quad \text{Volume Ratio} = \frac{257\ 714}{55\ 383}$$

$$= 4.6 : 1$$

Trials would have to be carried out to establish to what extent the above-mentioned compacted refuse to dewatered sludge volume ratio of 4,6 : 1 would effect the on-site workability of a steel-wheeled compactor.

In comparison, the Safe Working Ratio of refuse to sludge liquor (by volume) for the winter and summer seasons at the Coastal Park landfill was determined to be 6:1 and 4:1 respectively (refer Chapter 6, Page 6.6 of the Main Report).

9. GENERAL DISCUSSION

9.1 Water balance predictions

On the basis of the water balance prediction of Blight *et al.* (1990), the Coastal Park landfill site will reach a field capacity of 60% moisture content in 1993, whereafter the predicted rate of leachate production would be 200 mm per year.

On the basis of the simplistic water balance carried out in this study, a measure of co-disposal with sewage sludge would be permissible, especially during the drier months of the year. The following degree of co-disposal with sewage sludge from the Cape Flats waste-water treatment plant would be permissible to maintain a field capacity of 60% moisture content and density of 1 000 kg.m^{-3} at the Coastal Park landfill site:

a)	Addition of digested sludge liquor (2,3% total solids)	=	16,6% of total annual available volume at Cape Flats

OR

b)	Addition of dewatered digested sludge cake (12,4% total solids)	=	100% of total annual available volume at Cape Flats

9.2 Advantages of co-disposal of refuse and sewage sludge

The co-disposal of secondary sewage sludge (in particular digested sludge) with refuse in a landfill bioreactor assists in promoting and accelerating the microbiological, physical and chemical attenuation mechanisms responsible for more rapid stabilisation of the refuse.

Addition of sewage sludge (liquor or cake) would allow better moisture control of the refuse especially during the drier months of the year (September to April). The co-disposal operation should however be properly controlled so as to optimise both the physical requirements for improved compaction of the refuse and the biological requirements for accelerated stabilisation and biogas production, without generation of excess leachate. It is fortuitous that both the physical and biological requirements are largely satisfied at a moisture content of some 55 - 60%. This moisture content is equivalent to the field capacity of the landfill which is the maximum amount of water that can be retained under compaction.

9.3 Integrated management of municipal wastes such as refuse and sewage sludge

Siting of a waste-water treatment plant and a landfill in close proximity to each other, enables various treatment and disposal options to be exercised, especially as regards the end-products after stabilisation i.e. sludges, leachates and biogas (refer Figure 13.11). Such an integrated management of municipal wastes has various advantages in terms of improved pollution control and potential for biogas utilisation.

9.4 Formulation of a Code of Practice for co-disposal of refuse and sewage sludge

The practical implementation of a co-disposal operation will require a seasonal Code of Practice to be formulated. This Code of Practice will have to address the following important aspects:

a) Sewage sludge - thickening; dewatering; transport; controlled admixture with refuse

b) Landfill - compaction; seasonal moisture control; refuse/sludge volume ratios; degree of stabilisation; field capacity versus density

c) Leachate - collection; recycle; possible treatment

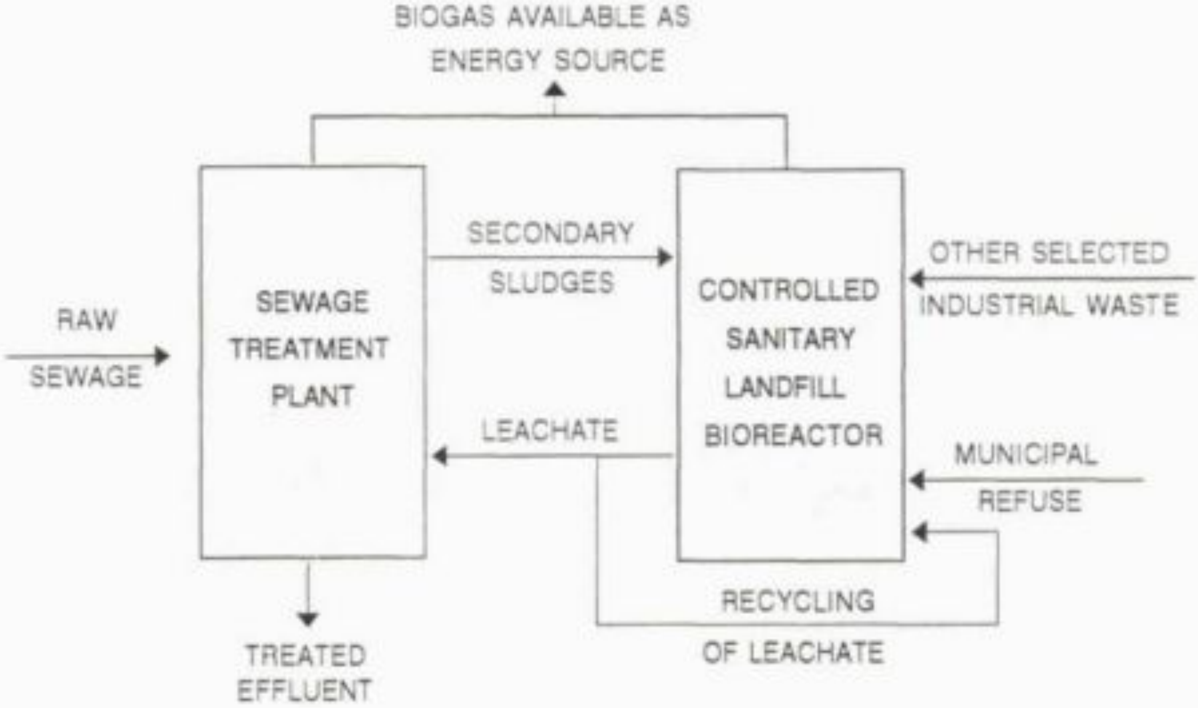

Figure 13.11 Integrated management of municipal waste.

d) Biogas - collection; utilisation as a renewable energy source

e) Cost evaluation of the integrated management

f) Monitoring, safety, pollution control, environmental and legislation aspects

g) Long term utilisation and management of landfill site

These aspects have been discussed in more detail in Chapter 8 of the Main Report.

10. CONCLUSIONS

- The co-disposal of refuse and sewage sludge is not without its side effects. Whether these are beneficial or detrimental, a balanced view must be taken in assessing the overall suitability of the process as a disposal option.
- The techniques employed for co-disposal of sewage sludge with refuse must not prejudice the landfill operation or have any adverse effects on the environment.
- The simplistic water balance predictions made in this report need to be verified, because of the variable properties of refuse and the uncertainties in the estimation of many of the parameters (especially evaporation) that influence the water balance equation.
- An assessment of the role that co-disposal of refuse and sewage sludge could play in the overall management of these two waste streams can be made once more reliable and complete water balance data is available.

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