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ANAEROBIC DIGESTION OF WASTE-WATER SLUDGE: OPERATING GUIDE

REPORT TO THE
WATER RESEARCH COMMISSION

by the
SLUDGE MANAGEMENT DIVISION
and
WATER CARE DIVISION
of the
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FOREWORD

Anaerobic digestion is the oldest known process harnessed for the treatment of organic matter. The formation of methane as the result of anaerobic decomposition was identified as early as the eighteenth century, while in the mid-nineteenth century the role of bacteria in this decomposition became clear. Since the 1930s, the application of anaerobic digestion for the treatment of waste-water sludge has grown steadily and the digester has become the workhorse of the municipal waste-water treatment works.

Although anaerobic digestion is a well recognised waste treatment technology, the process has unfortunately been neglected in many treatment works over the years. Due attention is not always paid to the well established theory and operating principles formulated by the early chemists, microbiologists and engineers. A survey of anaerobic digester practice would reveal significant areas of neglect such as sludge pretreatment, digester mixing, heating, gas measurement and routine monitoring and control, particularly in the rural areas. Many persons do not fully understand the anaerobic digestion process which, being hidden from view, tends to be subject to crisis management. Correction of a process failure may take months, with consequent environmental and cost implications.

A disconcerting problem is that often the status of the operating staff is not commensurate with their responsibilities in terms of the important role that they play in water pollution control. This unsatisfactory state of affairs must be rectified by a review of management strategy and training methods, in recognition of the importance of this role. More-over, communication between operating staff and the designers of the treatment works (and all intermediate levels) is often inadequate. Operating staff are not adequately informed of what the designer intended and the designer is not informed of operating problems, with the result that improvements in both design and operating procedures are lost. There is a need for the authority in charge of the works to ensure that these lines of communication are kept open and that adequate records are kept by the operating staff.

In view of these problems, the Sludge Management Division and the Water Care Division of the Water Institute of Southern Africa (WISA) resolved to upgrade current sludge digestion practices by the provision of an Operating Guide. The Water Research Commission has sponsored the production of this Guide to assist in the training of all responsible personnel and to promote better understanding and operating procedures for the anaerobic digestion of waste-water sludge.

The main objective of this Guide was to assist in the training of all operating staff to achieve higher operational standards at waste-water treatment works. It is also hoped that this Guide will encourage operating personnel to be more active in solving problems around the works and not to think of a digester as a "tank full of sludge" but rather in terms of a "microbial community of living organisms". In turn, it is the responsibility of Town Engineers to see that suitable literature is made available to operating staff to encourage them to read more about the subject matter. The operating staff should also be given the opportunity to attend seminars and to study courses relating to waste-water treatment works operation. Membership of WISA and participation in the activities of its various Technical Divisions should be encouraged.

P E Odendaal

Executive Director, Water Research Commission

EXECUTIVE SUMMARY

INTRODUCTION

Although anaerobic digestion is a well recognised waste treatment technology, the process has unfortunately been neglected in many treatment works over the years. Due attention is not always paid to the well established theory and operating principles formulated by the early chemists, microbiologists and engineers. A survey of anaerobic digester practice would reveal significant areas of neglect such as sludge pre-treatment, digester mixing, heating, gas measurement and routine monitoring and control, particularly in the rural areas. Many persons do not fully understand the anaerobic digestion process which, being hidden from view, tends to be subject to crisis management. Correction of a process failure may take months, with consequent environmental and cost implications.

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CONTENTS OF THE GUIDE

The Guide covers all aspects of sludge treatment and handling, including the pre-treatment stage, primary sedimentation, sludge thickening, the anaerobic digestion process, to the final drying and disposal of the sludge. Special emphasis is given to monitoring, control, trouble-shooting and maintenance aspects while general recommendations are made to improve the efficiency and reliability of the anaerobic digestion process. Where examples or calculations are given, these relate to a 10 000 m³ per day treatment works - a size selected for ease of calculation. The figures given in the calculations are intended only as guidelines.

RECOMMENDATIONS FOR IMPROVEMENTS TO THE ANAEROBIC DIGESTION PROCESS

- a) It is most important to ensure that the screening and grit removal units are well designed, operated and maintained. Any sub-standard performance of these units will have a detrimental effect on all processes at the works and most seriously on the anaerobic digesters. The majority of digester failures are caused by an accumulation of grit or scum (including plastics). Consideration should be given to incorporating a grit removal system, such as a cyclone and classifier, on the sludge pipeline feeding the gravity thickener or digester. The potential financial savings and the improvement in process reliability may be significant.
- b) *grease trap* The anaerobic digester must not be used as a sink to dispose of excess oils, fats or poorly biodegradable materials. If high concentrations of these materials are present in the influent then ideally they should be reduced at source. This would involve determining who is responsible for the discharge. Among the possible sources of oils and fats are abattoirs, restaurants, butcheries and garages. Removal at source is much easier than trying to remove the same material from a much larger volume of waste water. If individual sources cannot be traced then it would be advisable to install a more sophisticated oil and fat removal system. The same philosophy applies to high fibre loads such as hair, wool and other textiles.
- c) Primary sludge or mixed sludge thickening is an area in which significant savings can be effected. On large plants, a separate gravity thickener is recommended. On small plants, it is recommended that the primary sedimentation tank be designed and operated to produce a relatively thick sludge.
- d) Two stage anaerobic digestion should be regarded as essential. The primary digester should be mixed and preferably heated. The secondary digester would be neither heated nor mixed, but would be fitted with a number of supernatant withdrawal pipes. When the works is constructed in stages, it is feasible to upgrade the digestion system in stages. Stage One would contain only primary digestion, mixed but not heated; Stage Two involves adding a secondary digester and Stage Three involves providing heating for the primary digester. With each stage of development, the solids retention time in the primary digester may be reduced.
- e) To avoid drawing in air during supernatant withdrawal, secondary digesters should not have gas-tight roofs; in fact, they may be constructed without a roof.
- f) The degree of mixing of the primary digester is important, to ensure that dead pockets of sludge do not occur, which would result in other portions of sludge having a solids retention time less than a desirable lower limit. A gross power input of 5 to 10 watts.m⁻³ is recommended. It is preferable that the mixing system of a primary digester be operated continuously.

- g) Waste activated sludge should not be treated in anaerobic digesters. This is particularly important when the activated sludge works is operated with a long sludge age. The waste activated sludge is relatively well stabilised and will not generate much gas. Also, activated sludge cannot be thickened to the same degree as primary or humus sludge except by mechanical thickening e.g. by centrifuge. In nutrient removal plants, the digestion process will liberate the phosphorus that the works was specially designed to remove. Activated sludge should be pumped directly from the aeration tank to the dewatering/drying unit.
- h) The supernatant withdrawn from the secondary digester will contain high levels of nitrogen, phosphorus and soluble organic materials. This liquid is traditionally returned to the head of the works, even though it imposes additional load upon the works. Where suitable land is available, it is recommended that the possibility of irrigating the supernatant be investigated. This needs to be carefully planned and operated to avoid pollution of rivers and underground aquifers.
- i) As the degree of skill of the operating staff is crucial to the satisfactory operation of the waste-water treatment works, it is recommended that operating staff be encouraged to improve their knowledge of the treatment process by study. They should also receive training in operating the various stages of the works. They should have access to the various operating manuals and books available. These should ideally be kept at the treatment works. Where possible, the operating staff should be allowed to, and in fact encouraged, to attend seminars, etc. on the various aspects of waste-water treatment held from time to time at various centres in the country.

CONCLUSION

At most stages in the sludge treatment stream, the operating staff can play an important role in controlling and optimising the process. Process failure can be prevented by a sound understanding of anaerobic digestion. It is hoped that the Guide, while written primarily for the operating staff, will prove useful to decision-makers in the organisational hierarchy and to persons responsible for the planning and design of waste-water treatment works.

Local authorities and other organisations desiring further assistance with the implementation of the concepts discussed in this Guide (or who wish to suggest improvements to the contents of the Guide), are invited to contact the Sludge Management Division or the Water Care Division of the Water Institute of Southern Africa (WISA) at the following address:

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CHAPTER 1: INTRODUCTION

Waste water contains a mixture of organic and inorganic solids, suspended and dissolved in water. This Guide deals only with the anaerobic treatment of sludges and relevant processes. The sludge flow diagram of a typical works is shown in Figure 1.1.

On arrival at the waste-water treatment works, the larger solids, or SCREENINGS, are removed by the screens. The heavier inorganic solids, or GRIT, are removed in the grit removal unit.

Except in extended aeration activated sludge works, the waste water usually passes next into primary sedimentation tanks (PST). In this process, the settleable suspended material is allowed to settle out. The settled material is withdrawn from the base of the PST as underflow and is known as PRIMARY SLUDGE or RAW SLUDGE.

When secondary treatment is by biological filtration (trickling filters), some of the organic load is converted into a SECONDARY SLUDGE, generally known as HUMUS SLUDGE - which is allowed to settle out in a secondary sedimentation tank (SST), sometimes known as a clarifier or humus tank. Often, this sludge is returned to the head of the works and is allowed to settle out with the primary sludge. In this case, the sludge withdrawn from the primary sedimentation tank is known as MIXED SLUDGE or PRIMARY/ HUMUS SLUDGE.

If the secondary treatment is by the activated sludge process, the quantity of secondary sludge in the system increases continuously due to the conversion of influent organic material into biomass. To maintain the system biomass constant, secondary sludge generally known as WASTE ACTIVATED SLUDGE must be regularly withdrawn from the system.

Because it is generally difficult to withdraw the various sludges from the sedimentation tanks at optimum solids content (thickness), many works have a separate stage in the sludge treatment stream in which the sludge solids content is increased by thickening. In this case, the sludge with an increased solids content is known as THICKENED SLUDGE. At this stage, the solids content of the sludge is usually in the range of 3 to 6%. The sludge after anaerobic digestion, is usually known as DIGESTED SLUDGE.

After anaerobic digestion, it is usually necessary to increase the solids content further in order to reduce the volume to be transported or ultimately disposed of. Sludge with a solids content raised above about 10%, is generally known as DEWATERED SLUDGE, while sludge with a solids content raised above about 30% is generally known as DRIED SLUDGE (though still containing 70% water).

The volume of primary sludge removed represents about 2% of the influent waste-water volume being treated, but around 40% of the organic load received, expressed as the chemical oxygen demand (COD), or around 60% of the influent loading expressed as suspended solids. In a biological filtration works, the mixture of primary and humus sludge removed from the sedimentation tanks represents only 4 to 5% of the influent volume, but

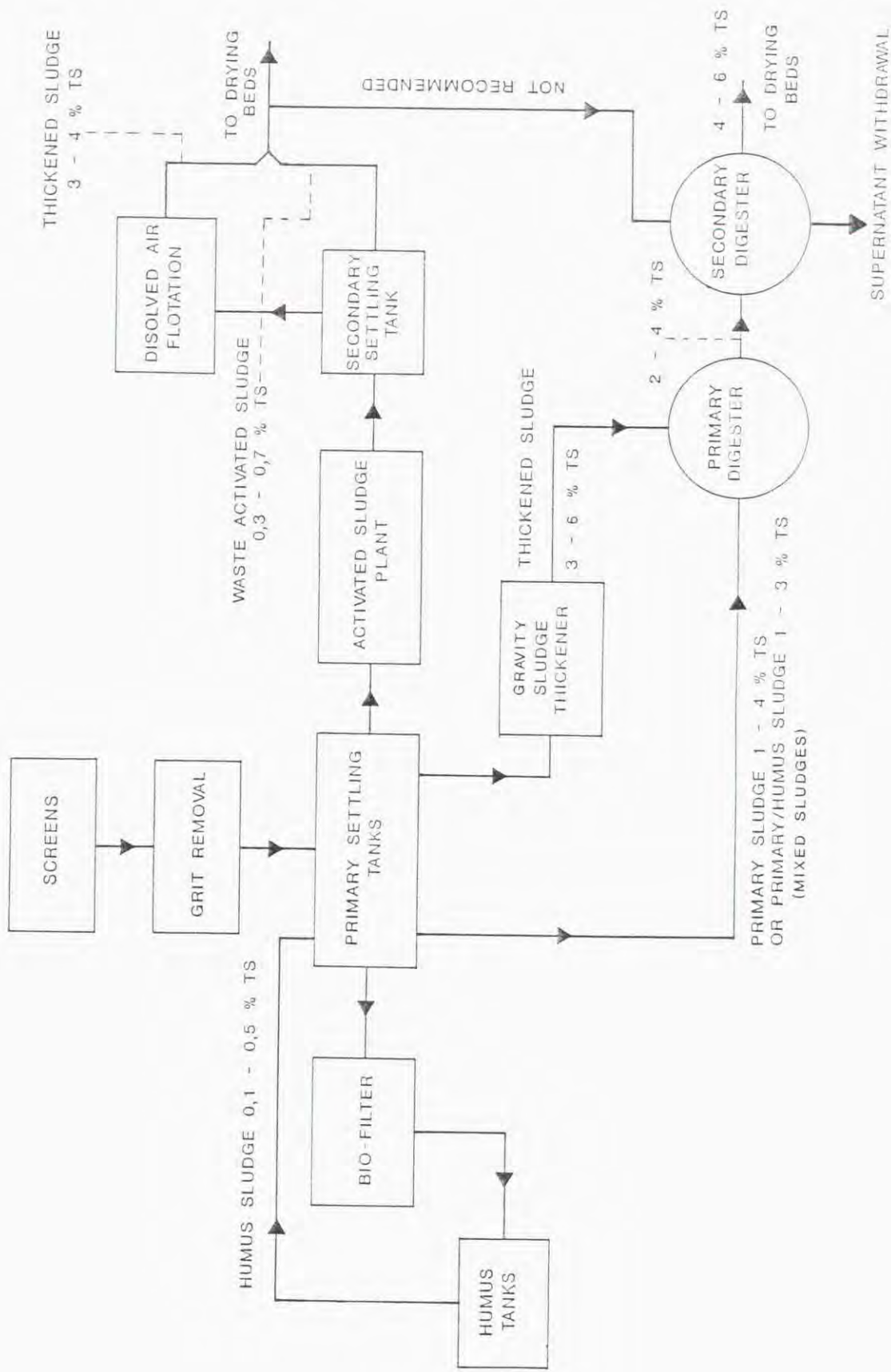


Figure 1.1
Sludge flow diagram of a typical waste-water works

comprises about 80% of the influent suspended solids. The total volume of the primary and secondary sludge removed from an activated sludge works, for further treatment, is greater than that removed from a biological filtration works. What is not generally realised is that, both in terms of capital outlay and operating cost terms, sludge handling usually accounts for over 50% of overall treatment costs.

This Guide covers all aspects of sludge treatment and handling, including the pre-treatment stage, primary sedimentation, sludge thickening, the anaerobic digestion process, to the final drying and disposal of the sludge. Special emphasis is given to monitoring, control, trouble-shooting and maintenance aspects while general recommendations are made to improve the efficiency and reliability of the anaerobic digestion process. Where examples or calculations are given, these relate to a 10 000 m³ per day treatment works - a size selected for ease of calculation. The figures given in the calculations are intended only as guidelines.

At most stages in the sludge treatment stream, the operating staff can play an important role in controlling and optimising the process. Process failure can be prevented by a sound understanding of anaerobic digestion. It is hoped that the Guide, while written primarily for the operating staff, will prove useful to decision-makers in the organisational hierarchy and to persons responsible for the planning and design of waste-water treatment works.

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CHAPTER 2: TROUBLE-SHOOTING CHECK-LIST

SECTION 2.1

PROCESS TROUBLE-SHOOTING

2.1.1 INTRODUCTION

The anaerobic digestion process may be regarded as being "upset" when the process control indicators (refer Section 4.8) show deviations from normal. Process trouble-shooting is the identification of the cause(s) of the process "upset", and determination of the best action to take.

The main changes indicating an upset digester, in typical order of increasing response time, are:

- a) Increased percentage CO₂ in the gas produced;
- b) Decreased gas production;
- c) Increased volatile acid/alkalinity ratio of the sludge;
- d) Production of a malodorous (smelly) sludge;
- e) Decreased pH;
- f) Increased solids in the supernatant;
- g) Decreased volatile solids reduction;
- h) Increased foaming.

2.1.2 IDENTIFICATION OF THE CAUSE OF THE PROBLEM

The first step in trouble-shooting is to try to identify the probable cause of the problem. To provide a systematic approach, each likely cause is categorised under one of the following headings in Figure 2.1.1:

- a) Loading;
- b) Mixing;
- c) Heating;
- d) Gas;
- e) Toxicity

The cause of the problem is then identified by proceeding step by step through all the possible causes and eliminating all the NO answers. This procedure allows the whole system to be checked to locate the cause of the problem(s).

2.1.3 TAKING THE APPROPRIATE ACTION

When the cause(s) have been identified, the second step is to consult the relevant section in the Guide to determine the most appropriate action to take.

CHANGE IN PROCESS CONTROL INDICATOR	
a) Rise in percent CO ₂	e) Decrease in pH
b) Decrease in gas production	f) High solids in supernatant
c) Rise in VA/alkalinity ratio	g) Decrease in VS reduction
d) Odorous sludge	h) Excessive foaming

(Refer to Section 4 B)

The process can be considered to be upset when the process control indicators show changes from normal. To identify the problem check each step until the cause is found and then refer to the relevant section.

Note : Several items may occur at the same time

Note: Several items may occur at the same time.

**SOLUTION TO PROBLEM
(SECTION REFERENCE)**

```

graph TD
    L[LOADING] -- YES --> L41[4.1 Screening and grit removal]
    L -- NO --> M[MIXING]
    M -- YES --> L46[4.6 Gas production and control devices]
    M -- NO --> H[HEATING]
    H -- YES --> L45[4.5 Heating and temperature control]
    H -- NO --> G[GAS]
    G -- YES --> L46
    G -- NO --> T[TOXICITY]
    T -- YES --> L41
    T -- NO --> T41[4.11 Toxicity]
  
```

LOADING

- a) Change in feed
- b) Thin feed sludge
- c) Thick feed sludge
- d) Change in pH of feed
- e) Reduced digestion capacity :
 - i) Excessive scum
 - ii) Grit accumulation

MIXING

- a) Mechanical problems
- b) Electrical problems
- c) Process problems :
 - i) Drop in gas production
 - ii) Excessive rags
 - iii) Scum

HEATING

- a) Temp. fluctuation
- b) Unable to maintain temperature
- c) Mechanical problems
- d) Hot water system not working

GAS

- a) Leaking gas
- b) Pressure above normal
- c) Pressure below normal
- d) Poor gas quality

TOXICITY

- a) Slow steady feed but has reached toxic limits
- b) Slug doses of toxic materials

4.1 Screening and grit removal

4.6 Gas production and control devices

4.5 Heating and temperature control

4.11 Toxicity

Figure 2.1.1
Process trouble-shooting : Problem indication, identification and solution

SECTION 2.2

EQUIPMENT TROUBLE-SHOOTING

2.2.1 INTRODUCTION

If the mechanical equipment of a waste-water treatment works is not suitably maintained and kept in good running order, then it will be impossible to treat the waste water to the required standard. The various processes cannot proceed efficiently without properly running mechanical equipment.

2.2.2 PLANNED OR PREVENTATIVE MAINTENANCE

The maintenance procedures detailed in the manufacturers maintenance manuals must be followed so that equipment can be serviced on a regular basis. Preventative maintenance involves replacing components before they reach the end of their service life, and so prevent the breakdown of equipment which could occur at a most inopportune time.

2.2.3 THE USE OF THE NATURAL SENSES AS A TROUBLE-SHOOTING GUIDE

Skilled operating staff can check the mechanical equipment during the routine inspections of the works by using their natural senses, i.e. eyes, nose, ears and touch. In this way it is possible to detect impending problems with the mechanical equipment and to take the appropriate action before the unit is damaged or fails.

EXAMPLES

- a) Regularly check ammeters for unusually high or low readings. Paint a line on the glass of the ammeter at the correct running current;
- b) Paint a line on the wheel of a rotating bridge as an aid to detect motion;
- c) Taking due care, lightly touch a bearing housing to establish if the bearings are running hotter than usual or if any unusual vibration is present;
- d) Listen for unusual noises emanating from equipment;
- e) Check for oil leaks indicating impending seal failure;
- f) Check for metal filings near rotating shafts;
- g) Check for large rag or scum build-up on screens, shafts, scrapers, tanks etc;
- h) Look for pieces of rubber at or near V-belt drives or at shaft couplings.

2.2.4 TROUBLE-SHOOTING BEGINS BY KNOWING THE WORKS

It is important to know:

- a) The purpose of all mechanical and electrical components of the works and how each should operate under normal conditions;
- b) How to recognise abnormal conditions;
- c) What alternatives are available when trouble develops;
- d) When a mechanical problem occurs first look for the obvious faults/problems such as:
 - i) Is the unit switched on;
 - ii) Is the lock stop or emergency stop button pushed in;
 - iii) Is the unit set to "HAND" or "AUTO" operation;
 - iv) Is the electricity supply to the electrical panel switched on;
 - v) Has the unit tripped out?

2.2.5 TROUBLE-SHOOTING CHECK-LISTS

The purpose of this section is to present a ready reference to process problems, probable causes and suggested action:

- a) Table 2.2.1: Inlet works;
- b) Table 2.2.2: Primary sedimentation tanks;
- c) Table 2.2.3: Digester mixing;
- d) Table 2.2.4: Digester heating;
- e) Table 2.2.5: Digester gas system;
- f) Table 2.2.6: Digester covers;
- g) Table 2.2.7: Gas holders.

TABLE 2.2.1: INLET WORKS

PROBLEM	PROBABLE CAUSE	ACTION
<u>SCREENS</u>		
High rag content downstream of screen	screen bar missing or displaced	check bars
Limit switches faulty	a) corroded	replace #
	b) burnt out	replace #
Not removing rags	a) rake not meshing with screen	adjust
	b) rake worn or teeth broken	repair or replace
Rake jamming	a) teeth bent	straighten or replace
	b) something jammed in bars	remove obstruction
Tripping out	a) overloaded motor	remove excess rags
	b) overloaded motor	rake jamming on bars, check motor current #
Rag build-up on screen	a) screen overloaded	remove build-up manually
	b) screen overloaded	increase frequency of raking
<u>CONVEYOR</u>		
Belt not turning	belt stretched	adjust end roller
Tripping out	overloaded motor	manually remove rags
Idlers not turning	a) rag build-up on idlers	clean
	b) idlers worn	replace idlers
	c) bearings worn	replace bearings
Belt slipping off	belt misaligned	align end roller idlers

Table 2.2.1 Continued

GRIT SCRAPERS

Excessive wear on wearing plates	chain stretched	shorten chain by removing links
Chain coming off cogs	chain stretched	replace chain
No grit being removed	a) scraper worn	replace scraper
	b) shaft broken	replace shaft

GRIT CHANNELS

Excessive grit in effluent	a) hydraulically overloaded	open another channel
	b) grit channel full of grit	clean channel manually

AIR LIFT GRIT REMOVAL UNIT

Grit not being removed	a) not enough air	check for air leaks
	b) blocked	clear blockage
Insufficient air	a) water in air lines	drain off water
	b) compressor worn	repair or replace
Compressor safety valve keeps blowing off	blockage in grit sump	agitate sump with high pressure water

NOTE: # indicates that check or repair must be done by an electrician.

TABLE 2.2.2: PRIMARY SEDIMENTATION TANKS

PROBLEM	PROBABLE CAUSE	ACTION
Scum accumulation	excessive scum/fat	remove manually
Short circuiting	a) baffle drum rusted through	repair or replace
	b) weir not level	relevel weir plate
	c) V-notch weirs blocked	clean weir
	d) build-up of algae on weirs	clean weir
Accumulation of scum and fat on surface	scraper rubber worn	replace rubbers
Tripping out	motor overloaded	check motor #
Sludge rising	a) scraper rubbers worn	replace rubbers
	b) scraper damaged	repair scraper
	c) desludge line blocked	unblock using high pressure water jet
	d) desludge valve activator faulty	check activating mechanism
Build-up of scum and fat in scum hopper	a) hopper blocked	unblock using high pressure water jet
	b) discharge line blocked	unblock using high pressure water jet
Fats and plastics on weir	outer baffle plate rusted through	repair or replace baffle plate
Sludge rising due to insufficient withdrawal	desludge valve not opening fully	adjust valve
Excessive wear on wheels	wheels not aligned	align wheel

Table 2.2.2 Continued

Motor frequently tripping out	thick sludge on the bottom	manually open desludge valve and increase desludging time
	something jamming bridge	empty PST and remove check for damage
Desludge pump not pumping but pump turning	a) suction line blocked	unblock using high pressure water jet
	b) delivery line blocked	unblock using high pressure water jet
	c) impeller blocked	unblock using high pressure water jet
	d) impeller worn	replace impeller
Desludge pump not pumping and pump not turning	a) coupling broken	replace coupling
	b) motor fault	check motor #
Bridge has jerky motion	scraper blade touching	empty tank and check floor scraper clearance
Very thin sludge being discharged	desludge valve jammed open	remove obstruction

NOTE: # indicates that check or repair must be done by an electrician.

TABLE 2.2.3: DIGESTER MIXING

PROBLEM	PROBABLE CAUSE	ACTION
<u>GAS MIXING</u>		
Compressor running hot and noisy	a) low oil level	top up with oil
	b) high ambient temperature	improve ventilation
	c) unit worn	check for excessive wear
Compressor will not start	electrical problem	check motor #
Low gas flow	lines blocked	flush with water
Compressor safety valve keeps blowing off	a) lines blocked	flush with water
	b) water in lines	drain off water
<u>MECHANICAL MIXING</u>		
Excessive noise in gear box	a) lack of proper lubrication	lubricate as per manual
	b) misalignment of equipment	check alignment
	c) unit worn	check for wear
Oil leak on output shaft	oil seal leaking	repack or replace
Poor mixing	rags accumulated on shaft or impeller	remove and clean

NOTE: # indicates that check or repair must be done by an electrician.

CAUTION: REMEMBER BIOGAS FORMS EXPLOSIVE MIXTURES WITH AIR

TABLE 2.2.4: DIGESTER HEATING

PROBLEM	PROBABLE CAUSE	ACTION
Low hot water feed rate	a) airlock in line	bleed air release in line
	b) valve partially closed	check valves
	c) internal leak	shut down digester for repair
Burner not firing on biogas	a) low gas pressure	check for leaks in system and repair
	b) low methane content	check methane content of gas
Low heat loss between inlet and outlet water	heat exchanger tubes fouled	clean heat exchanger tubes
Low rate of sludge feed through heat exchanger	a) blockage in heat exchanger	open up and clean
	b) blockage in feed lines	unblock lines
	c) blockage on pump	clean pump
Sludge temperature dropping at discharge	a) blockage in heat exchanger	open up and clean heat exchanger
	b) blockage on feed lines	unblock lines
Sludge temperature dropping in digester	inadequate mixing	improve mixing
Sludge temperature rising in digester	temperature controller not working properly	repair or replace #
Sludge temperature rising at discharge	blockage on discharge line	unblock line
Unable to maintain temperature in digester	hydraulic overloading	check sludge thickness - too thin?

NOTE: # indicates that check or repair must be done by an electrician.

CAUTION: REMEMBER BIOGAS FORMS EXPLOSIVE MIXTURES WITH AIR

TABLE 2.2.5: DIGESTER GAS SYSTEM

PROBLEM	PROBABLE CAUSE	ACTION
Pressure relief venting	a) excessive pressure due to blockage in gas line	drain condensate venting line
	b) valve not sealing properly seating	isolate and move unit to check
	c) diaphragm damaged	isolate and repair
Pressure relief not opening with high pressure	valve stuck	isolate and move unit to check seat
High pressure shown incorrectly	water in gas lines to manometer	drain condensate from line
Waste gas burner not burning	a) insufficient gas	check digester performance
	b) pilot flame out	relight in accordance with standard procedure
	c) excess water in lines	drain lines and traps
	d) burner isolated	open valve and relight flame
Waste gas flame lower than usual	a) low gas pressure	check digester performance
	b) high gas usage on plant	check and record
	c) gas leak in piping	check gas lines with soapy water
	d) low gas production due to process problems	investigate - could be loading problems
	e) high CO ₂ content	check CO ₂ content of gas

CAUTION: REMEMBER BIOGAS FORMS EXPLOSIVE MIXTURES WITH AIR

TABLE 2.2.6: DIGESTER COVERS

PROBLEM	PROBABLE CAUSE	ACTION
<u>FIXED COVERS</u>		
Gas pressure higher than usual	a) supernatant, gas or sludge lines blocked	unblock line
	b) pressure relief device faulty	isolate and check
Gas pressure lower than usual	a) pressure relief device faulty	isolate and check
	b) gas lines leaking	check using soapy water
	c) leak in structure	check using soapy water
<u>FLOATING COVERS</u>		
Cover tilting	a) weights missing or unbalanced	replace or adjust
	b) rainwater or condensate accumulated on roof	drain water
	c) large scum build-up	remove scum layer
	d) guides or rollers out of adjustment	adjust guides or rollers
	e) rollers or guides damaged	repair guides or rollers
Cover not moving freely	accumulated scum on guides or rollers	clean rollers or guides

CAUTION: REMEMBER BIOGAS FORMS EXPLOSIVE MIXTURES WITH AIR

TABLE 2.2.7: GAS HOLDERS

PROBLEM	PROBABLE CAUSE	ACTION
Cover not moving freely	a) scum accumulated on guides or rollers	clean rollers or guides
	b) internal guides damaged	repair guides
Gas pressure higher than normal	a) pressure relief device faulty	isolate and check
	b) gas lines blocked	drain condensate from line
	c) gas lines blocked	clean lines

CAUTION: REMEMBER BIOGAS FORMS EXPLOSIVE MIXTURES WITH AIR

CHAPTER 3: PRETREATMENT

SECTION 3.1

SCREENING AND GRIT REMOVAL

3.1.1 INTRODUCTION

Raw waste water contains solids which are of such a nature that, if they are not removed, will accumulate in the digester thus reducing the effectiveness of the digester, leading ultimately to process failure. The removal of these materials is important to extend the period between digester shutdown for maintenance. Larger particles are removed by screens, and grit by the grit removal system. If these materials are not removed they will cause problems such as the following:

- a) Blocked pipes;
- b) Blocked or damaged pumps;
- c) Accumulation of solids in the digester which will not decompose and will eventually fill the digester.

3.1.2 SCREENS

There are several types of screens, but all consist of a series of bars spaced across the inflow channel at the inlet works. The function of the screen is to remove large solids from the flow. Screens are raked either manually or mechanically.

a) Record keeping

If containers are being used to collect the screenings it is important to know the volume of the containers. The total number of containers removed each day must be recorded. The total volume of screenings removed can then be calculated.

Example: Calculation of volume of screenings

Volume of container:	=	40 ℓ
	=	0,04 m ³
Number of containers per day	=	5
Total volume of screenings per day	=	Volume of container x number of containers per day
	=	0,04 m ³ x 5
	=	0,2 m ³ screenings

A record of this daily volume is necessary so that the required size of future additional screens can be accurately determined.

b) Performance assessment

It is difficult to assess the performance of a screen. An indication of the anticipated volume of screenings removed per day is shown below:

TABLE 3.1.1: VOLUME OF SCREENINGS REMOVED

Opening between bars (mm)	12 - 25 - 50
Litre screenings.Mℓ ⁻¹ flow	40 - 20 - 5

Example: Calculation of volume of screenings

Average dry weather flow of works	= 10 000 m ³ .d ⁻¹
	= (10 Mℓ.d ⁻¹)
Assume screening opening	= 25 mm
From Table 3.1.1 : 25 mm	= 20 ℓ screenings.Mℓ ⁻¹ flow
Volume of screenings per day	= 20 ℓ.Mℓ ⁻¹ x 10 Mℓ.d ⁻¹
	= 200 ℓ.d ⁻¹
	= 0,2 m ³ .d ⁻¹

The operating staff should check the sludge to see if it contains a lot of rags and plastics. Weirs and the surface of the various process units should also be checked for the presence of rags, plastics, etc.

3.1.3 GRIT REMOVAL

Grit removal is essential because if not carried out will cause mechanical malfunctions and reduce the effective volume of the digesters. There are manually or mechanically operated grit removal systems.

a) Record keeping

The following information should be kept on a daily/weekly data sheet:

i) Flow through units

Each unit is designed to treat a certain flow rate. It is useful to indicate the design flow rate on the flow recorder to show when it is necessary to operate the next unit. If the flow rate exceeds the designed flow then grit will be carried over into the downstream treatment processes. If a totaliser is installed, the reading should be taken once every 24 hours, at a set time e.g. 09:00 every morning so that the total flow for 24 hours can be recorded.

ii) Performance assessment

The operating staff must record the number of grit containers filled so that the daily volume of grit removed can be calculated. This provides useful information that can be used to adequately size future units, or which will indicate the efficiency/ inefficiency of the grit removal system.

Example: Calculation of volume of grit

$$\begin{aligned}\text{Volume of grit container} &= 200 \text{ l} \\ &= 0,2 \text{ m}^3\end{aligned}$$

$$\begin{aligned}\text{Number of containers} \\ \text{removed per day} &= 5\end{aligned}$$

$$\begin{aligned}\text{Volume of grit removed} \\ \text{per day} &= \text{Volume of container} \times \text{Number} \\ &\quad \text{of containers per day} \\ &= 0,2 \text{ m}^3 \times 5 \\ &= 1 \text{ m}^3\end{aligned}$$

SECTION 3.2

PRIMARY SEDIMENTATION

3.2.1 INTRODUCTION

Primary sedimentation is the process by which the velocity of the waste water is reduced below the point at which it can transport the settleable and a major portion of the suspended solids. This results in much of the suspended matter settling out which can then be removed as sludge. The primary sedimentation tank will be referred to as the "PST" in the Guide.

3.2.2 REASONS FOR PRIMARY SEDIMENTATION

- a) Separation of the settleable and a major portion of the suspended solids from the waste water in order to treat the solids separately.
- b) Reduction of the load imposed on the aerobic biological treatment section by reduction of suspended solids in the waste water. Between 40 and 60% of the suspended solids are removed in primary sedimentation. This results in a 30 to 40% reduction in oxygen demand of the effluent being fed to the secondary treatment stage.
- c) If the settleable and larger suspended solids were not removed then these can cause blockages of the stone media in the biological filters resulting in ponding and eventual filter failure.
- d) Reduction in volume of aeration modules or biological filters is made possible by the reduction in organic loading, resulting in savings in capital costs of construction.
- e) The resulting sludge can be anaerobically digested and the methane produced can be utilised, resulting in savings in electricity or fuel oil usage.
- f) On an activated sludge plant, the mass of secondary sludge to be wasted is decreased.
- g) Removal of fats, oils and grease which float on the surface of the PST, and can be easily removed, to avoid operational problems in the downstream treatment stages.

3.2.3 DESCRIPTION OF PRIMARY SEDIMENTATION TANK

There are three basic shapes in PST designs:

- a) Circular tanks where the sludge is scraped to the centre and the liquid flow is predominately radially outwards (Figure 3.2.1);

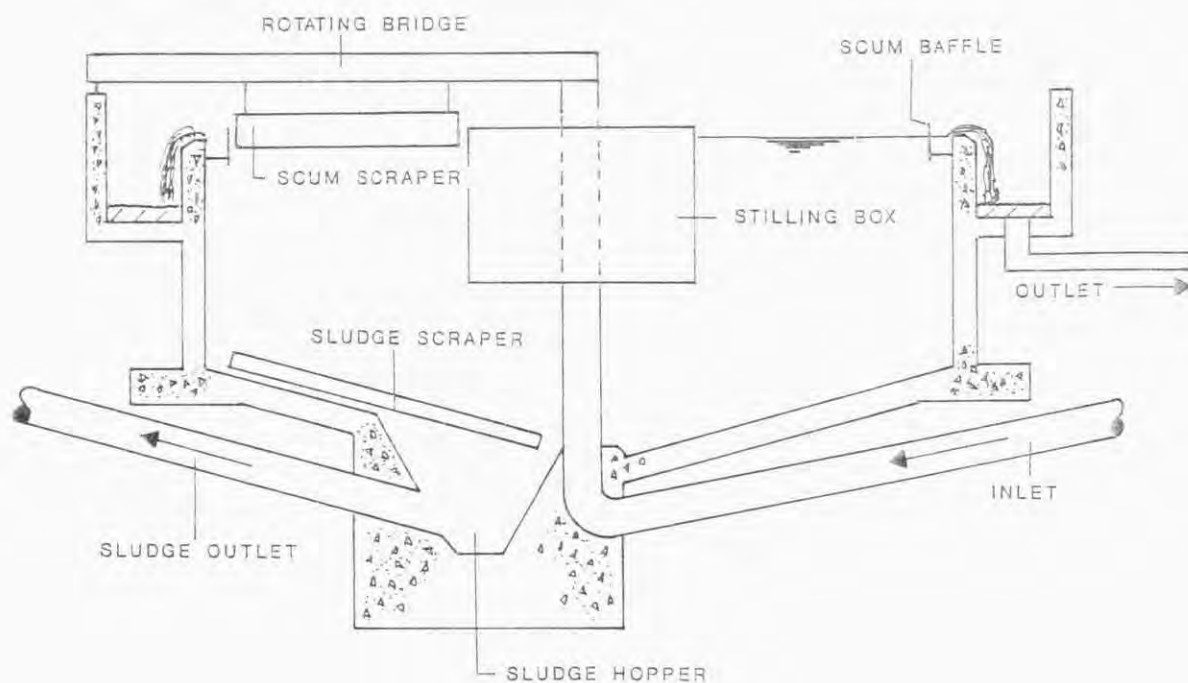


Figure 3.2.1.
Radial flow primary sedimentation tank

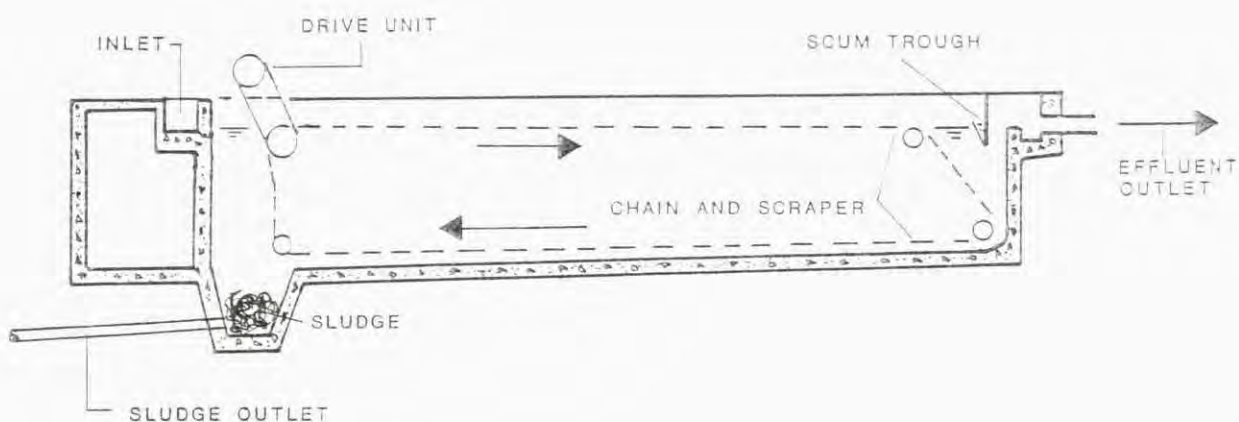


Figure 3.2.2
Horizontal flow primary sedimentation tank

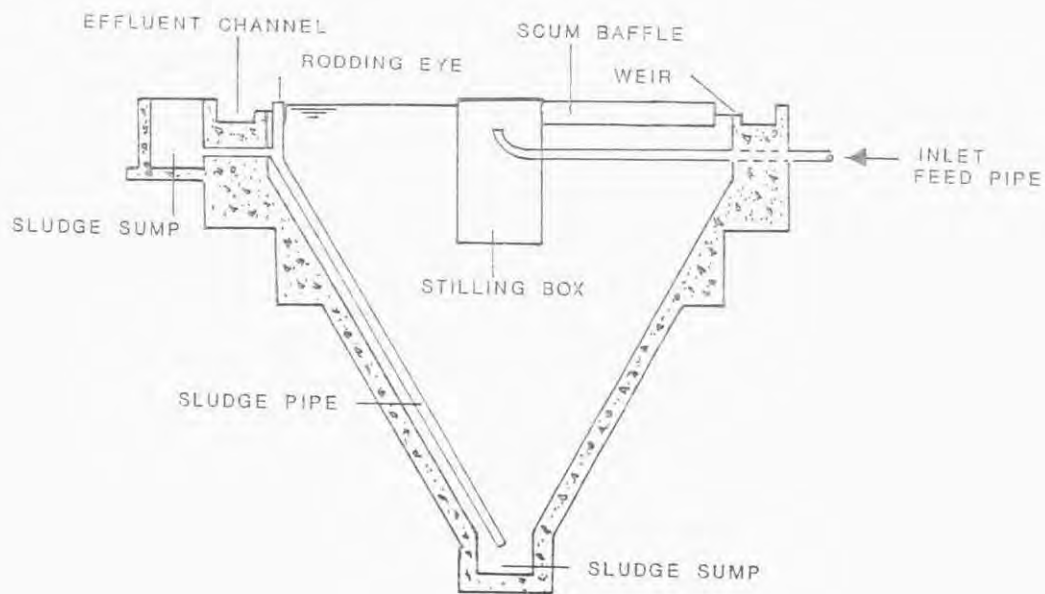


Figure 3.2.3
Upward flow sedimentation tank

- b) Rectangular tanks where the sludge is scraped to one end and the liquid flow is predominately horizontal (Figure 3.2.2);
- c) The Dortmund type of tank where the sludge gravitates to the central cone and the liquid flow is predominately upward (Figure 3.2.3).

The PST will consist of the following:

- a) A circular or rectangular tank;
- b) A central inlet feed for a circular tank and the Dortmund tank, and an inlet at one end for the rectangular tank;
- c) A stilling chamber or baffle ring extending 2 to 3 m into the tank at the inlet;
- d) A bridge that is stationary or moving;
- e) A top scraper for the removal of surface scum and except in the case of the Dortmund tank, a bottom scraper to move the sludge towards the discharge point;
- f) A scum hopper at the top water level of the PST;
- g) A sludge hopper in the bottom of the PST;
- h) A scum baffle near the outlet weir to prevent scum from leaving the tank and contaminating the effluent;

- i) An outlet weir that may be straight or "V" notched;
- j) An outlet channel to transport the effluent to the secondary treatment stage;
- k) A desludging valve to control sludge wasting.

3.2.4 OPERATION OF A PRIMARY SEDIMENTATION TANK

It is essential that the PST be operated correctly as this is the first process of water and solids separation in a treatment works. If this separation is not carried out correctly then the processes further on, either aerobic or anaerobic, will be adversely affected. Correct desludging plays an important role and should be optimised and carefully controlled.

There are various calculations that can be performed to determine if the PST is hydraulically overloaded. Analytical testing of the influent and effluent from a PST for chemical oxygen demand (COD) and suspended solids (SS) content will help to determine if the PST is being overloaded or not. If the COD removal across the PST is less than about 20% or the suspended solids removal less than about 25%, then hydraulic overloading should be expected.

On filling a one litre Imhoff cone with raw screened, degritted waste water, it would be found that after one hour settling there would be, on average, 20 ml of sludge in the bottom of the cone. This represents 2% of the volume of the cone. It can be seen that the volume of sludge is only 2% of the total volume of incoming flow. However, the removal of this sludge would reduce the COD of the waste water by 30 to 40% and reduce the suspended solids content by 40 to 60%.

To allow the settleable solids to settle out, the upward velocity of the waste water must be less than the settling velocity of the suspended solids to be removed. If the upward velocity is higher, then the solids will be carried over the weir. The average upward velocity may be calculated by dividing the average flow rate by the surface area of the PST.

Example: Calculation of retention time and upward velocity in PST

a) PST retention time (h)	=	$\frac{\text{Volume of tank (m}^3\text{)}}{\text{Flow rate (m}^3\text{.h}^{-1}\text{)}}$
Volume of PST	=	834 m ³
Flow rate	=	10 000 m ³ .d ⁻¹
	=	417 m ³ .h ⁻¹
Retention time	=	$\frac{834 \text{ m}^3}{417 \text{ m}^3\text{.h}^{-1}}$
	=	2 h
b) PST upward velocity (m.h ⁻¹)	=	$\frac{\text{Flow rate (m}^3\text{.h}^{-1}\text{)}}{\text{Surface area (m}^2\text{)}}$
Flow rate	=	417 m ³ .h ⁻¹
Assume surface area	=	348 m ²
Upward velocity	=	$\frac{417 \text{ m}^3\text{.h}^{-1}}{348 \text{ m}^2}$
	=	1,2 m.h ⁻¹

3.2.5 VARYING DESLUDGING TIMES

Incorrect desludging of the PST will adversely affect the efficient operation of the subsequent treatment processes. Desludging must occur at least twice a day, preferably more often, depending on the requirements of the works. It is necessary to determine the length of time of sludge withdrawal and how often during the day sludge must be withdrawn. These times can vary during the following situations:

- a) High and low flows during the day;
- b) Different days of the week i.e. weekdays and weekends;
- c) After heavy rains;
- d) Seasonal i.e. summer and winter.

3.2.6 IMPORTANCE OF SLUDGE THICKNESS DURING DESLUDGING

The solids content of the sludge being withdrawn from the PST should be maintained between 2% to 5% total solids (TS). Checking the solids content of the sludge on a weekly basis, while desludging, would assist in determining whether the sludge is at the required thickness.

It must be remembered that the longer the desludging period, the thinner the sludge will become. It is necessary to be careful not to over-desludge which will result in a very thin sludge being passed to the digester or the gravity thickener.

a) Thin sludge

If the sludge fed to the anaerobic digester is too thin i.e. too much water has been withdrawn with the sludge (sludge total solids concentration 1 to 2%), then the following would happen:

- i) The degree of stabilisation of the anaerobically digested sludge would be lessened because the retention time of the sludge in the digester was reduced.
- ii) More fuel (diesel or methane) would be required to heat the larger volume of sludge entering the digester each day.
- iii) Methane production will decrease as there would be a reduction in the solids retention time.

b) Thick sludge

If the sludge becomes too thick (greater than about 7% TS) then the following problems would arise:

- i) The sludge becomes too thick to pump and could cause blockages of pipes.
- ii) Sludge in the bottom of the PST would become septic as the retention time is too long. Various decomposition gases including hydrogen sulphide (H_2S) would be formed in the sludge and the gas bubbles would lift the sludge to the surface (this is called belching). If the sludge rises, odours are released and solids carry-over may occur.
- iii) Solids carry-over could block the stones in the biological filters and decrease filter efficiency.
- iv) Solids carry-over would increase the load (COD and SS) to be treated in the secondary treatment stage.

It is often believed that it does not matter what thickness of sludge is being removed from the PST when the sludge is discharged to a gravity thickener. As can be seen from the above, the

thickness is important for the efficient operation of the PST as well as the gravity thickeners. Gravity thickeners are usually designed to handle a sludge feed of total solids concentration of between 2% and 5% TS. If a very thin sludge is pumped to the gravity thickener, the extra volume will increase the upward velocity and this could result in loss of sludge over the weir. Therefore, proper desludging practice cannot be over-emphasised.

3.2.7 DESLUDGING PROGRAMME

A definite desludging programme must be established, and used as a guideline so that all operating staff will know how often and for how long to desludge. The desludging programme may vary from season to season and may also vary between weekdays and the weekend. An example of a desludging programme is given in Table 3.2.1.

TABLE 3.2.1: PRIMARY SETTLING TANK : DESLUDGING PROGRAMME

SUN	MON	TUES	WED	THURS	FRI	SAT	DESLUDGING PERIOD
08:00	08:00	08:00	08:00	08:00	08:00	08:00	15 MIN
22:00	16:00	16:00	16:00	16:00	16:00	20:00	15 MIN
-	24:00	24:00	24:00	24:00	24:00	-	15 MIN

NOTE: The above table is an example of a desludging programme. Every works will have its own programme and this must be determined by the operating staff.

An estimate of the period of sludge withdrawal from a PST may be established from the following test. This is done by sampling the sludge for % total solids (% TS). One would then plot the % TS against the time or sample number (refer Figure 3.2.4). One can then read off from the graph how much time is needed to desludge until the solids concentration drops below a predetermined thickness, usually about 3% TS. This would be used as a guide only. The actual periods of desludging would be modified on the basis of visual examination and operating experience.

Certain PSTs are designed so that when the bridge passes a certain point(s), the bridge will activate a trip valve and desludge the PST automatically. Under these circumstances the operating staff have little control over the thickness or the period of desludging, except by modifying the trip mechanism. Depending on the system used, this could be merely a matter of welding a piece of metal onto the trip mechanism. It is important to ensure that the bridge activates the desludging valve each time that it passes the trip mechanism. If this valve is not activated at least once every revolution of the bridge, insufficient sludge will be withdrawn and the sludge will become septic. The effluent will become dark in colour, gas generation and sludge rising (belching) will occur. Sludge solids may be carried over the effluent weir. Obnoxious odours may also develop.

To avoid the problems mentioned above during the low flow periods of the year, it may be advantageous or even advisable to reduce the number of PSTs in use. This will reduce excessive retention times which contribute to sludge rising and the development of obnoxious odours. A high hydrogen sulphide content in the effluent may adversely affect the secondary treatment process and can contribute to the corrosion of concrete and steel structures. The removal of a PST from service affords an excellent opportunity to carry out maintenance of the unit.

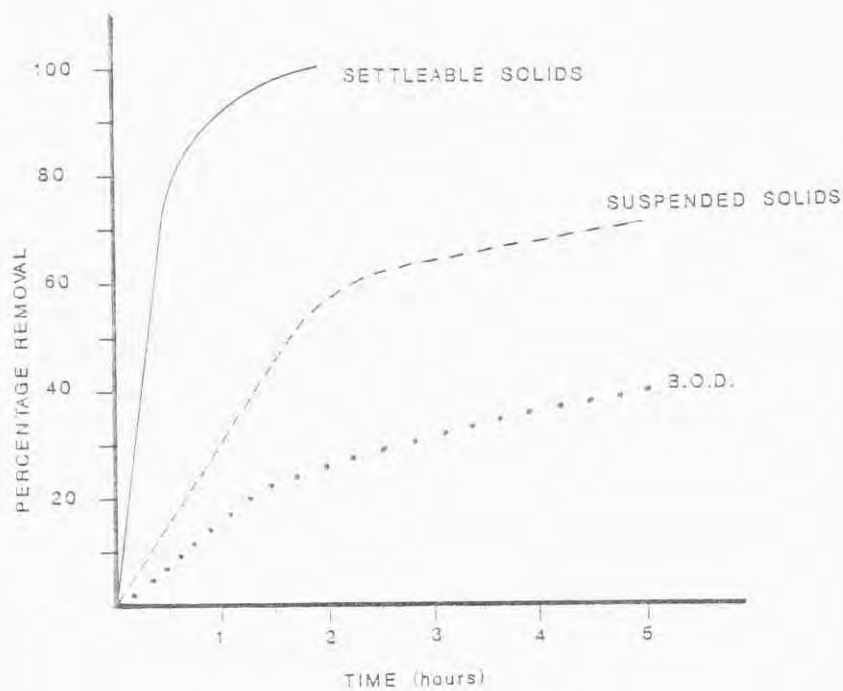


Figure 3.2.4
Plot of solids removal vs time

3.2.8 VISUAL AND OTHER CHECKS

There are various non-analytical checks that can be performed on a daily basis to ensure that the PST is operating correctly.

These are:

- a) Smell — check if there are any obvious odours being generated e.g. H_2S from outlet channel;
- b) Sludge rising (belching) — check if sludge is rising to the surface of the PST;
- c) Bubbling — check if many small bubbles appear on the surface of the PST;
- d) Excessive scum — check if there is more scum than usual on the surface of the PST;
- e) Thickness of sludge — check the thickness of the sludge at the gravity thickener inlet or the digester inlet;
- f) Carry-over of solids — using an Imhoff cone, check if there is more settleable solids than usual in the effluent.

If any of the first four signs above are detected, then the sludge may be septic. To rectify this, it would be necessary to increase the desludging time until the PST is cleared of excess sludge.

If the sludge is too thin then the desludging period must be reduced.

3.2.9 CONCLUSION

If the PST is operated incorrectly then problems will be created in both the subsequent treatment of the settled waste water and the anaerobic digestion of sludge. As the cost of sludge handling and treatment may exceed 50% of the operating cost of the works, the efficient operation of the sludge processing stream offers the potential for significant savings in treatment costs.

SECTION 3.3

SLUDGE TYPES

3.3.1 INTRODUCTION

In waste-water treatment, sludges are derived from various processes. Each type of sludge has its own characteristics. The moisture content of the sludge may be regarded the most significant characteristic affecting the design and operation of the stabilisation and disposal processes.

3.3.2 TYPES OF WASTE-WATER SLUDGES

a) Primary sludge

The principal component of primary sludge is human faeces and other domestic wastes. The polluting material is mainly organic in nature (70 to 80% of dry mass) and in its raw state is putrescible and rapidly develops strong and obnoxious odours.

Fresh raw waste water contains settleable as well as suspended solids in varying amounts. Most of the settleable solids and about 50% of the suspended solids are removed from the incoming raw waste water in the primary sedimentation tank (PST) (refer Section 3.4). The primary sludge is withdrawn from the bottom of the tank as underflow while the settled waste water overflows from the top of the tank. The average percentage dry solids of the underflow sludge stream is 2 to 5% TS.

b) Humus tank/trickling filter sludge

In a biological filtration (trickling filter) works most of the dissolved organic matter as well as the non-settleable solids passing through the PST are converted into settleable solids. This occurs through adsorption and biological flocculation by bacteria and other organisms within and around the layer of zoogloea (slime) which covers the stationary media (stones). This film undergoes biological breakdown and is periodically sloughed (washed) off by the effluent. The effluent from the biological filters passes through the secondary sedimentation tank (SST) in which the settleable solids are removed as underflow. The average percentage dry solids of the SST underflow is 1 to 3% TS.

c) Waste activated sludge

In the activated sludge process, bacteria and other micro-organisms feed on the incoming organic matter and produce additional cell mass. In order to keep the total mass of sludge in the system at a constant level, a certain quantity of sludge must be removed periodically from the system. The sludge removed is known as waste activated sludge. The concentration of the waste activated sludge depends on the location of the draw-off point.

Traditionally, the waste sludge is drawn off from the SST underflow and the concentration

may vary according to the time of day. The modern trend is to control the sludge age hydraulically by withdrawing a fraction of the reactor volume daily. For example, to operate at a 20-day sludge age, one wastes 1/20 of the volume of the reactor each day. The waste activated sludge solids concentration can vary from 0,3 to 0,7% dry solids, depending on the mixed liquor suspended solids (MLSS) concentration in the reactor.

Waste activated sludge is an aerobic sludge and should be treated separately from the primary sludge. Furthermore, the dewaterability of digested mixtures of primary and waste activated sludges is inferior to the dewaterability of digested primary sludge.

d) Chemical sludge

Chemical sludge contains precipitated chemicals and 70 to 90% of the suspended solids in the raw waste water, depending on the effectiveness of the chemical dosing. Ferric chloride is an example of a coagulant used in waste-water treatment and 1 mg.ℓ⁻¹ ferric chloride dosed will produce 0,66 mg.ℓ⁻¹ of ferric hydroxide in the sludge. More and more inland waste-water treatment works are including chemical treatment along with biological treatment in order to reduce the phosphate levels to below the 1 mg.ℓ⁻¹ as P limit in accordance with the requirements of the Department of Water Affairs and Forestry.

e) Mixtures of the above-mentioned types of sludge

In reality, waste-water treatment works rarely handle only one type of sludge but usually handle mixtures, with differing proportions, of the above-mentioned types of sludges. Table 3.3.1 gives a few common combinations of sludges which may be found in waste-water treatment works in Southern Africa.

TABLE 3.3.1: COMBINATIONS OF DIFFERENT SLUDGES GENERALLY TREATED IN AN ANAEROBIC DIGESTER

	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

3.3.3 SLUDGE CONCENTRATION

All sludges are mixtures of solid matter (both organic and inorganic) and water. Primary sludges are removed from the incoming waste water in the PST and comprises about 70% organic and 30% inorganic solids. The organic solids are problematic and have to be reduced or stabilised; it is this fraction which is mostly used as the food for the anaerobic bacteria. The inorganic fraction is not generally considered a problem and usually passes through the various biological processes unchanged. Larger inorganic materials should have been removed in the preliminary treatment stages.

Figure 1.1 gives a breakdown of waste-water sludge treatment and disposal routes along with typical percentage dry solids contents. One of the primary objectives of treating waste-water sludge is to obtain a stable dry cake at the end of the process. Various thickening and drying stages are employed in order to promote the effective and economical achievement of these goals.

Figure 3.3.1 gives the relationship between sludge consistency and sludge treatment, transportation and disposal.

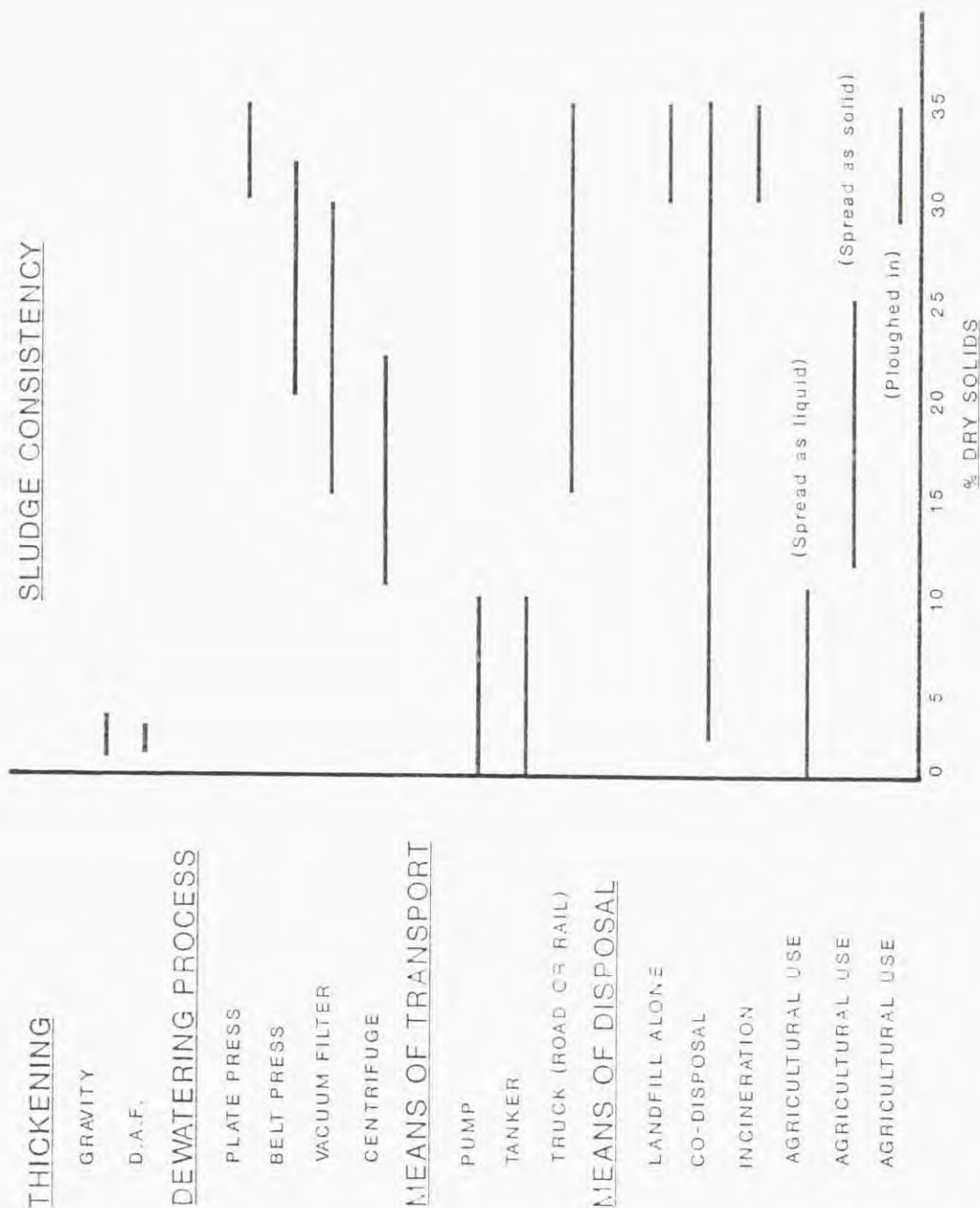


Figure 3.3.1
Relationship between sludge consistency, sludge treatment, transportation and disposal

SECTION 3.4

SLUDGE THICKENING

3.4.1 INTRODUCTION

Thickening is the process in which the concentration of suspended solids in a sludge is increased by the separation and removal of some of the liquid phase.

The thickening of sludges plays an important role in reducing capital costs relating to the provision of the sludge handling equipment and the operational costs of the handling and treatment of the sludge.

There are three accepted methods used for pre-digestion sludge thickening. These are: gravity thickening, dissolved air flotation and centrifugation. Centrifuges are not commonly used in Southern Africa for pre-digestion sludge thickening, and will not be covered in this Guide.

3.4.2 EXAMPLE OF REDUCTION OF SLUDGE VOLUME BY THICKENING

The following example gives an indication of the reduction in sludge volume effected by thickening.

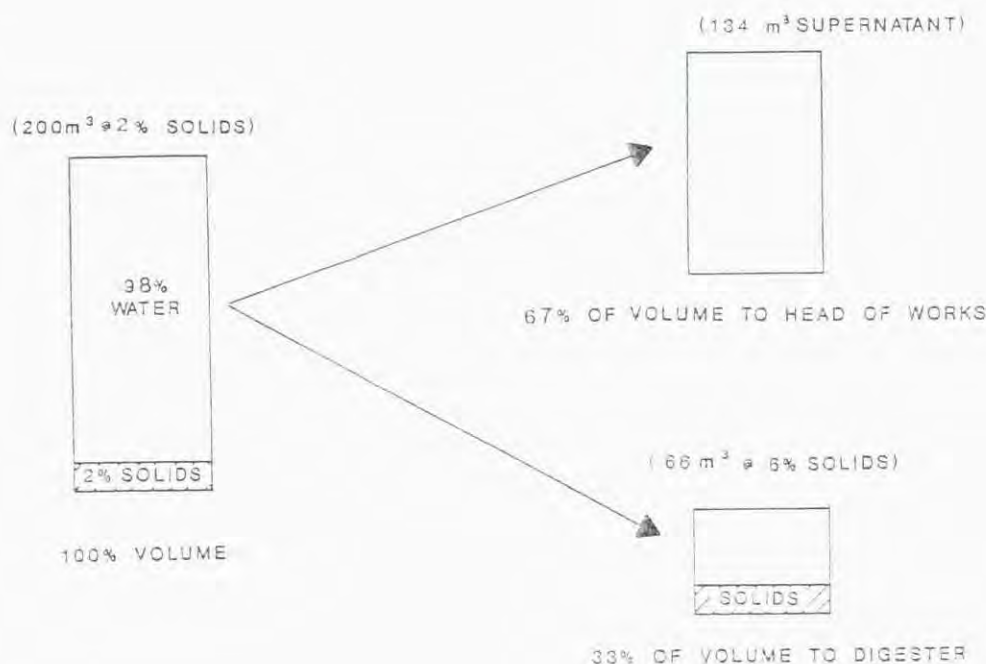


Figure 3.4.1
Illustration of volume reduction by means of the thickening process

A treatment works produces 200 m³ per day of 2% TS primary sludge which has to be digested in an anaerobic digester. The sludge is thickened to 6% TS before being pumped to the digester. Figure 3.4.1 illustrates that the volume after thickening is reduced to 33% of the initial volume, by increasing the total solids content from a 2% to a 6% solids.

If an anaerobic digester with a retention time of about 25 days had to treat the unthickened sludge (2% TS) then a digester with a capacity of 5 000 m³ would be required. However, if the digester was required to treat the thickened sludge (6% TS) then a volume of only 1 667 m³ would be required.

It can, therefore, be seen that reduced digester volumes can be achieved in waste-water treatment works where pre-digestion thickening is utilised.

3.4.3 REASONS FOR THICKENING SLUDGE BEFORE ANAEROBIC DIGESTION

Regardless of the type of sludge, the concentration of solids should be as high as possible in order to promote effective digestion, but not too high to adversely affect pumping and mixing of the sludge.

The main reasons for thickening a sludge prior to digestion are:

- a) To maximise the use of the available digester capacity in the digestion of the solids, i.e. excess water uses up digester capacity and reduces retention time;
- b) The prevention of the dilution of the feed material which would cause difficulty in the utilisation of the food by the bacteria;
- c) Excess water with the sludge also requires heating in order to keep the digester contents at the required temperature, i.e. thickening reduces the amount of heat required in a heated digester;
- d) To prevent the washout of solids and organisms from a hydraulically overloaded digester;
- e) The prevention of the dilution of the alkaline buffer which could cause pH instability.

The preferred concentration of the feed sludge to an anaerobic digester is 3 to 6% TS. Total solids of 3% should be accepted as the minimum and sludges with concentrations of less than 3% TS should be considered too thin. If the concentration consistently exceeds 7% TS then pumping may become a problem as blockages may occur.

3.4.4 GRAVITY THICKENING

Gravity thickening makes use of the force of gravity as the main agent in the thickening process. The mixture of sludge and water enters the thickening tank and the heavier sludge particles settle out and are removed from the bottom of the tank as thickened sludge while the liquid overflows at the top. This liquid is called supernatant and is usually returned to the head of the works where it is mixed with the incoming waste-water flow.

This process is widely used for thickening primary sludges. Some application has been found for thickening waste activated sludges with reasonably fast settling rates (SVI less than 100 ml.g^{-1}).

There are a number of different designs of thickener in operation throughout Southern Africa. Figure 3.4.2 shows a typical gravity thickener. The gravity thickener consists of a circular tank with two steel scraper arms mounted on a central drive shaft which is in turn connected to the drive mechanism mounted on the bridge. The bridge is usually fixed to the tank walls and provides support for the entire scraper mechanism. There is a central baffle drum to prevent short-circuiting and to create an upward flow in the thickener.

The floor of the thickener tank is similar to that of a PST, but usually has a greater bottom slope. The bottom scraper arm often has a picket fence arrangement fixed to it. The role of the picket fence is to:

- a) Release entrained gas bubbles;
- b) Prevent bridging (binding) of sludge particles;
- c) Minimise scum formation;
- d) Form channels (voids) in the sludge blanket through which the liquid can travel upwards.

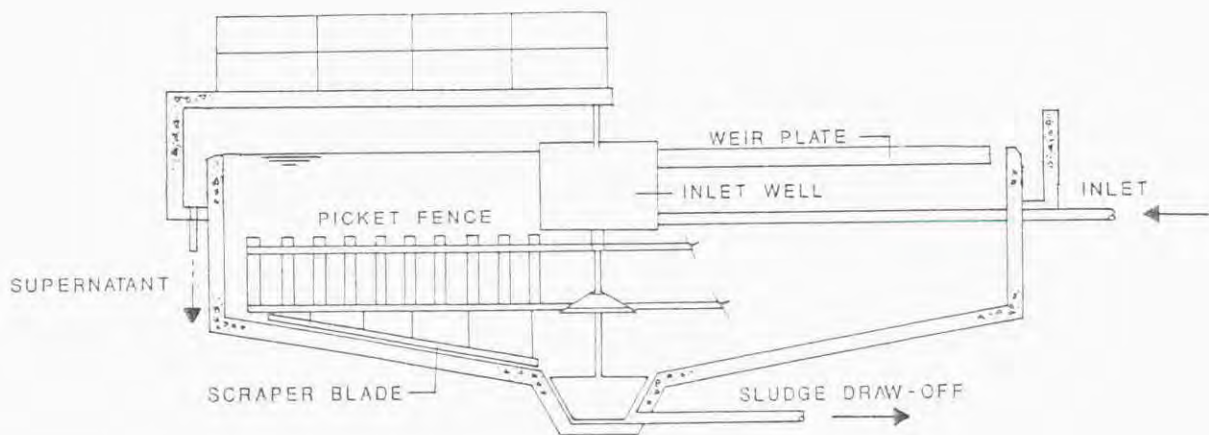


Figure 3.4.2
Typical gravity thickener

Primary sludge enters the thickener in the centre about half way up the depth of the central column. The solids settle into the dense sludge blanket at the bottom. The scraper mechanism moves the sludge towards a central sump from where it is pumped to the digester. The liquid rises with an upward velocity which is insufficient to upset the settling sludge, and passes over the weir.

The actual operation of a gravity thickener depends on the design of the unit as well as on the piping size and configuration. The operating staff must, therefore, familiarise themselves with the manufacturer's operating instructions. The concentration of the thickened sludge must be high enough to aid digestion but must not be too thick as to cause blockages in outlet pumps or pipework (consistently 7% TS or higher).

It may be advantageous to screen or macerate the primary sludge prior to gravity thickening in order to prevent blockages due to rags, plastics, etc.

The feed to the gravity thickener should be as near to continuous as possible as this promotes a stable sludge blanket and also tends to reduce gasification and the resultant floating sludges. The concentration of feed sludge is usually between 2 and 5% TS and that of thickened sludge between 3 and 6% TS. The preferred concentration for anaerobic digestion is about 5% TS.

Regular solids concentration determinations should be carried out to ensure proper operation of the gravity thickener. It is suggested that the thickened sludge be tested daily and that the solids concentration in the inlet sludge, thickened sludge and supernatant be determined weekly on 24-h composite samples. Refer to Sections 6.1 and 6.3 for sampling procedures and test methods.

In order to optimise the desludging frequency and period, the operating staff should carry out the following test procedure from time to time. This should also be carried out when a new gravity thickener is commissioned.

a) Gravity thickener desludging optimisation tests (Table 3.4.1)

- i) The thickener should not be desludged for about 2 h;
- ii) The desludging procedure must be started and a sample of the thickened sludge must be taken immediately;
- iii) Further individual samples must be taken at 2 min intervals for 10 min, then every 5 min for about 1 h (or until the sludge becomes very thin);
- iv) The solids concentration must be determined using the method detailed in Section 6.3;
- v) The solids concentration is plotted against time on graph paper and a curve similar to that given in Figure 3.4.3 should be obtained;

- vi) The point at which the thickened sludge concentration drops to 3% TS should be taken as the time to stop desludging; e.g. from Figure 3.4.3 the sludge concentration drops below 3% TS after 40 min therefore the sludge desludging time should be 40 min or shorter;
- vii) This process should be repeated a few times, but the period without desludging should be varied i.e. start with a tank which has not been desludged for 1 h then carry out the procedure set out above; repeat for 2 h and 3 h etc., between desludging;
- viii) The starting sludge concentration will indicate the desludging frequency: for primary sludges alone it could be 12 to 15% TS, whilst for mixtures of primary and secondary, 7 to 10% TS could be expected.

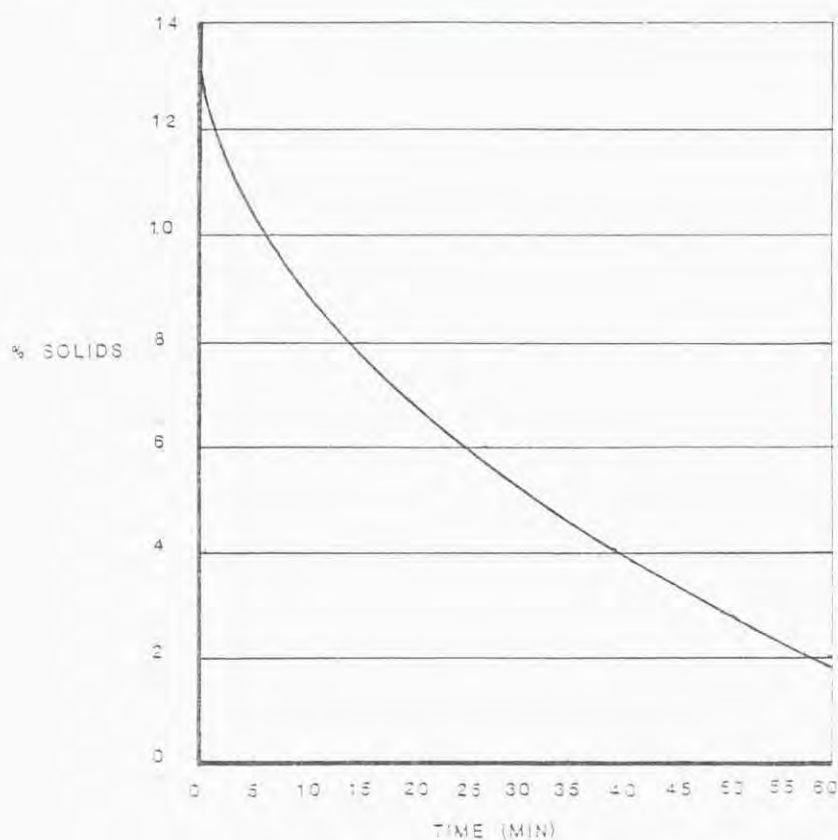


Figure 3.4.3
Sludge concentration vs time plot for use in the desludging
optimisation of a gravity thickener

A gravity thickener used for primary sludge was tested as set out above and the following results were obtained:

TABLE 3.4.1: RESULTS OF GRAVITY THICKENER DESLUDGING OPTIMISATION TESTS (% solids)

	1 h	2 h	3 h
START	10	14	18
2 min	9,5	12	17
4 min	9,0	11	16
6 min	8,2	10	14
8 min	8,0	9	12
10 min	7,0	7,5	10
15 min	5,5	7,0	9
20 min	4,8	6,0	7,5
25 min	4,0	5,0	6,0
30 min	4,0	4,5	5,8
35 min	3,5	4,0	5,6
40 min	3,0	3,5	5,0
45 min	2,8	3,0	4,0
50 min	2,0	2,0	3,5

All three lines can be plotted on the same axis as has been done in Figure 3.4.4.

- i) The initial sludge concentration of 18% TS is too high which indicates that a period of 3 h between desludging is too long. Similarly an initial concentration of 10% TS can be considered low. Therefore the interval between desludging should be 90 to 120 min.
- ii) If 3% TS is the cut-off point then the thickener should be desludged for 45 min i.e.
 - 120 min thickening
 - 45 min desludging
 - 120 min thickening
 - 45 min desludging.
- iii) As the tank is a continuous flow thickener the feed will enter the tank throughout both the thickening and desludging periods.

NOTE: This was just an example and this test should be carried out by the operating staff. It is a rough test but is better than doing no optimisation at all.

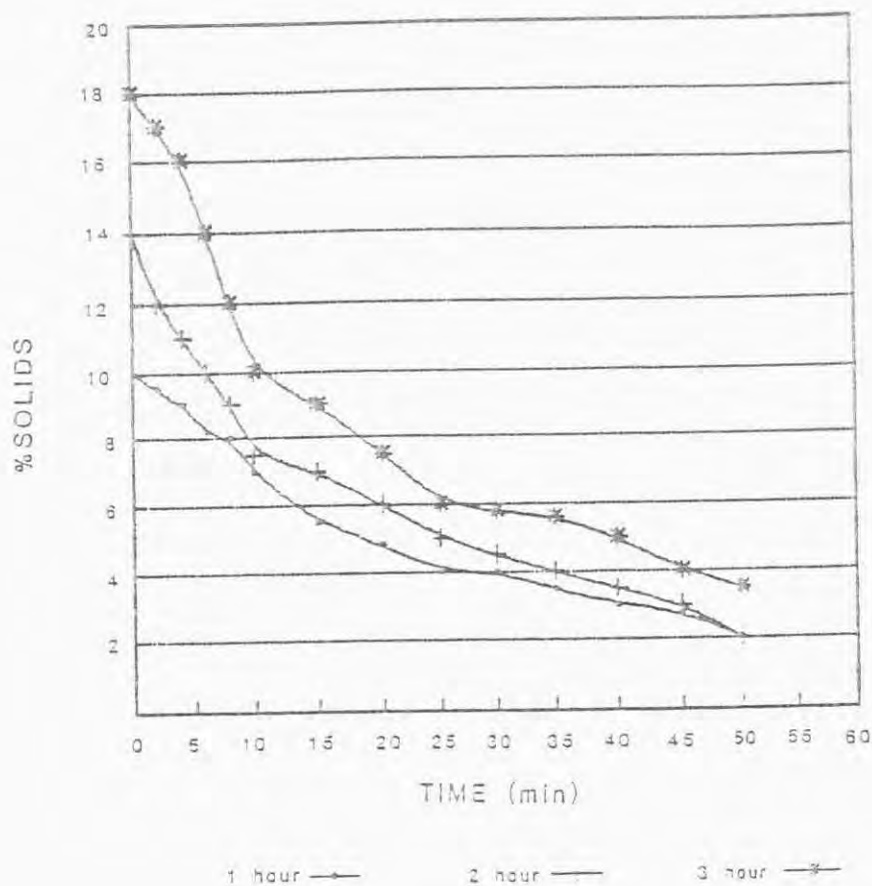


Figure 3.4.4
Sludge concentration vs time for the three different time intervals between desludging cycles

b) Problems associated with gravity thickening

- i) Grease and scum handling — scum problems are often encountered when the sludge is kept too long in the tank.

These problems can often be solved by fitting a high pressure spray that covers a portion of the tank. Grease build-up in underflow lines is a potential problem especially in works where no grease and fat removal is practiced. Grease and fat particles cling to the sludge particles and settle out. High pressure water hoses can be used to flush out the sludge lines.

- ii) Rising sludges — characterised by rising or floating sludge and foul odours which can result in poor supernatant and dilute underflow. Causes can vary from septicity to problems associated with the other unit processes.
- iii) Odours — usually resulting from long retention times and septicity in the PST and gravity thickener. Aeration of the thickener influent or a reduction in retention time will usually help reduce odours. Deodorising liquids or powders can be used to counter-act the odours in the short term.

- iv) Rat holing or coning — this occurs when liquid of low solids concentration is drawn through the sludge blanket to the draw-off point yielding a low thickened sludge concentration. Desludging rates should be reduced and the period of desludging should be increased.
- v) Blocked piping — this usually occurs due to grease build-up in the sludge lines. The best solution is to prevent the grease from reaching the thickener tank. High pressure water jets can be used to flush out blocked lines. If the pipes are blocked solid, then a drain cleaning rod may have to be used.

3.4.5 DISSOLVED AIR FLOTATION

Dissolved air flotation is a process in which minute air bubbles become attached to the sludge particles causing them to become buoyant and rise to the surface. The process has been developed to thicken sludges which will not settle satisfactorily in gravity thickeners.

Waste activated sludge (WAS) falls into this category and is usually thickened more successfully by dissolved air flotation than by gravity thickening.

The equipment required to achieve dissolved air flotation includes:

- a) A flotation unit;
- b) A saturator tank for dissolving the air in water;
- c) A recycle pump;
- d) An air compressor.

The flotation unit is used to separate the sludge (solids phase) from the liquid portion of the WAS. The saturator dissolves air into water under pressure, usually about 450 kPa. The air saturated water is usually introduced into the WAS flow and this mixture passes into the flotation unit. When the pressure is reduced, the dissolved air bubbles come out of solution and form very small bubbles. These bubbles become attached to the sludge particles forming air bubble/sludge particle agglomerates which are lighter than water. The increased buoyancy causes the sludge particles to rise to the surface of the tank where they accumulate, forming a float. In this manner, separation of the solid phase from the liquid phase is achieved.

The thickened sludge float, the top of which rises above the water level, is removed by means of a surface scraper. Figure 3.4.5 shows a simplified diagram of a rectangular dissolved air flotation unit.

Sludge thickening occurs in the float blanket above the water level, which can be between 50 and 200 mm above the water level. Up to 500 mm of the float can extend below the water level. The buoyant mixture of sludge and air below the water level forces the top of the float above the water level which allows drainage of water from the sludge. Float concentrations of 3 to 4% TS can be obtained without the use of polyelectrolytes from an inflow with an 0,3 to 1% TS concentration.

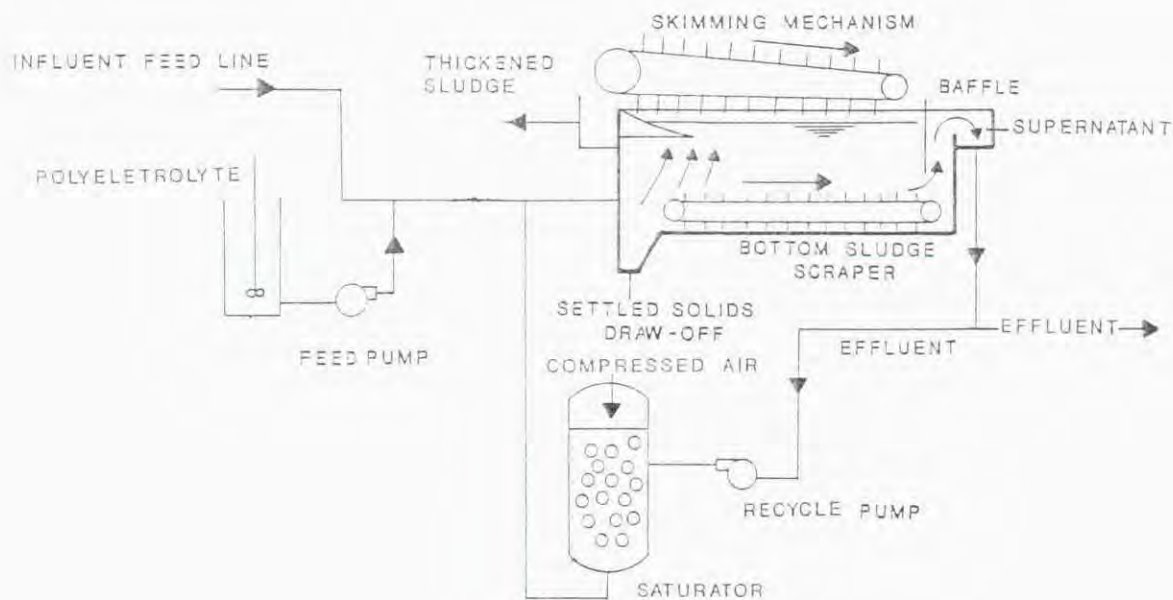


Figure 3.4.5
Schematic layout of rectangular diffused air flotation plant

Saturator units can be designed to saturate either the entire WAS flow, a separate feed water stream, or recycled supernatant from the flotation tank. The latter is usually accepted as the most suitable and economically viable system.

As with other thickening methods, regular solids concentration determinations are recommended with dissolved air flotation to ensure optimum operation of the unit. It is suggested that the concentration of the float be tested daily on grab samples and that the solids concentration in the inlet WAS, float and supernatant be tested weekly on 24-h composite samples.

Under normal conditions, satisfactory thickening can be obtained in the dissolved air flotation tank by manipulating the process variables i.e. the solids loading rate and air/solids ratio. If the unit is overloaded and successful clarification of the supernatant cannot be achieved or if the operation of the unit is such that satisfactory thickening cannot be achieved, then polyelectrolytes can be used to aid the separating and thickening process. The use of polyelectrolytes is not straight forward and a proper dosing installation should be used. There are many types of polyelectrolytes on the market. Optimisation of the type and dosage of polyelectrolytes should be carried out before usage.

In the operation of a dissolved air flotation unit the following factors should be borne in mind:

- a) The operating staff should as far as possible follow the manufacturer's instructions in order to correctly operate the system. On-site optimisation and control is usually necessary;

- b) Visual checks should be carried out at least once an hour on the following:
 - i) The condition of the float;
 - ii) The turbidity of the supernatant liquid;
 - iii) The speed setting on the skimmer arm;
 - iv) The recycle rate;
 - v) The saturator pressure;
- c) Mechanical checks should be carried out at least every two or three hours on all mechanical equipment such as pumps, compressors, etc;
- d) Regular samples should be taken and analysed as set out in Section 6.1 and 6.3.

CHAPTER 4: SLUDGE DIGESTION

SECTION 4.1

THE BASICS OF THE ANAEROBIC DIGESTION PROCESS

4.1.1 INTRODUCTION

In waste-water treatment considerable quantities of sludge are constantly being produced. In their raw state these sludges are putrescible and rapidly develop strong and obnoxious odours. These sludges will also contain pathogenic (disease causing) organisms harmful to man. It is, therefore, necessary to contain and treat these wastes so that:

- a) The treated sludge is stable;
- b) The offensive odour is removed;
- c) The quantity of pathogenic bacteria is reduced;
- d) The mass and volume of sludge is reduced;
- e) The sludge can be readily dewatered and dried.

4.1.2 THE ADVANTAGES AND DISADVANTAGES OF ANAEROBIC DIGESTION

Anaerobic digestion is the most common method in use today for treating waste-water sludges. Its attractiveness comes from it being a relatively stable process if properly controlled, with low operating costs and the production of a useful by-product, a combustible gas, which can be used as a source of energy.

Advantages of the process

- a) The organic content of the sludges is significantly reduced by conversion into gaseous end-products;
- b) The obnoxious odour of the sludge is removed. The final digested sludge has a characteristic "tarry" odour;
- c) Fats and grease are broken down by the process;
- d) There is a significant reduction in the quantity of pathogenic bacteria;
- e) There is a marked chemical change after digestion. The liquid fraction (supernatant) contains increased levels of ammonia as a result of the breakdown of organic nitrogen (proteins). This makes the digested sludge liquor potentially suitable for agricultural use (refer Section 5.2);
- f) The biogas which is evolved is a mixture of carbon dioxide (CO_2) and methane (CH_4) which can be used for digester heating or to generate power.

Disadvantages of the process

- a) A relatively high initial capital cost is involved, which tends to limit the process to medium to large size works;
- b) The slow rate of bacterial growth requires long periods of time for start-up and limits the flexibility of the process to adjust to changing feed loads, temperatures and other environmental conditions;
- c) The process is prone to upsets if not regularly monitored and if corrective action is not taken timeously.

4.1.3 THE MICROBIOLOGY OF THE PROCESS

Anaerobic digestion is a multi-stage biological process whereby bacteria, in the absence of oxygen, decompose organic matter to carbon dioxide, methane and water. In this way the sludge is stabilised and the obnoxious odour is removed.

The process can, however, be described adequately and simply as occurring in two stages, involving two different types of bacteria (refer Figure 4.1.1).

First Stage: The organic material present in the feed sludge 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 the process is:

- a) A well-stabilised sludge in which 40 to 60% of the volatile solids have been destroyed;
- b) A combustible gas consisting of 60 to 75% methane with the remainder largely being carbon dioxide.

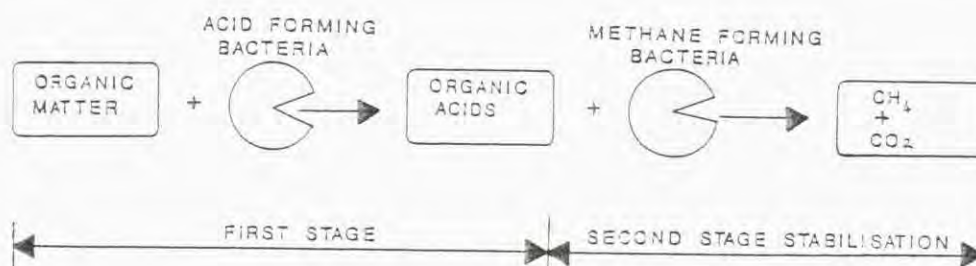


Figure 4.1.1
Diagram of anaerobic waste stabilisation

4.1.4 FACTORS AFFECTING SLUDGE DIGESTION

The digestion process is continuous. Fresh feed sludge must be added continuously or at frequent intervals. The gas formed during digestion is removed continuously. In high-rate digestion stabilised sludge is displaced from the digester during feeding. In low-rate digestion, sludge supernatant is normally removed as the feed sludge is added, stabilised sludge is removed at less frequent intervals.

It is essential that the organic acids which are formed in the first stage are converted to methane at the same rate at which they are formed. If not, they accumulate and ultimately lower the pH, leading to inhibition of the second stage of the digestion process and digester failure. Temperature and pH must be maintained within certain ranges. The factors which affect the process are:

a) Sludge composition

- i) Nutrient level;
- ii) Sludge solids content;
- iii) Type of sludge e.g. primary, secondary or mixed;
- iv) Toxicity e.g. heavy metal content.

b) Method of sludge addition

- i) Ideally should be fed continuously or as frequently as possible to avoid large fluctuations in gas production and temperature.

c) Degree of mixing

- i) To promote intimate contact between bacteria and substrate (food);
- ii) To maintain uniform temperature and solids concentration throughout the digester;
- iii) To discourage scum formation;
- iv) To facilitate the release of gas from the lower levels of the digester.

d) Temperature

- i) Heating increases the activity of the anaerobic bacteria, thus reducing the required digestion time;
- ii) Three forms of digestion are identified according to the temperature range employed:
 - Cryophilic (cold) digestion ($< 15^{\circ}\text{C}$)
 - Mesophilic digestion (15 to 40°C)
 - Thermophilic digestion (55 to 65°C)

For high rate mesophilic digestion a uniform and sufficiently high temperature, usually 32 to 37°C , is essential for satisfactory operation.

The influence of temperature on gas production rate in the mesophilic range is shown in Figure 4.1.2.

e) pH Value

- i) A pH of 7,0 to 7,5 is recommended to encourage the methane-producing stage. A correctly operating digester will have sufficient buffer capacity (alkalinity) introduced from the breakdown of organic compounds.

f) Solids retention time

- i) When the solids retention time is too short, the slow growing methane producing bacteria will be washed out. For high rate digestion, retention times of 25 to 30 days may be used. For cold digestion, retention times in excess of 50 days are required.

g) Anaerobic conditions

- i) No free oxygen must be present.

4.1.5 TYPES OF DIGESTER SYSTEMS

There are basically two types of anaerobic digestion systems in use in Southern Africa today:

a) The standard rate system (Figure 4.1.3)

The digester is not heated, and in some cases, not mixed. Raw sludge is usually added to the system two or three times per day. In the unmixed digester, as decomposition proceeds, three distinct zones develop. A scum layer is formed at the top of the digester, and beneath it are supernatant and sludge zones. The sludge zone has an actively decomposing upper layer and a relatively stabilised bottom layer from which the sludge is drawn off. The supernatant is normally returned to the head of the works. In the mixed single digester, the mixers are stopped some hours before supernatant is withdrawn to allow the sludge to settle and the supernatant to separate.

b) The high rate system (Figure 4.1.4)

The contents of the digester are well mixed, either continuously or intermittently, and the digester is heated in the optimum mesophilic temperature range (32 to 37°C). Consequently the system operates well at lower retention times and higher loading rates. A separate secondary digester is required for thickening by means of supernatant withdrawal. In the secondary digester the contents are not mixed and there is no heating. The stabilised sludge is allowed to settle and supernatant can be drawn off at various levels from the digester as stratification or banding usually occurs.

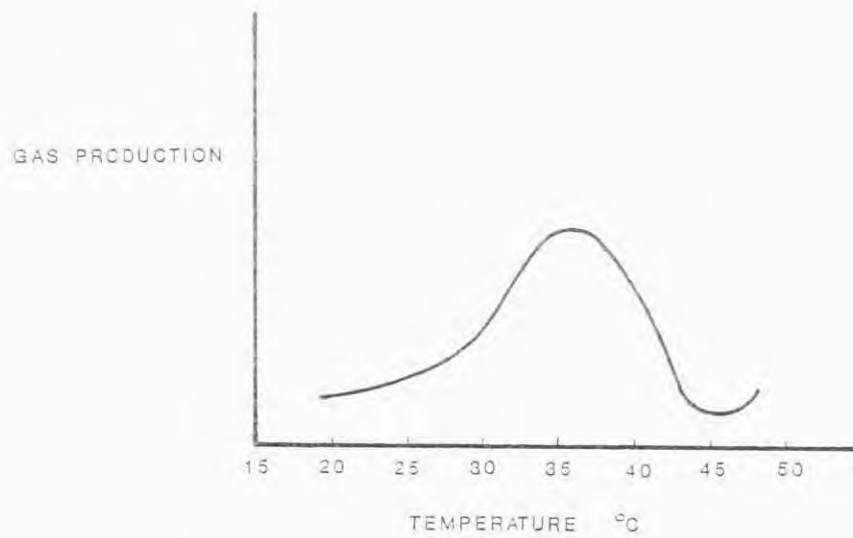
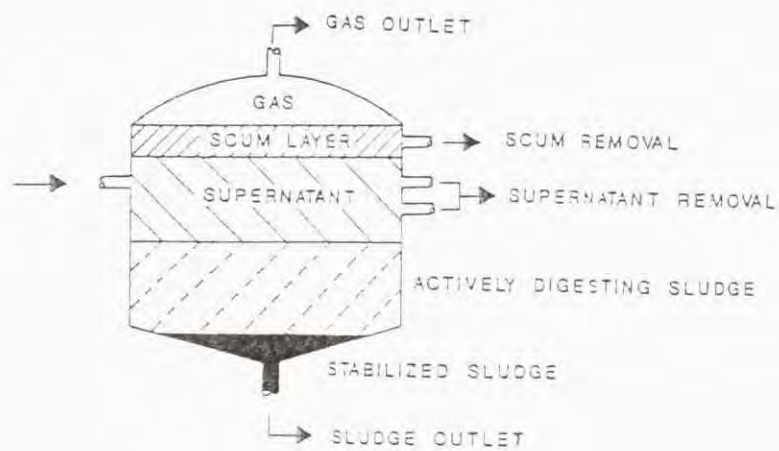
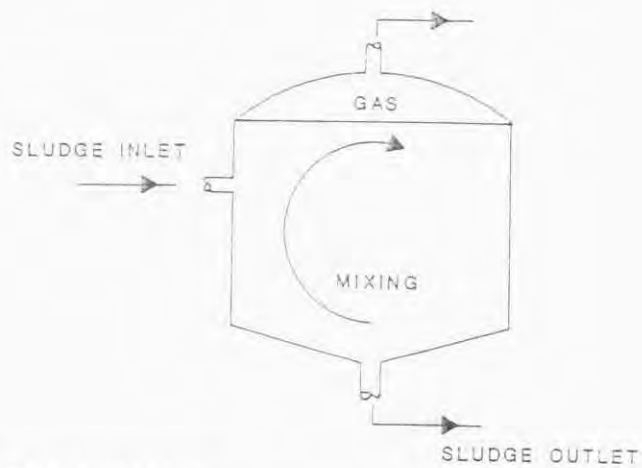


Figure 4.1.2
Effect of temperature on gas production



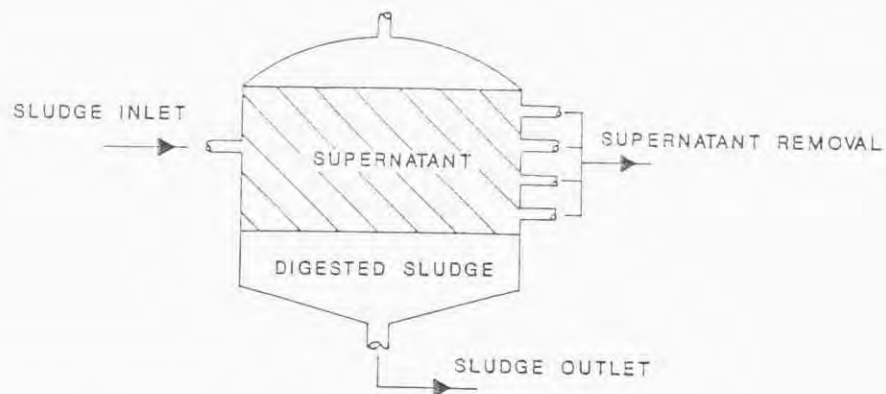
1. UNHEATED
2. RETENTION TIME 30 - 60 DAYS
3. LOADING 0.5 - 1.6 kg VS/m³/d
4. INTERMITTENT FEEDING AND WITHDRAWAL
5. STRATIFICATION

Figure 4.1.3
Standard rate digestion



HIGH RATE DIGESTION

1. HEATED TO 30 °- 38 °C
2. RETENTION TIME 15 - 25 DAYS
3. LOADING 1.6 - 6.0 kg VSS/m³/d
4. CONTINUOUS OR INTERMITTENT FEEDING AND WITHDRAWAL
5. CONTENTS WELL MIXED



SECONDARY DIGESTION (THICKENING)

1. UNHEATED
2. RETENTION TIME 15 - 60 DAYS
3. MINIMAL GAS PRODUCTION
4. CONTINUOUS OR INTERMITTENT FEEDING
5. INTERMITTENT WITHDRAWAL
6. STRATIFICATION

Figure 4.1.4
High rate digestion with secondary digestion (thickening)

SECTION 4.2

DIGESTER START-UP, INTERRUPTION, SHUT-DOWN AND CLEANING

4.2.1 START-UP PROCEDURE OF A DIGESTER WITHOUT SEED SLUDGE

The goal for start-up of a digester is to achieve the reduction of volatile matter and the production of a combustible gas under stable operating conditions as soon as possible. A stable condition usually means a volatile acids/alkalinity ratio below 0,3 and near neutral pH without continued addition of chemicals. It is most important to note that the start-up phase in an unseeded digester is much longer than when a digester is seeded with an actively digesting sludge. The most common malpractice during start-up is overfeeding, especially during the initial phase.

The following is a general outline of the steps to be taken in starting up a digester without seed sludge:

- a) Fill the digester with screened and degritted waste water or water up to the overflow level and close the system from the atmosphere;
- b) If the digester is to be maintained at mesophilic temperatures, begin heating the contents to the required temperature as rapidly as possible;
- c) Begin mixing and/or recirculating at the maximum rate;
- d) The amount of raw sludge to be fed to the digester per day depends on whether chemicals such as slaked lime or soda ash will be used to maintain the digester pH above a value of 6,8 or not;
 - i) If no chemicals are to be used then feed as much sludge as the digester can handle without going below pH 6,8 and/or above a volatile acid/alkalinity ratio of 0,3 (these process control aspects are discussed in Section 4.8). As a rough guide, the sludge feed should **not exceed 10%** of the normal daily design loading capacity, based on volatile solids, for the first 20 days (refer Section 4.3 for the method to calculate the daily feed design loading).
 - ii) If chemicals are to be used, then the raw sludge feed should **not exceed 15%** of the normal daily design loading capacity, based on volatile solids, for the first 20 days. Continue feeding raw sludge at this loading rate until stable digester conditions are achieved without the use of chemicals i.e. a volatile acids/alkalinity ratio of less than 0,3 and pH greater than 6,8.

In both cases i) and ii), the raw sludge should preferably be added at a uniform rate over 24 hours.

- e) The chemical used (to adjust the pH and to increase the alkalinity) should be added to the digester feed at a point where there is good mixing. The use of slaked lime for pH adjustment is discussed in Section 4.9;
- f) Daily records should be kept and results plotted on a graph. The following information should be recorded:
 - i) Quantity of raw sludge fed;
 - ii) Total and volatile solids of the raw sludge;
 - iii) Total and volatile solids of the digester contents;
 - iv) Volatile acids, alkalinity and pH of the digester contents;
 - v) Temperature, gas production and carbon dioxide content of the digester gas.

The need for close monitoring of a digester during start-up cannot be over-emphasised.

- g) Fairly stable digester conditions should be reached in 20 to 30 days if the raw sludge loadings do not exceed 15% of the design loading capacity based on volatile solids;
- h) The rate of raw sludge addition can thereafter be gradually increased until the design feed loading is achieved. Generally this takes from 60 to 90 days at an operating temperature of 35°C and somewhat longer for unheated digesters. The feed load should not be increased until the volatile acids/alkalinity ratio is less than 0,3 and the pH greater than 6,8;
- i) The digester will not produce combustible gas immediately. Gas production and composition are important in determining the status of start-up. A digester gas production of 1,0 m³ per kg volatile solids destroyed generally indicates that proper digestion is occurring. A high carbon dioxide level, i.e. above 35% CO₂, (refer Section 6.5 for measurement of carbon dioxide content) or a reduction in gas production are indicators of unstable conditions within a digester. Under such unstable conditions the feed rate should be reduced immediately;
- j) It is important not to light the waste gas burner after start-up of a digester until all the air (oxygen) is flushed from the gas system, as this could cause an explosion (refer to Section 4.6.13 for safety precautions to be taken);
- k) Hydraulic overload of a digester also can cause incomplete digestion. If the raw sludge feed is too thin, the digester contents will be diluted by the wash-out of solids.

4.2.2 START-UP PROCEDURE OF A DIGESTER WITH SEED SLUDGE

Thickened digested sludge from a secondary digester is the best type of seed sludge as it provides the necessary bacteria and alkalinity for reducing the start-up time. The mass of seed sludge required is about 10 times the anticipated mass of volatile solids in the raw sludge feed to the digester per day under normal operating condition.

Example: Calculation of mass and volume of seed sludge required for start-up

Assume thickened raw sludge volume	= $80 \text{ m}^3 \cdot \text{d}^{-1}$
Assume TS concentration of raw sludge	= 5% or $50 \text{ kg} \cdot \text{m}^{-3}$
Assume VS concentration of raw sludge	= 84%
Mass of VS in raw sludge feed	= $80 \text{ m}^3 \cdot \text{d}^{-1} \times 50 \text{ kg} \cdot \text{m}^{-3} \times 0,84$ = $3\,360 \text{ kg VS} \cdot \text{d}^{-1}$
Mass of seed sludge required	= 10 x mass of VS in raw sludge feed per day = $10 \times 3\,360 \text{ kg VS}$ = $33\,600 \text{ kg VS}$
Assume the TS concentration of the seed sludge	= 5% or $50 \text{ kg} \cdot \text{m}^{-3}$
Assume the % VS of seed sludge	= 68%
Volume of seed sludge required	= $33\,600 \text{ kg VS}$ = $50 \text{ kg} \cdot \text{m}^{-3} \times 0,68$ = 988 m^3

The following is a general outline of how the digester should be started up:

- Transfer the calculated amount of seed sludge into digester;
- Fill up the digester with screened and degritted waste water or water up to the overflow level and close the system from the atmosphere;
- If the mesophilic temperature range will be used, begin heating the contents to the required temperature;
- Begin mixing and/or recirculating at the maximum rate;
- Start feeding raw sludge to the digester at a rate **not exceeding 20%** of the normal daily design loading capacity based on volatile solids, for the first 20 days. Raw sludge should be fed, if possible, at a uniform rate over 24 hours;

- f) Follow steps (f) through to (k) of Item 4.2.1 dealing with the start-up procedure of a digester with no seed sludge available;
- g) No addition of chemicals for pH adjustment or alkalinity boosting should be necessary if raw sludge is fed evenly. However, if the analyses show a drop in pH or a rise in the volatile acids/alkalinity ratio, more seed sludge should be transferred to the digester or chemicals should be used to maintain the volatile acids/alkalinity ratio below 0,3 and the pH value above 6,8;
- h) After 20 days of low feeding, gradually increase the feed to achieve normal design loading between 30 to 40 days, based on an operating temperature of 35°C;
- i) If foaming occurs, make sure mixing is adequate, but not too intense. If foaming persists, temporarily reduce loading until conditions improve. Continuous mixing is preferable to intermittent mixing.

4.2.3 INTERRUPTION OF DIGESTER OPERATION

There are times when digester operation must be interrupted for varying periods of time for mechanical or process reasons. Certain precautions need to be taken and procedures followed when putting the digester back into operation.

- a) Mixing and heating of the digester contents should be continued even though feed to the digester has been stopped. When feeding is resumed, care must be taken not to overload the digester. It is advisable to commence the raw sludge feed at 25 % of the normal daily design loading capacity. Frequent monitoring of volatile acids and alkalinity will indicate the digester's reaction to restarting. This applies when the digester was not emptied. If the digester was emptied then it must be started up from scratch as described in Section 4.2.1 or 4.2.2.
- b) Repairs to equipment may require opening access holes in the digester roof. Under those conditions, precautions against explosion and an oxygen deficient atmosphere must be taken. The initial volume of gas removed from the digester following the resumption of operation should be vented to the atmosphere for 12 hours prior to lighting the waste gas burner, in order to flush out any air present in the system.
- c) When normal heating is interrupted and the digester contents cool down, the feed rate should be reduced and kept as low as possible. The re-heating of the digester should not be greater than 2°C per day when operation has resumed, while the feed rate is gradually increased.

4.2.4 PROCEDURES TO SHUT DOWN A DIGESTER

The main reason to shut a digester totally down is for scheduled cleaning, generally as a result of grit and grease accumulation. Grit and grease accumulation will interfere with effective digester operation and significantly reduce digester capacity. A typical well designed digester will need cleaning approximately every 3 to 8 years. In this time period, 20 to 25 % of the digester volume becomes unused. From time to time it is necessary to ascertain the approximate volumes of grit and grease that have accumulated. For this purpose, a digester survey should be made twice a year. This involves taking samples at various depths in the digester and determining the temperature and solids content of each sample. Data from the survey are used to plot temperature and total solids content. Profiles may also be compared with previous data to identify trends. This information is used to schedule digester cleaning.

The following is a general outline of the steps to be taken:

- a) Stop the feed to the digester but continue heating and mixing for at least 30 days or until digester gas is no longer being produced. This is to eliminate further methane production before draining the digester.
- b) Before draining the digester, it must be vented to atmosphere, otherwise a vacuum may be created inside the digester.
- c) Close all cross-connections, sludge valves and gas valves which should be tagged off or chain locked and checked that they do not leak.
- d) All electrical connections for mixing equipment, pumps, etc., must be locked out and tagged.
- e) The operating staff must keep in mind the fact that as sludge is drained from the digester, air will be drawn in, either through the vacuum relief device or through open hatches. The most explosive conditions exist when the biogas-air mixture contains a methane concentration of 5 to 15 %. For this reason the atmosphere in the tank should be continually monitored during the cleaning operation and any equipment that could cause a spark must not be used. Safety considerations with biogas systems are discussed in more detail in Section 4.6.13.
- f) Consideration must be given to alternative ways of treating the raw sludge when the digester is out of service and also where the digester contents will be disposed of. The sludge may be stored temporarily in a lagoon and later pumped back into the digester for treatment. The sludge may be spread on the ground and ploughed in. As a last resort, the sludge may be heavily dosed with lime and dried on sludge drying beds.
- g) Safety signs reading "No smoking", "No spark producing" or "No open flames" should be prominently displayed in the area.
- h) Open hatches must be barricaded off.

4.2.5 PROCEDURES TO CLEAN A DIGESTER

An important consideration is determining who will clean the digester i.e. either the operating staff or contracting the work out. There are several nationwide firms who specialise in cleaning digesters and guarantee completion within a specific time period. For a small town with limited facilities or for works that require minimum downtime, this is an attractive possibility. Even though the cost of employing an outside contractor may seem high, it should be noted that if the operating staff carry out the work, they may have to neglect their other duties to clean the digester. The basic equipment needed for emptying and cleaning a digester is summarised in Table 4.2.1.

A useful apparatus for cleaning out a digester is an air-powered loader together with a portable conveyor, as used in the coal mining industry.

a) Safety precautions

Precautions must be observed to prevent the following:

- i) Falls (use of safe ladders, safety harness, etc.);
- ii) Infection (basic hygiene and protection of open cuts);
- iii) Injuries during use of equipment (staying clear of moving equipment and of overhead objects, and wearing a safety helmet);
- iv) Asphyxiation or suffocation (testing atmosphere for oxygen content and use of breathing apparatus);
- v) Explosions (testing for explosive conditions, use of non spark-producing tools and flameproof motors). These aspects are discussed more fully in Section 4.6.13;
- vi) There must be at least two men on top of a digester for each man inside, to facilitate the removal of the worker in case of emergency;
- vii) It is essential to use forced ventilation before and during work in a digester to eliminate the possibility of an explosive atmosphere or of an oxygen deficient atmosphere occurring in the digester. It is most important that no one enter the digester until all the above precautions have been strictly observed. Extreme caution must be taken when entering a digester. The testing of the atmosphere and a declaration made by a competent person that it is safe is a requirement of the MOS Act. This safety aspect is discussed in Section 7.1.

b) Volume of water needed

The approximate volume of wash water needed to remove the solids to the disposal site is generally two to four times the volume of the digester.

c) Inspection of all equipment

Periodic cleaning also allows inspection of the digester structures and components and provides an opportunity to perform necessary maintenance tasks before digester start-up. Once the digester has been filled with waste water, it is important to check that all equipment functions and that there are no leaks in the system.

TABLE 4.2.1: DIGESTER CLEANING CHECK LIST

- A Gravity flow to an on-site disposal area;
 B Pumped to an on-site disposal area;
 C Pumped to a tanker for off-site disposal;
 D Solidified solids, heavy grease and grit accumulation.

X = definitely needed; O = possibly needed.

	A	B	C	D
Sludge line valves	X	X	X	X
Sludge line (permanent)	X	X	X	X
Sludge line (temporary)	X	X	X	X
Digester access	X	X	X	X
Explosion-proof vent fan	X	X	X	X
Explosion meter	X	X	X	X
Safe ladder	X	X	X	X
Self-contained breathing apparatus	X	X	X	X
Safety harness	X	X	X	X
Explosion-proof lights	X	X	X	X
Water source	X	X	X	X
Wash down hose	X	X	X	X
Nozzle with shut-off	X	X	X	X
Wash water pump	O	X	O	X
Fixed sludge pump		X	O	X
Portable sludge pump		X	O	X
Turret nozzle			O	X
Tripod or hoist	O	X	O	X
Tank truck			X	X
Crane				X

SECTION 4.3

FEED SCHEDULE TO CONTROL LOADING

4.3.1 INTRODUCTION

The concepts of feeding and loading a digester are interrelated yet are quite different. In order to successfully operate a digester, both have to be considered. Feeding concerns the physical transfer of sludge to the digester only without taking into account the volume or contents of the digester; whilst loading considers the feeding in relation to the contents and volume of the digester.

The sludge feed can contain any combination of different sludges, as discussed in Section 3.3. Most digesters have to cope with a mixture of sludges as the feed sludge.

4.3.2 FEED SCHEDULE

Although the operating staff have little control over the characteristics and total mass of sludge that has to be treated in the digester, control can be exercised over the concentration of the sludge being fed and the frequency of feeding.

The frequency of feeding can vary from once a day to continuous feeding. The best feed schedule is a continuous feed at a low rate. Frequent feeding for short periods is the next best alternative. The system of feeding once a day or less frequently is the worst possible procedure and should be avoided. If digesters are fed only once a day, unnecessary stress is placed on the biological system and the process is destabilised.

Continuous or near continuous feeding will eliminate any abrupt flow rate or organic loading changes that could result in shock loading. Shock loading can result in fluctuations in gas production, pH, alkalinity, organism growth rate, volatile acids concentration etc. Large fluctuations in these parameters can lead to digester instability and if fluctuations are severe enough, to digester failure.

If there is more than one primary digester, then it is essential that each receives an equal volume of feed daily. A splitter box (Figure 4.3.1) may be used to achieve this. It is important to note that when feeding, excess water should not be permitted to enter the digester. Proper control of the solids concentration of the feed sludge is necessary and should be checked on a regular basis. Several ways of testing for the solids concentration are described in Section 6.3. Another common fault occurs when the feed pump is started manually and is left switched on accidentally, resulting in hydraulic wash-out. This loss of solids is one of the major causes of digester failure. Hydraulic wash-out occurs when a large percentage of the active biomass in the digester is displaced by a large volume of inactive organic solids. In such a situation, the digester becomes biologically overloaded and eventually fails. Significant time is then required for the biological process to recover.

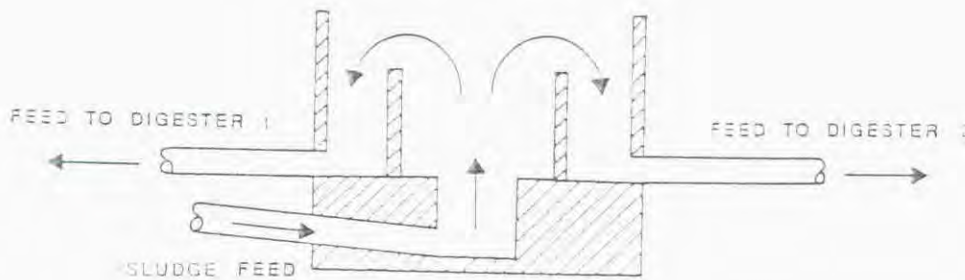


Figure 4.3.1
A typical sludge splitter box for the equal feeding
of more than one digester

Another problem resulting from excess water being pumped to the digester is due to the phenomenon known as "coning". This occurs when a whirlpool is allowed to develop at the pump suction point which causes thick sludge to accumulate near the pump suction. This leads to filtering of the sludge and liquid is pumped to the digester. The use of several pumping periods instead of a single period will help in preventing this problem from occurring. Coning of sludge is difficult to detect without determining the concentration of sludge reaching the digester. More often than not, a blockage later occurs in the suction side of the pump. This can occur hours after coning starts and the damage can already be done to the digester before the necessary steps are taken to rectify the situation.

Feed schedules can vary considerably from works to works and it must be ensured that the type of feed schedule used is the most suitable one for the works configuration and the type and concentration of sludge to be digested. Optimisation by trial and error is usually necessary.

4.3.3 FEED LOADING

As seen in Section 4.3.1, loading is the feeding of a digester in relation to the contents and volume of the digester. In order to calculate loading, a record must be kept of the mass (kg) of volatile solids per day being fed to the digester and the usable volume i.e. capacity of the digester, must be known.

Usually about 80% of the total solids entering a digester are classed as volatile. During digestion about 60% of the volatile solids is broken down whilst the remaining 40% remains as undigested volatile solids. Figure 4.3.2 shows this solids breakdown schematically.

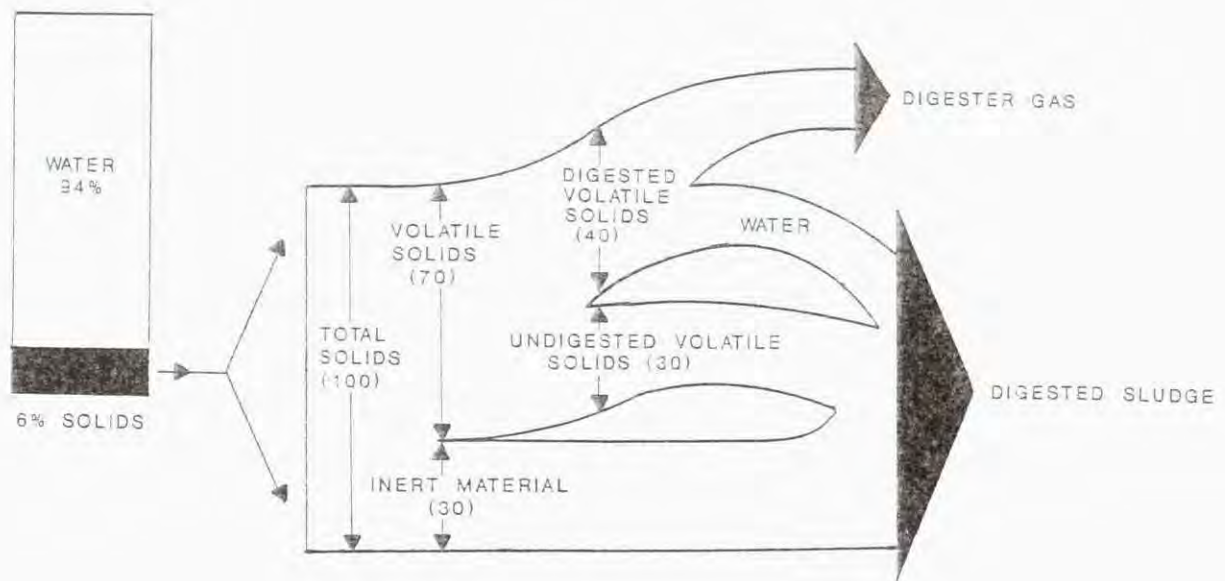


Figure 4.3.2
Solids breakdown path during anaerobic digestion

The volatile solids represents the organic load or food that is fed to the digester each day and is usually calculated as kg volatile solids per day per m^3 ($\text{kg VS} \cdot \text{m}^{-3} \cdot \text{d}^{-1}$) of usable digester volume.

The following procedure can be used to calculate the organic loading on a digester. The following information must be known:

- The average volatile solids content of the feed sludge;
- The total mass of sludge (volume x sludge concentration) fed into the digester in a given period ($\text{kg} \cdot \text{d}^{-1}$);
- The available volume of the digester (m^3);

$$\text{Loading (kg VS} \cdot \text{m}^{-3} \cdot \text{d}^{-1}) = \frac{\text{mass of feed sludge (kg} \cdot \text{d}^{-1})}{\text{available digester volume (m}^3)} \times \frac{\text{volatile solids (\%)}}{100\%}$$

Example: Calculation of loading on a digester

A new anaerobic digester has a diameter of 14 m and a sludge depth of 15 m. If $80 \text{ m}^3 \cdot \text{d}^{-1}$ of 5% raw sludge with a volatile solids content of 84% is added per day, what is the volatile solids loading on the digester?

$$\begin{aligned}\text{Total mass of feed sludge} &= 80 \text{ m}^3 \cdot \text{d}^{-1} \times 50 \text{ kg} \cdot \text{m}^{-3} \\ &= 4\,000 \text{ kg} \cdot \text{d}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Total digester volume} &= (\text{radius})^2 \times \text{height} \times 3,142 \\ &= (7\text{m})^2 \times 15\text{m} \times 3,142 \\ &= 2\,309 \text{ m}^3\end{aligned}$$

$$\begin{aligned}\text{Loading} &= \frac{4\,000 \text{ kg} \cdot \text{d}^{-1}}{2\,309 \text{ m}^3} \times \frac{84 \text{ VS}}{100} \\ &= 1,46 \text{ kg VS} \cdot \text{m}^{-3} \cdot \text{d}^{-1}\end{aligned}$$

Assume that the same calculation is to be carried out on an old digester with the same dimensions and feed characteristics. However, it has been found that there is an average grit layer of 3,7 m and a static scum layer of 2,2 m. What is the organic loading on this digester?

$$\begin{aligned}\text{Effective volume} &= \text{total volume} - (\text{volume of grit} + \text{volume of scum}) \\ &= 2\,309 \text{ m}^3 - (569 \text{ m}^3 + 338 \text{ m}^3) \\ &= 1\,402 \text{ m}^3\end{aligned}$$

i.e. the effective volume has been reduced by 39% and the volatile solids loading has increased to:

$$\begin{aligned}\text{Loading} &= \frac{4\,000 \text{ kg} \cdot \text{d}^{-1}}{1\,402 \text{ m}^3} \times \frac{84 \text{ VS}}{100} \\ &= 2,40 \text{ kg VS} \cdot \text{m}^{-3} \cdot \text{d}^{-1}\end{aligned}$$

The above example shows how the volatile solids loading increases significantly in a digester which has been in operation for a long time without regular cleaning.

4.3.4 HYDRAULIC RETENTION TIME

The hydraulic retention time is a simpler method for the operating staff to use to evaluate loading. The solids concentration must however be kept high.

Hydraulic retention time is calculated by dividing the flow into the digester volume:

$$\text{Hydraulic retention time (days)} = \frac{\text{digester volume (m}^3\text{)}}{\text{daily flow (m}^3\text{.d}^{-1}\text{)}}$$

4.3.5 LOADING RATES AND RETENTION TIMES FOR HIGH AND STANDARD RATE DIGESTERS

The loading rates for high and standard rate digesters differ considerably and the operating staff must not make the mistake of overloading a low rate digester or underloading a high rate digester.

The following loading rates are recommended for anaerobic digesters:

- | | | |
|---|---|---|
| a) High rate (with heating and mixing) | : | 1,5 to 3,0 kg VS.m ⁻³ .d ⁻¹ |
| b) Standard rate (no heating but with mixing) | : | 1,0 to 1,5 kg VS.m ⁻³ .d ⁻¹ |
| c) Standard rate (no heating and no mixing) | : | 0,5 to 1,0 kg VS.m ⁻³ .d ⁻¹ |

The following hydraulic retention times are recommended for anaerobic digesters:

- | | |
|-------------------|------------|
| a) High rate: | 15 to 25 d |
| b) Standard rate: | 30 to 60 d |

4.3.6 OPERATIONAL GUIDELINES

The feeding and loading of a digester can be controlled by maintaining the best possible balance between the incoming raw sludge and the sludge in the digester by considering the following points:

- a) A feed schedule must be established which is based on frequent feeding of small amounts;
- b) The digester should be fed with a sludge of between 3% and 6% dry solids content;

- c) The digester must be mixed well — the mixing should be sufficient to turn over the entire digester contents every 24 h or less (refer Section 4.4);
- d) Do not overfeed the digester; establish the required loading rate and keep it constant;
- e) Do not withdraw too much digested sludge at any one time i.e. retain a high buffering capacity (refer Section 4.8);
- f) Prevent grit and rags from entering the digester (refer Section 3.1);
- g) Keep a constant record of digester loading and hydraulic retention time i.e.
 - i) Volume of raw sludge produced and fed to the digester per day;
 - ii) Effective volume of the digester must be established regularly;
 - iii) Calculate loading regularly and record it graphically;
 - iv) Calculate hydraulic retention time daily and record it graphically.

SECTION 4.4

MIXING OF DIGESTER CONTENTS

4.4.1 INTRODUCTION

Mixing plays a very important role in the digestion process. By providing good mixing in the primary digester, effective use is made of the entire digester volume and the biological reactions proceed more efficiently. Good mixing improves process stability and increases the rate of volatile solid destruction and biogas production.

The type of systems available to provide sludge mixing include:

- a) Gas mixing;
- b) Mechanical mixing;
- c) Natural mixing.

Secondary digesters are not mixed in order to allow the sludge to settle so that thickening may take place (refer Section 4.1).

4.4.2 BENEFITS OF GOOD MIXING

The benefits provided by good mixing are as follows:

- a) Prevents stratification (banding) and promotes good contact between feed sludge and bacteria, provides even distribution of contents throughout digester, and ensures that no short circuiting of raw feed sludge takes place.
- b) Reduces grit settlement and scum formation so that there is less reduction in effective digester volume. It should be noted however that whatever type of mixing system is employed some grit settlement and scum formation will inevitably take place. The operating staff should be aware of steps needed to control these effects (refer Section 3.1). It should be noted that if mixing is too vigorous then foaming can become a problem (refer Section 4.10).
- c) Reduces the effects of toxic substances by promoting rapid dispersion and dilution.
- d) Provides an even temperature profile throughout the digester.
- e) High rate digestion is made possible due to the efficient mixing and heating of the digester contents. Higher loading rates and shorter retention times are possible in comparison with standard rate digesters as indicated in Table 4.4.1.
- f) Enables chemicals added for pH control to be evenly distributed throughout the digester so as to correct the pH value in the shortest possible time (refer Section 4.9).

TABLE 4.4.1: GENERAL COMPARISON OF LOADING DATA BETWEEN STANDARD AND HIGH RATE DIGESTERS

PARAMETER	STANDARD RATE	HIGH RATE
HEATING	NO	YES *
MIKING	SOMETIMES	YES *
LOADING (kg VS.m ³ .d ⁻¹)	0,5 - 1,5	1,5 - 3,0
RETENTION TIME (d)	30 - 60	15 - 25

* in primary digester only

4.4.3 GAS MIXING

Gas mixing is the most common system used. Gas is withdrawn from the digester, compressed and discharged through outlet points within the digester. The gas rises to the surface carrying sludge particles with it thereby creating a circulating action of the digester contents.

The four major gas mixing systems in use are:

a) Sequentially discharged lances

Gas is passed sequentially through a number of discharge points (lances) strategically located within the digester (Figure 4.4.1). Although the straight pipe design seldom plugs, if plugging does occur the lances can be rodded by removing the top cap. The valve which provides for the sequential application of gas needs to be inspected regularly and the sleeve in the control valve needs to be greased annually.

b) Floor mounted diffusers

Gas is passed through a set of diffusers set in the base of the digester. There should be an even distribution of gas to each diffuser. This should be checked periodically to ensure that no plugging is taking place. A plugged diffuser may be unblocked by directing the entire gas flow through it. Alternately the diffuser may be cleaned with high pressure water.

c) Draft (Burper) tubes

Gas is injected into the draft tube through lances positioned in the centre of the tube (Figure 4.4.2). The normal discharge point is just below midpoint. As the gas is released, sludge is drawn in at the base and discharged at the top of the draft tube.

In large digesters as many as four strategically placed tubes are used. For a small digester, one tube positioned centrally is normally adequate.

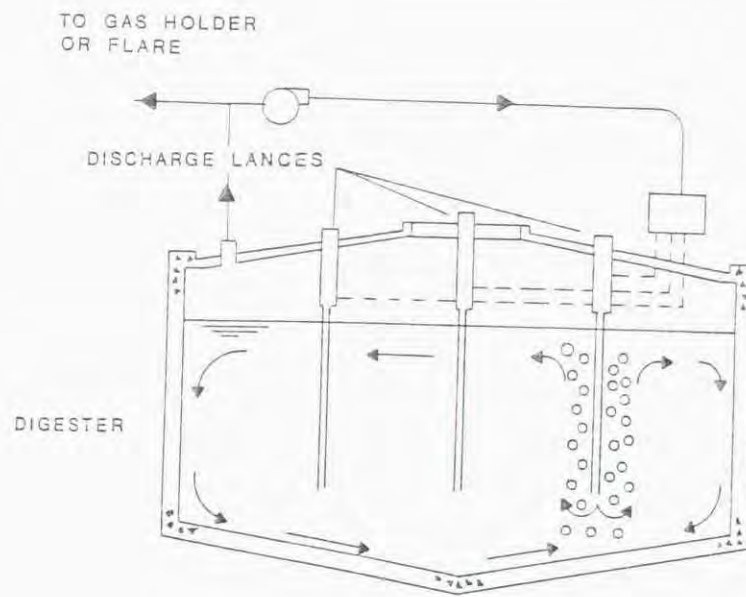


Figure 4.4.1
Mixing by sequentially discharged lances

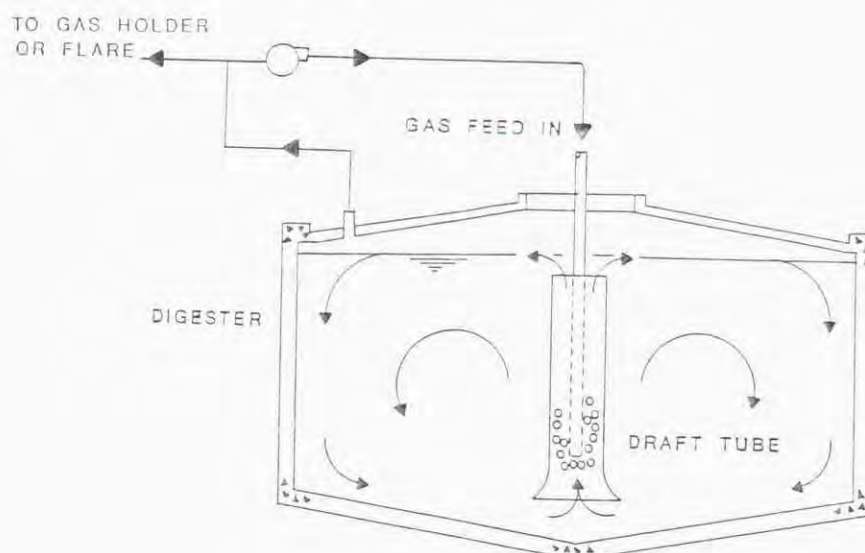


Figure 4.4.2
Draft tube mixing

d) Bubble guns

Gas is allowed to build up in a bubble generator set at the base of a vertical barrel (Figure 4.4.3) and is then released as a large bubble. As each bubble leaves the top of the barrel a new bubble is generated, this provides a continuous flow of sludge and sets up a circular mixing pattern. Each gun is strategically located within the digester to provide even mixing. The number of guns used will depend on the size of the digester.

Even distribution of gas to each gun is important. Flow balancing controls should be provided and should be checked periodically. If plugging does occur, a rodding point is normally provided. The full gas supply may also be directed onto the blocked bubble generator to clear any blockage.

If neither of these methods work then the digester needs to be drained in order to gain access to the bubble generator.

Amongst the other components used in a gas mixing system are the compressors. The most popular compressors in current use are the rotary lobe, rotary vane and liquid ring. In a system using either the rotary lobe or rotary vane compressor, some form of filter/scrubber is necessary upstream to clean the gas before compressing it. Any form of grime or solids entering the pump housing could cause the rotor(s) to bind. Periodically the lobes/vanes need to be cleaned and this should be done according to the manufacturer's recommendation. The filtering/ scrubbing equipment needs to be cleaned regularly to avoid blinding.

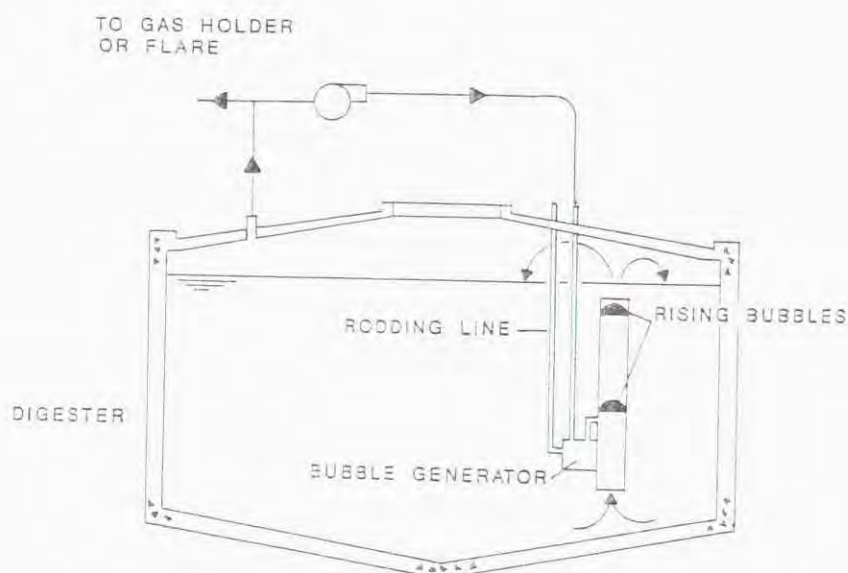


Figure 4.4.3
Bubble gun mixing

In a system using a liquid ring compressor, solids removal is not necessary due to the flushing action of the water. Plant effluent may be used in the liquid ring but if so it must be strained to remove any solid particles.

A typical gas system will also comprise of pressure and vacuum relief devices, water traps, flame traps, pressure regulators, gas meters, check valves, pressure guages, a waste gas burner and a gas holder. These components are all discussed in Section 4.6.

4.4.4 MECHANICAL MIXING

The most common method of mechanical mixing consists of an arrangement of propeller, drive shaft and drive unit. Most are mounted on top of a draft tube (Figure 4.4.4) to direct the flow within the digester.

A major problem with propeller type mixers is clogging with rags, hair and other stringy and fibrous materials thus reducing mixing efficiency. This can be largely prevented by ensuring that the direction of rotation of the propeller is reversed at regular intervals. The build-up can be monitored by measuring the ammeter reading at the motor. To clear the propeller, some drive shafts can be removed with a crane; otherwise the digester must be drained. In addition to monitoring the build-up of rags, the drive unit and bearings should be serviced regularly according to the manufacturer's recommendation.

The other main mechanical mixing system uses a pump rather than a propeller arrangement. The pump draws sludge from the digester (usually near the bottom) and discharges the flow through nozzles mounted on the digester wall.

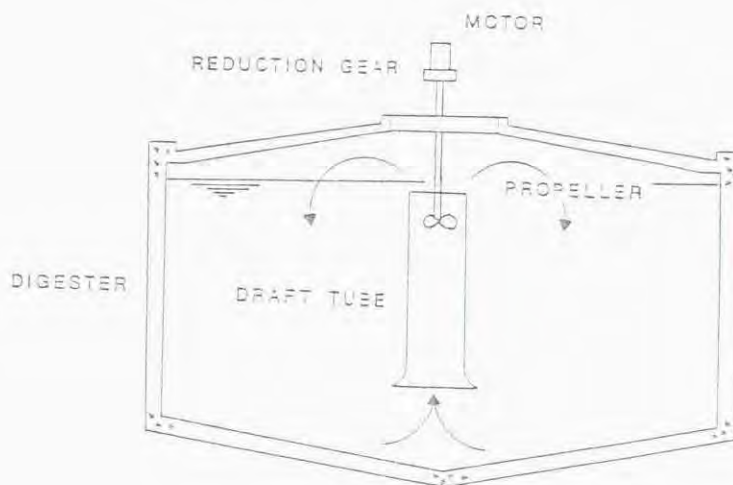


Figure 4.4.4
Mechanical mixing with draft tube

4.4.5 NATURAL MIXING

A certain amount of natural mixing does take place due to rising gas bubbles and thermal convection currents. However, natural mixing is not sufficient at high loading rates to ensure stable performance and has to be supplemented with artificial mixing methods. It should be noted that if the breakdown of volatile solids continues in the secondary digester, then natural mixing may cause settling problems, resulting in a poor quality supernatant.

4.4.6 METHODS TO TEST THE EFFICIENCY OF MIXING

It is generally recommended that for adequate mixing, the entire contents of the digester need to be turned over at least once every 24 h. Mixing may be continuous or intermittent, provided that complete mixing is maintained. A large number of mixing systems are fitted with time switches to control the period of mixing. Ideally, mixing should be stopped only during supernatant and sludge withdrawal. Raw sludge should enter the area of highest mixing intensity.

To determine whether or not there is adequate mixing, samples of sludge should be taken at various points around the digester (the supernatant withdrawal points can be used). If the solids concentration does not vary by more than 10% relative (except for sludge deposits containing sand and floating scum), then the digester can be considered to be completely mixed. Mixing efficiency can be rapidly tested by measuring sludge temperatures at the various sampling points. A variation in temperature of less than 2°C indicates adequate mixing.

It must be remembered that it is easier to keep sludge particles in suspension than to re-suspend them after they have settled.

SECTION 4.5

HEATING AND TEMPERATURE CONTROL

4.5.1 INTRODUCTION

Anaerobic digesters are heated for two principal reasons:

- a) to increase the activity of the methane-producing bacteria thus reducing digestion time;
- b) to liquify fats and greases to hasten their decomposition.

4.5.2 TEMPERATURE RANGES AND CONTROL

The most favourable temperature range for mesophilic digestion is in the range 32 to 37°C. Digestion may proceed with equal effectiveness between 29 to 32°C provided that the digester retention time is increased. Cryophilic (cold) digestion (< 15°C) which is practised at many small works is slow and requires retention times in excess of 30 days. Thermophilic digestion (55 to 65°C) is not practised in South Africa.

The methane-producing bacteria are sensitive to temperature changes, and their activity is severely affected by sudden changes in excess of 2 to 3°C. Controlling the temperature within such fine limits is largely determined by the degree of mixing in the digester.

It is important therefore that if high temperatures are to be maintained the digester contents must be well mixed. To summarise: **"A UNIFORM AND SUFFICIENTLY HIGH TEMPERATURE IS ESSENTIAL FOR SATISFACTORY OPERATION"**.

To ensure that the above objective is met the digester temperature should be measured at a point which represents the active part of the digester and the heating system should control the temperature evenly.

It should be noted that if cold weather makes temperature control erratic, then the operating temperature should be lowered to a level that can be kept more constant. It is preferable to operate the digester at a lower but more constant temperature, even though this requires a longer retention period.

4.5.3 SLUDGE HEATING

Heating is required in the process to raise the temperature of the incoming sludge and to maintain the digester operating temperature. It is advantageous to thicken the incoming sludge as much as possible to reduce the quantity of water requiring heating.

External heating provides the most effective means of sludge heating, and is now established as the preferred method. Common practice is to locate the heat exchanger near the boiler or water heater to reduce heat loss in transporting the hot water to the exchanger. Sludge is pumped through a series of pipes submerged in a hot waterbath or through coils close to

pipes carrying hot water in a spiral heat exchanger (see Figure 4.5.1). The three common types of external heat exchangers in use today are the tube-in-bath, tube-in-tube and spiral plate.

In an external system, sludge is removed from the tank and pumped through a heat exchanger. This may be done by mechanical pump or gas lift. The heated sludge is then returned to the digester. Most systems make provision for heating the feed sludge before it enters the digester. The pipework is arranged in such a way that blending and preheating of the feed and actively digesting sludge together is possible, thus minimising the formation of cold spots within the digester. Typically two parts actively digesting sludge with one part feed are blended together. The flow velocity of sludge through the heat exchanger should be maintained at about 1.2 m.s^{-1} . This is to prevent the sludge caking on the walls of the pipework.

a) Automatic operation at fixed time intervals

A number of heat exchanger systems are operated automatically at fixed time intervals, usually every 1 h, when sludge is pumped from the digester to the heat exchanger. A thermostat senses the temperature of the sludge. If the sludge temperature is below the set-point then the hot water pump is activated and heat is applied to the sludge, until the desired temperature is reached.

b) Continuous automatic operation

The sludge recirculation pump may also be operated on a continuous basis independent of the sludge thermostat. The thermostat, however, continues to control the hot water pump to ensure that heat is only applied when necessary. The continuous mode is advantageous in that it provides additional mixing.

4.5.4 MONITORING HEAT EXCHANGER PERFORMANCE

It is important for the heat exchanger sludge inlet and outlet temperatures to be monitored on a regular basis. If the difference between the two decreases significantly then this is an indication that less heat is being transferred. If this does occur then the sludge pump, water pump, and hot water supply need to be checked to ensure that they are operating properly. If these items are satisfactory, then the exchanger itself should be checked for plugging, scale build up or blockages. The temperature should be noted only after the recirculation sludge pump has been running for several minutes. This is to allow sufficient time for the temperature to stabilise.

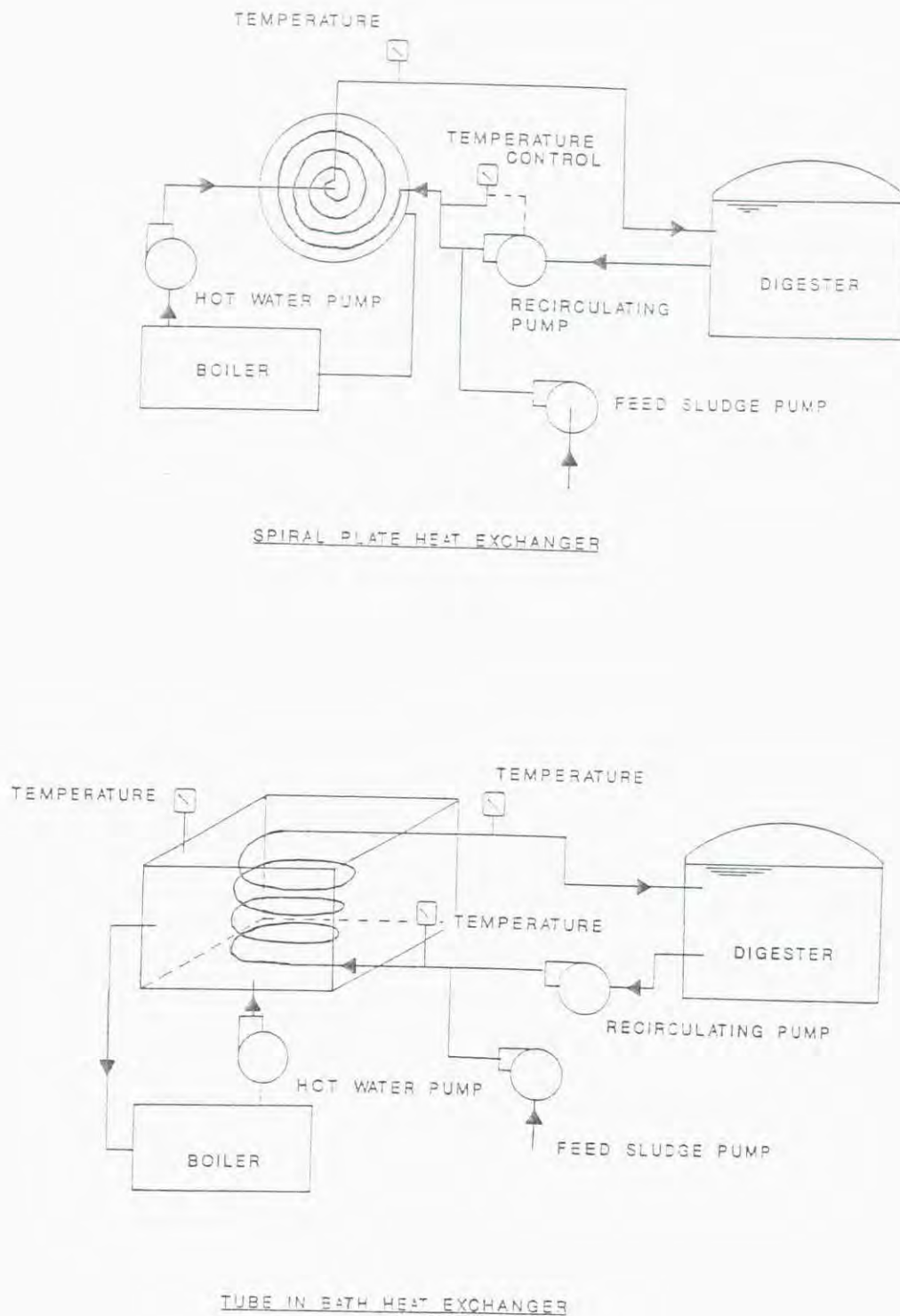


Figure 4.5.1
External heat exchangers

SECTION 4.6

GAS PRODUCTION AND CONTROL DEVICES

4.6.1 INTRODUCTION

The main constituents of the gas produced in a digester are carbon dioxide (25 to 40%) and methane (60 to 75%). Small amounts (1 to 5%) of nitrogen, hydrogen sulphide and hydrogen are also produced. Precautions must be taken as methane and air can form an explosive mixture (refer Section 4.6.13 for safety precautions).

A typical gas system (Figure 4.6.1) comprises the digester cover, pressure and vacuum relief devices, water trap, flame trap, pressure regulator, gas meter, check valve, pressure gauges, waste gas burner and a gas holder. Mixing of digesters by means of gas recirculation requires a compressor (refer Section 4.4).

The operating staff have various duties to perform to ensure the gas system operates successfully. These are discussed below.

4.6.2 DIGESTER COVER

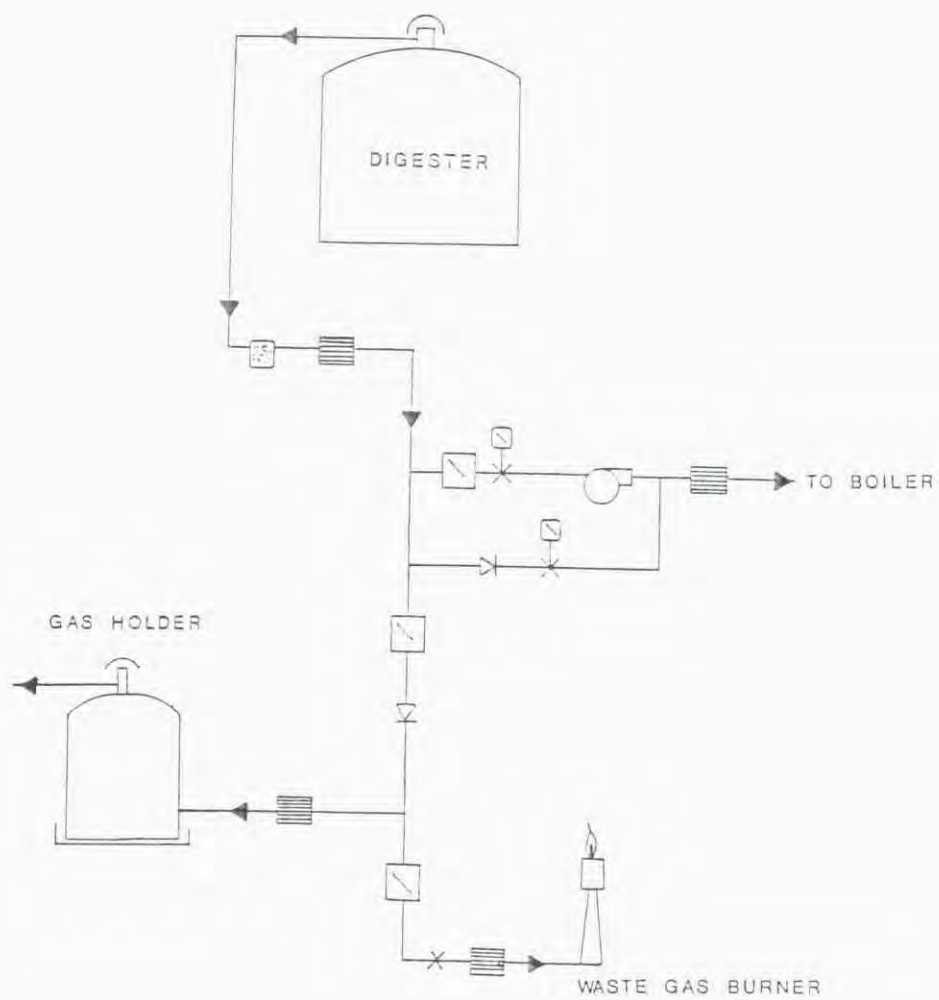
The digester is covered to contain odours, maintain temperature, keep air out and to collect the gas. Fixed covers are more usual in South Africa than floating covers. During normal operation there is space for gas collection between the cover and the liquid surface of the digester contents. The cover of a digester has certain unique features which the operating staff must be aware of, for example, how the variation in pressure and the level inside the digester may affect the cover.

a) Excess positive pressure

The biggest danger associated with the operation of fixed cover digesters occurs when the pressure relief device mounted on top of the digester fails or the sludge overflow line blocks and the liquid level in the digester continues to rise. In such a situation, the excess gas pressure inside the digester can exceed the maximum design pressure and damage the cover or its mountings.

b) Excess negative pressure (vacuum)

Fixed covers can also be damaged by excess negative pressure (vacuum) or if the rate of sludge withdrawal exceeds the feed rate or the vacuum relief device fails.



LEGEND

	PRESSURE AND VACUUM RELIEF VALVE
	WATER TRAP
	FLAME TRAP
	PRESSURE RELIEF VALVE
	CHECK VALVE
	PRESSURE REGULATOR
	GAS METER
	GAS COMPRESSOR

Figure 4.6.1
Typical biogas system

4.6.3 PRESSURE RELIEF DEVICE

The function of the pressure relief device is to allow pressure which exceeds a safe level to escape from the digester (Figure 4.6.2). The manufacturer's specification should provide the following information to enable the operating staff to safely control the gas system:

- a) The system's normal operating pressure (mm water gauge).
- b) The pressure at which the pressure relief device should operate (generally 12 mm water gauge — approximately 0,12 kPa). This is set by varying the weights on the pressure relief device.
- c) The rated gas flow capacity of the pipes.

A gas system generally comprises three pressure relief devices; one mounted on the cover of the digester (Figure 4.6.1), one on the gas holder and one situated at the end of the gas line before the gas burner. This device releases gas to the waste gas burner before the design gas pressure of the digester cover is reached.

Precaution: An increase of more than 20 mm water gauge (0,2 kPa) above the normal operating pressure indicates that:

- a) Either the line to the waste gas burner is blocked; or
- b) The gas flow is greater than the rated flow capacity of the pressure relief device and the waste gas burner.

Routine duties: The operating staff must perform the following routine duties:

- a) Fortnightly, check the pressure relief device for moisture accumulation;
- b) Every three months, inspect and clean the pressure relief device. During this inspection:
 - i) Note the condition of the diaphragm;
 - ii) Check that the relief device stem travels freely. The unit must be protected against freezing during cold weather by using the correct lubricant;
 - iii) Check that all weights are intact;
 - iv) Maintain equipment as specified in the manufacturer's manual.

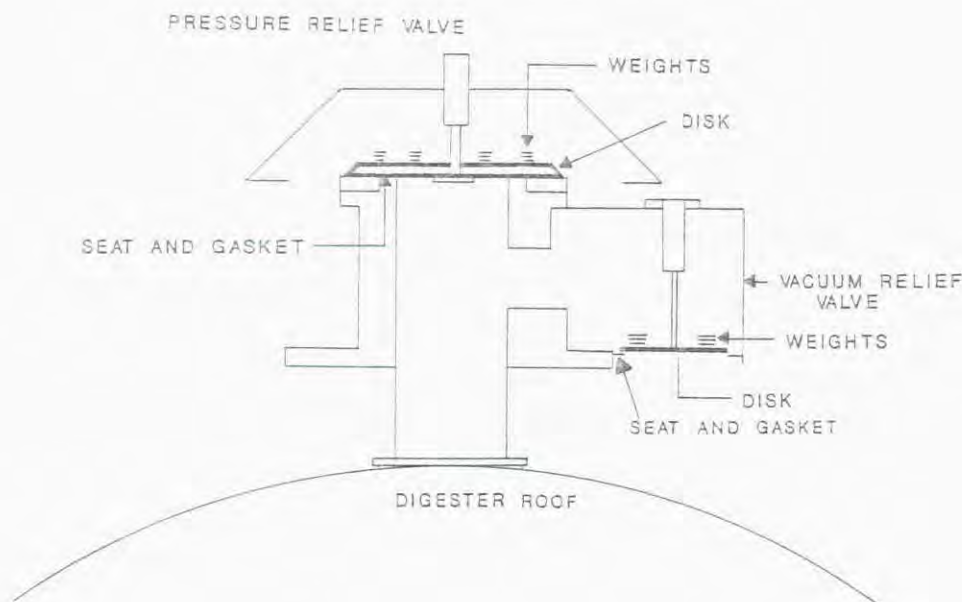


Figure 4.6.2
Pressure and vacuum relief devices

4.6.4 VACUUM RELIEF DEVICE

The vacuum relief device (Figure 4.6.2) functions in the opposite manner to the pressure relief device and allows air to enter the digester in the event of sludge being withdrawn too rapidly. Air should not under normal conditions be allowed to enter the digester because a mixture of air and methane, is potentially highly explosive (refer Section 4.6.13 for safety precautions).

The operating staff can check that the vacuum relief device is free by lifting the base a few millimetres by hand. There should be a sudden discharge of gas due to the higher pressure inside the digester. It is essential to be prepared for this and also to make sure that there is no possibility of the gas being ignited.

4.6.5 WATER TRAP ASSEMBLY

Gas leaving the digester is almost saturated with water vapour. As the gas cools, the water vapour condenses and causes problems. The problem is more severe when digesters are heated. Gas leaving a digester at about 35°C has a much higher water vapour content than gas from an unheated digester. This means that more water will condense from the gas produced in a heated digester.

a) Problems due to moisture or condensed water vapour

- i) Moisture accumulation in pressure/vacuum relief devices, check valves, gas meters and pressure regulators may affect their performance by restricting the flow of gas and causing corrosion;
- ii) Moisture can accelerate the deterioration of the membranes or diaphragms of gas-controlling and measuring equipment;
- iii) Moisture combines with hydrogen sulphide to form an acidic solution which is corrosive to iron and concrete.

b) Location of water traps

It is essential to remove as much of the moisture as possible before the gas comes into contact with the gas system devices. For this reason, water traps should be located as close to the digester as possible. All piping should be sloped a minimum of 1 % towards the water trap, which should be situated at a low point in the gas line.

c) Frequency of draining

Water traps should be properly drained on a daily basis. Water traps can be designed to drain automatically, but still need to be checked regularly by the operating staff.

4.6.6 FLAME TRAPS

Flame traps are emergency devices installed in gas lines to prevent flames travelling back up the gas line (flashback) and reaching the digester.

The flame trap generally consists of a box filled with stone or a metal grid. If a flame develops in the gas line, the temperature of the flame is reduced below the ignition point as it passes through the trap and the flame is extinguished.

Flame traps should be installed:

- a) On the atmospheric side of the vacuum and pressure relief devices;
- b) After water traps on the gas line;
- c) At waste gas burners;
- d) Before the boiler or water heater.

- CLEANING:**
- i) The biogas does contain impurities such as foam and scum and the flame trap will eventually become blocked and prevent the gas from passing through. The flame trap should be inspected and disassembled once per week and thoroughly cleaned.
 - ii) If the flame trap is of the metal grid insert type then consideration should be given to purchasing a spare insert which can be used as a replacement when one of the flame traps has to be cleaned. This will save on down time.
 - iii) It is safer to isolate the flame trap before removal or arrange a suitable bypass to allow the gas to flow through a standby flame trap.

4.6.7 PRESSURE REGULATOR

Pressure regulators are used when a lower pressure than the system operating pressure, is required for a specific device such as a boiler water heater or incinerator. Regulators maintain a constant gas pressure at the point of use.

The operating staff should:

- a) Check the gas pressure of the system with a pressure gauge or manometer (refer Section 4.6.10);
- b) Make adjustments to the regulator according to the manufacturer's instructions.

4.6.8 GAS METER

The rate of gas production is probably the most sensitive process control indicator at the disposal of the operating staff. This aspect is discussed in Section 4.8.6. Every effort should be made to understand the working mechanism of the gas meter and have it serviced so that it will give reliable results. To ensure reliability, the gas meter should be calibrated every six months.

4.6.9 CHECK VALVE

Check valves (also known as non-return valves) are installed in the gas line to allow gas flow in one direction only i.e. out of the digester. The operating staff must inspect and clean these valves on a monthly basis or more often if necessary to ensure that all moving parts move freely and are free of corrosion and debris.

4.6.10 GAS PRESSURE GAUGES

Pressure gauges indicate the pressure in the gas system and assist in locating any blockages in the line. If a line blockage occurs, a pressure gauge reading downstream of the blockage will register a lower pressure than that of a gauge upstream.

A portable test pressure gauge or manometer can be connected to various taps in the gas line so as to aid in locating blockages. Blockages generally result from accumulated moisture and dirty control devices. Gas pressure gauges are available in both dial and manometer design. Gauges should be calibrated twice per year to ensure accurate readings. Gauges should be fitted with an isolating valve, to isolate the gauge before it is removed.

4.6.11 WASTE GAS BURNER

The pressure relief device at the waste gas burner safely flares excess gas to the atmosphere and thus reduces the potential for a dangerous accumulation of gas in the system.

a) Pilot flame

To function properly, the burner should maintain a pilot flame to ensure ignition of waste gas whenever it is produced. The operating staff must check the pilot flame on a daily basis to ensure that it is lit. Before manually lighting the pilot flame, the gas feed to the main burner should be temporarily shut off to avoid injury from a sudden gas flare up.

b) Colour of flame

The colour of the gas flame at the waste burner can be used to give an indication of the state of the digestion process:

- i) A yellow flame with blue at the base is typical of good digestion performance (65 to 70% CH_4);
- ii) If too much blue is present or the flame will not stay lit, this may indicate too much carbon dioxide (more than 35% CO_2). This is an indication of poor digestion;
- iii) An orange flame with smoke may indicate a poor air supply for combustion. The gas jet and the air holes should be cleaned.

4.6.12 GAS HOLDER

Many anaerobic digestion plants have a means of storing excess gas. This can be in the form of either a floating roof on the digester or a separate gas holder. On both types metal guides and rollers are mounted between the cover and the wall superstructure to allow the cover to travel up and down without binding. If the gas holder is of the type in which the cover floats on water then severe corrosion of the cover and retaining concrete structure occurs. This is due to acid formation when hydrogen sulphide is present in the gas. Experience has shown that the pH can drop to low levels and this can be rectified by ensuring that the water level is maintained and by adding an alkali such as slaked lime to the water to maintain the pH between 7 and 8, or by continually feeding final effluent to the water seal of the gas holder. Membrane bag-type gas holders may also be used as an alternative to the above-mentioned

gas holders.

The following inspections must be performed on a monthly basis;

- a) Determine whether or not accumulation of scum around the edge between the cover and the walls is causing excessive friction and are preventing free travel;
- b) Keep pressure and vacuum relief devices in good operating condition to maintain the desired pressure;
- c) Monitor the gas flow rate from the digester to the gas holder;
- d) Ensure that gas holder guide rails are not clogged and the guide rollers are free to rotate;
- e) If the volume of gas in the holder is lower than expected, immediately check for leaks in the system.

4.6.13 SAFETY CONSIDERATIONS WITH BIOGAS SYSTEM

A mixture of biogas and air can be explosive. Methane in concentrations of between 5% and 15% in air by volume is explosive. In fact methane concentrations as low as 1,25% are potentially dangerous. The operating staff must ensure that no air is allowed to enter the digester or gas holder. Leakage of air into the gas system can be prevented by maintaining a positive pressure in all gas lines. It is also essential that all piping and equipment be properly sealed to prevent gas from escaping to the outside.

- CAUTION:
- a) There must be no smoking, sparks or any open flames when biogas may be present. Safety signs should be prominently displayed in the area. Electrical installations, including light switches, torches, temporary devices or fixtures must be of the explosion-proof type;
 - b) Flammable gas detectors and oxygen concentration measuring equipment must always be used before entering an empty digester. Biogas can cause asphyxiation due to lack of oxygen. The operating staff must realise that biogas is colourless and odourless. The testing of the atmosphere inside the digester and a declaration made by a competent person that it is safe is a requirement of the MOS Act. This safety aspect is discussed in Section 7.1;
 - c) It is essential to use forced ventilation before and during work in a digester;
 - d) After repairs, gas lines and digester domes should be purged with nitrogen gas or carbon dioxide before being put into service. If gas mixing is used then the whole circuit should be purged before the gas compressor is switched on;
 - e) All tools used on the maintenance of the digester roofs, gas holder, etc. should be manufactured from non-conducting and non-sparking materials,

e.g. aluminium bronze. If these tools are not available, iron or steel tools may be used if handled very carefully and wrapped in rags during use. This should be only as a last resort and is not recommended. Tools such as hammers and chisels must not be used due to the high risk of sparks being produced;

- f) Treat any mixture of biogas and air as potentially explosive. **THIS FACT CANNOT BE OVER-EMPHASISED;**
- g) The waste gas burner should preferably be situated at least 15 m away from the gas holder, digester(s) or any buildings, together with due consideration to the prevailing wind.

SECTION 4.7

SUPERNATANT AND SLUDGE WITHDRAWAL

4.7.1 INTRODUCTION

Anaerobic sludge digestion can be divided into two phases viz. primary and secondary. The main role of the primary phase is to stabilise the sludge while the secondary phase is to allow for solid/liquid separation. There is no mixing in the secondary phase and the sludge can therefore settle to the bottom of the digester. This creates a layered structure of the contents inside the secondary digester. A scum layer is often formed on the surface while the middle zone of liquor, called supernatant, is relatively solids free.

It is important that the supernatant and sludge are drawn off correctly from the digesters as incorrect procedures can upset the sludge stabilisation process, cause physical damage to the digester dome or create explosive mixtures of biogas and air due to vacuum conditions being created and air being drawn into the digester through the vacuum relief valve.

The method of drawing off supernatant and sludge will vary between a single stage digester and a two-stage digestion process as well as between fixed domed digesters and floating dome digesters.

4.7.2: REASONS FOR SUPERNATANT AND SLUDGE WITHDRAWAL

a) Supernatant withdrawal

Supernatant can be easily identified by its pale appearance. However, a slight brownish discolouration could occur due to the presence of small quantities of solids.

i) Single-stage digestion

Supernatant is withdrawn to increase the solids concentration and the alkalinity levels;

Supernatant is withdrawn to increase the retention time of the sludge in the digester;

ii) Two-stage digestion

Supernatant is withdrawn to increase solids concentration of sludge being applied onto the sludge beds;

Supernatant is withdrawn to reduce the sludge volume to be dried.

b) Sludge withdrawal

- i) Sludge is withdrawn to maintain the correct retention time of the sludge in the digester for complete stabilisation to take place;
- ii) Sludge is withdrawn to maintain the alkalinity to provide a good buffering capacity against variation in pH value.

4.7.3 WITHDRAWAL POINTS

A general arrangement of withdrawal pipes is shown schematically in Figure 4.7.1.

a) Supernatant withdrawal points

For successful supernatant withdrawal to be carried out, a digester must have several withdrawal points (usually 3 to 5) at different levels within the digester. This is done to establish the clearest supernatant with the lowest solids concentration (refer Figure 4.7.2).

Supernatant withdrawal points should be situated opposite the raw sludge feed pipe to prevent short-circuiting of the raw sludge. The above arrangement is the same for single or two-stage digestion. The withdrawal of supernatant can be controlled by opening a valve on the supernatant withdrawal pipe or by removing a transfer ring from the top of the supernatant pipe in the transfer box (refer Figure 4.7.2).

This transfer ring can be of various heights (e.g. 100 mm, 150 mm, 300 mm). The higher the transfer ring used, the faster the withdrawal rate becomes. A high withdrawal rate is not advisable (refer Section 4.7.5).

b) Sludge withdrawal points

In a single-stage digester, the sludge is normally withdrawn from the centre of the digester at floor level. This is to ensure that the oldest sludge is withdrawn from the process. Short-circuiting of the raw feed sludge to the withdrawal point can occur if there is poor mixing in the digester (refer Section 4.4). In a two-stage process, the sludge is withdrawn from the same point as in the single stage, but instead of the sludge going to the sludge drying beds, the sludge will be discharged to the secondary digester via a transfer box.

The sludge withdrawal points from the secondary digester will be the same as in a single-stage digester.

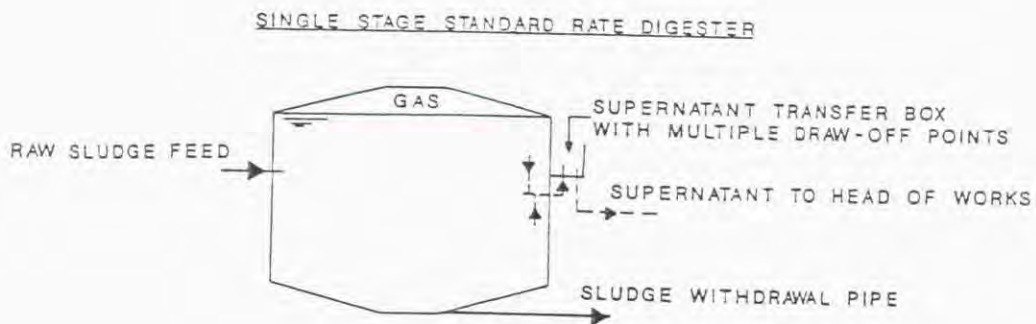
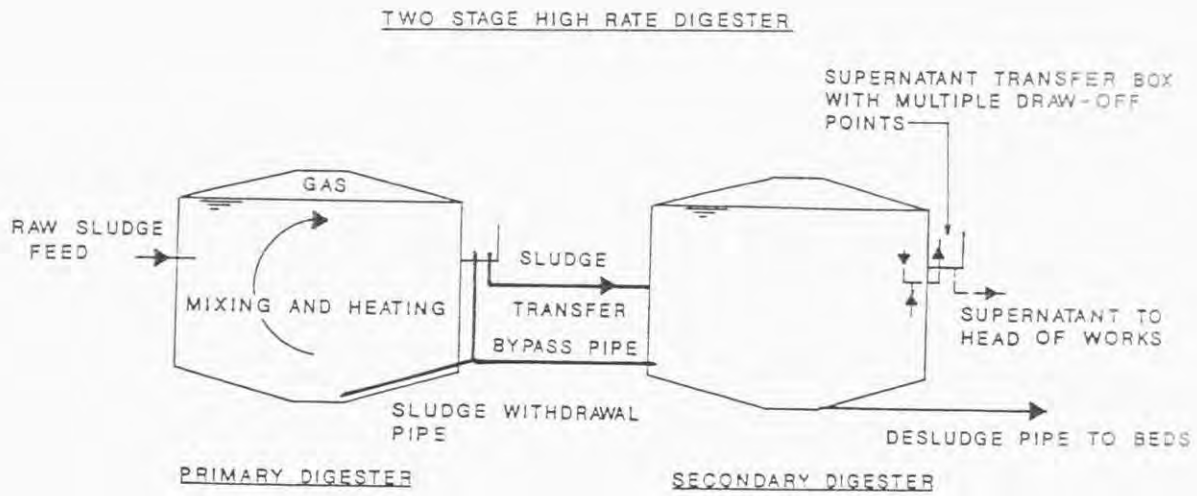


Figure 4.7.1
General arrangement of supernatant and sludge withdrawal pipes

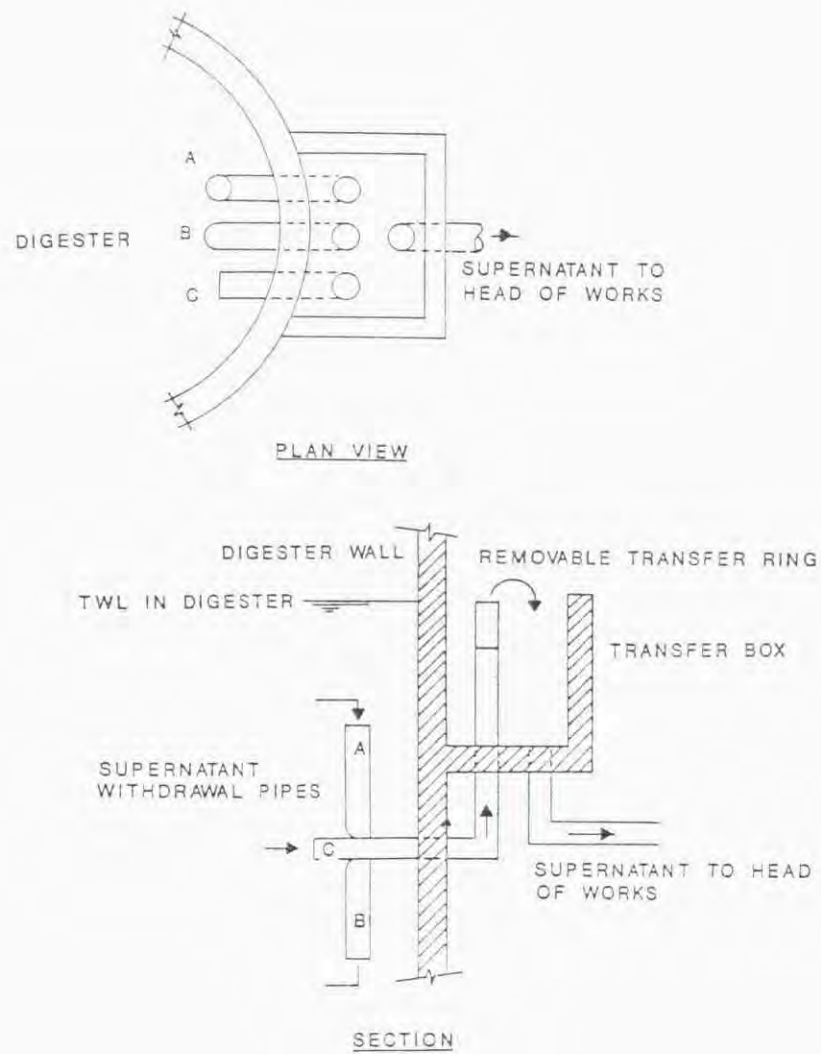


Figure 4.7.2
Multiple supernatant withdrawal points

4.7.4 WITHDRAWAL OPERATION

a) Supernatant withdrawal

In a single-stage digestion process, mixing of the digester contents must be stopped 6 to 12 h before supernatant withdrawal begins. This is to allow the sludge to settle before the supernatant can be withdrawn. The various supernatant withdrawal points must be sampled to establish which has the cleanest supernatant. Care must be taken to ensure that the entire contents of the supernatant withdrawal pipe are flushed out prior to determining which withdrawal point is suitable. The reason for this is that solids/liquid separation usually takes place in the pipe itself.

In a two-stage digestion process, there is no mixing in the secondary digester and therefore supernatant can be withdrawn whenever it is available without having to make any operational changes.

b) Sludge withdrawal

In a single-stage digestion process mixing of the digester contents must be stopped 6 to 12 h before desludging commences (this is the same as for supernatant withdrawal). If the mixing was not stopped then a thinner sludge (less than 3% total solids) could be withdrawn giving rise to a less efficient system. This would be the situation with a digester receiving a continuous feed.

As with supernatant withdrawal, care must be taken not to withdraw digested sludge too quickly (refer Section 4.7.5). In a two-stage digester process, sludge is displaced from the primary digester to the secondary digester whenever raw sludge is fed into the primary digester (Figure 4.7.1).

The sludge from the secondary digester is withdrawn after the maximum volume of supernatant has been withdrawn.

4.7.5 CAUTION TO BE TAKEN DURING THE WITHDRAWAL OPERATION

Care must be taken in withdrawing sludge and supernatant from fixed domed digesters because if the withdrawal rate is too fast, it can create a lower pressure inside the digester and one of the following can occur:

- a) Air could be drawn into the digester through the vacuum relief device, thereby creating an explosive mixture of air and methane (refer Section 4.6);
- b) If the vacuum relief device is faulty, then the dome or roof of the digester could collapse or crack.

These problems will not occur in a digester that has a floating dome as long as the dome is **not** resting on its supports. If the dome is resting on its supports then (a) or (b) above can occur. One way of solving this problem is to ensure that supernatant and sludge withdrawal rate is equal to raw sludge feed rate. Here it is necessary to be careful of short-circuiting of the raw feed sludge which would cause the supernatant to be of a poor quality.

4.7.6 DISPOSAL OF SUPERNATANT AND SLUDGE

a) Supernatant

Supernatant usually has a high concentration of ammonia nitrogen. This high concentration can cause an increase in the loading to secondary or advanced treatment facilities where nitrification is required. Supernatant is more odorous than the raw waste water and will require further treatment before disposal. Supernatant is generally returned to the head of the works (i.e. PST influent) or to the feed of an activated sludge plant for further treatment. However, if the concentration of phosphate in the plant effluent is an important factor (i.e. must comply with the Special Phosphorus Standard) then consideration must be given to the removal of phosphate from the supernatant by chemical precipitation.

b) Sludges

The sludges withdrawn from the single-stage digester or from the secondary digester in the two-stage system should be discharged to a dewatering process such as sludge drying beds or mechanical dewatering processes (refer Section 5.1).

SECTION 4.8

PROCESS CONTROL INDICATORS

4.8.1 INTRODUCTION

The operating staff must maintain control of the anaerobic digestion process at all times. Reliance only on sensory evaluation or the digester pH value alone is not conducive to proper control of the digestion process. There are various process control indicators which measure the progress of sludge digestion and give warning of impending upset so that preventive control action can be taken timeously. No one indicator should be used alone to predict problems; several indicators should rather be considered together.

Control indicators which should be routinely monitored are:

- a) Volatile acids;
- b) Alkalinity;
- c) Volatile acids/alkalinity ratio;
- d) pH value;
- e) Biogas production rate;
- f) Carbon dioxide content of the biogas;
- g) Volatile solids reduction;
- h) Temperature;
- i) Volatile solids loading;
- j) Sensory evaluation (hands, eyes, nose and ears).

Because these control indicators will vary with different types of sludges and digester systems, it is the responsibility of the operating staff to monitor, graphically plot and ultimately determine what is the best range for each indicator in order for the works to produce a well-digested sludge. An example of a graphical plot of certain digester process control indicators is given in Figure 4.8.2.

There are various analytical methods and procedures to determine the above-mentioned parameters and these are discussed in Section 6.

4.8.2 VOLATILE ACIDS

Section 4.1 discussed how organic material present in the feed sludge is converted into simple organic material, chiefly volatile organic acids, in the first stage of the digestion process by acid-forming bacteria. The methane-producing bacteria then convert the volatile acids into biogas in the second stage of the digestion process.

The acid-forming bacteria are relatively resistant to adverse environmental factors, whereas the methane-producing bacteria are relatively sensitive to adverse environmental factors. This means that when a problem is developing, the rate of volatile acid formation starts to exceed the rate of volatile acid removal, and the concentration of volatile acids increases. The

volatile acid concentration is, therefore, one of the best digester control indicators to predict digestion difficulties. When used together with alkalinity and pH values, it provides additional useful information.

The production of volatile acids is largely dependent upon the mass of sludge fed to the digester. In a healthy digester, volatile acids will be used as food by the methane-producing bacteria at about the same rate as they are produced. Under these conditions, the volatile acid concentration of the digesting sludge is usually in the range 50 to 300 mg. ℓ^{-1} expressed as acetic acid.

If the same amount of sludge is fed daily, a population balance between the acid-forming bacteria and the methane-producing bacteria will be maintained. On the other hand, if an overload of sludge feed were added suddenly, excess amounts of volatile acids would be produced which could reduce the alkalinity and subsequently lower the pH value. When this occurs, the activity of the methane-producing bacteria is decreased and the concentration of volatile acids increases further.

4.8.3 ALKALINITY

The alkalinity of a digesting sludge is important because it represents the ability of the digester to neutralise the volatile acids formed during digestion. The ability to neutralise or absorb acid at a certain pH value is called the buffer capacity of the liquid at that pH. The buffer capacity of a digester at its operating pH is estimated by measuring the alkalinity.

Ammonium bicarbonate is an example of a substance that can absorb acid. This compound is normally generated in a digester from the decomposition of protein substances in the feed sludge and therefore the digestion process generates alkalinity which is used for pH control.

The amount of buffer produced is usually enough to balance the acids produced so that the pH will remain at a constant level in the range 6,8 to 7,2. pH values greater than 6,8 are required for proper methanogenic activity i.e. the biological conversion of acids to methane.

a) Definition of alkalinity

Total alkalinity is calculated by determining the mass of acid added per litre of solution to reduce the pH of the digester liquor from the value in the digester to 4,3 which is the pH of a standard solution of pure water with just some carbon dioxide dissolved in it. This standard solution is called the equivalent carbonic acid (H_2CO_3) solution and is used as a datum for measuring the alkalinity. Because different acids can be used to titrate down to pH 4,3; the mass of acid added also is specified in terms of a standard compound. For alkalinity the standard compound is not an acid but calcium carbonate, chosen for amongst other reasons because it has a convenient molecular mass of 100. Typical total alkalinity concentrations in a healthy digester are in the range 2 000 to 3 000 mg. ℓ^{-1} as CaCO_3 . The higher the alkalinity value the more acid needs to be added to a litre of digester liquor to reach a pH of 4,3 and therefore the higher the buffer capacity.

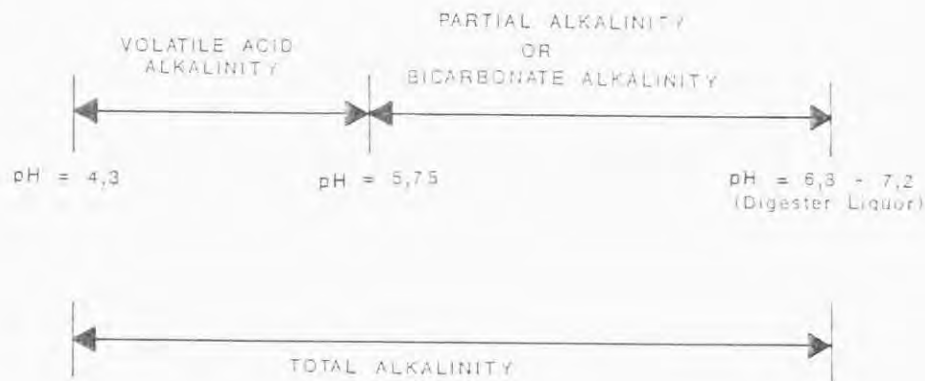


Figure 4.8.1
Explanation of bicarbonate and volatile acid alkalinity

b) Different types of alkalinities

The total alkalinity titration from the digester pH down to pH 4,3, comprises the alkalinity of all substances present in the digester liquor (refer Figure 4.8.1). The first one, as already mentioned is bicarbonate and if the titration is taken to a pH 5,75, the alkalinity contribution of the bicarbonate is obtained. Titrating to pH 5,75 determines the bicarbonate alkalinity. By titrating to pH 4,3 the alkalinity of the other buffering substance in the liquor apart from the bicarbonate is obtained, the principal one being the volatile acids. This may seem contradictory that volatile acids can act both as an acid and provide alkalinity and buffer capacity. The reason is that the volatile acids are weak acids and this gives them this dual character. So between pH 5,75 and pH 4,3, the volatile acids can react with acid and hence provide buffer capacity and alkalinity. The mass of acid added per litre digester liquor in titrating from pH 5,75 to pH 4,3 is a measure of the alkalinity of the volatile acids in the liquor.

4.8.4 VOLATILE ACIDS TO TOTAL ALKALINITY RATIO

Volatile acids and total alkalinity are the first measurable changes that take place when the process of digestion is becoming upset. However, the levels of these two parameters change daily. In order not to confuse the day to day variations with the start of a problem, it is useful to plot the ratio of volatile acids to alkalinity. As the volatile acids rise and the alkalinity falls when a problem is developing, the ratio will change faster than the individual values. This gives the operating staff additional warning of an impending problem. In anaerobic digestion, early treatment of an impending problem is absolutely essential to prevent process failure.

Example: Calculation of VA/ALK ratio

Volatile acids concentration = 150 mg.ℓ⁻¹ as CH₃COOH

Alkalinity concentration = 3 000 mg.ℓ⁻¹ as CaCO₃

$$\frac{\text{Volatile acids}}{\text{Alkalinity}} \text{ Ratio} = \frac{150 \text{ mg.}\ell^{-1} \text{ as acetic acid}}{3\,000 \text{ mg.}\ell^{-1} \text{ as calcium carbonate}} = 0,05$$

The digester works best if the ratio is less than 0,3.

Sampling and analytical methods

Each waste-water treatment works must develop a standard procedure in relation to the feeding of the digester. When sludge is added intermittently, samples should be taken just before the sludge feed is started.

These aspects are discussed in more detail in Section 6.1. The volatile acids and alkalinity tests are carried out on sludge samples from the primary digester. The sample must be relatively free of solids which would require the sludge to be settled, centrifuged or filtered. The same sample should be used for both the volatile acids and the alkalinity tests. The volatile acids to alkalinity ratio should be measured at least once per week during normal operation and plotted on a graph (refer Figure 4.8.2). When a digester is showing signs of stress or deviation from the normal trend, the ratio should be measured more frequently.

Various analytical methods are available to determine the volatile acids and alkalinity concentration of the digesting sludge. A very simple titration procedure (refer Section 6.3.4 for the Ripley method) can be used when the conventional laboratory facilities are not available.

4.8.5 pH VALUE

One of the most important requirements for effective digestion is the maintenance of the proper pH value. For example, the acid-forming bacteria can function satisfactorily above pH 5, but the methane-producing bacteria are inhibited when the pH falls below 6,8. In digester operation, even if the pH is above 6,8, sudden decreases in pH will seriously inhibit the activity of the methane-producing bacteria.

The pH of the sludge undergoing anaerobic digestion is controlled by the amount of volatile acids produced and the alkalinity in the digester. The best operating pH range is 6,8 to 7,2. An overload of feed sludge will cause an imbalance in operating conditions in that more acids than alkalinity would be produced and this would decrease the pH value. Section 4.9 discusses chemicals commonly used to adjust the pH value of the digesting sludge if it drops below a value of 6,8.

The measurement of pH is a simple test and for this reason it should be carried out at least once per day. Sludge pH should be measured as soon as possible after collection of the sample to ensure valid results. This important aspect is discussed in detail in Section 6.3.3.

The pH value should be plotted on a graph so as to be able to observe any decreasing trends. The danger lies in depending too much on pH alone as a process control indicator as the value generally changes very slowly. During a digester upset, the volatile acids begin to rise well before the alkalinity is consumed. By the time pH depression is detected, the digestion process may be well on its way to failure. The pH test must therefore be used in conjunction with other process control indicators.

4.8.6 BIOGAS PRODUCTION RATE

Effective anaerobic digestion of sludge cannot occur without the production of the correct volume of biogas. The conversion of organic matter (as reflected by the daily mass of volatile solids in the sludge fed to the digester) to biogas is therefore a very useful process control indicator which provides an early warning of upset conditions or problems in the digester. Measurement of the daily volume of gas produced can substitute for all the other process control indicators when the feed loading is uniform and process upsets are infrequent.

Experience has shown that some 1 m³ of biogas should be produced per kg volatile solids destroyed over a period of some 20 days at a digestion temperature of 35°C. It is thus possible to calculate how much biogas should be produced based on the daily feed loading to the digester. Routine measurement or observation (estimation) of the biogas being produced on a daily basis enables the operating staff to immediately assess the activity of the micro-organisms in the primary digester. A reduction in gas production is an obvious sign of digester difficulty if there has been no interruption in the amount of solids fed and no change in the temperature of the digesting sludge.

The measurement of the biogas produced and the associated biogas control devices are discussed in Section 4.6. The most accurate measurement of the volume of gas produced is by means of a gas meter. Readings at fixed time intervals will enable the operating staff to determine the daily gas production. This value should be plotted on a graph together with the daily mass of sludge fed to the digester. Trends in the biological activity of the micro-organisms can then be easily observed and correlated with other routine process control indicators.

Skilled operating staff soon learn to distinguish an actively gassing sludge from a declining one. Various simple routine methods can be used as an estimate of the rate of gas production, if a reliable gas meter is not available:

- a) Measurement of the change in the height of the floating dome of the gas storage vessel if no gas has been flared;
- b) Visual observation of the height and colour of the gas flare;
- c) Visual observation of the intensity or rate of the biogas bubbling through water;

- d) Visual assessment of the rate of biogas flow by inserting a gas rotameter (or some other type of float device alongside a measuring scale) in the main biogas line or a by-pass line;
- e) Audio evaluation of the intensity of the gas flow rate within the biogas flow lines, especially at a liquid/gas interface;
- f) A simple laboratory method can be used to determine the rate of gas production i.e. the volume of gas produced by a standardised volume of digesting sludge during a fixed time interval. Details of this method as an index of micro-organism activity are given in Section 6.4.

4.8.7 CARBON DIOXIDE CONTENT OF THE BIOGAS

The biogas generally contains 25 to 40% carbon dioxide and 60 to 75% methane by volume. During digester overload conditions, the carbon dioxide content of the biogas will increase and the methane content will correspondingly decrease. The main reason for this phenomenon is that the methane-producing bacteria are inhibited at the lower pH values caused by an increase in the volatile acid concentration. An increase of the carbon dioxide content of the biogas can be an early indicator of digester problems. If the carbon dioxide content is too high, the biogas will not burn.

The carbon dioxide content is the most easily measured component in the digester gas and a simple method is described in Section 6.5, if other instrumentation is not available. The best procedure for carrying out the test is to always sample the biogas the same time after feeding the digester. Each plant must develop a standard procedure and a history of biogas analyses and the operating staff must be on the look-out for deviations from the normal trend.

4.8.8 VOLATILE SOLIDS REDUCTION

Digestion process efficiency can be measured by the reduction in the volatile solids content of the feed sludge to the digester and the sludge withdrawn from the digester. Anaerobic digestion of primary sludge generally results in a reduction between 40 and 60 % of the volatile solids. O'Shaunessy's formula can be used to calculate the volatile solids (VS) reduction in a digester:

$$\% \text{ VS reduction} = \frac{V_i - V_o}{V_i - (V_i \times V_o)} \times 100$$

where V_i = volatile fraction in feed sludge

V_o = volatile fraction in digested sludge

Example: Calculation of VS reduction

Assume volatile solids of feed sludge = 84%
Therefore volatile fraction of feed sludge = 0,84 = V_i
Assume volatile solids of digested sludge = 68%
Therefore volatile fraction of digested sludge = 0,68 = V_o

$$\begin{aligned}\% \text{ VS reduction} &= \frac{0,84 - 0,68}{0,84 - (0,84 \times 0,68)} \times 100 \\ &= 59\%\end{aligned}$$

4.8.9 TEMPERATURE

Temperature influences the rate of biological reactions. Since sludge digestion is a biological process, the reaction rate is markedly influenced by temperature.

The efficiency of anaerobic digestion is greatly reduced at approximately 10°C. Most digesters are therefore heated and operated in the mesophilic temperature range of 32 to 38°C. The optimum temperature is approximately 35°C which will result in effective digestion in some 20 days.

If the digester cannot be heated to this temperature, then the operating staff should attempt to maintain control at a lower temperature (at a constant value) rather than to fluctuate between high and low temperatures over a short period of time.

The best temperature for a particular digester should be based on the highest gas production and ability to maintain a pH value near 7,0.

4.8.10 VOLATILE SOLIDS LOADING RATE

This process control parameter is of utmost importance, as excessive feeding is the most frequent cause of digester upset.

Guidelines are available for establishing the permissible load rate that can be applied to the primary digester. These aspects are discussed in more detail in Section 4.3. For example, the loading on high rate digesters (where heating and continuous mixing are applied) is in the range 1,5 to 3,0 kg VS.m⁻³.d⁻¹.

Feeding of the digester in terms of the volatile solids loading per day is one parameter under direct control of the operating staff.

The following must be considered:

- a) The total solids concentration of the incoming sludge;
- b) The percentage of volatile solids in the incoming sludge - a measure of its food value to the bacteria and, indirectly, of the grit content;
- c) The volume of feed sludge fed to the digester per day, i.e. the hydraulic loading or retention time. This retention time is generally equivalent to some 20 days.

The following formula determines the digester volatile solids loading rate:

$$\text{Digester volatile solids loading rate (kg VS.m}^{-3}\text{.d}^{-1}\text{)} = \frac{\text{sludge concentration (kg VS.m}^{-3}\text{)} \times \text{sludge volume fed per day (m}^3\text{.d}^{-1}\text{)}}{\text{Digester volume (m}^3\text{)}}$$

4.8.11 SENSORY EVALUATION

Skilled operating staff can obtain an immediate indication of the efficiency of the anaerobic digestion process by using their senses i.e. by means of their hands, eyes, nose and ears. Sensory evaluation is common sense but is so often neglected. The following examples illustrate the point:

- a) Hands:
 - i) The presence of grit in the digester sludge can be easily felt by rubbing the fingers together (using a disposable glove);
 - ii) The temperature of the sludge is easily discernable by touching the pipework.
- b) Eyes:
 - i) The degree of gasification occurring in the sludge is easily visible;
 - ii) Well-digested sludge has a lustrous, black colour;
 - iii) A yellow biogas flame with blue at the base is typical of good digestion performance.
- c) Nose:
 - i) Well-digested sludge is free of objectionable odour;
 - ii) Badly digested sludge has a pungent and putrescent smell due mainly to volatile acids such as butyric acid.
- d) Ears:
 - i) Experienced operating staff can hear if a pump is running efficiently;
 - ii) The intensity of the biogas flow rate can be heard at a liquid/gas interface.

4.8.12 GRAPHICAL RECORDING OF PROCESS CONTROL INDICATORS

The operating staff should keep accurate records of the various routine process control indicators. A graphical plot (Figure 4.8.2) of the various process indicators versus time is the best way to assess trends and to institute timely control and corrective measures. Graphs more readily reveal trends than columns of figures. These graphs should be prominently displayed on the control room wall and should cover the whole year's operation so as to facilitate detection of operational difficulties caused by climatic conditions, and would make any slowly changing trends more readily visible.

The control indicators must be plotted below each other by joining standard graph paper together. Experience will guide the operating staff in determining the most sensible and accurate scale to select for the Y-axis and the relevant range of each control indicator. It is suggested that a horizontal dotted line be drawn to indicate the normal operating conditions so that deviations can be more readily detected.

Each works will have its own characteristic values for the various process control indicators for good digestion. Operating staff are cautioned against relying too much on an absolute value for any of the indicator tests. The rate of change or trends in the graphs is much more significant for predicting the progress of digestion and as signals or forecasts of process upset.

The "Remarks Column" in Figure 4.8.2 is very important as future operating staff can refer to previous incidents and to the preventive control action that was taken to correct the plant upset. When anything unusual happens it should be noted; without records there will be no history of what happened or what was done and why, to correct the plant upset.

4.8.13 EXAMPLE OF HOW PROCESS INDICATORS CHANGE WITH A DIGESTER UPSET

The data in Figure 4.8.2 indicates that a digester upset arose on Day 5 due to an increased solids load arising from industrial discharges. The following action was taken by the operating staff to overcome this shock load:

a) Reduction in daily feed load to primary digester

The operating staff anticipated digester problems due to the feed overload and immediately reduced the daily feed load to one-third of the normal daily rate. The feed load was maintained at this level until the control indicators could be restored to their normal operating levels.

b) Restoration of digester temperature

The reduced digester temperature (30°C) prevailing at the time of the shock load was due to a malfunctioning sludge heat exchanger. Priority was given to repairing the temperature control equipment so as to restore the temperature of the digester sludge to 35°C.

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REMARKS

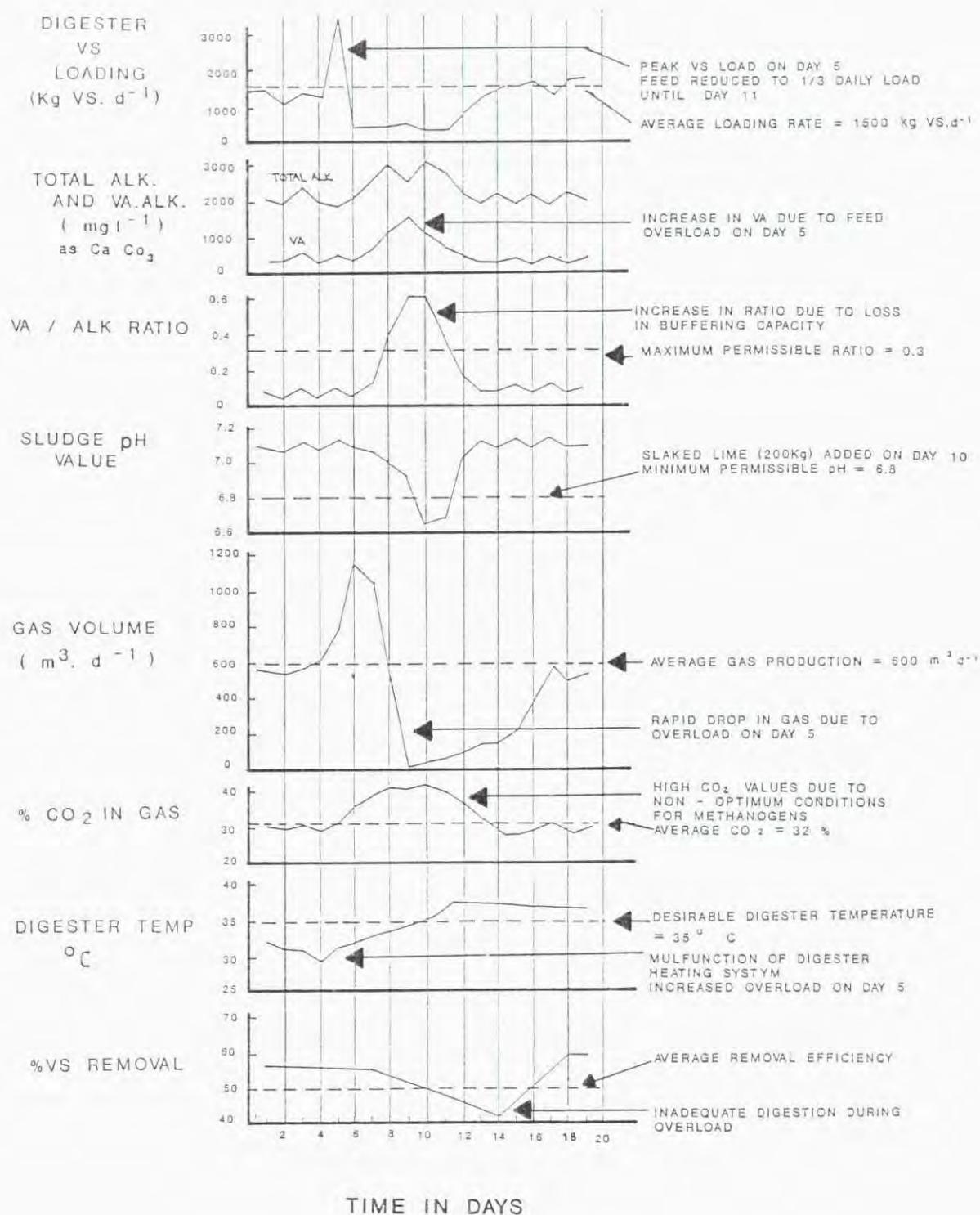


Figure 4.8.2
Graphical plot of certain digester process control indicators

c) Reseeding of the primary digester

Attempts were made to restore the activity of the primary digester by recirculation of seed sludge from the secondary digester to the primary digester. This control measure did not result in the timely restoration of the volatile acids, alkalinity, pH and gas production indices; and chemicals were used for this purpose.

d) Addition of slaked lime to restore digester pH

The change in trend of the pH graph was slower than the other process indicators and a value of 6,6 was only evident by Day 10. The operating staff determined how much slaked lime to dose according to the procedure discussed in Section 4.9.7. Slaked lime (200 kg) was added to the primary digester under good mixing conditions to neutralise the volatile acids and raise the alkalinity of the digesting sludge. This accelerated the pH recovery to 6,8 and a reduction in the volatile acids/alkalinity ratio to below 0,3. Thereafter production of biogas started to increase and reached its normal level on Day 17.

e) Conclusions

The above-mentioned example illustrates how the operating staff anticipated problems arising from a shock load. The necessary corrective action was taken and digester failure was averted. Digesters respond slowly once they are upset; therefore, best results are obtained by preventing upsets. Operating staff must realise that digester failures are costly in terms of both money and time.

SECTION 4.9

USE OF SLAKED LIME FOR DIGESTER pH ADJUSTMENT

4.9.1 INTRODUCTION

An imbalance in operating conditions will cause the digester pH value to deviate from the desirable pH range of 6,8 to 7,2. The digester pH seldom increases above 7,2 and is more likely to decrease below 6,8 due to an increase in the amount of volatile acids produced with resultant decrease in alkalinity (buffer capacity). The methane-producing bacteria are very sensitive to decreases in pH value and become inactivated at pH values below 6,2.

Every effort must be made to establish why the pH value is decreasing. The pH value must not be relied on alone to assess the health of the digester but must always be used in conjunction with the graphical recording of other process control indicators, as discussed in Section 4.8. The following control measures (i.e. without adding chemicals) can be taken if the digester pH shows a downward trend below a value of 6,8 or if the volatile acids/alkalinity ratio increases above 0,3:

- a) Reduce or stop the feed rate of sludge;
- b) Reseed the primary digester by recirculation of sludge from the secondary digester or some other healthy digester;
- c) Maintain both a digester temperature of about 35°C and continuous mixing of the digester contents.

Chemicals should only be used if the above-mentioned measures are unsuccessful in restoring the pH above a value of 6,8. Section 4.8.13 describes a typical example of a digester upset and the procedures that were taken to restore activity.

4.9.2 CHEMICALS THAT CAN BE USED TO INCREASE DIGESTER pH

Chemicals commonly used to increase the pH value of digester contents include slaked lime, sodium bicarbonate, sodium carbonate (soda ash) and sodium hydroxide. Each chemical has advantages and disadvantages and the choice of which chemical to use is generally governed by availability, cost, safety factors, storage and handling preference.

It is suggested that a survey be carried out by the operating staff to determine the relative cost and availability of the above-mentioned chemicals so that in an emergency sufficient quantities can be obtained quickly if required.

Slaked lime is relatively inexpensive and is furthermore the most readily available chemical, even in the rural areas of Southern Africa. For this reason, its use for digester pH adjustment is discussed. The necessary instructions can be obtained from text books, consultants or colleagues from other centres, e.g. larger municipalities, if chemicals other than slaked lime are used for digester pH adjustment.

4.9.3 DIFFERENT TYPES OF LIME (PRODUCTS OF LIMESTONE)

a) Slaked lime (commonly called hydrated lime)

Slaked lime [$\text{Ca}(\text{OH})_2$ - calcium hydroxide] is the preferred form since it is already hydrated and ready to be used. Many grades of slaked lime contain significant amounts of sand. The cheaper grades contain up to 14% sand. Most sand entering a digester with the sludge or in slaked lime will accumulate in the bottom of the digester and will have to be removed during a cleaning operation. If possible and if finances permit, air separated lime which contains no sand should be used.

CAUTION: Slaked lime is a powder and messy handling of the lime or lime slurry may cause skin or eye irritations. For this reason, the operating staff must wear eye protection, a powder mask and exercise great care when working with slaked lime. Any lime falling on the skin must be washed off immediately with plenty of water. Lime solutions are strongly alkaline.

b) Agricultural lime (also known as dolomitic lime)

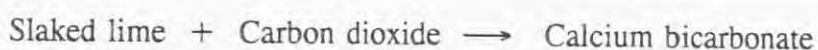
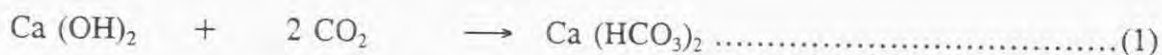
Agricultural lime or dolomitic lime, consists of natural limestone (CaCO_3 and MgCO_3 deposits). Although cheaper than slaked lime, it is much less efficient in correcting the pH value. It can be used for digester pH control if slaked lime is not available. The insoluble carbonates only become soluble in the digester when the pH drops to below 6,5 to form bicarbonate alkalinity. Greater quantities of agricultural lime must be added to a digester compared with slaked lime and a much longer reaction time is required to achieve the same results.

c) Quick lime (or unslaked lime)

The use of quick lime (CaO) is not recommended as it requires special safety precautions to be taken by the operating staff and also special equipment. An explosion can result if water is added to quick lime in an uncontrolled way. This can splash persons with lime and cause skin burns.

4.9.4 HOW SLAKED LIME WORKS IN A DIGESTER

When slaked lime is added in the concentration range 500 to 1000 $\text{mg.}\ell^{-1}$ in the digester, it combines with dissolved carbon dioxide to form calcium bicarbonate. The hydroxide (OH^-) reacts with the carbon dioxide from the liquid to form bicarbonate (HCO_3^-) which increases the alkalinity and raises the pH as follows:

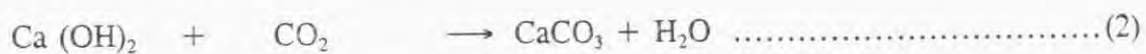


The calcium bicarbonate (soluble up to a concentration of 1 000 $\text{mg.}\ell^{-1}$) acts as a buffering agent in the same way as ammonium bicarbonate mentioned in Section 4.8.3 and neutralises the volatile acids in the digester thus allowing the pH to increase. Addition of slaked lime

must be commenced when the pH drops below 6,6 but must be terminated when the pH reaches 6,8. Should it be desired to have a somewhat greater reserve of alkalinity in the digester above a pH value of 6,9, this can be achieved by the addition of a chemical such as sodium bicarbonate.

4.9.5 DANGERS OF ADDING SLAKED LIME ABOVE A DIGESTER pH VALUE OF 6,8

Addition of too much slaked lime (in the concentration range above 1 000 mg.ℓ⁻¹ in the digester) causes the insoluble calcium carbonate precipitate to form, which generally settles to the bottom of the digester:



Slaked lime + Carbon dioxide → Calcium carbonate + Water

This reaction has several serious implications:

- a) Consumption of dissolved carbon dioxide causes carbon dioxide from the overlying gas to enter solution. Removal of carbon dioxide can cause a decrease in gas pressure and a vacuum to develop within the digester which can draw air into the digester;
- b) The vacuum relief device on the digester must be checked to be sure it is working. Slaked lime addition must be stopped whenever the vacuum relief device operates and only recommenced a day later;
- c) Slaked lime can continue to react with carbon dioxide without producing additional alkalinity. The pH may then increase to a point above the desirable pH range (6,8 to 7,2). However, once the carbon dioxide content of the digester gas drops to about 10%, the pH would start to increase rapidly to a value above 8;
- d) Excess slaked lime addition may also result in enhanced scale formation.

4.9.6 WHERE AND HOW TO DOSE SLAKED LIME

The following general procedures should be followed when dosing with slaked lime for pH adjustment of the digester contents:

- a) The most convenient place to dose the slaked lime is the feed sludge sump;
- b) The slaked lime powder must not be added directly to the sludge sump as this will not only result in inferior mixing but also cause blockages of the sludge pipelines;
- c) The slaked lime must rather be added to the sump in the form of a slurry as this will provide better mixing with the feed sludge. A convenient slurry can be made by adding one bag (25 kg) of slaked lime to approximately 200 ℓ of water;

- d) It is also important to provide continuous mixing of the digester contents so as to distribute the slaked lime throughout the whole volume of the digester;
- e) The calculated mass of slaked lime (refer Section 4.9.7 below) must not be added to the digester all at once but rather over the period of a few days. As a rough guide, one bag of slaked lime (25 kg) should be added per 100 m³ digester volume per day;
- f) The conventional process control procedures such as pH, volatile acids, alkalinity, carbon dioxide content of the biogas and biogas production rate (as discussed in Section 4.8) should be monitored more frequently during chemical pH control, so as to assess the effectiveness of the chemical treatment.

4.9.7 DETERMINATION OF HOW MUCH SLAKED LIME TO DOSE

a) Procedure if a laboratory scale is available

The following laboratory method can be used to calculate how much slaked lime to add to restore the digester pH to 6,8:

- i) Take a representative sample of sludge from the digester (say 25 ℓ);
- ii) Standardise the pH meter and measure the pH of the sludge sample as quickly as possible (for reasons see Section 6.3);
- iii) Pour 20 ℓ of the sludge sample into a clean bucket;
- iv) Place slaked lime powder in a beaker and weigh the total contents to get the initial mass (assume Mass 1 = 100 g);
- v) Carefully add small amounts of slaked lime powder from the beaker to the sludge sample in the bucket and mix well with a stick after each addition;
- vi) Measure the pH value of the sludge in the bucket from time to time and stop adding slaked lime when the pH reaches a value of 6,8;
- vii) Weigh the beaker and contents again to get the final mass (assume Mass 2 = 85 g);
- viii) Calculate the mass of lime used (Mass 3) to restore the pH of 20 ℓ of sludge to 6,8. i.e. Mass 3 = Mass 1 - Mass 2.

$$= 100 - 85$$

$$= 15 \text{ g};$$
- ix) To get a better estimate of Mass 3, repeat the experiment three times and average the results;
- x) Knowing the total volume of sludge in the digester and using the results of

Step ix, the lime needed to treat the total digester contents can be calculated (refer example below):

NOTE: In this test, the slaked lime powder is added directly to the sludge, while in practice the lime is first added to water to make a lime slurry. The reason for this test procedure is that the lime readily settles out in the slurry which will cause inaccuracies in determining the mass used unless the slurry is very well stirred.

Example: Calculation for Item 4.9.7 (a)

Volume of sludge sample	=	20 ℓ or 0,02 m ³
Initial sludge pH	=	6,6
Final sludge pH	=	6,8
Initial mass of beaker and lime (Mass 1)	=	100 g
Final mass of beaker and lime (Mass 2)	=	85 g
Mass of lime used per 20 ℓ sample (Mass 3)	=	Mass 1 - Mass 2 = 15 g or 0,015 kg
Assume available digester volume	=	2 309 m ³
Mass of lime required to raise the digester pH from 6,6 to 6,8	=	$\frac{\text{Digester volume} \times \text{Mass 3}}{\text{Volume of sludge sample}}$ $= \frac{2\,309\text{ m}^3 \times 0,015\text{ kg}}{0,02\text{ m}^3}$ = 1 732 kg = 70 bags (if the bags have a mass of 25 kg)

NOTE: Resultant concentration of slaked lime in the digester

$$\begin{aligned}
 &= \frac{1\,732\text{ kg}}{2\,309\text{ m}^3} \\
 &= 0,75\text{ kg.m}^{-3} \\
 &= 0,75\text{ g.}\ell^{-1} \\
 &= 750\text{ mg.}\ell^{-1}
 \end{aligned}$$

The resultant slaked lime concentration in the digester is $750 \text{ mg} \cdot \ell^{-1}$ which is in the required concentration range (i.e. below $1\,000 \text{ mg} \cdot \ell^{-1}$) to form calcium bicarbonate according to equation (1) in Section 4.9.4.

b) Procedure if a laboratory scale is not available

- i) Repeat steps i) to iii) in item (a) above, except use 100ℓ of sludge;

Note: A 44 gallon drum = 200ℓ
 One half of a 44 gallon drum = 100ℓ
 = $0,1 \text{ m}^3$

- ii) Make a lime slurry by adding one 25 kg bag of slaked lime to 100ℓ of water;
- iii) Stir the slurry as well as possible and add it slowly to the 100ℓ volume of sludge sample ($0,1 \text{ m}^3$) until the pH reaches a value of 6,8. This procedure (b) is not as accurate as procedure (a) above due to the fact that the lime settles out in the slurry unless it is very well mixed;
- iv) Calculate the volume of lime slurry used (m^3). To get a better estimate, repeat the experiment three times and average the results;
- v) Knowing the total volume of sludge in the digester and using the results in step iv, the lime needed to treat the total digester contents can be calculated:

Example: Calculation for Item 4.9.7 (b)

Total volume of lime slurry to add to digester (m^3)	=	$\frac{\text{Digester volume } (\text{m}^3)}{0,1 \text{ m}^3 \text{ sludge sample}}$	x	volume lime slurry added to sample (m^3)
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SECTION 4.10

SCUM AND FOAM FORMATION AND CONTROL

4.10.1 INTRODUCTION

Scum formation is one of the major problems associated with anaerobic digestion resulting in reduced available volume. Scum, which is a hard and crusty material accumulates on the liquid surface of anaerobic digesters. It is comprised of grease, vegetable and mineral oils, and other floating materials such as hair, rubber goods, animal fats, waxes, etc.

Foaming is more of a nuisance than a problem in that gas lines become fouled and the foam escapes from the digester resulting in messy conditions.

Foam is "frothy" and light and occupies the gas space. It often occurs during digester start-up, during an organic overload or when an imbalance in the digester occurs.

4.10.2 CAUSES OF SCUM AND FOAM FORMATION

a) Scum formation

There are many reasons for scum formation, including the following:

- i) High grease content;
- ii) Inadequate mixing;
- iii) High percentage of waste activated sludge in feed.

b) Foam formation

The following may be contributing factors to foam formation:

- i) Severe temperature fluctuations;
- ii) Low total solids;
- iii) Excessive mixing rates;
- iv) High organic loading, especially during start-up.

4.10.3 DISADVANTAGES OF SCUM AND FOAM FORMATION IN DIGESTERS

a) Scum formation

- i) Reduces the available volume for digestion;
- ii) Interferes with effective mixing and circulation;
- iii) Causes problems with temperature control;
- iv) Occupies space usually occupied by supernatant, thereby preventing withdrawal of good quality supernatant.

b) Foam formation

- i) Interferes with gas separation and collection;
- ii) Results in messy conditions, caused by overflow of foam.

4.10.4 SCUM AND FOAM CONTROL

a) Scum control

Scum control usually falls into one of three general categories. It is important that the three control measures listed below are used in the sequence given in order to control the build up of scum.

- i) Prevention by elimination or reduction of oils, greases and waxes. It may be necessary to establish the source of the oil, grease or wax and try to reduce the concentration in the waste water. It is advantageous to skim the floatables off in the PST and gravity thickener, thereby protecting the digester. These must be disposed of elsewhere.
- ii) If the scum layer builds up in the digester the undesirable materials can be removed through manholes in the digester, during a major digester cleanout (refer Section 4.2).
- iii) In certain cases, increased mixing will enhance the digestion of the scum layer. An in-depth look into mixing is covered in Section 4.4.

In digesters with inadequate mixing, it has been found that loading rates of about 2,0 kg VS.m⁻³.d⁻¹ will provide excellent mixing and scum control by the natural high rate of gas evolution. Tight control will be required for these loading rates to prevent digester failure. Small plants with limited man-power may find this procedure difficult to use.

b) Foam control

Foaming can usually be controlled by:

- i) Reducing the digester operating level;
- ii) Reducing or ceasing the feed to the digester for a few days;
- iii) Stopping the mixing until foam disappears.

4.10.5 OPERATIONAL GUIDELINES

Although the causes of scum and foam are different, their control is the same. The following should be carried out:

- a) Remove scum and grease from the system - usually at the PSTs. These should be buried on site;
- b) Preferably mix continuously or improve inadequate mixing;
- c) Try reducing mixing and see if the situation improves;
- d) Ensure continuous feeding;
- e) Prevent large temperature fluctuations to keep gas production rates reasonably constant;
- f) Reduce waste activated sludge loading on the digester by wasting some or all waste activated sludge directly to drying beds. This may result in longer drying times and hence a reduction in available drying area.

SECTION 4.11

TOXICITY

4.11.1 INTRODUCTION

Certain toxic substances will inhibit (slow down) or kill the bacteria in the anaerobic digestion process, if present in the sludge above certain critical concentrations, thereby causing digester upset.

The plants most likely to have potential toxicity problems are those receiving large quantities of waste water from industrial areas. Typical toxic materials include amongst others:

- a) Heavy metals;
- b) Sulphides;
- c) Phenols;
- d) Ammonia;
- e) Cyanides;
- f) Insecticides and fungicides.

4.11.2 IDENTIFYING TOXICITY

Identification of a toxic material requires the services of a full-scale laboratory service. If toxicity is suspected then some form of specialised advice will be required. The general signs of toxicity are:

- a) A complete upset in all process control indicators for no identifiable reason i.e. loading, mixing, heating and gas system all normal;
- b) A foul smelling sludge like rancid butter;
- c) A corresponding loss of nitrification in the biofilter or activated sludge plant.

4.11.3 OVERCOMING TOXICITY

The toxicity problem can be cured by effecting some form of dilution by either:

- a) Recycling secondary digested sludge to the primary digester;
- b) Decreasing the feed sludge concentration;
- c) Adding final effluent or raw waste water to the digester affected by toxicity.

Procedures (a) and (c) will result in the toxic material ultimately being flushed from the system and onto the drying beds.

If possible, the source of the toxic material should be located and the industry responsible should be informed so as to prevent a re-occurrence of the discharge of the toxic material to the sewerage system. If necessary, action should be taken in terms of the Municipal By-laws. The services of a chemical consultant or an industrial effluent inspector may be required to identify the toxic material and to trace the origin.

CHAPTER 5: POST-TREATMENT

SECTION 5.1

DEWATERING OF DIGESTED SLUDGE ON DRYING BEDS

5.1.1 INTRODUCTION

The term dewatering refers to the removal of water from the sludge after the stabilisation process (digestion) has taken place. Dewatering is part of the problem of sludge disposal and the dewatering processes depend on the type and characteristics of the sludge to be dewatered. Usually the operating staff have little or no control over the selection of the dewatering process but have the arduous task of operating whatever process is provided. Sludge beds are by far the most widely used dewatering method in Southern Africa. This section will therefore concentrate on drying beds.

5.1.2 DRYING BEDS — BACKGROUND

Drying beds are by far the most common method of dewatering sludges at waste-water treatment works. Dewatering on land has been used for most of this century to reduce the water content of sludge prior to disposal.

Although drying beds are gradually being replaced or supplemented with other dewatering processes on large works, they are still used extensively on small to medium sized works.

The primary objective in drying bed operation is to reduce the moisture content of the sludge cake to a level consistent with the mode of sludge cake removal and final dry cake utilisation.

Most well operated treatment works have standard procedures for sludge discharge to drying beds and the removal of the dry cake from the bed. These standard procedures are usually derived from experience gained over a number of years for the type of sludge and prevailing weather conditions. The means of removing the sludge cake may be a controlling factor because the allowable moisture content depends on the mode of removal and the method of disposal.

5.1.3 MECHANISM OF DRYING

After sludge has been applied to a drying bed, the following processes occur, as illustrated in Figure 5.1.1:

- a) The sludge solids settle onto the surface of the sand forming a layer through which much of the water drains;

- b) A layer of supernatant water forms on the surface, which is drawn off in certain bed designs thus reducing the volume of water which must be either drained or evaporated from the sludge;
- c) Drainage of the sludge occurs from the time the sludge is applied to the bed, with the water moving downwards under the influence of gravity into the sand layer. It is the sludge characteristics which determine the drainage rate as the water has to flow through the consolidating layer of sludge on the surface of the sand;
- d) Finally, drying of the sludge occurs through the loss of moisture to the atmosphere by evaporation.

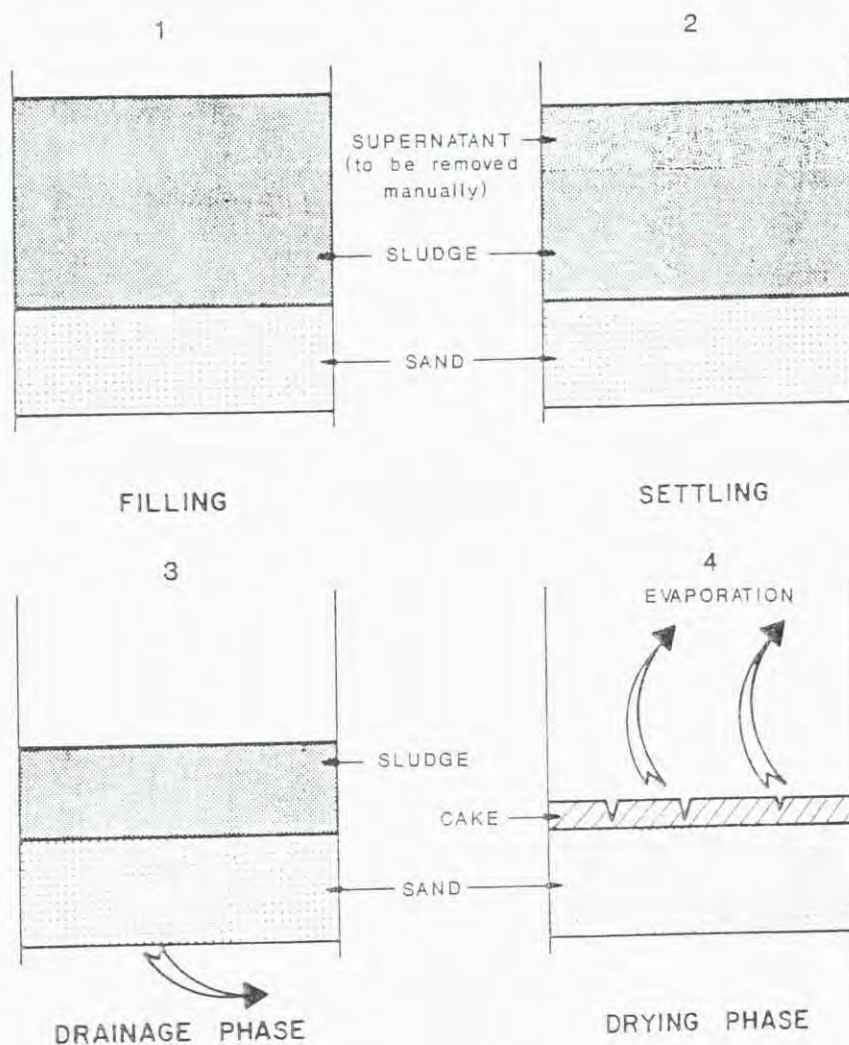


Figure 5.1.1
Loss of water from sludge on a drying bed

5.1.4 DESIGN ASPECTS

The following points will assist in understanding the process of sludge bed operation and provide a means to determine whether sufficient bed space is provided.

a) Loading rate

The quantity of sludge that can be dewatered on a unit area of drying bed per year is a key factor determining the required drying bed area. Other important factors are the sludge characteristics and weather conditions for a particular site.

Table 5.1.1 gives some figures which may be useful in determining the sludge loading rate for anaerobically digested sludge for the summer as well as winter rainfall areas.

TABLE 5.1.1: ESTIMATION OF SLUDGE LOADING RATE*

SOLIDS CONC. (% TS)	LOADING RATE (kg.m ⁻²)	DEPTH OF SLUDGE (mm)	DRYING TIME (d)	ANNUAL SOLIDS LOADING (kg.m ⁻² .a ⁻¹)	BED AREA PER CAPITA (m ² .capita ⁻¹)
WINTER RAINFALL AREA					
2,5	2,0	80	10	66	0,17
2,5	3,0	120	10	100	0,11
2,5	4,0	160	10	133	0,08
3,5	2,0	57	10	66	0,17
3,5	3,0	86	10	100	0,11
3,5	4,0	114	10	133	0,08
SUMMER RAINFALL AREA					
2,5	2,0	80	7	91	0,12
2,5	3,0	120	7	137	0,08
2,5	4,0	160	7	183	0,06
3,5	2,0	57	7	91	0,12
3,5	3,0	86	7	137	0,08
3,5	4,0	114	7	183	0,06

* After Palmer (1988)

b) Number and arrangement of beds

Beds should be rectangular and a roadway should be provided along one side so that the distance from the centre of the bed to the edge is not large. The calculation of the sludge bed area requirements is given in the following example.

Example: Calculation of sludge bed area requirements

Volume of sludge discharged to beds	=	$125 \text{ m}^3 \cdot \text{d}^{-1}$
Concentration of sludge	=	2% TS ($20 \text{ kg} \cdot \text{m}^{-3}$)
Mass of sludge discharge to beds	=	$2\,500 \text{ kg} \cdot \text{d}^{-1}$
Area requirement - assuming 200 mm of wet sludge applied (i.e. 0,2 m)	=	$\frac{125 \text{ m}^3 \cdot \text{d}^{-1}}{0,2 \text{ m}}$
	=	$625 \text{ m}^2 \cdot \text{d}^{-1}$
Sludge loading rate	=	$\frac{2\,500 \text{ kg} \cdot \text{d}^{-1}}{625 \text{ m}^2 \cdot \text{d}^{-1}}$
	=	$4 \text{ kg} \cdot \text{m}^{-2}$
Annual solids loading (assuming 15 days required for drying)	=	$\frac{365\text{d}}{15\text{d}} \times 4 \text{ kg} \cdot \text{m}^{-2}$
	=	$97 \text{ kg} \cdot \text{m}^{-2} \cdot \text{a}^{-1}$
Annual mass of sludge produced	=	$2\,500 \text{ kg} \cdot \text{d}^{-1} \times 365\text{d}$
	=	$912\,500 \text{ kg} \cdot \text{a}^{-1}$
Area required per year	=	$\frac{912\,500 \text{ kg} \cdot \text{a}^{-1}}{97 \text{ kg} \cdot \text{m}^{-2} \cdot \text{a}^{-1}}$
	=	$9\,407 \text{ m}^2$
Number of beds required (assuming beds are 500 m^2 each)	=	$\frac{9\,407 \text{ m}^2}{500 \text{ m}^2}$
	=	19 beds

c) Inlet and outlet arrangement

One or two inlet points are generally adequate and provision for preventing erosion of the sand base must be made e.g. splash plates. The inlet should be controlled with a handstop or a valve.

If a supernatant withdrawal arrangement is provided then it should be positioned at the end opposite to the inlet.

d) Sand selection

Typical specifications for sand require an effective size (minimum) of 0,3 mm with not more than 5% of the sand being greater than 4,75 mm. Certain locally available sands are often smaller grained, with effective size of about 0,2 mm. Although these sands can be used, problems may occur due to blockages (blinding).

The thickness of the sand layer should be at least 200 mm.

e) Underdrainage

If underdrainage is provided then a layer of crushed stone (6 to 13 mm in size) is needed to prevent sand from washing into the underdrainage pipes.

Pipe spacing of 3 m is typical and pipes should have a diameter of about 110 mm.

Figure 5.1.2 gives a typical drying bed cross section.

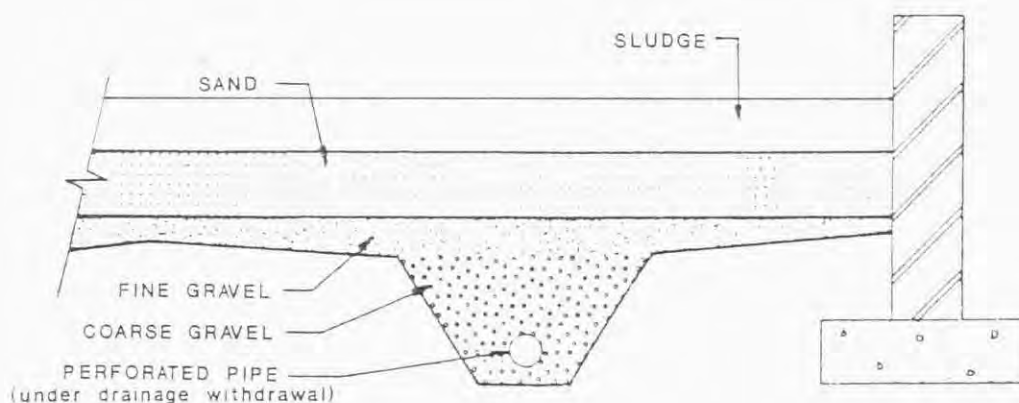


Figure 5.1.2
Typical sludge drying bed cross-section (After Palmer, 1988)

5.1.5 OPERATING PROCEDURES

Sufficient attention must be given to operation procedures to ensure the most effective use of sludge drying beds.

a) Sludge stability

Before the digested sludge is discharged to the drying bed it should have been sufficiently stabilised (digested) so that the occurrence of biological activity on the bed is not significant enough to cause bad odours and/or fly breeding problems.

b) Application of sludge

- i) A thin layer of sludge e.g. 200 mm will dry more rapidly, permitting quicker removal and reuse of the bed;
- ii) The application of sludge and subsequent removal of sludge cake is labour intensive, therefore it is not financially viable to remove a small amount of sludge cake frequently, as the labour cost per unit volume is higher for small amounts of dried sludge;
- iii) Loss of sand will increase with more frequent sludge cake removal;
- iv) Multiple applications of a thin film of sludge will result in slower drying times and is, therefore, not recommended;
- v) It is important to optimise beds with respect to thickness of application, available bed space and sludge characteristics.

Figure 5.1.3 shows the optimum depth of sludge which can be applied as well as the expected thickness of the dry sludge cake for varying digested sludge concentrations versus bed applications per year.

c) Removal of sludge cake

The removal of sludge cake from the beds is a labour intensive operation.

Increasing labour costs have resulted in the manual removal of sludge cake being limited to small or medium sized treatment works whilst the larger works tend to use mechanical means e.g. a front end loader.

For manual removal, hand tools are used to lift the dry sludge cake from the sand; one of the best tools is a shovel-like fork with several tines (prongs), approximately 25 mm apart, called a ballast fork.

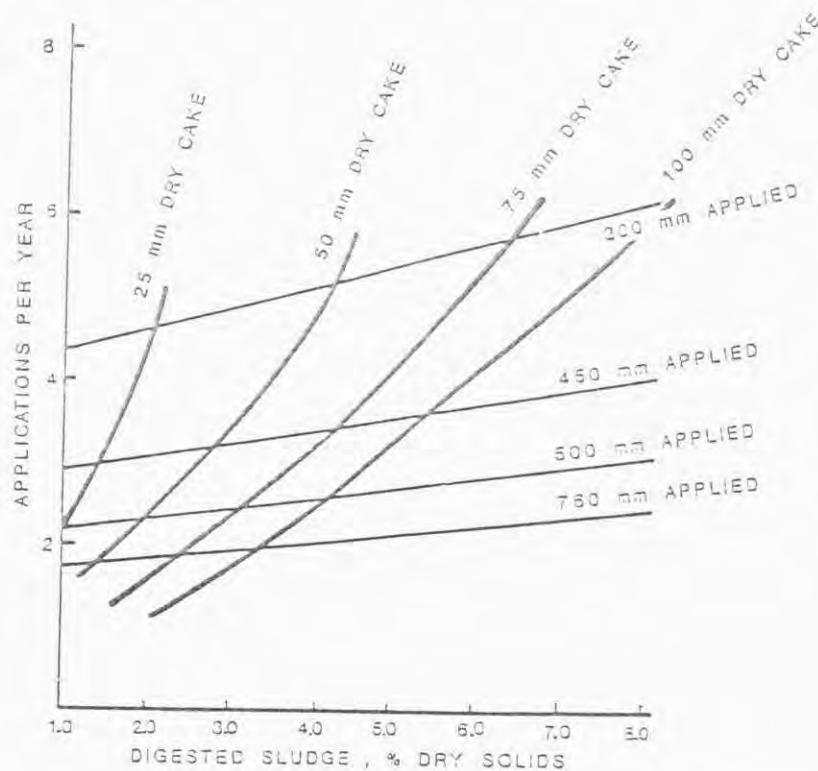


Figure 5.1.3
Optimum sludge depth for varying sludge concentrations

Wheelbarrows are generally used to move the dried sludge from the bed to a heap on the side from where it can be moved by dumper or by truck. Temporary planking should be used to take the wheel load of the wheelbarrow.

A minimum solids content of 30 to 40% TS should be aimed at to allow efficient manual sludge cake removal. At this dryness, the cake will be cracked and will peel away from the sand.

The drier the sludge cake, the less sand is removed from the bed along with the cake.

On large works, the dried sludge is removed by front end loader or by truck mounted vacuum removal systems thereby reducing labour requirements for sludge removal to a minimum. Care must however be taken when using a front end loader to prevent the bucket from going too deep into the sand causing damage to the underdrainage system.

It is recommended that when using a front end loader, the tines (teeth) be removed from the bucket.

Mobile conveyor belts or elevated railway lines on which cocopan type wagons run, can be used to transport the dried sludge from the bed to a central point.

d) Disposal of the dried sludge

Section 5.2 gives guidelines for the utilisation and disposal options of digested sludges.

e) Sand replacement

A few millimetres of sand are lost with each cleaning cycle and sand therefore needs to be replaced at regular intervals to compensate for this loss.

It is very important to keep the surface of the sludge drying bed level. If this is not done, the sludge will be thicker in the lower areas and this thicker layer will take longer to dry, hence delaying the overall drying time.

5.1.6 CHECK-LIST FOR NORMAL SLUDGE BED OPERATION

a) Initial inspection

- i) Clear all sludge lines of debris;
- ii) Check all valves for efficient operation;
- iii) Ensure sand surface is level and smooth;
- iv) Clear all debris and weeds from sand surface;
- v) Make sure the splash plate is in place;
- vi) Check drainage system.

b) Start-up

- i) Start sludge flow to bed and stop flow when sludge is at required thickness e.g. 200 mm throughout the bed. Metal or wooden stakes hammered into the ground serve as a convenient indicator of sludge level;
- ii) Do not apply new sludge on top of a layer of dry sludge.

c) Routine operations

- i) Inspect beds every few days noting odour and/or insect problems e.g. fly breeding;
- ii) Remove weed growth;
- iii) When sludge is dry, remove sludge cake, taking care not to damage sand and stone layers; remove as little sand as possible;
- iv) Do not operate vehicles directly on the sand; lay planks on top of sand; care must be exercised when a front end loader is used;
- v) Inspect empty beds, rake surface and add make-up sand if necessary;
- vi) Begin the next application of sludge.

5.1.7 OTHER DEWATERING METHODS

These mechanical dewatering systems are usually provided with suitable instruction manuals and these should be followed.

- a) Centrifuges;
- b) Belt filter press;
- c) Vacuum filter;
- d) Filter press;
- e) Rapid sludge dewatering system;
- f) Tubular filter press.

SECTION 5.2

GUIDELINES FOR UTILISATION AND DISPOSAL OF DIGESTED SLUDGE

5.2.1 INTRODUCTION

A very large percentage of the solids loading received at the waste-water treatment works is present as, or is converted into sludge. Although the anaerobic digestion process reduces the mass of sludge produced, the remaining sludge mass has to be disposed of in one or another way. It is necessary to ensure that secondary pollution does not occur as a result of unsuitable disposal practices.

After anaerobic digestion, the sludge would contain about 35% organic and about 65% inorganic material. The digested sludge contains about 2,5% nitrogen, about 1% phosphorus and about 0,2% potassium. In addition to these so-called macro-nutrients, the sludge also contains the minor nutrients such as calcium, magnesium, iron, sulphur etc. Depending on the source of the waste water, the sludge would also contain metals such as copper, chromium, nickel, zinc and cadmium.

Certain components of the sludge may be advantageously utilised when the sludge is incorporated into agricultural land. In fact, as a result of the organic content and the presence of the nutrients and the trace elements essential for plant growth, sludge is generally valued as a soil conditioner. However, due to the presence of certain contaminants such as heavy metals, viable pathogenic and other organisms, and complex organic compounds, careful consideration must be given to its potentially dangerous and hazardous properties when disposing of sludge.

5.2.2 CLASSIFICATION OF SLUDGE TYPES

The Department of National Health and Population Development has produced a set of guidelines indicating the permissible utilisation and disposal routes for waste-water sludge. In these guidelines, sludge is classified into three types A, B and C in decreasing order of its potential to cause odour nuisances and fly-breeding and to transmit pathogenic organisms to man and his environment. In addition, a type D is identified which is of similar hygienic quality to type C sludge but has a specified maximum concentration of metals and certain other elements.

Briefly the types may be described as:

- Type A: Unstable with a high odour and fly nuisance potential, contains a high content of pathogenic organisms - primary or raw sludge falls into this grouping.
- Type B: Stable with low odour and fly nuisance potential, has a reduced content of pathogenic organisms - humus, waste activated and anaerobically digested sludges fall into this grouping.

Type C: Stable with insignificant odour and fly nuisance potential, contains insignificant numbers of pathogenic organisms - anaerobically digested sludge when preceded or followed by pasteurisation falls into this grouping.

Type D: As type C but with contents of specified elements below prescribed limits.

The purpose of describing the sludge in terms of the above classification and placing certain restrictions on the disposal of sludge is to minimise nuisances and the transmission of pathogenic organisms either directly to man or indirectly through the food chain, as well as protecting water resources and the environment from pollution.

5.2.3 UTILISATION OF WASTE-WATER SLUDGE AS A SOIL CONDITIONER

As indicated above, sludge contains nutrients which can be used beneficially to improve the condition of the soil. Sludge helps to break up heavy (clayey) soils and improves the moisture retaining ability of sandy soils. Although the nitrogen, phosphorus and potassium contents of sludges are low when compared with the inorganic fertilisers, these nutrients are not leached out as quickly as those from the inorganic fertilisers.

Sludges derived from domestic waste-water treatment contains trace elements and minor nutrients in relative concentrations that are of the same order as required by most crops. This means that provided reasonable spreading rates are used, one should not experience metal accumulation problems with domestic sludges. However, when industrial effluents are present in the waste water, significant concentrations of metals and other undesirable constituents may be present in the sludge, and it becomes most important to ensure that the spreading rate is such that undesirable concentrations of metals etc, do not accumulate in the soil.

The Guidelines of the Department of National Health and Population Development referred to above contain a number of tables that indicate, inter alia, crop types that may be fertilised with sludges of the different types referred to in 5.2.2 above; the maximum soil metal content; and the permissible sludge application rate in relation to the concentration of metals present in the sludge.

5.2.4 THE AVOIDANCE OF SECONDARY POLLUTION CAUSED BY UNSUITABLE SLUDGE DISPOSAL PRACTICES

When sludge is used as a soil conditioner, the nitrogen in the sludge becomes solubilised with time. The crops planted in sludge enriched soil can utilise some of this soluble nitrogen. The actual amount utilised by the crop and incorporated into plant material depends on the crop being grown, the amount of sludge added to the soil, the rainfall, etc. Where the rate of nitrogen solubilisation exceeds the rate of incorporation into plant material, the excess nitrogen will be oxidised by bacteria in the soil to the very soluble nitrate form of nitrogen. This nitrate can contaminate ground water and can create major problems. The nitrate content of potable water must be strictly limited since the ingestion of water containing a high level of nitrate is harmful to infants.

The metals and certain organic and inorganic compounds contained in sludges may migrate

down into the water table and can create taste and odour problems when this water is used for municipal purposes.

5.2.5 CO-DISPOSAL OF WASTE-WATER SLUDGE AND REFUSE IN A SANITARY LANDFILL

Where sludge cannot be disposed as a soil conditioner, it may be desirable or even necessary to co-dispose the sludge in admixture with refuse on a sanitary landfill site. The co-disposal of refuse and secondary waste-water sludge (in particular digested sludge) in sanitary landfills is being practised in many parts of the world, especially in drier areas which have a perennial water deficit.

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 excess leachate (depending on the moisture content of the waste-water sludge and the refuse/sludge ratio applied). The techniques employed for co-disposal of waste-water sludge with refuse must therefore not prejudice the landfill operation or have any adverse effects on the environment.

The operation of the landfill as a bioreactor by the co-disposal of refuse and waste-water sludge can, however, have various advantages:

- a) The additional moisture in the waste-water sludge significantly improves the compaction and subsequent rate of settlement of the generally too dry refuse. This can greatly extend the lifespan of the landfill airspace;
- b) The added moisture promotes and accelerates the microbiological, physical and chemical attenuation mechanisms responsible for the decomposition of the refuse and the leachate thereby greatly reducing the time necessary for stabilisation of the landfill. This greatly reduces the long-term care requirements of the landfill and allows productive final usage of the site surface;
- c) Addition of digested sewage sludge has the beneficial effect of inoculating the refuse with the necessary methanogenic bacteria (together with nutrients and trace elements) for enhancing the formation of biogas which is a valuable by-product for utilisation as an energy resource.

5.2.6 CONCLUSION

Although the utilisation of sludge to improve soils used for agricultural processes 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 very costly and time-consuming to rectify.

The Guidelines issued by the Department of National Health and Population Development provide the operating staff of a waste-water treatment works with vital information to enable them to ensure the satisfactory and nuisance-free disposal of sludge. It is strongly recommended that a copy of the latest edition be obtained from the Department at Private Bag X828, Pretoria 0001.

CHAPTER 6: MONITORING AND CONTROL ASPECTS

SECTION 6.1

SAMPLING PROCEDURES AND FREQUENCY

6.1.1 INTRODUCTION

What is a sample?..... A sample is a small part taken from a larger body and is presented as being representative of the whole body.

Good sampling procedures are the key to meaningful laboratory analyses, yet it is the task which is most likely to be delegated to the person least qualified to do it.

The taking of representative and meaningful samples requires thought and understanding of all the relevant sampling procedures as well as of the consequences resulting from poor sampling methods.

Sampling on a waste-water treatment works, especially on the sludge treatment side, is usually a dirty, boring and extremely repetitive job and is in some cases ignored by the operating staff running the works or carrying out the analyses. It is a known fact that no matter how accurate and precise the results obtained from a laboratory are, if the sample is contaminated or not representative of the conditions of the process at the time of sampling, then the results obtained will be misleading. All subsequent decisions or action steps based on the results of the sample initially collected could be misdirected and this in turn could lead to financial implications or operational problems.

6.1.2 REASONS FOR SAMPLING

There are a number of reasons why sampling should be carried out accurately and carefully and why more attention should be paid to sampling procedures. These include:

- a) Process efficiency can be improved by using reliable laboratory results in the optimisation and control of the various unit processes, including the anaerobic digestion process;
- b) Decision-making on process matters can be based on results from reliable samples and pure speculation and "thumb sucking" can be eliminated;
- c) Costs associated with treatment can be reduced and controlled by operating an optimised plant which cuts out wastage of chemicals, power, etc.;
- d) The environment can be protected by the prevention of discharges of poor quality final effluents to rivers and other receiving waters. It should be noted that it is an offence in terms of the Water Act to discharge an effluent that does not comply with the required

standards and the permit of the particular works.

6.1.3 CATEGORIES OF SAMPLING

There are two distinct categories of sampling, namely grab and composite samples.

a) Grab samples

A grab sample is a sample which is collected at a particular instant and is only representative of the conditions existing at that moment.

b) Composite samples

Composite samples are representative of conditions over a longer period of time. The sample is made up by mixing a number of samples taken at regular intervals over a set period e.g. 24 samples taken at the same sampling point at hourly intervals over a 24 hour period when mixed together represent a 24 hour composite sample.

The representativeness of a composite sample increases with the number of individual samples which are taken in a set period e.g. a 24 hour composite sample which is made up of 24 individual samples taken at hourly intervals is more representative than a 24 hour composite sample made up of 12 individual samples taken at two hourly intervals.

6.1.4 SAMPLING PROCEDURES

Sampling procedures depend primarily on the consistency of the sample, the variation in the concentration and the type of analyses to be performed.

The important objective in sampling is to extract a small portion from the source which is representative of that source. This small portion should reflect, in every respect, the chemical and physical characteristics of the source at the specific time of sampling. It must be noted that this objective is not easily met. However, with proper sampling procedures the sample can give an indication, within accepted statistical variability, of the existing conditions.

The following considerations must be remembered when sampling:

- a) Prevent cross-contamination by always using the same bottles for the same type of sample and always sample the cleanest sample first, moving progressively to the dirtiest;
- b) Ensure that sample containers are clearly marked and dated with labels that do not fall off when wet;
- c) The sample scoop and bottle must be rinsed thoroughly with the sample before sampling commences;
- d) Sample away from walls, bottom, surface etc., to prevent deposits from entering sample;

- e) The sample must be transported immediately to the laboratory for analysis;
- f) The volume of the sample taken must be sufficient for all the analyses which have to be carried out;
- g) Samples should always be taken from areas of good mixing;
- h) Sample taps should be flushed for at least a minute or more depending on the length of pipe between the source and the tap, before the sample is taken.

6.1.5 PRESERVATION PROCEDURES

The best possible practice is to analyse samples immediately after sampling. This ideal situation is not always possible and some form of preservation of the sample is required when there is a time delay between sampling and analysis.

The ideal and minimum preservation required for samples of sludge is set out in Table 6.1.1.

TABLE 6.1.1: PRESERVATION REQUIREMENTS

DETERMINAND	MINIMUM REQUIRED PRESERVATION	MAXIMUM STORAGE
pH	Analyse immediately	2 h
TS	Refrigerate	7 d
Conductivity	Refrigerate	28 d
Alkalinity	Analyse immediately	2 h
Volatile acids	Analyse immediately	2 h
Kjeldahl N	Refrigerate #	7 d
Ammonia N	Refrigerate #	7 d

A far better form of preservation is to add sulphuric acid until the pH is less than 2 and then to refrigerate.

6.1.6 SLUDGE SAMPLING

As was mentioned earlier, sampling is the first step in any analysis. The following basic rules can be used to obtain reliable results from the sludge analyses:

- a) The sample must be representative - when sampling from an on/off pumping operation, allow the pump to run for a few minutes to clear the line of old sludge, make a composite sample whilst the pump is running - at least three samples should be taken during the pumping period and composited;
- b) Always carry out temperature, pH, alkalinity and volatile determinations immediately to avoid deterioration;
- c) Always preserve the sample if tests are not run immediately (refer Section 6.1.5);
- d) Always clean the sample container thoroughly before and after use;
- e) Analyses of raw sludge should be carried out on a composite sample;
- f) Analyses on digested sludge can be carried out on a grab sample (digested sludge has less variability than primary sludge);
- g) Digester recirculation samples should only be taken after a reasonable recirculation period;
- h) Dried sludge should be sampled by combining a number of samples taken systematically into a gross sample. The larger the number of samples the more closely the gross sample will represent the bulk material. The gross sample can be reduced to a manageable size by systematic crushing and grinding and by successive divisions by one-half by the coning and quartering method or by the use of a riffle (sample splitter).

6.1.7 SAMPLING FREQUENCY

A suggested frequency of analyses for a selection of sample points and certain determinants is given in Table 6.1.2. This table is a suggestion only and should be modified for a specific works to deal with specific sludge types and concentrations. The sampling frequency as well as samples taken and determinants tested should be reviewed regularly.

TABLE 6.1.2: SUGGESTED SAMPLING FREQUENCY

	TEMP	TOTAL SOLIDS	VOLATILE SOLIDS	pH	ALKALINITY/ VOLATILE ACIDS
Raw sludge		2W	2W	D	2W
Thickened sludge		D	2W		
Recycled sludge	D	2W			
Primary digester	D	2W	2W	D	3W
Secondary digester	D	2W	2W	D	3W
Supernatant		2W			
Dewatered sludge		D - 2W			
Dry sludge		W - M	W - M		

Key: D - Daily
 W - Weekly
 2W - Twice weekly
 3W - Thrice weekly
 M - Monthly
 W - M - Between weekly and monthly as needed.

SECTION 6.2

LOG SHEETS AND DATA PROCESSING

An important, yet often neglected, aspect in the control of anaerobic digesters is the collection of accurate and full records of the input and control data. However, for data collection to be meaningful, it is essential that all the necessary process design criteria of the digesters (i.e. volume, retention time, loading rates, etc.) be tabulated to provide a means of comparing actual operating conditions with the design conditions.

6.2.1 REASONS FOR KEEPING ACCURATE RECORDS

The keeping of accurate records is generally recommended for the following reasons:

a) Trends

Graphing of essential operating data and chemical analyses will provide a forewarning of possible impending digester failure and will assist in the trouble shooting of process malfunctions.

b) Planning

It is important to keep a record of sludge flows, loading rates, etc. as these will assist in the design and planning of future digester requirements.

c) Costing

For controlling and budgeting of expenses, it is important to keep records of what work was done, by whom it was done and the cost of materials used.

d) Maintenance

Proper records assist greatly in the timely servicing and repair of mechanical plant.

e) History

If one has detailed records of the action taken in response to digester upsets and the results thereof, then these can assist when the problem re-occurs. It is just as important to know which steps helped relieve the problem as which steps appeared to have no effect.

An important point to remember is that the benefit of the collection of data will be lost if the information is not processed and evaluated correctly.

6.2.2 RECOMMENDED TYPES OF DATA LOGGING

a) Daily log

A large page-a-day diary is adequate and it is strongly recommended that any unusual information pertaining to problems encountered or improved operating procedures are accurately described. This information is generally of great use to both plant management and site personnel. Repetitive comments in the daily log should be avoided as far as possible as these do not encourage a critical assessment of the plant operation.

b) Log sheets

The logging of data required for anaerobic digestion operation is usually only required on a daily basis and this information should be read and logged at a fixed time each day. Figure 6.2.1 is an example of the type of log sheet which should be maintained to ensure thorough digestion control.

If sludge drying beds are to be used for the dewatering of the digested sludge, a log sheet similar to that shown in Figure 6.2.2 should be maintained for each drying bed.

6.2.3 COMPUTERISED PROCESSING OF DATA

The above system of data processing can be improved upon and simplified by capturing and storing the information on computer which when processed will be in a format which is readily accessible to the user. This system can be suitably programmed to produce a comprehensive report at selected periods.

DATE	P.S.T. SLUDGE		GRAVITY THICKENER SLUDGE		THICKENED WASTE ACTED SLUDGE		PRIMARY DIGESTER IN				PRIMARY DIGESTER OUT					SECONDARY DIGESTER OUT			REMARKS				
	m ³ /d	% TS	m ³ /d	% TS	m ³ /d	% TS	m ³ /d	% TS	% VS	RETEN TION DAYS	% TS	% VS	TOT. ALK.	VA. ALK.	VA/ TOT. ALK.	pH	TEMP.	GAS m ³ /d		MIXING HRS	% TS	SUPER NATANT m ³ /d	SLUDGE RETEN TION DAYS
1																							
2																							
3																							
4																							
5																							
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28																							
29																							
30																							
31																							
TOTAL																							
AVG.																							

Figure 6.2.1
Log sheet example - summary of sludge digestion operation

SECTION 6.3

BASIC ANALYTICAL METHODS FOR PROCESS CONTROL

6.3.1 INTRODUCTION

This section describes three simple analytical methods which, if used and applied correctly, will improve the control over the anaerobic digestion process. The three methods were chosen for their simplicity and are attractive due to the relatively low cost of the equipment required.

The methods are:

- a) Total solids;
- b) pH;
- c) Volatile acids to alkalinity ratio.

It is not intended that these methods replace the Standard Methods for analysing sludges. Indeed if the operating staff have access to a full laboratory service then this service should be used. A full discussion of the main process control indicators is given in Section 4.8.

6.3.2 MEASUREMENT OF TOTAL SOLIDS

a) Definition

Total solids in sludge is a measure of all the material present in the sludge, both suspended and dissolved. This simple test is accomplished by drying a measured volume of sample under an infra-red lamp (refer Figure 6.3.1). All the material remaining after the water has been evaporated is considered as the total solids. The result, total solids, is expressed as a percentage of the total mass of the sample.

b) What samples should be tested and why?

The samples which should be tested routinely (refer Section 6.1) are the feed and digested sludges, and the digester supernatant.

The feed sludges are tested to ensure that the sludge thickening units are being operated correctly, and to determine the digester loading. It is advantageous to feed the digester with the thickest sludge possible in order to reduce the quantity of water requiring heating and to avoid dilution of the digester contents. Feed sludge solids should be above 4% TS.

Solids from a high rate primary digester, with no supernatant withdrawal, are tested to give an indication of the degree of solid breakdown in the digestion process and to determine the loading on the secondary digester or sludge drying beds. The "high rate"

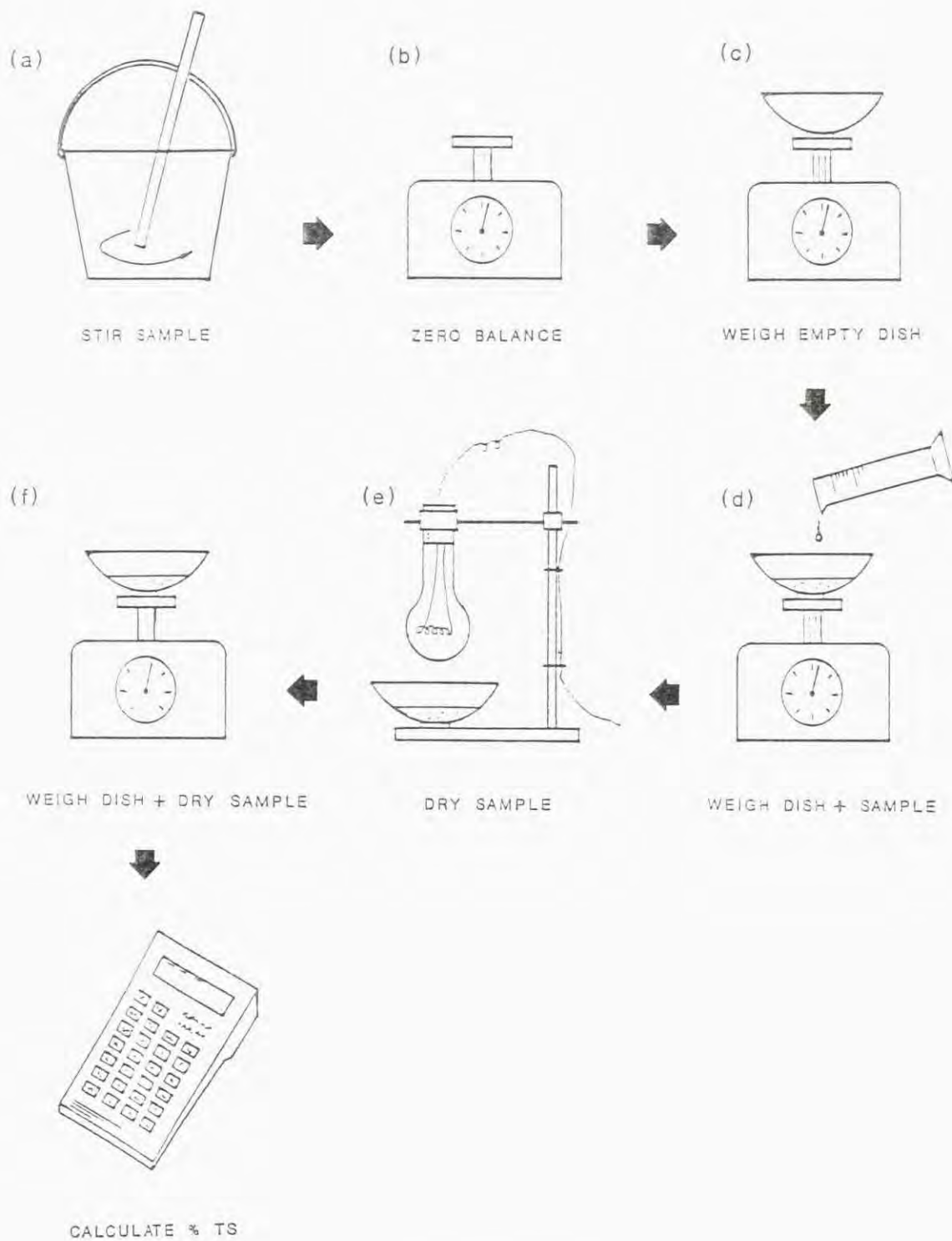


Figure 6.3.1
Procedure for measurement of total solids

digested sludge solids should be approximately half that of the average feed sludge solids levels. If sample points are available at different levels in the digester then these should be tested monthly to ensure that there is adequate mixing taking place within the digester (refer Section 4.4.6).

Solids from a low-rate primary digester or secondary digester are tested to ensure that adequate thickening is being achieved (refer Section 4.7). Samples of both the sludge and supernatant are taken. Secondary or "low rate" digested sludge should be greater than 4% TS (after supernatant withdrawal) and the supernatant solids content should be less than 0,5% TS.

c) The required apparatus

- i) Porcelain or glass (pyrex or similar) evaporating dish (100 ml);
- ii) 150W infra-red lamp;
- iii) Mounting for the lamp;
- iv) Analytical top loading balance (0 to 500 g) capable of measurement to the nearest 0,01 g;
- v) Measuring cylinder (50 ml).

d) The method

- i) Thoroughly mix the sludge sample by stirring;
- ii) With nothing on the balance set the reading to 0,00 g (tare);
- iii) Place the empty evaporating dish on the balance and record the mass as:

Mass of dish = ... g; M1

- iv) Using the measuring cylinder, pour 50 ml of well mixed sludge into the dish and record the mass as:

Mass of dish plus wet sample = ... g; M2

- v) Place the dish plus sample beneath the lamp and allow to dry for 3 hours (the distance between lamp and dish should be approximately 100 mm);
- vi) After the dish has been allowed to cool, place onto the balance and record the mass as:

Mass of dish plus dry sample = ... g; M3

vii) The total solids (%) is calculated as follows:

$$\% \text{ TS} = \frac{M3 - M1}{M2 - M1} \times 100$$

6.3.3 MEASUREMENT OF pH

a) Definition

pH is one of the most important process control indicators (refer Section 4.8) and is particularly attractive due to the ease with which readings can be taken. It should, however, be remembered that pH in itself is not entirely satisfactory as an indicator of stable digester performance due to the slow response time of pH at the onset of digester upset. pH measurements should therefore be made in conjunction with some form of volatile acid and alkalinity monitoring (refer Section 6.3.4). It is important to note that pH measurement should be made as soon as possible after sampling; as the pH of sludge is prone to change if the sludge is left standing.

b) Reason why digester sample pH must be measured immediately

Although the pH value is a simple test to perform, it is necessary to take the measurement as soon as possible in order to obtain an accurate value. The objective is to establish the pH value of the sludge **in the digester**. Firstly, it is important to ensure that the sample is representative of the digester contents. Secondly, the conditions in the digester are very different to those outside the digester. When the sample is withdrawn from the digester and comes into contact with the atmosphere, the carbon dioxide will be lost to the atmosphere. Loss of carbon dioxide increases the pH of the sample and so with time the pH value becomes less representative of the pH in the digester. The fact that the pH increases, with exposure to the atmosphere, could make one think the pH in the digester is within limits whereas the pH of the digester contents may be below the recommended limit.

It is therefore vitally important to do the pH measurement immediately after taking the sample, and to avoid doing anything that may cause carbon dioxide to be lost from the sample, such as shaking, stirring, keeping the container open or having a large headspace in the sample bottle. Once the pH is measured, carbon dioxide loss from the sample is no longer so critical because the alkalinity test is not affected significantly by carbon dioxide loss.

c) What samples should be tested and why?

Both the feed and digested sludges should be routinely tested for pH (refer Section 6.1).

The primary feed sludges are tested for pH to ensure that septic conditions do not develop in the primary settling or gravity thickening tanks which would upset the thickening processes (refer Section 3.4). The pH of primary sludge should remain above 5.0.

Digested sludges are tested for pH to ensure that conditions in the digester are satisfactory for the methane-producing bacteria (refer Section 4.1). In a healthy digester the pH should be between 6,8 and 7,2. If the pH drops below 6,8 then this is a definite indication of process upset, and steps will have to be taken to alleviate the situation; either by reducing the feed (refer Section 4.3) or by adding a chemical such as slaked lime (refer Section 4.9).

d) The required apparatus and reagents

- i) pH meter;
- ii) Combination pH electrode;
- iii) Thermometer 0 to 50°C;
- iv) pH 4,0 and pH 7,0 buffer solutions (500 ml of each);
- v) Two 40 ml (approx.) plastic containers with screw caps (for the buffer solutions);
- vi) Two 50 ml glass beakers;
- vii) 250 ml wash bottle;
- viii) Water (distilled or demineralised).

e) The method (refer Figure 6.3.2)

- i) Take the buffer solution(s) out of the refrigerator about 1 h before they are required, to allow them to reach room temperature. Switch on the pH meter. The electrode should always be kept in a beaker of water to avoid it drying out;
- ii) Lift the electrode out of the water and rinse with the wash bottle;
- iii) Place the electrode in the pH 7,0 buffer solution. Take the temperature of the solution and adjust the temperature control on the pH meter to that of the buffer solution. Calibrate the pH meter to a pH of 7,0 (**Note:** do not adjust slope or sensitivity controls);
- iv) Lift the electrode out of the buffer solution, place over the water beaker and rinse with the wash bottle. Make sure no water gets into the buffer solution;
- v) Place the electrode in the pH 4,0 buffer solution. Calibrate the pH meter to a pH of 4,0 using the "slope control". If the pH meter has no slope control, then ignore this step (**Note:** do not adjust temperature or sensitivity controls);
- vi) Lift the electrode out of the buffer solution, place over the water beaker, and rinse with the wash bottle. Again make sure no water gets into the buffer solution;

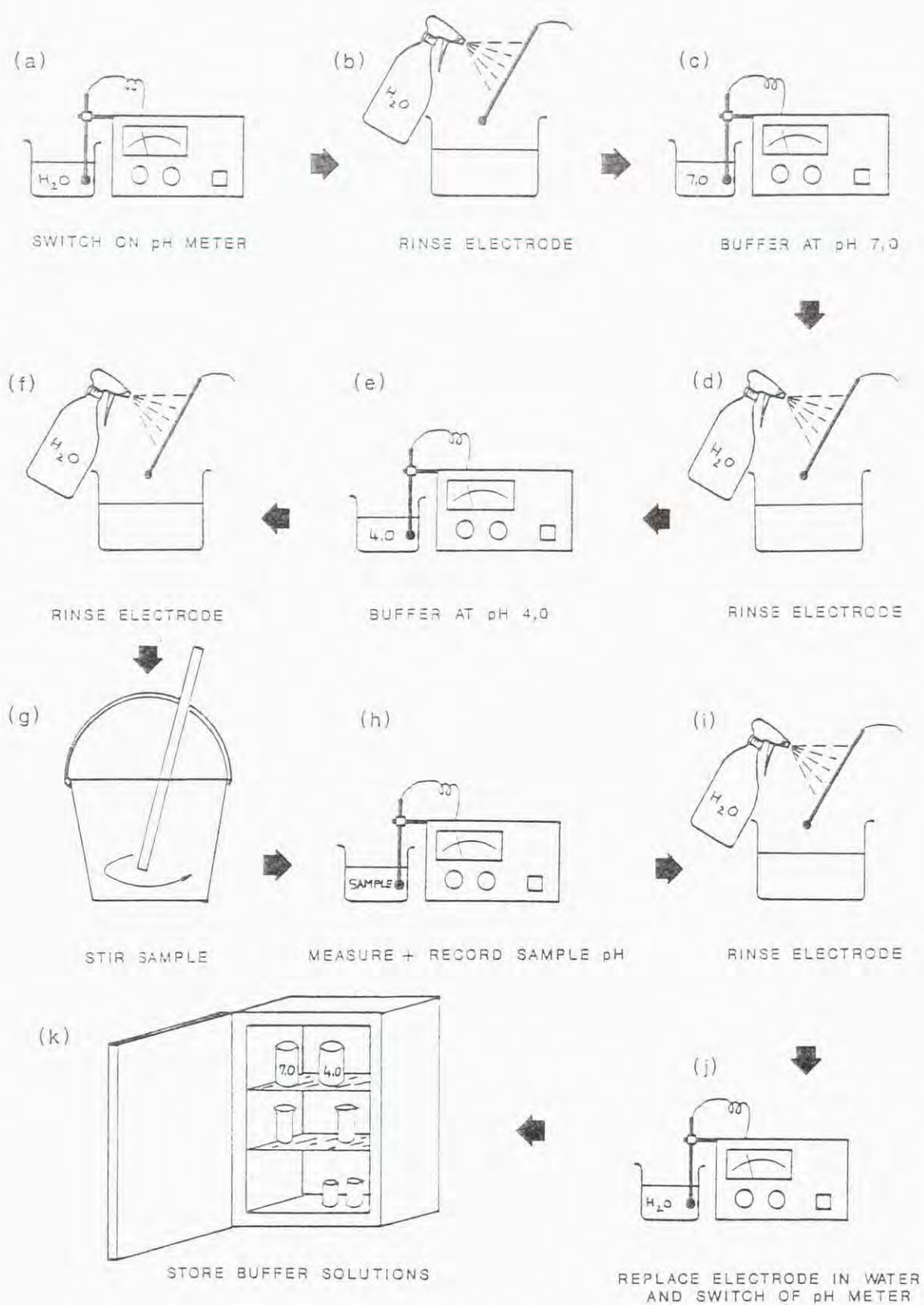


Figure 6.3.2
Procedure for measurement of pH

- vii) Thoroughly mix the sludge sample by stirring gently;
- viii) Pour some sludge into a glass beaker and place the electrode into the sludge swirling gently. Take the temperature, adjust the temperature control on the pH meter. Record the pH reading;
- ix) Lift the electrode out of the sludge beaker and rinse with the wash bottle;
- x) Store the pH electrode in a beaker containing clean water and switch off;
- xi) Replace the caps on the buffer solution containers and return to the refrigerator. Buffer solutions should be renewed once per week or sooner if contamination takes place.

NOTE: The bulb of the pH probe is a sensitive glass membrane and continual use in sludge results in a protein coating which affects sensitivity. It is suggested that the probe be soaked overnight in household enzyme solution (e.g. biotex) every six months to counteract this. pH probes are often discarded prematurely because of this phenomenon.

6.3.4 MEASUREMENT OF THE VOLATILE ACIDS TO ALKALINITY RATIO (EMPIRICAL)

a) Definition

Determining the volatile acids to alkalinity ratio (VA/ALK) of a sludge sample gives a more direct indication of the acidity/alkalinity balance in the sludge. This empirical relationship gives an adequate measure of the state of the anaerobic digestion process and can warn about an impending upset. These aspects are discussed in more detail in Section 4.8.4.

Various analytical methods are available to determine the volatile acids and alkalinity concentrations of the digesting sludge. A very simple titration procedure with two end points was developed by Ripley et al. (1986) and this can be used when the conventional laboratory facilities are not available. According to the Ripley method:

Alkalinity is approximated by titration with acid from the original sample pH to a value of pH 5.75.

Volatile acids are approximated by further titration from the pH 5.75 to a pH 4.3.

$$\text{Ripley } \frac{\text{VA}}{\text{ALK}} \text{ Ratio} = \frac{\text{Volatile acids titration}}{\text{Alkalinity titration}}$$

A low ratio implies good operating conditions while an increase in the ratio indicates that an upset has occurred.

Operating staff must determine by experience what is the best ratio for their particular plant.

b) What samples should be tested and why?

The digester sludge should be tested routinely for VA/ALK ratio. Samples should be taken at a point which is representative of the whole contents of the digester. The "Ripley" VA/ALK ratio is a useful digestion monitoring tool which increases rapidly with a process upset, then decreases with recovery.

c) The required apparatus and reagents

In addition to that required for the pH test the following items are required:

- i) 1 ℓ measuring cylinder;
- ii) Two 50 ml measuring cylinders;
- iii) 50 ml burette;
- iv) 250 ml beaker;
- v) Hydrochloric swimming pool acid (Hydrochloric acid = 30% HCl; SG = 1,12);
- vi) 2 ℓ beaker;
- vii) 2 ℓ glass bottle;
- viii) Glass stirring rod;
- ix) Clamp stand.

d) Method (refer Figure 6.3.3)

- i) Calibrate the pH meter as in Figure 6.3.3 and Section 6.3.3 (e) steps (i) to (vi);
- ii) Make up the approximate 0,5 M hydrochloric acid solution as follows (if necessary):
 - * Add 1,5 ℓ of water to a 2 ℓ beaker;
 - * Add 130 ml of hydrochloric swimming pool acid and stir gently;
 - * Make up to 2 ℓ with water;
 - * Store in a 2 ℓ glass bottle.

- (a) CALIBRATE THE pH METER AS IN FIGURE 6.3.2 STEPS (a) TO (f)
 (b) MAKE UP THE 0,5 Molar HYDROCHLORIC ACID (HCl) SOLUTION AS FOLLOWS:

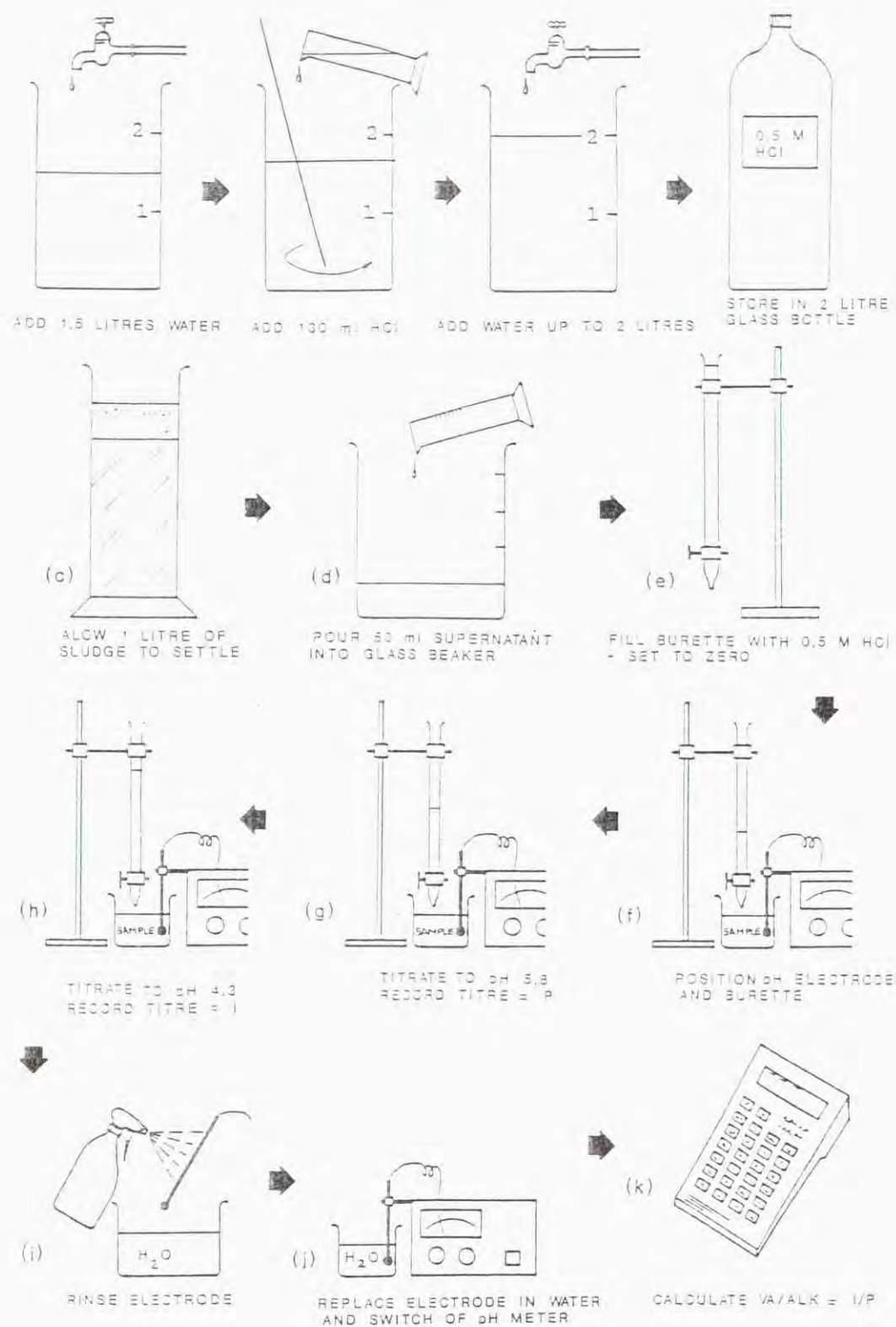


Figure 6.3.3
Procedure for measurement of volatile acids to alkalinity ratio

- iii) Pour the sludge sample into the 1 ℓ measuring cylinder and allow to stand;
- iv) Pour 50 ml of supernatant into a 250 ml beaker (use the measuring cylinder);
- v) Fill the burette with the 0,5 M hydrochloric acid solution, and set the level at zero;
- vi) Place the pH electrode into the supernatant and position the burette directly above; Check the temperature of the supernatant and set the pH meter temperature accordingly;
- vii) Slowly titrate until the pH reaches 5,75, swirling gently. Record the titre as P;
- viii) Continue to titrate to pH 4,3. Record the additional titre as I, swirling gently;
- ix) Lift the electrode out of the supernatant beaker and rinse with wash bottle;
- x) Store the pH electrode in a beaker containing clean water and switch off;
- xi) The determination of the Ripley ratio is illustrated in Figure 6.3.4 and calculated as follows:

$$\text{Ripley ratio} = \frac{\text{VA}}{\text{ALK}} = \frac{(c - b)}{(b - a)} = \frac{I}{P}$$

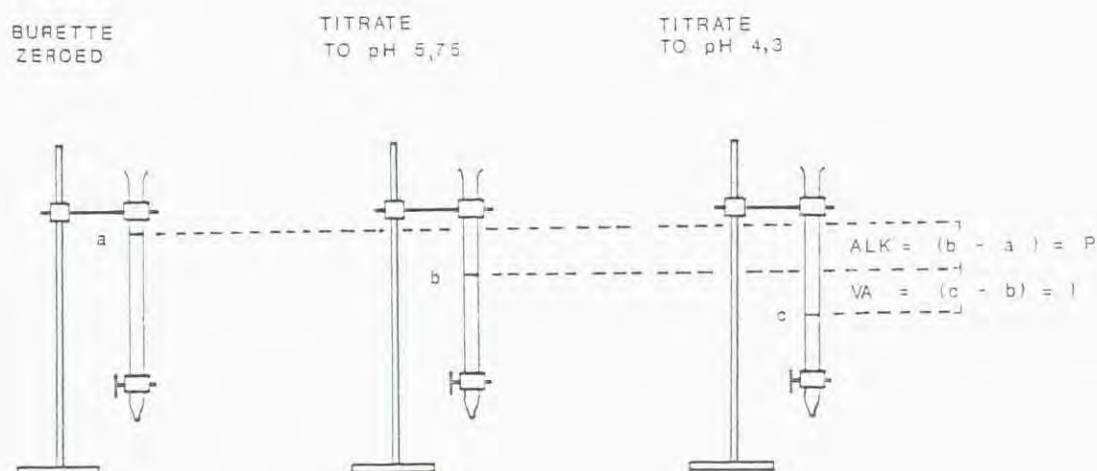


Figure 6.3.4
Calculation of volatile acids to alkalinity ratio

The comparison of the results obtained using the Ripley ratio with those obtained using a conventional analytical method (Dilallo and Albertson, 1961) is illustrated in Figure 6.3.5.

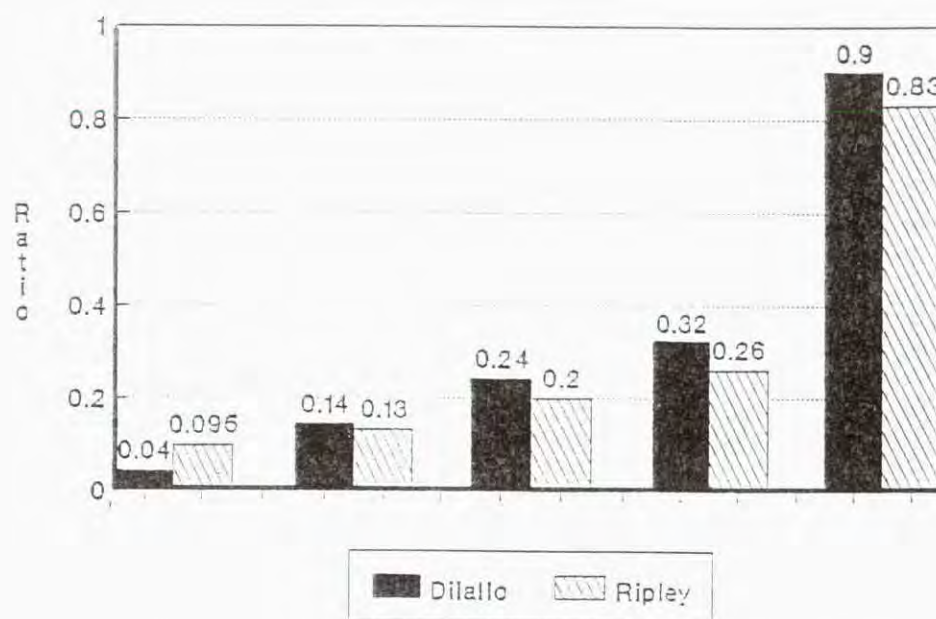


Figure 6.3.5
Comparison of Ripley's ratio to conventional alkalinity
and volatile acids determinations

SECTION 6.4

MEASUREMENT OF MICRO-ORGANISM ACTIVITY

6.4.1 INTRODUCTION

The volume of biogas produced per kg volatile solids destroyed is probably the most important and sensitive process control indicator to assess the activity of the micro-organisms and the progress of sludge digestion. No stabilisation of primary sludge can take place if biogas is not produced. As seen in Section 4.8.6, about 1 m³ of biogas should be produced per kg volatile solids destroyed over a period of some 20 days at a digestion temperature of 35°C.

Problems are often reported with the accurate measurement of the daily biogas volume. However, the blame cannot always be placed on the unreliability of the gas metering equipment, as in many instances the designer of the system has not provided the necessary equipment (such as water traps) to protect the gas meter from fouling.

Furthermore, the operating staff often neglect to routinely drain the water traps, clean the flame traps and to arrange for the servicing of the gas meter and associated equipment. These aspects have been discussed in detail in Section 4.6.

Various qualitative procedures can also be used by the operating staff to assess the rate of biogas production in the primary digester, whenever a gas meter is not available or is not operating. These procedures have been discussed in Section 4.8.6.

This section describes a simple laboratory test which measures the rate of biogas production of the digesting sludge. The test can be used as a process control indicator of digester performance as it is an index of the micro-organism activity in the digester. A sudden drop in gas production is normally due to toxic substances in the feed (such as heavy metals and halogenated solvents) or a digester overload.

6.4.2 APPARATUS REQUIRED

Figure 6.4.1 illustrates the type of laboratory apparatus required which consists of the following:

a) Digester bottle

- i) A container (some 5 ℓ) which serves as a digester bottle with a top opening which can be tightly closed with a bung (rubber or cork);
- ii) A hole is provided in the bung for the connecting tubing;

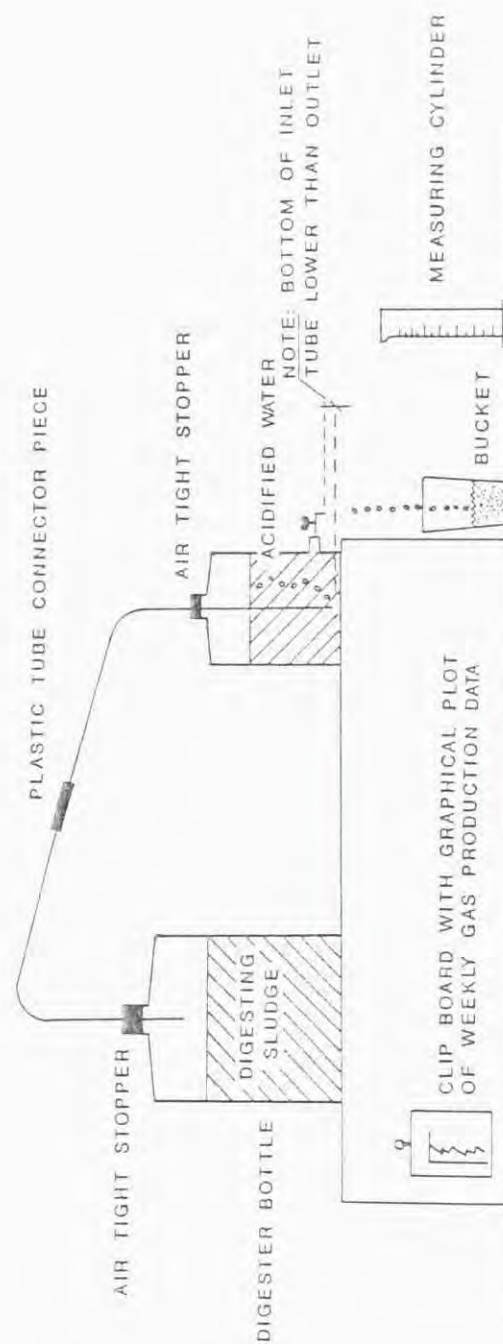


Figure 6.4.1
Basic laboratory apparatus to measure the rate of gas production of digesting sludge

- iii) No provision has been made in Figure 6.4.1 for the controlled heating or mixing of the sludge in the digester bottle so as to minimise the costs of the apparatus and to keep the test as simple as possible;
- iv) A measure of mixing of the contents of the digester bottle can be achieved by gently shaking the container at standard intervals (say once per hour);
- v) Join the plastic tubing system between the two bottles with a connector piece.

b) Acidified water bottle

- i) This container (about 2 l capacity) serves to collect the gas produced in the digester bottle. It is important that the container is made of a clear material (such as glass or perspex) so as to be able to see the rate at which the gas bubbles are being produced as this gives an immediate indication of the sludge activity;
- ii) This bottle has two openings which can be tightly closed with bungs. Holes are provided in the bungs for the inlet and outlet tubing. The bottom of the inlet tubing is adjusted so that it is lower than the outlet tubing as shown in Figure 6.4.1. In this situation the biogas is collected at a pressure greater than atmospheric pressure and the incoming gas then displaces an equal volume of the acidified water;
- iii) The outlet tubing is provided with a stop-cock or valve which is closed when the apparatus is not being used;
- iv) The acidified water (0,5 M HCl) used in this test is the same as is used for the volatile acids/alkalinity ratio test (refer Section 6.3.4) and the carbon dioxide content of the biogas test (refer Section 6.5). Instructions for preparing the dilute acidified water from swimming pool acid are given in Section 6.3.4. The acidified water prevents the carbon dioxide in the biogas from dissolving in the water and giving a lower gas reading. The methane in the biogas is not significantly soluble in water;
- v) A plastic bucket is placed below the outlet of the bottle to collect the displaced water. A suitable plastic measuring cylinder is used to accurately measure the volume of the water in the bucket at the end of the experiment. The acidified water is returned to the bottle after the experiment but it is not necessary for the bottle to be completely filled.

6.4.3 PRINCIPLE OF THE METHOD

The biogas produced by the digesting sludge in the digester bottle displaces an equal volume of water from the acidified water bottle which is collected and measured.

NOTE: Volume of biogas produced by the sludge in digester bottle = Volume of acidified water displaced from the other bottle

In order to keep the test procedure as simple as possible, the correction factors for changes in ambient temperature and pressure have not been incorporated in the test procedure as these factors do not result in significant errors (5%) in the measurement of the gas volume. Likewise, the error in the volume of water displaced due to the partial pressure of water vapour can also be neglected in the temperature range 10 to 40°C.

It is suggested that each waste-water treatment works develop a standardised procedure for carrying out this test so as to be able to compare the results on a routine basis.

6.4.4 EXPERIMENTAL PROCEDURE

- a) Select a sludge sampling point which is representative of the contents in the primary digester;
- b) Flush the sampling line and then collect some 5 l of digesting sludge at a standard time after feeding the digester. It makes sense to use this same sludge sample for the routine chemical analyses, as the information can then be correlated with the gas production measurements;
- c) Immediately measure the temperature and pH of the sludge sample as these parameters influence the activity of the micro-organisms;
- d) Stir the sludge sample and pour a standard volume (say 3,0 litre) into the digester bottle and tightly replace the rubber bung;
- e) Join the tubing between the two bottles using the connector piece. This connection must be very tight because the pressure in it is less than atmospheric pressure and it will have a tendency to draw air in and artificially increase the volume of water displaced;
- f) Open the outlet valve of the acidified water bottle. A little water will initially run out until a vacuum has formed in the system;
- g) Allow the whole system to come to equilibrium which will be evident by a steady evolution of gas bubbles into the acidified water bottle and a steady displacement of water from the bottle;
- h) Commence the experiment by noting the time (start) that the emptied bucket is placed below the outlet of the acidified water bottle;
- i) Carry out the experiment over a standard time interval (say 5 hours) and measure the volume of water collected in the bucket;

- j) The procedure should be carried out on a weekly basis. Enthusiastic operating staff will routinely carry out this simple test, even if the digester gas meter is functioning well;
- k) The results of the gas production data must be graphically plotted to assess trends in plant performance from week to week. Changes in the trends will alert the operating staff to take timely control and corrective measures. An example of a typical plot is given in Figure 6.4.2;
- l) It is important to interpret the results in relation to the chemical analyses that were carried out on the same digester sludge sample and also in relation to other process control indicators (refer Section 4.8). This test shows how the operating staff can, at little expense and some ingenuity, assess digester performance and timeously solve digester problems.

STANDARD TEST PROCEDURES

- a) Sludge sampled 3 hours after feeding of primary digester.
- b) 3.0 litres of digesting sludge sample used for activity test.
- c) Digester bottle stirred by shaking once per hour.
- d) Total time of gas measurement equals 5 hours.

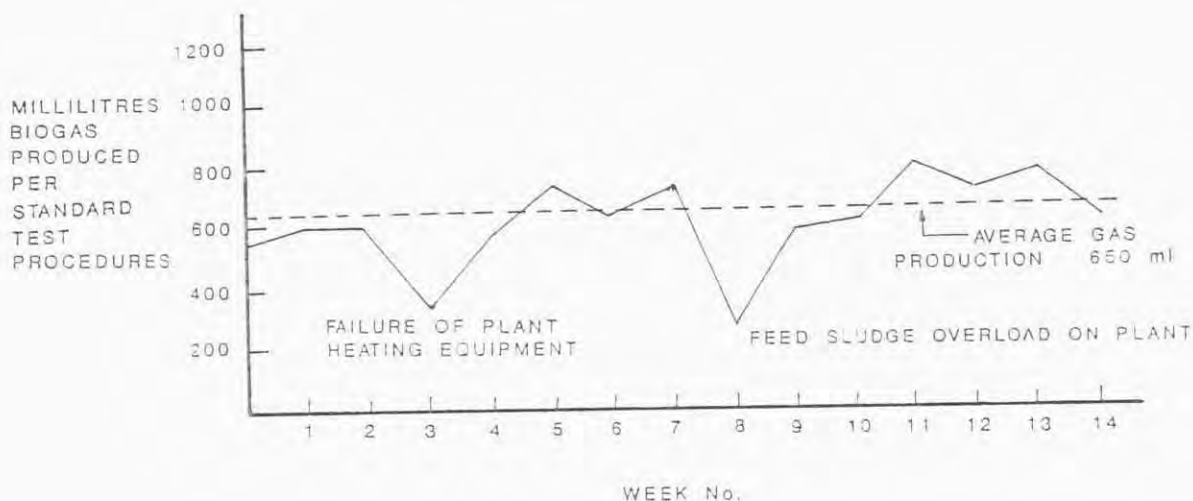


Figure 6.4.2
Weekly results of rate of gas production of digesting sludge

Example: Results of a typical micro-organism acitivity test

a) Source of sludge sample : Primary digester : No.2 b
Date sampled : 15/10/1991

b) Routine analyses of digester sludge sample

Total solids	=	50 g.l ⁻¹
Volatile solids	=	35 g.l ⁻¹
pH value at time of sampling	=	7,1
Temperature at time of sampling	=	27°C
Total alkalinity	=	2 600 mg.l ⁻¹ as CaCO ₃
Volatile acid	=	220 mg.l ⁻¹ as CH ₃ COOH

c) Laboratory micro-organism activity test

Volume of sludge in digester bottle	=	3,0 l
Time experiment started	:	10:30 on 15 October
Time experiment finished	:	15:30 on 15 October
Total time of gas measurement	=	5 h
Volume of water collected in bucket (This equals volume of gas produced)	=	575 ml

d) Result

Rate of biogas production = 575 ml of biogas per
per standard test 3 l sludge sample per
procedure 5 hour test period

SECTION 6.5

MEASUREMENT OF BIOGAS CARBON DIOXIDE CONTENT

The biogas generally contains 25 to 40% carbon dioxide and 60 to 75% methane. Section 4.8.7 covered the usefulness of the carbon dioxide content of the biogas as an early warning process control indicator of digester problems. For example, during digester overload conditions, the trend in the carbon dioxide content will increase and the methane will correspondingly decrease.

6.5.1 APPARATUS REQUIRED FOR GAS ANALYSIS

- a) 50 ml graduated measuring cylinder with a stopper;
- b) Plastic or rubber tubing with a valve so as to adjust the flow of biogas and also a bent outlet at the end to insert under the cylinder;
- c) Tall container of approximately 1 l capacity;
- d) Retort stand and clamp to support the measuring cylinder.

6.5.2 REAGENTS REQUIRED

- a) Dilute acidified water: The same 0,5 M hydrochloric acid (HCl) solution can be used for this test that is used for the volatile acids/ alkalinity ratio test. Instructions for preparing the dilute 0,5 M hydrochloric solution from swimming pool acid (approximately 30% HCl) are given in Section 6.3.4.
- b) Carbon dioxide absorbant solution: Dissolve 200 g sodium hydroxide (NaOH) or potassium hydroxide (KOH) in water and make up to 1 l.

- CAUTION:
- i) Be careful not to get any of the swimming pool acid solution or the carbon dioxide absorbant solution on your skin or clothes. Wash immediately with running water or severe burns can occur.
 - ii) Short contact with the dilute acidified water (0,5 M HCl) will not damage your skin if you rinse and dry your hands immediately afterwards. The safest procedure is to use disposable gloves.
 - iii) Never allow any smoking or flames near the digester while doing this test as biogas can form explosive mixtures with air (refer Section 4.6.13 for safety considerations with the biogas system).
 - iv) Add the sodium or potassium hydroxide slowly to the water while stirring well. Wear a face mask as the solution is strongly alkaline.

6.5.3 PRINCIPLE OF THE METHOD

The carbon dioxide in the biogas is soluble in tap water but not in the dilute acidified water which has a pH of less than 1. The collected gas displaces an equal volume of the acidified water from the measuring cylinder. Addition of excess sodium or potassium hydroxide neutralises the dilute acidified water and absorbs the carbon dioxide which reduces the volume occupied by this gas in the measuring cylinder. The difference between the initial and final volumes occupied by the gas allows the operating staff to calculate the percentage carbon dioxide content of the biogas.

Each waste-water treatment works must develop a standard procedure for carrying out this test e.g. sampling of the biogas at a fixed time after feeding of the digester.

6.5.4 PROCEDURE (REFER FIGURE 6.5.1)

- a) Choose a suitable gas sampling point close to the outlet of the gas dome of the digester so that the gas sample is representative of the actual conditions in the digester;
- b) Completely fill the 50 ml measuring cylinder with dilute acidified water and insert a stopper so that no air bubbles remain;
- c) Pour approximately 600 ml dilute acidified water into the 1 l container;
- d) Invert the measuring cylinder into the container and make sure the stopper is under the acidified water level. Clamp the cylinder using the retort stand (Figure 6.5.1a);
- e) Remove the stopper ensuring that no air enters the measuring cylinder. Short contact of the dilute acidified water with your hand will not damage your skin if you rinse and dry your hands afterwards; preferably wear a glove when removing the stopper;
- f) Attach the tubing to the biogas sampling point and open the valve completely so that the biogas escapes for a few minutes and cleans the gas lines;
- g) Partially close the valve and test with your finger that the rate of escape of the biogas from the bent outlet is not so excessive as to cause splashing when inserted in the dilute acidified water;
- h) Make finer adjustments of the valve by inserting the bent outlet under the surface of the acidified water (but not yet under the cylinder) (Figure 6.5.1b);
- i) Now insert the bent outlet under the inverted measuring cylinder and collect about 45 ml gas (Figure 6.5.1c);
- j) Remove the bent outlet from the cylinder while the gas is still escaping and now turn off the gas by closing the valve completely;
- k) Loosen the clamps and adjust the height of the cylinder so that the liquid levels inside and outside the measuring cylinder coincide;

- l) Record the initial volume of the gas in the cylinder to the nearest ml (V_1) (Figure 6.5.1d);
- m) Add 200 ml of the carbon dioxide absorbant (NaOH) to the 1 l container and loosen the clamps to allow the cylinder to be gently swirled to mix the biogas in the measuring cylinder with the carbon dioxide absorbant. Be careful not to let air into the cylinder by keeping it under the liquid level at all times (Figure 6.5.1e);
- n) Tighten the clamps and allow the cylinder to stand for about 5 min for the carbon dioxide in the gas to be absorbed;
- o) Repeat the swirling procedure until the liquid level no longer continues to rise in the measuring cylinder;
- p) Adjust the liquid levels inside and outside the measuring cylinder and record the final volume of the gas in the cylinder to the nearest ml (V_2) (Figure 6.5.1f);
- q) A graphical plot of the carbon dioxide concentration of the biogas will enable deviations from the normal trend in the digestion efficiency to be assessed (Refer Figure 4.8.2). An increase in the carbon dioxide content of the biogas can be an early indicator of digester problems.

Example: Calculation of CO₂ content in biogas

$$\begin{aligned}
 V_1 &= 43 \text{ ml} \\
 V_2 &= 30 \text{ ml} \\
 \% \text{ CO}_2 \text{ in the biogas} &= \frac{(V_1 - V_2)}{V_1} \times 100 \\
 &= \frac{(43 - 30)}{43} \times 100 \\
 &= 30,2\%
 \end{aligned}$$

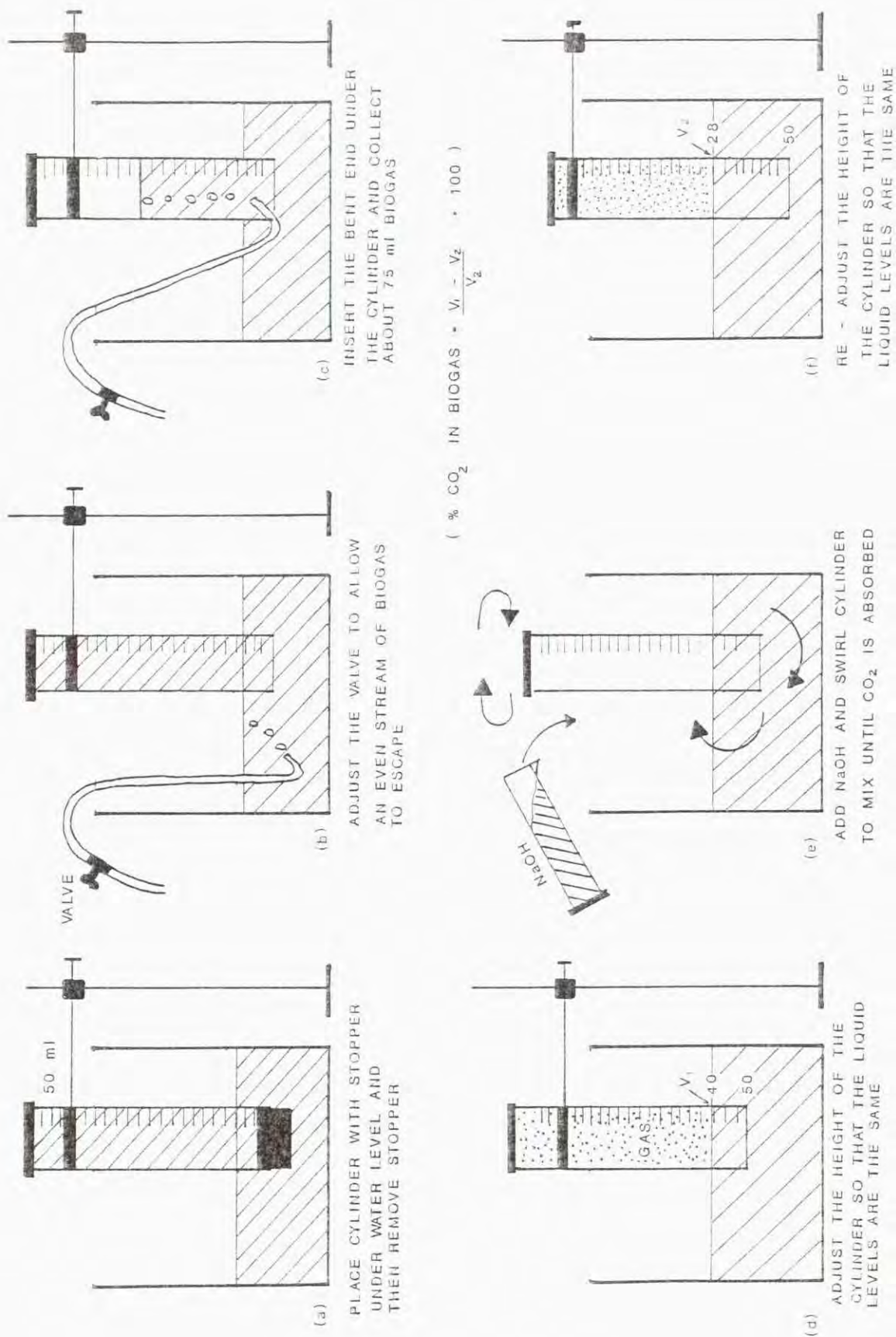


Figure 6.5.1
Procedure for laboratory measurement of biogas carbon dioxide content

SECTION 6.6

FLOW MEASUREMENT

6.6.1 INTRODUCTION

In order to control the loading and operation of the sludge handling side of the works, waste water and sludge flows entering and leaving the various unit processes should be known.

Flow meters should be provided on all the necessary lines and it must be ensured that the readings obtained are correct. This can be done by using the fairly simple volumetric or flow in open channels method for calculating flow rates.

If flow meters are not available or if they are not functional then the above-mentioned flow determining methods can be used as an interim measure.

6.6.2 TYPES OF FLOW MEASUREMENT SYSTEMS

In general, a distinction is made between two configurations for the measurement of liquid or sludge flow rates:

- a) Open systems where the flow rate is proportional to the depth of flow of the liquid or sludge in a channel or open weir;
- b) Closed systems where the flow rate is proportional to the velocity of the liquid or sludge in a completely filled pipe.

6.6.3 MEASUREMENT OF FLOWS BY THE VOLUMETRIC METHOD

In this method use is made of available and suitably sized tanks or sumps. A stop-watch or wrist watch which is able to time accurately to the nearest second is used to measure the time intervals. A measuring tape is used to measure height or depth.

The test is simple and measures the liquid or sludge discharged during a given time. The liquid is collected in a container from which the volume can be read or calculated and the time is taken at the beginning of and end of pumping.

Example: Measurement of flow by volumetric method

Primary sludge flows from the PSTs to a sump from where it is pumped to the gravity thickeners.

In order to determine the flow rate from a PST, the level in the sump is allowed to drop below the normal operating level by about 500 mm in order to facilitate the carrying out of a volumetric test.

The inlet valve into the sump, from the PST, is opened and when the level rises past a predetermined point, the stop-watch is started. As soon as the level has risen sufficiently (about 500 mm), the stop-watch is stopped and the valve is closed. The change in level in the sump and the time taken is recorded.

Calculation:

Level of sludge in sump at end	=	1 770 mm
Level of sludge in sump at start	=	1 255 mm
Increase in level of sludge in sump	=	515 mm
	=	0,515 m
Assume surface area of sump	=	2 m x 2 m
Volume of sludge entering sump	=	2 m x 2 m x 0,515 m
	=	2,06 m ³
	=	2 060 ℓ
Time taken for sludge to enter sump	=	12 min 13,6 s
	=	733,6 s
Flow rate of sludge from PST	=	$\frac{\text{Volume of sludge entering sump}}{\text{time to enter sump}}$
	=	$\frac{2\,060\ \ell}{733,6\ \text{s}}$
	=	2,8 ℓ.s ⁻¹

6.6.4 MEASUREMENT OF FLOW BY THE WEIR METHOD

This is generally accepted as one of the most accurate methods. The most common types of weirs are the rectangular, triangular (V-notch) and trapezoidal. By measuring the height of the liquid surface above the edge of the weir and then using the applicable tables for the type and size of weir, the flow rate can be calculated. The method commonly used, and most easily constructed weir, is the V-notch type which can be used for small as well as large flows.

A 90° V-notch is recommended as this is easily measured and cut. The use of non-corrodible materials is recommended e.g. stainless steel, plastic, bronze etc. The weir must be placed at right angles to the flow in the channel and the edges and bottom must be sealed.

Figure 6.6.1 shows the design of a 90° V-notch weir. H represents the height of water flowing over the weir.

For a 90° V-notch where the height of water (H) is measured in mm, the flow can be calculated reasonably accurately from the formula:

$$\text{Flow (l.s}^{-1}\text{)} = \frac{4,35 H^{2.5}}{10^5}$$

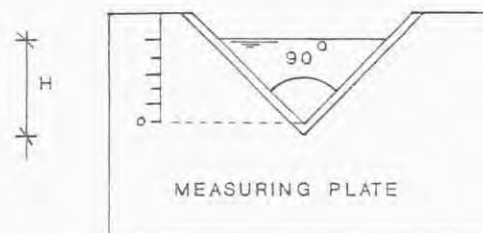


Figure 6.6.1
A typical 90° V-Notch weir plate

Table 6.6.1 gives the flow for a 90° V-notch for heights varying from 5 mm to 200 mm (intermediate heights can be calculated).

A graph of these values can be constructed from which the flow can easily be read once the height of the head of water has been obtained.

TABLE 6.6.1: FLOW FOR A 90° V-NOTCH WEIR

HEIGHT (H) (mm)	FLOW ($\ell \cdot \text{min}^{-1}$)	($\ell \cdot \text{s}^{-1}$)
5	0,14	0,0024
20	4,66	0,078
35	18,9	0,315
50	46,1	0,769
65	88,8	1,48
80	149,1	2,49
95	229,2	3,82
110	330,6	5,52
125	455,1	7,60
140	604,2	10,1
155	779,3	13,1
170	981,7	16,4
185	1212,8	20,2
200	1473,8	24,6

6.6.5: MEASUREMENT OF FLOW USING A MEASURING BOX

A measuring box is an open box containing a measuring weir, normally accompanied by a downflow baffle. The incoming liquid is forced to flow under the downflow baffle, distributing the liquid uniformly over the width of the measuring box. The velocity of the liquid flow before the measuring weir is thereby considerably reduced.

The measuring weir backs up the liquid which then flows through the cut out in the measuring weir. The flow rate is directly proportional to the height of flow over the V-notch.

The measuring box can be made of concrete, steel, masonry or other suitable material.

For precise flow measurements, the following must be included in the design of the measuring box (refer Figure 6.6.2):

- The water velocity before the measuring weir must not be more than $6 \text{ cm} \cdot \text{s}^{-1}$ (can be

calculated from flow and cross-sectional area of the weir box);

- b) The distance (A) between the measuring weir and the downflow baffle should be greater than or equal to 1,5 m;
- c) The distance between the measuring weir and downflow baffle and the ends of the box should be at least 500 mm;
- d) The width (B) of box should be greater than or equal to 800 mm;
- e) The height (P) from the bottom of the measuring box to the overfall edge of the measuring weir must be greater than or equal to 450 mm;
- f) The ratio between the overfall height (H) and the box width (B) should be : $H/B = 0,3$.

The measuring box can be manufactured and inserted in pipelines. Care must be taken to ensure that the outlet of the box runs free i.e. that liquid flows away from the box and does not back up and flood the measuring box and V-notch weir.

If a 90° V-notch is used in the measuring box then the flow figures given in Table 6.6.1 can be used to calculate flows.

Figure 6.6.2 gives an annotated drawing of a measuring box.

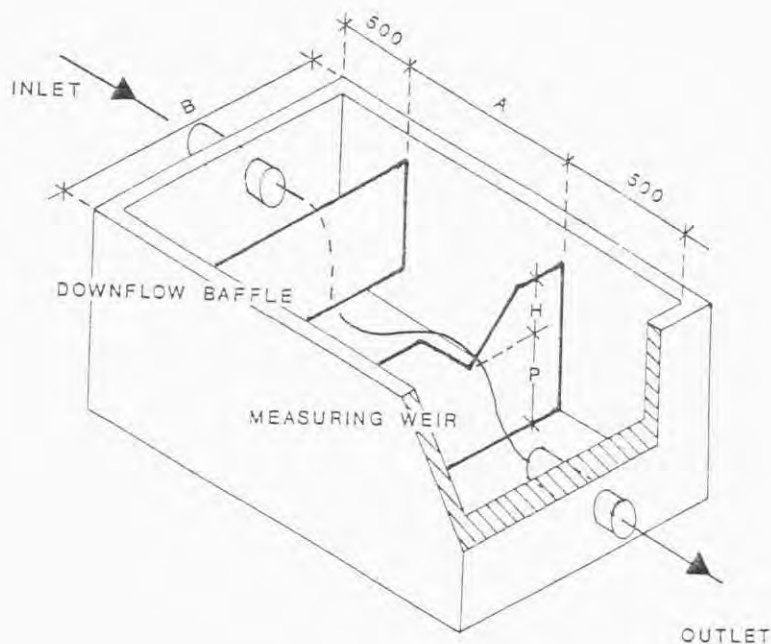


Figure 6.6.2
A typical flow measuring box

6.6.6 MEASUREMENT OF FLOW BY THE STREAM METHOD

This method makes use of floats to measure velocities. The method consists of measuring flow velocity and the cross-sectional area. A measuring site is selected and the flow cross-sectional area is calculated by measuring the width of the channel and the depth of flowing water in the channel.

Most channels on a waste-water treatment works are uniform in width and depth and therefore only the method for uniform channels will be discussed.

A section of the channel is measured and marked out, e.g. a 25 m length. Provision must be made to have enough space to release the float as well as to retrieve it from the channel.

A small plastic container which is slightly weighted to reduce the effects of wind on the test is used e.g. a plastic bottle of 25 ml capacity containing about 3 ml of sand. The weight should not be so heavy as to cause the float to sink.

A simple fishing net or similar device can be used to retrieve the float.

A stop-watch is necessary in order to accurately time the passage of the float.

Figure 6.6.3 gives details of the stream flow method of estimating flow rates.

Example: Measurement of flow by stream method

The flow rate in an open channel has to be checked. No flow meter is available so the stream flow method is used. A stop-watch, a float, a measuring tape and a small fishing net are needed in order to carry out the test.

Step 1: Calculate the cross sectional area of the liquid in the channel by measuring the width and the depth of the liquid:

$$\begin{aligned}\text{Width} &= 0,75 \text{ m} \\ \text{Depth} &= 0,50 \text{ m} \\ \text{Cross sectional area} &= \text{width} \times \text{depth} \\ &= 0,75\text{m} \times 0,50\text{m} \\ &= 0,38 \text{ m}^2\end{aligned}$$

Step 2: Measure a set length of the channel (A to B) and mark it out with chalk or paint:

$$\begin{aligned}\text{Assume length of} \\ \text{channel AB} &= 25 \text{ m}\end{aligned}$$

Step 3: Release the float about 5 m upstream from the start of the measured section of channel.

Step 4: Start the stop-watch as the float passes the start of the measured section (point A).

Step 5: Stop the stop-watch as the float passes the end of the measured section (point B):

Assume time for float = 1 min 10 s
= 70 s

Step 6: Retrieve float from channel using fish net.

Step 7: Velocity of float = $\frac{\text{Length of channel AB (m)}}{\text{Time for float (s)}}$
= $\frac{25 \text{ m}}{70 \text{ s}}$
= $0,36 \text{ m.s}^{-1}$

Step 8: Calculation of flow rate = Velocity of float x cross sectional area
= $0,36 \text{ m.s}^{-1} \times 0,38 \text{ m}^2$
= $0,137 \text{ m}^3.\text{s}^{-1}$
= 137 l.s^{-1}

Step 9: Repeat this method at least five times and calculate an average flow.

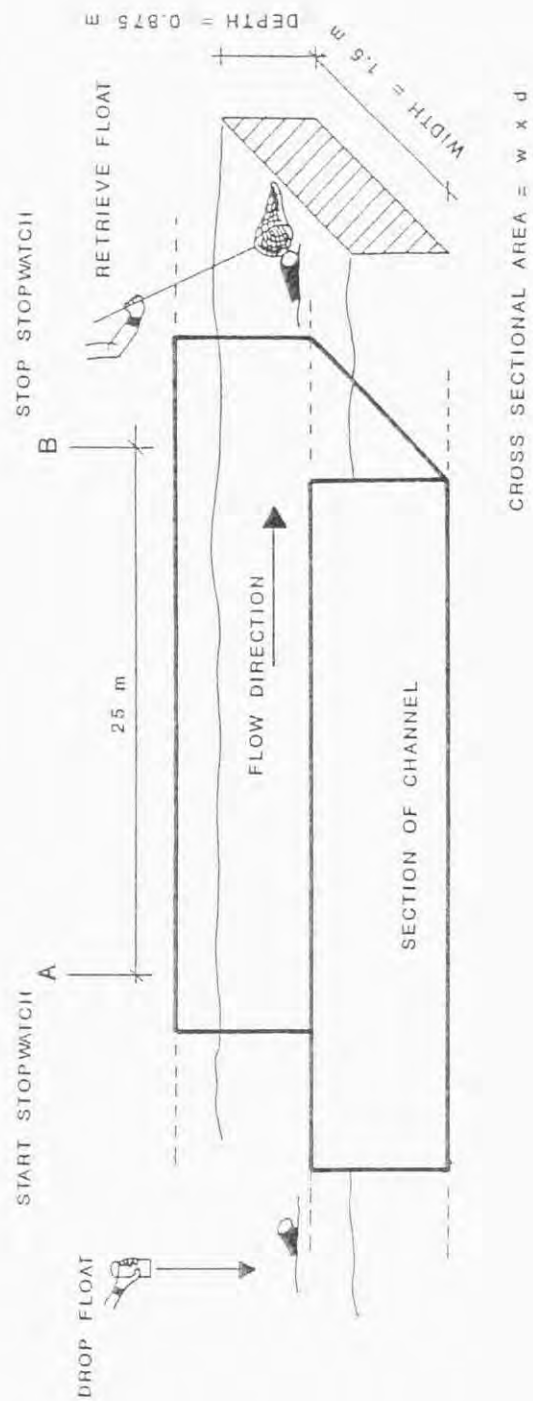


Figure 6.6.3
Procedure for estimating flow rates by the stream flow method

6.6.7 FLOW METERS AND RECORDERS

A large variety of makes and models of flow meters and flow recorders are available for use on waste-water treatment works. Regular checks and basic maintenance on these devices must be carried out in accordance with the manufacturer's instructions. Repairs, calibration and installation should, however, be carried out by qualified personnel. Detailed operating and maintenance handbooks must be obtained from the supplier on installation and kept on the works.

A most important rule which applies to flow metering devices on a treatment works is, when in doubt, call in the agents to service the instrument. Do not try to fix it yourself.

SECTION 6.7

EXAMPLE OF A SLUDGE SOLIDS MASS BALANCE

6.7.1 INTRODUCTION

The mass balance concept is based on the principle that what goes into the digester must come out. The operating staff may be said to be "in control" if at least 90% of what enters the digester can be accounted for, whether it leaves in solid, liquid or gaseous form. This approach permits a close overview of the function of:

- a) metering devices (refer Sections 4.6 and 6.6);
- b) sampling procedures (refer Section 6.1);
- c) analytical techniques (refer Section 6.3).

If annual averages are kept, the calculated and measured values of the actual digester inputs and outputs should agree to within 10 to 15 %, failing which the accuracy of flow meters and laboratory results should be reviewed.

6.7.2 CALCULATION OF AN IDEAL MASS BALANCE

- a) System monitored - High rate primary anaerobic digester.

- b) Sludge data (annual averages)

SLUDGE TYPE	FLOW $\text{m}^3 \cdot \text{d}^{-1}$	TOTAL SOLIDS $\text{kg} \cdot \text{m}^{-3}$	VOLATILE SOLIDS % of TS
Feed	75	40*	84
Digested	75	20	68

* NOTE: $40 \text{ kg} \cdot \text{m}^{-3} = 4\% \text{ TS}$

- c) Gas data (annual average)

Metered flow = $1\,500 \text{ m}^3 \cdot \text{d}^{-1}$

Approximate density of biogas = $1 \text{ kg} \cdot \text{m}^{-3}$

Mass of gas produced = $1\,500 \text{ kg} \cdot \text{d}^{-1}$

d) Example of calculation of feed sludge inputs:

According to the data in item (b):

$$\begin{aligned}\text{Total mass} &= (\text{Flow} \cdot \text{m}^3 \cdot \text{d}^{-1}) \times (\text{TS} \cdot \text{kg} \cdot \text{m}^{-3}) \\ &= 75 \text{ m}^3 \cdot \text{d}^{-1} \times 40 \text{ kg} \cdot \text{m}^{-3} \\ &= 3\,000 \text{ kg TS} \cdot \text{d}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Volatile mass} &= (\text{Flow} \cdot \text{m}^3 \cdot \text{d}^{-1}) \times (\text{TS} \cdot \text{kg} \cdot \text{m}^{-3}) \times (\% \text{VS}) / 100 \\ &= 75 \text{ m}^3 \cdot \text{d}^{-1} \times 40 \text{ kg} \cdot \text{m}^{-3} \times 84 / 100 \\ &= 2\,520 \text{ kg VS} \cdot \text{d}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Ash mass} &= \text{Total mass}(\text{kg} \cdot \text{d}^{-1}) - \text{Volatile mass}(\text{kg} \cdot \text{d}^{-1}) \\ &= 3\,000 \text{ kg TS} \cdot \text{d}^{-1} - 2\,520 \text{ kg VS} \cdot \text{d}^{-1} \\ &= 480 \text{ kg} \cdot \text{d}^{-1}\end{aligned}$$

e) Example of calculation of digested sludge outputs:

Similarly as in items (b) and (d):

$$\begin{aligned}\text{Total mass} &= 75 \text{ m}^3 \cdot \text{d}^{-1} \times 20 \text{ kg} \cdot \text{m}^{-3} \\ &= 1\,500 \text{ kg TS} \cdot \text{d}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Volatile mass} &= 75 \text{ m}^3 \cdot \text{d}^{-1} \times 20 \text{ kg} \cdot \text{m}^{-3} \times 68 / 100 \\ &= 1\,020 \text{ kg VS} \cdot \text{d}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Ash mass} &= 1\,500 \text{ kg TS} \cdot \text{d}^{-1} - 1\,020 \text{ kg VS} \cdot \text{d}^{-1} \\ &= 480 \text{ kg} \cdot \text{d}^{-1}\end{aligned}$$

f) Mass balance for a primary digester (annual average)

The data calculated in items (c), (d) and (e) is summarised as follows:

	INPUTS		=	OUTPUTS	
MASS PARAMETERS	FEED SLUDGE		=	DIGESTED SLUDGE + BIOGAS	
TOTAL MASS (kg.d ⁻¹)	3 000		=	1 500	+ 1 500
VOLATILE MASS (kg.d ⁻¹)	2 520		=	1 020	+ 1 500
ASH MASS (kg.d ⁻¹)	480		=	480	+ 0

CHAPTER 7: GENERAL

SECTION 7.1

SAFETY ASPECTS

The dangers associated with the operation of a waste-water treatment works, and in particular anaerobic digesters, are numerous and emphasise the need for safety practices. Accidents such as explosions and asphyxiations from gases or oxygen deficiency and physical injuries have occurred and emphasises the need for safe work practices and the use of safety equipment.

Generally all waste-water treatment works, irrespective of their size, have to comply with the requirements of the Machinery and Occupational Safety (MOS) Act No. 6 of 1983. The function of this Act is briefly "to provide for the safety of persons at a work place or in the course of their employment or in connection with the use of machinery; to establish an advisory council for occupational safety; and to provide for incidental matters". In the General Safety Regulation R5 of the MOS Act: "Work in confined spaces" describes the minimal legal requirements for a person entering a space in which toxic/inflamable gas may be present.

It is the responsibility of the owner or local authority to be fully acquainted with all aspects of this Act and for the purpose of this Guide it is assumed that this situation exists at all waste-water treatment facilities. Copies of the Act are obtainable from the Government Printers in either Cape Town or Pretoria.

The two main areas of safety associated with anaerobic digestion are covered in this Guide in Section 4.2.5 (procedures to clean a digester) and Section 4.6.13 (safety considerations with biogas system).

THE POTENTIAL DANGERS OF AN EXPLOSION OF BIOGAS AND AIR MIXTURES CANNOT BE OVER-EMPHASISED.

SECTION 7.2

HEALTH ASPECTS

7.2.1 INTRODUCTION

The health hazards associated with the treatment of waste water and specifically sludge handling should not be under-estimated. It is the responsibility of the supervisor and the operating staff to acquaint themselves of the dangers and to take the necessary steps to avoid them.

7.2.2 HEALTH DANGERS

a) Pathogenic bacteria

A wide variety of disease-causing organisms are present in both the liquid phase and the sludge. Amongst these are *Salmonella*, *Shigella* and *Vibrio* which cause diarrhoea and other intestinal tract problems.

b) Viruses

Viruses are usually present in waste water and in sludges. Amongst these are viruses causing infectious hepatitis, poliomyelitis, sore throats, gastroenteritis and the human immunodeficiency virus (HIV), which can cause AIDS.

c) Protozoa

Amongst these are *Entamoeba* and *Giardia*. These generally cause intestinal distress.

d) Helminths

Amongst these are *Ascaris* (roundworm), *Taenia* (tapeworm) and *Trichuris* (whipworm). The ova of these pass through the body and are fairly resistant to normal treatment processes including anaerobic digestion. Very high ova counts are usually found in sludge. The ova can survive in soil for several years.

7.2.3 BASIC RULES FOR OPERATING STAFF HYGIENE

- a) Never eat any food or put anything into your mouth without first washing your hands;
- b) Try to avoid touching your face without first washing your hands;
- c) Refrain from smoking whilst on the works; it is very easy to ingest disease-causing organisms (reserve smoking for the mess room, after hands have been washed);

- d) Always wear protective outerware including gloves, boots and overalls when working with waste water and sludges;
- e) Use rubberised or rain suits when working in wet or dirty places so that dirt can be washed off with running water;
- f) Never wear your "going home" shoes on the works and especially not when working inside tanks etc;
- g) Do not wear boots or overalls that you wear at work, in your car or at home;
- h) Always wear rubber or plastic coated gloves when cleaning out pumps etc;
- i) Always shower before going home, wash your face as well;
- j) Use disposable hand towels or a roller towel to dry your hands and face;
- k) The common or shared drinking cup must be banned. Each person should have their own cup or disposable cups should be used;
- l) Preferably clean showers, washbasins, toilets, etc. with a disinfectant soap;
- m) Wear a hard hat when working in sludge tanks and other deep channels or units;
- n) Keep your hair short and washed frequently;
- o) Keep finger-nails short and clean and use a nail brush when washing hands;
- p) Beware of final effluent irrigation sprays and aerosols. Irrigate in calm or gentle wind conditions and use low trajectory jets;
- q) Keep the works clean and tidy as this will reduce fly breeding and reduce dust nuisance;
- r) Make sure that any wounds are well covered with sticking plaster;
- s) Promptly treat any wounds caused on the works;
- t) Wash your hands BEFORE going to the toilet.

7.2.4 FIRST AID

All waste-water treatment works are classified as Factories and must have first aid kits as required by the MOS Act. The location of these kits should be prominently displayed as well as the name of the First Aider on site. It is recommended that all senior operating staff be trained as First Aiders. Suitable first aid courses are offered by the Red Cross, St Johns Ambulance or similar organisations. It should be noted that the qualifications are valid for a limited period only - usually 3 years. There should always be at least one First Aider on duty on the works at all times.

All open wounds should be treated by a doctor and it is important to receive a tetanus injection. It is important to always advise the doctor of the type of work you do.

It should always be remembered that no cut or scratch is too minor to receive attention.

SECTION 7.3

RECOMMENDATIONS FOR IMPROVEMENTS TO THE ANAEROBIC DIGESTION PROCESS

The following are some general recommendations that will improve the efficiency and reliability of the anaerobic digestion process used in a waste-water treatment works.

- a) It is most important to ensure that the screening and grit removal units are well designed, operated and maintained. Any sub-standard performance of these units will have a detrimental effect on all processes at the works and most seriously on the anaerobic digesters. The majority of digester failures are caused by an accumulation of grit or scum (including plastics). Consideration should be given to incorporating a grit removal system, such as a cyclone and classifier, on the sludge pipeline feeding the gravity thickener or digester. The potential financial savings and the improvement in process reliability may be significant.
- b) The anaerobic digester must not be used as a sink to dispose of excess oils, fats or poorly biodegradable materials. If high concentrations of these materials are present in the influent then ideally they should be reduced at source. This would involve determining who is responsible for the discharge. Among the possible sources of oils and fats are abattoirs, restaurants, butcheries and garages. Removal at source is much easier than trying to remove the same material from a much larger volume of waste water. If individual sources cannot be traced then it would be advisable to install a more sophisticated oil and fat removal system. The same philosophy applies to high fibre loads such as hair, wool and other textiles.
- c) Primary sludge or mixed sludge thickening is an area in which significant savings can be effected. On large plants, a separate gravity thickener is recommended. On small plants, it is recommended that the primary sedimentation tank be designed and operated to produce a relatively thick sludge.
- d) Two stage anaerobic digestion should be regarded as essential. The primary digester should be mixed and preferably heated. The secondary digester would be neither heated nor mixed, but would be fitted with a number of supernatant withdrawal pipes. When the works is constructed in stages, it is feasible to upgrade the digestion system in stages. Stage One would contain only primary digestion, mixed but not heated; Stage Two involves adding a secondary digester and Stage Three involves providing heating for the primary digester. With each stage of development, the solids retention time in the primary digester may be reduced.
- e) To avoid drawing in air during supernatant withdrawal, secondary digesters should not have gas-tight roofs; in fact, they may be constructed without a roof.

- f) The degree of mixing of the primary digester is important, to ensure that dead pockets of sludge do not occur, which would result in other portions of sludge having a solids retention time less than a desirable lower limit. A gross power input of 5 to 10 watts.m⁻³ is recommended. It is preferable that the mixing system of a primary digester be operated continuously.
- g) Waste activated sludge should not be treated in anaerobic digesters. This is particularly important when the activated sludge works is operated with a long sludge age. The waste activated sludge is relatively well stabilised and will not generate much gas. Also, activated sludge cannot be thickened to the same degree as primary or humus sludge except by mechanical thickening e.g. by centrifuge. In nutrient removal plants, the digestion process will liberate the phosphorus that the works was specially designed to remove. Activated sludge should be pumped directly from the aeration tank to the dewatering / drying unit.
- h) The supernatant withdrawn from the secondary digester will contain high levels of nitrogen, phosphorus and soluble organic materials. This liquid is traditionally returned to the head of the works, even though it imposes additional load upon the works. Where suitable land is available, it is recommended that the possibility of irrigating the supernatant be investigated. This needs to be carefully planned and operated to avoid pollution of rivers and underground aquifers.
- i) As the degree of skill of the operating staff is crucial to the satisfactory operation of the waste-water treatment works, it is recommended that operating staff be encouraged to improve their knowledge of the treatment process by study. They should also receive training in operating the various stages of the works. They should have access to the various operating manuals and books available. These should ideally be kept at the treatment works. Where possible, the operating staff should be allowed to, and in fact encouraged, to attend seminars, etc. on the various aspects of waste-water treatment held from time to time at various centres in the country.

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CHAPTER 9: GLOSSARY OF TERMS AND ABBREVIATIONS

Acid forming bacteria	Bacteria which metabolise organic material as food and produce chiefly volatile organic acids.
Aerobic	In the presence of free oxygen.
Agricultural lime	Also known as dolomitic lime and consists of natural limestone (CaCO_3 and MgCO_3 deposits).
Air lift pump	Pump which lifts liquid by the injection of air at the base of a pipe.
Alkalinity	Capacity of a water or sludge to neutralise acids, usually made up of the bicarbonate, carbonate and hydroxide species.
Anaerobic	A condition in which no free oxygen or nitrates are present.
Anaerobic digestion	Bacterial decomposition in the absence of free oxygen.
Anoxic	Contains oxygen only chemically bound in the nitrite and nitrate form.
Archimedian screw	A rotating spiral screw used as a conveyor to move liquids from one level to another.
Ascaris	Parasitic worm (round worm), the eggs of which are present in sludge.
Bacteria	Living micro-organisms of very small size (average diameter of 1 micrometer) which are largely responsible for the decomposition of waste-water sludge.
Baffle	Device for retaining floating scum.
Biogas	A mixture of mainly methane and carbon dioxide formed in the anaerobic digestion process.
Blinding	Blocking by forming a mat over the filter media.
Buffering capacity	A measure of the ability to resist pH change.
Centrifuge	Mechanical device using centrifugal force for separating solids from liquids.

Chemical oxygen demand	A measure of the organic content of a sample.
Composite sample	Sample made up of small amounts taken over a period of time.
Cryophilic bacteria	Bacteria which are most active at temperatures of less than 10°C.
Decompose	Break down into simpler substances by chemical or bacterial action.
Detritus	Inorganic grit associated with a high percentage of organic matter.
Dewatering	The removal of water from a sludge.
Digester	A tank or other vessel in which sludge is placed to allow sludge digestion to occur.
Dissolved air flotation	Process in which air is used to effect thickening - air bubbles attach themselves to solid particles forcing them to rise to the surface.
Draft tube	Tube fitted upright in a digester into which gas bubbles are forced to induce currents for the purpose of mixing.
Effluent	Liquid which flows out of a process.
Explosive mixture	Mixture of methane in air in the explosive range of 5 to 15% (v/v).
External heating	Heating system based outside the confines of the digester.
Feed schedule	Pre-determined schedule which sets out the digester feed programme.
Feeding (digester)	Concerns the sludge system only without taking into account the digester volume.
Flame trap	Device which prevents the flash-back of a flame.
Float layer	Thickened sludge which floats on the surface after dissolved air flotation.

Gasification	A process in which organic matter is converted into biogas. The production of biogas in a digester causes a slight bubbling effect on the digester surface.
Grab sample	Sample which is collected at a specific instant.
Gravity thickening	Thickening process making use of the force of gravity as the main agent.
Grit	Heavy mineral matter associated with waste water e.g. sand.
Grit channel	A channel through which waste water flows at a controlled velocity allowing any grit to settle out.
Heat exchanger	A unit in which heat is transferred from a hot liquid to a cold liquid.
Heavy metals	Metals such as copper, zinc, cadmium, nickel, and lead which can inhibit biological processes.
Horizontal flow	Flow that is mainly in the horizontal plane.
Humus tank	Sedimentation tank found after the biological filtration process.
Influent	Flow into a process or tank.
Inorganic	Chemical substances of mineral origin e.g. sand, glass, iron, calcium, etc.
Landfill site	Site for the controlled disposal of solid waste.
Loading (digester)	Concerns feeding the digester in relation to the volume of the digester.
Manometer	An instrument for measuring pressure.
Mass balance	A process of accounting for all mass inputs into a system and comparing it with mass outputs.
Mesophilic bacteria	Bacteria which are most active in the temperature range 32 to 37°C.
Methane-producing bacteria	Bacteria which utilise the volatile organic acids as food and produce methane and carbon dioxide.

Natural mixing	Mixing due to the formation of gas bubbles produced in the digestion process.
Non-quantitative	Qualitative - the presence of a constituent is established.
Organic	Material of animal or vegetable origin, can usually be consumed by bacteria.
Pathogenic	Micro-organisms such as bacteria and viruses which can cause disease (typhoid, cholera, dysentery).
Pig	Device used to clean drains or blocked pipes.
Polyelectrolyte	A macromolecule usually used to aid settling or thickening.
Polymer	A macromolecule usually used to aid settling or thickening.
Pre-digestion	Before the digestion process.
Pressure relief device	Device which allows excess pressure to escape from the digester or gas holder.
Primary digester	Tank in which anaerobic digestion takes place; it is usually heated and mixed.
Quantitative	Exact concentration of constituents present.
Recirculation	The return of a proportion of the effluent or sludge from a unit to the inlet of the unit.
Retention time	Period of time that the incoming sludge is retained in the digester for completion of the biological reactions - calculated by dividing the digester volume by the incoming flow.
Sample	Small part taken from a larger body which is presented as being representative of the whole body.
Saturator tank	Tank in which air is dissolved into water by means of high pressure.
Screenings	Large solids in waste water intercepted and removed by the screens.
Screens	Device for the removal of large solids from the waste water.

Scum	Layer of fats and oils which floats on the surface.
Secondary digester	Tank in which the separation of the sludge from the supernatant takes place, usually unheated and unmixed.
Seeding	The use of an actively digesting sludge to aid the start-up of a digester by supplying a quantity of the preferred types of organisms. This usually reduces the time taken for a digester to become fully active.
Sensory evaluation	Use of one's senses to monitor the operation of a digester e.g. smell, feel, taste, sight and hearing.
Septicity	Condition giving off foul odours and becoming anaerobic.
Settleable solids	Those suspended solids that will settle out in a predetermined time (usually 60 minutes).
Single stage digestion	Includes only primary digesters; sludge passes through one tank only.
Slaked lime	Calcium hydroxide or hydrated lime - can be used to control the digester pH.
Sludge	The general term applied to the accumulated solids separated from waste water. A large portion of the sludge material in a digester consists of bacteria which are responsible for its decomposition.
Sludge blanket	Layer of sludge in a tank.
Sludge cake	Dried sludge which is removed from a sludge bed.
Sludge volume index	Rough measure of sludge settleability.
Splash plate	Spreads sludge evenly over the surface without washing away the sand layer.
Splitter box	Used when more than one digester is available; ensures that an equal amount of sludge is fed to each digester.
Stabilised sludge	A well digested sludge that does not produce foul odours.
Stilling zone	Zone designed to reduce the turbulence of flow.

Stratification	Formation of layers in a liquid due to density or temperature differences.
Supernatant	Liquid that lies above settled sludge.
Suspended solids	Undissolved solids present in waste water, some of which may be present as settleable solids.
Thermophilic bacteria	Bacteria which are most active in the temperature range 50 - 60°C.
Total solids	The sum of dissolved and suspended constituents in waste water or sludges, usually stated in milligrams per liter.
Totaliser	Instrument for indicating cumulative flows.
Toxicity	Any inhibitory action of a substance on the rate of reproduction of living organisms.
Two stage digestion	Includes both primary and secondary digesters.
Underdrainage	Pipework installed under sludge beds to carry away the liquid that drains through the sludge.
Underflow	Flow from the bottom of a tank.
Vacuum relief device	Device which allows air to be drawn into the digester when a vacuum occurs in the digester tank.
Velocity	Speed in a certain direction.
Vertical flow	Flow from top to bottom or vice versa.
Volatile acids	Short chain organic acids, mainly acetic, butyric and propionic, produced by the anaerobic digestion process.
Volatile solids	Organic solids which are lost on ignition at 600°C.
Waste water	General term (when used as a noun) to denote a combination or mixture of domestic sewage and industrial effluents.
Waste-water	General term (when used as an adjective) of the word "waste water".

Water gauge	Pressure in a system measured by height of water which it could support.
Water trap	Device which collects and removes condensate and moisture from the biogas line.
Zoogloea	Gelatinous mix of bacteria and other organisms found attached to the media of biological filters.

LIST OF ABBREVIATIONS

ALK	-	Alkalinity
COD	-	Chemical oxygen demand
MLSS	-	Mixed liquor suspended solids
PST	-	Primary sedimentation tank
SS	-	Suspended solids
SST	-	Secondary sedimentation tank
SVI	-	Sludge volume index
TS	-	Total solids
VA	-	Volatile acids
VS	-	Volatile solids
WAS	-	Waste activated sludge

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