Operating Manual for Biological Nutrient Removal Wastewater Treatment Works

Prepared for the
Water Research Commission
by

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EXECUTIVE SUMMARY

1 INTRODUCTION

Eutrophication of South Africa's natural waters is greatly accelerated by human activities which result in the discharge of the nutrients nitrogen (N) and phosphorus (P). Gross eutrophication is marked by large visible blooms of algae, which makes water treatment difficult. Many algae have the ability to fix nitrogen into the water and therefore phosphorus is the element that should be restricted in order to minimise eutrophication.

Nutrients are introduced into the water from point sources, e.g. wastewater treatment works, and diffuse sources, e.g. from fertilizers or the excreta of animals and birds. It is easier to control the emission of nutrients from the point sources than from diffuse sources, hence restrictions on wastewater discharges.

Nutrients can be removed from wastewater effluents either by chemical or by biological means. The former is necessary if biological filters are being used to treat the wastewater but the latter is more economical and is suitable for various forms of activated sludge systems. Both have advantages and disadvantages.

This manual has been prepared to assist managers and owners of biological nutrient removal wastewater treatment plants by providing information which is aimed at improving the understanding of the mechanisms that are at work and providing information to optimise the performance of the works.

2 LEGAL REQUIREMENTS

At present the Department of Water Affairs and Forestry controls water pollution from point sources by requiring that effluents comply with uniform standards which are set at technologically and economically attainable levels. These controls limit the rate of deterioration of the receiving waters.

The Water Act (Act 54 of 1956) is the controlling legislation. It is currently under review and may be amended within the near future. The right to use water as well as the discharge of any effluent resulting from such use is regulated in terms of the Act. The person so using the water must purify the resultant wastewater to conform to standards published in the Government Gazette. The standards may apply either generally, in relation to water used for any particular purpose, in relation to discharge into any particular stream or into the sea, or to any particular area. There are the General and Special Standards with certain sensitive areas scheduled where the discharge of orthophosphate is limited to 1 mg/ℓ as P. It is however possible to apply for exemption which may be granted by the Minister under certain circumstances.

The Department of Health administers the Health Act (Act 63 of 1977) which aims *inter alia* to promote a safe and healthy environment. In terms of this legislation the Minister of Health may make regulations relating to the supply of water for human use, the location of water and wastewater treatment works and the quality of water intended for human consumption.

3 GENERAL DESCRIPTION OF BIOLOGICAL NUTRIENT REMOVAL THEORY

The principal nutrient elements for maintaining and reproducing life are carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and phosphorus (P). By limiting the discharge of nutrients the growth of unwanted aquatic organisms can be restricted.

Organic and inorganic carbon is removed from wastewaters in a series of oxidation-reduction reactions. A fraction of the carbon which is soluble and non-biodegradable cannot be removed, and this is discharged with the effluent. The soluble fraction that is readily biodegradable is rapidly utilised by the organisms.

Some of the non-biodegradable particulate fraction is removed in the primary sedimentation tanks and the remainder with the waste sludge. The biodegradable particulate fraction is used slowly by the organisms.

Nitrogen in the wastewater is converted from the ammoniacal and organic forms to nitrate in an aerobic environment. The nitrate can be reduced to nitrogen gas in an anoxic environment (a process called denitrification). Under anoxic conditions the most readily biodegradable carbonaceous material is used as the food source.

Phosphorus removal is achieved by a group of micro-organisms, collectively known as poly-P storers, which have the facility to store and release phosphorus under appropriate conditions. Under anaerobic conditions and in the presence of short-chain fatty acids (SCFA) the poly-P storers release the phosphorus as ortho-phosphate into the water. The energy released in this action is used to store the short-chain fatty acids for future use. When entering an anoxic or aerobic environment they utilise the SCFA for growth and to replenish their poly-P store by abstracting orthophosphate from the wastewater resulting in an uptake of phosphorus in excess of systems without anaerobic zones. The stored phosphorus is removed from the wastewater with the sludge that is wasted from the system.

Phosphorus can also be removed from the wastewater chemically using either a metallic salt such as iron or aluminium, or with lime. The disadvantages of metallic salts are that they cause drops in the pH and alkalinity of the liquid as well as increase the concentration of dissolved salts in the effluent. The disadvantage of using lime is that the dose required depends on the pH and alkalinity of the wastewater.

4 BIOLOGICAL NUTRIENT REMOVAL SYSTEM CONFIGURATIONS

4.1 Introduction

It is necessary to create zones that are either aerobic (dissolved oxygen present), anaerobic (absence of dissolved oxygen as well as nitrate) and anoxic (absence of oxygen but not of nitrate) to effect biological nutrient removal. The anaerobic zone is required to effect the removal of phosphorus while the anoxic zone is necessary for the removal of nitrate.

Various configurations have been developed for the removal of these nutrients.

4.2 Nitrogen removal systems

The first system was developed by Wuhrmann and consisted of an aerobic zone followed by an anoxic zone. Denitrification in this system is limited by the amount of carbon entering the anoxic zone. The carbon for the denitrification process is supplied by the endogenous decay of the micro-organisms and as a result was very slow.

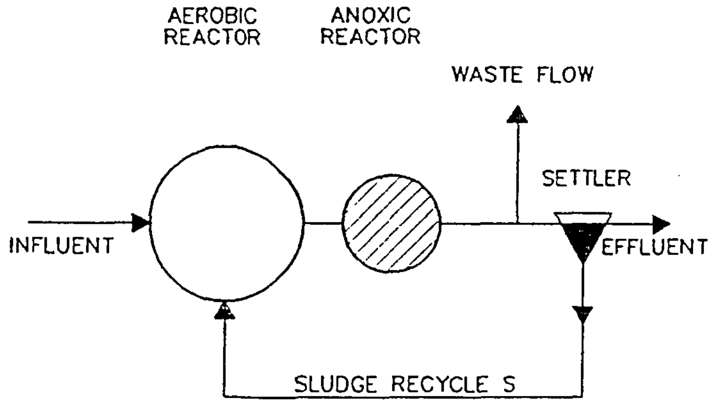
In the Modified Ludzack-Ettinger process (MLE) the anoxic zone is placed ahead of the aerobic zone so that the carbon in the incoming sewage can be used for denitrification. The recycle from the aerobic zone to the anoxic zone which recycled the nitrate for stripping was introduced. Complete denitrification is not possible and nitrate is discharged with the effluent.

The Bardenpho system introduced a secondary anoxic stage, followed by a small intensely aerated zone to strip the nitrogen bubbles from the sludge. At low $^{TKN}/_{COD}$ ratios the Bardenpho system will produce an effluent with a lower nitrate concentration than the MLE system.

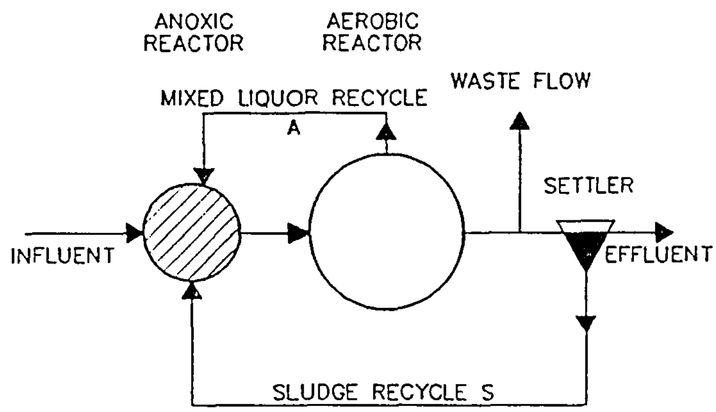
4.3 Nitrogen and phosphorus removal systems

Phosphorus removal is dependent on the creation of an anaerobic zone in the system. In all the full-stream processes this has been achieved as a modification to the nitrogen removal systems described above.

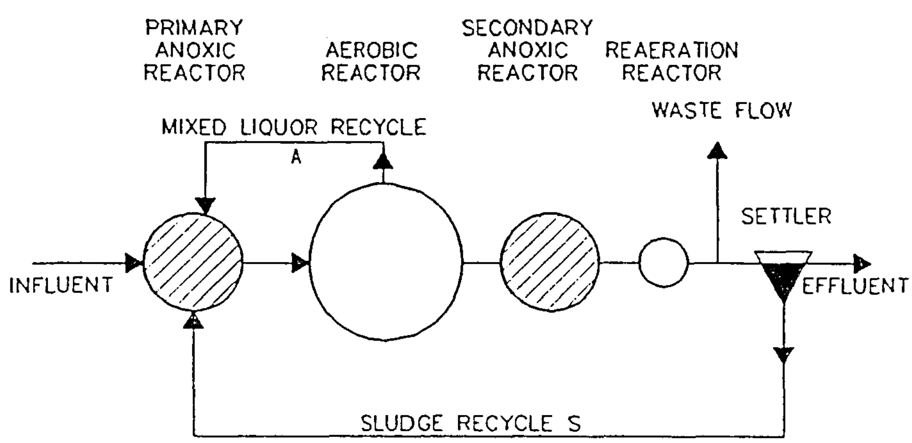
The various systems in common use in South Africa are shown diagrammatically overleaf.



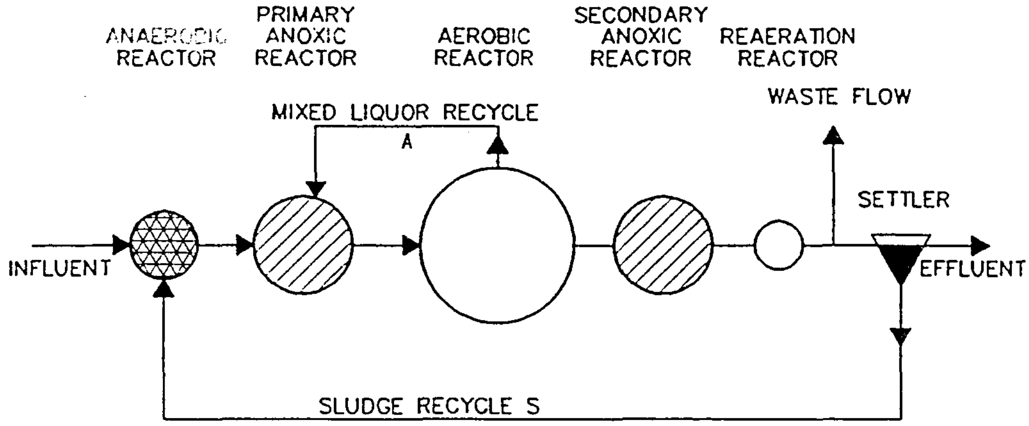
The Wuhrmann process for nitrogen removal



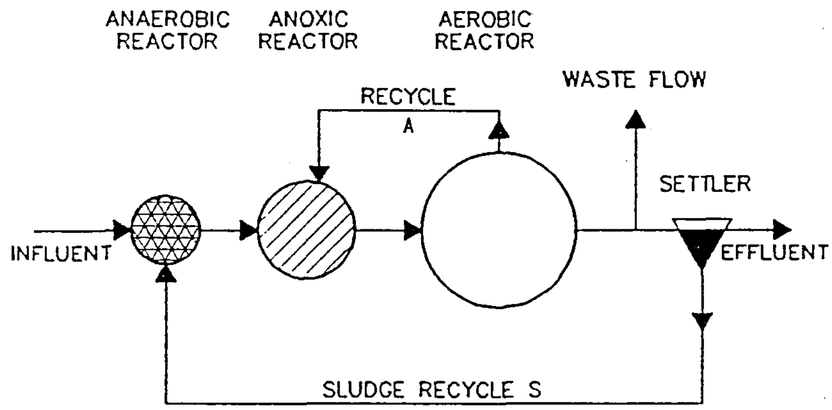
The modified Ludzack - Ettinger process for nitrogen removal



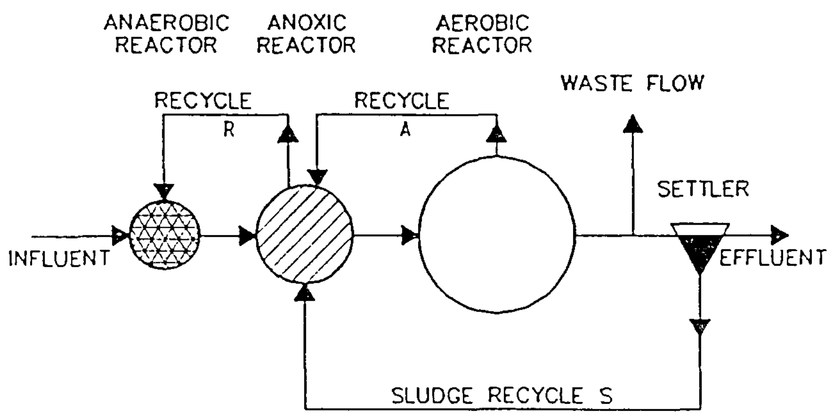
The Bardenpho process for nitrogen removal



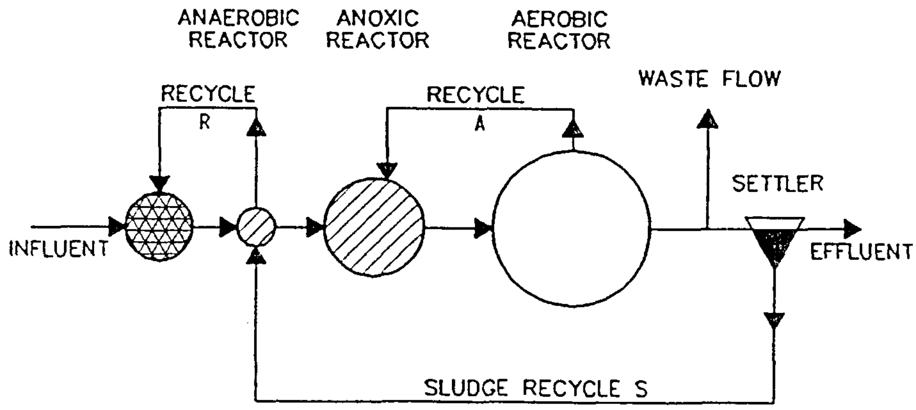
The Phoredox process for
biological nitrogen and phosphorus removal



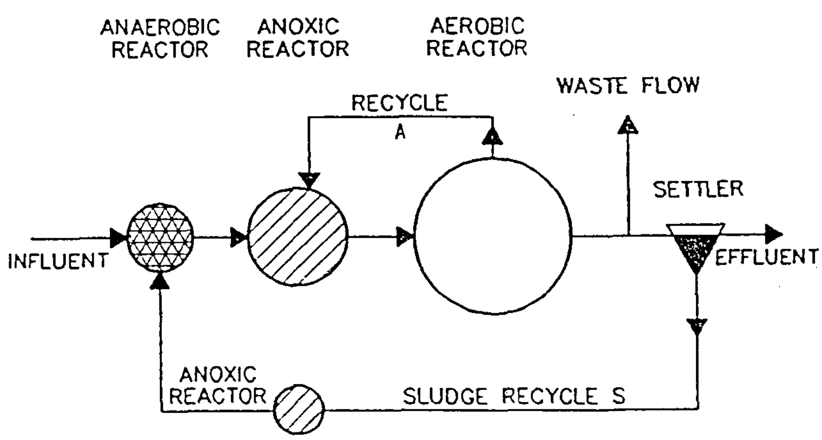
The 3 stage Phoredox process for
biological nitrogen and phosphorus removal



The UCT process for
biological nitrogen and phosphorus removal



The modified UCT process for
biological nitrogen and phosphorus removal



The Johannesburg process for
biological nitrogen and phosphorus removal

The selection of these systems is dependent on the $^{TKN}/_{COD}$ ratios of the wastewater being treated and the need to avoid returning nitrate into the anaerobic zones. The table below sets out the advantages and disadvantages of each configuration.

Table 1: Advantages and disadvantages of nitrogen and phosphorus removal systems

Process	Advantages	Disadvantages
Phoredox	Optimal nitrogen removal due to maximum use of anoxic volume.	The S-recycle discharges directly into the anaerobic zone and thus any nitrate in the effluent will decrease the effectiveness of the anaerobic zone.
UCT	The R-recycle should be very low in nitrate and oxygen and thus near optimal use of the anaerobic reactor is achieved.	The A-recycle rate must be carefully controlled so as not to overload the anoxic zone with nitrate which will be returned to the anaerobic zone. The introduction of a third recycle complicates the operation of the plant.
Modified UCT	The same as for the UCT system except that the first anoxic zone is exclusively for denitrifying the S-recycle. Careful control of the A-recycle is not required.	The same as for the UCT process except that by utilising the first anoxic zone for denitrifying the S-recycle the overall ability of the plant to reduce nitrates is further reduced.
Johannesburg	The anoxic zone between the settler and the anaerobic zone is exclusively for denitrifying the S-recycle. This results in the return flow to the anaerobic zone being very low in oxygen and nitrogen and near optimal use of the anaerobic reactor is achieved. The volume of the underflow anoxic reactor is small.	The anoxic volume available for denitrification of the A-recycle is reduced due to the exclusivity of the underflow anoxic zone.

4.4 Sidestream configurations

A side-stream system, known under the patented name of Phostrip, was developed in America for the removal of phosphorus. The initial concept was to provide an anaerobic zone into which a portion of the return activated sludge could be diverted. Release of the phosphorus occurred as a result of the extended anaerobic periods to which the sludge was subjected. An elutriant stream was used to wash the phosphorus out of the system, to be precipitated with lime. In subsequent developments, settled sewage was used as the elutriant and a separate anoxic zone was provided on the return to reduce any nitrate present in the return activated sludge before it entered the anaerobic zone. In both cases the sludge was returned to the aerobic reactor. The advantages and disadvantages are shown in Table 2.

Table 2 : Advantages and disadvantages of the Phostrip process

Process	Advantages	Disadvantages
Phostrip System	The excess phosphorus in the waste sludge is chemically bound. Thus if the sludge should be subjected to anaerobic conditions, the P will not be released back into the liquid phase.	Additional reactors and operational complexity and additional maintenance will also be required. The effects of nitrification on the different Phostrip layouts will reduce the anaerobic state of the stripper significantly. Chemical handling facilities and dosage equipment would be required.

5 PRIMARY SEDIMENTATION

Primary sedimentation reduces the organic load entering the activated sludge reactor. The reduction in load is achieved as the result of the solid material in the wastewater settling out in relatively quiescent conditions under the influence of gravity. The solid matter is removed for further treatment.

Poor performance of the primary settling tanks can adversely influence the operation of a biological nutrient removal works by increasing the load to the reactor, decreasing the oxygen to a point at which nitrification is lost, and increasing the biosolids concentration to the point of secondary clarifier failure. Septicity of the sludge will cause odour problems and toxic sludges can cause complete digester failure.

The primary sedimentation tanks can be used for the fermentation of the primary sludge to generate additional rapidly biodegradable COD and SCFA for improved phosphorus removal. This requires the elutriation of the fermenting sludge, either within the tank or more usually by recycling the fermenting sludge to the incoming sewage. It is important to maintain a constant sludge recycle and to waste sufficient sludge daily to avoid an excessive sludge build-up.

6 FERMENTATION

Short-chain fatty acids (SCFA) are essential for the successful removal of the phosphorus from the wastewater. These are either generated in the anaerobic zone of the reactor by the acidic digestion of the rapidly biodegradable COD (RBCOD) or can be supplemented by the fermentation of primary sludge. RBCOD generation from primary sludge can be maximised by preventing the onset of methane formation through control of the period for which the sludge is fermenting. The fermentation period should be kept between 3 to 6 days.

Fermentation can be effected in either a batch process or in a continuous process. In the former case the sludge is introduced into a tank and allowed to ferment for the required period before the SCFA is elutriated and the sludge removed. In continuously fed tanks the sludge is introduced daily. The elutriation and sludge wasting is continuous. It is normal for elutriation to be achieved by recycling the sludge and allowing it to resettle. Alternatively settled sewage can be pumped into the base of the fermenter tank and allowed to overflow into the main stream.

The most important aspect of the operation is the determination and control of the solids retention time (SRT). The appropriate SRT should be determined by measurement of the SCFA that are being developed at different sludge ages and thereafter the sludge wasting cycle established. This is a function not only of the temperature, but also of the degree of fermentation that has occurred already due to long retention in the outfall sewer.

7 FLOW BALANCING

The objective of flow balancing is to even out the variations in flow rate and loads that occur throughout the day. It enables the peak oxygen demand rate to be reduced, it smooths out the concentration of carbonaceous material entering the reactor, thus assisting denitrification, it provides an appropriate point of return for concentrated recycle streams from elsewhere on the works and, where chemical dosing is practised, it simplifies the chemical feed control.

The contents of the tanks require constant mixing, not only to prevent the deposition of solids, but also to spread the load across the tank. The outflow of the tank is often controlled electronically by means of valves or penstocks as the varying depth within the balancing tank generally makes hydraulic and manual control difficult.

8 REACTOR OPERATION

8.1 Mixing of unaerated zones

Mixing of the unaerated zones is imperative in order to prevent the deposition of solids and thus varying the mass fractions unintentionally. Mixing intensities should be as low as possible in order to limit the introduction of air as this adversely affects nutrient removal.

8.2 Oxygen utilization rate

The oxygen utilisation rate (OUR) is the rate at which the oxygen is used by the organisms. It varies in a plug flow reactor according to the distance from the inlet. It is at its highest nearest to the inlet, reducing along its length. This effect is also magnified according to the temperature, being far higher at the inlet at elevated temperatures.

8.3 Measurement of dissolved oxygen (DO)

The dissolved oxygen (DO) varies throughout the reactor, especially in reactors with surface aerators. Measuring points should be carefully selected and multiple points used in the larger works. Even self-cleaning and self-calibrating DO probes require regular checking and calibration.

8.4 Aeration equipment

There are essentially two types of aeration equipment - mechanical aerators and diffused air. The former rely on the agitation of the liquid to introduce the oxygen into spray as well as the powerful mixing action induced. The latter rely on the transfer from the small bubbles that are formed at the diffuser head as they rise through the liquid.

8.5 Control of diffused air aeration equipment

Control of the rate of aeration by diffused air equipment is effected by either using damping valves on the inlet to the blowers or by varying the speed of the blower in order to contain the DO within predetermined high and low set points.

8.6 Control of mechanical aerators

There are three basic methods in use for the control of the aeration achieved with mechanical aeration systems.

- Dissolved oxygen probe generated, with controlled switching on and off of aerators with manual or automatic liquid level maintenance to maintain the dissolved oxygen, as measured at one or more points between fixed upper and lower limits.

- Time-generated controlled switching on and off of aerators with manual or automatic liquid level maintenance. The timing sequence can either be set manually or be based on historic data.

- Dissolved oxygen probe generated, with oxygen transfer of aerators controlled by immersion depth variation with automatic liquid level maintenance initiated by dissolved oxygen measurements.

8.7 Control of sludge age

Control of sludge age is important in controlling the performance of a works. Sludge age is defined as the mass of sludge in the reactor, including that in the unaerated reactors, divided by the mass of sludge wasted per day. Therefore, in order to waste a fixed fraction of the total mass each day the most simple and accurate method is to waste a fixed volume of mixed liquor each day and hence a fixed proportion of the total sludge mass. Such wasting should preferably take place over a long period each day to prevent overloading of the sludge handling facilities.

8.8 Control of internal recycles

Control of the internal recycles is the next most critical operation for the successful removal of nutrients.

- A-recycle (aerobic-anoxic recycle)

This recycle returns nitrate to the anoxic zone for denitrification. Control is important as too high a rate can result in reduced phosphorus removals, higher pumping costs and as recent research has shown, a bulking sludge. It can be optimised as indicated in the table below.

Table 3 : Optimisation of A-recycle rate

Nitrate Concentration	Required Adjustment of Recycle Rate
High effluent nitrate; zero nitrate at the end of the anoxic zone.	Increase recycle rate, further denitrification may be possible.
High nitrate at the end of the anoxic zone; decrease in P-removal in the UCT process; bulking sludge.	Reduce recycle rate to save power - the anoxic zone is operating at its full denitrification potential and no further denitrification is possible.

- S- recycle (clarifier recycle)

Control of the return rate of the clarifier underflow is important as it has a similar concentration of nitrate as is in the effluent. In the Phoredox system it affects phosphorus removal directly and the rate should be minimised. In the Johannesburg and UCT systems it is possible to overload the anoxic zone and to exceed the denitrification potential of the zone. Strict control is required to prevent nitrate passing into the anaerobic zone reducing phosphorus removal.

- R-recycle (anoxic-anaerobic recycle)

This is applicable only to the UCT and MUCT processes and should be controlled to ensure that sufficient solids are returned to the anaerobic zone to maintain the design anaerobic mass fraction.

9 FINAL CLARIFIERS

The final clarifiers are used to separate the solids from the liquid, ensuring a clear effluent and return of the thickened biomass to the reactor. Poor performance of the clarifiers is usually due to reduced settleability of the sludge caused by over- or under-aeration, poor control of the A-recycle and low pH values.

Clarifiers can be circular, the more popular South African selection or rectangular in plan. The sludge is either collected by gravity in Dortmund type tanks or by mechanical scraping. The sludge is discharged continuously either through a rate controlling valve or directly into the pump suction to be pumped back to the reactor. Sidewall depth is important to ensure adequate depth for the settling and compression zones. An alternative sludge removal system is the suction lift type for flat-bottomed clarifiers. Scum removal systems need to be able to remove scums quickly before the release of phosphorus can occur. Alternatively no scum boards may be fitted, preventing the accumulation of scums, but this can result in an increase in effluent suspended solids.

Sludge can be recycled either by means of centrifugal or Archimedean screw types of pumps. The latter type has the advantage of being able to pump at the same rate as the incoming flow but can add air to the return flow, an undesirable feature for BNR works. Rate of flow adjustment is required, in order to prevent the retention of the sludge in the clarifiers for too long a period which can lead to the release of phosphorus and rising sludges due to denitrification.

10 SLUDGE THICKENING AND DISPOSAL

Phosphorus is transferred from the liquid to the biological solids in the system in a BNR works. Provided the sludge remains in an aerobic state the phosphorus remains bound to the sludge. However when the sludge becomes anaerobic, phosphorus will once again be released to the liquid phase. This occurs relatively quickly after aeration ceases. Release can also occur in aerobic digestion, once the substrate has been exhausted.

In order to reduce the digester size, the waste sludge will require thickening particularly if it has been wasted directly from the biological reactor. Gravity thickening and dissolved air flotation thickening are the methods commonly used in South Africa. These are compared below.

Table 4: Advantages and disadvantages of gravity thickening compared to DAF thickening

Advantages	Disadvantages
Has sludge storage capabilities.	Requires more area.
Requires less operational skill.	Can produce odours.
Lower operation and maintenance cost.	Solids liquid separation can be problematic especially if "bulking" sludges are thickened.
	Produces a lower thickened sludge concentration than DAF thickening.
	Denitrification can occur causing flotation and subsequent sludge carryover.
	P release into the clarified liquor can occur should the sludge become anaerobic.

Table 5: Advantages and disadvantages of DAF thickening compared to gravity thickening

Advantages	Disadvantages
Provides greater solid/liquid separation and solids concentration when thickening WAS.	Has very little sludge storage capacity - can only store for a couple of hours which may have an advantage in minimising P release.
Is effective in removing grease and oil.	Operating and electricity costs are much higher than gravity thickeners.
Requires a smaller tank area.	Requires more skill in operation than a gravity thickener.
Does not produce odours.	
Anaerobic phosphorus release into the clarified liquor is prevented.	
Can be operated in batch mode as it is relatively easy to start up and switch off.	

Both of these systems will produce a thickened sludge which is rich in phosphorus. As a result any liquors subsequently emanating from these sludges will be rich in phosphorus especially when digested anaerobically.

Anaerobic digestion is more fully described in *"Anaerobic Digestion of Waste Water Sludge-Operating Guide"*(WRC Project No 390). The main problem as it effects biological nutrient removal is the management and treatment of the liquors that come from the digester itself and in particular from the dewatering stages. Such liquors are characterised by very high nitrogen and phosphorus concentrations.

Depending on circumstances these can be treated either by transferring them back to the head of the works or in a separate dedicated plant. The former will affect the $^{TKN}/_{COD}$ ratio of the incoming sewage detrimentally. The latter will require the addition of chemicals, to remove phosphorus and control the pH. Alternatively they could be disposed of by irrigation, subject to approval by the Dept of Water Affairs and Forestry, and the addition of sufficient dilution water to prevent nitrogen poisoning of the vegetation and nitrate pollution of groundwater.

The disposal of sludge should be carried out in accordance with the guidelines produced by the Department of Health.

11 SIDESTREAM SYSTEMS FOR PHOSPHORUS REMOVAL

A system of phosphorus removal was developed in America by Dr Levin, which has been patented under the name of

Phostrip. No theoretical basis has been developed for this system and control and operation are empirical relying on the use of the laboratory to determine the mass of incoming and outgoing phosphorus in the liquid phase.

The operator has a number of control strategies available. By decreasing the sludge age in the aerobic reactor he can increase the active mass of the sludge and hence the ability of the sludge to store phosphorus. The concentration of the return sludge can be increased by reducing the S-recycle rate and hence the concentration in the stripper. This in turn affects the solids retention time in the stripper and the release of phosphorus. Varying the rate of bleed off from the S-recycle into the stripper will also affect the solids retention time. The rate at which the underflow is withdrawn also affects the solids retention time. All these actions will affect the amount of phosphorus released from the sludge.

The stripper operates in the same manner as a thickener and care should be taken not to overload it in terms of sludge loading.

12 CONTROL TESTS

The performance of the works should be monitored regularly in order to ensure that it is meeting its performance criteria and that it is doing so in an efficient manner. The monitoring can take place in the following ways:

12.1 Visual inspections and observations conducted on a daily basis. The operator needs good experience, linked to formal measurements, in order to detect impending problems. The senses of sight, hearing and smell should all be used so that any abnormality can be detected quickly.

12.2 *In situ* measurements which can be taken either manually or automatically or be the product of on-line instrumentation. This is usually limited to DO and pH measurements, although larger works may have more sophisticated on-line equipment.

12.3 Analysis of samples in the laboratory, whether on site or at an outside laboratory. This is the most usual method of monitoring the performance of the works. Samples may either be grab samples or composite samples, depending on the tests to be carried out. The accuracy of the results depends as much on the correct sampling and handling procedures as on correct analytical work. Such tests are necessary to ensure compliance with legal requirements and the speedy identification of developing problems. Graphs of the measured data should be plotted to identify trends.

12.4 The systematic collection and collation of data including visual observations can be referred to for improved plant performance. It is important to maintain full and comprehensive records on the works, but these should be limited to those that will help the operators to recognise trends or provide designers with the necessary data to design the next extension.

13 TROUBLE SHOOTING

The operator is referred to the trouble shooting guide in this manual in the event of any specific problem arising at any point on the works.

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LIST OF NOMENCLATURE

1. Aerobic - a zone where oxygen is present
2. Anaerobic - a zone which is deficient in nitrate and oxygen and the input of both is severely restricted
3. Anoxic - a zone where nitrite and nitrate are present, but deficient in oxygen
4. BNR - Biological nutrient removal
5. COD - Chemical oxygen demand
6. DAF - Dissolved air flotation
7. Denitrification - process in which nitrate is reduced to nitrogen
8. DO - Dissolved oxygen
9. F_{xt} - unaerated sludge mass fraction
10. MLSS - Mixed liquor suspended solids
11. N - Nitrogen
12. NH_4^+ - Ammonia
13. Nitrification - process in which ammonias are oxidised to nitrates
14. NO_3^- - Nitrate
15. Oxidation - donation of electrons
16. PST - Primary sedimentation tank
17. RAS - Return activated sludge
18. RBCOD - Rapidly biodegradable COD
19. Redox reaction - pair of reduction/oxidation reactions
20. P - Phosphorus
21. Reduction - acceptance of electrons

22. SBCOD - Slowly biodegradable COD

23. SCFA - Short chain fatty acids

24. Supernatant - liquid overflowing from PSTs, clarifiers and gravity thickeners

25. μm - 10^{-6} m

26. Underflow - liquid drawn from the bottom of PSTs, clarifier and gravity thickeners

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CHAPTER 1

INTRODUCTION

The Nature and Extent of the Water Pollution Problem

"Man is both creature and moulder of his environment, which gives him physical sustenance and affords him the opportunity for intellectual, moral, social and spiritual growth. In the long and tortuous evolution of the human race on this planet a stage has been reached when, through the rapid acceleration of science and technology, man has acquired the power to transform his environment in countless ways and on an unprecedented scale. Both aspects of man's environment, the natural and the man-made, are essential to his well-being and to the enjoyment of basic human rights — even the right to life itself"

Declaration of the Report of the United National Conference on the Human Environment. Stockholm 1972.

1.1 Effects of nutrients on bodies of water

The continuous enrichment of waters with nutrients notably nitrogen and phosphorus in conjunction with carbon dioxide results in the prolific growth of algae (algal blooms), a process referred to as eutrophication. Eutrophication is a natural ageing process which occurs regularly in lakes over hundred of years and is usually limited to quiescent bodies of waters such as lakes and impoundments. The natural eutrophication process is however greatly accelerated by human activities in the catchment areas of lakes and impoundments, through the increased input of nutrients.

Gross eutrophication is marked when the inorganic soluble nitrogen (N) and phosphorus (P) in waters reaches concentrations in excess of 0,3 mg N/ℓ and 0,015 mg P/ℓ respectively. Large visible algal blooms occur when these conditions are met. If eutrophic impoundments are utilised as sources of potable water then additional costs are incurred by water purification works using these waters, due to problems associated with tastes and odours, filter and screen clogging, slime accumulation in pipes and toxicity caused by certain algae. In addition to these treatment problems the appeal of the water for recreational purposes is also reduced.

Furthermore, although algae form an essential part of the aquatic environment excessive algal growth is detrimental to the aquatic ecosystem. For example, when large numbers of algae die at the same time, a large pool of nutrients is released into the water body, resulting in an accelerated growth of other organisms, which depletes the water of oxygen and may result in fish kills.

The species of algae associated with eutrophication can be divided into four broad groups, namely, the blue-green algae (*Cyanobacteria*), the green algae (*chlorophyta)*, the diatoms, and the flagellates.

The blue-green algae bloom extensively during late summer and play an important role in the nitrogen cycle. The ability of these algae to fix nitrogen from the atmosphere can be regarded as the starting point of the nitrogen cycle. Nitrogen, assimilated by these algae from the atmosphere, is released by the algal cells when they die and is then available to all the other aquatic life forms. It is therefore virtually impossible to control eutrophication by limiting nitrogen and in most cases phosphorus has been shown to be the limiting nutrient. It is for this reason that much research into biological phosphorus removal has been carried out in recent years.

1.2 Sources of nutrients

Nutrients resulting in rapid eutrophication are introduced to waters by human activities from both diffuse and point sources. Nutrients introduced from diffuse sources are difficult to control because as the name suggests they are introduced in relatively small concentrations over large areas from sources such as fertilizers, livestock, water fowl, informal settlements etc. Nutrients introduced from point sources are easier to control as the nutrients that originate from residential and industrial areas are concentrated at a point by means of sewers. The focus of this manual is on the effective operation of various biological works to remove nutrients responsible for eutrophication from these point sources.

1.3 Systems used to limit nutrients

Limitation of nutrient discharges into waters from point sources is usually achieved by biological means, either by way of biological trickling filters or activated sludge systems. Both these systems utilize naturally occurring bacteria to reduce the nutrient concentrations entering waters. Artificial conditions favourable for the controlled growth of these bacteria are created within these systems and results in concentrations of at least a million times that found in the natural environment. The bacteria in these systems utilize the nutrients for growth and in this way the nutrients pass from the liquid phase into the solid phase and are concentrated in the biological culture.

Although the biological trickling filters and activated sludge works are effective in removing carbon it is only the activated sludge works that can be designed to remove nitrogen and phosphorus from wastewater streams effectively. This is achieved *biologically* by the incorporation of aerobic (oxygen and nitrate present), anoxic (nitrate present but deficient in oxygen) and anaerobic (deficient in nitrate and oxygen) zones. In the aerobic zone, carbon is removed and ammonias are oxidised to nitrate, in a process called nitrification. In the anoxic zone, the nitrates are reduced to nitrogen gas via the denitrification process. The anaerobic zone is essential for inducing biological P removal. Systems which do not incorporate these features generally rely on iron (Fe) salts such as ferric chloride ($FeCl_3$) and aluminium (Al) such as aluminium sulphate ($Al_2(SO_4)_3$) or lime $Ca(OH)_2$ to precipitate phosphorus and so limit eutrophication.

Both chemical and biological nutrient removal have a place in limiting the eutrophication of waters. The advantages and disadvantages of each are listed below.

1.3.1 *Advantages of chemical phosphorus removal*

With proper control and dosage, a consistently low effluent P concentration can be ensured.

Chemically precipitated phosphorus is not easily dissociated, thus reducing release back into the liquid medium.

The dosing systems can be easily incorporated into existing systems at a reasonable cost and are not greatly influenced by wastewater characteristics. The dosage is, however, affected by the diurnal phosphorus patterns.

1.3.2 *Disadvantages of chemical phosphorus removal*

The chemicals used are corrosive in nature and require care when handling, thus necessitating more expensive equipment.

Chemical costs result in significant increases in treatment costs.

It increases the salinity in receiving waters, particularly when these waters are reused a number of times.

Careful control of chemical dosing to match diurnal phosphorus load patterns is required.

The chemical (e.g. iron and aluminium) dosing ratio is much higher than the stoichiometric relationship.

The sludge volumes and masses produced are increased by the generation of chemical sludges.

Chemical addition results in sludges which are more difficult to de-water prior to disposal.

Excessive dosing can affect the efficiency of biological P removal. However, this may not always be true for all wastewater works.

1.3.3 *Advantages of biological nutrient removal*

Savings in chemical costs.

It does not add significantly to the salinity of receiving waters.

The long sludge ages required by the process produce sludges which are not odorous.

It produces sludges suitable for use as soil conditioners if the wastewater does not contain excessive heavy metals due to industrial wastes.

Some of the alkalinity and oxygen used during nitrification is recovered in the denitrification process.

1.3.4 *Disadvantages of biological nutrient removal*

The efficiency of removal is influenced by the wastewater characteristics.

The phosphorus-rich biological sludge wasted from the system will release phosphorus back into the liquid stream if it is not treated correctly.

Because unaerated zones are introduced, relatively long solids retention times (sludge ages) are required in the biological reactors to ensure nitrification in winter, resulting in large biological reactors.

Anaerobic digestion of phosphorus-rich biological sludges in the presence of magnesium can result in struvite precipitation causing blockages in digester pipework. Unfortunately the maximum concentration of magnesium to avoid precipitation is not known.

It requires greater skills from the operating staff.

1.4 **Purpose of Manual**

This Manual is intended for use by managers and owners of biological nutrient removal wastewater treatment works in South Africa and the staff who operate them.

The objective of the Manual is to provide information which will assist trained operators to understand the complexities of biological nutrient removal and to optimise the control of these systems. The presentation assumes that the reader has some experience with activated sludge systems and wastewater treatment works at a level equivalent to a Class IV operator.

The Manual does not cover the operation of the inlet works, which comprises screening and degritting, as their operation is common to most wastewater treatment works and has little influence on the performance of the biological nutrient processes. It is however important for the protection of mechanical equipment installed in downstream processes.

CHAPTER 2

LEGAL REQUIREMENTS

2.1 Policy

The policy of the Department of Water Affairs and Forestry, which is the regulatory body, is best summarised by the following quotation from the Annual Report of the Department, 1988/89.

"The Department is responsible for protecting the water quality of the country's water resources.
The proper management of water quality requires that comprehensive water quality and quantity plans are developed and implemented for each drainage basin in the RSA. For the development of such water resource management plans, pollution control must be integrated with the Department's other water quality and quantity management activities and must be aimed at achieving water use-related quality objectives.

Major economic, political, social and demographic changes are taking place in the RSA. These changes are manifested in increasing competition for State funds; the increasingly important role the informal sector and small businesses are playing in the national economy; and changes taking place in urbanisation patterns. These changes also have an impact on water quality and the management thereof. At the same time there is an increasing awareness among South Africans of water quality and the need for its proper management.

At present, the Department controls water pollution from point sources by requiring that effluents comply with uniform (general and special) standards which were set at technological and economically attainable levels. Relaxation of these standards is negotiated in certain individual cases on the basis of technological, economic and socio-political considerations, often without the benefit of knowing the impact of the standards or their relaxation on the quality of the receiving waters. It is believed that, in general, these standards serve a useful purpose by limiting the rate of deterioration in water quality focusing attention on pollution and promoting improvements in waste-water treatment technology and management. However despite these efforts to control pollution, the deterioration of the quality of our water resources is continuing."

2.2 Legislation primarily affecting the source of pollution or dealing with activities which produce pollution

2.2.1 Pollution resulting from the use of water for industrial purposes

The use of water for industrial purposes is governed by the Water Act, (Act No 54 of 1956). The Water Act is currently being reviewed by the Department of Water Affairs and Forestry and will be amended. Because industrial effluent, when returned to a water source, disadvantages other users, the authority to grant rights to the use of public water for industrial purposes has been conferred on a water court. No-one may use public water for industrial purposes without the permission of a water court except in the case of water supplied by the Minister from a state waterworks, a local authority or similar body that has the right to control or supply water to any person using public water for industrial purposes in terms of section 62(2I)(a) of the Water Act, and any person not exceeding the quantity of water lawfully used by him previously. A further exception is made in the case of a person who has a right to use public water for agricultural purposes. A person also may obtain a permit from the Minister to use water for the development of power or for the winning or washing of sand, gravel or stone, etc.

In addition to the right obtained from a water court to use public water for industrial purposes, if the use of public water is to exceed 150 m^3 on any day, a permit from the Minister is required. In addition, in an appropriate case, a permit for a water care works as defined in the Water Act 1956 will be required.

The sanction for the use of water for industrial purposes exceeding during any day 150 m^3 except under the authority of a permit and strictly in accordance with the conditions thereof is that the supply will be suspended or reduced to a quantity determined by the Minister.

Certain duties and exceptions must be noted:

(a) Duty to purify effluent

Where any water, including sea water, is used for industrial purposes, the person so using the water must purify any resultant wastewater, effluent or waste so as to conform to such requirements as the Minister of Water Affairs & Forestry may, after consultation with the South African Bureau of Standards, prescribe by notice in the Gazette. These requirements provide a large degree of flexibility in that they may be prescribed either -

(i) generally, or

(ii) in relation to water used for any particular industrial purpose, or

(iii) in relation to water or effluent to be disposed of by discharging it into any particular stream, or into the sea, or

(iv) in relation to water or effluent to be disposed of in any particular area.

Standards at present comprise a General Standard applied universally, a Special Standard for specified streams and a Special Standard for Phosphate applicable to certain sensitive catchments. These effluent standards as well as the methods of testing waste water or effluents have been promulgated and are conveniently summarised and consolidated in the *Management of the Water Resources of the Republic of South Africa.*

Table 1.1 summarises the effluent standards, which have been reproduced from the above publication.

Table 2.1: Effluent Standards Applicable to Direct Discharge into Freshwater Sources as Promulgated in Terms of Section 21 of the Water Act 1956.

Note: All units in mg/ℓ unless specified otherwise

General and Special Standards for Effluents								
Property		Maximum allowable except where marked (*)		Property		Maximum allowable except where marked (*)	
		General	Special			General	Special
1.	Colour, odour or taste	Nil	Nil	12.6	Total chromium (as Cr)	0,5	0,005
2.	pH	5,5-9,5	5,5-7,5	12.7	Copper (as Cu)	1,0	0,02
3.	Dissolved oxygen (percentage saturation)	75*	75*	12.8	Phenolic compound (as phenol)	0,1	0,01
4.	Typical faecal coli (per 100 mℓ	Nil	Nil	12.9	Lead (as Pb)	0,1	0,1
5.	Temperature (°C)	35	25	12.10	Soluble ortho-phosphate (as P)	-	1,0
6.	Chemical oxygen demand (after chloride correction)(mg/ℓ)	75	30	12.11	Cyanides (as Cn)	0,5	0,5
7.	Oxygen absorbed (from N/80 potassium permanganate in 4 hours at 27°C)(mg/ℓ)	10	5	12.12	Iron (as Fe)	-	0,3

General and Special Standards for Effluents					
Property	Maximum allowable except where marked (*)		Property	Maximum allowable except where marked (*)	
	General	Special		General	Special
8. Conductivity			12.13 Sulphides (as S)	1,0	0,05
8.1 Above that of intake water	75 mS/m	15%	12.14 Fluorides (as F)	1,0	1,0
8.2 In respect of mining effluent (mS/m at 25°C)	250	250	12.15 Zinc (as in Zn)	5,0	0,3
9. Suspended solids (mg/ℓ)	25	10	12.16 Manganese (as Mn)	0,4	0,1
10. Sodium content (above that of intake water) (mg/ℓ)	90	50	12.17 Cadmium (as Cd)	0,05	0,05
11. Soap, oil or grease (mg/ℓ)	2,5	Nil	12.18 Mercury (as Hg)	0,02	0,02
12. Other constituents (maximum in mg/ℓ):			12.19 Selenium (as Se)	0,05	0,05
12.1 Residual chlorine (as Cl)	0,1	Nil	12.20 Sum of concentrations of cadmium (as Cd), chromium (as Cr), copper (as Cu), mercury (as Hg) and lead (as Pb)	1,0	-
12.2 Free and saline ammonia (as N)	10,0	1,0	12.21 The wastewater or effluent shall contain no other constituents in concentrations that are poisonous or injurious to		
12.3 Arsenic (as As)	0,5	0,1	• humans, animals, fish other than trout, or other forms of aquatic life, or that are deleterious to agricultural use	Applicable	-
12.4 Boron (as B)	1,0	0,5	• trout or other fish, or other forms of aquatic life	-	Applicable

General and Special Standards for Effluents					
Property	Maximum allowable except where marked (*)		Property	Maximum allowable except where marked (*)	
	General	Special		General	Special
12.5 Hexavalent chromium (as Cr)	0,05	-			

Special Standard for Phosphates

Effluents discharged into the following rivers or their tributaries in the RSA shall not contain soluble orthophosphate (as P) in a higher concentration than 1,0 mg/ℓ:

(a) Vaal River upstream and inclusive of the Bloemhof Dam

(b) Pienaars and Crocodile River upstream and inclusive of the Loskop Dam

(c) Great Olifants River upstream and inclusive of the Loskop Dam (Transvaal)

(d) Umgeni River upstream of the influence of tidal water (Natal)

(e) Umlaas River upstream of its point of discharge into the sea (Natal)

(f) Buffels River upstream and inclusive of the Bridle Drift Dam (Cape Province)

(g) Berg River upstream of the influence of tidal water (Cape Province)

(b) Duty to return water and effluent to origin

Purified or treated water that has been used for industrial purposes, including water recovered from any effluent, if derived from a public stream must be discharged at the place where it was taken from the stream or at such other place where the Minister of Water Affairs & Forestry may indicate.

If the water was sea water it must be returned into the sea at the place where it was taken from the sea or at such other place as the Minister of Water Affairs and Forestry may indicate.

In addition the person making the discharge into the stream or sea must furnish the Director-General of the Department of Water Affairs and Forestry with the written particulars as may be prescribed by regulations under Section 26 of the Water Act, of such use and disposal. Any person who contravenes or fails to comply with any of the above-mentioned duties, commits an offence.

(c) Exemptions

Provision is made for the duty to purify effluent or to return used water to its origin. Unless the Minister directs otherwise, the discharge of industrial effluent into a sewer of a local authority is not subject to the requirements of the Water Act.

A person who is supplied by a local authority or by the Minister of Water Affairs and Forestry and the local authority or Minister has undertaken the duty of disposing of such water, effluent or waste after the water has been used is not bound to treat the wastewater after it has been discharged into the municipal sewer.

Since a local authority that uses water for the purification or disposal of sewage, effluent or waste is deemed to use such water for industrial purposes, it must comply with the two duties discussed above.

In short, this means that the local authority can either completely or partly take over the duties of the industries, so depending on its own water supply and waste acceptance policy. However, industries are responsible for the disposal of effluents unless the local authority accepts such effluent.

After consultation with the South African Bureau of Standards and the Department of Population Development in cases where health hazards may exist, the Minister of Water Affairs and Forestry may grant exemption from compliance with the standards and from the requirement to return purified water to the stream of origin.

Anyone prejudiced by the exemption granted may appeal against the decision to a water court. The Minister of Water Affairs and Forestry may himself withdraw any exemptions or amend, withdraw or impose any condition in connection therewith. Any person who contravenes or fails to comply with the conditions of an exemption, commits an offence.

2.2.2 Pollution detrimental to public health

Almost all water pollution control is aimed at protecting the health of people. Among the functions entrusted to the Department of Health Services by the Health Act 63 of 1977 is the promotion of a safe and healthy environment.

The Minister may delegate this function to a provincial administration, subject to such regulations and conditions as may be imposed. If the Minister is satisfied that a local authority is able to perform this function and/or any other function that the Minister may delegate, or if the local authority requests delegation of the functions, these can be delegated to the local authority.

Finally, the Minister of Health Services has wide powers to make regulations for the control of water pollution, relating, *inter alia*, to the following -

- The supply of water for human use and the establishment of sewage and water purification works.
- The quality of water intended for human use, the quantity of water to be available for human use and the system of distribution of such water.
- Water sampling and analysis and the addition of any substance to water intended for potable purposes.
- Materials used for the construction of water care works or water supply schemes.

2.3 Amendments brought about to the Water Act by legalisation subsequent to publication of environmental concerns in South Africa

(a) A definition of *"effluent"* was introduced into the Act by sl of Act 96 of 1984. The definition of water pollution occurring in s23 of the Act was expanded by s13 of the same Act.

(b) The use of private water for industrial purposes has been made subject to the same provisions of the Act as applied to the use of public water for industrial purposes — ie ss 12, 21, 22, 23 and 24 of the Act. See s2 of Act 96 of 1984. Section 5 of Act 68 of 1987 gives a local authority in certain circumstances the same authority and discretion to control the use of private water by permit as is conferred on the Minister in terms of Section 5(2) of the Water Act.

In this way local authorities can ensure that private water is put to the best public use.

(c) Section 21(3) of the Water Act as substituted by all of Act 96 of 1984 makes the requirements of purifying water to a standard and the penalties in connection therewith applicable to local authorities in the purification of effluent sent to them for processing.

The definition of *"use for industrial purposes"* was extended by s1(e) of Act 96 of 1984 to include *"any sewage system or work or any water care work"*.

Therefore a local authority is obliged to clean the water entering its sewage works whether produced by industrial or urban use to the required standard and is subject to the sanctions imposed.

(d) The Water Amendment Act 68 of 1987 introduced certain improvements aimed at regulating water pollution, and increased the penalties for pollution.

CHAPTER 3

GENERAL DESCRIPTION OF BIOLOGICAL NUTRIENT REMOVAL

3.1 Introduction

All life forms require a source of energy and matter to sustain their existence.

Simple life forms such as algae and plant life obtain energy from the sun and are thus termed phototrophs.

More complex life forms prey on phototrophs as a source of energy.

As the energy obtained from phototrophs is organic in nature, this group of organisms is termed heterotrophs.

In cases where the hydrogen and carbon sources are inorganic compounds, the group of organisms is termed autotrophs.

In all three groups of organisms, the process whereby the organisms grow occurs through a series of reduction-oxidation or redox reactions in which electrons are accepted or donated (acceptance of electrons is known as reduction and donation of electrons is known as oxidation).

Matter required for maintaining and reproducing life is obtained from five major nutrient sources, carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and phosphorus (P). Hydrogen and oxygen are readily obtainable from water and carbon from carbon dioxide. More often the limiting nutrients, although nitrogen can be readily obtained from air, are nitrogen and phosphorus. The availability of nitrogen and phosphorus (and sometimes carbon), therefore, often limits the growth of algae and plant life. This in turn limits the growth of the heterotrophs. Therefore by minimising the mass of nutrients discharged to a water body, the risks of causing eutrophication are minimised.

In wastewater treatment, the objective of Biological Nutrient Removal (BNR) is to remove the primary nutrients which cause eutrophication namely carbon, nitrogen (N) and phosphorus (P) from wastewaters. Probably the most important nutrient to remove is P since N is readily obtained from air i.e. P, and sometimes C, are limiting for growth in receiving waters.

This chapter discusses the biochemical removal mechanisms of these nutrients from wastewaters.

3.2 Carbon removal

Carbon in a wastewater stream occurs in organic and inorganic compounds. Organic compounds can be utilised by heterotrophs and inorganic compounds by a group of organisms termed autotrophs.

Both forms of carbon are removed from the wastewater through a series of redox reactions, oxidising the carbon source to carbon dioxide and water. The carbon dioxide then escapes to the atmosphere, removing carbon from the waste stream.

Carbonaceous material (that which contains carbon) in wastewater can be split into two principle forms: biodegradable and non-biodegradable. Each form has two fractions, viz. soluble and particulate. The relative fractions of each constituent can vary considerably with different types of wastewater.

The non-biodegradable material is not broken down within the treatment process. Generally the non-biodegradable particulate material becomes enmeshed in the sludge, settles out in the sedimentation tanks and is removed from the system with the waste sludge. The non-biodegradable soluble fraction passes through the treatment process and is discharged with the effluent, sometimes giving rise to high effluent concentrations.

The biodegradable carbonaceous material is broken down in the treatment process by heterotrophic organisms under aerobic conditions (oxygen present) in an aeration basin. The soluble biodegradable material is rapidly used by the organisms (and is thus called readily biodegradable COD) whereas the particulate fraction is rapidly adsorbed but assimilated more slowly (and is thus called slowly biodegradable COD).

Within the chemical reactions associated with the breakdown of carbonaceous material, electrons are transferred and accepted in redox reactions.

The two main reaction paths within these reactions are termed the catabolic and anabolic pathways. In the catabolic pathway, a fraction of the organic molecules is taken up by the organism and oxidised to carbon dioxide and water. Associated with these reactions is the release of a large amount of energy. A small amount of this energy is captured by the organism and can be utilised e.g. for cell growth while the remaining energy is lost as heat.

The anabolic pathway is the pathway by which the organisms construct new cell mass i.e. grow. A small fraction of the organic molecules taken up in the catabolic pathway is modified to form part of the cell mass.

These two cycles put together form the metabolism of the organism and in this manner energy is removed from the wastewater. Under aerobic conditions, it has been established that the amount of energy released in the anabolic and catabolic pathways is proportional to the mass of oxygen utilised for cell growth, which in turn can also be related to the number of electrons donated in the oxidation of organic compounds.

In order to determine the energy content of a wastewater, and consequently the oxygen requirements for carbon removal, two main tests are used. These are the 5-day Biochemical Oxygen Demand (BOD_5) test and the Chemical Oxygen Demand (COD) test.

The BOD_5 test is an empirical test performed under strictly specified conditions, and measures the oxygen utilised by organisms over a 5-day period. Although this parameter is still used, elsewhere in the world research has established that the BOD_5 test underestimates the actual energy within the wastewater. The time required to obtain the test results often makes this test impractical for use as a monitoring parameter at treatment works. Furthermore, nitrifying organisms (see Section 3) in the test sample may utilise oxygen to convert ammonia (NH^{+}_{4}) to nitrates (NO^{-}_{3}) giving an inflated carbonaceous energy measurement.

From the above it would appear that the BOD_5 test does not give an absolute value but is nevertheless useful for comparison purposes.

The COD test uses a strong oxidising agent (a hot dichromate sulphuric acid solution) to oxidise organic compounds to water and carbon dioxide. Ammonia is not oxidised and thus the test gives an accurate estimate of the carbonaceous energy within the wastewater, provided the test is conducted in strict accordance with the procedures set out in Standard Methods (see section 12.3). The test takes approximately 3 to 4 hours to complete and is thus far shorter that the BOD_5 test. It is therefore a reasonably quick and accurate method to measure the carbonaceous energy within a wastewater.

In this Manual, reference will be made to COD as it is believed that this measurement is better suited for application within the wastewater field.

In the treatment process the biodegradable COD (or carbonaceous material) is broken down by the heterotrophic organisms under aerobic conditions. A small percentage of the energy derived from the reactions is utilised for synthesis or growth of new cell material - the remaining fraction is used as energy to bring about the synthesis reactions and is eventually lost as heat. The micro-organisms are then separated from the liquid and discharged from the treatment system for further treatment. The liquid or effluent, which is now low in COD, is then discharged from the treatment system. In this manner, carbonaceous energy is removed from a wastewater.

3.3 Nitrogen removal

Nitrogen in wastewaters can be subdivided into two main forms: free and saline ammonia and organically bound nitrogen. The organically bound nitrogen can be subdivided further into non-biodegradable and biodegradable, both forms having soluble and particulate fractions. Generally wastewaters do not contain any nitrate or nitrite in the influent.

Nitrogen is characterised by the Total Kjeldahl Nitrogen (TKN) and the free and saline ammonia tests. Any nitrite or nitrate in the wastewaters is not measured in these tests.

Biodegradable organic nitrogen is broken down into free and saline ammonia within a sludge age of approximately 3 days. Non-biodegradable particulate nitrogen is generally settled out in sedimentation tanks and removed with the waste sludge stream. The non-biodegradable soluble nitrogen passes through the treatment system and is discharged with the effluent.

The first step in the nitrogen removal process is called nitrification. In this process free and saline ammonia obtained from the breakdown of organic nitrogen is oxidised to nitrite (NO_2^-) and then nitrate (NO_3^-) in the presence of oxygen. The groups of organisms responsible for the oxidation are termed autotrophic organisms. These organisms have quite different behavioural characteristics compared to the heterotrophs (carbon removing organisms).

There are two specific autotrophs, namely *Nitrosomonas* and *Nitrobacter*. *Nitrosomonas* converts free and saline ammonia to nitrite and *Nitrobacter* converts nitrite to nitrate. The oxygen requirement associated with this conversion amounts to 4,57 mg oxygen / mg N utilised.

The rate of conversion of ammonia to nitrite by *Nitrosomonas* is much slower than the conversion of nitrite to nitrate by *Nitrobacter*. The rate-limiting step is therefore due to *Nitrosomonas*. The specific growth rate of these organisms is much slower than the growth rate of the heterotrophic organisms and consequently the sludge age of a particular plant must be greater than the minimum time required for these organisms to multiply and survive within the system.

The nitrifying organisms are sensitive to the pH and alkalinity of the wastewaters. The growth rate of these organisms is severely inhibited outside the pH range of 7 to 8,5. During the conversion of ammonia to nitrate hydrogen ions are released resulting in a decrease in the alkalinity of the wastewater. Stoichiometrically, for every 1 mg of (NH_4-N) converted to nitrite or nitrate, 7,14 mg of alkalinity (as $CaCO_3$) is destroyed. If the alkalinity of a wastewater drops below 40 mg/ℓ (as $CaCO_3$), the pH becomes unstable resulting in a sharp decrease in nitrification efficiency due to the retarded growth rate of the autotrophs.

Low pH values can also adversely affect the sludge settleability and produce a corrosive effluent.

The disadvantages of nitrification discussed above can be partially overcome by the second step of the nitrogen removal process called denitrification. In this process the nitrates from nitrification are reduced to nitrogen gas.

This series of biological redox reactions takes place in an anoxic zone and is the only zone in a treatment process in which substantial nitrogen removal is achieved. An anoxic zone implies that there is nitrite and nitrate present but no oxygen. Within this zone the nitrite and nitrate formed in the aerobic zone are reduced to nitrogen gas, which escapes to the atmosphere. The nitrite and nitrate serve the same function as oxygen within the aeration basin, i.e. as an electron/hydrogen ion acceptor.

From stoichiometric relationships, when nitrate acts as an electron acceptor, 1 mg NO^-_3 as N is approximately equivalent to 2,86 mg O (as O) if oxygen was the terminal acceptor. If one thus combines the nitrification and denitrification processes, up to approximately 63% ($^{2,86}/_{4,57}$) of the oxygen demand for nitrification can be recovered if complete denitrification is achieved. Even if denitrification is not complete, any amount of denitrification will result in some "oxygen recovery".

Besides oxygen recovery the effect of nitrification on pH and alkalinity can be reduced as during the denitrification step, for every mg of nitrate denitrified to nitrogen gas, 3,57 mg (as $CaCO_3$) alkalinity is produced. It is therefore possible to recover up to 50% of the alkalinity lost during nitrification.

The chemical reactions associated with phosphate removal using alum are:

$Al_2(SO_4)_3 + 6OH^- \rightarrow$

$2Al(OH)_3 + 3SO^{2-}_4 + 6CO_2s + Al(SO_4)_3 +$

$2PO^{3-}_4 \rightarrow 2AlPO_4 + 3SO^{2-}_4$

Phosphate removal using alum is also dependent on pH, which is a function of a particular wastewater. The optimum range is between 5,5 and 6,5. The pH of a wastewater can be adjusted downwards by the addition of sulphuric acid, but the added complexity of dosing sulphuric acid is often omitted in favour of dosing greater alum quantities. Decreasing the pH also adversely affects nitrification.

The molar ratio of alum consumed per unit P removed varies between 2:1 and 3:1 and the actual ratio must be established for each different wastewater.

Choice in selection of an aluminium salt must be conducted carefully as anions of various salts may cause the effluent to exceed acceptable residual sulphate and chloride concentrations.

3.4.2.3 Lime

Lime has a variety of uses within wastewater treatment and is used for phosphate removal in the Phostrip process (see Chapter 11) and in a fixed and fluidised-bed crystalliser process. In the removal process the calcium and hydroxide ions react with orthophosphate to form a crystalline precipitate termed calcium hydroxy apatite.

The chemical precipitation depends on pH and alkalinity. The carbonate alkalinity competes with orthophosphate for the calcium cation to form a calcium carbonate precipitate, which enmeshes the hydroxy apatite precipitate. At pHs greater than 11, addition of lime results in a magnesium hydroxide precipitation, in addition to calcium carbonate and phosphate precipitates, which aids in enmeshing the calcium carbonate and hydroxy apatite precipitates. However, the magnesium floc is gelatinous and may adversely affect subsequent sludge dewatering operations.

The simplified chemical reactions are:

For hydroxy apatite:

$Ca^{2+} + 3PO^{3-}_4 + OH^- \rightarrow Ca_5(OH)(PO_4)_3$

For calcium carbonate:

$Ca^{2+} + HCO^-_3 + OH^- \rightarrow CaCO_3 + H_2O$

For magnesium:

$Mg^{2+} + 2OH^- \rightarrow Mg(OH)_2$

The optimum lime dosage rates are controlled by controlling the pH and can be determined from jar tests.

3.4.2.4 Polyelectrolytes

In all three chemical precipitates discussed above, use of a polyelectrolyte is recommended as a flocculant aid for phosphate precipitation. These macro-molecular compounds come in a wide range of products and destabilize or enhance flocculation of suspended and colloidal

The phosphates found in wastewater occur in three principal forms: orthophosphate, poly-phosphate and organic phosphate. In the biological treatment process, most of the phosphates and converted to orthophosphate, which is the easiest form of P to precipitate chemically. The chemicals commonly used for phosphate precipitation are iron and aluminium salts and lime. Each is described below.

3.4.2.1 Iron salts

Chemical precipitation of phosphates can be achieved using Ferrous (Fe^{2+}) and Ferric (Fe^{3+}) ions, both of which are available as iron salts e.g. ferrous sulphate, ferric sulphate and ferric chloride. The main disadvantage when using these salts is that they cause decreases in both pH and alkalinity of the wastewater and add to the salinity of the water.

Ferric and ferrous iron combine with ortho-phosphate in the precipitating reaction and with hydroxide in competing reactions. Both these reactions are essential for successful phosphate removal.

The simplified chemical reactions are as follows:

For ferrous salts:

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$$

$$3Fe^{2+} + 2PO^{3-}_4 \rightarrow Fe_3(PO_4)_2$$

For ferric salts:

$$Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3$$

$$Fe^{3+} + PO^{3-}_4 \rightarrow FePO_4$$

In both the above reactions , the ions react with hydroxide to form iron hydroxide floc which destabilizes the negatively charged phosphate colloids, enmeshes them and provides an absorption capacity for condensed phosphates.

A high degree of phosphate removal can be achieved with both ions, provided optimum conditions exist. The optimum environment for precipitation is largely dependent on pH. For ferrous ions the optimum pH is around 8 while for ferric ions the pH should be in the range of 4 to 5, but is often used at higher pH values.

The optimum pH is a function of the wastewater and should be determined for each particular wastewater. Since both iron salts are strongly acidic, and consume $(OH)^-$ thus decreasing the alkalinity, the pH declines when these salts are added and some form of pH adjustment would be required to maintain optimum conditions.

Dosage rates for these iron salts need to be determined from influent phosphate and alkalinity concentrations as well as floc settling characteristics which are determined in jar tests. The theoretical iron (Fe) to phosphate (P) mass ratio for $(Fe)_3(P0_4)_2$ is 2,7:1 and for $FeP0_4$ 1,8:1, but these need to be determined in practice as the actual mass ratios usually exceed these theoretical values.

3.4.2.2 Aluminium salts

Aluminium salts are used extensively for phosphate removal in wastewaters. Examples of these salts are $Al_2 (S0_4)_3$, $Na_2 Al_2 O_4$ and $AlCl_3$. The principle source of aluminium is alum, which is a hydrated aluminium sulphate with the approximate chemical formulae $Al_2(S0_4)_3.14H_2O$.

for growth and to replenish their poly-P pool by abstracting ortho-phosphate from the surrounding medium. This gives rise to the phenomenon known as excess P uptake which occurs in aerobic environments.

To promote the growth of these poly-P organisms one needs

(i) to create an anaerobic environment which receives or generates an adequate supply of SCFA, the mass of P released (and subsequent uptake in the aerobic zone) being proportional to the mass of SCFA obtained by the Poly-P organisms, followed by

(ii) an aerobic environment for P uptake by the Poly-P organisms.

Normally very little SCFA is present in the influent in South Africa. SCFA are generated in the anaerobic reactor by non-Poly-P acid fermenting organisms in the activated sludge mass acting on the influent sewage COD. However extensive experimental investigations have shown that in the anaerobic reactor only the readily biodegradable fraction of the influent COD, the RBCOD fraction, is converted to SCFA. In South Africa this fraction ranges around 20 percent of the unsettled influent COD.

It has been shown that the rate of generation of SCFA by the non-poly-P organisms within the anaerobic zone is a first-order reaction with respect to the RBCOD and the non-poly-P heterotroph active mass concentration and is therefore promoted if the anaerobic zone is subdivided into a series of two or more sub zones. The rate of uptake (sequestration) of SCFA by the poly-P organisms usually is faster than the rate of generation of SCFA by the poly-P organisms so that usually no SCFA are measurable in the liquid phase in this zone.

In the activated sludge process SCFA are very rapidly biodegraded by the non-poly-P organisms in the presence of an external electron acceptor such as oxygen or nitrate, at a rate much faster that the poly-P organisms can utilise SCFA. Furthermore, in the presence of an external electron acceptor the non-poly-P organisms will not generate and release SCFA from the RBCOD, but will use the RBCOD. Therefore in order to preserve and generate the SCFA in the anaerobic zone for the sole use of the poly-P organisms, great care has to be taken to minimise the introduction of oxygen and nitrate into that zone. If high concentrations of nitrate for instance, are introduced into the anaerobic zone in the S-recycle, non-poly-P organisms will use the nitrate as an electron acceptor to metabolise the SCFA and RBCOD thereby reducing the supply of SCFA to the poly-P organisms and detrimentally affecting the biological P removal. It is thus critical to the process that as little oxygen and nitrate as possible is introduced into the anaerobic zone.

3.4.2 *Chemical removal*

As P can also be precipitated chemically in either a side-stream process (e.g. Phostrip) or in a main-stream process (e.g. in trickling filters) or in a process combining biological and chemical removal, it is necessary to discuss P removal mechanisms induced by chemical precipitation.

3.4 Phosphorus removal

Phosphorus can be removed from a wastewater by either biological means or by chemical precipitation. Although the main emphasis of this manual is biological nutrient removal, chemical removal is sometimes used in conjunction with biological removal and is therefore also discussed.

3.4.1 Biological removal

Studies conducted into the bacteriological aspects of biological nutrient removal (BNR) have led to a basic theoretical understanding of biological phosphorus (P) removal enabling optimisation of the design of BNR plants and increasing their efficiency and reliability. These theories are discussed below.

It is generally accepted that enhanced P removal occurs as a result of the ability of certain organisms, for example *Acinetobacter* spp, to accumulate large quantities of polyphosphate (poly-p) within the cellular mass. The secret to designing and running an activated sludge plant successfully for P removal lies therefore in creating conditions in the plant which favour propagation and growth of these particular organisms over organisms which do not have this propensity. For simplicity these organisms will be referred to here as poly-P organisms as opposed to non-poly- P organisms which cannot accumulate phosphate.

In order to create conditions for the growth of poly-P and non-poly-P organisms, a plant must have three distinct zones: anaerobic, anoxic and aerobic. The aerobic and anoxic zones have been defined in section 2 and 3 above and the anaerobic zone is described below.

The term "anaerobic" means that the contents of the zone are kept, as far as possible, deficient of nitrate and dissolved oxygen and that the input of nitrate and oxygen to these zones is severely restricted. This zone is fundamental to the biological removal of P because it allows the organisms principally responsible for this phenomenon to proliferate in the system.

At present the most widely accepted theory of how enhanced biological phosphorus removal works is set out below.

Under aerobic conditions the poly-P organisms are not able to compete with non-poly-P organisms for substrates (food sources) such as glucose or other saccharides. Under anaerobic conditions (no nitrate or oxygen present) and in the presence of short-chain fatty acids (SCFA) the poly-P organisms break down or hydrolyse stored polyphosphate. This process releases ortho-phosphate to the surrounding liquid and leads to the phenomenon known as phosphorus release in the anaerobic zone. The bond energy released in hydrolysing polyphosphate is utilised by the poly-P organisms to absorb, process and store the SCFA within the organisms, thereby reserving substrate for their exclusive use when they enter an environment which contains external electron acceptors such as nitrate or oxygen. In this way they do not have to compete with the non-poly-P organisms which are unable to utilise SCFA under the anaerobic conditions because of the lack of a suitable electron acceptor.

When re-entering the aerobic environment the poly-P organisms utilise the reserved SCFA both compounds in water. Anionic polyelectrolytes are used as flocculation aids for systems with a pH less than 6,5 and above this pH value a cationic polyelectrolyte is usually used. Neutral polyelectrolytes are used when charge neutralisation is not a factor.

Addition of lime or alum to a wastewater forms a fine, light floc which settles very slowly, often resulting in solids carry-over in the effluent. Addition of a polyelectrolyte produces a floc which settles very rapidly. A polyelectrolyte may be added to a wastewater to which ferric chloride has been dosed to reduce colloidal iron particles. Otherwise these particles escape with the effluent and give the effluent a brownish colour.

3.4.2.5 Dosing point

Another important aspect which affects the performance of chemical phosphate removal is the dosing point. Different dosing points within a treatment stream for a particular wastewater can produce different P^- removal efficiencies.

The main problem of chemical dosage with iron salts in conjunction with biological P removal is that for a short period the P removal is enhanced, but in the long term the overall biological removal efficiency decreases. Dosage rates then need to be increased. It is therefore recommended that P removal by iron salt addition should only be used for very short periods in a biological P^- removal system.

CHAPTER 4

NUTRIENT REMOVAL SYSTEM CONFIGURATIONS

4.1 Introduction

It is not always possible to achieve complete biological nitrogen and phosphorus removal. However, to achieve biological nutrient removal (BNR) of nitrogen and phosphorus, the process must incorporate an anaerobic zone, an anoxic zone and an aerobic zone. In most processes, it is usual to have the anaerobic zone first, the anoxic zone second and the aerobic zone last. A secondary anoxic zone may be placed after the aeration zone to facilitate additional nitrogen removal from the effluent discharged to the clarifiers.

The anaerobic zone is essential for P removal and the anoxic zone for N removal. For a particular design, the degree and success of achieving optimum removal in each zone depends on controlling the different recycle rates to each zone. A number of mainstream removal streams have evolved in South Africa over the years. There are, however, other configurations which have been developed overseas. These are not discussed in this manual, as they are not common wastewater treatment processes used in South Africa. The configurations commonly used in South Africa are shown in Figures 4.1 to 4.6. In referring to the figures it is necessary to define the following terms:

The nomenclature and symbols used in the WRC manual "Theory, Design and Operation of Nutrient Removal Activated Sludge Processes", which are specific to South Africa, but have different symbols in other countries, are followed in this manual.

a) Anaerobic zone

This is a zone within the activated sludge plant which is virtually free of oxygen and nitrate and has virtually zero input of these materials. This zone is fundamental to the biological removal of phosphorus because it allows the organisms principally responsible for this phenomenon to proliferate in the system.

b) Anoxic zone

This is a zone of the activated sludge plant which is virtually free of oxygen but which does contain nitrite and nitrate or has substantial input of nitrate. This zone is fundamental to the biological removal of nitrogen because the absence of oxygen allows non-poly-P organisms to utilise nitrate as electron acceptors, reducing it to nitrogen gas, thus carrying out denitrification of the mixed liquor and allowing the elemental nitrogen formed to escape to the atmosphere as a gas.

c) Aerobic zone

This is a zone within the activated sludge plant which is aerated by introducing either air or oxygen. In this environment the utilisation of biodegradable organic matter is virtually completed while ammonium nitrogen is converted to nitrate by the nitrifiers present in the population of micro-organisms.

d) Unaerated mass fraction (f_{xt})

This is the fraction of the sludge mass which is in the anaerobic and anoxic zones. Its maximum value is limited by the necessity of having a sufficient aerated sludge mass to allow nitrification to occur. The fraction present in the anaerobic zone only is called "anaerobic mass fraction" (f_{xa}) and it affects the overall phosphorus removal potential of the plant. The fraction present in the anoxic zone is known as the "anoxic mass fraction" (f_{xn}) and affects the overall nitrogen removal potential of the plant. The f_{xt} of a process is the sum of the f_{xa} and f_{xn}.

See Figures 4.1 to 4.5 for illustration of the recycle flow.

e) S-recycle

This is the activated sludge recycle from the underflow of the secondary clarifiers back to

i) the anaerobic zone in the Phoredox system,

ii) the anoxic zone in the UCT or Modified UCT systems downstream of the anaerobic zone,

iii) the settler anoxic zone in the Johannesburg system.

f) A-recycle

This is an internal recycle of mixed liquor from the aerobic zone to the inlet of the anoxic zone. Its function is to introduce the nitrate formed in the aerobic zone into the anoxic zone, so that the nitrate can be reduced to elemental nitrogen by non-poly-P organisms in the process called denitrification.

g) R-recycle

This is an internal mixed liquor recycle from the anoxic zone to the anaerobic zone which is required for the UCT and Modified UCT process configurations.

4.2 Nitrogen removal systems

Figure 4.1 depicts one of the first nitrogen removal processes. The process comprises an aerobic zone followed by an anoxic zone. The influent is discharged directly into the aerobic zone in which nitrification takes place. The flow is then discharged to the anoxic zone. The underflow from the clarifier (S-recycle) is returned to the aerobic zone. The substrate source for denitrification in the anoxic zone is obtained from the death of organisms. However, the release rate of substrate is very slow. This unfortunately leads to large anoxic zones and small aerobic zones. If the plant is designed for low temperatures (< 15°C) the anoxic zone may have to be so large that nitrification may be severely hampered.

Theoretically, with this system it is possible to achieve complete denitrification. However, this is not practically possible because the anoxic zone would have to be very large due to the slow denitrification rate which may lead to a loss of nitrification.

Figure 4.2 shows the modified Ludzack-Ettinger (MLE) nitrogen removal process. The process consists of an anoxic zone ahead of an aerobic zone.

In this process, the influent is discharged directly into the anoxic zone. A recycle (A-recycle) from the aerobic zone recycles nitrite and nitrate back to the anoxic zone. The underflow recycle (S-recycle) from the clarifiers also recycles nitrite, nitrate and mixed liquor to the anoxic basin. As the influent contains substrates or COD that can be used rapidly, a high rate of denitrification in the anoxic zone is observed. Complete denitrification cannot be achieved because part of the total flow from the aerobic reactor (containing nitrite and nitrate) is discharged directly with the effluent and is not recycled back to the anoxic zone.

The Bardenpho system, shown in Figure 4.3, was developed to overcome incomplete denitrification of the MLE system. Barnard (1973) considered that the low nitrate concentration discharged from the aeration zone could be denitrified in a secondary anoxic zone placed after the aerobic zone, to give a relatively nitrate-free effluent. Prior to discharge to the clarifier a flash aeration basin was introduced after the second anoxic zone to strip the nitrogen bubbles from the sludge flows to assist with sedimentation of the sludge. The flash aeration also served to nitrify any ammonia released within the anoxic zone.

This process also has the theoretical propensity to remove all the nitrate, but in practice this is not always possible as described below.

For a fixed underflow S-recycle ratio, the mixed liquor A-recycle governs the distribution of nitrate between the primary and secondary anoxic zones. The best denitrification performance will be obtained when A- and S-recycle values are chosen such that the primary anoxic zone is just loaded to its denitrification potential (maximum amount of nitrate the reactor could remove) and the nitrate concentration in the flow leaving this zone will thus be zero.

The balance of nitrate generated in the aerobic zone (and not recycled to the primary anoxic zone) flows to the secondary anoxic zone. If this load of nitrate to the secondary anoxic zone is less than the denitrification potential of this zone then complete denitrification will be achieved. If not, complete denitrification will not be achieved.

In practice the Bardenpho system for nitrogen removal is appropriate if the calculated effluent nitrate is less than 5 to 7 mg N/ℓ. If the effluent nitrate concentration is greater than 5 to 7 mg N/ℓ (which is usually the case for $^{TKN}/_{COD}$ ratios > 0,1 mg N/mg COD) then the MLE process is better suited for higher nitrogen removal efficiency.

For the MLE process, optimum nitrogen removal is obtained when the anoxic zone is just loaded to its denitrification potential. For a selected S-recycle rate an A-recycle rate which just loads the anoxic zone to its denitrification potential will yield the lowest effluent nitrate concentration. This recycle is termed the optimum A-recycle.

In the design of the MLE process, the lower the nitrification capacity with respect to the denitrification potential (i.e. the lower the $^{TKN}/_{COD}$ ratio) the lower the effluent nitrate concentration and the higher the optimum A-recycle.

In practice the A-recycle rate is limited to a maximum of 6:1 as it is uneconomical to operate at higher recycle ratios: Only an additional 5% increase in nitrate removal will be achieved by increasing the recycle rate to 10:1.

By limiting the recycle rate to 6:1, theory has indicated that the MLE process can only achieve a minimum effluent nitrate concentration of 5 to 7 mgN/ℓ. In practice, this restriction is not limiting, as wastewaters with $^{TKN}/_{COD}$ ratios of less than 0,1 mg N/mg COD are more effectively treated using the Bardenpho process.

If complete or near complete nitrogen removal is not required, the optimum A-recycle rate for the MLE process can be reduced by reducing the sludge age. In doing this the maximum allowable unaerated mass fraction to ensure nitrification will be reduced resulting in a lower denitrification potential and associated A-recycle rate.

The advantages and disadvantages of these systems are given in Table 4.1.

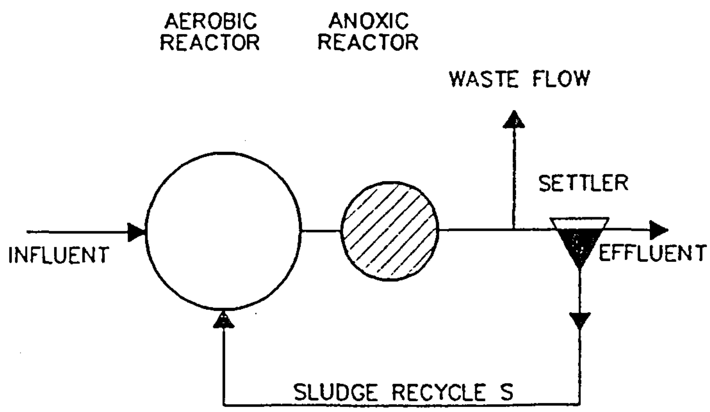

FIGURE 4.1 The Wuhrmann process for nitrogen removal

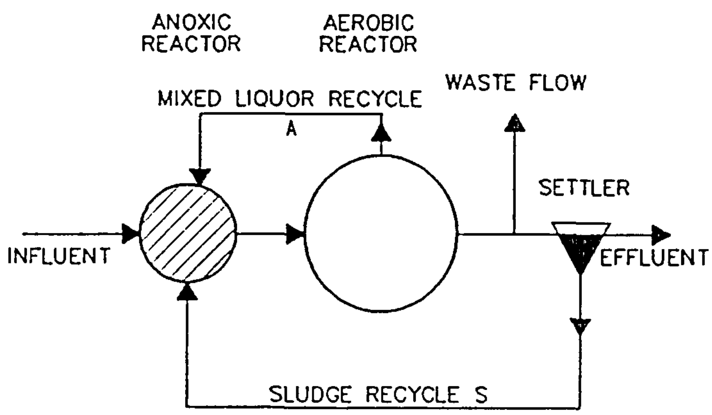

FIGURE 4.2 The modified Ludzack–Ettinger process for nitrogen removal

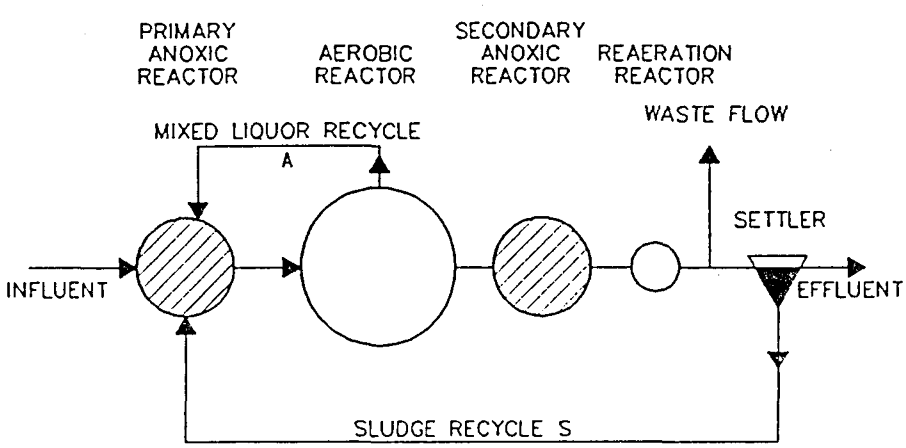

FIGURE 4.3 The Bardenpho process for nitrogen removal

Table 4.1 : Advantages and Disadvantages of Nitrogen Removal Processes

Process	Advantages	Disadvantages
Wuhrmann	Theoretically possible to remove all nitrate.	Large anoxic mass fraction required which may inhibit nitrification. Due to organism die-off, ammonia and organic nitrogen are discharged with the effluent. Low denitrification rate.
Modified Ludzak-Ettinger	High rate of denitrification. Simple configuration. Higher N-removal than the Bardenpho system for $^{TKN}/_{COD}$ ratios > 0,1.	Complete denitrification cannot be achieved. Effluent nitrate concentrations will be greater than 5 mg N/ℓ. A-recycle limiting.
Bardenpho	Theoretically possibly to remove all the nitrate, but not possible in practice. Higher N-removal than the MLE system for $^{TKN}/_{COD}$ ratios <0,1.	Complex configuration. A-recycle limiting. Mainly used for treating raw wastewaters where $^{TKN}\backslash_{COD}$ ratios < 0,1.

4.3 Nitrogen and phosphorus removal systems

Mainstream processes have been developed for both nitrogen and phosphorus removal. These processes are the Phoredox, the 3-stage Phoredox, the Johannesburg, the UCT and the Modified UCT. Referring to Figures 4.4 to 4.8, it can be clearly seen that all the systems stem from the MLE and the Bardenpho processes discussed earlier. Each process has an anaerobic zone included at the head of the treatment process and the recycle discharge point has been changed to achieve the desired process for P removal.

In evaluating the overall performance of the P removal systems, it is important to remember that the anoxic mass fraction of the process is reduced due to a fraction of the total unaerated mass fraction being set aside for the anaerobic reactor.

In the Phoredox and 3-stage Phoredox processes (Figures 4.4 and 4.5) the anaerobic zones receive the influent flow and underflow recycle from the final clarifier. Nitrate present in the recycle is introduced into the anaerobic zone. The effectiveness of the anaerobic zone in creating optimal anaerobic conditions is therefore dependent on the amount of nitrate recycled back from the clarifiers (See Chapter 3, Section 3.4). If no nitrate is to be recycled back to the anaerobic zone, complete denitrification must be achieved within the available anoxic sludge mass fraction.

Due to the decrease in the anoxic sludge mass fraction of the Phoredox process the upper limit of the $^{TKN}/_{COD}$ ratio for complete denitrification is less than that for the Bardenpho process. Design guidelines for the Phoredox process recommend that in order for complete denitrification to be achieved, the $^{TKN}/_{COD}$ ratio should not exceed 0,07 to 0,08. As most municipal wastewaters have $^{TKN}/_{COD}$ ratios of between 0,07 and 0,09 for raw sewage and greater than 0,10 for settled sewage the use of this type of process is often limited.

If for example, the $^{TKN}/_{COD}$ ratio increases due to an increase in TKN, the Phoredox process offers few options to reduce the effluent nitrate concentrations and consequently the discharge of nitrate into the anaerobic zone by operational measures, other than by reducing the underflow recycle. This is considered to be risky as the performance of the clarifier will have to be monitored closely.

This restriction led to the development of the UCT process which is depicted in Figure 4.6. In this system a single primary anoxic zone is used as per the 3-stage Phoredox process. However, the S-recycle from the clarifier is returned to the anoxic zone and not the anaerobic zone. The anoxic zone still receives the A-recycle from the aeration basin. An additional recycle, the R-recycle, is provided to recycle from the anoxic zone to the anaerobic zone which also receives the influent flow.

The principle behind the UCT system is that the amount of nitrate discharged to the anaerobic reactor is independent of the amount of nitrate in the effluent, which could not be adequately controlled in the Phoredox systems.

In the UCT process the A-recycle rate can be adjusted such that the anoxic reactor is just loaded to its denitrification potential. The nitrate concentration in the anoxic zone would therefore be approximately zero. Consequently, the R-recycle from the anoxic zone to the anaerobic zone would contain very little if any nitrate and optimal use of the anaerobic reactor would be achieved.

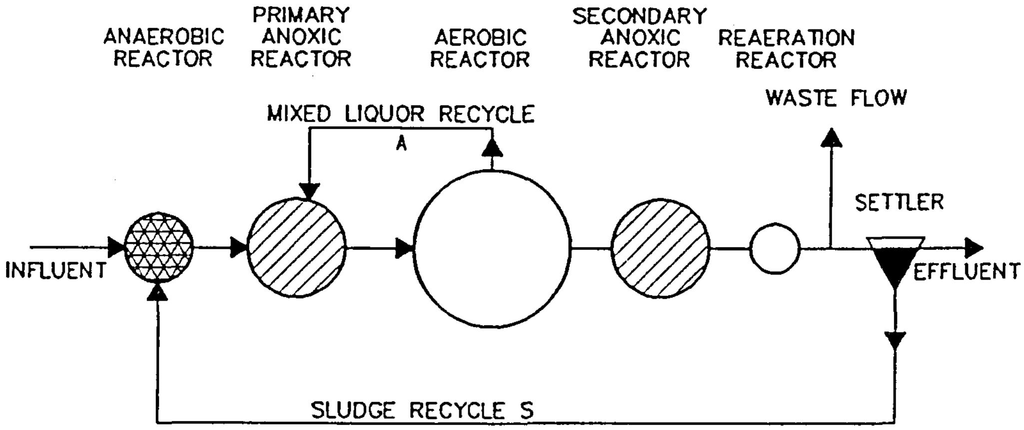

FIGURE 4.4 Phoredox process for biological nitrogen and phosphorus removal

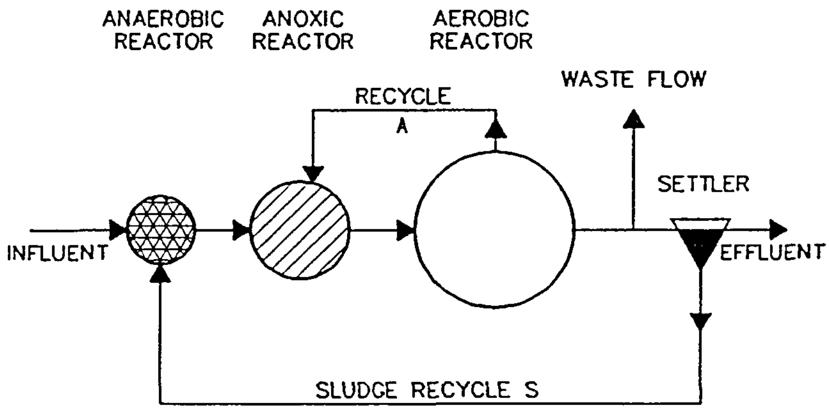

FIGURE 4.5 3 stage Phoredox process for biological nitrogen and phosphorus removal

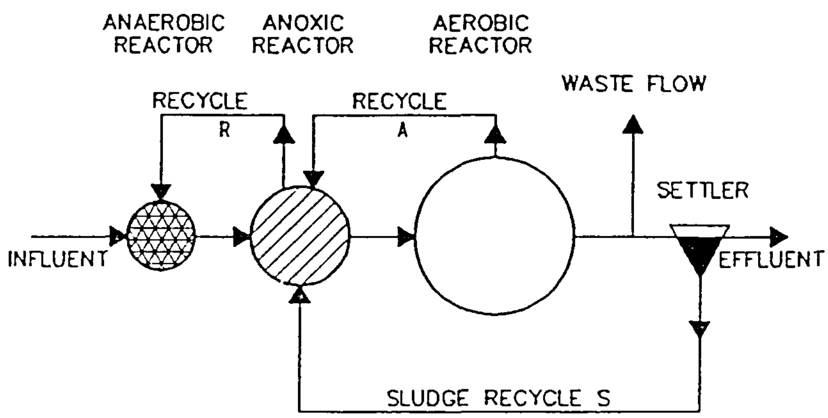

FIGURE 4.6 UCT process for biological nitrogen and phosphorus removal

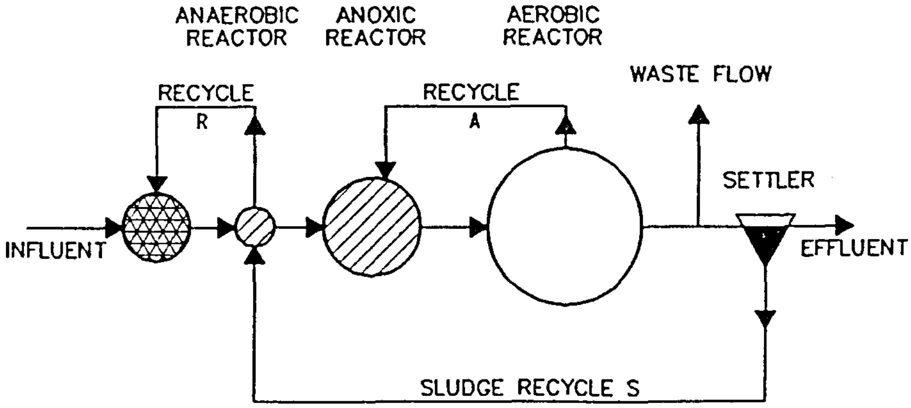

FIGURE 4.7 The modified UCT process for biological nitrogen and phosphorus removal

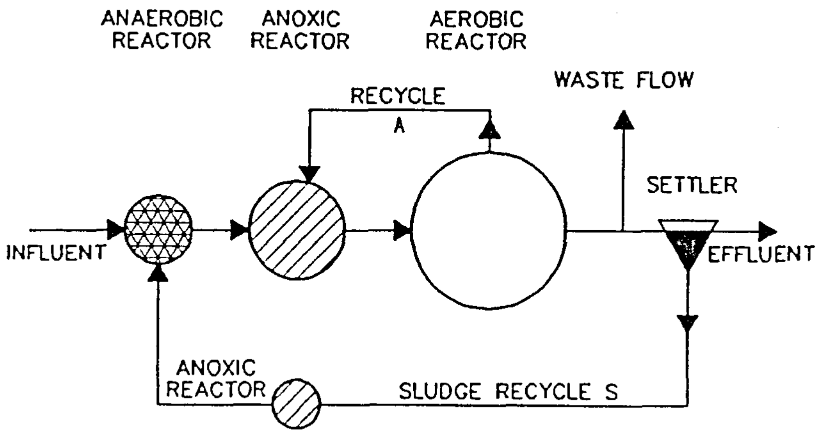

FIGURE 4.8 Johannesburg process for biological nitrogen and phosphorus removal

With this process therefore, by correctly manipulating the A-recycle rate for any S-recycle rate, optimal use of the anaerobic zone would be achieved despite variations in the influent $^{TKN}/_{COD}$ ratio.

However, research has shown that at a $^{TKN}/_{COD}$ ratio of 0,14 (at 14^0C) and a sludge age of 25 days the nitrate concentration in the effluent is so high that the S-recycle fully loads the anoxic zone to its denitrification potential. In this instance the A-recycle rate would be reduced to zero to avoid overloading the anoxic zone. At $^{TKN}/_{COD}$ ratios of greater than 0,14, nitrate will be present in the anoxic zone and will thus be recycled back to the anaerobic zone, decreasing the anaerobic efficiency and P removal. The $^{TKN}/_{COD}$ ratio of most raw and settled wastewaters is below 0,14.

The main problem associated with the UCT process is that strict control of the A-recycle must be ensured so that the anoxic zone is never overloaded by nitrate in the recycle flow. This is extremely difficult at full scale due to varying $^{TKN}/_{COD}$ ratios experienced under cyclic load conditions.

In order to overcome this problem, the Modified UCT process was developed as shown in Figure 4.7. In this process the primary anoxic zone is split into two zones. The first zone has a sludge mass fraction of approximately 0,1, the remainder incorporated into the second anoxic zone. The S-recycle is returned to the first anoxic zone. The R-recycle is abstracted from this zone and discharged into the anaerobic reactor which also receives the influent flow. The second anoxic zone receives the A-recycle from the aeration basin. If we consider the A-recycle rate to be a minimum when it just introduces sufficient nitrate to load the second anoxic zone to its denitrification potential, then any recycle greater than that will merely overload the anoxic zone and introduce nitrate into the effluent from the anoxic zone. The higher recycle rate does not introduce any additional nitrate into the aerobic zone as the nitrate concentration remains constant when this rate exceeds the minimum required.

This modification to the UCT process does however lower the maximum $^{TKN}/_{COD}$ ratio for zero nitrate to approximately 0,11. At ratios below this value, the first anoxic zone is capable of denitrifying all nitrate in the underflow, thus achieving maximum use of the anaerobic zone.

The Johannesburg system was also developed to overcome the major disadvantage of the Phoredox system in that nitrate present in the underflow will be discharged to the anaerobic zone, thus reducing the efficiency of the zone. Referring to Figure 4.8, the S-recycle passes through a small anoxic zone in the underflow.

Any nitrate present in the underflow will be denitrified before being discharged to the anaerobic zone. The influent is also discharged to the anaerobic zone and the A-recycle rate operates as for the Phoredox process.

The advantages and disadvantages of each process are listed in Table 4.2 overleaf.

Table 4.2: Advantages and Disadvantages of Nitrogen and Phosphorus Removal Processes

Process	Advantages	Disadvantages
Phoredox	Optimal nitrogen removal due to maximum use of the anoxic volume.	The S-recycle discharges directly into the anaerobic zone and thus any nitrate in the effluent will decrease the effectiveness of the anaerobic zone.
UCT	The R-recycle should be very low in nitrate and oxygen and thus near optimal use of the anaerobic reactor is achieved. Because the sludge concentration in the anaerobic reactor is low for the same unaerated volume the overall unaerated sludge mass fraction is less than the Phoredox and Johannesburg processes, and is thus less likely to develop a bulking sludge or lose nitrification in winter.	The A-recycle rate must be carefully controlled so as not to overload the anoxic zone with nitrate which will be returned to the anaerobic zone. The introduction of a third recycle complicates the operation of the plant. Complete denitrification is not possible.
Modified UCT	The same as for the UCT system except that the first anoxic zone is exclusively for denitrifying the S-recycle. Careful control of the A-recycle is less critical.	The same as for the UCT process except by utilising the first anoxic zone for denitrifying the S-recycle the overall plant ability to reduce nitrate is further reduced.
Johannesburg	The anoxic zone between the settler and the anaerobic zone is exclusively for denitrifying the S-recycle. This results in the return flow to the anaerobic zone being very low in oxygen and nitrogen and near optimal use of the anaerobic reactor is achieved. The volume of the underflow anoxic reactor is small.	The anoxic volume available for denitrification of the A-recycle is reduced due to the exclusivity of the underflow anoxic zone. As the S-recycle has a higher solids concentration than the reactor, the overall unaerated mass fraction is increased for the same overall volume. This could increase the propensity for developing a bulking sludge and also increases the chances of nitrification loss in winter. The denitrification rate of the underflow in the anoxic reactor is low due to the lack of readily available carbon.

4.4 Side-stream configurations

In addition to the main stream processes above, a side-stream process was developed for P removal, using biological and chemical methods. Phostrip is the name given to the patented system held by Biospherics for a sidestream process for the removal of phosphate from sewage.

The system was the first to utilise biological phosphorus release and uptake with chemical precipitation to achieve phosphate removal from the wastewater flow. Designs were based on observed behaviour patterns and the system requirements evolved largely empirically. No quantitative detailed investigations into the different biological/biochemical processes active in the system appear to have been undertaken. However with the present understanding of the processes contributing to biological excess phosphate removal it is possible to infer and comment on the Phostrip system configuration and the environmental conditions it imposes to bring about phosphate removal.

4.4.1 Basic Phostrip system

The original Phostrip system consisted of an aerobic reactor discharging to a secondary clarifier (Figure 4.9). The clarifier underflow stream (recycle ratio approximately 1:1) was split in two, approximately half returning to the aerobic reactor and half passing to a "stripper" tank. In the stripper tank the sludge is retained for an extended period ranging up to 18 h. The sludge in the stripper achieves an anaerobic state and phosphate is released from the sludge into the liquid phase. The sludge settles in the stripper and the thickened underflow is pumped back to the head of the aerobic reactor. The supernatant containing the released phosphate is dosed with a chemical to precipitate the phosphate. The phosphate-rich chemical sludge is separated out in a small settling tank and the clarified liquid thus denuded of phosphate, is returned to the aerobic reactor.

The Phostrip system relies on the same biochemical mechanisms and processes identified in the main stream biological excess phosphorus removal systems described in Chapter 3 of this report, but the manner in which some of the essential chemical components (SCFA, poly-P, etc) are generated differs substantially from the main stream systems.

In the main stream systems SCFA are generated from the readily biodegradable COD (RBCOD) derived from the influent wastewater. Slowly biodegradable COD (SBCOD) from the influent is not processed within the period of time the mixed liquor resides in the anaerobic zone.

In contrast, in the Phostrip system the underflow from the secondary settling tank is subjected to anaerobic conditions. This sludge has passed through the aerobic zone where the RBCOD and a significant fraction of slowly biodegradable COD (SBCOD) have been metabolised. Production of SCFA now necessarily depends on (1) solubilisation of SBCOD derived from the remnant unmetabolised SBCOD in the mixed liquor from the aerobic zone and from the death of organisms in the anaerobic stripper environment, and (2) acid fermentation of the solubilised SBCOD. Very likely the rate limiting step is the solubilisation process but no information is available on this process in the stripper environment. Clearly SCFA are being generated because the poly-P organisms release phosphate - these organisms cannot utilise any substrate except SCFA in the anaerobic environment. Clearly, also, the solubilisation/

acid fermentation sequence occurs at slow rate because, as noted previously, the retention time in the stripper ranges up to 18 h.

It should be noted that originally these plants were operated to obtain "adequate" P release (approximately 40 mg P/ℓ) at sludge ages so low that nitrification would not occur. This means that the active fraction of the sludge is high, and the reaction rate near maximum. Should the sludge ages of this system approach that of the main stream nutrient removal systems, 15 to 25 days - the active fraction and reaction rate will be low so that it is not clear if adequate P release would be obtained in the stripper even with long stripper retention times. The advantages and disadvantages of the Phostrip process are listed in Table 4.3.

4.4.2 Augmented Phostrip system

It would appear that the difficulties experienced in obtaining adequate P-release in the stripper was the main reason for the incorporation of the first definitive modification in the Phostrip system (see Figure 4.10). A portion of the influent equal to 0,2 - 0,3 of the clarifier underflow flow rate was directed to the stripper tank via a pre-stripper tank with about 10 to 30 minutes retention time. The influent to the two stripper tanks now contains RBCOD and SBCOD; the former would be readily converted to SCFA and the latter would assist in reducing the redox potential and in this fashion probably assist in inducing solubilisation and acid fermentation. In any event the reported response by Biospherics, is that P-release was significantly improved with a reduction of 50 percent in the volume of the stripper.

Furthermore, they report that the biologically mediated phosphorus removal was so improved that some plants could satisfy a 2 mg/ℓ phosphate effluent standard without the need to add chemicals to the supernatant overflow of the stripper. In effect the stripper tank unit process now only serves as a device for effectively storing a large mass of sludge for phosphorus release. Both the P-laden overflow and the thickened underflow are returned to the influent line to the aerobic reactor, where P^- uptake occurs. The mixed liquor wasted from the system will contain an augmented P-concentration similar to the sludge wasted from main stream processes.

In the basic Phostrip configuration (Figure 4.9), should nitrification take place for any reason, bleeding a fraction of the influent to the stripper or pre-stripper/stripper, would reduce the nitrate entering the stripper. If nitrate is returned in the mixed liquor of the underflow a relatively high redox potential would develop and retard the development of a "deep" anaerobic state. The RBCOD introduced by bleeding a fraction of the influent sewage into the prestripper/stripper should rapidly reduce the nitrate to zero and thus assist the development of a low redox potential and acid fermentation conditions improving P removal.

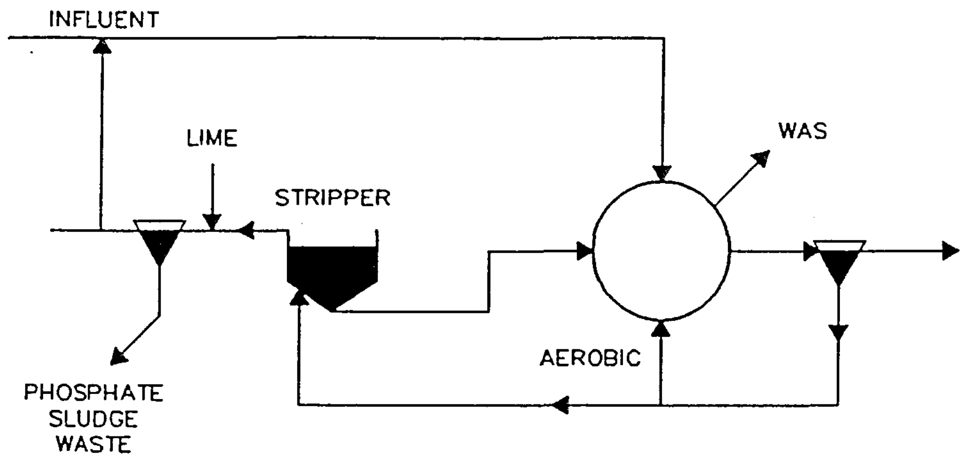

FIGURE 4.9 The original patented Phostrip process for nitrogen and phosphorus removal

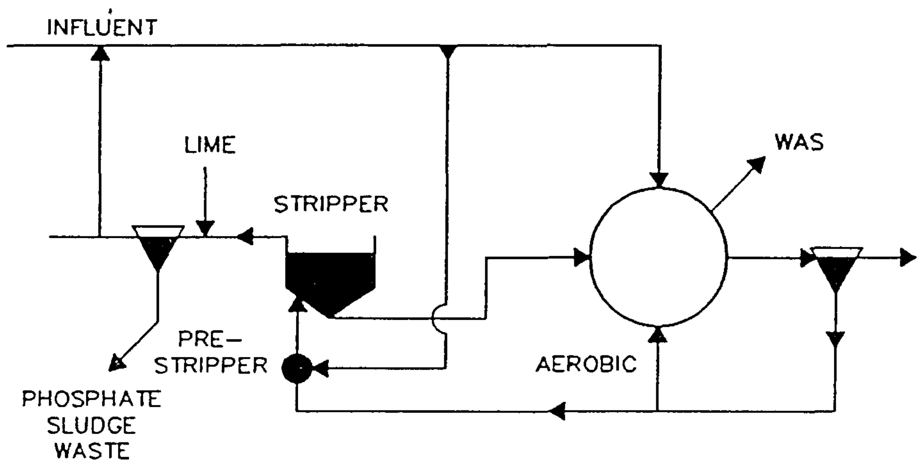

FIGURE 4.10 The augmented Phostrip process for nitrogen and phosphorus removal

Table 4.3: Advantages and Disadvantages of the Phostrip Process

Process	Advantages	Disadvantages
Phostrip System	The excess phosphorus in the stripper supernatant liquor is chemically bound and will not be released.	The effects of nitrification on the different Phostrip layouts will reduce the anaerobic state of the stripper significantly. Chemical handling facilities and dosage equipment would be required unless the liquor and sludges can be disposed of directly to land.

CHAPTER 5

PRIMARY SEDIMENTATION

5.1 Introduction

Primary sedimentation is the first step of a treatment process in which appreciable organic material is removed from an influent wastewater stream. A small fraction of the organics may be removed in the screening or degritting operations (if any), but the primary sedimentation tanks (PSTs) are capable of removing up to 40% of the incoming organics and up to 70 to 90% of the suspended solids.

In a PST the incoming flow velocities are greatly reduced and insoluble or settleable organic matter and colloids settle out of the liquid and collect at the bottom of the tank. The rate at which they settle is greatly dependent on the particle size, temperature of the liquid and whether or not a chemical flocculant has been added. Most PSTs are also equipped with scum baffles to trap and remove surface scum, fats and greases. Generally the removal of floatables improves the aesthetics of the plant, protects some of the downstream processes and reduces the pollutants discharged with the final effluent.

Besides organic and scum removal, a further function of the PSTs is to concentrate the settled solids prior to discharge to digesters or other treatment processes. In cases where additional thickeners have been provided in the process, the thickening function of the PSTs is not critical.

5.2 General description of a primary sedimentation tank

PSTs can either be circular or rectangular with or without mechanical scrapers. A typical circular PST is shown in Figure 5.1. Mechanically scraped circular PSTs have a vertical side water depth of 3 to 4 metres and a floor slope of 8 to 12 degrees to the horizontal. The side water depth is required for clarification and sludge storage functions, whereas the cone formed by the sloping floor acts as a thickening zone. Rectangular PSTs also have a side water depth of 3 to 4 metres, but the floor slopes upwards from the inlet side to the opposite side, which is the outlet. In some instances the floor might not be sloped and scrapers move the sludge to the inlet end.

In circular PSTs raw wastewater is discharged into a central stilling chamber where most of the incoming flow energy in the wastewater is dissipated. The flow then travels downwards until it exits the stilling chamber and starts to flow radially outwards. The stilling chamber should be sufficiently deep to prevent solidified fats and greases being drawn down the chamber and discharged with the main flow.

Whilst flowing outwards the particulate material, which is slightly heavier than water, starts settling to the bottom of the tank, provided the upflow velocity within the tank is sufficiently low. The settled solids are scraped inwards to a central sludge hopper. The scraping mechanism may be a simple chain arrangement or properly angled rubber blades (much like windscreen wipers) fixed to a steel lattice structure.

The main liquid flow exits the PST over a peripheral weir and is discharged to the main reactor. The overflow weir is normally a weir plate into which V-notches have been cut. This arrangement ensures equal overflow along the entire length of the weir. Surface scum is trapped by a baffle which extends both above and below the water level. The trapped scum is moved along the surface by a skimmer arm which rotates with the scraper mechanism and pushes it to a submerged collection trough. As the arm reaches the trough a valve is automatically opened and scum is discharged from the tank to a dedicated sump. From here, the scum can be treated further by thickening or combined with the PST sludge or waste activated sludge and discharged to the digester. Generally the scum is very dilute and a measure of thickening is required before discharging to the digesters.

In rectangular PSTs, the flow enters at one end through a baffle system, to dissipate incoming flow energy, and flows out at the opposite end. Most of the sludge settles near the inlet of the tank and is best removed using mechanical scrapers, which moves the sludge to a trough located at one end of the tank. The scraper mechanism is normally fitted with a surface scum scraper which moves the scum to a trough located at the end of the tank.

Sludge is withdrawn from PSTs via a pipe and control valve which usually discharges sludge into a pump station sump. The driving force required to force the sludge out of the tank is often provided by a 1.5 to 2.0 m hydrostatic head i.e. the discharge level of the sludge pipe is placed sufficiently below top water level in the PST so that the resultant hydraulic head can drive the sludge out of the PST.

Rectangular type tanks are generally not common in South Africa and the circular type tank is preferable, due to:

(i) less short-circuiting of flow,

(ii) easier method of sludge collection and discharge,

(iii) shorter sludge retention times, and

(iv) additional maintenance being generally required on rectangular tanks.

5.3 PST desludging

Most PSTs are desludged by gravity. The time required for desludging depends on the anticipated volume of sludge, the required sludge density and the nature of the following sludge treatment process. On large works where there is more than one PST, the desludging cycle is controlled by a programmed logic controller (PLC), which sends a signal to a control valve on a single PST. A sequential pattern is often used to desludge the PSTs.

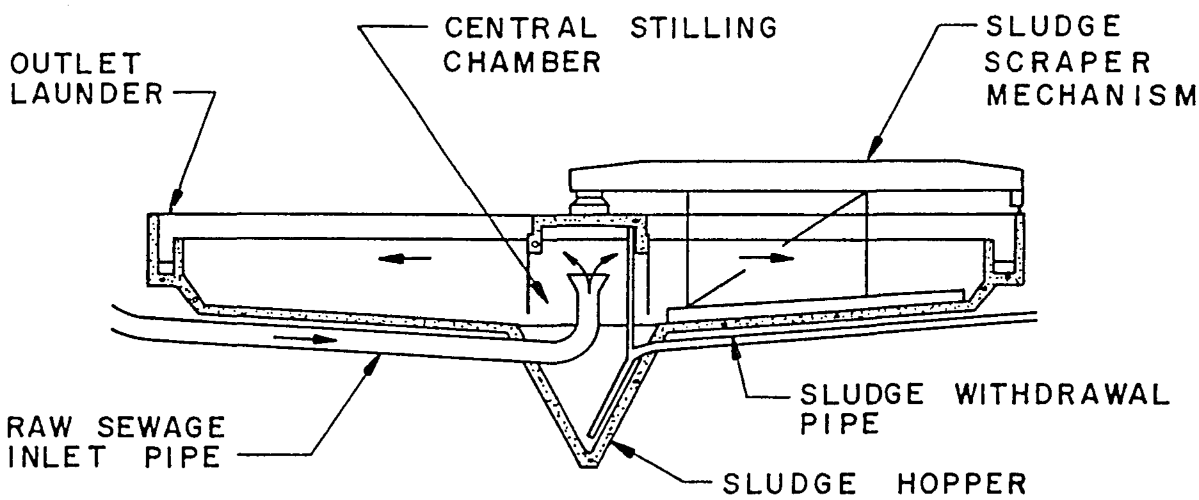

FIGURE 5.1 TYPICAL CIRCULAR PRIMARY SEDIMENTATION TANK

The types of desludging valves commonly used on PSTs are:

(i) Gate valve with an electronic or pneumatic actuator

(ii) Diaphragm valve with an electric or pneumatic activator

A most important function of these valves is to open fully when required. This is important to minimise fouling by rags, rope etc on the gate or other protruding parts. Fouling will cause problems in closing the valve once the required volume of sludge has been withdrawn.

The density of the settled sludge is important when discharging directly to digesters. Experience has shown that a short opening and closing valve cycle coupled with a short rest period yields higher sludge densities.

Where sludge density is not important the number of opening and closing cycles can be reduced and the valve open time increased. Care must be taken by operators not to extend the opening time for too long a period as there is a danger of forming a funnel within the sludge blanket through which clear water can be withdrawn, leaving large quantities of sludge remaining within the sludge hopper.

The size of the desludging pipework is crucial for effective PST operation. Design guidelines recommend a minimum pipe diameter of 150 mm to 200 mm. This size is generally not based on the required volumetric discharge rate but is intended to minimize blockages. It is also common practice where pneumatic desludging valves are used to install an air connection so that, should a blockage occur, the pipe can be cleared using the full compressed air pressure.

Another method of sludge removal, although not that common, involves direct pumping of the sludge from the PST sludge hopper. This method has found application in some of the smaller treatment works.

Advantages of this system are:

(i) No deep sludging chambers are required as the pump can be located at ground level.

(ii) The sludge is drawn directly into the pump and is not exposed to the atmosphere, thus eliminating the possibilities of fly and odour problems often associated with primary sludge.

(iii) An almost constant draw-off can be achieved, thus reducing the peak loadings on downstream treatment processes such as digesters.

Disadvantages of this type of system are:

(i) A separate dedicated pump must be installed at each PST, thus increasing capital and running costs.

5.4 Aspects affecting PST performance

The performance of a PST is closely linked to the design assumptions and to the quality of the influent sewage. The most basic parameter affecting PST performance is the hydraulic loading rate, which is proportional to the flow rate and inversely proportional to the PST surface area.

The depth of a tank and consequently the volume also play a role in sedimentation. Typically the retention time within a PST should be not less than 2 hours at peak dry weather flow. This is important in order to allow sufficient time for the solid particles to settle within the tank. However, it must not be too long as biological activity within the sludge blanket of the PST may start and cause the breakdown of some of the solids to methane gas, carbon dioxide and water. The gases will rise to the surface of the tank, carrying settled solids with them and thus decrease the effectiveness of the settling tank.

Also too long a retention period could cause the wastewater to turn septic. Septic sewage creates major odour problems and reduces the settling characteristics of the organic particles as the overall particle size is diminished by biological degradation.

Correct design of the central stilling well and inlet baffles can also enhance the particle removal efficiency of the PST. The stilling chamber is vital for reducing influent flow velocities and distributing the flow uniformly across the entire cross section of the PST. The outlet weir must also be correctly designed to withdraw flow uniformly along the entire weir length and thus prevent short-circuiting and "static" areas within the PST.

The settling characteristics of similar sewages will differ depending on the sewer system, the industrial content, the number of pumping installations and the retention time within the sewer network. Temperature effects may also increase or decrease the viscosity and density of the influent wastewater. Varying PST performance can thus be observed during summer and winter periods.

Recycling flows through the PSTs can also affect settling performance. Not only do these flows add to the hydraulic load on the PST, but if for example a recycle flow contains dissolved oxygen, the bubbles would adhere to smaller sludge flocs, causing them to float to the surface of the tank.

Other recycled flows that affect PST performance are digester supernatant return flows, which induce septicity and create odour problems; return waste sludge from other processes may overload the sludge pumping capacity, causing septicity or solids carry over; backwash water from filters may increase the hydraulic loading and often contains solids that do not settle within the PST. To minimise the effects on the hydraulic and solids loading rates on the PSTs all return flows should be returned at a relatively constant rate when the incoming flow to the works is reduced.

5.5 Effect on downstream processes

Poor performance of primary sedimentation can adversely affect the downstream processes in a BNR plant as follows:

(i) A reduction in organic removal efficiency increases the load on the aeration basin. The resultant oxygen demand due to the increased load may exceed the capacity of the aeration equipment which can lead to incomplete nitrification.

(ii) The increased organic and solids loading increases the overall sludge mass within the system and may cause failure of the secondary clarifiers. Solids will then be discharged with the effluent.

(iii) Grease and fat carry-over can affect aeration efficiency and reduce the final effluent quality.

(iv) A decrease in sludge density from the PSTs can cause hydraulic overloading of the digesters or further thickening processes, thus increasing handling costs.

(v) Septicity can cause severe odour problems in subsequent thickening processes.

(vi) Toxic sludges can cause complete digester failure.

(vii) Primary settlement also has the effect of increasing the $^{TKN}/_{COD}$ ratio because about 10% of the influent TKN is removed whilst 40% of the COD is removed. This has an adverse effect on denitrification and can lead to an increase in the nitrate entering the anaerobic zone.

5.6 PST operation

Successful operation of PSTs revolves around the following:

(i) Sludge thickening

(ii) Scum removal

(iii) Hydraulic control

(iv) Odour control

(v) Housekeeping

Each is discussed below.

5.6.1 Sludge thickening

The degree of thickening achievable in a PST depends on the influent settleable solids and the removal efficiency of the PST. The resultant sludge must be thickened to suit the downstream processes. Where digesters are used, the sludge should be thickened up to approximately 6% to reduce hydraulic loading. Where thickeners are placed ahead of the digesters, a sludge density of 1% may be acceptable.

The degree of thickening and the removal efficiency of the PST can be controlled by the operator by careful selection of the desludging cycle. The desludging cycle should also be selected to suit the capacity of the pumping plant. Continuous pumping at a slower discharge rate will not load downstream process as severely as intermittent pumping at higher rates, although with constant pumping there may not be sufficient time to thicken the sludge within the PST adequately.

5.6.2 Scum removal

Scum, fats, greases, etc, should be removed continuously to prevent carry-over and odours developing. More frequent removal measures may be required if fats and greases are noticed in the final effluent.

5.6.3 Hydraulic control

Operators have little or no control over the rate of flow into the works. However, if flow is pumped into the works, the pumping times and cycles can be periodically changed to reduce the peak flow into the works and to make use of the storage capacity within the sewer system.

Where more than one PST is available, the operator must ensure equal flow distribution between all the duty tanks. When a tank is removed from service for maintenance, this should be done at times when no extreme peak flows are expected.

Manipulation of return flows to the PST can also reduce hydraulic shocks on the PSTs.

5.6.4 Odour control

The control of odours in PSTs can be very difficult particularly if the influent wastewater is septic. However, possible odours can be reduced by:

- not allowing any scum build-up in the PSTs,
- timeous removal of sludge thus preventing partial digestion within the PST,
- keeping all launders, weirs, etc free of algae,
- regular washing down of exposed sludge pipework and chambers,
- addition of chemicals such as activated carbon if the sludge is septic.

5.6.5 Housekeeping

An operator should generally ensure the following for efficient PST operation and better working conditions:

- Regular cleaning of stilling well, inlet baffles, overflow weirs and launders and scum removal equipment,
- Immediate cleaning up of sludge spills,
- Maintaining all painted surfaces to give a neat appearance,

- Checking mechanical equipment regularly.

5.7 Sludge fermentation in PSTs

With the increasingly strict effluent P discharge standards imposed in recent years, primary settling tanks are now being used not only for solids removal but also for fermentation of the settled solid material. Under these circumstances the solids are generally constantly removed and recycled back into the influent stream to the PSTs. Sludge wasting is done periodically once the solids accumulation within PST becomes excessive.

Under these conditions, the primary function of the PST changes to increasing the readily biodegradable COD fraction (RBCOD) of the influent by partial fermentation of the primary sludge. The secondary function then is to remove as much of the settleable solids as possible.

The RBCOD produced in the PST is elutriated (washed out) from the sludge blanket into the liquid phase and flows out with the overflow. In the anaerobic reactor the RBCOD is converted to short-chain fatty acids, which are essential for biological P removal.

The sludge is constantly recycled as the RBCOD produced in the fermentation stage is often bound within the sludge mass and must be elutriated into the liquid phase. A separate set of recycle pumps is often dedicated to this duty and a further set of pumps is dedicated to pumping the waste sludge from the system for further treatment.

During this mode of operation the PST is susceptible to blockages created by above average sludge densities being formed in the bottom of the PST. This is caused by the additional solids loading imposed on the PST by the sludge recycle.

The most critical aspect is to maintain a constant sludge recycle and to waste sufficient sludge from the system on a daily basis to prevent excessive solids build up in the PST. Excessive build up would lead to failure of the scraper mechanism, blockages occurring within the sludge pipework and sludge carry-over to the aeration basin (see section 5.5).

Fermentation is discussed in more detail in the following chapter.

5.8 Operator checks

5.8.1 Daily checks

- The tyres on the bridge wheels should be checked for wear.

- The weirs and overflow channel of the primaries should be kept clean and free from obstructions that may collect. The operator should brush these on a regular basis.

- The scum skimming mechanism and discharge box should be checked for obstructions and build up of material that is not easily discharged or flushed away or prevents the discharge.

- Material collecting on the surface of the water inside the stilling well should be removed by the operator.

- The traction wheel path on the top of the concrete wall should be inspected at regular intervals for foreign material and soundness of the concrete surface.

- The depth of the sludge blanket should be checked daily using a secchi disc. Ideally it should be more than 1 m below the overflow weir.

- If solids carry-over is taking place due to a high sludge blanket level, then the timer must be adjusted to desludge a larger amount.

- Check that adequate sludge thickening is being achieved and that sludge, not liquid, is being discharged from the hopper.

- Check and record the current drawn by the motor.

- If for some reason the rotating mechanism of the tank should be stopped the inflow to the tank should be isolated. Flow should be resumed once the mechanism is again rotating and the cause of stoppage eliminated.

- When the mechanism is operational, check for abnormal vibration or noise from the drive arrangement.

- Check for oil leaks and overheating of the motor and drive casings.

- Check that the bridge is rotating smoothly without juddering or jerking. If observed, investigate immediately.

5.8.2 Monthly checks

- Check oil level in drive gearbox.

- Check that all required points are lubricated and not running dry e.g. chain drivers.

- Check electrical connections for damage.

- Check all mounting bolts for security.

5.8.3 Yearly checks

- Drain and change all lubricants and oils.

- Drain tank and check scrapers for wear and for corrosion of steelwork.

CHAPTER 6

FERMENTATION

6.1 Introduction

In section 3.4.1 of Chapter 3, the importance of SCFA in the biological P removal process was highlighted. In South Africa the influent wastewater stream contains very little if any SCFA; these are generated from the acid fermentation of the RBCOD in the anaerobic zone of a treatment stream. The maximum mass of SCFA that can be generated is therefore largely a function of the RBCOD fraction of the incoming wastewater.

Research at pilot and full scale has shown that the SCFA fraction of the wastewater can be increased by fermenting primary sludge in either the PSTs or in separate fermentation tanks. The SCFA generated in this manner significantly improve the phosphorus removal and also the nitrogen removal in a BNR plant.

Fermentation of primary sludge takes place under anaerobic conditions. Particulate degradable organic matter starts breaking down to form SCFA. This process is much the same as the initial stages of anaerobic digestion and is termed acidogenesis. The principal SCFA formed during acidogenesis are acetic, propionic and butyric acids.

In order to maximise the mass of SCFA produced during acidogenesis, the fermentation period must be terminated prior to the onset of the second stage of digestion called methanogenesis. In this stage, the SCFA produced are utilised by methane producing organisms to form methane, carbon dioxide and water. Due to the flammability and wide explosive limits of methane, methanogenesis must be avoided. Fortunately, these bacteria are very slow growing and their presence or absence can be controlled by maintaining the sludge age or fermentation period below approximately 6 days. In some cases, it may be possible to exceed the 6-day fermentation period without observing any methane forming. However, in practice, the most economic fermentation period, based on construction costs and mass of SCFA produced, is approximately 3 to 4 days. The SCFA formed within the sludge blanket are then washed out (elutriated) into the liquid medium using settled sewage. The acid rich flow is then returned to the influent stream for use by the poly-P organisms in the anaerobic zone.

During the fermentation period, the pH decreases and may decline to below 6,0. This however, does not adversely affect the acid forming bacteria, but does retard the growth of the methane producing bacteria. Increases in ammonia are also observed during the fermentation period. However, this does not increase the overall nitrogen load on the plant substantially.

6.2 Fermentation processes

Fermentation tanks can be either off-line or on-line, depending on the availability of space and funds for the particular plant. On-line fermentation takes place within the primary sedimentation tank, the sludge being continuously recycled to elutriate the fermentation products. This mode of fermentation has been discussed in section 5.7 of Chapter 5.

Off-line fermenters receive either a fraction of the primary sludge or the total primary sludge flow from the PSTs. The fermenters may be circular or rectangular tanks and can be operated as a batch fermentation system, or as a continuous system. The tanks themselves are similar to the PSTs described in chapter 5.

6.2.1 Batch fermentation system

If a single fermentation tank is used, primary sludge is discharged to the tank over a 3 to 4 day period. During this period, the sludge ferments and is continuously recycled. Elutriant is continuously introduced into the tank to wash out the SCFA formed within the sludge blanket. This ensures a constant feed of fermentation products into the influent wastewater stream. Once the fermentation period is complete, the sludge is drained completely from the tank and the cycle recommences.

Where multiple batch fermenters are used, it is usual to have the same number of units as the fermentation period in days. Primary sludge is discharged to a single unit until this unit is full whereupon it is discharged to the next fermentation unit. A single tank is usually full within a 24-hour period. The sludge is then fermented within this tank for a 3 to 4 day period. During this period, the sludge is continuously recycled to prevent the sludge thickening to too great a density. Should the sludge density increase too much, overloading and possibly failure of the mechanical equipment might occur. While the primary sludge is being fermented, no elutriant is introduced into the tank.

Once the fermentation period is complete, elutriant is introduced into the tank to wash out the SCFA formed within the sludge blanket. Elutriating the SCFA usually takes place over a 24-hour period. During this stage the tank is completely desludged and emptied before receiving a new batch of primary sludge. Elutriant is then introduced into the next unit, thus ensuring a constant discharge of SCFA into the influent stream.

6.2.2 Continuous fermentation

Continuous fermentation takes place in either a single unit or multiple units operated in parallel. In either scenario, the primary sludge, as it becomes available, is fed to each unit simultaneously. Elutriant is fed continuously to each unit.

The sludge accumulates and thickens within the fermentation tanks. The SCFA are continuously elutriated from the sludge blanket by means of stirring and recycling.

The sludge age or fermentation period within each fermenter is controlled by wasting a measured volume of sludge from each unit each day. Wasting is usually done sequentially from unit to unit. Sludge is continuously recycled during the fermentation period and is stopped only when sludge wasting is being done to allow the thickening of the sludge prior to wasting.

6.3 Typical fermentation system

A typical fermentation system will comprise fermenter tanks, a pump station and possibly elutriant/mixing tanks.

6.3.1 Fermentation tanks

Fermentation tanks are designed as gravity thickeners and are generally circular. They typically have a 4 m side wall depth and a sloping floor with a central sludge hopper. The cone formed by the sloping floor acts as a sludge storage fermentation zone. Each tank has a centrally driven picket fence thickener drive arrangement and scum removal equipment. The picket fence thickener must be designed to take high torques as it is possible to achieve a 10% sludge density within the fermenter. It must be fitted with a safety device which should stop the mechanism if torques in excess of the operating limit should develop. This is the only method of preventing serious damage to the thickener mechanism in cases where densities in excess of the design are reached.

Scum removal equipment in a fermenter comprises a skimmer board attached to the scraper arm mechanism which sweeps floating scum into a drowned scum box. A peripheral baffle is provided to prevent scum from being discharged over the weirs. The scum discharged from the fermenter tanks is generally discharged with the wasted sludge for further treatment.

Primary sludge and elutriant are introduced into a central stilling chamber within the fermenter in a similar fashion to the PSTs.

6.3.2 Fermentation pump stations

Depending on the particular characteristics of the treatment works, the pump station may house primary sludge feed pumps, elutriant feed pumps and sludge recycle/wasting pumps. Each fermenter tank generally has a dedicated set of pumps unless a batch type system is installed. In a batch system it is necessary to have only one set of primary sludge and elutriant feed pumps, but each unit must have dedicated recycle pumps.

The primary sludge, elutriant and recycle flow are generally mixed together in a common pipe discharging into the central stilling chamber. This is essential to promote adequate elutriation of the fermentation products. Alternatively, a separate mixing/elutriant tank can be provided into which all flows are discharged before flowing into the fermenter. A high mixing intensity ensures that maximum elutriation occurs.

The primary sludge is generally discharged under gravity from the PSTs to a sump, from where it is abstracted and pumped to the fermentation units.

Elutriant, normally settled sewage, is abstracted from the main flow to the treatment basins. The recycle pumps are connected directly to the central sump in the fermentation units. In this manner the sludge is continuously abstracted and recycled. In some installations, the recycle pumps can be used for wasting sludge from each unit.

6.4 Operation

The most important aspect of the operation of fermentation tanks is the determineation of a suitable fermentation sludge age for the system. In general this may be anywhere between 2 and 6 days, and is a function of the sewer network serving the treatment works and temperature. Where the raw sewage resides in the sewer network for long periods, the maximum sludge age for fermentation is generally reduced due to partial fermentation occurring in the sewer system. Where the residence time in the sewer system is short, longer fermentation periods may be necessary.

In starting a fermentation process, a detailed analysis of the SCFA produced will have to be carried out. It is most important to monitor production and to establish at what sludge age production suddenly decreases, or at what stage a decrease in SCFA concentration is observed due to the onset of methanogenesis.

Once a suitable fermentation sludge age has been determined, the appropriate sludge wasting cycle can be established.

Although it appears that the amount of SCFA produced is independent of the solids concentration of the influent primary sludge, the primary sludge received from the PSTs should be at a concentration of at least 3%. At lower concentrations, greater pumping rates are required to pass the necessary sludge mass through the fermentation system.

The required volumetric flow rate of elutriant required for SCFA elutriation is approximately equal to the daily volume of primary sludge discharged to the fermenter.

The sludge recycle pumps should be sized such that the entire sludge mass within the fermenter is recycled at least once a day.

6.5 Operator checks

The operator of a fermentation system should check the following on a daily basis:

- That the thickener mechanism is rotating and that the safety cut-off device is operating.
- Check oil levels in gearboxes, etc and that all parts are suitably lubricated according to the manufacturers' details.
- That the recycle pumps are recycling sludge and not liquor.
- That the scum collection equipment is operating and that there is no accumulation of scum on the surface of the fermenter.
- That primary sludge is being pumped into the system at the correct density. If the sludge density from the PSTs is too low, then the PST desludging cycle must be changed to deliver a suitably thick sludge.
- The required waste sludge volume is being wasted per day.
- Regular samples should be taken and analysed to check that adequate SCFA production is being achieved within the

fermentation units. If the performance is unsatisfactory or has radically decreased, it may be necessary to reduce the fermentation sludge age by increasing the daily waste sludge volume. If this proves unsuccessful then the entire sludge from the unit will have to be wasted and the fermentation cycle begun from scratch.

- The fermentation tanks should also be checked mechanically as described in Section 5.8.

CHAPTER 7

FLOW BALANCING

7.1 Introduction

Every treatment plant is subject to diurnal and seasonal flow variations. Generally the smaller the plant the larger the peak flow factor. In some cases the peak flow factor may be as much as 6 times the annual average daily flow (AADF). In larger works the peak factor may only be as high as 2. However, in many designs the peak flow into a treatment works is limited to 2 or 3 times the AADF. The excess flow is diverted to a storm tank. This flow is then returned to the works for treatment once the peak flow has passed and the remaining flow rate has decreased.

Wastewater plants also experience diurnal variations in the influent strength which tend to follow a similar pattern to that of the flow rate. As a result the maximum COD loading may be as high as twice the average COD load and the minimum COD loading may be as low as 0,2 times the average COD loading.

In the design of a treatment plant, the process is designed for AADF conditions with a peak factor applied to the aeration requirements and the hydraulics are designed for peak wet weather flow (PWWF) or the restricted peak wet weather flow.

In order to minimise the effects of these flow and load peaks, a flow balancing tank can be included ahead of the main treatment basin. The prime function of the tank is to protect the works from high peak flows and to even out the flow and organic load variations on the plant.

Other advantages of a balancing tank are:

(i) Protection of the aeration basin against shock toxic loads.

(ii) Improvement of aeration tank performance where the aeration equipment is only marginally adequate in coping with normal peak oxygen loads.

(iii) Adverse effects on denitrification are greatly reduced when minimising the cyclic load conditions.

(iv) The tank provides the most appropriate point of return for concentrated recycle streams from digesters and sludge dewatering facilities.

(v) In processes which utilise chemical phosphate removal, the equalisation of organic loads simplifies the chemical feed control and reduces instrumentation complexity.

(vi) Balancing of the flow also reduces variations in the design mass fractions because recycles, such as are required with the UCT systems, are generally not sized to keep pace with the peak inflow.

7.2 Tank description

The tanks can have any shape although rectangular or square tanks are most common. The tanks are positioned after screening, degritting and primary sedimentation to prevent settling and accumulation of solids material on the bottom of the tank. The tanks are usually mixed using vertical spindle mixers. Mixing is needed to prevent particulate organic matter settling to the bottom of the tank and to mix the influent with the return flows. The tanks should have floors which slope towards the outlet to allow complete drainage.

They also usually have a central drainage channel and should be emptied once a day.

Control valves are used to regulate the outflow from the tank, which should be as constant as possible and close to the average flow over the day. Generally, this flow control is difficult to achieve by manual operation of the control valves due to varying liquid depths within the tank. Also, the total inflow into the tank varies from day to day, and in plants receiving industrial effluent, weekend flow is typically lower than weekday flow and the effects of stormwater can affect flow rates on other days. Due to the above variations, the outflow from the balancing tank is usually controlled via a computer program.

The programs available are based on historical inflow data which is constantly updated. The program anticipates periods of high inflows and prior to the anticipated increase in flow, the valves are opened reducing the storage volume in the tank. The storage volume available is calculated by the program based on the area of the tank and the water level within the tank. The water level is monitored by a suitable depth measuring device. The incoming peak flow can then be stored thus reducing the flow to the downstream process. To prevent the sewage from becoming septic, the tank should be emptied once every 24 hours.

An important aspect of the design of these tanks for BNR plants is to limit aeration as the flow enters the tank. Any aeration occurring within the tank will reduce the available RBCOD, which is essential for P removal.

CHAPTER 8

REACTOR OPERATION

8.1 Introduction

Numerous operating configurations can be selected to remove nutrients from wastewaters depending on the particular wastewater characteristics. The current trend among South African designers is to incorporate several nutrient removal systems in one reactor. This enables the operator to change the system configuration if the wastewater characteristics change. This is generally achieved by opening or closing penstocks to redirect the recirculated and influent flows towards different compartments. The mass fractions and operating systems can thus be changed.

8.2 Mass fractions

The mass fraction of a particular compartment in an activated sludge reactor is simply defined as the mass of sludge in that compartment divided by the total mass of sludge in the reactor. Even in completely mixed reactors the concentration of sludge will not always be the same in each compartment. Two particular cases are the Johannesburg and UCT or MUCT configurations. In the Johannesburg system the sludge concentration in the unaerated compartment to which the clarifier recycle discharges will be approximately twice that in the rest of the reactor when the influent and clarifier return flows are the same. In the UCT and MUCT systems, the anaerobic compartment will have a sludge concentration approximately half of that of the rest of the reactor when the anaerobic recycle and influent flow are equal.

An example of how to calculate the mass fractions follows for a Johannesburg configuration.

Table 8.1 : Calculation of Sludge Masses in Reactor Compartments

Compartment	Volume (m^3)	Measured MLSS Concentration (mg/ℓ)	Mass of Sludge (kg) = Vol * MLSS
Anaerobic	3 600	3 500	12 600
Primary Anoxic	3 500	3 490	12 215
Aerobic	9 700	3 450	33 465
Clarifier Anoxic	1 200	7 000	8 400
TOTAL	18 000		66 680

From the above masses, the mass fractions are calculated as follows:

Anaerobic mass fraction = 12 600 ÷ 66 680 = 0,19

Primary anoxic mass fraction = 12 215 ÷ 66 680 = 0,18

Aerobic mass fraction = 33 465 ÷ 66 680 = 0,50

Clarifier anoxic mass fraction = 8 400 ÷ 66 680 = 0,13

The mass fractions calculated above are influenced by the diurnal flow pattern entering the reactor. At low flows the clarifier anoxic mass fraction will decrease unless the clarifier recycle is adjusted to match the influent flow.

Mass fractions are relevant to the process as they influence:

- the minimum sludge age for nitrification
- the extent to which the plant will denitrify
- the phosphorus removal ability.

8.3 Mixing of unaerated zones

Mixers are usually provided in the unaerated compartments to:

- prevent short-circuiting of flows
- prevent sludge settlement
- ensure that the organisms are in intimate contact with the influent sewage.

Mixing can be provided either by submersible or bridge-mounted vertical spindle mixers. The energy intensity provided must be such that adequate mixing is provided without vortexing or air entrainment. Mixing intensities generally vary between 5 and 15 W/m^3. It is therefore useful to have two speed mixers that can provide a range of intensities.

8.4 Oxygen Utilization Rate (OUR)

Oxygen utilization rate (OUR) is the term given to the rate at which the micro-organisms use oxygen. In full-scale plants it is usually expressed in terms of kg O_2/h. When measured it is a combination of the oxygen required to oxidize both COD and nitrogen entering a plant as well as the oxygen used by the organisms in endogenous respiration. In laboratory-scale plants it is measured by elevating the dissolved oxygen concentration to about 6 mg O_2/ℓ and then cutting the oxygen supply. The dissolved oxygen concentration is then monitored and plotted against time. A linear plot should be obtained. The slope of the plot then gives the OUR.

In full-scale plants this parameter is difficult to measure accurately because, if the air supply is turned off, the mixing caused by the aeration equipment will cease. This will result in settlement of the sludge and erroneous results can be obtained.

The OUR is highest at the point where the influent sewage enters the aerated reactor and decreases in the direction of flow. This phenomenon is the result of the higher COD and ammonia concentrations entering the aerobic reactor. In the case of dewatering liquors the OUR drops significantly through the reactor due to the relatively high ammonia concentrations entering this zone being rapidly oxidized.

At summer temperatures the change in the OUR through the reactor is marked due to the increased activity of the micro-organisms. At low winter temperatures the OUR is more constant through the reactor. The total oxygen demand is however virtually identical in summer and winter. This can be seen from the expected oxygen demands calculated for winter and summer conditions.

Table 8.2 : Oxygen Utilisation Rates at Different Temperatures in a Plug Flow Reactor

Aerator No.	O_2 Required @ 20°C kg O_2/h	O_2 Required @ 14°C kg O_2/h
1	84	55
2	79	55
3	69	54
4	51	53
5	34	50
6	27	46
7	26	38
8	25	29
TOTAL	395	380

The power requirements in winter are however lower, due to the greater oxygen transfer efficiency at the lower temperatures. To illustrate this point the oxygen demands given in Table 8.2 above have been recalculated as power requirements in Table 8.3.

Table 8.3 : Power Requirements at Different Temperatures in a Plug Flow Reactor

Aerator No	Aerator size (kW)	Power required @ 20°C	Power required @ 14°C
1	90	73	43
2	90	68	42
3	90	59	42
4	55	43	41
5	55	29	39
6	45	23	36
7	45	22	29
8	45	21	23
TOTAL	515	338	295

This point should be noted by plant operators as power savings may be possible during winter months when power demand elsewhere is at a premium.

8.5 Measurement of Dissolved Oxygen (DO)

In larger nutrient removal plants metering of the dissolved oxygen (DO) concentrations is usually provided at several locations in the aeration basin. The position at which metering is provided must be carefully selected to ensure that power input is minimized as well as that a minimum DO concentration of 1 mg O_2/ℓ is maintained.

The DO concentration will vary along the reactor as it is not possible to match aeration equipment exactly with the expected OUR in the basin. Although positions where DO meters should be installed can be suggested by plant designers, the operator should use a portable DO probe to determine a DO profile through the basin before all final positions are established.

Where surface aerators are installed the DO concentration will also vary with depth and this should be taken into account when selecting DO set points.

A high DO concentration will always be measured near the aerator at the surface. Lower down the DO concentration will be lower and at the bottom of the aeration basin it may be zero. The measurements should therefore be taken at some intermediate depth.

Although many of the DO meters available today are of the self-cleaning, self-calibrating type these should be cross-checked daily and calibrated regularly.

When installing DO probes it is prudent to allow for extra cabling so that they can be moved if required.

The manufacturer's instructions should be followed, or alternatively, these should be calibrated by immersing the probes in a beaker of saturated solution of sodium sulphite to give a reading of 0 mg O_2/ℓ. The maximum reading should be checked against the saturated oxygen concentration given in the following tables when immersed in a vigorously aerated beaker of distilled water.

Table 8.4 : Saturated Oxygen Concentration in Water at 1 Atmosphere (Sea Level) for Various Temperatures (Landine, 1971)

T°C	p Sat water Vap pressure mm Hg	Cs Saturated Oxygen concentration mg O/ℓ
0	4,58	14,53
5	6,54	12,67
10	9,21	11,23
15	12,78	10,04
20	17,51	9,07
25	23,69	8,20
30	31,71	7,50

8.6 Characteristics of various types of aeration equipment

The various types, advantages and disadvantages of available aeration equipment are given in Table 8.6 overleaf.

The above C_s values are affected by elevation above sea level. These effects and the temperature effect on C_s can be closely approximated using the following formula:

$$C_s = C_{s_{std}} \frac{P - p}{P_{std} - p_{std}} * \frac{51,6}{(31,6 + T)}$$

where

C_s = saturation concentration of oxygen at test site

$C_{s\,std}$ = saturation concentration at 1 atmosphere (9,07 mg/ℓ)

P = atmospheric pressure (mm Hg) at test site (see Table 1)

P_{std} = 1 atmosphere (760 mm Hg)

p = saturated water vapour pressure at the particular water temperature (estimated from Table 8.4)

p_{std} = saturated water vapour pressure at standard temperature (17,51 mm Hg)

T = Temperature in °C

Table 8.5 : Relationship Between Altitude (height above sea level) and Atmospheric Pressure Expressed in mm Hg and Millibar.

Altitude (m)	Atmospheric Pressure	
	(mm Hg)	(millibar)
Sea Level	760	1013
500	715	953
1000	673	897
1500	633	844
2000	595	793
2500	560	746
3000	525	700

Table 8.6 : Advantages and Disadvantages of Aeration Equipment

Equipment Type	Equipment Characteristics	Processes where Used	Advantages	Disadvantages	Reported Transfer Efficiency kg O_2/kWh
DIFFUSED AERATION (BUBBLER) Porous Diffusers	Produce fine or small bubbles. Made of ceramic plates or tubes, plastic-wrapped or plastic-cloth tube or bag.	Large, conventional, activated sludge process.	High oxygen transfer efficiency; good mixing; maintains high liquid temperature. Varying air flow provides good operational flexibility; dome density can be varied easily to provide tapered aeration. Noise of blowers can be fairly easily contained.	High initial and maintenance costs; tendency to clog; total life span of only 15 years.	2,5 - 3,5
MEMBRANE DIFFUSER	Produce fine or small bubbles. Made of ceramic or plastic plates which are rubber or synthetic material.	All sizes of activated sludge process.	Advantages as per porous diffusers and non clogging due to elasticity of the membrane.	High initial and maintenance costs. Total life span about 20 years.	2,5 - 3,5
NON-POROUS DIFFUSERS	Made in nozzle, valve, orifice or sheer types they produce coarse or large bubbles. Some made of plastic with check-valve design.	All sizes of conventional activated sludge process.	Non-clogging; maintains high liquid temperature; low maintenance cost.	High initial cost; low oxygen transfer efficiency; high power cost. Clogging can occur.	-
(STATIC)	Produces high shear and entrainment as water-air mixture is forced through vertical cylinder containing static mixing elements. Cylinder construction is metal plastic, or polyethylene.	Primarily aerated lagoon applications.	Economically attractive; low maintenance; high transfer efficiencies for diffused air systems. Well suited for aerated lagoon application.	Ability to mix aeration basin contents adequately is questionable. Application for use in high-rate biological systems unconfirmed.	2,0 - 3,0
MECHANICAL AERATION RADIAL FLOW - SLOW SPEED	Low output speed of 30 to 60 rpm; large diameter tubing, usually fixed-bridge or platform mounted. Used with gear reducer.	All sizes of conventional activated sludge and aerated sludge processes.	High oxygen transfer efficiency; tank design flexibility. High pumping capacity.	Some icing in cold climates. Initial cost higher than axial flow aerators. Gear reducer often causes maintenance problems. Difficult to contain noise.	2,1 - 2,4
AXIAL FLOW - HIGH SPEED	High output speed. Small diameter propeller. They are direct motor-driven units mounted on floating structure.	Aerated lagoons and activated sludge processes.	Low initial cost; simple to install and operate; good transfer efficiency; adjust to varying water level.	Some icing in cold climates; poor maintenance accessibility. Pitting of propeller caused by grit.	1,2 - 1,8
BRUSH AERATION	Low output speed; used with geared speed reducer	Oxidation ditch applied whether as an aerated lagoon or as an activated sludge process.	Relatively low initial cost, easy to install and operate, good maintenance accessibility, moderate transfer efficiency.	Subject to operational variables which may affect efficiency.	-
TURBINE AERATION	Units contain a low speed turbine and provide compressed air on sparge ring; fixed-bridge application.	Conventional, activated sludge process.	Good mixing; high capacity input per unit volume; deep tank application; moderate efficiency; wide oxygen input range; operational flexibility.	Requires both gear reducer and compressor; tendency to foam; high total power requirements. High noise levels. Aerosol production.	1,7 - 2,4

Of the aeration equipment listed above, the types most commonly found in South African nutrient removal plants are ceramic diffused aeration bridge mounted turbine aerators and radial flow-low speed aerators. The control of these two types is discussed below.

8.7 Control of diffused aeration equipment

This type of aeration equipment requires a minimum air pressure at the diffusers to overcome the pressure of the liquid. The blowers may be signalled by a DO probe to control a variable speed drive regulating the DO concentrations. Usually high and low set points of 1 mg O/ℓ and 2 mg O/ℓ are selected to prevent "hunting" of the blowers. Alternatively, the flow of air can be varied by controlling or adjusting the inlet valves of the blower.

8.8 Control of mechanical aerators

The process performance of the plant requires the dissolved oxygen concentration of the liquid in the aeration basin to be maintained within a predetermined range; and that homogeneous conditions be maintained for effective mixing. To achieve this condition three automatic independent control systems operated by programmed PLCs are commonly used. The three systems are broadly defined as follows:

- Dissolved oxygen probe generated with controlled switching on and off of aerators with manual or automatic liquid level maintenance (DOCS).

- Time-generated controlled switching on and off of aerators with manual or automatic liquid level maintenance (TGCS). The timing sequence can either be set manually or be based on historic data.

- Dissolved oxygen probe generated with controlled oxygen transfer of aerators by immersion depth variation with automatic liquid level maintenance (VAID).

8.8.1 Dissolved Oxygen Control System (DOCS)

The aerators within the aeration basin are normally grouped together such that the basin is divided into a number of compartments, each with a set of aerators.

To control the aerators using the DOCS, a single DO probe is placed in each compartment. The position of the probe in each compartment may vary, i.e. it is not critical to place the DO probe in an identical position within each compartment.

The signal received from each probe will be analysed to establish deviations from the established DO concentration required. When the DO level in the individual compartments reaches a predetermined upper set point one aerator will be switched off. The aerator will be automatically selected to ensure that no two adjacent aerators are switched off at the same time. Should the dissolved oxygen level continue to rise then the next alternate aerator will switch off. Thereafter should the DO continue to rise in that compartment an alarm should sound which will require the operator to investigate and, if necessary, to alter the depth of immersion of the aerators. Conversely when the DO level falls to a predetermined low set point, or continues to drop or remain at the low set point an aerator will switch on after a predetermined period. An alarm should be initiated if, after a specified period, the DO continues to drop or remains at a low level. An adjustable buffer period is normally provided between compartments to permit an increase or decrease in the DO level.

Alternatively, one control DO meter or the average of all three meters may be used to switch on or switch off alternate aerators progressively.

The period between aerator switching should be limited to a maximum of four starts per hour.

During the above operation the predetermined liquid level will be automatically maintained in the basin irrespective of the depth of flow over the weir using a level detector and automatic actuator on the overflow weir. A step function with adequate time intervals should prevent "hunting" of the actuator. A signal indicating the position of the weir should be provided to give a closed loop. A manual override control of all automatic controls is normally provided.

8.8.2 Time Generated Control Systems (TGCS)

A continuous DO profile is maintained and updated on the PLC at known immersion depths for the aerators and this is used to set timer controls on the PLC for switching on and off of the aerators. Provision should be made for daily control based on historical flow and load. Provision should also be made for manual time setting.

The water level in the reactor is maintained either automatically as set out above or manually.

8.8.3 Varying Aerator Immersion Depth (VAID)

The rate of oxygen transfer is controlled by varying the depth of immersion of the aerators. If the oxygen transfer/depth relationship is a zero order function for the different aeration sizes the slope of the graphs should be virtually identical. A single overflow weir level adjustment will, therefore, provide equal proportional control of oxygen input to each aerator. In plants where there are a number of different sizes of aerators present, it may be necessary to provide internal baffles for flow depth control or it must be accepted that some aerators will be operating at less than optimal immersion. Provision should be made for controlling the system by selecting a control probe from each compartment or by averaging the signal from all three.

When the DO is suppressed or increased by a predetermined amount - say 0,2 mg/ℓ - the overflow weir will be raised or lowered by a preset amount - say 20 mm - using an actuator and incremental control. A feedback signal from the level detection equipment will confirm when this level has been reached and thus provide a closed-loop function. The system should then be monitored for a predetermined adjustable period and if the DO concentration is not corrected or continues to increase or decrease, the procedure will be repeated. This control activity will continue until the upper and lower levels of immersion depth have been reached, at which point an alarm will be initiated. The operator should then take corrective action such as manually switching on or off an aerator. Caution must be exercised with this type of control so that the weir is not lowered rapidly resulting in hydraulic overload of the final clarifiers.

During the above activity, the level detector will monitor the set level in the aeration basin and adjust to accommodate increases or decreases in flow and hence height over the weir. This again will be a step function to prevent "hunting" of the actuator.

The step periods are normally limited to four per hour.

8.9 Control of sludge age

In any process, control of the sludge age is the most important factor in achieving stable operation within a particular process.

By controlling the sludge age, the operator is able to maintain the sludge concentration at some value specified in the design or established from operating experience.

The sludge age of a plant can be defined as the mass of sludge in the reactor(including that of the unaerated reactors) divided by the mass of sludge wasted per day.

The sludge age is controlled by wasting a fixed mass of sludge from a process on a daily basis. There are two points in a process from which sludge is wasted: the clarifier underflow and directly from the reactor.

Wasting sludge from the clarifier underflow has the benefit of the thickening function of the clarifier. However, this method of sludge wasting is not recommended as the solids concentration in the underflow varies considerably with the daily cyclic flow pattern through the plant. It is therefore necessary for the operator to measure the concentration of the underflow to determine the mass of sludge wasted, and thus to calculate the sludge age. This method is therefore not recommended, if precise control of sludge age is required.

A simple more preferable method of determining the mass of sludge wasted per day is to waste sludge directly from the reactor. The mixed liquor concentration within the reactor is not affected by the diurnal flow patterns as much as in the clarifier underflow. By wasting a fixed volume of mixed liquor from the aeration basin, the mass of waste sludge can be easily calculated from the MLSS concentration as the MLSS concentration in the reactor is the same as in the waste sludge. Using this type of control, if a sludge age of say 15 days is required, one-fifteenth of the reactor volume is wasted every day.

The sludge should be wasted over a complete day and not over a short period. This prevents hydraulic and solids overloading of the downstream treatment facilities.

The most important aspect to remember when using the hydraulic control technique is that if a fixed volume and mass of sludge is wasted every day, the sludge age is automatically fixed, regardless of any COD load variations over the day. This method also allows the sludge age to be changed fairly easily, by increasing or decreasing the volume and mass of sludge wasted per day.

8.10 Control of internal recycles

Once the sludge age of a plant has been established and effectively controlled, plant efficiency is dictated by the influent sewage and by controlling the internal recycles. As little or no control of the influent sewage is possible, control must be achieved by manipulating the recycle rates.

The various recycles have been described in Chapter 4. Each of the recycle rates discussed below operates on a continuous basis. The recycle rates are normally automatically controlled on a large works and manually on small works.

8.10.1 A-recycle (aerobic/anoxic recycle)

In all of the BNR processes, the A-recycle introduces nitrate from the aerobic zone to the anoxic zone.

In the Phoredox and Johannesburg systems the recycle rate should be controlled such that the anoxic zones are not loaded beyond their denitrification potentials. Recycles greater than those required will not improve nitrogen removal and will result in higher costs for the extra pumping. In the UCT system, this recycle rate needs to be carefully controlled, as excess nitrate in the anoxic zone will be recycled back to the anaerobic zone, detrimentally affecting P-removal and causing sludge bulking.

Recent research work by the Water Research Group (WRG) of the University of Cape Town has indicated that the control of this recycle has a great impact on the likelihood of bulking. Work on bulking in BNR plants shows that it is related to the concentrations of nitrite entering the aerobic zone. Rapid deterioration in sludge settleability was observed when nitrite was present in the influent to the aerobic zone at concentrations greater than 1-2 mg N/ℓ. The effect on bulking of nitrite entering the aerobic zone from the anoxic zone was far more rapid than that caused by the nitrate. The WRG postulate that bulking is affected by the presence of nitrate in the stream passing to the aerobic zone, but this is only because during denitrification, nitrite is formed. To minimise the effect of nitrite on the sludge settleability therefore, the A-recycle ratio needs to be controlled at rates which load the anoxic zone to just less than its denitrification potential, thus ensuring minimal flow of nitrate and nitrite into the aerobic reactor.

The pre-set recycle rate requires adjusting only when the full denitrification of the anoxic zone is not being utilised, or when excess nitrate is being recycled to the anaerobic or aerobic zone. By monitoring the nitrate in the effluent and in the anoxic basin outlet the recycle rate can be optimised for both power consumption and effluent nitrate quality as summarised in the table below:

Table 8.7 : Optimisation of A-Recycle Rate

Nitrate Concentration	Required Adjustment of Recycle Rate
High effluent nitrate; zero nitrate at the end of the anoxic zone.	Increase recycle rate, further denitrification may be possible.
High nitrate at the end of the anoxic zone: decrease in P-removal in the UCT process; "bulking sludge".	Reduce recycle rate to save power - the anoxic zone is operating at its full denitrification potential and no further denitrification is possible.

8.10.2 S-recycle (clarifier recycle)

In the Phoredox process the P-removal efficiency is affected by the nitrate concentration in the S-recycle which is similar to the effluent nitrate concentration. The S-recycle should thus be controlled such that the amount of nitrate returned to the anaerobic zone is minimised. It must however not be too low to allow sludge to accumulate within the clarifier, resulting in loss of sludge with the effluent overflow.

In the Johannesburg systems the S-recycle rate to the anoxic zone must be controlled such that this zone is just loaded to its denitrification efficiency. This is difficult because the S-recycle rate is also dictated to by the operation requirements of the clarifier. Any nitrate in the anoxic zone will be discharged into the anaerobic zone, adversely affecting the overall P-removal. However the recycle rate must be sufficiently high to prevent solids accumulation within the clarifiers.

In the UCT system, the S-recycle rate does not have to be controlled as described for the previous systems, since the nitrate concentration in the anoxic is controlled by the internal A-recycle rate.

In MUCT systems, the S-recycle discharges into a small primary anoxic zone which is normally sized to denitrify nitrate that could possibly be returned in the S-recycle. Adjustment of this recycle is therefore normally made to suit clarifier operating requirements only and not to control the nitrate returned to the primary anoxic zone. However, greater control of the S-recycle with regard to nitrate return may be required should the influent TKN/COD ratio increase considerably from that of the original design.

8.10.3 R-recycle (anoxic/anaerobic recycle)

The R-recycle applies to the UCT and MUCT processes only. This recycle needs to be controlled such that sufficient solids are returned to the anaerobic zone to maintain the design anaerobic mass fraction. The recycle rate is normally linked to the influent flow in a 1:1 ratio.

CHAPTER 9

FINAL CLARIFIERS

9.1 Introduction

The final clarifiers are an essential part of the treatment process. In this unit solids/liquid separation takes place using gravity, and clear effluent is produced. Although the primary function of the clarifier is to separate the treated wastewater from the biological sludge mass, the clarifier also has a thickening function. The thickening function produces a continuous thickened sludge which is returned to the main treatment stream.

Should the clarifier fail in any one of these two functions, sludge will be present in the final effluent. Should conditions arise in the clarifier causing appreciable loss of sludge over the overflow weir, the behaviour of the biological process could be adversely affected. This is primarily due to the sludge age within the system being reduced. Should it fall below the minimum required for nitrification, loss of nitrification and denitrification could result.

The sludge settleability within the clarifier is a function of the sludge characteristics and of the conditions within the reactor.

Sludge settling characteristics of different sludges and BNR processes vary considerably. Sludge settleability may also improve or deteriorate within a single treatment process.

Examples of operating conditions affecting settleability are:

- Over-aeration may lead to break up of the sludge flocs within the aeration basin resulting in a small pin-point floc within the clarifier. Although the sludge shows good settling characteristics, poor clarification is achieved.

- Under-aeration generally reduces the sludge settleability.

- In BNR processes with large unaerated sludge mass fractions, poor settling characteristics are observed.

- If low pHs result in the process, the sludge settleability is adversely affected.

- As discussed in Section 8.10.1 nitrite concentrations in excess of 1 to 2 mg N/ℓ passing from the anoxic to the aerobic zone can lead to sludges settling poorly.

In light of the above, it is important to consider the operation of the reactor and the clarifier together and not as individual units.

9.2 Clarifier description

Most clarifiers are circular, although rectangular and square clarifiers have been used. They fall into two broad categories, mechanical and non-mechanical. The non-mechanical type of clarifier is often referred to as a Dortmund tank and is commonly used on small works in South Africa. Dortmund tanks generally have a minimum vertical side wall depth of either 0,6 m or 15% of the tank diameter. The bottom of the tank is a deep cone with sides that slope 60° to the horizontal.

Influent is piped upwards into a deep central stilling chamber which dissipates the incoming energy. The liquor then flows down the stilling chamber into the tank. It then flows upwards to the surface from where it is drawn off over a peripheral weir into a collection channel. The sludge draw off-pipe is usually laid along the inside surface of the cone and terminates just short of the end of the cone. Sludge is then withdrawn using hydrostatic head or pumped directly out of the tank. These tanks are therefore very easy to operate due to the absence of mechanical equipment.

Mechanical clarifiers generally have a sidewall depth of 3,5 m and either a sloping floor with a central sludge hopper or a flat floor with no sludge hopper, depending on the method of sludge removal.

The sidewall depth is important as it must provide sufficient depth for clarification, settling, storage and compression. The mixed liquor from the aeration basin is introduced into a central circular stilling chamber in a similar fashion to that of the PSTs. The liquor exits the stilling chamber at the bottom and flows radially outwards towards the overflow weirs.

In clarifiers with a sloping floor and central sludge hopper, the settled sludge is moved to the hopper by a scraper mechanism which generally rotates at 1 m/min at the outer edge of the tank. The sludge is then continuously abstracted from the hopper through a pipe under hydraulic head and flows to a sump. The rate of abstraction is controlled by a telescopic valve on the discharge pipe. With this valve it is possible to vary the hydrostatic driving head and consequently the discharge rate.

The main disadvantage of this system is that in order to vary the sludge draw-off rate with respect to the influent flow rate, the valve requires continuous adjustment. On large treatment works, therefore, it is often automatically controlled.

In order to overcome this drawback there is, a recent tendency to join the sludge withdrawal pipe directly to the suction side of a variable speed pump. In this manner, the wet sump and telescopic valve are avoided and the rate of sludge abstraction is controlled by the speed of the pump.

Where flat-bottomed clarifiers have been installed, it is usual to use a suction lift arrangement to abstract the sludge. The suction pipe work is usually run along the rotating bridge mechanism, with branches going vertically downwards into suction heads. Each branch may be fitted with a control valve to vary the rate of abstraction at each branch. A sufficient number of suction heads are installed such that the entire floor area of the clarifier is covered. Sludge is then continuously removed while the bridge rotates within the clarifier into a sump mounted on the bridge. It is then discharged from the sump by means of a siphon into an annular channel and from there to a sump.

Although the suction method of sludge removal enables the sludge to be removed rapidly from the clarifier particularly in clarifiers with large surface areas, it has a number of disadvantages which are listed below :

- Constant attention by the operator is required to ensure that the siphon action is operating correctly.
- There is generally no way of observing from individual suction heads what the concentration is of the sludge being returned.
- The siphon method is not an infallible method of sludge abstraction because, if failure of the siphon action is not detected, sludge will rapidly accumulate and be discharged with the effluent.
- The suction type of mechanism produces an unstable hydraulic regime within the clarifier which is likely to cause mixing and greater deviation from ideal flow conditions.

Most clarifiers in large works are equipped with scum removal equipment. In some of the smaller works however this feature is omitted. The scum removal equipment consists of a skimmer arm attached to the rotating mechanism, a baffle which extends above and below the liquid surface to prevent scum from reaching the overflow weir and a submerged scum trough.

Surface scum is moved radially outwards to the scum baffle by the skimmer arm. This arm also moves the sludge to the submerged scum trough. As the skimmer arm reaches the scum trough an electrical or mechanical device opens the discharge valve on the trough. Scum is then swept into the trough and discharged to a central collection point. It is good practice not to return this scum to the liquid treatment phase but rather to treat it along with sludge removed from the system. If scum is continually recirculated in the system the plant can be continually reseeded with problematic foam-forming organisms such as *Nocardia.*

Phosphorus can be released from floating scums, which should not be allowed to accumulate.

9.3 Sludge recycling (S-recycle)

As the top water level within the clarifiers is below the top water level in the treatment basin, the sludge abstracted from the clarifiers must be pumped back to the treatment basin. The most common form of return sludge pump is the archimedean screw type pump. This pump is ideally suited to this duty as the pumping head is generally low and minimal adjustment of the pumping rate is required. The pump speed is maintained such that the maximum pump flow rate can always be returned to the aeration basin. However, if the sludge flow from the clarifiers is less than the maximum pumping capacity, the pump will merely return the sludge flow and no speed adjustment is required.

The archimedean screw type pump is likely to entrain air and thus aerate the sludge return flow.

The rate of sludge return is therefore controlled by adjusting the slide valve on the desludging pipe of the clarifier. Generally the sludge recycle ratio with respect to the influent flow should be 1:1. During peak flow periods and during periods when poor settleability is observed this ratio should be increased to 1,5 to 2,0:1 with respect to the average dry weather flow (ADWF) to prevent an accumulation of sludge within the clarifier which could result in sludge being carried over the discharge weirs with the effluent.

The only other time the recycle rate needs to be increased is when the sludge level starts rising within the clarifier. This phenomenon is generally caused by denitrification occurring within the sludge blanket due to excessive sludge residence times. The nitrogen gas bubbles are enmeshed in the sludge and cause large flocs of sludge to rise to the surface. By increasing the withdrawal rate, the sludge residence time is reduced and denitrification should stop.

The ratio with respect to the influent flow at which sludge is recycled from the clarifier affects the performance of the biological reactor. High recycle ratios have the following effects:

The sludge returned from the clarifier will become more dilute. This will lower the mass fraction and hydraulic retention time in the underflow anoxic reactor in the Johannesburg system. In addition to this a larger volume of nitrate will be returned to the unaerated zones. As discussed in Chapter 4, if nitrate enters the anaerobic reactor a deterioration in phosphorus removal will be noted.

Low recycle ratios have the following effects:

The sludge returned from the clarifier will become more concentrated. This will raise the mass fraction and hydraulic retention time in the underflow anoxic reactor in the Johannesburg system. The longer sludge retention time and higher concentration in the clarifier will result in a lower nitrate concentration and volume being returned to the unaerated reactors, resulting in better phosphorus removal. The adverse effects of low recycle rates however are - possible sludge carry-over with the final effluent and loss of nitrification due to the increase in unaerated mass fractions.

Should a decrease in the thickness of the sludge being returned to the main treatment basin be observed, the recycle rate should be lowered so that a degree of thickening within the clarifier can be achieved. However, the lower the recycle rate, the longer the sludge retention time in the clarifier and the greater the chances of denitrification and P- release occurring. P-release may not necessarily be a problem if it stays enmeshed within the sludge blanket, but if it diffuses into the upper liquid layers within the clarifier it will be discharged with the effluent.

9.4 Operator checks

The plant operator must check throughout the day the quality of the sludge withdrawal from clarifiers. He should also regularly check that sludge is being discharged from the clarifier and not supernatant liquid.

These daily checks should include:

- Checking the drive and trail wheels on the scraper mechanism for uneven wear or damage.
- Checking that the top of the clarifier walls are clean and free of grease etc.
- Checking the drive gearbox for oil leaks etc.
- Checking for scum build-up in the central stilling chamber. If excessive scum build up has occurred, it must either be washed out or physically removed.
- Checking and recording the current (amps) drawn by the mechanism drive motor. Excessive current drawn by mechanism motors is an indication that either the sludge within the clarifier is too thick or that fouling of the mechanism has occurred. If the sludge is not thick, the tank should be emptied to check for fouling below the water level.
- Checking that the scum removal mechanism is working correctly and that no excess scum build-up is occurring on the clarifier surface.
- Algae growth within the overflow launders should be removed to create a good impression, but it can be left without detrimental effect.

CHAPTER 10

SLUDGE THICKENING AND DISPOSAL

10.1 Introduction

Phosphorus is removed from the influent sewage stream by wasting phosphorus-rich aerobic biological sludge from the system. A release of phosphorus takes place under anaerobic conditions. This is followed by phosphorus uptake in the anoxic and aerobic compartments. This is a fundamental principal used in nutrient removal plants and is described in Chapter 3.

A similar release phenomenon will take place in the sludge which is wasted from the plant should it become anaerobic. It is therefore important that the waste-activated sludge is handled correctly to avoid phosphorus release back into the liquid phase.

The trend in most activated sludge plants is to waste activated sludge from the aerobic zone in the reactor. This is done not only because it is the best method of controlling the sludge age but also because this sludge is surrounded by more nitrate and oxygen than the underflow from the clarifiers. Also, immediately after P uptake the P concentration within the sludge is the highest.

In waste activated sludge residual dissolved oxygen is depleted very rapidly by the organisms. The nitrate is also used for respiration after the oxygen is depleted. The rate at which the nitrate is used, however is much slower than that at which the oxygen is used.

As soon as all the nitrate is depleted the biological sludge will start to release phosphorus. This is not always observed in plants since the released phosphorus is often trapped in the sludge blanket if gravity thickeners are used.

Phosphorus release can also occur when the sludge is kept under aerobic conditions for long periods of time in the absence of substrate. This happens when sludges are stabilized in aerobic digesters. Aerobic phosphorus release is due to cell lysis and is much slower than anaerobic phosphorus release.

10.2 Sludge thickening

Thickening is the first step in the solids treatment and disposal system. The main reason for thickening sludges is to reduce the volume to be handled by the subsequent sludge treatment steps. Thickening a sludge from 0,5% to 4% will for example reduce its volume eight times. Besides the obvious benefit of reduced tank sizes, thickening also reduces the volume of conditioning chemicals required and the heating requirements of anaerobic digesters. Two methods of thickening common to South African wastewater plants, namely, gravity and dissolved air flotation (DAF) are described in this chapter. The aspects of thickening discussed are specific to waste-activated sludge since raw sludge can be thickened adequately in the primary settling tanks.

10.2.1 Influence of thickening on BNR plants

The sidestreams (gravity thickener overflow or DAF underflow) from thickening processes are generally returned to the activated sludge plant for treatment. These sidestreams can at times contain significant concentrations of suspended solids and thought must be given to where they are reintroduced into the main treatment stream.

If a thickener sidestream is introduced into the influent wastewater stream micro-organisms which make up the suspended solids in the sidestream can use RBCOD in the influent if air entrainment due to turbulence occurs. This will have an adverse effect on both denitrification and phosphorus removal.

Sidestreams from thickening are commonly fed back into the aerobic zone of the activated sludge reactor. In the case of DAF it is of particular importance that the underflow stream is not fed to the anaerobic zone since it will contain nitrate and may contain oxygen. If these two components are fed into the anaerobic zone less RBCOD will be available to the poly-P organisms for phosphorus removal.

10.3 Gravity thickeners

Gravity thickeners, as the name suggests, thicken sludge through gravitational force. Gravity thickeners are generally circular. Rectangular thickeners are also used but generally do not perform as well as circular thickeners.

The advantages and disadvantages of thickening by gravity compared to DAF thickening are listed in Table 10.1.

Table 10:1 : Advantages and Disadvantages of Gravity Thickening Compared to DAF Thickening

Advantages	Disadvantages
Has sludge storage capabilities.	Requires more area.
Requires less operational skill.	Can produce odours.
Lower operation and maintenance cost.	Solids/liquid separation can be problematic especially if "bulking" sludges are thickened.
Can be used to thicken both waste-activated and primary sludge	Produces a lower thickened waste-activated sludge concentration.
	Denitrification can occur causing flotation and subsequent sludge carry-over.
	P- release can occur should the sludge become anaerobic.

Three types of settling occur in thickeners, these being:

- *Discrete settling*

  This type of settling occurs when the solids concentration in the incoming feed is low. The settling rate of individual particles is affected to some extent by the proximity of other particles, but depends primarily on the size and density of the individual particles. Settlers operating in this mode of settling are uncommon because the solids loading rates would have to be very low.

- *Zone or hindered settling*

  This type of settling occurs in thickeners at the recommended solids loading rates. In this type of settling the solids particles are influenced by neighbouring particles. As the solids settle they maintain position relative to one another, supported by the liquid being displaced as they settle.

- *Compression settling*

  This type of settling occurs when the solids are supported by one another. The settlement rate is dictated by the rate of channel formation in the floc structure allowing water to escape.

Gravity thickeners are designed for loading rates which give rise to zone settling. The downward transport of solids is due to the effects of gravity and the withdrawal of thickened sludge.

10.3.1 Description of gravity thickeners

Gravity thickeners are most commonly circular in shape with diameters of up to 25 m and are similar to PSTs. Sludge is fed into the centre stilling chamber and flows radially outwards to the launder. Solids in the liquid settle downwards due to gravity and the drawoff of the solids from the central sludge hopper. The solids are moved towards the central hopper by a rotating thickener mechanism as well as by the steep floor slope. The thickener mechanism is usually fitted with a torque-limiting device to prevent damage to the mechanism should excessive torque be developed due to very thick sludge.

The floor slopes in gravity thickeners are steeper (between 1:6 and 1:3) than in conventional clarifiers. The steeper floor slope maximises the depth of sludge being withdrawn which aids the thickening process. Pickets are sometimes attached to the thickener mechanism to create a gentle stirring action which will release gas, prevent bridging of sludge particles, minimise scum formation and form channels to release liquid.

It is current practice to prevent carry-over of scum in the supernatant by providing scum baffles, boards, skimmers and boxes. This is important if the supernatant is to be returned to the activated sludge reactor as excessive solids will increase the COD load on the reactor. The supernatant from the thickener should however be analysed for phosphorus if it is returned to the reactor. If the supernatant contains excess phosphorus, phosphorus release due to anaerobic conditions in the thickeners is occurring. If phosphorus release is occurring, the rate at which sludge is being withdrawn from the central sludge hopper must be increased.

10.3.2 Operation checks

10.3.2.1 Start-up checks

- Ensure that the peripheral wall is free of debris.
- Check that the bridge is rotating in the correct direction.
- Check the drive mechanism alarm and cutout switch to ensure that they are operating correctly.
- Switch on drive mechanism before feeding sludge.
- Before pumping thickened sludge to further treatment allow sufficient time for sludge to accumulate in the sludge withdrawal hopper.
- Check that the weir is level. Low spots will become apparent by looking for areas where solids carry-over is occurring.
- Adjust the scum box to maximise scum draw-off and minimise supernatant draw-off.
- Adjust the thickened draw-off rate to maintain the sludge blanket at approximately a metre below the launder.

10.3.2.2 Daily checks

- Check for smooth rotation of the thickener mechanism.
- Check the depth of the sludge blanket and adjust the desludging rate if necessary.
- Check supernatant for excessive solids carry-over.
- Check for formation of gas bubbles. This is an indication of anaerobic conditions developing and probable P-release.
- Clean the weir and launder.

10.3.2.3 Weekly checks

- Check all oil levels.
- Check drive limit switches.
- Check that the scum skimmer is making proper contact with the scum baffle and box.

10.3.2.4 Monthly checks

- Check scum skimmer wipers for wear or damage.
- Adjust drive belts or chains.

10.3.2.5 Yearly checks

- Empty thickener and check condition of coatings, pipe connections, etc.

Note: *If for some reason the rotating mechanism is stopped, the feed to the thickener should also be stopped. The flow to the thickener should only be resumed when the mechanism is rotating again.*

10.3.2.6 Shut-down

- The rotating mechanism must be kept turning whenever there is sludge in the thickener.

- Thickened sludge draw-off must be stopped only if there is no more thickened sludge in the thickener. The rotating mechanism can also be stopped at this point.

10.4 Dissolved air flotation thickeners

The process of liquid solids separation and solids thickening using Dissolved Air Flotation (DAF) is a separation technique employing the production of micron size (10-100 μm dia) air bubbles. In dissolved air flotation, bubbles are produced from the release of gas (air) at atmospheric pressure from liquid which has been supersaturated with air under pressure in a saturation vessel. The release of the air is designed to take place in the presence of the solids to be floated. The released bubbles attach themselves to the sludge particles, imparting buoyancy. This causes the sludge particles to rise to the surface from where they can be removed by surface scrapers. The compaction of layer upon layer of rising sludge forces the float above the water surface. The float above the water surface drains and a waste-activated sludge float of 4% solids is commonly achieved without polyelectrolyte or chemical dosing of the influent.

There are three ways in which saturation by air is normally achieved:

- Total or full pressurisation

  In this type of system all the sludge is passed through a saturator where it is saturated with air prior to entering the flotation tank.

- Partial pressurisation

  In this system only part of the sludge volume is passed through the saturator. The air-saturated sludge is then blended with the remainder of the sludge before being introduced into the flotation tank.

- Recycle pressurisation

  In this system the flow passing through the saturator is either recycled clear subnatant or an alternative water source with a low suspended solids concentration.

Of the three methods, recycled pressurisation is the preferred and most widely used method in South Africa for the following reasons:

- Reduced floc shear
- Less clogging in the saturator. The advantages and disadvantages of DAF thickening compared to gravity thickening are listed in Table 10.2. A typical DAF installation is shown in Figure 10.1.

Table 10:2 : Advantages and Disadvantages of DAF Thickening Compared to Gravity Thickening

Advantages	Disadvantages
Provides greater solids/liquid separation and solids concentrations when thickening WAS	Has very little sludge storage capacity - can only store for a couple of hours which may have an advantage in minimising P release
Is effective in removing grease and oil	Operating and electricity costs are much higher than for gravity thickeners
Requires a smaller tank area	Requires more skill to operate than a gravity thickener
Does not produce odours	
Anaerobic phosphorus release is prevented	
Can be operated in batch mode as it is relatively easy to start up and switch off	

A DAF system consists of three main unit processes:

- The pressurisation system,
- The flotation tank and
- The recycle system

Each are described below.

10.4.1 Pressurisation system

The DAF pressurisation system comprises air compressors, a saturator vessel including the interconnecting pipework, valves and controls.

The system operates under pressure (typically 350-450 kPa), the liquid stream being pumped into the saturator under pressure through misting nozzles located inside the saturator vessel. A cushion of air is maintained within the saturator and saturation of the liquid is achieved by the fine droplets falling through the air. The volume of the air cushion is controlled by a level switch located in a manifold on the side of the tank. This switch controls the liquid level in the saturator between an upper and lower level by cycling the air into the saturator.

Air compressors (duty/standby) are provided to pump air into the saturator. As air is introduced into the saturator the water level decreases; when the air flow is cut off, the water level increases as air is removed via saturation. The degree of saturation depends on the temperature of the liquid, the efficiency of the misting nozzles, the composition of the air in the saturator and the retention time in the saturator. The compressors are sized to supply a specified free air flow which is dependent on the air/solids ratio. The compressed air is normally stored in an air receiver which is sized to reduce the number of starts per hour of the compressors.

The air receiver is usually provided with a pressure indicator and a drain pipe with an isolating valve and condensate trap. The outlet from the air receiver is connected to the saturation vessel. This line is usually provided with a condensate trap mounted at a low point in the line to trap and remove moisture, an air filter, a pressure regulating valve, a pressure indicator, a needle valve for flow rate control, a rotameter with isolating valves upstream and downstream to measure the air flow, a solenoid valve, non-return valve and isolating valves at the inlet to the saturator. The solenoid valve is controlled by means of a level control switch mounted on the side of the saturator. When the water level within the saturator rises to a predetermined level, the valve is opened and air is pumped into the saturator.

The saturator is provided for saturation of the recycle flow from the flotation tank and consists of a vertical pressure vessel with pressure relief valve and pressure gauge mounted at the top, air inlet, bottom outlet and recycle inlet.

10.4.2 Flotation tanks

Flotation tanks can be either rectangular or circular and are equipped with surface skimmers with a sludge collection trough or troughs, bottom scrapers and a central stilling tank.

The saturated air/water mixture is blended into the raw feed at the inlet to the flotation tank with the pressurised stream undergoing rapid depressurisation. This causes the release of fine air bubbles and the combined flow is introduced at the bottom of the stilling tank of the flotation tank. The tiny bubbles attach themselves to the sludge particles causing them to rise. The rising sludge is guided upwards and outwards to form a floating scum which is removed from the surface by skimmers which deliver the sludge into a collection trough. The surface skimmers are set at a level above the water level to allow float to form above the water surface. This allows drainage of the upper float layer, and thickening. Unfloated material or material that settles to the bottom of the tank is moved via bottom scrapers into a sludge hopper, which is periodically desludged.

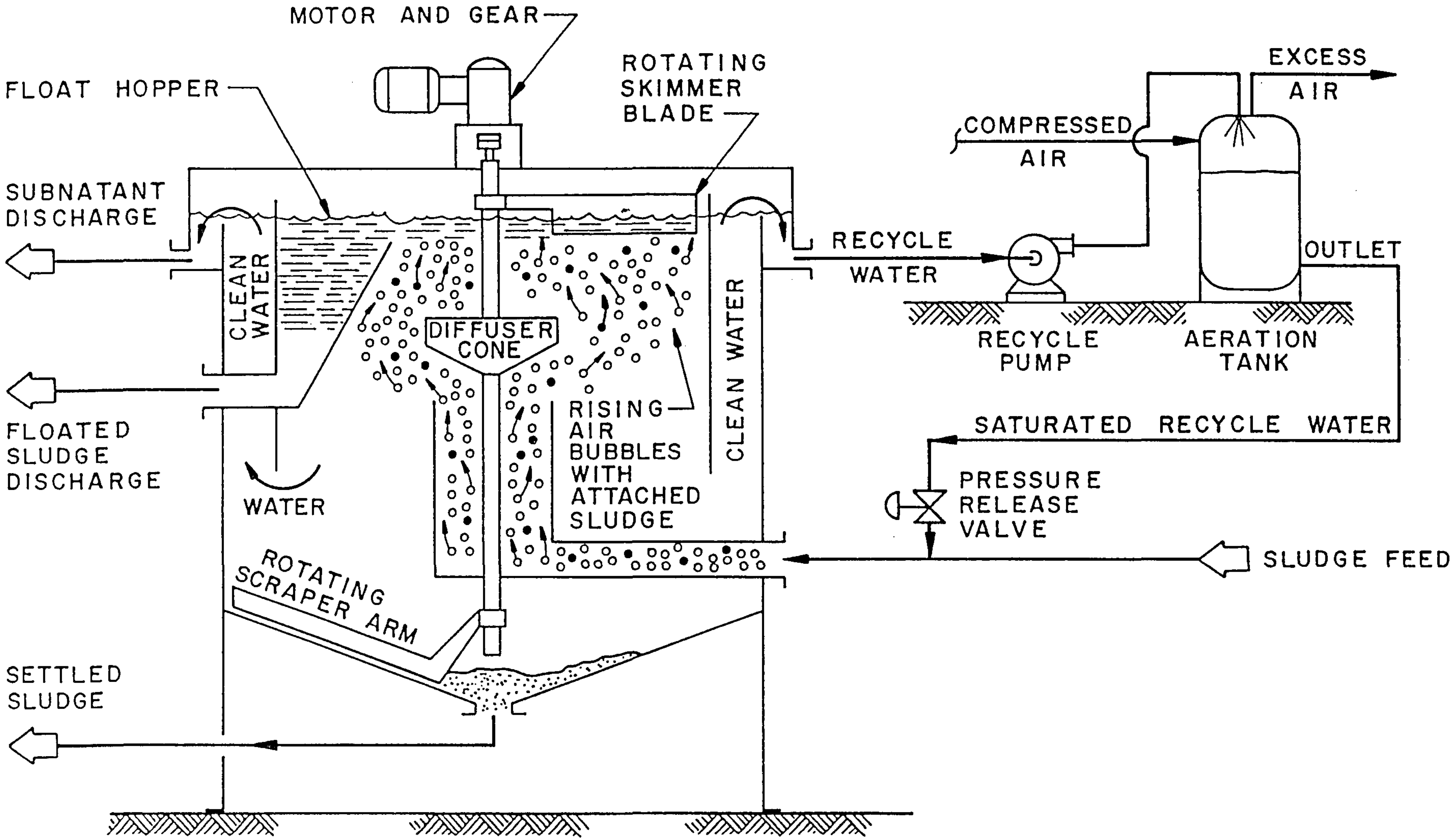

FIGURE 10.1 DISSOLVED AIR FLOTATION SYSTEM

10.4.3 Recycle system

The clear subnatant passes under a skirt ring into a collection launder from where a fraction of the flow is discharged to the recycle pumps. These pumps deliver the liquid under pressure to the saturator. The remaining subnatant flow is returned to the main treatment stream, usually to the aerobic zone as discussed in section 10.2.1.

10.4.4 Operation checks

There are a number of different DAF installations available from various manufacturers, each with their own specific operating procedures. A general procedure of operator checks is detailed below, but reference to the specific operating instructions for a particular installation must be consulted.

10.4.4.1 Start up-checks

- Check and remove any debris from the floating tank.
- Check skimmer gearbox oil level and lubrication of all pump bearings.
- Check operation of scraper system.
- Set all switches for pumps, compressors and skimmer/scraper drives in the "off" position.
- Close all valves on the compressed air lines.
- Close all isolating and operating valves on effluent recycle lines.
- Check that there is recycle liquor available.
- Select duty recycle pump.
- Open the valve on the suction line to the duty pump and ensure that the line is fully primed.
- Select the duty compressor.
- Open air valves.
- Start the duty compressor and allow the unit to run until the manufacturer's operating pressure has built up within the air receiver. Once this pressure has been reached the compressor should automatically switch off.
- The operating pressure should be checked against that indicated on the local indicator.
- Where a pressure indicator has been provided downstream of the pressure regulating valve on the line to the saturator, adjust the valve to read the pressure specified by the manufacturer.
- Open the isolating valve on the outlet of the saturator.
- Set the required recycle rate.
- Start the DAF scraper mechanism.
- Start the duty recycle pump.

- Recycled effluent will now flow via the saturator into the inlet DAF tank. Once the water level in the saturator has reached the upper level, check that the level control switch located in the manifold on the side of the saturator will automatically open the solenoid valve on the air supply line allowing air to enter the saturator.

- Check that recycled effluent and air are entering the flotation tank. A short period should elapse whilst the saturation process becomes operational. When water in the tank starts to turn milky, saturation has been established.

- Start feeding sludge into the DAF tank.

10.4.4.2 Daily DAF tank checks

- Establish the required inflow rate of sludge into the flotation tank and adjust if necessary.

- Check regularly that the level in the saturator is being maintained between the upper and lower levels.

- Check regularly that the skimmer is operating correctly and that adequate thickening is being achieved. Also, check that sludge is being effectively removed from the surface of the tank.

- Check clarified liquor for excessive solids and desludge if necessary.

- Check pumps and piping to ensure that there are no leaks.

- Check and record pump operating pressure.

- Check and record compressor operating pressure.

- Check air flow to the saturator.

- Check operating pressure of the saturator.

- Check and record voltage and amperage.

- Check bearings for lubrication and temperature.

10.4.4.3 Shut-down checks

- Stop sludge feed.

- Allow recycle pumps and scraper mechanism to operate until no further float remains in the flotation tank.

- Slowly close the valve on the recycle pump and switch off the pump.

- Close the valve on the outlet from the compressor and switch off the compressor.

- Switch off the DAF drive.

10.5 Anaerobic digestion

10.5.1 Introduction

Anaerobic digestion is included briefly in this manual because the liquors arising from this treatment step can have an adverse effect on nutrient removal if returned to the activated sludge plant for treatment. For a detailed description of anaerobic digestion and operational guidelines the reader is referred to "Anaerobic Digestion of Waste Water Sludge - Operating Guide" WRC, Project No 390.

Anaerobic digestion is a multi-stage biological process commonly employed to stabilise the sludge i.e. reduce the potential of odours, and reduce the number of disease-causing bacteria in municipal sludges.

One of the most important aspects of digestion is to minimise the liquid volume discharged to the digester. Excess liquor (i.e. insufficiently thickened primary or waste-activated sludge) increases the overall volume requirements, electricity costs and final volume for disposal. As the name implies the process takes place in the absence of oxygen. Organics present in sludges are broken down during anaerobic digestion. The process can be simply described as a two-step reaction. In the first step organic matter is broken down by acid-forming organisms into volatile fatty acids, *inter alia* acetic, butyric and propionic acids, as well as hydrogen and carbon dioxide gas. The products of the first step in anaerobic digestion are sometimes used to augment the RBCOD of influent sewage to improve phosphorus removal when acid fermentation is incorporated in a plant.

The second step in anaerobic digestion is the conversion of the volatile fatty acids formed in the first step of anaerobic digestion into methane (CH_4) and carbon dioxide (CO_2) and other trace gases.

Although these reactions do result in a reduction in the carbon and volatile suspended solids concentration, very little reduction in the nitrogen and phosphorus concentrations entering the digester is achieved. If waste-activated sludge from a biological phosphorus removal plant is digested along with primary sludge, the dewatering liquor from the sludge will have high concentrations of both phosphorus and ammonia. If the sewage carriage water has a high magnesium concentration struvite precipitation can occur when digesting WAS and primary sludges, resulting in excessive scale-formation and blockages of pipes.

The anaerobic liquors that are treated in the mainstream process are the liquors emanating from dewatering processes. These liquors generally have high TKN and phosphorus concentrations and sometimes a relatively high solids concentration. The options available for the treatment of these liquors are discussed overleaf.

10.5.2 Treatment of anaerobically digested dewatering liquors

10.5.2.1 Treatment of dewatering liquors by returning to the head of works

If these liquors are returned to the activated sludge plant for treatment, they are generally returned to the head of works. The mainstream process can be adversely affected mainly due to the relatively high $^{TKN}/_{COD}$ ratios of the liquor stream. The ammonia will be nitrified in the system but the remaining carbon available as an energy source is usually insufficient to denitrify the nitrate adequately. This can result in:

- Excess nitrate being returned to the anaerobic zone, affecting phosphorus removal.

- An added loss in alkalinity and an unstable low pH necessitating the addition of lime.

In addition to the problems associated with the additional nitrate generated, the following should also be taken into account:

- Additional oxygen will be needed to oxidise the increased COD and ammonia load.

- The increased phosphorus load will increase the effluent P concentration.

10.5.2.2 Treatment in a dedicated biological plant

Dewatering liquors can be treated in a separate plant dedicated to this purpose e.g. existing biofilters or an activated sludge plant without biological P removal. Regardless of what type of biological treatment plant is chosen the following will invariably have to be included:

- Chemical (e.g. $FeC\ell_3$) dosing to remove phosphorus and to ensure that sufficient alkalinity (e.g. lime) is available if complete nitrification occurs.

- Dilution of the influent by recycling effluent streams to avoid ammonia toxicity.

10.5.2.3 Disposal by irrigation to land or artificial wetlands

If sufficient land is available, this option could be considered. Guidelines have been published by the Department of Health Services regarding the use of sewage effluents as irrigation water. The guidelines do not specifically cover dewatering liquors. It can be inferred from these guidelines that any land irrigated by dewatering liquors cannot be used for the cultivation of crops which are intended for human or animal consumption.

10.6 Sludge disposal

A set of guidelines has been produced by the Department of Health Services for the disposal of sewage sludges. The guidelines group the sludges into four categories. The types of sludge and the principles according to which these sludges are grouped are as follows:

Table 10.3 : Classification of Wastewater Sludge to be Used or Disposed of on Land (from Department of Health Services)

Classification	Origin/Treatment Examples	Characteristics Quality of Sludge
Class A Sludge	Raw sludge	• Usually unstabilised and can cause odour nuisance and fly breeding
	Cold digested sludge	• Contains pathogenic organisms
	Septic tank sludge Oxidation Ponds (Night soil)	• Variable metal and inorganic content
Class B Sludge	Anaerobic digested sludge (heated digester) Waste-activated sludge	• Fully or partially stabilised - should not cause significant odour nuisance or fly breeding
	Humus tank sludge	• Variable metal and inorganic content
		• Contains pathogenic organisms
Class C Sludge	Pasteurised sludge	• Certified to comply with the following quality requirements: (if not certified, this sludge is considered a type B sludge)
	Heat-treated sludge	• Stabilised - should not cause odour nuisance or fly breeding
	Lime-stabilised sludge	• Contains no viable *Ascaris* ova per 10 g dry sludge
	# Composted sludge	• Maximum 0 *Salmonella* organisms per 10 g dry sludge
	Irradiated sludge	• Maximum 1000 faecal coliforms per 10 g dry sludge, immediately after treatment (disinfection/sterilisation)
	Fumigated sludge	• Variable metal and inorganic content

Table 10.3 (continued)

Classification	Origin/Treatment Examples	Characteristics Quality of Sludge
Class D Sludge	Pasteurised sludge	• Certified to comply with the following quality requirement:
	Heat-treated sludge	* Stabilised - should not cause odour nuisance or fly breeding
	Lime-stabilised sludge	* Contains no viable *Ascaris* ova per 10 g dry sludge
		* Maximum 0 *Salmonella* organisms per 10 g dry sludge
	Irradiated sludge	* Maximum 1000 faecal coliforms per 10 g dry sludge immediately after treatment (disinfection/sterilisation)
Produced for un-restricted use on land with or without addition of plant nutrients or other materials	Fumigated sludge	• Maximum metal content and inorganic content in mg/kg dry sludge:
		* Cadmium 20
		* Cobalt 100
		* Chromium 1750
		* Copper 750
		* Mercury 10
		* Molybdenum 25
		* Nickel 200
		* Lead 400
		* Zinc 2750
		* Arsenic 15
		* Selenium 15
		* Boron 80
		* Fluoride 400
		• User must be informed about moisture and NPK content
		• User must be warned that no more than 8 t/ha/yr (or kg/10 m²) (dry sludge) may be applied to soil and that the pH of the soil should be preferably higher than 6.

\# Requirements for classification as composted sludge
Sludge heated to 55-65°C for 5 days or
$>$ 65°C for 3 days

* These figures may be in the process of being revised by the Department of Water Affairs and Forestry.

CHAPTER 11

SIDESTREAM SYSTEMS FOR PHOSPHORUS REMOVAL

11.1 Introduction

One of the first observations of the phenomenon, known as the luxury uptake of phosphorus by activated sludge, was made in the United States of America by Dr G Levin. He noted the ability of certain organisms to store phosphorus and then release it under anaerobic conditions. He put this effect to use in the patented Phostrip Process. A number of such plants have been built in the United States and one in Kempton Park, South Africa.

The initial process consisted of a stripper tank through which a portion of the underflow from the clarifiers was passed and allowed to thicken and become anaerobic. Water or final effluent was used to elutriate liquors rich in phosphorus out of the sludge which was then returned to the aeration basin. The phosphorus-rich liquors, which formed a small fraction of the total flow, were then treated with lime to precipitate the phosphorus. In this way the quantities of lime needed to raise the pH for phosphorus precipitation was reduced. In all cases phosphorus was also removed from the system with the waste-activated sludge and discharged to the digesters. Thus an additional problem of handling the phosphorus-rich digester liquors was also experienced.

As the majority of the works in America at the time of Dr Levin's observations was not designed to nitrify, no problems of inhibition of the release of the phosphorus in the stripper zone were experienced although this problem did sometimes manifest itself during summer periods. The initial modification was to use settled sewage to elutriate the phosphorus with the intention of assisting its release by the addition of SCFA.

The second major modification was to introduce a pre-stripper tank with approximately 30 minutes of hydraulic retention. This was sufficient to allow any nitrate that was in the return activated sludge to denitrify and thus not to inhibit the release of phosphorus in the stripper.

Detailed process descriptions of this and other possible process modifications to the Phostrip Process are given in Chapter 4, Section 4.4.

11.2 Mass balances in the process

As stated in Chapter 4, no definitive theory has been developed in regard to the underlying reactions and the rates of reaction in the deeply anaerobic stripper units. A simpler method of measuring what reaction is occurring on a works, is to conduct mass balances of phosphorus in solution and bound as poly-phosphate in the activated sludge.

A number of laboratory determinations are required in order to perform such a balance. Many of these will be performed routinely and others will have to be supplementary. The analyses are as follows:

11.2.1 Incoming phosphorus load

Measure P in raw sewage or if primary sedimentation is carried out, on the settled sewage. The samples should be flow-weighted in order to make a realistic assessment of the true phosphorus load entering the works. The flow should be measured during the period of sampling.

11.2.2 Effluent phosphorus load

Measure the ortho-P concentration in the final effluent. This should also be done on a flow weighted sample. Measure the P-content of the activated sludge. The concentration of the suspended solids in the effluent needs to be measured so that the total loss of P through the final effluent can be determined.

11.2.3 Phosphorus in the sludge sent to the stripper

Measure the P-concentration in the underflow from the secondary clarifier. This should be the total P in the sludge.

11.2.4 Flow rates

It is important to know what the flows are, in and out of the stripper, including the flow of elutriant and overflow. Note that the two do not necessarily have to be the same if the stripper is being operated as thickener tank.

11.3 Control strategies

The operator of a Phostrip works generally has a number of strategies available to control and vary the retention time of the sludge in the stripper and hence the degree of release that is achieved. He can also vary the mass of phosphorus that is carried into the stripper and hence the potential amount that can be removed. There are nevertheless limitations to how much can be done. The following section outlines some of these and their effects. It is however difficult to quantify what happens as there is little theoretical knowledge of the sidestream compared to the full-stream systems available.

In the discussion that follows it is assumed that the works has been designed to effect the changes in the recycle flow rates, either by variable speed or multiple-pump selections or by control valves if the flow is by gravity and the valves provided are suitable for the purpose.

11.3.1 Control of sludge age

The sludge age at which the main plant is operating affects the mass of phosphorus that can be assimilated in the sludge due to the change in the fraction of active mass in the sludge as sludge age changes. This is because only the active fraction can store phosphorus. Thus the lower the sludge age the greater the active fraction and the higher the mass of phosphorus stored in the sludge.

A reduced sludge age will also result in a reduced mixed liquor suspended solids concentration with consequent reduction in the solids loading rate of both the secondary clarifiers and in the stripper, the operation of which is similar to a thickener.

The sludge age does not affect the residence time in the stripper or the release of phosphorus.

11.3.2 Rate of return activated sludge

Varying the rate of return of the activated sludge from the final clarifiers will affect the concentration of the underflow inversely. Consequently the amount of sludge being discharged to the stripper will change according to the concentration for a fixed rate of bleed to the stripper. If a fixed fraction of the return activated sludge flow is passed to the stripper a change in the RAS flow will have a similar effect on the flow to the stripper.

Any increase in the RAS flow rate will reduce the solids concentration and hence the mass of sludge going to the stripper if the flow rate to the stripper is unaltered, thereby reducing the flux in the stripper and reducing the chances of sludge loss with the overflow.

11.3.3 Flow rate to the stripper

The flow to the pre-stripper and stripper is generally taken off the return activated sludge pipeline. Depending on the configuration of the plant the rate of flow will be governed either by pumps or by a flow control valve. The mass of phosphorus entering the stripper and hence the potential to remove phosphorus through elutriation is a function of :

- The sludge age

  This affects the active mass fraction in the sludge in which the phosphorus is stored.

- The concentration of sludge in the clarifier underflow

  This is a function of the MLSS and the S-recycle pumping rate.

- The fraction of the S-recycle that is passed to the stripper.

11.3.4 Underflow from the stripper

The rate of withdrawal of solids from the stripper will have a number of important effects.

The time that the solids will remain in the stripper and hence the degree to which the sludge becomes anaerobic is inversely related to the rate of withdrawal of sludge from the underflow. This in turn influences the degree to which the phosphorus is released. Too low a rate of withdrawal could easily lead to flux failure and a loss of solids from the system. A careful balance needs to be struck.

11.3.5 Pre-stripper

The operation of the pre-stripper is identical to the operation of the anoxic basin in the Johannesburg configuration and is not discussed further.

CHAPTER 12

CONTROL TESTS

12.1 Introduction

The performance of a treatment works needs to be assessed regularly to ensure that an effluent of adequate quality is produced and that the process is operating efficiently.

The frequency at which tests should be carried out depends on the size of the works, the cost of testing, the availability of testing or laboratory equipment, and the proximity of a commercial laboratory. Most large plants have small laboratories in which most of the tests can be conducted. Smaller plants and unmanned plants on the other hand do not have any laboratory facilities and have to rely on the analyses being conducted by a commercial laboratory, or at a central off-site laboratory.

The number and types of tests will vary for different processes and plants and should be viewed in a holistic approach to plant performance. This statement implies that the tests should be linked to a structured, regular appraisal of plant performance.

Plant performance can be assessed under the following headings :

- Visual inspection and observations conducted on a daily basis.
- *In-situ* measurements which can be taken either manually or automatically.
- Laboratory analysis of samples, either on site or off-site.
- Systematic and ordered filing of observations and analysis with constant referral to past information and analyses to improve plant performance.

Each of the above categories should be aimed at improving or controlling plant performance such that near optimum and stable operation is achieved regularly. Each aspect is discussed below.

12.2 Visual inspections and observations

A planned inspection tour of the plant should be conducted daily by the operator. Using all his senses, **EXCEPT TASTE**, the operator should record observations pertaining to the performance of the plant e.g. scum present on the clarifier, etc.

Many operators have a good feel for their plants and often by observing or smelling something in particular, adjustments to the process can be made timeously, thus avoiding complete or partial failure of the treatment process. Periods when the plant is operating extremely well should also be noted. Observations should also be made of the plant hydraulics, to see whether or not the plant is still hydraulically capable of treating the influent flow.

Equipment should be inspected to determine any unusual noises, vibrations or overheating. Hourly meter readings should be recorded to ascertain whether the plant is running for the correct period.

The condition of analytical or control probes should also be ascertained and recorded.

12.3 *In-situ* measurements

Measurements that can be taken on site e.g. pH, conductivity and dissolved oxygen concentration should be taken and/or recorded at the time of the visual inspection. This type of information can give the operator a basic insight into operating conditions and may give early indications that the process may not be operating correctly.

12.4 Laboratory analysis

Composite (24-hour samples) or grab samples are taken and analysed in a laboratory. The results from these samples are therefore not available immediately and may take up to 24 hours to obtain, depending on the proximity of the laboratories, the type of analyses required and the current work load at the laboratory.

Typical tests conducted at a laboratory are COD, TKN, free and saline ammonia, nitrite, nitrate, suspended solids, P, ortho-P, SCFA and filament identification. In some instances where effluent is being used as irrigation water in public areas, or discharged to a public water course, the faecal coliform count will be required to ensure that adequate disinfection of the effluent has taken place. In areas where extensive irrigation of golf courses with effluent is practised, a variety of other tests may be required to prevent damage to the grassed areas.

The BOD test is not recommended as a control test as it takes at least 5 days to determine and therefore gives historic rather than control information. The COD test is more suitable in this instance and can be completed in less than 4 hours.

The frequency of sampling and analysis is determined by the purpose of the test, the costs associated with sampling and testing, the size of the works and the resources available.

The costs of the analyses must take into account the following :

- If routine monitoring is not taking place, financial penalties for discharging sub-standard effluent may be levied by the relevant authority monitoring the effluent quality. The costs of the penalties may far outweigh the costs of a regular monitoring programme.

- The costs of rectifying a problem that has not been identified at an early stage may also exceed the costs of a regular monitoring programme.

In both the examples above, a regular monitoring scheme would be financially feasible.

Weekly sampling is often used on South African works where the costs of rectifying a problem are high compared to penalties liable to be imposed by the relevant authority. Very large plants with their own laboratories may test daily.

In order to avoid the influences of a weekly cycle, 5- or 6-day sampling intervals can be used to determine plant performance. In some instances it may be necessary to take additional tests to provide more precise information on plant performance.

The methods of analyses of the samples within a laboratory are generally in accordance with the latest editions of Standard Methods for the Examination of Water, Sewage and Industrial Wastes of the American Public Health Association or Methods of Chemical Analysis as applied to Sewage and Sewage Effluents of the British Ministry of Housing and Local Government. The test methods are prescribed in various SABS Standards and are listed at the end of this chapter.

Generally samples to be analysed should be collected as composite samples over a 24-hour period and not as grab samples.

24-Hour composite samples are usually collected by automatic samplers. Where these are not available, 8-hour or 24-hour flow proportioned composite samples can be collected. This is done by collecting grab samples at hourly intervals in volumes proportional to the hourly flow rates. Equal volume samples may also be used, but proportional volumes are preferred. The 24-hour composite samples should, however, be taken occasionally to obtain a full picture of the daily load variations.

Where only grab samples can be taken, the results need to be carefully interpreted as the sample may have been taken during a period of minimum or maximum flow or load. This is particularly important when the treatment works receives industrial effluent. Grab samples should be taken at times when average conditions prevail and a 1-litre sample should be abstracted.

More errors result from poor sampling procedures and incorrect handling of the samples than from any other cause. Care must be exercised for BNR plants, particularly where samples are taken of the mixed liquor or where there is any significant quantity of activated sludge. It must be remembered that the reactions that take place in the plant continue in the sample bottle if any activated sludge is present. Dissolved oxygen will be utilised and nitrates will be reduced. Phosphates will be released as orthophosphate.

In order to stop these reactions it is common to use an inhibitor that is toxic to the micro-organisms in the collection vessel. An example is the use of mercuric chloride.

This is not suitable if there is to be any bacteriological examination, as the viable micro-organisms would have been killed by the inhibitor. If determinations are to be made for orthophosphate the sample should be filtered immediately after it has been taken.

All sample bottles should be filled to the brim to minimise the presence of oxygen and all collected samples must be stored in a refrigerator at 4°C or lower. The samples should be analysed as soon as possible after collection, preferably within 24 hours. The sample bottles should be glass jars with tight sealing lids. Where microscopic identification is required, the bottles must be sterilised.

The bottles should be washed immediately after use and rinsed thoroughly with clean tap or distilled water. They should be allowed to drip dry rather than be dried with a cloth. If detergents are used and not thoroughly rinsed off, the detergent will distort certain results.

Where commercial laboratories are used, it may be possible to obtain clean or sterilised bottles from them prior to sampling.

12.5 Recording

All observations made as described in sections 12.2 and 12.3 and analyses received should be recorded on standard pre-printed sheets. These sheets should be completed so that they are in chronological order and are easily accessible to operational staff.

Files should be kept as an intrinsic part of plant monitoring and should not be treated as "old records". The operator should also be able to justify each test conducted and each type of record stored, i.e. why the sample was taken and what the significance of the result was.

Most analytical information is presented in tables. The information should also be grouped and plotted on graphs, as graphs visually highlight the trends. The graphs should be kept up-to-date to provide operators with an easily accessible warning of trend changes.

Graphs can also be readily converted into process control type charts using statistical methods. By plotting upper, lower and average limits on a graph, the operator can quickly assess whether the plant is operating efficiently or not. Corrective measures can also be implemented before a control limit is exceeded.

Operators must, however, be aware that certain parameters, such as effluent COD and suspended solids, vary randomly around the average values making it difficult for the operator to assess deviations from normal performance.

For the operator, the most useful statistical limits are the upper 1% and 5% and the lower 5%, which are derived from reference distributions for a particular parameter. The upper 1% limit is generally exceeded by only 1% of values and the upper 5% limit by 5% of values. This means that when stable plant operation is achieved the measured parameters will exceed the upper 1% level one day in every hundred days. Similarly, the upper 5% will be exceeded one day in twenty days.

When the upper 5% limit is exceeded, the operator must monitor the behaviour of the plant more carefully for the next couple of days, as this is an indication of something starting to upset the performance of the plant. Any exceeding of the upper 1% limit indicates a deviation from normal operating efficiency, and that some upset is likely to occur.

The lower 5% value is normally used to identify periods when the plant is operating extremely efficiently. The operator must record the operating conditions during this period to establish why the plant is operating so well. These observations will help to identify conditions that may not be present when an upset has occurred.

Average values are useful to determine whether there has been any marked changes in plant performance with time.

The upper and lower limits can be calculated using at least one year of collected data. The data values must be plotted on a graph versus time. (Figure 12.1).

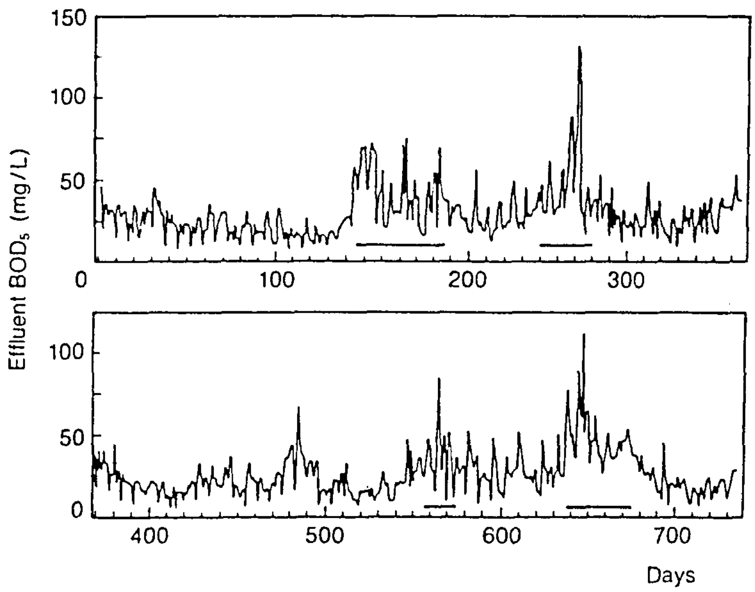

Fig. 12. I *Two-year series of daily effluent BOD data used to construct a reference distribution. The solid bars indicate periods that were treated as upsets (Berthouex and Hunter).*

From this graph, the operator can assess periods of normal and abnormal plant behaviour.

Using the data from normal behaviour only, a distribution is plotted by grouping the values into intervals of magnitude. These are then plotted against the number of days that they occurred. (Figure 12.2)

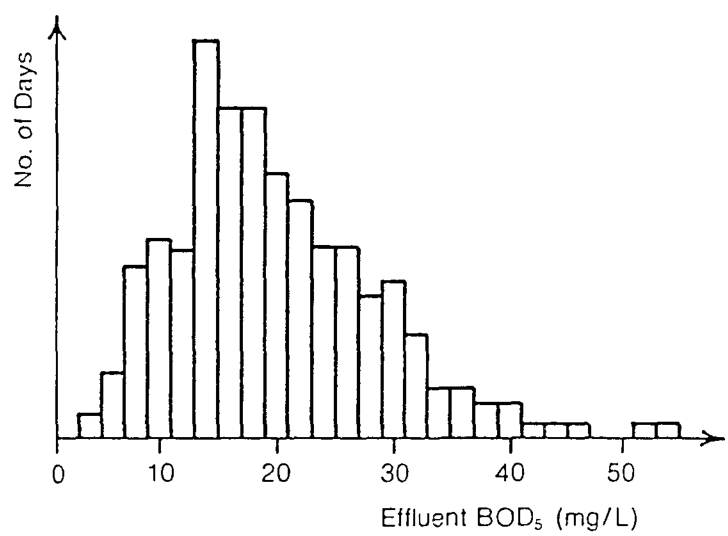

Fig. 12. 2 *Reference distribution for daily effluent BOD data during 1152 days of stable operation. Constructed from a 1339 day period which included the two years shown in Fig. 12.1. The upper 5% level was 32 mg/L and the 1% level 40 mg/L. (Berthouex and Hunter).*

The upper 1% limit is found by removing the highest 1% of values from the distribution. From Figure 12.2 it can be seen that the upper 1% limit was 40 mg/ℓ. The upper 5% is found by removing the highest 5% of values. This corresponds to 32 mg/ℓ in Figure 12.2.

The average value is calculated in the normal way be taking the sum of all the values and dividing it by the total number of values.

These limits and the means value can all be plotted on a graph to provide the operator with a visual representation of plant performance. A typical figure is shown in Figure 12.3.

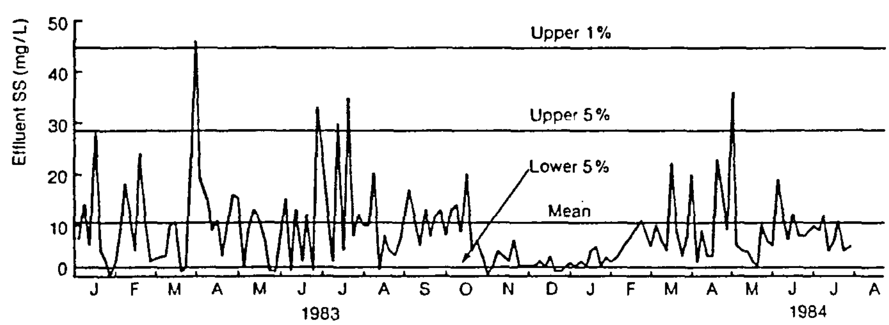

Fig. 12. 3 *Example of a control chart for effluent SS for a plant sampled at 4 day intervals. Data for the extraordinarily good period November 1983 to January 1984 were excluded in determining control limits. The mean is 10.4 mg/L and the coefficient of variation 0.77. (Data from Glenelg Sewage Treatment Works — A Plant, courtesy South Australian Engineering and Water Supply Department.)*

Another useful tool for predicting and assessing plant behaviour is to plot the moving average. By plotting these moving averages on graphs, general trends in plant performance are highlighted and random variations averaged. A moving average is calculated by taking a small number of data values and dividing by the number of values taken.

Where daily parameters are recorded such as influent flow, the moving 7-day average is the most useful. In plants where sampling is less frequent, the 7-day moving average may be too sluggish to be of any use in predicting variances. All graphs, together with their control limits must be kept up-to-date in order to provide the operator with the earliest warning as to when deviations in plant performance are occurring. The causes must be quickly identified and steps taken to rectify them as soon as possible.

Examples of typical recording charts are given overleaf:

NAME OF WORKS : .... MONTH : ....

FLOW RATE AND AERATOR RUNNING HOUR LOG SHEET

Day	Date	Daily Total Flow to Works (m^3)	Unit Aerators			
			No 1	No 2	No 3	No 4
Maximum						
Average						
Minimum						

NAME OF WORKS: .... MONTH: ....

DAILY SLUDGE ANALYSES LOG SHEET

Day	Date	MLSS (mg/ℓ)	SVI (mℓ/g)	DSVI (mℓ/g)
Maximum				
Average				
Minimum				

NAME OF WORKS: .... MONTH: ....

PUMPS RUNNING HOUR LOG SHEET

Day	Date	Running Hour Meters														
		WAS Pumps		RAS Pumps		Filter Backwash Pumps		Final Effluent Pumps			Phosphate Treatment Pumps		Thickened Sludge Pumps		Drying Beds Filtrate Pumps	
		P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15
Maximum																
Average																
Minimum																

NAME OF WORKS : . . . . MONTH : . . . .

RAW SEWAGE ANALYSIS

Date	pH	COD (mg/ℓ)	TKN (mg N/ℓ)	Free and Saline Ammonia (mg/ℓ)	Suspended Solids (mg/ℓ)	Total Phosphorus (mg P/ℓ)	Ortho-Phosphate(mg P/ℓ)	Conduc-tivity (mS/M)
Maximum								
Average								
Minimum								

12.6 Tests required

The following section describes the recording, sampling and analysis requirements to evaluate fully the performance of a BNR works.

12.6.1 Sampling and analyses

12.6.1.1 Raw sewage

Daily samples should be taken as described above. A 24-hour composite sample of the raw sewage should be taken. The sample should be taken immediately downstream of the screens at the inlet works.

The following analyses should be carried out on the raw sewage:

pH
COD
TKN
Free and saline ammonia (as N)
Suspended solids
Total P
Orthophosphate (as P)
Conductivity

If primary sedimentation has been included in the process a 24-hour composite sample of the settled wastewater is recommended. The following analyses are recommended:

COD
TKN
Suspended solids (SS)

These analyses are required to monitor the performance of the PSTs in removing COD, TKN and SS.

12.6.1.2 Biological reactor

Grab samples should be taken of the mixed liquor in the anaerobic, anoxic and aerobic basins of the biological process. The following analyses should be carried out on each sample:

MLSS
DSVI (Described below)
NO_3 (as N)

Regular dissolved oxygen (DO) readings and the temperature of the reactor should also be recorded.

If ortho-P is to be measured, the sample should be filtered immediately. No inhibitor should be used as this will cause any sludge present to release phosphorus.

Diluted Sludge Volume Index (DSVI)

The MLSS concentration is used in conjunction with a 30-minute settling test to estimate the diluted sludge volume index (DSVI). The DSVI for the aeration basin should be determined weekly or more often if bulking or badly settling sludges occur.

The purpose of the DSVI is to monitor the settling characteristics of the mixed liquor and to bring to the attention of the operator whether or not the sludge has bulking characteristics. A DSVI result in excess of 150 mℓ/g is regarded as being indicative of a "bulking" sludge i.e. a sludge with poor settling characteristics. The DSVI test is outlined below and should be carried out independently for each process stream.

As the name suggests, it involves the settling of a diluted mixed liquor sample. Four 1000 mℓ measuring cylinders are required. A plastic jug should be used to obtain about a 3-ℓ sample of clarified effluent from the overflow of the clarifier. Another jug should be filled with mixed liquor from the outlet of the aeration basin. The four measuring cylinders should be set up next to one another and then after stirring the mixed liquor in the jug, each of the cylinders should be filled as follows : the first should be filled to the 1000 mℓ mark; the second to the 500 mℓ mark the third to the 250 mℓ mark and the fourth to the 125 mℓ mark. After that, cylinders 2, 3 and 4 should be filled to the 1000 mℓ mark with the clarified effluent. Then, covering the top of a cylinder with one hand, the cylinder should be inverted a few times to mix the sludge well. Each cylinder should then be set down on a flat surface and allowed to settle for 30 minutes. After 30 minutes of settling, the volume of the sludge in each of the cylinders should be recorded. The method of calculation of the DSVI is set out below:

Two calculations are required for the test. The first is for measuring cylinder number 1, which only contained MLSS. The calculation shown below gives a value which is known as the SVI: This value should be recorded on the log sheet:

$$\text{SVI} = \frac{\text{settled volume of sludge in cylinder No 1 after 30 minutes (ml}}{\text{MLSS (g/l)}}$$

The DSVI is now calculated from the volume of sludge in the cylinder which has a sludge volume of **less than 200 mℓ after settling**, as follows:

$$\text{DSVI} = \frac{\text{settled volume of sludge (less than 200 ml) after 30 minutes settling}}{\text{adjusted MLSS (g/l)}}$$

The adjusted MLSS is calculated from the dilution of the MLSS in each of the cylinders 2, 3 and 4. The MLSS in each of these cylinders is different and the factor by which to divide the MLSS is given in the table below for each cylinder.

Cylinder Number	**Dilution**	**Factor to divide MLSS by to adjust MLSS**
1	Nil	1
2	50%	2
3	25%	4
4	12,5%	8

12.6.1.3 Final effluent

A 24-hour composite sample should be taken of the effluent from the secondary clarifiers. The analyses recommended are the following :

pH
Conductivity
COD
Free and saline ammonia (as N)
Nitrate (as N)
Total P
Orthophosphate (as P)
Suspended solids

The results can be used in conjunction with the DO reading and the weekly analyses to ensure that all sections of the plant are operating correctly or to establish where a problem may lie, e.g. insufficient recycling into the anoxic zone. The overall performance of the plant with regard to nutrient removal can also be determined.

12.6.1.4 Fermentation

Where primary fermentation is part of a treatment process, weekly samples must be taken from the fermenter. The following analyses are required :

MLSS of underflow
SCFA concentration of the overflow

12.6.1.5 Sludge treatment

Where sludge is being thickened prior to further treatment or disposal weekly samples must be taken of the thickened sludge. The following analyses are recommended :

MLSS.

Weekly samples should also be taken from the clear water of the thickening process. The following analyses are required :

Orthophosphate (as P)

12.6.2 Recording

12.6.2.1 Flow measurement

The most convenient method for determining flow into a treatment works is by means of a venturi flume at the inlet with a flow recorder to record the flow rate and cumulative flows.

The cumulative flow should be recorded **daily** as

(i) Total flow into the BNR works.
(ii) Total flow discharged to the fermenter/ thickeners.
(iii) The WAS flow.

Every week the accuracy of the flow meters should be checked by measuring the depth of flow in the approach channel to the flume and comparing the indicated flow with that calculated for the flume from the measured depth. The results of these checks should be entered in a record book. The variation between measured and indicated value should be within 5%.

Should the two readings differ by more than 5% the flow should be measured again. If the difference is still greater than 5%, the supplier should be contacted and asked to come out and check the calibration of the flow meter.

12.6.2.2 Running hour meters

The data have to be recorded in a book maintained specifically for this purpose. Selection of the duty items of the plant is done manually by the operator for some of the equipment supplied e.g. duty mixer selections should be made so that near equal running hours are maintained between various duty/standby motors. For the automatically selected items, a large discrepancy in running hours between the duty/standby motors could mean a fault in the control system. This should be reported and rectified.

12.6.2.3 Dissolved Oxygen (DO)

The most crucial task that an operator must perform **daily** is to ensure that the DO in both aeration basins is maintained in the range of 1,0 to 2,0 mg/ℓ (refer to Section 8.4). The operator should use the portable meter to check the DO at points away from the fixed probes. Very regular cleaning of the oxygen probes will be required to obtain the optimum performance of the system.

12.7 SABS standard test methods

All tests should be carried out in accordance with methods prescribed by and obtainable from the South African Bureau of Standards, referred to in the Standards Act, No. 30 of 1982, as listed below:

TEST	Reference Number of SABS
Ammonia - free and saline	217
Arsenic	200
Bacteriological - faecal coliform, etc.	221
Boron	1 053
Cadmium	210
Calcium hardness	216
Chemical oxygen demand	1 048
Chloride	202
Chlorine - residual	1 052
Chromium - total	1 054
Chromium VI	206
Colour	198
Conductivity	1 057
Copper	203
Cyanide	20

TEST	Reference Number of SABS
Fluoride	205
Hardness - total	215
Iron	207
Lead	2208
Magnesium	1 071
Manganese	209
Mercury	1 059
Nitrate plus nitrite	210
Nitrite	219
Oil and grease	1 051
Oxygen absorbed	220
Oxygen demand (chemical)	1 048
Oxygen dissolved	1 047
pH	11
Phenolic compound	211

TEST ...... Reference Number of SABS		TEST ...... Reference Number of SABS	
Phosphate-ortho	1 055	Sulphate	212
Selenium	1 058	Sulphide	1 056
Sodium	1 050	Turbidity	197
Solids - suspended	1 049	Zinc	214

CHAPTER 13

TROUBLE SHOOTING

Problem	Possible Causes	Possible Remedial Action
13.1 PRIMARY SEDIMENTATION		
13.1.1 Sludge		
Sludge too thick resulting in frequent pipe blockages.	Excess sludge accumulation within the PST due to excessive retention time.	Increase the number of sludge draw-off cycles.
	Excessive grit in hopper.	Check quality of sludge for grit content. Check grit removal system.
Sludge rising to surface.	Worn or damaged scraper blades preventing sludge from being scraped to the central hopper	Empty tank and check clearances; replace blades if necessary.
	Desludging lines blocked.	Unblock line using air or high-pressure water jet.
	Desludging valve actuator faulty.	Check actuator mechanism.
	Desludging valve not opening fully.	Check and adjust valve settings.
	Sludge starting to digest.	Remove sludge more frequently at higher rates.
Very thin sludge being withdrawn.	Either sludge is being removed too quickly or desludging valve is opening for too long a period.	Decrease the number of opening/closing cycles and decrease the length of time that the valve is open.
	PST hydraulically overloaded.	Measure inflow into the tanks.
	Desludging valve partially blocked.	Clear blockage using air or high pressure water jet.
	Short-circuiting within the PST.	Check that weirs are level, V-notches are not blocked, or algae are growing on weir.

Problem	Possible Causes	Possible Remedial Action
Sludge sometimes thick, sometimes thin.	Accumulation of sludge within the PST is variable, due to varying suspended solids concentrations in the influent.	Desludging cycle should be varied such that a desludging cycle can be established for each day of the week. Regular checks should be made to establish whether the cycle is adequate.
Short-circuiting.	Uneven weir settings.	Adjust weir settings.
	Central stilling chamber rusted through.	Repair or replace stilling chamber.
	V-notches on weirs blocked.	Clean weir notches.
	Build-up of algae on weir plates.	Clean weirs regularly.
	Flow between concrete weir and baffle plate.	Repair seal.
Black and odorous sludge or wastewater.	Sludge scraper blades worn.	Replace blades.
	Sludge retention time excessive.	Increase frequency and rate of sludge withdrawal.
	Septic sewage entering tanks due to inadequate pretreatment of organic wastes.	Pre-aerate sewage or have pre-treatment carried out on site by industry prior to discharge into the sewer.
	Retention time in sewer excessive.	Pre-aerate within the sewer system or dose with chemicals. Check for sewer line blockages.
	Recycling of digester supernatant.	Check quality of digester supernatant prior to discharge. Prevent discharge if a poor quality is noted. Divert to sludge lagoons or drying beds if necessary.
	Desludging line blocked.	Unblock line using air or high power water jet.
	Scraper mechanism rotating too slowly.	Increase speed of rotation.

Problem	Possible Causes	Possible Remedial Action
13.1.2 Scum		
Scum accumulation on the tank surface.	Excess debris not being caught in the screens.	Check operation of screens.
	Worn scum scraper blade.	Replace rubber.
	Blocked scum hopper outlet pipe.	Unblock pipe using air or high power water jet.
	Removal frequency inadequate.	Increase removal frequency.
	Skimmer box incorrectly aligned.	Adjust alignment of skimmer box.
Fat and oil accumulation on liquid surface.	Excess fats being discharged down the main sewer.	Remove manually or attempt to trap before the PSTs.
Accumulation of scum, fats and oils in central stilling chamber.	Surface slots blocked.	Unblock slots with a high-pressure water jet.
Scum discharged with overflow.	Scum baffle is too shallow.	Adjust depth of scum baffle.
13.1.3 Mechanical		
Scraper mechanism keeps tripping out.	Torques in excess of the design are being applied to the scraper mechanism.	Check sludge density and decrease if required. Check motor. Check setting of the protection device. Empty the PST and check for fouling within the tank.
Excessive wear on scraper wheels.	Wheels are not aligned.	Align wheels.
	Track is dirty.	Clean surface on which wheels run.
Bridge exhibits erratic motion.	Scraper mechanism is catching in certain places.	Empty tank and check clearances.
Sludge pumps are not pumping sludge.	Motor may be faulty.	Check motor.
	Coupling broken.	Replace coupling.

Problem	Possible Causes	Possible Remedial Action
Sludge pumps are not pumping sludge.	Suction line blocked.	Unblock using air or high-pressure water jet.
	Delivery line blocked.	Unblock using air or high-pressure water jet.
	Rags etc, fouling impeller or impeller worn.	Clean impeller and replace if necessary.
	Non-return valve on delivery line jammed closed.	Clear valve.
	Isolating valve closed.	Check that all valves are open.
Noisy chain drive.	Chain fouling.	Check alignment and clean chain.
	Chain stretched.	Replace chain.
	Chain loose.	Adjust chain.
	Worn sprockets or drive chain parts.	Check and replace where necessary.
	Faulty lubrication.	Lubricate correctly.
13.2 BIOLOGICAL REACTOR		
13.2.1 Biological		
Decrease in P removal efficiency.	The DO concentrations in the return flow to the anaerobic zone are too high.	Decrease aeration such that the DO concentration in the return flow is less than 0,2 mg O/ℓ.
	The nitrate concentration in the recycled flow to the anaerobic zone is too high, or has increased. This may be due to an increase in influent TKN.	Check the nitrate concentration in the recycle and adjust the A-recycle to reduce the concentration being returned to the anaerobic zone.
	A decrease in the RBCOD fraction of the influent to the anaerobic zone.	Analyse the influent for RBCOD concentration and check with historical data as to whether there has been a decrease. Dose with chemical salts if P concentrations continue to rise.

Problem	Possible Causes	Possible Remedial Action
Accumulation of brown scum on reactor surface.	Growth of scum-forming filaments occurring within the process.	Change aeration pattern such that scum can be removed continuously from the aeration basin.
		Spray the foam with water jet.
		Dose RAS with chlorine.
		Reduce MLSS concentrations by increased wasting for a period until situation improves.
		Increase recycle rate from clarifiers.
	Low DO levels in the aeration basin due to excessive COD loads being returned in recycles from digesters, thickeners etc.	Increase DO levels.
White scum or foam on reactor surface.	Sludge age is too short resulting in low MLSS.	Increase sludge age.
	Increased industrial discharge.	Analyse influent for change in feed constituents.
13.2.2 **Mechanical**		
Solids settling within basins.	Insufficient mixing intensity.	Increase power input into the reactor.
Mechanical aerators keep switching on and off.	DO meter is out of calibration.	Check and recalibrate DO meters.
Surface aerators keep tripping.	Motors are overloading due to excessive immersion.	Check depth of immersion at various flow rates.
	Motor overheating.	Check motor.
	Aerators are fouled by rags.	Check for fouling.
Mixers keep tripping.	Motor overheating.	Check motor.
	Fouling by rags.	Check for fouling.

Problem	Possible Causes	Possible Remedial Action
Decrease in nitrification/denitrification.	Sludge age has reduced significantly to below 3-4 days.	Check the MLSS of the plant to ensure that no excess wasting has occurred.
	Shock loading of toxins in the influent flow. (Can sometimes be seen due to changes in colour of raw sewage)	Sample influent sewage and analyse for toxic constituents e.g. Chrome
	Oxygen levels in the aeration basin are low, causing loss of nitrification.	Check if DO in aeration basin is less than 2 mg O/ℓ or increase aeration time. Check control DO meter calibration.
	Low pH causing inhibition of nitrification.	Increase pH by dosing lime.
Low pH.	Alkalinity in influent wastewater has dropped or denitrification has decreased.	Check nitrate concentration in anoxic zone and determine if there has been a marked increase. If so, see above. Dose lime to increase pH. Check influent pH for possible pH drop due to excess industrial discharge.
Dark brown or black sludge.	Solids retention time in reactor is too long.	Check MLSS and increase sludge wasting.
	Low DO levels.	Check DO concentration and if so ? increase aeration. Check DO meter calibration.

Problem	Possible Causes	Possible Remedial Action
Pockets of boiling mixed liquor in diffused air system.	Diffusers broken or air pipework cracked.	Empty basin and check diffusers and pipework.
13.3 CLARIFIERS		
13.3.1 MLSS		
High DSVI resulting in solids carry-over.	Sludge age may be too short or too long.	Change sludge age thus changing MLSS.
	Low DO concentrations in the aeration basin.	Increase aeration.
	Anoxic fraction is too large.	Alter feed arrangements such that a fraction of the settled sewage can be fed into the anoxic zone.
		Decrease the size of the anoxic zone.
	Nitrite concentrations in excess of 1 to 3 mg N/ℓ entering aerobic zone from anoxic reactor causing bulking sludges.	Reduce A-recycle rate.
	Bulking sludge.	Shock dose mixed liquor with chlorine.
High concentration of solids in the effluent.	Clarifier is hydraulically overloaded.	Check flow to clarifier and reduce if possible or operate another clarifier.
	S-recycle rate is too low.	Increase recycle rate.
	Pin point flow resulting from shearing.	Reduce aeration.
	Solids loading on clarifier excessive.	Reduce MLSS in aeration basin.
Turbid effluent.	Hydraulic flow rate excessive.	Operate extra clarifier.
	MLSS concentration too high.	Reduce MLSS.

Problem	Possible Causes	Possible Remedial Action
Turbid effluent.	Flocs sheared.	Reduce mixing intensities and turbulence in transfer channels.
	Sludge age too short.	Increase sludge age.
	pH too low.	Dose with lime.
Sludge rising to clarifier surface.	Denitrification occurring in clarifier due to prolonged retention times.	Increase recycle rate.
		Increase scraper speed.
		Decrease nitrate concentrations of feed by additional denitrification in anoxic basin.
		Inhibit nitrification by reducing the sludge age or aeration rate.
		Empty clarifier and check scraper clearances.
Sludge turned black and gassing, giving off odours.	Septic sludge within clarifier.	Increase recycle rate.
		Increase aeration in reactor.
		Reduce MLSS.
Return sludge too thick resulting in pipe blockages.	Excess sludge accumulation within the clarifier.	Increase recycle rate.
	Scraper blades worn or damaged preventing sludge being scraped into the hopper.	Empty tank and check blades.
Very thin sludge being withdrawn.	Sludge is being removed too quickly from the clarifier.	Reduce recycle rate.
13.3.2 Scum		
Scum accumulation on the tank surface.	Worn scum scraper blade.	Replace rubber blade.
	Blocked scum hopper.	Unblock outlet pipe with air or high-pressure water jet.
	Removal frequency inadequate.	Increase removal frequency.

Problem	Possible Causes	Possible Remedial Action
Scum accumulation on the tank surface.	Skimmer box incorrectly aligned.	Adjust alignment of skimmer box.
13.3.3 Mechanical		
As per Section 13.1.3 above		
13.4 FERMENTATION		
In addition to section 1:		
Loss of SCFA production.	Sludge starting to digest.	Reduce sludge age.
	Growth of methane-producing bacteria has occurred.	Empty entire fermenter and start with fresh primary sludge.
13.5 GRAVITY THICKENER		
13.5.1 Thickening		
Excessive solids thickener effluent.	Weir not level.	Level weir.
	Flotation due to denitrification.	Increase sludge draw-off rate.
	Poorly settling ("bulking") sludge.	Identify filament and adjust reactor operation.
		Condition sludge with polymer.
	Excessive loading on thickener.	Feed sludge to thickener over more hours in a day.
Odours.	Septic sludge	Increase sludge draw-off rate.
		Add oxidizing agent to influent sludge.
Phosphorus release.	Anaerobic conditions in sludge blanket.	Increase sludge drawoff rate.
Insufficient thickening.	High overflow rate.	Reduce overflow rate.
	High sludge draw-off rate.	Reduce drawoff rate.
	Short-circuiting of flow.	Level effluent weirs.

Problem	Possible Causes	Possible Remedial Action
Insufficient thickening.	Blockage in sludge draw-off pipework.	Clear blockage.
Slime growth in launders and weirs.	Excess nutrients and light.	Clean regularly.
		Chlorinate.
13.5.2 Mechanical		
Pump overload trips.	Incorrect packing.	Adjust packing.
	Foreign object in pump.	Clear pump.
	Sludge is too thick.	Increase sludge draw-off rate.
Bridge mechanism overload trips.	Excessive sludge accumulation.	Increase sludge draw-off rate.
	Foreign object jamming mechanism.	Remove object.
	Improper mechanism alignment.	Realign mechanism.
13.6 DISSOLVED AIR FLOTATION		
13.6.1 Thickening		
Excessive solids in effluent.	Sludge accumulation on floor.	Desludge.
	System overloaded.	Reduce loading rate by feeding over more hours in a day.
	Low air : solids ratio.	Increase air flow.
	Float skimmer too high or too slow.	Replace or increase speed.
Sludge float too thin.	Float skimmer too close to water surface.	Raise float skimmer.
	Skimmer speed too high.	Reduce speed.
	High air:solids ratio.	Reduce air flow.
	Low dissolved air.	Increase airflow to saturator.
Frothy float.	High air:solids ratio	Reduce air flow.

Problem	Possible Causes	Possible Remedial Action
High water level in saturator.	Air supply pressure too low.	Check compressor and level control system.
	Air injection insufficient.	Check compressor and air injection lines.
Low water level in saturator.	Recirculation pumps not operating correctly.	Check operation.
	Level control system faulty.	Check level control system.
Recirculation pump capacity low.	Saturator pressure too high.	Check pressure control valve.
Phosphorus release.	Anaerobic sludge on floor.	Desludge.
13.6.2 Mechanical		
		As each manufacturer's plants differ greatly in design and operation, it is recommended that the manufacturer's detailed maintenance manual be consulted should problems arise with the mechanical plant.

REFERENCES: Use was made of the following publications in drawing up this guide. The references are general in nature and are not specifically listed in the text.

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