ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshao

WASTEWATER TREATMENT MANUALS

PRIMARY, SECONDARY AND TERTIARY TREATMENT

This document contains 131 pages

WASTE WATER TREATMENT MANUALS

PRIMARY, SECONDARY and TERTIARY TREATMENT

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WASTE WATER TREATMENT MANUALS

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PREFACE

The Environmental Protection Agency was established in 1993 to license, regulate and control activities for the purposes of environmental protection. In Section 60 of the Environmental Protection Agency Act, 1992, it is stated that "*the Agency may, and shall if so directed by the Minister, specify and publish criteria and procedures, which in the opinion of the Agency are reasonable and desirable for the purposes of environmental protection, in relation to the management, maintenance, supervision, operation or use of all or specified classes of plant, sewers or drainage pipes vested in or controlled or used by a sanitary authority for the.....treatment or disposal of any sewage or other effluent to any waters* ". Criteria and procedures in relation to the treatment and disposal of sewage are being published by the Agency in a number of manuals under the general heading: 'Waste Water Treatment Manuals'. Where criteria and procedures are published by the Agency, a sanitary authority shall, in the performance of its functions, have regard to them.

This manual on Primary, Secondary and Tertiary Treatment sets out the general principles and practices which should be followed by those involved in the treatment of urban waste water. It provides criteria and procedures for the proper management, maintenance, supervision, operation and use of the processes and equipment required for the secondary treatment of wastewater. The Agency hopes that it will provide practical guidance to those involved in plant operation, use, management, maintenance and supervision. Where reference in the document is made to proprietary equipment, this is intended as indicating equipment type and is not to be interpreted as endorsing or excluding any particular manufacturer or system.

The Agency welcomes any suggestions which users of the manual wish to make. These should be returned to the Environmental Management and Planning Division at the Agency headquarters on the enclosed User Comment Form.

ABBREVIATIONS

[..]	concentration of .. parameter
Agency	Environmental Protection Agency
BOD	biochemical oxygen demand
BOD_5	five-day biochemical oxygen demand
cm	centimetre
COD	chemical oxygen demand
°C	degrees Celsius
d	day
DAF	dissolved air flotation
dB(A)	decibels (A-weighting filter that simulates the subjective response of the human ear)
DO	dissolved oxygen
DWF	dry weather flow
EC_{50}	concentration of toxin required to cause a specified effect on 50% of the test organisms
EPA	Environmental Protection Agency
F/M	food to micro-organism ratio
FOG	fats, oils and grease
g	gram
h	hour
Hz	hertz
IPC	Integrated Pollution Control
ISO	International Standards Organisation
kg	kilogram
K_{La}	oxygen transfer coefficient
km	kilometre
kP	kilopascal
l	litre
m	metre
mg	milligram
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
mm	millimetre
m/s	metres per second
N	Newton
NAB	National Accreditation Board
OC	oxygenation capacity

Pa	Pascal
p.e.	population equivalent
PHB	polyhydroxyl butyrates
ppm	parts per million
RAS	return activated sludge
RBC	rotating biological contactors
s	second
SCFA	short chain fatty acids
S.I.	statutory instrument
SSA	specific surface area
SS	suspended solids
SSVI	specific sludge volume index
SVI	sludge volume index
TOC	total organic carbon
TSS	total suspended solids
UWWT	urban waste water treatment
WAS	waste activated sludge

1. TREATMENT OF WASTE WATER

1.1 TREATMENT OF WASTE WATER

Section 60 of the Environmental Protection Agency Act, 1992 permits the Agency to specify and publish criteria and procedures, which in the opinion of the Agency are reasonable and desirable for the purposes of environmental protection. This manual is prepared in accordance with the foregoing, in respect of **waste water treatment** and should be read in conjunction with the manual prepared on preliminary treatment.

The purpose of this manual is to:

- ensure that waste water treatment plants are operated to the highest possible standards,
- improve maintenance practices,
- ensure that assets provided are maintained,
- educate operators and equip them with the essential skills,
- develop management skills,
- provide operators with essential process theory,
- provide operators with a knowledge of treatment standards, and
- create an awareness of the extent and uses of the equipment provided.

Note that safety procedures (acceptable to the Health and Safety Authority) must be adopted in operating urban waste water treatment plants and nothing in this manual should be construed as advice to the contrary.

1.2 LEGISLATION

The Environmental Protection Agency Act, 1992 (Urban Waste Water Treatment) Regulations, 1994 (S.I. 419 of 1994) were enacted on 14 December, 1994 to transpose into Irish law EU Directive 91/271/EEC; these provide a framework for action to deal with the pollution threat from urban waste water. Specific requirements apply in relation to:

- collecting systems,
- treatment plants and
- monitoring of discharges.

Traditionally, secondary urban waste water treatment plants were designed to a 20/30 standard (i.e. 20 mg/l BOD and 30 mg/l SS) which was set by the UK Royal Commission on Sewage Disposal in 1912. This standard has now been superseded and the current quality requirements of secondary treatment plant outflows are outlined in the Urban Waste Water Treatment (UWWT) Regulations, which has set the following limits:

BOD	:	25 mg/l
COD	:	125 mg/l
SS	:	35 mg/l

The Regulations allow for a limited number of samples to fail provided that in the case of BOD, COD and SS respectively, the limits of 50 mg/l O_2, 250 mg/l O_2 and 87.5 mg/l are not exceeded.

For discharges to sensitive waters the Regulations prescribe annual mean limits for total phosphorus (2 mg/l P) and total nitrogen (15 mg/l N) where the agglomeration population equivalent is between 10,000 and 100,000. Larger agglomerations must comply with standards of 1 mg/l P and 10 mg/l N. The limits can apply to one or both parameters.

Discharges of industrial waste water to sewers are licensed under Section 16 of the Local Government (Water Pollution Acts) 1977 and 1990 or Section 85 of the Environmental Protection Agency Act, 1992. It is essential to ensure that the characteristics of waste water entering a treatment plant do not affect the performance of the plant.

It is important that the costs incurred by sanitary authorities in treating industrial waste water are recouped under the "Polluter Pays" principle, which *inter alia* encourages industry to reduce the load entering the sewer system. This also places a responsibility on sanitary authorities to operate treatment plants efficiently.

1.3 OVERVIEW OF WASTE WATER TREATMENT

Waste water treatment can involve physical, chemical or biological processes or combinations of these processes depending on the required outflow standards. A generalised layout of a waste water treatment plant is shown in Figure 1.1.

The first stage of waste water treatment takes place in the preliminary treatment plant where material such as oils, fats, grease, grit, rags and large solids are removed. These processes are described in greater detail in the preliminary treatment manual (EPA,1995).

Primary settlement is sometimes used prior to biological treatment. Radial or horizontal flow tanks are normally employed to reduce the velocity of flow of the waste water such that a proportion of suspended matter settles out.

Biological treatment of waste waters takes place in fixed media or suspended growth reactors using activated sludge, biofiltration, rotating biological contactors, constructed wetlands or variants of these processes.

Nitrification/denitrification and biological phosphorus removal can be incorporated at this stage and will reduce nutrient concentrations in the outflow.

Chemical treatment is used to improve the settling abilities of suspended solids prior to a solids removal stage or to adjust the properties or components of waste water prior to biological treatment (e.g. pH adjustment, reduction of heavy metals or nutrient adjustment). It may also be used for precipitating phosphorus in conjunction with biological phosphorus treatment.

Secondary settlement separates the sludge solids from the outflow of the biological stage.

Tertiary treatment refers to processes which are used to further reduce parameter values below the standards set out in national regulations. The term is often used in reference to nutrient removal.

Sludge treatment can be a significant part of a waste water treatment plant and involves the stabilisation and/or thickening and dewatering of sludge prior to reuse or disposal.

1.4 ROLE OF THE PLANT OPERATOR

Individual sections of this manual outline the role of the plant operator in the management, maintenance and operation of each process.

The plant operator should manage the plant with the following objectives:

- where required, meeting the emission limits set in the UWWT Regulations for secondary treatment systems;
- meeting the standards for sensitive waters where prescribed;
- minimising odours and thus avoiding nuisance complaints;
- operating the waste water treatment plant efficiently;
- minimising energy consumption; and
- implementing an effective preventative maintenance programme.

For additional advice on the operation and maintenance of plants, reference should be made to:

- the manufacturers' and suppliers' manuals of operation; and
- the training programmes implemented by the Tipperary (N.R.) County Council/FÁS training group.

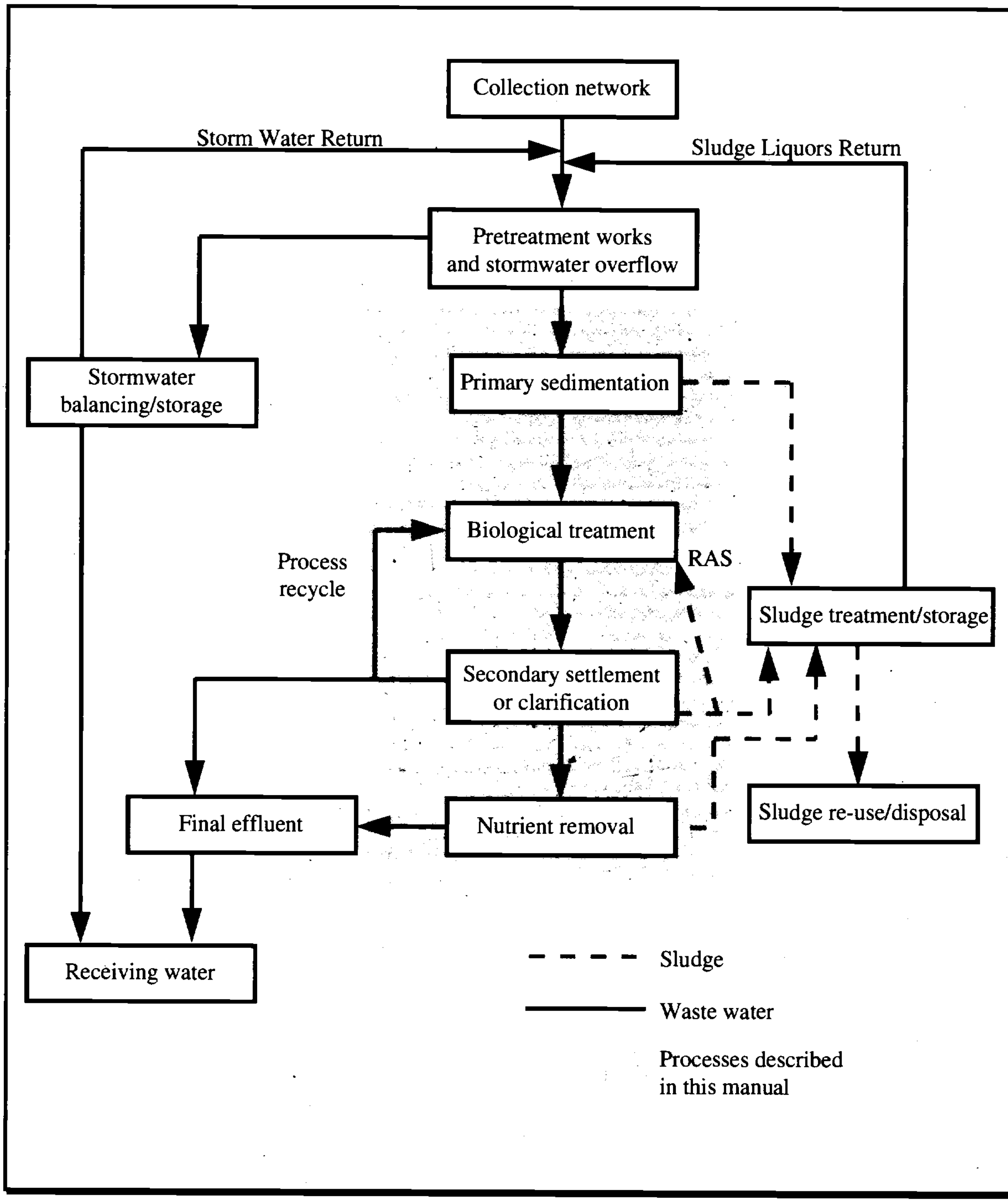


FIGURE 1.1 WASTE WATER TREATMENT PLANT OVERVIEW

2. GENERAL CONSIDERATIONS FOR THE TREATMENT OF WASTE WATER

2.1 CHARACTERISTICS OF URBAN WASTE WATER

Urban waste water is characterised in terms of its physical, chemical and biological constituents. These characteristics and their sources are listed in Table 2.1.

The strength of waste water is normally measured using accurate analytical techniques. The more common analyses used to characterise waste water entering and leaving a plant are:

- BOD_5
- COD
- TSS
- pH
- total phosphorus
- total nitrogen

2.2 PARAMETERS BY WHICH WASTE WATER IS MEASURED

Biochemical oxygen demand (BOD): BOD is the amount of oxygen used by organisms while consuming organic matter in a waste water sample. It is possible to assess the performance of a waste water treatment plant by measuring the BOD_5 of the inflow and the outflow. Many factors can influence this test, such as temperature of incubation, dilution rate, nitrification, toxic substances, nature of bacterial seed and presence of anaerobic organisms.

The method of measurement for the BOD_5 test in the UWWT Regulations requires:

- that the sample is homogenised, unfiltered and undecanted; and
- that a nitrification inhibitor is added.

The UWWT Regulations allow for the BOD_5 test to be replaced by another parameter, total organic carbon (TOC) or total oxygen demand (TOD) if a relationship can be established between BOD_5 and the substitute parameter.

Chemical oxygen demand (COD): The COD test uses the oxidising agent potassium dichromate (specified in the UWWT Regulations) to oxidise organic matter in the sample. The test is extensively used because it takes less time (about 3 hours) than other tests such as the BOD_5, which takes 5 days. The COD test does not, however, differentiate between biodegradable and non-biodegradable organic matter.

For municipal waste water it is generally possible to establish a relationship between COD and BOD. Once a correlation has been established, the COD test can be a very useful indicator for the operation and control of the plant.

Total suspended solids (TSS): This is the sum of the organic and inorganic solids concentrations and can be subdivided into:

suspended solids: which represent the solids that are in suspension in the water. Generally comprised of 70% organic and 30% inorganic solids and can be removed by physical or mechanical means.

organic solids: about 50% of solids present in urban waste water derive from the waste products of animal and vegetable life. Sometimes called the combustible fraction or volatile solids as these can be driven off by high temperature.

inorganic solids: these substances are inert and are not subject to decay. Include sand, gravel and silt.

settleable solids: this is a subset of suspended solids and represents that fraction of suspended solids that will settle in a given period.

colloidal suspended solids: these refer to solids that are not truly dissolved and yet do not settle readily. They tend to refer to organic and inorganic solids that rapidly decay.

Dissolved solids refers to that fraction of solids that pass through a 0.45μm filter paper.

TABLE 2.1 PHYSICAL AND CHEMICAL CHARACTERISTICS OF WASTE WATER AND THEIR SOURCES
(Mod. Metcalf & Eddy, 1991)

CHARACTERISTIC	*SOURCES*
Physical properties :	
Colour	Domestic and industrial waste water, natural decay of organic materials
Odour	Decomposing waste water, industrial waste water
Solids	Domestic water supply, domestic and industrial waste water, soil erosion, inflow/infiltration
Temperature	Domestic and industrial waste water
Chemical constituents :	
Organic:	
Carbohydrates, fats, oils and grease, proteins, surfactants, volatile organics	Domestic, commercial and industrial waste water
Pesticides	Agricultural waste water
Phenols	Industrial waste water
Other	Natural decay of organic materials
Inorganic:	
Alkalinity, chlorides	Domestic waste water, domestic water supply, groundwater infiltration
Heavy metals	Industrial waste water
Nitrogen	Domestic and agricultural waste water
pH	Domestic, commercial and industrial waste water
Phosphorus	Domestic, commercial and industrial waste water natural runoff
Gases :	
Hydrogen sulphides, methane	Decomposition of urban waste water
Oxygen	Domestic water supply, surface-water infiltration

pH: This is the concentration of hydrogen ions in solution and indicates the level of acidity or alkalinity of an aqueous solution. If the pH of the waste water is outside the range 5-10, there may be considerable interference with biological processes. Figure 2.1 illustrates the effect of pH on bacterial growth.

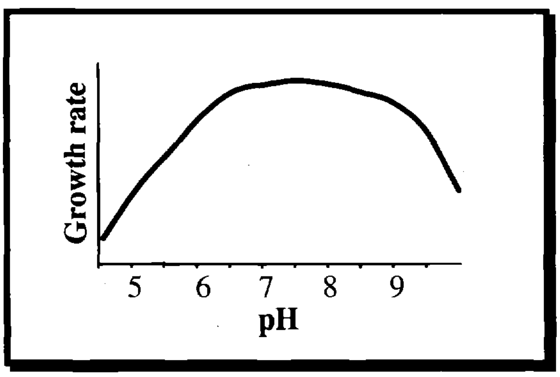


FIGURE 2.1 GROWTH RATE OF MICRO-ORGANISMS AS A FUNCTION OF pH

Total phosphorus: This parameter is normally divided into three fractions, namely:

orthophosphate:	dissolved inorganic phosphate (PO_4^{3-})
polyphosphates:	complex compounds generally derived from detergents
organically bound phosphate:	dissolved and suspended organic phosphates

Total phosphorus analysis requires two steps:

- conversion of polyphosphates and organically bound phosphorus to dissolved orthophosphate, and
- colorimetric determination of the dissolved orthophosphate.

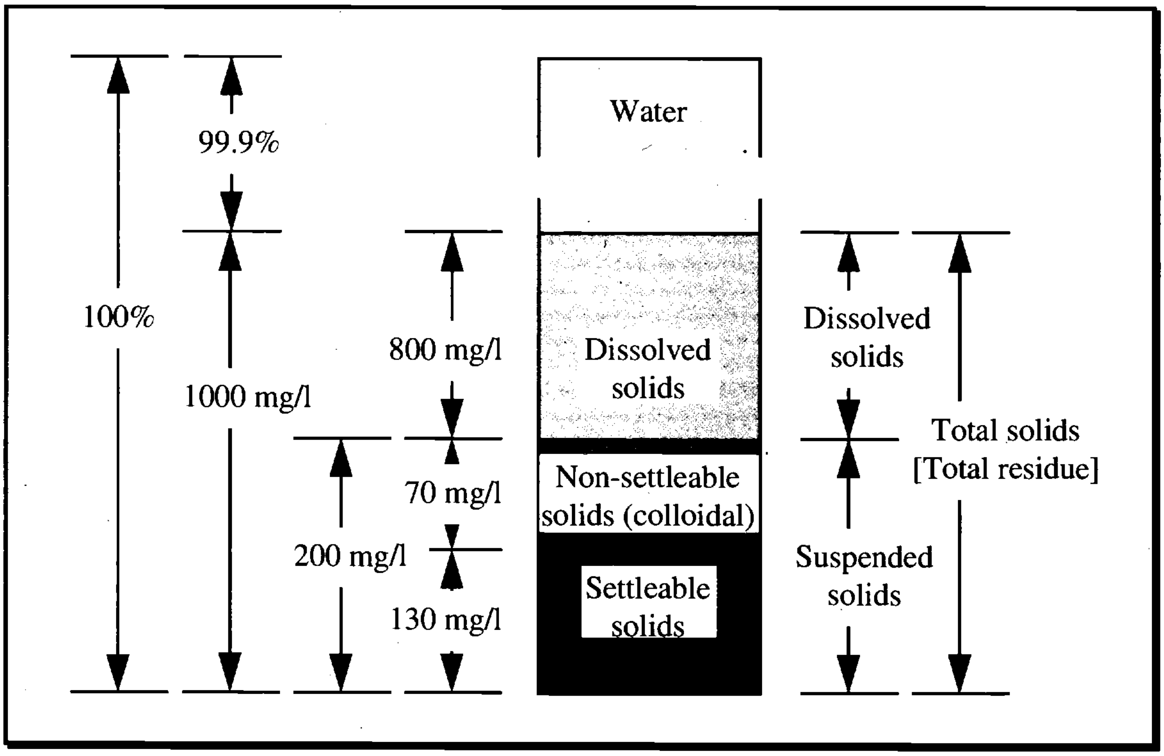


FIGURE 2.2 TYPICAL COMPOSITION OF URBAN WASTE WATER
(U.S.EPA, volume 1, 1992.)

In instances where phosphorus is a growth limiting nutrient the discharge of waste water containing phosphorus may stimulate the growth of vegetation in the water body. The third schedule of the UWWT Regulations specifies a total phosphorus limit for discharges to sensitive water bodies.

Total Nitrogen: This refers to the sum of measurements of total oxidised nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen (ammonia and organic nitrogen). This parameter is a growth limiting nutrient in marine environments and a limit is specified in the UWWT Regulations for discharges to sensitive water bodies.

BOD(C) : Nitrogen(N) : Phosphorus(P) ratio: In order to operate satisfactorily, micro-organisms require a balanced diet. This is normally achieved by maintaining the level of BOD:N:P in the waste water at about the ratio 100:5:1. Domestic sewage is not normally deficient in these elements but industrial effluents may be and this can lead to a nutrient deficiency in the inflow to a plant. To monitor the BOD:N:P ratio the BOD, total nitrogen and total phosphorus analytical results are used.

2.3 LABORATORY ACCREDITATION

It is desirable that laboratories undertaking analyses be certified by a third party accreditation scheme such as that administered by the National Accreditation Board.

As a step towards formal accreditation, the Agency has established a laboratory inter-calibration programme. This programme is designed to measure the performance and proficiency of each participating laboratory on a regular basis by objectively reviewing the analytical results produced. Identical samples are sent to participating laboratories and the results compared to each other. Duplicate analyses are also undertaken by the participating laboratories to estimate the precision of the results within each laboratory.

Appendix A provides examples of forms which operators are encouraged to use in order to standardise analyses and reporting.

2.4 PLANT LOADING

Measurement of the inflow and composition of waste water is of critical importance to the design and operation of both the collection system and the treatment plant.

For large scale treatment plants, it is common to design the plant for a maximum 3 times Dry Weather Flow (DWF). On smaller plants, the scale of plant and the cost implications of a higher design coefficient are less significant and the figure is normally taken as 4 to 6 times DWF depending on whether the sewerage system is combined or partially separate. This approach is generally followed for treatment plants up to 2,000 p.e. and may well be desirable up to at least 5,000 p.e.

2.4.1 HYDRAULIC LOADING

The flow entering an urban waste water treatment plant includes:

- domestic waste water;
- industrial waste water discharges: data can be obtained from discharge licences issued in accordance with the Local Government (Water Pollution) Acts 1977 and 1990 or the IPC licence issued under the EPA Act, 1992. Alternatively, an industry's metered water consumption figures can be used;
- infiltration;
- surface water and storm water (except in separate systems).

The flow entering a plant can vary from hour to hour, day to day, week to week and season to season. Figure 2.3 illustrates an example of diurnal flow variation.

Appendix B contains a summary table of the characteristics of some common industrial discharges.

2.4.2 ORGANIC LOADING

The organic loading entering the waste water treatment plant will be determined by the volume and strength of the industrial waste water in addition to the population served.

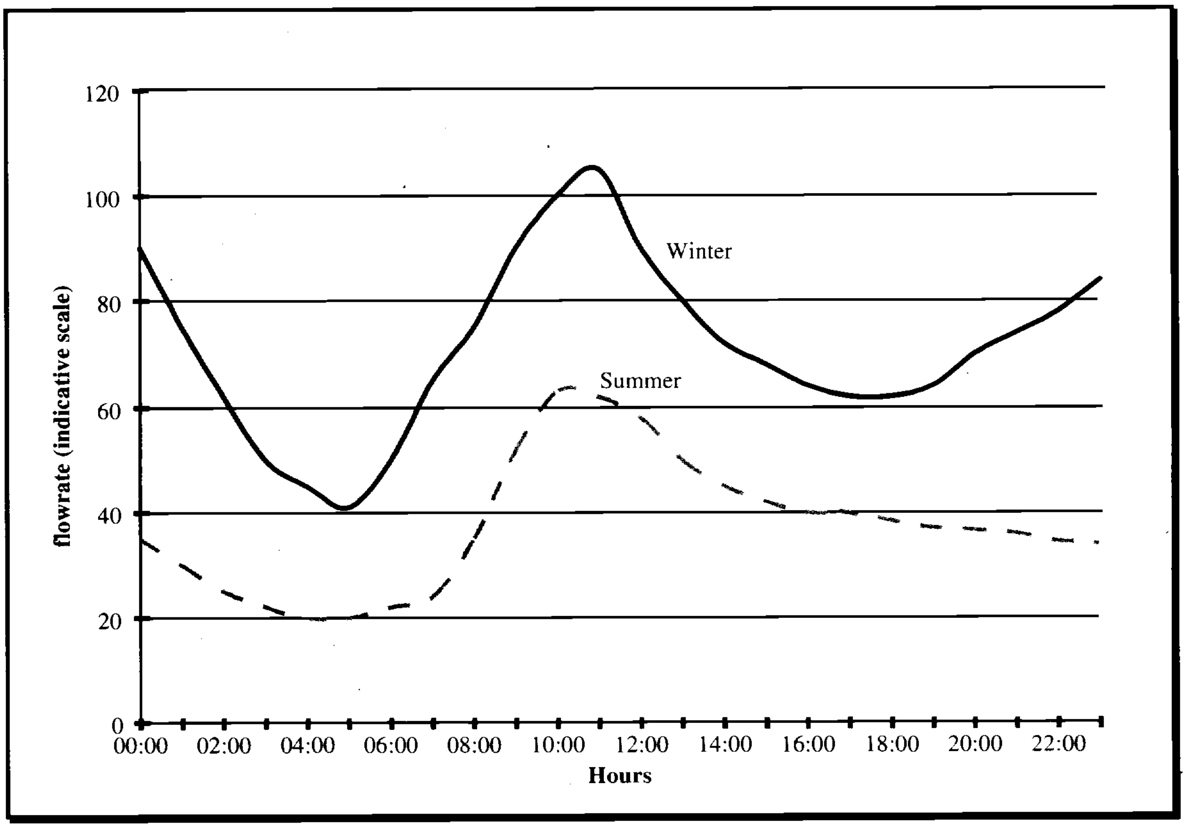


FIGURE 2.3 DIURNAL AND SEASONAL FLOW VARIATIONS TO A TREATMENT PLANT

The UWWT Regulations define one population equivalent (p.e.) as the load resulting from 60g of BOD_5. The Regulations prescribe that the population equivalent of a plant (organic load) is to be "calculated on the basis of the maximum average weekly load entering the treatment plant during the year, excluding unusual situations such as those due to heavy rain".

Industrial and domestic loads may be seasonal and hence it is important that the organic load entering the plant is accurately measured. The COD test in particular is a fast and reliable method of establishing the organic load contributed from an industrial premises. The COD test results should always be used in addition to the BOD_5 test results.

Typical values of the principal constituents of urban waste water are given in Table 2.2

TABLE 2.2 TYPICAL CHARACTERISTICS OF URBAN WASTE WATER

Parameter	Concentration mg/l
BOD	100 - 300
COD	250 - 800
Suspended solids	100 - 350
Total nitrogen (as N)	20 - 85
Ammonia (NH_3 as N)	10 - 30
Organic phosphorus (as P)	1 - 2
Inorganic phosphorus (as P)	3 - 10
Oils, fats and grease	50 - 100
Total inorganic constituents (Na, Cl, Mg, S, Ca, K, Si, Fe)	100
Heavy metals (Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn)	<1mg/l each

The daily organic load to a plant may be calculated using the following formula:

EQUATION 2.1

$$\text{Organic load} = \frac{\text{Daily flow x BOD}}{1000}$$

Note: Organic load is expressed in kg/day, daily flow in m^3/day and BOD concentration in mg/l.

Flow proportional sampling should be used in order to account for diurnal variations in flow and waste water strength.

2.4.3 RETURN SLUDGE LIQUORS

Where sludge dewatering processes are used, the separated water or liquor from the process is generally returned to the main treatment stream. This can amount to 0.5-1.0% of the average incoming flow and can contribute BOD concentrations of 200-5000 mg/l to the process stream. Large concentrations of ammonia (300-2000 mg/l) may be present in return liquors and these can prove toxic to biological treatment units. Similarly, high concentrations of heavy metals can accumulate in sludge liquors as can large concentrations of phosphorus (where biological P removal is practised). The prudent management of return liquors should ensure that they do not harm the biological treatment process and that they are adequately diluted or pretreated if detrimental effects are expected.

2.5 INSTRUMENTATION

With improvements in technology, process instrumentation is now available that will assist the operator in the control of the waste water treatment plant. It is important that process instruments such as suspended solids and dissolved oxygen meters are:

- appropriate for the intended application;
- located in areas where representative samples can be obtained; and
- are regularly calibrated and maintained to manufacturers' specifications.

Optical instrumentation exists for monitoring the suspended solids in the inflow and outflow as well as the more concentrated flows such as mixed liquor, sludge return and excess sludge. Instruments should be capable of detecting concentrations from 30 mg/l to several percent solids.

Common problems encountered with these probes include:

- solids build-up on optical surfaces;
- the difficulty of choosing a location to obtain a representative sample;

- the need to take a sample at the probe for calibration purposes;
- servicing and maintenance;
- stray light causing erroneous results; and
- air bubbles in the sample.

Dissolved oxygen (DO) meters are used to monitor levels of oxygen available in the aeration tank to sustain biological activity. Suspended and dissolved solids and some gases such as chlorine, hydrogen sulphide, carbon dioxide and sulphur dioxide can interfere with the measurement of dissolved oxygen.

The following basic information should be retained at the plant for each instrument being used:

- the manufacturer;
- the type, model and serial number;
- the date of installation; and
- the maintenance and calibration manual.

The accuracy of a probe should be obtained from the manufacturer's literature. Accuracy expresses how close a probe reading is to the true value of the parameter being measured.

For optimum performance, probes should be regularly cleaned.

2.6 TELEMETRY

Telemetry is the remote interrogation of a process plant for the control of equipment and the monitoring of parameters. For small treatment plants where the cost of continuous human presence for control and monitoring purposes would be excessive, consideration should be given to its use. Telemetry links are important as incidents arising at small treatment plants may have severe repercussions if not corrected quickly. Examples include the breakdown of aeration equipment or the escape of sludges over secondary settlement tank weirs.

Techniques available for the transmission of data include:

- private telephone lines;
- leased telephone lines;
- modems via standard telecommunication line; and
- VHF radio.

Such systems (or combination of systems) are highly practical for short duration transmissions such as calling out personnel after a specified incident has occurred. In remote situations where telephone links are not practical, radio based systems should be considered.

2.7 SCADA SYSTEMS

There are a number of variables that can be measured and controlled on a waste water treatment plant. These include:

- physical parameters (e.g. flow, pressure, temperature);
- chemical parameters (e.g. pH, turbidity, DO); and
- biological parameters (e.g. sludge growth rate).

Process control systems like 'Supervisory Control and Data Acquisition' (SCADA) monitor these variables and implement actions in response. The systems typically include:

- a measurement instrument for the variable(s);
- a signal transmitting device;
- a computer display;
- a control loop; and
- a controller.

The system can be designed to meet requirements unique to a plant. SCADA systems typically monitor and control all streams through the plant and archive the data received.

2.8 INSTRUMENTATION AND CONTROL SYSTEMS

The level of instrumentation and computer control required at a waste water treatment plant will essentially depend on:

- the size and complexity of the plant;
- the number of operators required and their skills;
- any process data needed for problem solving;
- the costs involved;
- the hours of manned operation;
- the qualifications of personnel available (including instrumentation people); and

- the type of control: manual, supervisory, automatic or computer control.

If automatic controls are selected, decisions should be made concerning the number of control elements and loops, the accuracy needed, the operating range, the response time of process variables and the frequency of operator input. The economics of instrumentation and controls should be compared with the savings achieved by plant automation.

3. BIOLOGICAL TREATMENT OF WASTE WATERS

3.1 WASTE WATER FLORA AND FAUNA

The biology of waste water treatment is based on the consumption of organic matter by micro-organisms which include bacteria, viruses, algae and protozoa. An operator's job is to regulate these micro-organisms so that they perform in an efficient and economic way. Therefore, a knowledge of their metabolism is necessary in order to control the process effectively.

Bacteria are the most populous of the micro-organisms used in waste water treatment; these single-celled organisms directly break down the polluting matter in waste waters. Bacteria are lower life forms and occupy the bottom of the waste water treatment food chain. Bacteria can be sub-divided into different groups but in all cases their metabolism is based on the mechanism illustrated in Figure 3.1. Enzymes, both internal and external, are used to break down the substrate (food) into a form which can be more readily used by the bacteria for the maintenance and propagation of life. For aerobic bacteria, oxygen is required in breaking down the substrate. Anaerobic bacteria operate in the absence of oxygen. Facultative micro-organisms have the ability to operate aerobically or anaerobically.

Heterotrophic bacteria break down organic material like carbohydrates, fats and proteins; these are characterised by the BOD and COD of a waste water. These compounds are generally easily biodegradable and so the bacteria thrive and enjoy high growth rates; their doubling time can be measured in hours (and sometimes minutes). The two basic reactions for carbonaceous oxidation can be represented as follows:

(i) Organic matter + O_2

$$\xrightarrow[enzyme]{bacteria +} CO_2 + H_2O + \text{Energy}$$

(ii) Organic matter + P + NH_3 + O_2 + Energy

$$\xrightarrow[enzyme]{bacteria +} \text{New cell material}$$

Autotrophic bacteria derive their cell carbon from CO_2 and use a non-organic source of energy for growth. Nitrifying bacteria oxidise ammonia (which is either present in the waste water or is produced from the breakdown of proteins and other nitrogen rich organic compounds) to nitrite and nitrate under aerobic conditions. These bacteria tend to be slower growing than the heterotrophs. They are sensitive to environmental changes such as toxic shock loads.

$$2NH_4^+ + 3O_2 \xrightarrow{Nitrosomonas} 2NO_2^- + 2H_2O + 4H^+ + \text{Energy}$$

$$2NO_2^- + O_2 \xrightarrow{Nitrobacter} 2NO_3^- + \text{Energy}$$

Under anoxic conditions, many heterotrophic bacteria have the ability in the absence of dissolved molecular oxygen to utilise the oxygen contained in nitrate molecules. Nitrate is reduced to nitrogen gas during these denitrification reactions and the gas bubbles away to atmosphere.

Anaerobic bacteria thrive in the absence of oxygen and, in urban waste water treatment plants, are most often encountered under septic conditions where oxygen is not available or has become depleted, for example in long sewers or in sludge storage tanks. Foul odours are generally associated with septic conditions. Anaerobic processes are most commonly used for the pretreatment of high strength industrial wastes and for the digestion of sludges.

Higher life forms in the waste water treatment food chain include protozoa and rotifers. These are illustrated in Figure 3.2. These animals require time to become established in a treatment facility and will appear and predominate in the order of flagellates, free swimming ciliates, stalked ciliates and rotifers. Their function is to prey on bacteria and on larger solid particles that have not been consumed by bacteria. They consume any loose suspended material thus ensuring a clear outflow. The relative quantity of these animals when viewed through a microscope is an excellent indicator of the state of health of a biological treatment system and in the hands of an experienced operator can be as indicative as chemical analyses.

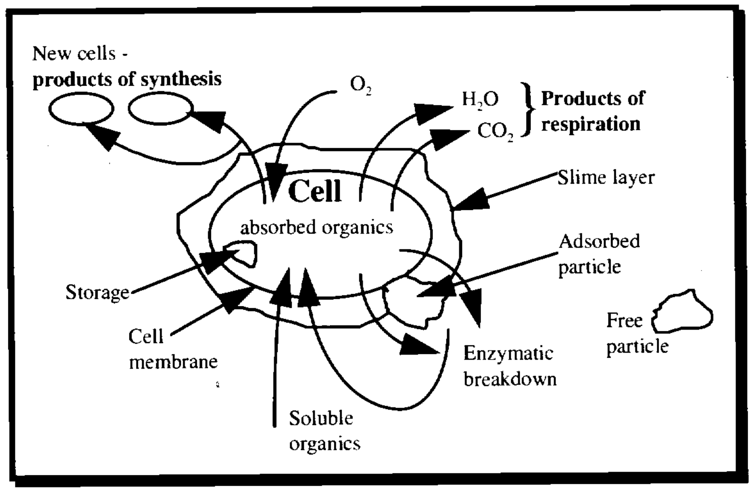


FIGURE 3.1 METABOLISM AND TRANSPORT MECHANISMS IN BACTERIAL CELLS
(CRS Group, 1978)

Bacterial and protozoan populations do not exist in isolation; they interact, causing modifications to each other's population and activities. Although protozoa remove bacteria by predation, treatment of waste water occurs at a faster rate when both classes of micro-organism are present.

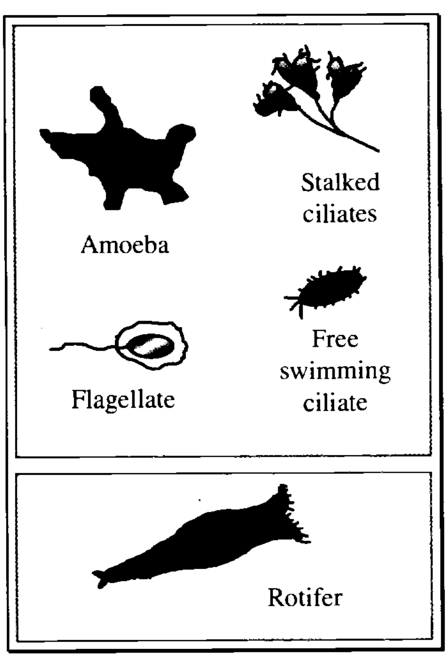


FIGURE 3.2 EXAMPLES OF PROTOZOA AND ROTIFERA

Still higher in the food chain are nematodes and higher worms, snails and insects. Figure 3.3 illustrates the inter-relationship between the animals important to waste water treatment and their relative abundance.

3.2 BACTERIAL GROWTH

Under batch conditions bacterial growth can be predicted using the growth curve illustrated in

Figure 3.4. At time zero, the bacteria begin to absorb substrate. As energy becomes available for reproduction, the bacterial population will increase at an exponential rate. The substrate is consumed at high rates until it becomes limiting, i.e. it is in short supply. The metabolism of the bacteria then slows down to a conventional rate and will eventually become stationary. In this mode sufficient substrate exists only to maintain life, not to promote growth. As the shortage of substrate becomes more critical, bacteria die off and other bacteria feed on the dead cells. This process is called endogenous respiration or cryptic growth and results in a decrease in the mass of bacteria. At this point, if a bacterial mass is returned to a food rich environment, the cycle will begin again.

Many bacterial processes are continuous and operate, theoretically, at a constant food loading rate at a particular point on the curve. Every effort should be made to control a process at the desired point in order to maintain the bacterial population in an unstressed condition.

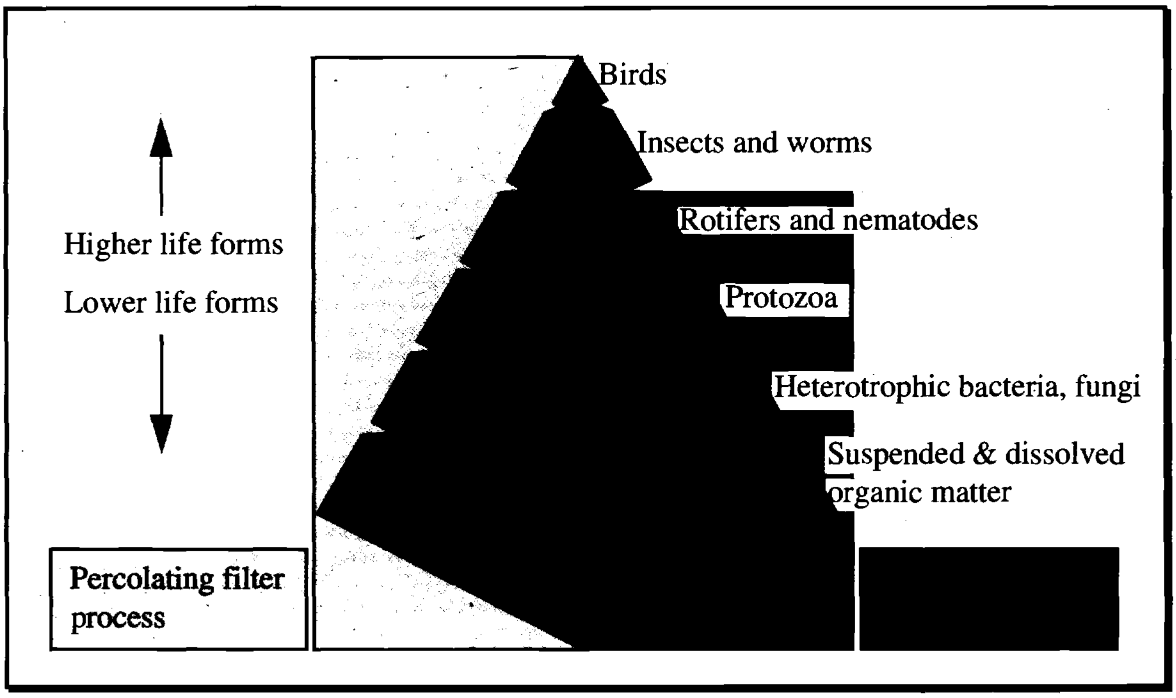


FIGURE 3.3 RELATIVE PREDOMINANCE OF ORGANISMS USED IN WASTE WATER TREATMENT (Wheatley, 1985)

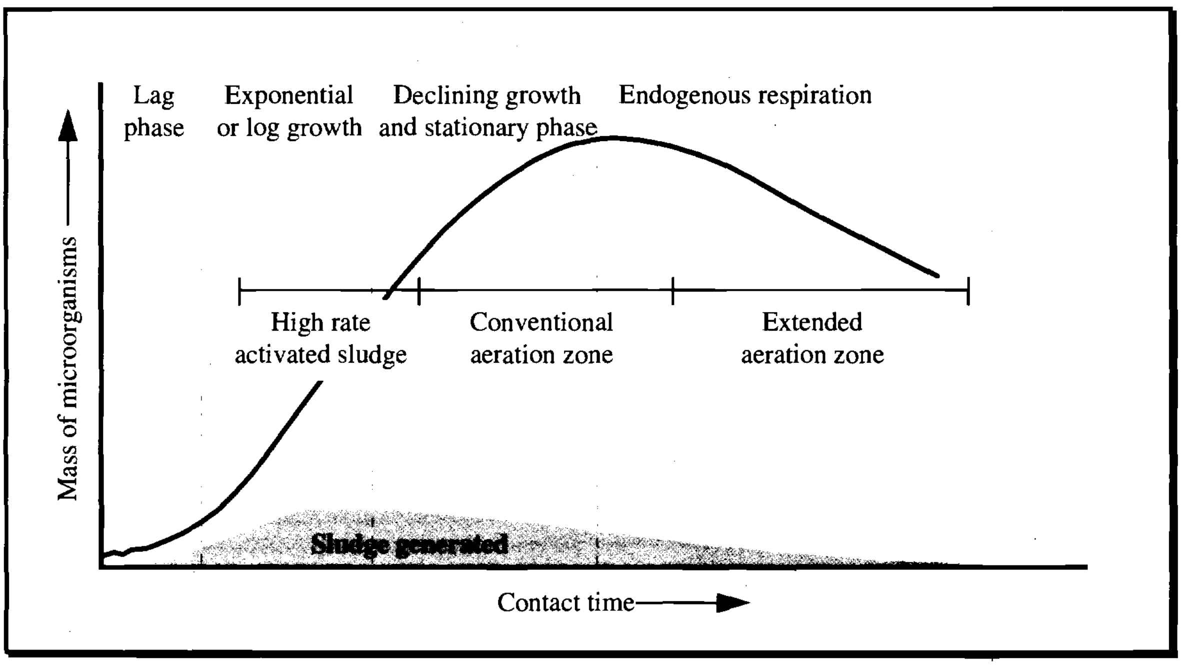


FIGURE 3.4 BACTERIAL GROWTH CURVE

3.3 INHIBITION

The performance of the waste water treatment plant is dependent upon the activity of micro-organisms and their metabolism which can be dramatically affected by the presence of toxic material in the raw waste water. The extent to which inhibition may cause a problem in waste water treatment plant depends, to a large extent, on the constituents of the waste water undergoing treatment. Many materials such as organic and inorganic solvents, heavy metals and biocides can inhibit the biological activity in the treatment plant.

Table 3.1 lists the inhibitory levels reported for some metals, inorganic and organic substances. The discharge of these materials from industrial activities should be controlled under the licensing provisions of the Local Government (Water Pollution) Acts, 1977 and 1990, and the Environmental Protection Agency Act, 1992.

There are two forms of toxicity: acute and chronic.

Acute toxicity occurs when the level of toxic material in the waste water is high enough to inactivate the biological activity. This happens rapidly. *Chronic toxicity* occurs slowly (over days or weeks) and results in process failure due to a gradual accumulation of toxic material in the biomass.

Toxic materials in the waste water can selectively inhibit single species of micro-organism. For example, inhibition of one species of bacteria in the two species chain responsible for nitrification can lead to nitrite rather than nitrate being present in the outflow. Damage to protozoa in the activated sludge process can lead to a turbid outflow which may persist for days while damage to grazing micro-organisms in a percolating filter (e.g. protozoa, rotifers) will take time to exhibit itself but may eventually result in clogging of the filter media.

The net effect of inhibition is an increase in the plant loading. A toxin with an EC_{50} (Effective Concentration which causes 50% toxicity) of 6.7% means that a 6.7% solution of the toxin in the waste water would cause 50% inhibition. A (6.7/50%=) 0.134% solution would cause 1% inhibition, thereby adding 1% to the effective BOD load to the plant.

The toxicity of industrial discharges to micro-organisms is measured by respiration inhibition (a reduction in the O_2 consumption rate) and its measurement should be considered where the treatment plant may be subject to shock loads of toxic material. The composition of waste water entering the treatment plant should be monitored on a daily basis. Industrial outflows and domestic waste waters may react with one another in the collection system and enhance or reduce the overall toxicity in an unpredictable way.

Temperature and pH can also, individually or in combination, affect the biological activity in the plant. Other materials such as oils, fats, grease and hair can affect the operation of mechanical plant. Where significant levels of such materials are present in an industrial discharge, consideration should be given to the installation of pretreatment devices (such as screens, oil separators or dissolved air flotation) or monitoring equipment (in the case of temperature and pH) in order to control their discharge to the foul sewer.

Appendix C lists some of the toxic and non-toxic parameters that are commonly associated with various industrial sectors. Where significant levels of toxicity are suspected in an industrial discharge entering the sewer, data on the respiration rate and microbial inhibition potential should be obtained.

TABLE 3.1 REPORTED INHIBITION THRESHOLD LEVELS
(Water Environment Federation, 1994)

Metals, non-metals, inorganics and organics	Reported range for activated sludge units mg/l
Cadmium	1-10
Total Chromium	1-100
Chromium III	10-50
Chromium VI	1
Copper	1
Lead	0.1-100
Nickel	1.0-2.5
Zinc	0.3-5.0
Arsenic	0.1
Mercury	0.1- 2.5 as Hg(II)
Silver	0.25-5.0
Cyanide	0.1-5
Ammonia	480
Iodine	10
Sulphide	10
Anthracene	500
Benzene	100-500
2-Chlorophenol	5
Ethylbenzene	200
Pentachlorophenol	0.95-50
Phenol	50-200
Toluene	200
Surfactants	100-500

4. PRIMARY TREATMENT OF WASTE WATER

4.1 PROCESS DESCRIPTION

Conventional activated sludge units and percolating filters are normally preceded by treatment units commonly called primary sedimentation or settlement tanks or primary clarifiers.

Settlement tanks that follow biological treatment are called secondary settlement tanks or final clarifiers and these units separate solids that have been generated through biological activity.

Primary and secondary settlement tanks operate in almost exactly the same way; the main difference is the density of the sludge they handle. Primary sludges are usually more dense (and more unstable) than secondary sludges. The supernatant from the secondary settlement tank is clearer than that from the primary settlement tank.

The manner in which solids settle out in a settlement tank is of vital importance to the operation of the waste water treatment plant. There are four types of settlement which are dependent on the type of solids present in the liquid. These are:

- **discrete settling:** this applies to sand and grit, where the particles' physical properties such as specific gravity, shape and size remain constant during settlement;
- **flocculent settling:** settling particles join together increasing their density and settling ability. This type of settlement is associated with primary settlement tanks;
- **hindered settling:** this is associated with the settlement of activated sludge, where particles form a blanket which then settles and consolidates as a mass;
- **compression settling:** compression of particles is very slow and is only made possible by the weight of new particles pressing down on the sludge layer.

Figure 4.1 illustrates the settling pattern that occurs when a uniform but concentrated suspension is placed in a graduated cylinder.

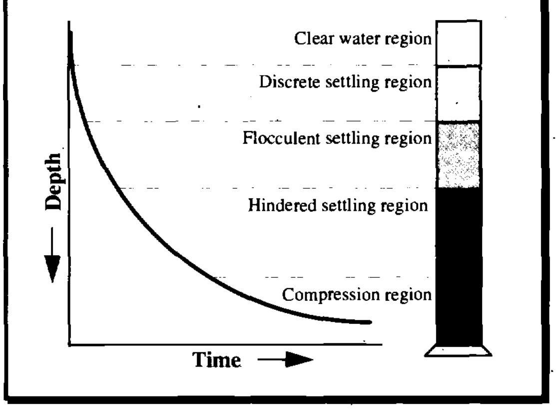


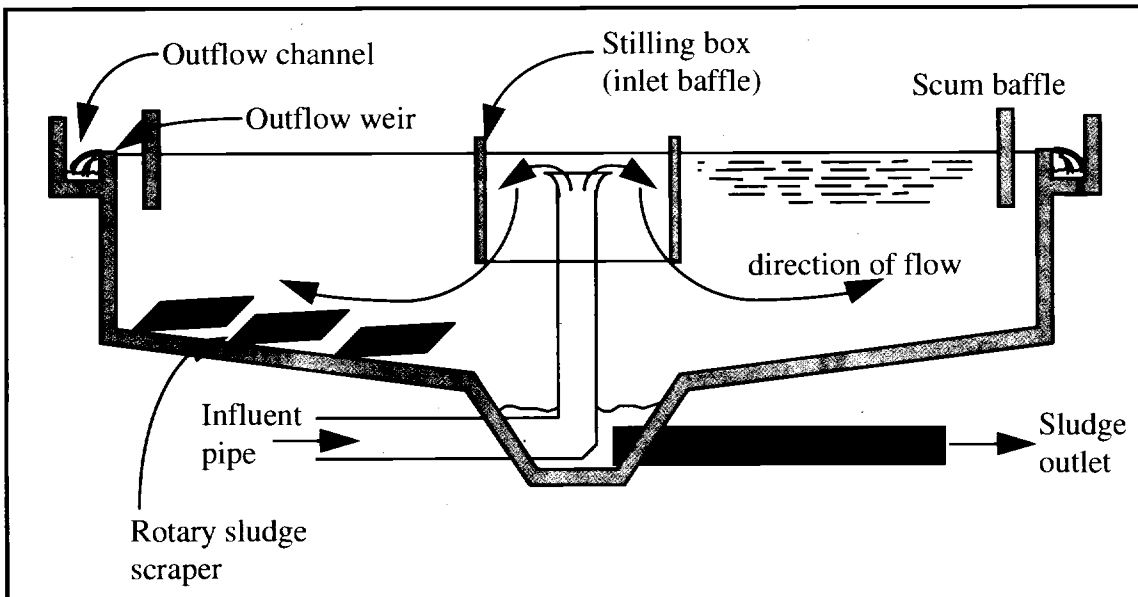
FIGURE 4.1 SETTLING THEORY

In practice, it is common for all four types of settlement to occur in a settlement tank simultaneously. The settlement of solids is concentration dependent and in situations where high suspended solids are present, both hindered and compression settling can occur in addition to discrete and flocculent settling.

4.2 PRIMARY SETTLEMENT TANKS

Primary settlement tanks are generally circular or rectangular in shape and are illustrated in Figure 4.2 and Figure 4.3 respectively. Their purpose is to reduce the velocity of the incoming waste water stream thereby allowing the settleable solids to fall to the bottom of the tank.

Typically, 50-70% of suspended solids are removed in primary settlement tanks. In addition, BOD is reduced by 20-50% and the bacterial count by 25-75%. The pH is generally unaffected by primary settlement.



Part	Purpose
Stilling box	Reduces the velocity and distributes flow radially through the tank.
Outflow weir	Ensures equal flow along the periphery of the outflow channel.
Outflow channel	Collects the outflow and carries it to the next treatment stage.
Rotary sludge scraper	Moves the sludge down the floor slope to the collection hopper.
Scum baffle	Extends above the water surface and prevents floating material from reaching the outflow channel. The collected scum is directed by a surface skimmer to a scum box from where it is typically discharged with the excess sludge.

FIGURE 4.2 CIRCULAR RADIAL FLOW SETTLEMENT TANK

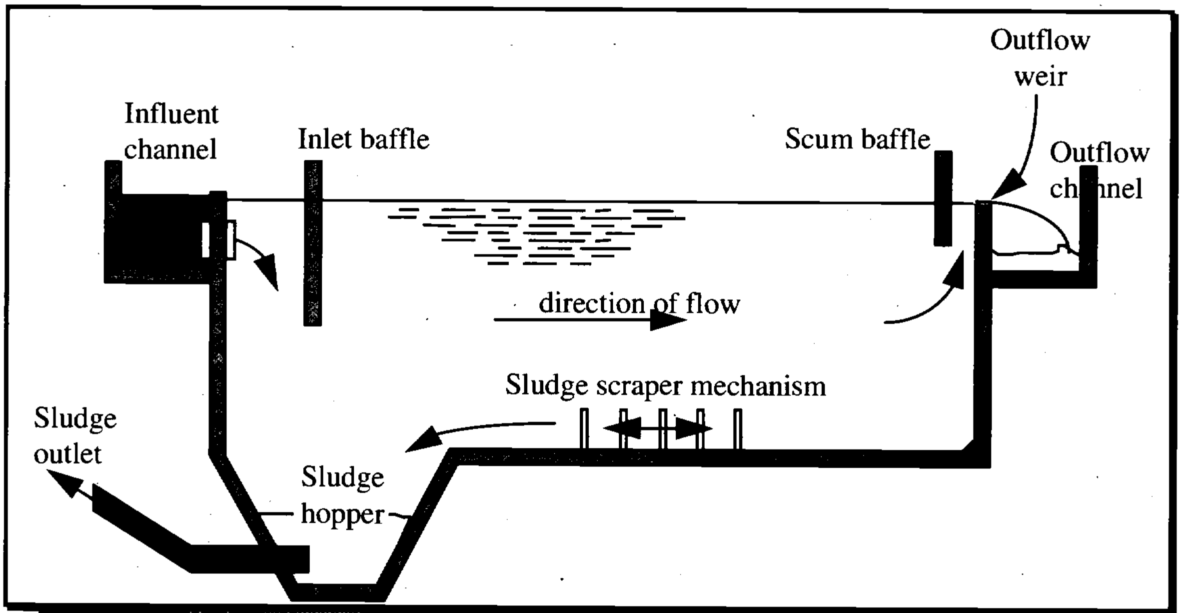
The efficiency of the primary settlement tank is dependent on a number of factors, including:

- the type of solids present in the waste water: this will typically be influenced by the type and quantity of industrial waste entering the plant;
- the length of time the waste water is in the collecting system: degradation of the waste water can generate gas bubbles (H_2S) as a result of anaerobic conditions and this can affect the settlement of solids;
- design criteria being exceeded: the most important criteria being the retention time in the tank which is usually about 2 hours at maximum flow, the overflow (surface loading) rate which is typically 28.8-36 $m^3/m^2/day$ (at peak flow) and the weir overflow rate measured in $m^3/m/day$;
- sludge withdrawal: sludge should be removed regularly to prevent septicity which can cause floating sludge; and
- return liquors from other treatment stages (e.g. sludge dewatering) which may contain suspended solids with varying settlement qualities.

Notwithstanding the above, primary sludge lends itself well to anaerobic digestion and resource recovery as well as to the production of well stabilised sludges. Resource recovery (i.e. methane gas) is economically viable because of the high level of substrate available as opposed to waste activated sludge where the substrate has already been substantially digested.

4.3 SEPTIC TANKS AND IMHOFF TANKS

The oldest type of primary treatment is the septic tank which has been often used to provide waste water treatment for single houses and small communities. The conventional system consists of a septic tank and a percolation area. Percolation areas are also known as seepage fields or beds, subsurface areas or soil absorption systems.



Part	Purpose
Inlet baffle	Distributes the inflow evenly and prevents short-circuiting along the tank surface.
Outflow weir	Ensures equal flow along the length of the outflow channel.
Outflow channel	Collects the outflow and carries it to the next treatment stage.
Sludge scraper	Moves the sludge along the floor to collection hopper.
Scum baffle	Extends above the water surface and prevents floating material from reaching the outflow channel. The collected scum is directed by a surface skimmer to a scum box from where it is typically discharged with the excess sludge.

FIGURE 4.3 RECTANGULAR HORIZONTAL FLOW SETTLEMENT TANK

The main function of a septic tank is to act as a primary settlement tank removing some of the BOD and the majority of the suspended solids from the waste water; the removal of suspended solids significantly reduces the extent of clogging in the subsurface percolation area.

The extra chamber of an Imhoff tank prevents the re-suspension of settled solids and allows for their decomposition in the same unit.

Figure 4.4 shows a typical cross section of an Imhoff tank. Waste water flows through the upper compartment and the settled solids are allowed to digest in the lower compartment. The compartments are partially separated from each other thus preventing digestion gases or digesting sludge particles in the lower section from entering/returning to the upper section. Any gas or solids rising are routed to the gas vent or scum outlet.

Chemical treatment can be used to enhance settlement in the these tanks. Chemicals such as aluminium sulphate (alum), ferric chloride, lime and polymer can be added to the incoming waste water to produce a floc, which will form an insoluble compound that adsorbs colloidal matter, attracts non-settleable suspended solids and encourages settlement.

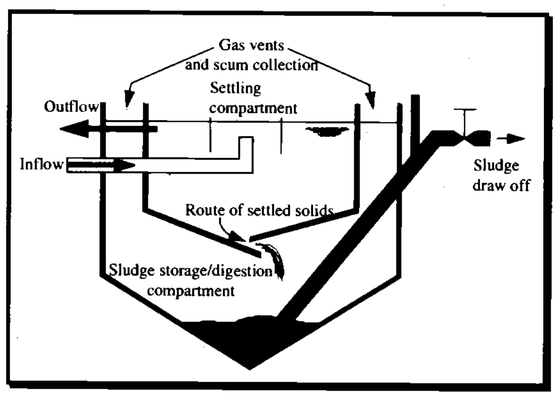


FIGURE 4.4 IMHOFF TANK

4.4 TUBE AND LAMELLA SETTLERS

Inclined surfaces in a settlement tank increase the effective surface area available for settlement and also increase efficiency by more closely approximating to ideal settlement theory. The increased surface area is provided by a series of inclined plates (lamellae) or tubes (which may be circular, square, hexagonal or other) occupying up to 70% of the tank depth and lying less than 30 cm beneath the water surface. Typical tube size or diameter is 25-50 mm. They are set at an angle greater than 40° so that settled sludge falls to the base of the tank from where it may be removed by conventional methods of desludging. Providing an increased available surface area can result in:

- the use of a smaller tank thereby saving capital costs; and
- an increased capacity in an overloaded tank by retrofitting.

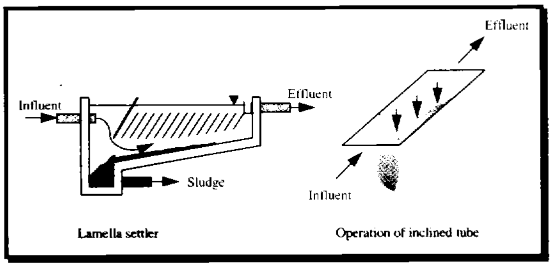


FIGURE 4.5 INCLINED SETTLEMENT SYSTEM

Some drawbacks of tube and lamella settlers include:

- a tendency to clog due to an accumulation of fats and grease. These materials should be removed upstream;
- growth of plants and biofilms on the plates or tubes; and
- the accumulation of sludge on the plate or tube surfaces which may cause septicity and the outflow quality to deteriorate.

Tube and lamella settlement tanks should be frequently drained down and the plates or tubes cleaned to remove any accumulated material. Tube and lamella settlers are commonly used with package plants on a small scale in order to economise on space and costs. Due to a lack of storage capacity they may require more frequent desludging than other systems. They may be installed in circular settlement tanks but are more frequently used in new rectangular units.

4.5 DISSOLVED AIR FLOTATION

Dissolved air flotation (DAF) involves the dissolution of air in waste water by pressurising it in a pressure vessel. When the air saturated waste water is released to the flotation tank, the sudden decrease in pressure causes the air to come out of solution as micro-bubbles which will attach themselves to solid particles in the waste water and make them float. The result is a floating mat of sludge on the surface which is skimmed off. Clarified waste water exits under a solids retention baffle. DAF tanks can be circular or rectangular in shape. As in a gravity settlement tank, the retention period must be long enough to allow for adequate separation of the solid and liquid fractions.

A variation on the process called *dispersed* air flotation does not use expensive pressure vessels and pumps to entrain air in the waste water. Instead, mechanical devices such as rapidly rotating impellers incorporating air sparges provide small bubbles which will attach themselves to solid particles. This method is cheaper to purchase and operate and is generally available on a smaller scale for use in package plants.

DAF is not commonly applied for the routine separation of solids and liquids in urban waste water but is more frequently used on difficult wastes or for the pretreatment of effluents, for example, in the removal of fats, oil and grease. Other applications have included the thickening of mixed liquor wasted directly from the activated sludge aeration basin.

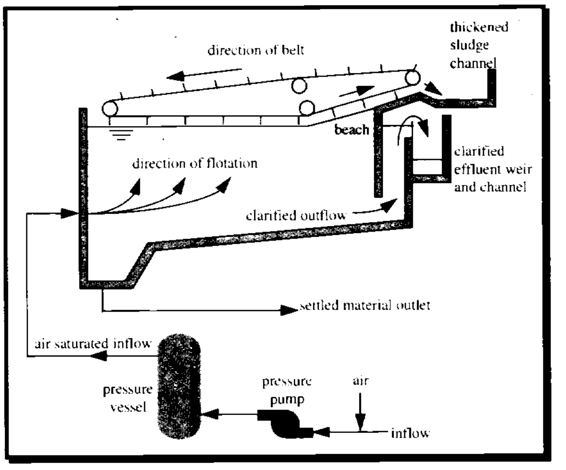


FIGURE 4.6 DISSOLVED AIR FLOTATION

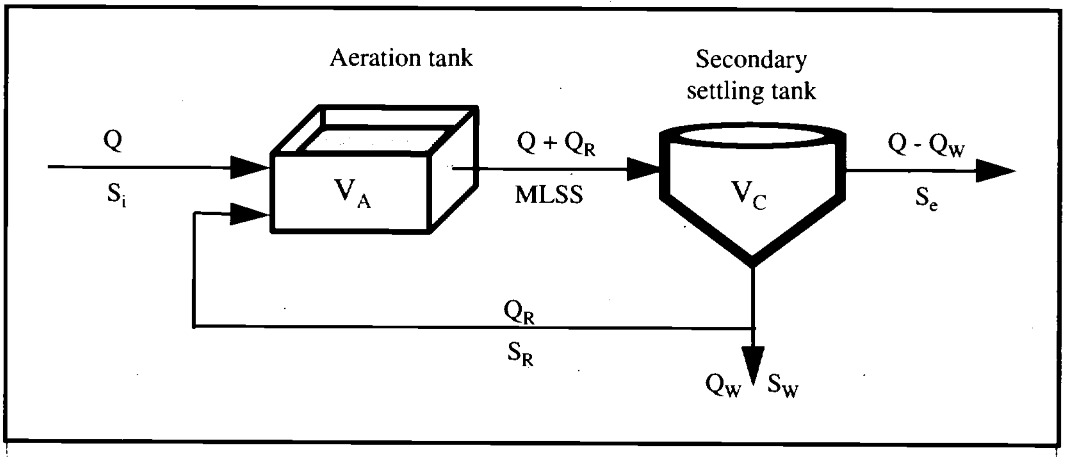
5. ACTIVATED SLUDGE (SUSPENDED GROWTH) PROCESSES

5.1 PROCESS DESCRIPTION

The activated sludge process was developed in 1914 by Arden and Lockett. It was so called because it involved the production of an activated mass of micro-organisms capable of aerobically stabilising the organic content of a waste. Though many configurations of this process now exist, the basic units (Figure 5.1) have remained the same.

Waste water is introduced into an aerated tank of micro-organisms which are collectively referred to as activated sludge or mixed liquor. Aeration is achieved by the use of submerged diffused or surface mechanical aeration or combinations thereof, which maintain the activated sludge in suspension. Following a period of contact between the waste water and the activated sludge, the outflow is separated from the sludge in a secondary settlement tank. To maintain the desired micro-biological mass in the aeration tank, sludge is returned to the aeration tank (RAS) while an excess due to biological growth is periodically or continuously wasted (WAS). The concentration at which the mixed liquor is maintained in the aeration tank affects the efficiency of treatment.

The basic unit of operation of the activated sludge process is the floc. The floc is suspended in the aeration tank and consists of millions of aerobic micro-organisms (bacteria, fungi, yeast, protozoa, and worms), particles, coagulants and impurities that have come together and formed a mass. This mass is irregular in shape and helps to collect pollutants, both organic and inorganic, in the waste water by adsorption, absorption or entrapment. To operate the process on a continuous basis, the floc must be separated in the secondary settlement tank and returned to the aeration tank.



Q = inflow, m^3/day	S_i = inflow suspended solids, mg/l
Q_R = return activated sludge, m^3/day	S_R = return activated sludge suspended solids, mg/l
Q_W = waste activated sludge, m^3/day	S_W = waste activated sludge suspended solids, mg/l
V_A = aeration tank volume, m^3	MLSS = mixed liquor suspended solids in the aeration tank, mg/l
V_C = secondary settlement tank volume, m^3	S_e = outflow suspended solids, mg/l

FIGURE 5.1 ACTIVATED SLUDGE PROCESS

Although all flocs have a specific gravity of approximately 1.0, only well developed flocs settle out in the secondary settlement tank, the remainder being carried over to the outflow (or to a tertiary treatment stage).

Hydraulic retention time is critical in the aeration tank as the waste water needs adequate contact time with the floc to be "consumed" by what ever means.

Well developed flocs consist of filamentous and non-filamentous organisms with the latter being the dominant species as these are better floc formers. A good mixed liquor will consist of light brown masses which tend to clump together and settle at a uniform rate. Microscopic examination will reveal very few flagellates and amoebae and a large number of free swimming ciliates and some stalked ciliates.

To achieve the desired outflow quality objectives, the operator is required to react to several dynamic situations. These situations have inter-related factors some of which are:

- the characteristics of the inflow - including the hydraulic and organic loading rates;
- the amount of solids in the aeration tank;
- the amount of oxygen needed to satisfy the respiratory requirements of the organisms present;
- ensuring a suitable environment exists for the micro-organisms;
- the volume of the aeration tanks and secondary settlement tanks required to accommodate seasonal variations; and
- the control and disposal of scum and supernatants.

5.2 MIXED LIQUOR SUSPENDED SOLIDS

The solids present in the aeration tank of an activated sludge process are termed mixed liquor suspended solids (MLSS) while the liquid suspension is called mixed liquor. MLSS concentrations are measured and used by operators to monitor the biomass levels present in the aeration tank. Different activated sludge processes operate at different MLSS values for different process objectives.

The MLSS concentration is usually measured by filtering a small sample of mixed liquor through fibre glass filter paper. This is a crude method of monitoring the micro-organisms present in the system. However, the test does not distinguish between the organic and inorganic fraction of the solids. The convenience of the test, however, generally outweighs this disadvantage. The organic fraction can be analysed by subsequently burning off the organic fraction of the filtered sample at 500 ± 50°C. This fraction is called the mixed liquor volatile suspended solids (MLVSS) and, like MLSS, is expressed as mg/l. For day to day monitoring of the waste water treatment plant the use of MLSS is sufficient.

5.3 OXYGEN REQUIREMENTS AND TRANSFER

Oxygen (dissolved in the mixed liquor) is required for respiration by the micro-organisms in the aeration tank. The activated sludge process depends on the activity of these aerobic micro-organisms and consequently, accurate control of oxygen in the aeration tank is vital.

Too much or too little oxygen in the aeration tank is undesirable for different reasons. Too much oxygen adds unnecessary cost due to increased power consumption and too little can decrease the metabolism of the micro-organisms and the efficiency of the process.

The oxygen added must:

- satisfy the inflow biological oxygen demand; and
- maintain a concentration of between 1 and 2 mg/l dissolved oxygen in the mixed liquor.

5.3.1 THEORY

The theoretical oxygen requirement can be calculated by assuming that the biodegradable matter is converted to carbon dioxide, water and energy.

If the simple sugar glucose is the only compound in the waste water, it is possible to estimate the exact oxygen requirement by writing down a balanced equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

To completely oxidise one glucose molecule, 6 molecules of oxygen are required. In reality however, such theoretical calculations become complex because of the diversity of the chemical compounds found in waste water.

If nitrification is required, then the oxygen demand for the conversion of ammonia to nitrate must be taken into account.

$$2NH_4^+ + 3O_2 + \text{nitrifying bacteria} \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

$$2NO_2^- + O_2 + \text{nitrifying bacteria} \rightarrow 2NO_3^-$$

5.3.2 TYPES OF EQUIPMENT

Most aeration equipment is of proprietary manufacture and is constantly being upgraded and refined. Oxygen is supplied by three basic methods as illustrated in Figure 5.2:

- mechanical agitation of the waste water promoting the entrapment of air from the atmosphere;
- submerged diffusion using air blowers; and
- combinations of mechanical and diffused systems.

5.3.2.1 Diffusers

Diffused air systems use diffusers which break up the air stream into bubbles.

Diffusers are traditionally divided into coarse and fine bubble systems; theoretically, the finer the bubble the greater is the oxygen mass transfer. These units are divided into three categories:

- porous or fine pore diffusers;
- non-porous diffusers; and
- other devices such as jet aerators, aspirating aerators and u-tubes.

The transfer of oxygen to the waste water depends on factors such as:

- the type, size and shape of the diffuser;
- the air flowrate;
- the depth of submergence; and
- the geometry of the tank.

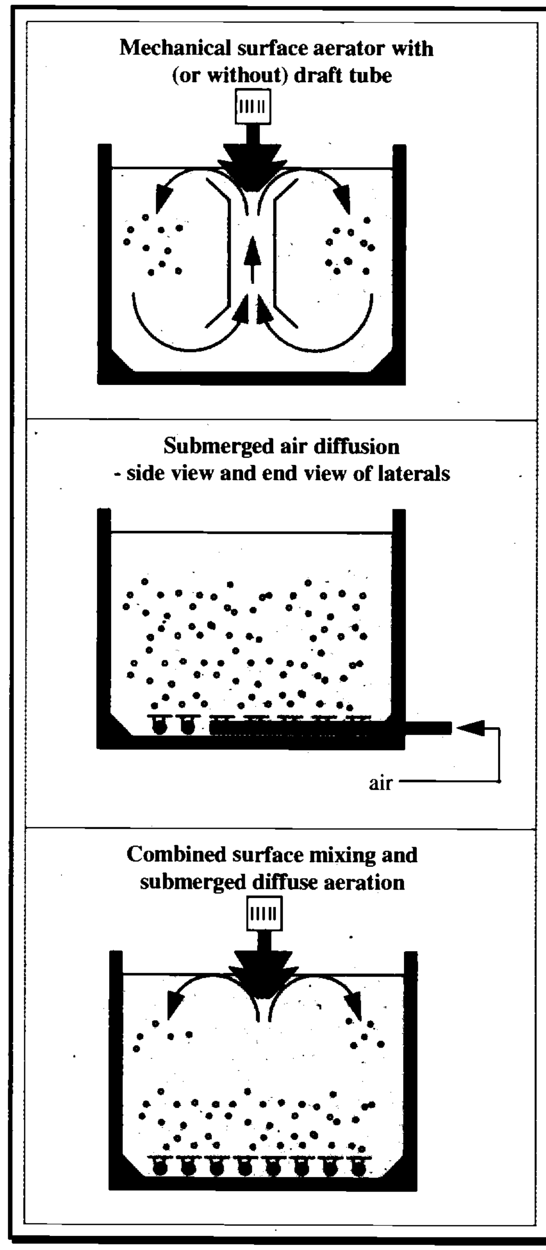


FIGURE 5.2 AERATION DEVICES

5.3.2.2 Mechanical aeration

Mechanical aerators use paddle wheels, mixers or rotating brushes to induce drafts (either upwards or downwards) or violent agitation to achieve oxygen transfer. They are broadly classified into vertically or horizontally mounted equipment and into submerged or surface aeration equipment.

Surface mechanical aeration equipment with a vertical axis consists of different impeller types, namely centrifugal, radial-axial or axial.

The amount of oxygen supplied to the waste water and the power consumed by the aerator is dependent on the depth of submergence of the aerator. This is controlled by raising or lowering the aerator or the liquid surface level.

To alter the liquid surface level, the outlet weir may be adjusted either manually or automatically (in response to a signal from a dissolved oxygen probe). Power consumption typically increases with the depth of immersion of the aerator. However, as Figure 5.3 shows, a point will be reached where the oxygen transfer will not always increase in tandem with an increase in power. In the example, after two thirds immersion no appreciable increase in oxygen transfer occurred but the power consumption increased by a further 30%. Aeration equipment is a significant energy user, therefore the aerator should be checked to ensure that the depth of immersion does not exceed the required oxygen transfer capacity.

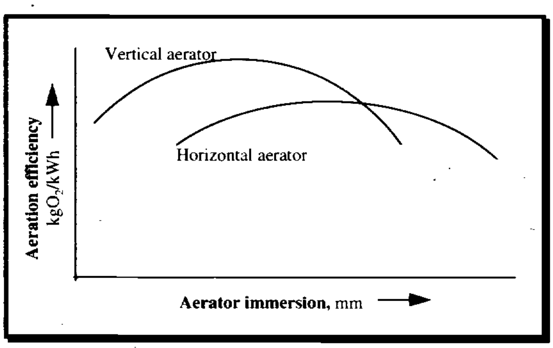


FIGURE 5.3 COMPARISON OF AERATION EFFICIENCY AND DEPTH OF IMMERSION OF AERATORS

(Rachwal & Waller, 1982)

Many treatment plants nowadays have two speed mechanical aerators or variable speed motor control. At such plants, operation at low speed should be exercised whenever possible in order to save energy costs.

5.3.3 TRANSFER EFFICIENCY

Aeration equipment is compared by the amount of oxygen transferred per unit of air introduced to the waste water under standard operating conditions (temperature, chemical matrix and depth of immersion), expressed as kgO_2/kWh.

The oxygen transfer rate of selected aeration systems is presented in Table 5.1.

To determine the oxygen transfer efficiency of an aerator in clean water the following procedure is used. Residual dissolved oxygen is removed from the liquid by adding sodium sulphite and a catalyst (cobalt chloride). Aeration is started and the rate of oxygenation of the liquid is measured by recording the DO at regular intervals. The oxygen transfer coefficient (K_{La}) may then be determined.

TABLE 5.1 TYPICAL PERFORMANCE DATA FOR SELECTED AERATION DEVICES

Aeration Device	Oxygen Transfer Rate, kgO_2/kWh
Fine bubble diffusers	2.0 - 2.5
Coarse bubble diffusers	0.8 - 1.2
Vertical shaft aerators	up to 2.0
Horizontal shaft aerators	up to 2.0

The oxygen transfer coefficient is affected by the following factors:

- temperature;
- mixing intensity;
- tank geometry; and
- characteristics of the water.

The solubility of oxygen in water is temperature dependent, so:

EQUATION 5.1

$$K_{La(T)} = K_{La(20^\circ C)}\theta^{T-20}$$

where θ is a temperature correction factor typically taken as 1.024 for aeration devices and T is the temperature at which the test is carried out.

Mass transfer coefficients are usually measured in clean water which does not have the same surface tension as waste water. Two coefficients are used to compensate for the difference between measured and actual values. These are the α and β-values.

The α-value is used to compensate between the measured and actual values of K_{La} with regard to surface tension, tank geometry and mixing intensity.

EQUATION 5.2

$$\alpha = \frac{K_{La}\,(\text{waste water})}{K_{La}\,(\text{tapwater})}$$

Typical α-values for diffused and surface aerators are in the range of 0.4-0.8 and 0.6-1.2 respectively. These values are related to the design of the tank used during the test procedure. This can lead to discrepancies when applied to other tank shapes.

β-values are used to account for the differences in the solubility of oxygen due to constituents in the waste water. The presence of salts, particulates and detergents may affect the oxygen transfer rate. The factor is computed as:

EQUATION 5.3

$$\beta = \frac{C_{s20}(\text{waste water})}{C_{s20}(\text{tap water})}$$

where C_{s20} is the saturation concentration of oxygen at 20°C. Values may vary from 0.7 to 0.98 with a value of 0.95 being commonly used.

To predict the oxygen transfer rates for mechanical surface aerators based on field measurements the following relationship is used:

EQUATION 5.4

$$OTR_f = SOTR\left(\frac{\beta C_s - C_w}{C_{s20}}\right)\theta^{T-20}.\alpha$$

where:

OTR_f	=	actual oxygen transfer rate under field operating conditions in a respiring system, kgO_2/kWh
SOTR	=	standard oxygen transfer rate under test conditions at 20°C and zero dissolved oxygen, kgO_2/kWh
C_s	=	oxygen saturation concentration for tap water at field operating conditions, mg/l
C_w	=	operating oxygen concentration in waste water, mg/l
C_{s20}	=	oxygen saturation concentration for tap water at 20°C, mg/l
θ	=	temperature correction factor, typically 1.024

For diffused aeration systems the C_s value is corrected to account for oxygen saturation concentrations higher than those measured at atmospheric pressure.

5.3.4 PRACTICAL APPLICATION

Operating rules of thumb are:

- that the aeration equipment is capable of supplying twice the average oxygen demand; and
- that dissolved oxygen concentrations of 1 to 2 mg/l and 0.5 mg/l are maintained at average and peak loads respectively.

A typical design equation to determine the total oxygen demand in an activated sludge system is as follows:

EQUATION 5.5

OD =	**0.75 Q (BOD_i - BOD_e)**
total demand	carbonaceous oxygen demand
	+ 2 V_A. MLSS
	endogenous oxygen demand
	+ 4.3 Q (Amm_i - Amm_e)
	nitrification oxygen demand
	- 2.83 Q [(Amm_i - Amm_e) - N_e]
	oxygen derived from denitrifiation in an anoxic zone

where: OD = mass of oxygen required (g/h)

BOD_i = inflow BOD (mg/l)

BOD_e = outflow BOD (mg/l)

Amm_i = inflow ammoniacal nitrogen (mg/l)

Amm_e = outflow ammoniacal nitrogen (mg/l)

N_e = outflow nitrate nitrogen (mg/l)

In a non-nitrifying plant, the anoxic zone term is not included. The value of N_e depends on the recycle ratio of nitrified effluent. When treating crude unsettled sewage, the first term (0.75) becomes 1.0. The difference accounts for BOD removed in primary settlement.

The aeration device must be capable of maintaining the activated sludge in suspension in the aeration tank. The power required for complete mixing varies from 10 to 30 W/m^3 depending on the tank volume and on the hydraulic pumping efficiency of the aeration equipment. In calculating the aeration or mixing power requirements of a system, the motor and shaft efficiencies and other losses must be taken into account.

5.4 CLARIFICATION OF MIXED LIQUOR

The purpose of a secondary settlement tank is to:

- remove suspended solids; and
- return settled sludge to the aeration tank.

Success in meeting the outflow quality objectives of the treatment system depends on the settleability of the mixed liquor. While settlement of solids is prevented from occurring in the aeration tank by the action of the aeration equipment, the secondary settlement tank is designed to promote settlement.

Design overflow rates are lower in a secondary settlement tank than in a primary settlement tank. Overflow rates are typically 21-28.8 $m^3/m^2/day$. Adequate retention time must be allowed in the settlement tank to allow good separation of the mixed liquor. Other design parameters to be considered include tank depth, weir placement and shape, MLSS, sludge settleability and drawoff rate and solids flux. Solids (or sludge) mass flux, expressed as kg/m^2h, bases the design of the settlement tank on the solids loading rate, the settleability of the sludge (SSVI) and the return sludge flowrate.

Figure 5.4 shows how the settling velocity is related to varying concentrations of mixed liquor. The diagrams show how the settling velocity varies with MLSS concentration and that the maximum settling velocity decreases as the MLSS concentration increases.

5.5 SLUDGE SETTLEABILITY

The sludge volume index (SVI) is used to assess the settling qualities of sludges. The SVI is measured by filling an Imhoff cone (or 1 litre graduated cylinder) with mixed liquor from the aeration tank and allowing the mixture to settle for 30 minutes. The volume of settled sludge (in 1 litre) is read after this period and the SVI is computed using the following formula:

EQUATION 5.6

$$SVI = \frac{\text{Volume of settled sludge (ml/l)} \times 1000}{\text{MLSS (mg/l)}}$$

where SVI (ml/g) is the volume in millilitres occupied by 1g of settled sludge and MLSS is expressed in mg/l. A sludge which settles well has a value of 80 ml/g or less. Values as low as 50 ml/g indicate a very good settling sludge and values greater than 120 ml/g indicate poor settling characteristics.

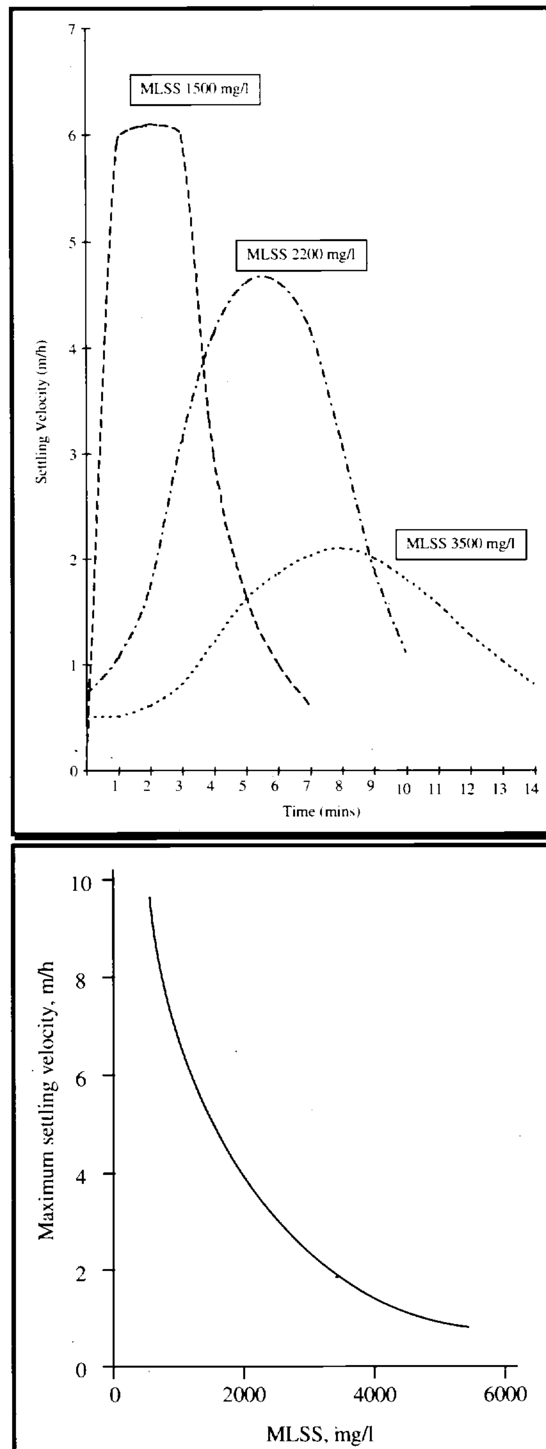


FIGURE 5.4 SETTLING VELOCITY V. TIME AND INITIAL MLSS CONCENTRATION FOR GOOD SETTLING MIXED LIQUORS

(IWPC, Activated Sludge, 1987)

For routine monitoring of sludge settleability, the SVI test is adequate; however, there are disadvantages to the test. The SVI test is carried out under quiescent conditions and therefore does not mirror the hydraulic conditions in the settlement tank where there is always some degree of turbulence and flocculation of the sludge solids. At MLSS concentrations in excess of 2500 mg/l, wall effects may occur in the measuring cylinder, resulting in interference in the rate of settlement. Other problems with the test include denitrification of the sludge and flotation of the sludge solids. To overcome these problems the stirred specific volume index (SSVI), traditionally used in design studies, should be used. Settlement is measured in a special settling column where wall effects are reduced by a stirrer rotating at one revolution per minute. The mixed liquor is maintained at a constant temperature. The test gives a better simulation of the settling pattern in the settlement tank due to reduced wall effects at high MLSS.

Depending on the density of a settled sludge (which is indicated by the SVI or SSVI), the volume of return activated sludge will need to be altered in order to maintain the desired mass of sludge solids in the aeration tank.

The visibility depth is a useful guide in assessing the performance of a secondary settlement tank. It measures the turbidity of the liquid by dipping a graduated disc to a depth at which it is no longer visible.

Many process problems are caused by secondary settlement tanks not performing efficiently. Instrumentation has been developed to monitor their performance. These instruments measure:

- the level of the sludge blanket;
- the concentration of suspended solids;
- the return activated sludge flowrate;
- the turbidity of the supernatant; and
- the concentration of dissolved oxygen.

5.6 RETURN ACTIVATED SLUDGE (RAS)

The purpose of RAS is to maintain an adequate number of micro-organisms in the aeration tank to deal with the load (food) entering the plant. The sludge returned contains micro-organisms that have the ability to feed on organic matter in the waste water.

If settled sludge is not returned quickly to the aeration tank or if it becomes septic, the treatment efficiency will be affected. The ability to respond to changes in inflow loading rates by adjusting RAS flowrates is vital to good plant performance. Typically, RAS flow rates are 50 to 100% of the waste water flow rate (DWF) for large plants and up to 150% of DWF for smaller plants. All RAS flowrates should be adjustable either manually or by using inverter drives on variable speed pumps. Having up to 150% of DWF in RAS pumping capacity will improve the flexibility of a plant in responding to varying operating conditions.

Many techniques are employed to determine the return sludge rate. The control strategies are based on either maintaining a target MLSS concentration in the aeration tank or a target sludge blanket level in the secondary settlement tank. The more common control techniques are:

- observation of the sludge blanket height;
- the sludge settleability test;
- maintaining a solids balance across the aeration tank; and
- maintaining a solids balance across the secondary settlement tank.

If the sludge blanket level is used as a control, the operator will be required to adjust the RAS rate to maintain a target level in the secondary settlement tank. To successfully use this control the operator will have to be aware of the variations in diurnal flow, sludge production variations and changes in the settling characteristics of the sludge.

Using the sludge settleability test, the return flow rate is based on the sludge volume index (SVI). The RAS flow rate (Q_R), in m^3/day, may be calculated from the following equation:

EQUATION 5.7

$$Q_R = \frac{\text{Settled sludge volume (ml / l) x Q (m}^3\text{ / day)}}{\text{1000ml / l} - \text{Settled sludge volume (ml / l)}}$$

A solids balance across the aeration tank may be used to determine the sludge return rate:

EQUATION 5.8

Solids entering the aeration tank = *Solids leaving the aeration tank* or, referring to Figure 5.1[1]:

$$Q \,.\, S_i + Q_R \,.\, S_R = MLSS\,(Q + Q_R)$$

Assuming that the inflow suspended solids term, S_i, is small in relation to S_R and can therefore be neglected, this equation can be rearranged to determine the RAS flow rate (Q_R) in m^3/day:

EQUATION 5.9

$$Q_R = \frac{MLSS\,.\,Q}{S_R - MLSS}$$

A solids balance across the secondary settlement tank may also be used to determine the sludge return rate. In other words:

EQUATION 5.10

Solids entering the secondary settlement tank = *Solids leaving the secondary settlement tank*

or, referring to Figure 5.1:

$$MLSS\,(Q + Q_R) = Q_R\,.S_R + Q_W\,.S_W + (Q - Q_W)\,S_e$$

Assuming that the effluent suspended solids term, S_e, is small in relation to S_R and S_W and can therefore be neglected, this equation can be rearranged to determine the RAS flow rate (Q_R) in m^3/day:

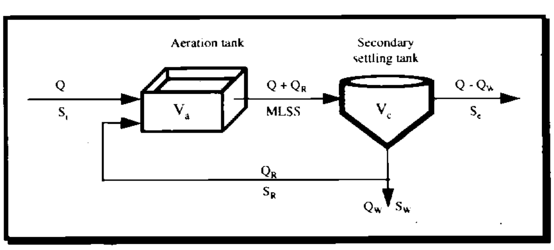
EQUATION 5.11

$$Q_R = \frac{MLSS\,.\,Q - Q_W.S_W}{S_R - MLSS}$$

5.7 WASTE ACTIVATED SLUDGE (WAS)

Excess activated sludge generated as a result of biological activity has to be removed from the system to maintain the desired MLSS in the aeration tank. Concentrated sludge is generally removed from the secondary settlement tank or from the return sludge line. Mixed liquor can also be extracted directly from the aeration tank. Typically, RAS and WAS pumps are located in the same chamber.

1



5.8 PROCESS CONTROL IN THE ACTIVATED SLUDGE SYSTEM

The activated sludge system is controlled by the removal of WAS. This is necessary to maintain the critical balance between the inflow (food supply), the biological population and the oxygen input. Since the operator has no direct control over what is received at the plant, the most critical parameter here is the maintenance of the microbiological population. Control over the microbiological population is achieved by:

- maintaining a constant Food to Micro-organisms ratio (F/M); or
- maintaining a constant sludge age.

5.9 SOLIDS LOADING RATE (F/M RATIO)

The solids loading rate or the food to micro-organism ratio is defined as the ratio between the mass of food entering the treatment plant and the mass of micro-organisms in the aeration tank.

EQUATION 5.12

$$F/M = \frac{kgBOD/day}{kgMLSS}$$

where:

$$kgBOD/day = \frac{BOD\,(mg/l) \times Q}{1000}$$

and

$$kgMLSS = \frac{MLSS\,.\,V_A}{1000}$$

The F/M ratio is an important control parameter as the quantity of biomass present will influence the removal efficiency. The F/M ratio relates to the biological state of the plant and is independent of the size of the aeration tank. Hence, two different activated sludge processes can have the same process efficiency by operating at the same F/M ratio. If the operator is aware of the load entering the plant he can ensure that sufficient biomass (micro-organisms) is present in the aeration tank to react with the load.

Where the optimum F/M ratio has been determined, the optimum or desired mass of MLSS may be calculated by re-arranging Equation 5.12:

EQUATION 5.13

$$kgMLSS = \frac{kgBOD/day}{F/M}$$

If the actual mass of MLSS is less than the desired mass of MLSS then the concentration of MLSS must be allowed to increase by reducing the amount of sludge wasted from the system. If the actual mass of MLSS is greater than the desired mass of MLSS then a proportion of the mixed liquor must be wasted from the system. The wastage rate may be calculated from the following mass balance:

EQUATION 5.14

$$\text{Actual kgMLSS} - \text{Desired kgMLSS} = \text{mass of sludge solids to be wasted, kg}$$

The WAS flow rate (Q_W) is then computed using the following relationship:

EQUATION 5.15

$$Q_W = \frac{\text{mass of sludge solids wasted x 1000}}{S_W}$$

where mass of sludge solids wasted is in kg/day, S_W is in mg/l and Q_W is in m^3/day.

5.10 SLUDGE AGE

Sludge age is defined as the total mass of sludge contained in the aeration tank divided by the total mass of sludge wasted daily, including suspended solids discharged with the outflow. Sludge age and mean cell residence time are taken to mean the same and relate to the length of time the bacterial cell/floc remains in the activated sludge system. It is calculated from the quantity of active solids in the system divided by the daily loss of active solids from the system:

EQUATION 5.16

$$\text{Sludge age} = \left(\frac{\text{MLSS}\left(V_A + V_C\right)}{Q_W . S_W + (Q - Q_W) S_e} \right)$$

The concentration of suspended solids in the outflow is normally small compared to the concentration in the WAS and so the term $(Q-Q_W)S_e$ can be ignored, i.e.

EQUATION 5.17

$$\text{Sludge age} = \left(\frac{\text{MLSS}\left(V_A + V_C\right)}{Q_W . S_W} \right)$$

The sludge age is influenced by the volume of aeration, the volume of final settlement, the sludge wasting rate and the mass of suspended solids in the system.

Where the optimum or desired sludge age has been determined, the amount of sludge which needs to be wasted on a daily basis in order to maintain this can be quantified using the formula:

EQUATION 5.18

$$Q_W = \frac{\text{MLSS}(V_A + V_C)}{\text{Sludge age x } S_W}$$

Sludge age measures the length of time (in days) that the sludge solids are held within the system. Sufficient time must be allowed for the micro-organisms in the system to react with the waste water, otherwise the quality of the outflow will be affected. Conversely, if too much time is allowed the micro-organisms tend to die off and the outflow will contain "fine" solids because large portions of the floc will be inactive.

5.11 COMPARISON BETWEEN F/M RATIO AND SLUDGE AGE

Waste water treatment plants can be operated using either the F/M ratio or the sludge age. Both methods rely on regulating the rate of growth and metabolism of the microbial population. Maintaining a constant F/M ratio requires fewer analytical results at the treatment plant in comparison to use of the sludge age technique. However, both methods are interrelated and changing one control affects the other control. Table 5.2 sets out a comparison of F/M ratio and sludge age.

5.12 ADVANTAGES OF HIGH AND LOW F/M RATIOS

Table 5.6 outlines the operating parameters associated with various modes of operating an activated sludge plant and should be referred to in determining what is a high or low F/M ratio.

A plant operating at the high end of the F/M ratio spectrum is characterised by a low concentration of MLSS and a low sludge age. The advantages and possible problems of operating in this mode are outlined in Table 5.3.

A plant operating at the low end of the F/M ratio spectrum is characterised by a high concentration of MLSS and a high sludge age. The advantages and possible problems of operating in this mode are outlined in Table 5.4.

Between these two extremes a satisfactory operating F/M and sludge age should be chosen. The plant operating manual should be consulted to determine the initial operating conditions but this may need to be adjusted in time to cater for changes in the process or the inflow to the plant. The operating F/M of a plant is influenced by:

- the desired mode of operation;
- the characteristics of the inflow;
- the BOD load (including variability); and
- temperature (ambient and waste water) and seasonal changes.

TABLE 5.2 COMPARISON BETWEEN F/M RATIO AND SLUDGE AGE

Parameter	F/M ratio	Sludge age
Sludge production	Operation at low F/M produces less sludge than a high F/M.	Operation at a high sludge age produces less sludge than a low sludge age.
Connection	A low F/M equates to a high sludge age.	A low sludge age equates to a high F/M.
Control	**Constant load**: select the desired MLSS and maintain it by wasting the correct amount of solids. **Variable load**: maintain a constant ratio by adjusting MLSS as inflow changes.	Waste a percentage of total solids regularly. *e.g. to control sludge age to 5 days, 20% of the solids will have to be removed daily.*
Measurements required	kg of MLSS, inflow BOD_5 concentration and daily flowrate.	kg of MLSS and kg of sludge wasted.
Sludge return	The return ratio is dependent on the MLSS and the RAS concentrations.	The return ratio is the same as in the F/M Ratio.

TABLE 5.3 OPERATING AT A HIGH F/M RATIO (LOW SLUDGE AGE)

Advantages	Possible problems
Reduced power consumption because less oxygen is required by the system. With constant loading to the plant a good quality outflow is produced.	There are fewer micro-organisms in the system so the ability to deal with shock loads of BOD, pH or toxicity is reduced. Deterioration in the quality of the final outflow. Poor sludge quality.

TABLE 5.4 OPERATING AT A LOW F/M RATIO (HIGH SLUDGE AGE)

Advantages	Possible problems
The high MLSS will help to buffer changes in BOD, pH, waste water composition or temperature. Reduced foaming problems. Operates well when BOD is variable or high.	Inadequate food for the population of micro-organisms. Enhanced growth of filamentous organisms. Design solids flux for the secondary settlement tank may be exceeded resulting in suspended solids in the outflow. Maintaining the required dissolved oxygen concentration can be difficult.

TABLE 5.5 OPERATIONAL RELATIONSHIPS BETWEEN RAS AND WAS

		RAS conc.	Waste Solids	MLSS	Changes in F/M ratio	Sludge age	Settling rate
Alter RAS, constant WAS	Increase RAS	↓	↓	↑	↓	↑	↑
	Decrease RAS	↑	↑	↓	↑	↓	↓
Alter WAS, constant RAS	Increase WAS	↓		↓		↓	↓
	Decrease WAS	↑		↑	↓	↑	↑
Change	Increase RAS/Decrease WAS	↑		↑	↓	↑	
	Decrease RAS/ Increase WAS	↓		↓	↑	↓	

Key: ↑ Increase ↓ Decrease

As a general rule of thumb, a higher MLSS should be maintained in the aeration tank during the winter than during the summer. This is because of decreased biological activity due to lower temperatures.

Operation at a desired F/M ratio or sludge age is dependent on the control of mixed liquor solids in the system. By adjusting the solids concentration, the desired F/M or sludge age can be achieved. The solids concentration can be modified by more than one method. However, the operator should be aware that by changing the solids concentration other aspects of the process may be affected.

Table 5.5 outlines changes in the operational procedures which will affect the process operation. The operator has various options open to the modify the sludge age and the MLSS.

To increase the sludge age and the F/M ratio the operator can:

- increase RAS flow rate and leave WAS constant; or
- decrease WAS flow rate and leave RAS constant; or
- increase RAS and decrease WAS.

To decrease the MLSS concentration, the operator can:

- decrease RAS flow rate and hold WAS constant; or
- increase WAS and hold RAS constant; or
- decrease RAS and increase WAS.

5.13 PROCESS VARIATIONS IN ACTIVATED SLUDGE

The activated sludge process is classified into three broad categories: low rate, conventional and high rate. The divisions are based on the organic and hydraulic loading rates and retention times. Subdivisions within these categories are based mainly on flow and method of aeration.

Table 5.6 gives a summary of the operating parameters for each of the processes described.

5.13.1 CONVENTIONAL AERATION

Conventional aeration is preceded by a primary settlement stage and operates at loading rates greater than 0.2 kgBOD/kgMLSS.day. A high quality outflow is produced and nitrification is possible. Greater nitrification is achieved at lower loading rates and longer sludge ages.

Sludge production is 0.5-1.0 kg dry solids/kg BOD removed and the RAS has a concentration of 8,000-12,000 mg/l MLSS. This is equivalent to 0.8-1.2% dry solids and requires thickening or dewatering prior to recovery or disposal. Conventional aeration sludge digests reasonably well as there will be some unoxidised organic matter remaining. It digests best however when mixed with primary sludge.

TABLE 5.6 LOADING AND OPERATIONAL PARAMETERS FOR ACTIVATED SLUDGE PROCESSES

Process	F/M kgBOD/d / kgMLSS	BOD loading *kgBOD/ m^3.d*	Hydraulic retention time *hours*	Sludge age *days*	MLSS *mg/l*	BOD removal efficiency *%*	Sludge production *kgDS/kgBOD removed*
Conventional aeration	0.2 - 0.5	0.5 - 1.5	5 - 14	3 - 10	2000-3000	90 - 95	0.5 - 1.0
Extended aeration	0.05 - 0.15	0.25 - 0.3	20 - 30	20 - 30	2000-6000	90 - 95	0.5 - 0.6
High rate activated sludge	1.0 - 2.5	1.6 - 16	2.5 - 3.5	0.5 - 10	5000-8000	60 - 70	0.8 - 1.2
Pure O_2	0.25 - 1.0	1.6 - 4.0	1.0 - 10	3 - 10	3000-8000	90 - 95	
Deep shaft	0.5 - 5.0	3.7 - 6.6	0.5 - 5.0	4 - 5	2000-6000		0.5 - 0.85

5.13.2 EXTENDED AERATION

Extended aeration is a low rate activated sludge process operating at low organic loading rates and F/M ratios with long hydraulic retention times and sludge ages. As a result, there is little food in the system to support the micro-organisms present. Competition is active and high quality outflows are produced. It is usually used without primary settlement and nitrification is normally achieved. Extended aeration plants are often used as package plants for small communities.

Because extended aeration is operated to the right of the bacterial growth curve (Figure 5.5), much of the sludge produced by cell multiplication is consumed by endogenous respiration (the consumption of dead cellular material by other micro-organisms). As a consequence, the quantity of sludge produced can be as low as 0.5-0.6 kg dry solids/kg BOD removed. The sludge is well stabilised because of the low concentrations of organic matter remaining. However, the sludge may be putrescible and must be kept aerobic if stored.

5.13.3 HIGH RATE ACTIVATED SLUDGE

High rate activated sludge processes are generally applied to strong industrial wastes (e.g. dairy or brewery) which require partial treatment in a roughing stage prior to another biological process, for example extended aeration or biofiltration. It is operated at a high loading rate and short retention time for the purpose of removing the more easily oxidised organic matter, typically 60-70% of applied BOD. Downstream unit processes are operated at low to conventional rates to achieve satisfactory emission limit values.

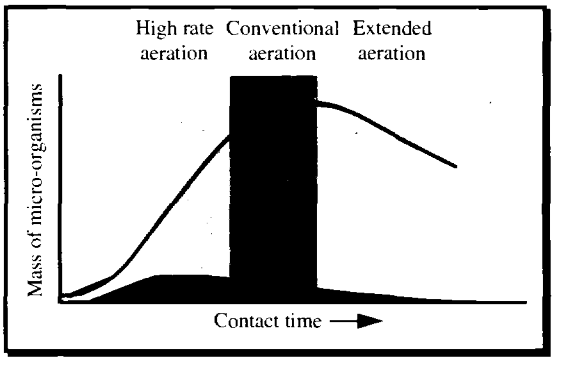


FIGURE 5.5 ACTIVATED SLUDGE GROWTH CURVE

A practical application of high rate activated sludge is the A-B (Absorption-BioOxidation) process developed in Germany. This is a two stage activated sludge process with the first highly loaded A-stage buffering the second more conventionally loaded B-stage. The loading rates are in the ranges of 3-6 kgBOD/kgMLSS.d and 0.15-0.30 kgBOD/kgMLSS.d respectively (Gray, 1990). There is no primary treatment of inflow so the load to the A-stage can be highly variable. High floc loading (F/M) to the A-stage contributes to good sludge settling and dewatering characteristics. The lower loading rates to the B-stage result in good BOD removal and nitrification at sludge ages of up to 25 days. Overall, the organic loading rate to an A-B system may be 50% greater than that to a comparably sized single stage activated sludge plant. Absorption (A) stages can be retro-fitted to existing plants; in new plants, the omission of primary settlement tanks can save capital costs.

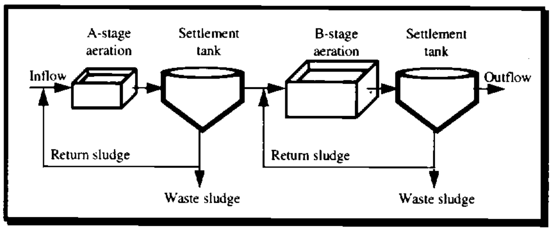


FIGURE 5.6 A-B ACTIVATED SLUDGE PROCESS

5.14 PROCESS CONFIGURATIONS IN ACTIVATED SLUDGE

The design of aeration basins encompasses a broad range of tank and operating configurations which can be broadly divided into the following categories;

- completely mixed;
- plug flow;
- tapered aeration;
- step feeding;
- sludge re-aeration;
- oxidation ditch;
- sequencing batch reactors; and
- high intensity.

5.14.1 COMPLETELY MIXED

Completely mixed activated sludge systems are the simplest; the concentration of available substrate and MLSS are the same throughout the tank. In this mode, the inflow is rapidly mixed throughout the whole tank so that DO, MLSS and soluble BOD are uniform throughout. Uniform distribution ensures that the outflow mixed liquor is identical to the mixed liquor in the aeration tank. An advantage of a completely mixed tank is that shock loads are rapidly dispersed and diluted. Completely mixed tanks are generally square or rectangular in shape with a length to width ratio less than 5:1.

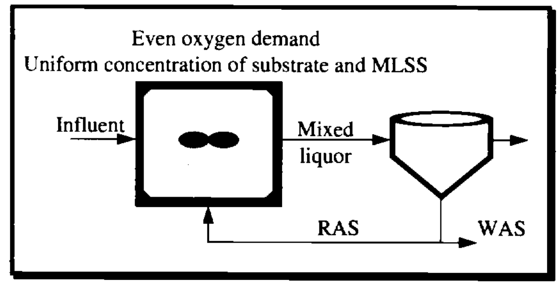


FIGURE 5.7 COMPLETELY MIXED ACTIVATED SLUDGE SYSTEM

5.14.2 PLUG FLOW

In plug flow systems (Figure 5.8) the tank shape is long and narrow with a length to width ratio of at least 12:1 (or the equivalent of at least 8 completely mixed tanks in series). Both the feed and return activated sludge are added at the beginning of the tank. The main characteristic of a plug flow configuration is a high ratio of organic loading (i.e. F/M) to the mixed liquor at the beginning of the tank. There is little longitudinal mixing in a plug flow tank except for that which is caused by diffused aeration; therefore, as the liquor flows through its length, substrate is used up and the mass of micro-organisms increases due to cell reproduction. If the F/M is sufficiently low in the latter stages of the tank, much of the oxygen is consumed by nitrification and endogenous respiration. The lack of longitudinal mixing reduces the ability to handle shock loads; there is little dilution of the inflow so micro-organisms may be affected by toxic material. Plug flow has the advantage of discouraging the excessive growth of filamentous organisms which can cause settlement problems in the secondary settlement tank.

Plug flow activated sludge plants allow for easy modification to provide contact, anoxic and anaerobic tanks for control of filamentous bulking, denitrification and biological phosphorus removal respectively.

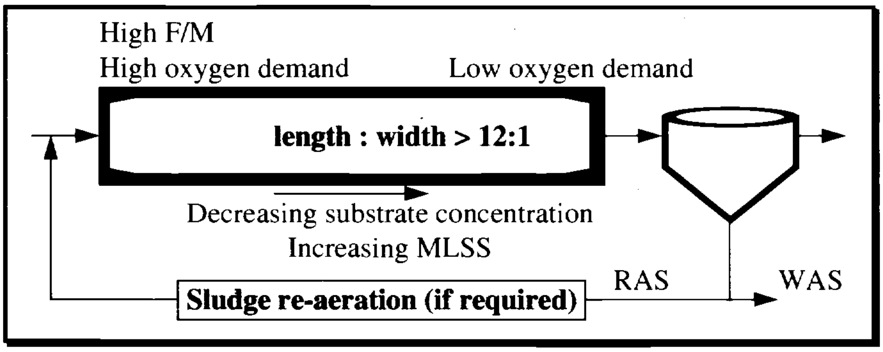


FIGURE 5.8 PLUG FLOW ACTIVATED SLUDGE SYSTEM

5.14.3 TAPERED AERATION

As the organic load is consumed along a plug flow tank, the oxygen demand decreases. In order to avoid providing excess oxygen where it is not needed, tapered aeration is used to modulate the air supply to meet the individual oxygen requirements of each section. At the beginning of the tank where the F/M ratio is high, up to three times as many diffusers may be required (in order to satisfy the oxygen requirement) compared with the end of a tank where food is scarce and hence oxygen demand is low.

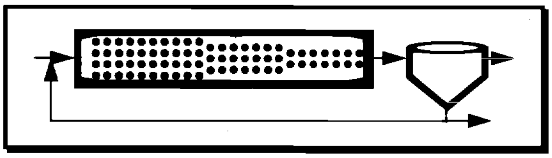


FIGURE 5.9 TAPERED AERATION

5.14.4 STEP FEEDING

The use of step or incremental feeding can avoid the need for tapered aeration by providing two or more inflow points along the first 50-70% of the length of the tank. This has the effect of evening out the BOD load and oxygen requirements as in a completely mixed system and also increases the ability to handle shock loads. It negates the benefits of having a plug flow tank in the first place and is not commonly applied.

5.14.5 SLUDGE RE-AERATION

Sludge re-aeration (Figure 5.8) involves aerating the RAS while it flows between the secondary settlement tank and the aeration tank with the object of ensuring complete oxidation of any stored substrate by providing extra oxygen. This ensures that the bacteria are "hungry" on introduction to the inflow and will absorb the maximum amount of substrate for stabilisation. This also has the beneficial effect of discouraging the growth of filamentous micro-organisms.

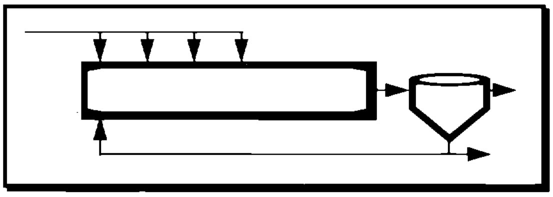


FIGURE 5.10 STEP FEED

5.14.6 OXIDATION DITCH

A specialised configuration of activated sludge known as the oxidation ditch is commonly used. The original oxidation ditch was developed by Pasveer in 1953. Since then it has undergone numerous modifications and improvements and nowadays provides the same range of treatment objectives as plug flow reactors, i.e. nitrification, denitrification and biological phosphorus removal. The oxidation ditch operates as a closed loop channel with aeration supplied by mechanical surface aerators and/or diffusers located on the floor of the ditch which provide both oxygenation and horizontal movement to keep the mixed liquor in suspension. Figure 5.11 shows the basic oxidation ditch configuration. To increase the circuit length, the carousel configuration shown in Figure 5.12 is commonly used.

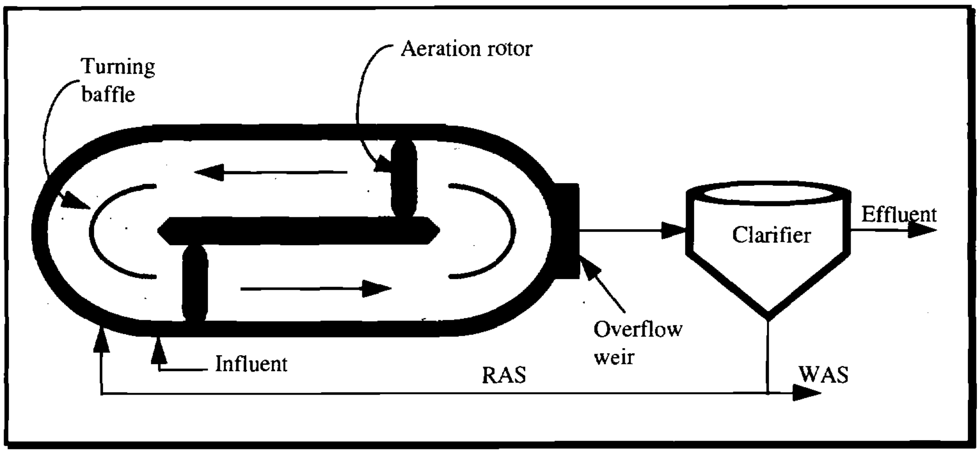


FIGURE 5.11 PASVEER OXIDATION DITCH

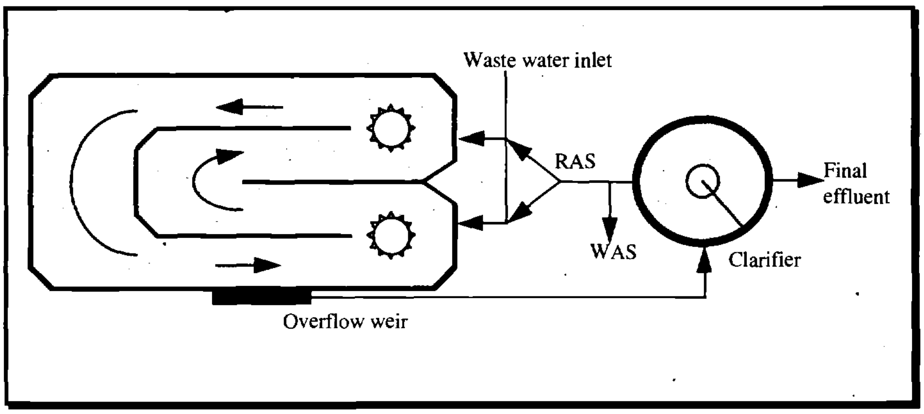


FIGURE 5.12 CAROUSEL OXIDATION DITCH

An oxidation ditch possesses properties attributable to both completely mixed and plug flow reactors. In one respect, due to its closed loop circulation, it acts as a completely mixed system. On the other hand, due to poor longitudinal mixing, DO and substrate gradients are evident downstream from surface aerators, as in a plug flow tank; as the flow progresses from one aerator to another, dissolved oxygen and substrate are consumed. These gradients allow for the incorporation of naturally occurring anoxic or low DO zones in nitrifying plants at the design stage. With the addition of separate anaerobic tanks, an oxidation ditch can be modified for biological phosphorus removal.

5.14.7 SEQUENCING BATCH REACTORS

Most activated sludge plants perform the two fundamental aspects of the activated sludge process in two tanks, one for aeration and one for solids separation. Sequencing batch reactors allow for both processes to be carried out in one tank (Figure 5.13). The tank is firstly charged and seeded with new waste water and RAS and is aerated until the BOD is satisfied. Aeration is stopped to allow the mixed liquor to settle and the clear supernatant is decanted off. New waste water and seed (if necessary) is added and the cycle repeats itself. Hydraulic and organic loading rates and sludge ages can be controlled in SBRs so a full range of treatment objectives can be achieved. Biological or physico-chemical nutrient removal are possible.

5.14.8 HIGH INTENSITY SYSTEMS

In treatment plants with a constant or periodic high loading, there may be deficiencies of DO where the potential rate of reaction by the micro-organisms cannot be achieved because of a lack of oxygen. High intensity systems such as pure oxygen and deep shaft increase the amount of available oxygen so that this demand can be satisfied. These systems are generally used on high strength industrial wastes and tend to be of high capital and/or operating cost.

High intensity systems can be operated, like conventional aeration, at various points on the bacterial growth curve and sludge production depends on how they are operated.

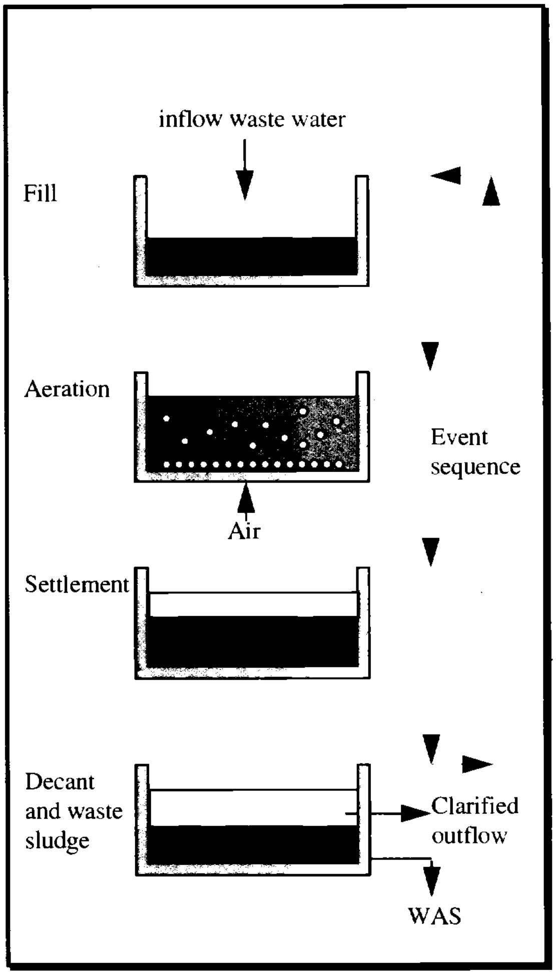


FIGURE 5.13 SEQUENCING BATCH REACTOR

5.14.8.1 Pure Oxygen

At constant temperature and pressure, oxygen has a fixed saturation concentration in water. Using air to oxygenate water, saturation concentration may not be reached because air contains only 21% oxygen. If 100% oxygen is used, the available oxygen is increased five-fold thus increasing the gradient and decreasing the gap between the saturation concentration and the actual concentration. An increased gradient increases the force driving the oxygen into solution. This increased transport across the gas/liquid interface helps satisfy the elevated oxygen demands of micro-organisms under high loading rates.

Pure oxygen systems operate as open or closed systems. Closed systems have the advantage of minimal loss of expensive oxygen to atmosphere whereas open systems must have an efficient gas transfer mechanism to ensure maximum dissolution of gas prior to dispersal to the atmosphere. Pure oxygen has found application as permanent or partial systems. Permanent systems operate using pure oxygen constantly. Partial systems are where the pure oxygen may be switched on on demand during periods of high loading.

5.14.8.2 Deep shaft

The deep shaft process operates at depths of up to 150m for the purpose of increasing the rate of oxygen transfer by increasing the pressure (and hence the saturation concentration of DO) in the liquid at the bottom of the shaft. As the depth and pressure of a liquid increases, so does its saturation concentration of air. By increasing the saturation concentration of oxygen, more dissolved oxygen becomes available to the micro-organisms thus ensuring that DO is non-limiting for metabolism.

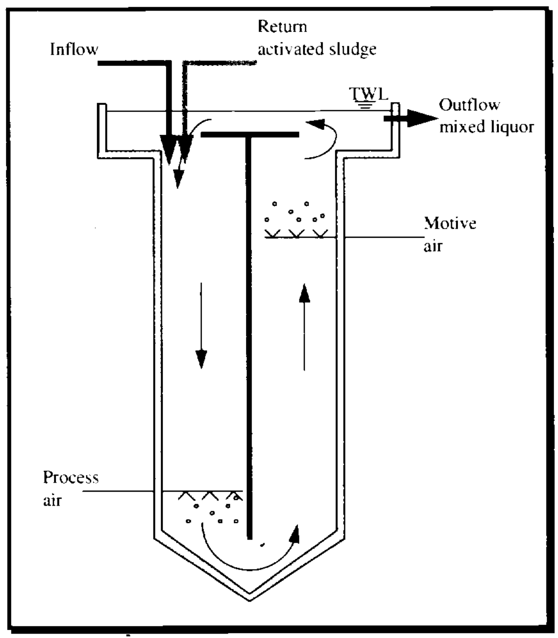


FIGURE 5.14 DEEP SHAFT ACTIVATED SLUDGE

The process is carried out in a shaft drilled into the ground, lined and divided by a partition into downflow and upflow sections. At the top of the shaft is a header tank where inflow and RAS are added. Circulation of the mixed liquor (up to 30 times) down the shaft ensures maximum stabilisation of the waste water. Sludge settlement is poor due to attached micro-bubbles on the bacterial flocs and flotation has on occasion been used successfully instead of settlement. Alternatively, a degassing stage could be used prior to secondary settlement. Nitrification and denitrification are possible.

5.15 NUISANCE

The main sources of nuisance from an activated sludge plant are odours from waste activated sludge storage and aeration blower noise. Because of its more highly stabilised condition, the waste sludge from an extended aeration process is less likely to putrefy and cause an odour nuisance. High rate processes have a significant odour potential. Due to the high rate of absorption of organic matter, a lot of biodegradable/putrescible material remains which can generate odours if the waste activated sludge is allowed to become anaerobic.

5.16 FOAMING

Many well operated activated sludge plants have a small layer of light chocolate coloured foam covering up to 30% of the aeration tank. However, if the foam becomes excessive, the operation of the plant will be affected.

Excessive build-up of foam can result in walkways and plant equipment being covered by foam during windy conditions. As well as creating an unsightly appearance in the plant this can lead to odours and wind blown foam.

Problem foams can be divided into white, brown and black foams.

Table 5.8, Table 5.9 and Table 5.10 illustrate the potential causes for each type of problem and suggest corrective actions.

TABLE 5.7 APPLICATIONS OF ACTIVATED SLUDGE PROCESS VARIATIONS

(modified from Gray, 1990)

Process type	Used for..				
	BOD removal	**Nitrification**	**Denitrification**	**Biological P removal**	**Chemical P removal**
Conventional or extended aeration, completely mixed	✔				✔
Conventional or extended aeration, plug flow	✔	✔			✔
Conventional or extended aeration, plug flow, anoxic zone	✔	✔	✔		✔
Conventional or extended aeration, plug flow, anoxic zone, anaerobic zone	✔	✔	✔	✔	✔
High rate activated sludge	✔				✔
Pure oxygen systems	✔				✔

TABLE 5.8 WHITE FOAM

Associated with	New plant Low sludge age Overloaded plants Low MLSS High F/M
Caused by	Inadequate return of sludge from secondary settlement tank to aeration basin Low MLSS Excessive wasting of activated sludge High organic loading after a prolonged period of low loading (e.g. weekends) Toxic material Low or high pH Change in temperature Low dissolved oxygen P or N deficiency Shock hydraulic loading or solids washout Poor distribution of flow and solids to secondary settlement tanks
Corrective action	Check return sludge rate Maintain the sludge blanket at 0.3-1.0m from the bottom of the secondary settlement tank Increase the MLSS in the aeration tank by not wasting sludge Seed the aeration plant and take steps to prevent the entry of toxic material Monitor/inspect the discharge of significant industrial discharges Balance the distribution of flow to the secondary settlement tanks

TABLE 5.9 EXCESSIVE BROWN FOAMS

Associated with	Plants operating at low loading rates Plants capable of nitrification Significant presence of *Nocardia spp.* (filamentous micro-organism) Plants with sludge re-aeration High sludge age
Caused by	Low F/M Greater than normal sludge production because of seasonal changes. This can occur during the transition from winter to summer which can promote increased microbiological activity due to higher temperatures Unplanned sludge wasting event
Corrective action	If nitrification is not required, increase the F/M ratio and decrease the sludge age Remove scum at the RAS pumping area Examine the sludge wasting schedule

TABLE 5.10 BLACK FOAMS

Associated with	Low dissolved oxygen Anaerobic conditions Dyes from industrial sources
Corrective action	Increase aeration Decrease MLSS Investigate industrial sources

5.17 SOLIDS WASHOUT

Solids washout occurs when large amounts of sludge solids are present in the secondary settlement tank. This phenomenon can occur despite the settleability test indicating satisfactory settling characteristics. The cause of solids washout is normally attributable to one or more of the following:

- equipment malfunction;
- hydraulic overload; or
- solids overload.

The operator should check all flow meters, pumps (particularly RAS), baffles and weir levels. When two or more secondary settlement tanks are in use it is important to ensure that all weirs are set to equal heights. To check for hydraulic overload, inflow data should be examined for the possibility of abnormal flows and infiltration. To check whether there is sufficient secondary settlement tank capacity, the upward flow velocity should be checked and compared with the design value.

To prevent suspended solids from overloading secondary settlement tanks, sludge wastage rates should be increased.

5.18 SLUDGE TYPES

Before attempting to deal with specific problems at the plant the operator must identify the various types of sludges that can be encountered at a plant.

Table 5.11 classifies sludges into a number of categories.

5.18.1 RISING SLUDGE

Denitrification occurs in secondary settlement tanks when oxidised nitrogen is reduced to molecular nitrogen in the absence of dissolved oxygen. Bubbles of N_2 adsorb to solid particles, causing them to rise. A number of conditions contribute:

TABLE 5.11 CLASSIFICATION OF ACTIVATED SLUDGES

Type of sludge	Description
Normal	Brown with a musty odour. SVI of 90-120 ml/g indicating good settling characteristics.
Rising sludge (denitrification)	Due to the entrapment of nitrogen gas bubbles produced during denitrification, the sludge becomes lighter than water and rises to the surface.
Ashing	The presence of dead cells, sludge particles and grease on the surface of the secondary settlement tank. If the 30 minute cone test releases bubbles after it has been stirred, denitrification, not ashing, is occurring.
Pin point floc	Small dense sludge particles suspended in the secondary settlement tank; often seen in plants operating between conventional and extended aeration.
Bulking sludge	*Filamentous bulking*: light brown, grey or white in colour with poor settling characteristics (SVI >150 ml/g). *Non-filamentous or dispersed growth bulking*: sludge floc has a large area and usually contains bound water.
Straggler floc	This can occur during periods of low MLSS and appears as small, transparent, fluffy sludge particles in the secondary settlement tank.

- **nitrification**: this will require a long sludge age to enable the slow growing nitrifying bacteria (which oxidise ammonia to nitrate) to be present in significant concentrations. High nitrate concentrations may also occur in effluents from industrial sources;

- **high temperature**: rising sludges are often a summer phenomenon;

- the **sludge blanket** in the secondary settlement tank will have a low dissolved oxygen (<0.5 mg/l); and

- the **sludge blanket** will contain nitrate concentrations in excess of 5 mg/l.

A similar condition called *sludge clumping* occurs when plants are operated at low F/M's and nitrification takes place. Clumps of sludge may appear on the surface of the secondary settlement tank when the sludge is being retained in the secondary settlement tank for too long a period. Clumping sludge may also occur during the summer when temperatures are high.

Rising and clumping sludge may be resolved by :

- increasing the return activated sludge flow rate; or

- decreasing the sludge age which reduces nitrification.

5.18.2 ASHING

Ashing is occasionally associated with dead cells and other sludge particles or grease floating on the surface of a settlement tank. The dead cells will not settle; the sludge may settle but not flocculate.

The possible causes are:

- extremely low F/M (less than 0.05); and

- MLSS containing high grease concentrations.

The problem may be resolved by:

- increasing the F/M ratio and decreasing the sludge wasting rate; and

- monitoring the inflow for fats, oils and grease to establish whether unusually high levels are present. Also, check that grease removal equipment, such as baffles, is operating efficiently.

5.18.3 PIN-POINT FLOC

This is characteristic of plants which are operating at low F/M and/or where there is excessive turbulence in the aeration tank causing "shearing" of the floc. The problem can be overcome by:

- decreasing the sludge age;

- maintaining dissolved oxygen above 2 mg/l

- (i.e. 2 -4 mg/l); or

- *as a temporary measure*, adding a flocculating agent.

5.18.4 FILAMENTOUS BULKING

Filamentous bulking occurs when filamentous organisms extend in significant numbers from the floc into the bulk solution. Though the quality of supernatant may still be good, the major problem with this form of bulking is poor consolidation of sludge. Maintaining the desired F/M ratio in the aeration tank can be difficult because thinner RAS reduces the MLSS concentration.

Filamentous bulking can be caused by:

- low F/M ratio;

- low dissolved oxygen concentration in the aeration tank;

- insufficient levels of P, N or other nutrients. This may occur if industrial loads entering the treatment plant are deficient in these nutrients and dilute the nutrient concentration in the aeration tank, e.g. brewery waste can promote the growth of *Thiothrix spp.* and *Sphaerotilus natans*;

- too high or low pH values. Fungi predominate at low pH;

- high waste water temperatures;

- widely fluctuating organic loading rates;

- industrial waste waters with a high BOD; or

- industrial waste waters with a high sulphide content, e.g. tannery waste or septic waste water, which can promote the growth of *Thiotrix spp.* and *Beggiatoa spp.*

If filamentous bulking is taking place on a regular basis, the type of filamentous organism may have to be identified in order to understand the nature of the problem. For example, the presence of fungi will indicate a low pH industrial discharge.

Thiotrix spp. may indicate that septic conditions are prevalent in the collecting system.

Where low F/M bulking has been a problem, selector or contact zones have been used to restrict the growth of filamentous bacteria by providing floc forming bacteria with a competitive edge that makes them more dominant. An extra zone is provided before an aeration tank where the RAS and inflow are mixed for a short hydraulic retention period (15-30 minutes based on the average flowrate). A high F/M ratio results which favours the floc formers. The high F/M ratio at the start of a plug flow tank is the reason that this configuration is more successful than completely mixed systems in preventing the development of filamentous bacteria. Anoxic selector zones have been applied to certain bulking/foaming conditions.

5.18.5 NON-FILAMENTOUS BULKING

Bulking can occur without filamentous organisms being present. This can occur in certain high F/M situations. If such a situation exists the operator should decrease sludge wasting.

5.18.6 STRAGGLER FLOC

Straggler floc is characterised by small, transparent and fluffy sludge particles in the settlement tank. The causes of straggler floc are:

- over aeration, particularly during process start-up;
- low MLSS, which may result from too high a sludge wasting rate; and
- batch sludge wasting.

The problem may be resolved by:

- decreasing the sludge wasting rate, thereby increasing the MLSS and the sludge age; and
- not wasting sludge during periods of high organic loading.

5.19 BIOLOGICAL ACTIVITY

The factors which affect the performance of the activated sludge process include:

- micro-organisms;
- oxygen; and
- food.

It is difficult to isolate a particular species of micro-organism as being responsible for a particular function in waste water treatment. However, as a group, the identification of the types of micro-organisms present, the predominance of each type, the diversity of the communities and the mobility of the micro-organisms are invaluable guide to the health and status of a plant and to predicting operational problems in the early stages. The micro-organism population will reflect their environment and be influenced by the contents of the mixed liquor and thus the incoming waste water. This can be used by the operator to provide the optimum conditions for growth.

The micro-organisms can be observed using a microscope with a magnification between 100X and 400X. Figure 5.15 illustrates the relative predominance of micro-organisms versus F/M, sludge age and SVI. It can be seen that flagellates (lower life forms) predominate at high F/M or low sludge age when the flocs are light or dispersed. At longer sludge ages, the rotifers and worms (higher life forms) become more predominant and this can sometimes indicate a poorer effluent quality and an over-oxidised sludge.

5.19.1 MONITORING BIOLOGICAL ACTIVITY

An experienced operator can assess an activated sludge plant by examining daily the microbial population of the mixed liquor. Each plant will operate under different conditions and individual characteristics will be empirically established with time. For example, an examination of the mixed liquor may yield 47% rotifers, 26% stalked ciliates and 23% free swimming ciliates; this can indicate a long sludge age.

The identification of the micro-organisms present in a sample of mixed liquor and the beneficial use of this information requires a lot of experience and reference should be made to standard texts.

TABLE 5.12 SIZE OF MICRO-ORGANISMS USED IN WASTE WATER TREATMENT

(Standard Methods, APHA, 1992)

Micro-organism group	Size, μm
Rotifers	400
Free swimming ciliates	100-300
Stalked ciliates	40-175
Flagellates	5-60
Amoeboids	10-30

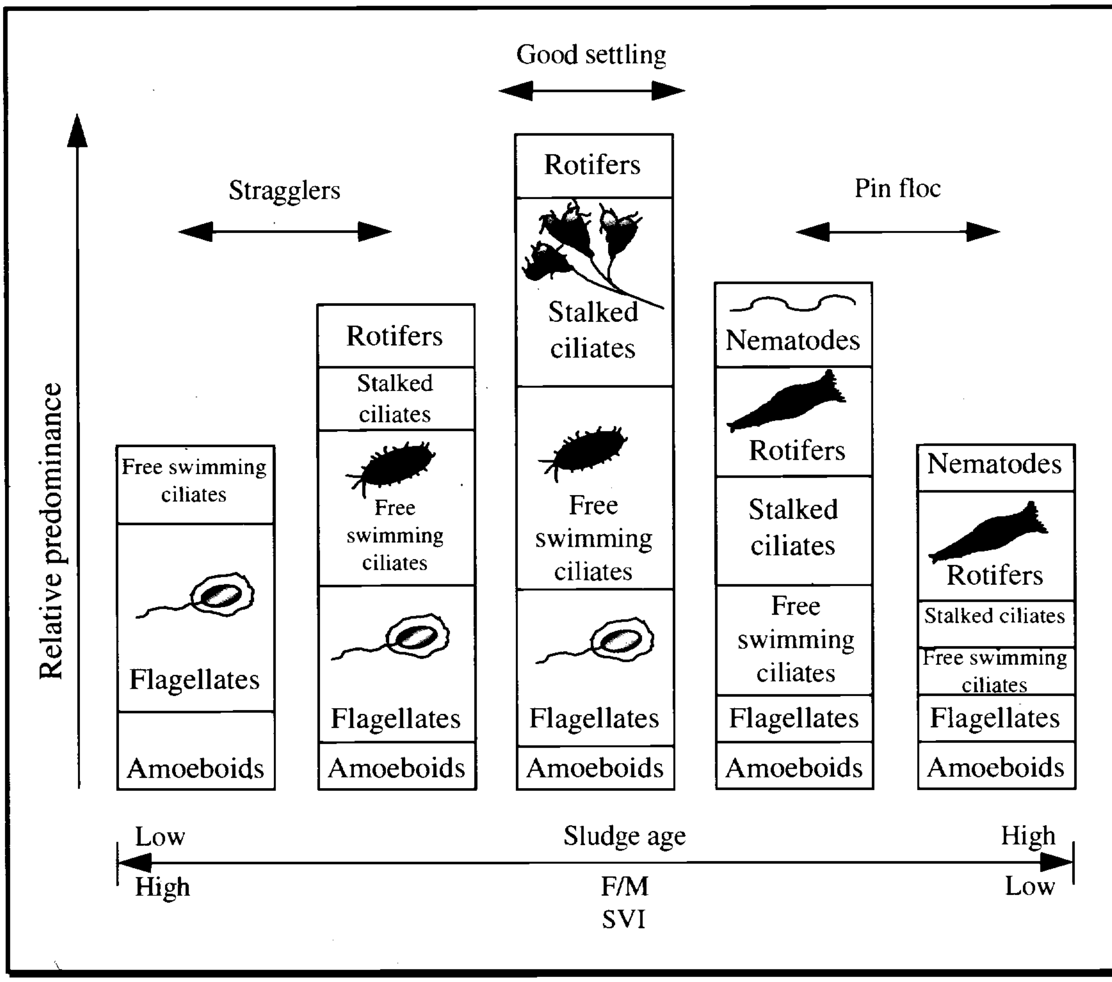


FIGURE 5.15 PREDOMINANCE OF MICRO-ORGANISMS IN RELATION TO OPERATING CONDITIONS (New York SDEC, 1988).

5.20 ENERGY

Table 5.13 gives the breakdown of costs associated with the operation of Killarney waste water treatment plant for 1995. The operation of a treatment plant requires power and this accounts for a significant portion (22% in 1995) of the annual operating costs.

By identifying the various units which contribute to power costs, operating costs may be reduced without compromising the quality of the final discharge.

Adjustments may be made to the activated sludge process in order to reduce the power demand. The process controls which can be optimised include:

- the number of units in operation;
- dissolved oxygen concentrations;
- sludge age; and
- return activated sludge flowrates and concentrations.

Urban waste water treatment plants are normally designed to take account of future growth and seasonal factors.

TABLE 5.13 OPERATING COSTS OF KILLARNEY WASTE WATER TREATMENT PLANT DURING 1995

Unit	Cost, £	% of total
Power	48,432	22
Labour	66,000	30
Chemicals	25,127	11.5
Maintenance	25,287	11.6
Sludge disposal	43,677	20
Laboratory	2,788	1.3
Other	7,689	3.5
TOTALS	**219,000**	**100**

Loading rates to Killarney WWTP in 1995

Average load: 21,000 p.e.
Winter load: 12,000 p.e.
Late summer load: 40,000 p.e.

For design purposes, it was stated earlier that aeration equipment should be selected to provide 1 to 2 mg/l and 0.5 mg/l based on the average weekly and peak load respectively. Adjusting aerator performance to match the oxygen requirement of the mixed liquor can result in significant energy savings. Figure 5.16 shows that twice as much energy is required to transfer a unit of oxygen to the mixed liquor at a DO of 5 mg/l as it does at a DO of 2 mg/l. Typically, the DO requirement during the night-time will be lower than during the day because the organic load is considerably less.

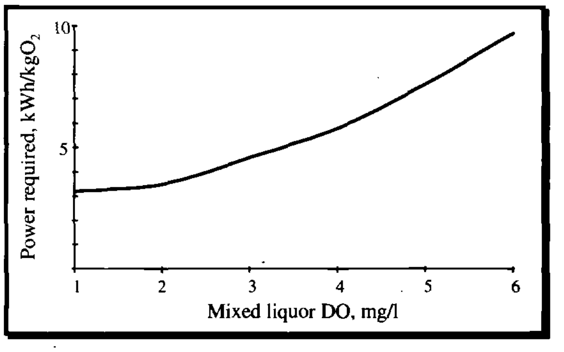


FIGURE 5.16 POWER REQUIREMENTS AS A FUNCTION OF MIXED LIQUOR DO

Figure 5.17 shows the oxygen consumed during carbonaceous BOD removal and nitrification. The figure shows that carbonaceous removal requires about 30-40% less power than the power required to satisfy both carbonaceous and nitrogenous BOD. If nitrification is not required, operating at a sludge age between 6-10 days will satisfy the carbonaceous oxygen demand. Care should be exercised in reducing the sludge age as this can be accompanied by a higher SVI and the production of more waste sludge.

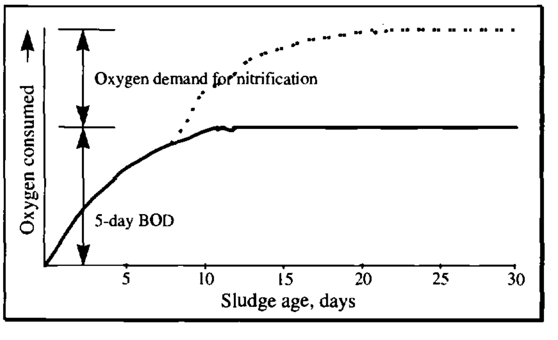


FIGURE 5.17 OXYGEN CONSUMPTION

RAS and WAS pumps, if continuously operated, will utilise a significant amount of energy. To reduce the energy consumption:

- avoid, where possible, operating with throttled discharge valves;
- use individual RAS pumps for individual settlement tanks;
- use variable speed controls for WAS pumps;
- use variable speed drive or multi-speed controls instead of fixed speed installations; and
- specify a smaller impeller size if operating at the low end of pump capacity.

An energy efficient strategy within the plant should also include selection of the appropriate electricity utility tariff system. Also, the availability of a standby generator may result in a financial saving as well as having a strategic piece of equipment for other occasions. Where loss of power could pose a significant threat to the environment, the installation of a standby generator or a dual mains supply is advisable.

The records provided by, for example, a SCADA system (section 2.7) will *inter alia* assist in monitoring the energy usage at the plant and also highlight points of high energy use.

5.21 LABORATORY EQUIPMENT

Laboratory facilities at a waste water treatment plant will depend both on the level of expertise available on site and on the proximity of a fully equipped laboratory.

The following is a general list of equipment that should be available at waste water treatment facilities where routine monitoring for BOD, COD, TSS and general microscopic analysis is required:

- analytical balance;
- oven and incubator (20°C);
- desiccator;
- filter papers, filtration apparatus and vacuum pump;
- DO meter and BOD accessories;
- BOD_5 test nitrification inhibitor;
- buffer chemicals, i.e. phosphate buffer solution, magnesium sulphate solution, calcium chloride solution and ferric chloride solution;
- glucose and glutamic acid as BOD standard and BOD seed;
- COD kit;
- homogeniser;
- wash and reagent bottles;
- pipettes, graduated cylinders and Imhoff cone;
- microscope;
- fridge;
- fume hood;
- pH meter;
- thermometer; and
- distilled de-ionised water.

6. BIOFILM (ATTACHED GROWTH) PROCESSES

6.1 PROCESS DESCRIPTION

Attached growth, biofilm and fixed film are terms relating to a treatment process where bacterial growth attaches itself to a surface. The resulting film or slime contains the micro-organisms necessary to treat the applied waste water. Fixed film processes can be sub-divided into units with:

- packed media (percolating filters and some submerged filters); and
- moving or buoyant media (rotating biological contactors and other submerged filters).

Biofilm processes are usually preceded by primary settlement to remove gross settleable solids which may interfere with oxygen transfer to the micro-organisms, block the filter media or result in high solids yields.

Biofilm processes are categorised as follows:

- **percolating** or **trickling filters:** these are made up of beds of packed media. The medium provides support for the growth of micro-organisms and applied waste water flowing in a downward direction through a medium provides food for these micro-organisms. Thus, the micro-organisms feed upon and remove the substances contained in the waste water. The media used are highly permeable; the word "filter" does not imply any straining or separation of solid material. Many variations on the arrangement of structure, media and distribution systems are available.

- **rotating biological contactors (RBC):** these units allow the growth of a biofilm on large diameter discs or structured modules. A central horizontal shaft rotates the discs or modules thereby exposing the biofilm sequentially to the waste water and to the atmosphere.

- **submerged (aèrated) filters:** these units have been commercially developed over the last ten years with claims of high loading rates and efficiencies and low land area requirements. They are intensive biofilm processes where large quantities of biomass are supported inside a tank through which the waste water is passed. A submerged aeration system is required in aerobic processes. The larger submerged filters tend to be highly engineered unit processes although simpler package versions have been developed for use as small waste water treatment plants.

6.2 PERCOLATING FILTERS

6.2.1 SHAPES AND CONFIGURATIONS

Two shapes of percolating filter exist: circular and rectangular. Rectangular filters are more old-fashioned and were used on large treatment plants where activated sludge or submerged filtration would typically be applied today. Rectangular deep bed filters are often used now as high rate filters. Circular percolating filters offer better distribution of waste water and are less cumbersome and have more easily maintained mechanical parts.

6.2.2 BIOLOGICAL SLIME

The basic bacterial unit in biofilm processes is the biological slime layer that grows on the support medium. The slime layer is characterised by zoogleal growth which is viscous and jelly-like and contains bacteria and other micro-organisms. As the bacteria grow in numbers, the film increases in thickness and any excess is removed by one of two mechanisms:

- the passage of liquid between the media causes a continuous erosion of small amounts of biofilm. The level of erosion is dependent on the rate of liquid flow over the biofilm and on the thickness of the biofilm. Thus, the size and thickness of the slime layer is partly controlled by the liquid flowing through the medium; or

- sloughing of biofilm is a rapid loss of large quantities of biofilm which is most noticeable when the biofilm has become thick. It is typically the result of anoxic or anaerobic conditions arising deep within the biofilm which can cause gas production and reduce the ability of the biofilm to adhere to the medium.

The bacterial population resident in the slime layer depends on a number of factors including the nature and loading rate of the applied waste water. At normal loading rates heterotrophic carbonaceous bacteria and fungi predominate. On more lightly loaded plants or near the base of bacteria beds, slow growing nitrifying bacteria will develop and compete with the faster growing heterotrophs. Photosynthetic algae and bacteria will reside near the surface of a percolating filter. On mature treatment plants, ciliated protozoa will consume any free suspended bacteria in the liquid film and so clarify the outflow, which would otherwise be turbid. Higher life forms which graze on the slime are represented successively by rotifers, nematode and annelid worms, larvae and adult dipteran flies (e.g. *Psychoda*), midges and other insects. In consuming slime, the grazing fauna decrease sludge production and increase the settleability of sludge solids. The food chain is topped by birds which consume the insects and worms near the surface of a bacteria bed. The grazing fauna are most active during the warmer months and this accounts for the drop-off in activity of percolating filters during the winter.

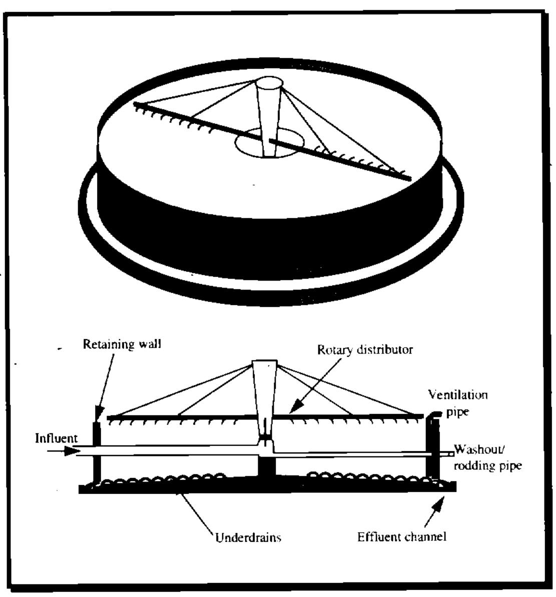


FIGURE 6.1 PERCOLATING FILTER

6.2.3 MEDIA

Media used in the past include granite, blast furnace clinker, structured plastic bales, structured or randomly packed plastic or stone shapes which vary in size from 4 mm to 200 mm. A medium is required to have:

- a high surface area per unit volume;
- a low cost;
- high durability;
- resistance to chemical attack;
- a consistent size distribution and weight density; and
- liquid paths which do not easily clog.

Modern media tend to be engineered plastics designed to maximise specific surface area[2] (SSA) and hence bacterial population. SSAs are highly variable and range in size from 50 m^2/m^3 up to 600 m^2/m^3 for some of the most specialised media.

Random packed media are made up of very large numbers of individual pieces which sit on a filter floor with no ordered pattern. The liquid flow path is random but intricate and good shapes will maximise contact between the liquid and the biofilm. Although smaller sizes will provide a greater SSA for bacterial growth, the voids tend to clog more easily which limits the passage of liquid and air.

Structured media are usually supplied as bales up to 1 m^3 in size which are fitted like bricks into a filter. They are constructed of corrugated sheets bonded together to form long intricate flow paths for the liquid. The surface is often roughened to maximise retention of biomass and to prevent complete sloughing of the surface. Different channel widths are available for different applications and bacterial growth rates.

6.2.4 MASS TRANSFER ACROSS SLIME INTERFACES

The composition of the bacterial slime may differ under different applications and loading rates but the transport mechanism of oxygen and nutrients to the bacterial cells remains the same. The mass transfer operation is illustrated in Figure 6.2.

The movement of substrate and dissolved oxygen through a biofilm is dependent upon two mechanisms:

diffusion; and

advection.

Diffusion of substrate and oxygen takes place by virtue of concentration gradients. The greater the difference in substrate and oxygen concentration between the biofilm and the bulk liquid, the

[2] The specific surface area is the total surface area per unit volume of medium expressed as square metres per cubic metre of total volume occupied. For example, a sphere of diameter 5 mm will have a surface area of 7.85×10^{-5} m^2, a volume of 6.5×10^{-8} m^3 and therefore an SSA of 1208 m^2/m^3. Similarly, a sphere of diameter 20 mm will have an SSA of 298 m^2/m^3 and a sphere of diameter 1 m has an SSA of 6 m^2/m^3. Thus the smaller the particle, the greater the SSA.

greater will be the gradient or driving force by which diffusion occurs; see Figure 6.3.

Advection is the movement of substrate and oxygen through channels in the biofilm structure.

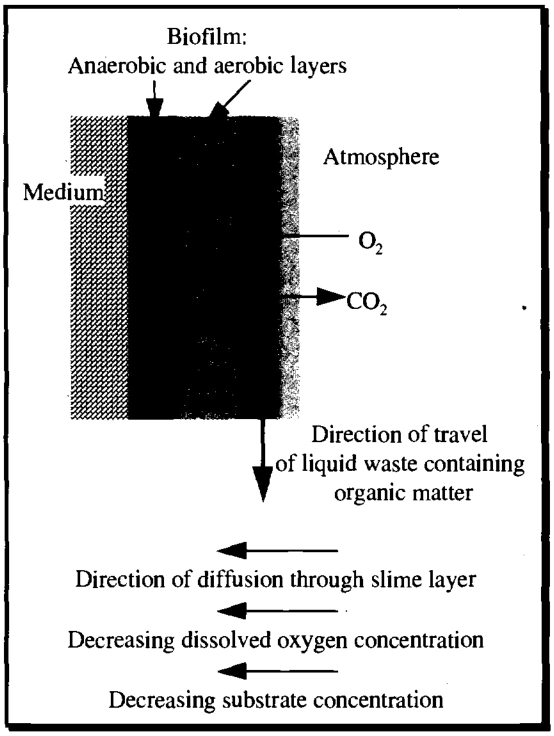


FIGURE 6.2 TRANSPORT MECHANISM ACROSS THE BIOFILM

Where substrate loading is high or the slime layer is thick, low dissolved oxygen conditions may exist deep within the slime layer and the generation of gas by anaerobic processes may enhance sloughing of the biofilm.

6.2.5 DISTRIBUTION OF FEED

As a biofilm grows and increases in thickness, the spaces between the media particles decrease in size and restrict the liquid flow; thus, the surface of a bacteria bed may become clogged unless the biofilm thickness is controlled and any excess biofilm removed. If any one area of a filter bed becomes more clogged than another (due to either poor liquid distribution or the break down of media), liquid must find an alternative flow path of less resistance. This may cause significant short-circuiting thus reducing contact time and causing incomplete treatment of the waste water.

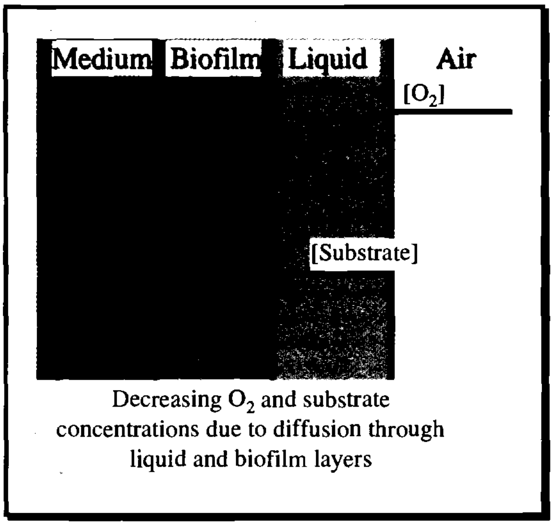


FIGURE 6.3 DIFFUSION ACROSS THE BIOFILM

Waste water is applied to the top of a percolating filter using mechanical distribution equipment. Typically, a rotary distributor, which consists of a central vertical column with two to four arms at right angles to each other, rotates in a horizontal plane above the filter bed. The sparge holes on the arms often use splash plates to increase the spread of the falling liquid. The distance between sparge holes near the centre of a circular bed is greater than that at the periphery. This compensates for the difference in the distance that particular sparge holes have to travel (i.e. their circumference of travel). Consequently, each sparge hole should wet a similar plan area of filter bed. On rectangular beds, travelling distribution arms apply the feed to the bed. Non-uniform distribution of feed can be a problem with these systems.

Circular distribution systems are usually rotated by using the applied head of water; 300-600 mm is typically required. Dosing siphons are used to prevent flow to a distributor when the head falls below that necessary to cause the arms to rotate. Fixed immobile distributors are not commonly encountered except in small or package percolating filter plants and in some biotowers. Disadvantages include the lack of easy access for maintenance and the potential for uneven distribution of waste water.

6.2.6 OUTFLOW COLLECTION (UNDERDRAINS)

At the base of the percolating filter is the underdrain or collecting system. The filter floor is sloped to a collection channel at either the centre or the periphery of the bed. The underdrains consist of a network of precast channels which:

- collect the treated waste water;
- support the media; and
- allow air flow.

These were traditionally precast blocks laid on the floor but nowadays can be, for example, of plastic perforated pipe or steel wedgewire construction. Underdrain durability is important as access for maintenance (except perhaps on raised or high rate plants) is not possible without first removing the medium. A problem regularly encountered with older percolating filters has been the deterioration and collapse of the underdrain system leading to short-circuiting and poor outflow quality.

6.2.7 OXYGEN SUPPLY

Biofilm processes used for urban waste water treatment are generally aerobic; the exception being for anoxic denitrifying filters. Therefore, oxygen must be supplied. The methods used vary from the natural draught used on percolating filters to activated sludge-like blower and fine-bubble diffuser systems on some submerged aerated filters. Air distribution is important to ensure all areas of a bed of micro-organisms remain aerobic. For example, short circuiting of air in packed bed reactors can generate channels through a medium which can provide an easy path for a liquid. Poor distribution of air, assuming satisfactory design and installation, is usually caused by clogging of a bacteria bed which is often the result of poor liquid distribution.

6.2.8 FINAL OR SECONDARY SETTLING

The erosion of biofilm from the medium used in percolating filters, RBCs and some submerged filters is a continuous process and the removed solids are carried away in the outflow. Before discharge to a water body, these solids must be separated from the liquid; this is usually done in secondary settlement tanks called *humus tanks* - so called because of the humus like nature of the sludge produced by percolating filters. Other types of submerged filters require periodic backwashing to remove excess sludge. Humus sludge can be processed separately but is frequently returned to the primary settlement tanks for co-settlement.

6.2.9 RECIRCULATION

Recirculation of the outflow in a biofilm process dilutes the inflow and increases the hydraulic loading rate. Low substrate concentrations at the top of a percolating filter encourage the growth of bacteria instead of fungi and also discourage excessive growth by operating at what is, in effect, a low food to micro-organism ratio. Excessive growth can clog a percolating filter. A dilute inflow will distribute the substrate more evenly throughout the depth of the bed. The increased hydraulic loading rate achieved through recirculation has two functions:

to keep the media wet during periods of low flow; and

to maximise the erosion of dead and excessive biofilm.

Recirculation of unsettled outflow, as illustrated in Figure 6.4, is advisable where the settlement/humus tank does not have adequate hydraulic capacity. A 1:1 recirculation ratio of settled effluent will double the flow passing through a humus tank. A similar ratio of recirculated unsettled effluent will not change the humus tank throughput. Similar consideration must be made for peak flows which will substantially dilute the incoming waste water. Whether designed for 3 DWF or 6 DWF, the hydraulic load to the humus tank must be maintained within the design range.

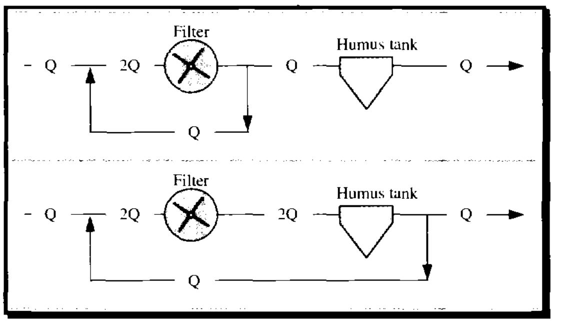


FIGURE 6.4 HYDRAULIC EFFECT OF RECIRCULATION ON HUMUS TANKS

6.2.10 COLD TEMPERATURE OPERATION

A number of changes occur in a percolating filter during cold weather:

bacterial metabolism slows down;

flies and other insects stop breeding; and

- worms, insects and other mobile invertebrates migrate to the warmer depths of the bed.

Thus, the activity of a percolating filter decreases; however, on a well sized and maintained plant this should not result in a deterioration in outflow quality. Nitrification does decrease significantly below about 10°C so ammonia concentrations in the outflow may increase. With the arrival of spring the above changes reverse, but not at the same rate. Thus, bacterial metabolism, particularly at the highly loaded top part of the bacteria bed, increases and the biofilm increases in thickness. This excess biomass, combined with the increasing activity of higher life forms, causes a slough which can continue for up to 4 weeks at the beginning of spring. This is commonly called the spring slough and occurs to a greater or lesser extent on all percolating filter plants.

6.2.11 CLASSIFICATION AND CONFIGURATION OF FILTERS

The outflow quality from percolating filters is dependent on their hydraulic and organic loading rates which are in turn governed by the inflow, the plant configuration and recirculation rates. Percolating filters are generally classified based on either their physical configurations, on their loading rates or on a combination of both. Examples of some of these configurations are described in Table 6.1 and illustrated in Figure 6.5.

6.2.11.1 Single stage filtration

At low organic loading rates, a single pass through a bacteria bed is sufficient to ensure full carbonaceous oxidation. Loading rates are also sufficiently reduced in the bottom of the bed to allow nitrifying bacteria to grow; hence nitrification is generally good. Due to the extent of treatment, sludge tends to be well stabilised and endogenous respiration is not uncommon.

Dosing siphons are used to ensure the distributors keep turning. Bed depths are about 2.0-2.5 m, which is deep enough for nitrification to occur, and the medium, usually stone, is generally no larger than 40-50 mm. Due to long retention periods and low biofilm removal rates, odours and filter flies are common sources of nuisance, particularly during mild weather. Few modern plants are constructed to operate at such low loading rates due to cost constraints.

TABLE 6.1 CLASSIFICATION OF PERCOLATING FILTERS

Parameter	Low rate	Intermediate rate	High rate	Very high rate
Hydraulic loading **m^3/m^2.d**	1.0 - 3.75	4.0 - 9.5	9.5 - 28.0	28 - 47
Organic loading **kg BOD/m^3.d**	0.08 - 0.32	0.24 - 0.48	0.48 - 0.96	0.8 - 1.6
Sludge production **kg TSS/kg BOD.d**	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0	1.0 or greater
Nitrification	Yes	Partial to full	Unlikely	No
Configuration used	Single filtration	Single with recirculation *or* two-stage filtration	High rate filtration	Roughing filtration

Notes:

m^3/m^2.d	m^3 applied flow/day per m^2 bed surface area
kgBOD/m^3.d	kg applied BOD/day per m^3 bed volume (total bed volume if using multiple stages)
kgTSS/kg BOD.d	kg total suspended solids produced/day per kg BOD removed

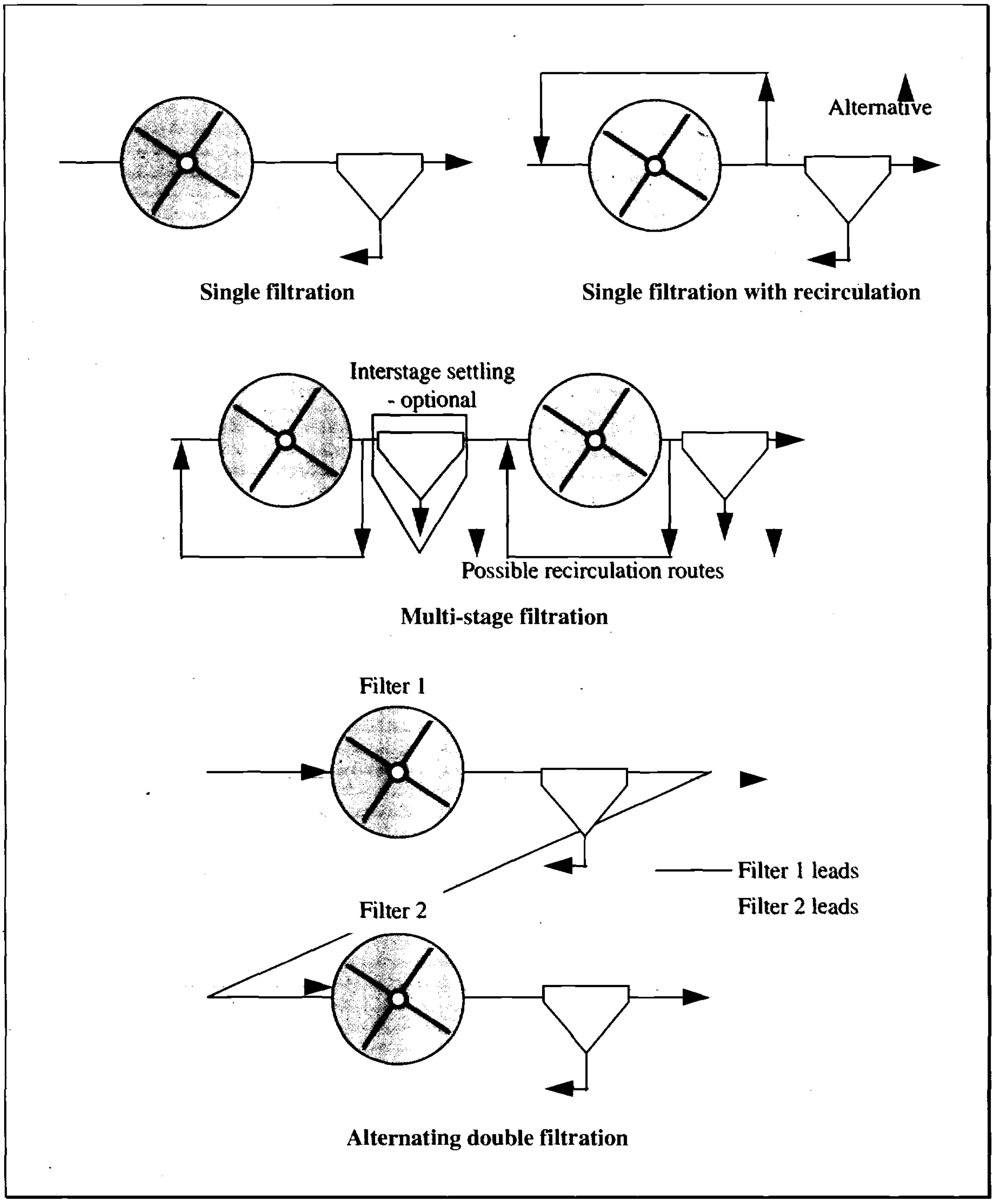


FIGURE 6.5 CONFIGURATIONS OF PERCOLATING FILTERS

At intermediate loading rates, recirculation of treated effluent may be necessary to dilute the inflow and hence the localised organic loading rate at the top of the bacteria bed. Often this is not continuous but is only operated during periods of high loading and is either manually or timer controlled. Recirculation may also be used to improve nitrification on plants where the organic load has gradually or suddenly increased causing deterioration in outflow quality. Recirculation combined with larger media sizes up to 100 mm reduces the clogging caused by an increased organic loading rate. Modern intermediate rate percolating filters would generally employ a plastic medium and outflow recirculation. A minimum wetting rate is often necessary for such media (to prevent the biofilm from drying out) so continuous recirculation may be necessary. Different media have different wetting rates and this must be taken into account in the design of a recirculation system and its relationship to incoming flow. Higher flow rates through the bacteria bed and increased sloughing rates reduce the opportunity for insect larvae to lodge and mature; odour and fly nuisances are therefore reduced, but not eliminated. Sludge production is higher than on low rate plants and will depend on such factors as the contents of the waste water, the hydraulic loading rate and the medium used.

6.2.11.2 High rate filtration

High rate filters may be larger in diameter and depth and use a larger medium than low and intermediate rate filters. Older plants may have large rock or similar media up to 100 mm in size. Modern designs will use either a structured or open random packed medium. Significant BOD removal is possible but nitrification will not occur. Recirculation is usually required to keep the media wet and to dilute the inflow. Biofilm erosion is continuous so sludge production is high but insect problems are low.

6.2.11.3 Roughing filters

Percolating filters operating at very high rates are generally used as pre-treatment stages where further treatment occurs downstream. The process is applied to trade effluents where the roughing filter typically removes 50-70% of the BOD. Downstream processes then operate at more conventional loading rates. A typical roughing filter will be square or rectangular, up to 12 m deep with very high hydraulic loading rates. Such large reactors are commonly called *biotowers*. High voidage structured media are used. Engineered structures are usually required to support the media. Usually a frame with a thin skin of corrugated steel shields the medium from external elements. On more heavily organically loaded filters, forced aeration using blowers can be used. At high organic loading rates and low retention periods, most soluble BOD is used in the production of new cells, so biomass and therefore sludge production rates are high. High recirculation ratios up to 5:1 are used to prevent the build-up of biomass. Fixed nozzle or channel distribution systems are often used on biotowers as are rotary distributors. Poor distribution of liquid and air can occur on biotowers leading to occasional odour nuisance.

6.2.11.4 Two-stage filtration

Two or more percolating filters in series can be used to produce high quality outflows. Typically, the first filter will remove the more easily biodegradable BOD and the second will complete the carbonaceous oxidation and nitrification of the waste water. High rate and roughing filters are often succeeded by another percolating filter (or activated sludge plant). In this case there is some difference between the media used in either unit. In the first stage, a large medium ensures that clogging or ponding does not occur while in the second more lightly loaded stage, a smaller medium increases the concentration of biomass in contact with the waste water and hence the process efficiency.

The above is easy to arrange when two filters are being constructed, each for a distinct function; where two identical parallel filters are to be modified for series use, alternating double filtration has been applied but is little used today. As both units will have identical (and probably small) media, one will become more clogged than the other due to the higher organic load being applied to it. The lead filter is therefore changed periodically (period to be established empirically) and the excess biomass removed with the aid of lower organic loading rates.

6.2.11.5 Bioaugmentation and nutrient deficiencies

Some plants have a poorly maintained bacterial population caused by such factors as:

- poor nutrient balance in the waste water;
- toxic components in the waste water; sometimes selectively affecting heterotrophs or autotrophs; or
- periodic excessive removal of biomass caused by shock hydraulic, organic or toxic loads.

In such cases, the addition of bacterial culture may provide the necessary microbial population to treat the waste water. When starting up a plant, culture can also be used to colonise the filter bed and reduce the time it takes for a filter to reach full operating capacity. Bacterial culture is supplied in different forms such as dehydrated gels in porous support bags, as powder to be reconstituted or as live culture to be grown and developed in an on-site facility prior to dosing. Dosing can be by batch (e.g. a bucket every day) or by timed or metered pump. Start-up bioaugmentation may be required for 2-3 months.

6.2.12 COMMON OPERATING PROBLEMS

6.2.12.1 Ponding and spring sloughing

Ponding on percolating filter plants results from the loss of open space or the filling of voids between the media causing liquid to collect and pond on the surface. Percolation through the bacteria bed is either very slow or non-existent. Ponding may affect local areas or the entire surface area of a bed. The causes, effects and solutions are explained in Table 6.2. Ponding may be a year round problem but on some plants it occurs in late winter/early spring when bacterial and slime growth increases dramatically but the grazing population has yet to become active. This type of ponding generally occurs in percolating filters with small or degraded media and is often solved by the heavy spring slough which is caused by the increased activity of micro-organisms both inside and outside of the biofilm. To minimise the effects of the spring slough the recirculation rate should be increased to prevent the clogging of the medium.

Where severe ponding occurs, the percolating filter can be flooded or dried out in order to remove excess growth. A filter can be flooded for up to 24 hours. Any existing oxygen is quickly depleted and the biofilm growths become anaerobic and loosen or liquefy. Care should be taken when releasing the flood to avoid hydraulically overloading the humus tanks and washing solids into the final outflow channel. Stopping the flow to a filter for several hours will cause the biofilm to dry out and it can be removed or loosened using a rake. Any loose material will then be washed away with the restarted flow.

The flooding or drying out of a bacteria bed are measures of last resort; the primary ponding control method should be to prevent it from occurring in the first place or to stop it at the early stages using the methods least likely to affect the outflow, as outlined in Table 6.2.

TABLE 6.2 PONDING ON PERCOLATING FILTERS
(US EPA, 1992)

		Solutions	
Cause	**Effect**	**Temporary**	**Long term**
Excessive organic loading with insufficient hydraulic loading.	Rapid biofilm growth and clogging of voids.	Periodically washout using pressure washer or by stopping distributor over affected area.	Install or improve recirculation system to increase hydraulic load to necessary level.
Poor primary settlement.	Excessive organic loading.	Increase recirculation.	Improve primary settlement.
Poor screening of raw waste water.	Build-up of rags and debris on the filter surface blocking flow.	Manual collection of debris and disposal.	Improve screening.
Medium too small *or* not uniform in size*. Medium unsuitable.	Becomes blocked by biofilm growth *or* smaller pieces fill voids between larger pieces. Breaks up too easily or cements/degrades under chemical attack.	Manually dig or rake medium to redistribute it and remove excessive biofilm. Increase hydraulic load periodically.	Replace medium.
Excessive growth of insect larvae or snails.	Accumulates in the voids between the media.	Manually dig out the excess or wash out by increasing flow.	Increase recirculation to avoid larval build-up.

* On older plants, this may be due to the breakdown of media over years or decades.

Hydraulic flow problems other than ponding can be caused by the clogging of distribution arms, vent pipes or collection underdrains. It is important that these are inspected regularly and any rags, leaves or other debris removed. Recirculation pump failure during periods of high flow can increase the effective organic load to a percolating filter and, while treatment efficiency may suffer in the short term, if repairs are promptly carried out, long term effects such as ponding are unlikely.

6.2.12.2 Humus tanks

High suspended solids in a humus tank outflow can be caused by a number of conditions:

- heavy sloughing of biomass from the filters;
- high hydraulic loading or short-circuiting through the humus tank;
- shock organic, hydraulic or toxic loads; and
- sludge floated by denitrification.

High solids loads which adversely affect a humus tank and which are associated with increased sloughing of a percolating filter may be solved by:

- minimising the solids washed out by operating a higher recirculation rate before increased sloughing of biomass occurs;
- ensuring there is no short-circuiting through the tank; and
- removing settled solids as frequently as possible while still allowing for good consolidation to occur.

High hydraulic loads result if the tank is too small for the flow being passed through it; that is, the flow is not slowed down enough for all of the settleable solids to fall from suspension. It may be that recirculation rates are too high. If the outflow is recirculated from a point between the percolating filter and the humus tank, then the latter is unaffected by the increased hydraulic loads. Short-circuiting may be caused by a build-up of consolidated solids in the corner of tanks or by poor inflow distribution or by uneven outflow weirs (all weirs should be set to the same height). Proper design and maintenance of the tank and particularly the outflow weirs should prevent this from happening.

All unit processes should be protected from shock loads. Percolating filters are less susceptible to shock loads than other biological processes but the knock-on effects are often seen at the humus tanks due to poor settleability or carry over of solids. Shock loads are best dealt with prior to the percolating filter plant; recirculation rates can be increased to dilute incoming organic loads or toxins. However, the maximum hydraulic load to a humus tank must not be exceeded in doing this.

Floating sludge in a humus tank is generally caused by gasification or denitrification occurring in the consolidated sludge at the bottom of the tank. The problem is often remedied by increasing the frequency of sludge withdrawal from the tank so that dissolved oxygen does not become depleted thus preventing anoxic conditions from developing in the first place.

6.3 ROTATING BIOLOGICAL CONTACTORS

The rotating biological contactor (RBC) is a biofilm process in which the biofilm support medium is cycled between being submerged where it comes into contact with the waste water and being emerged where the biofilm is exposed to air. Anaerobic biofilms do not adhere to the support medium very well.

There are a large variety of support media on the market but the characteristic unit consists of closely spaced (20-30 mm apart) plastic discs 1-3 m in diameter rotating around a horizontal shaft. The rotation of the discs is driven either by a geared motor connected directly to the shaft, by a peripheral drive on the discs or by air bubbles acting tangentially on vanes attached to the discs. Other RBC media use textured or otherwise modified surfaces with one common purpose: to increase the specific surface area of the medium and thus reduce the overall plant size and cost. Not all RBC media are discs; there are many variations on the market supplied by numerous manufacturers.

Most RBCs are supplied as proprietary package plants often in conjunction with package primary and secondary settlement tanks and thus plants can easily have additional units put on-line or taken off-line. This flexibility of operation of RBCs has been a major selling point particularly with smaller customers.

Loading rates to RBCs should not exceed 5 g soluble BOD/m^2.d (expressed in terms of the total surface area of media, free and immersed) for settled waste water or 7.5 g total BOD/m^2.d for raw waste water. Refer to manufacturers' literature for significant variations.

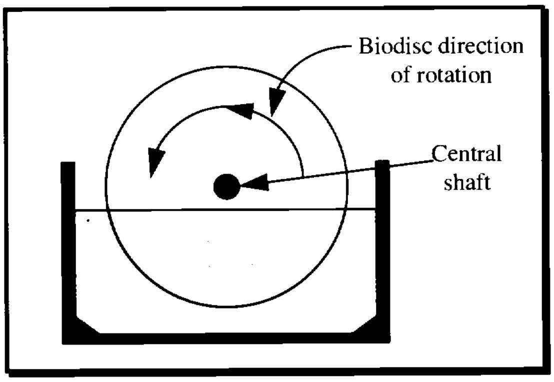


FIGURE 6.6 ROTATING BIOLOGICAL CONTACTOR

The speed of rotation of the biodiscs should not exceed 0.35 m/s so the rotation frequency will depend on the disc diameter. A fast rotation speed may erode the biofilm partly by the scouring action of the water and partly by centrifugal force and a slow rotation speed may not sufficiently aerate the biofilm or erode excess biomass. The rotation of the biodiscs must also prevent settlement of solids in the aeration tank.

Tapered spacing of discs in an RBC, with larger spaces at the upstream end, allows for high rates of biofilm growth in the initial stages of the process. It is important not to allow bridging of the biofilm between discs. Scrapers between the discs have been used to prevent the biofilm from exceeding a certain depth.

Many RBCs operate in a plug flow mode with little back-mixing of waste water. This is accomplished by having a number of compartments with weirs or other separators between stages.

The sludge produced by an RBC is settled in a secondary settlement tank. The sludge is often returned to the primary settlement tank for co-settlement or stabilisation. Some RBCs suffer from grit and sludge settlement in the aeration stage. This is often due to a low hydraulic loading rate and may be associated with the generation of a light feathery sludge which does not settle well; this is caused by the septicity of the settled material and should be treated as an early warning to desludge the aeration tank.

If the RBC stops the emerged biomass will become exposed to the air and it may dry out and break off the discs; this will result in a serious imbalance in the distribution of weight on the disc medium which may cause the shaft to fracture when the RBC is re-started. Although common in the past, this problem has largely been overcome by using stronger shafts and bearings and self-start motors with sufficient strength to overcome any imbalances on the biodiscs.

Odours have been associated with biodiscs but these are generally caused by organic overloads or septicity caused by deep biofilms or settlement of sludge in the aeration tank. Organic overloads may be remedied by providing additional treatment units or by recirculating the outflow to dilute the incoming waste water. Septicity of settled sludge is remedied by removing the sludge more frequently. Fat and grease can leave deep deposits on the biodiscs thus reducing the available treatment area.

6.4 SUBMERGED FILTERS

Submerged filters are marketed under a wide variety of names for a wide variety of purposes. They have been called submerged biological aerated filters and biological aerated flooded filters, but have probably been best known as BAFs. However, the term 'submerged filter' also refers to units which do not have any aeration equipment and which do not support biological growth. For this reason, the term used in this manual will be *submerged filters*.

6.4.1 PRINCIPLE OF OPERATION

Submerged filters combine some of the principles of the biofilm and activated sludge processes. A biofilm is attached to and grows on a submerged medium which may be under active aeration. There is little natural erosion of biomass so backwashing is required periodically to prevent the unit from becoming clogged due to excessive biomass growth. There are many configurations, shapes, sizes and media available and the different systems can be differentiated by:

- the direction of flow: upflow or downflow;
- the aeration of aerobic processes or the non-aeration of anoxic processes;
- the organic and hydraulic loading rates which depend on the function (e.g. BOD removal, nitrification, suspended solids removal);
- the sludge production and how it is separated from the liquors;
- the requirement or not of a separate secondary settlement stage;
- the outflow characteristics; and
- the relationship with other process units.

6.4.2 UPFLOW OR DOWNFLOW

Unlike percolating filters, submerged filters do not depend on gravity to draw the flow downwards through a bed of media. Because the medium is submerged, flow can travel either upwards or downwards. Some of the advantages of each mode of operation are shown in Table 6.3. Some manufacturers sell both upflow and downflow systems.

6.4.3 MEDIA SELECTION

The choice of medium used depends to some extent on whether upflow or downflow mode is used. Media types are based around:

- structured media which are similar to that used in percolating biotowers and may be used in either mode;
- packed (sunken) random granular media which range in size from 2 mm to 10 mm and are made up of materials as diverse as volcanic pumice, expanded shale and plastic extrusions can be used in either mode; and
- buoyant random granular media used in upflow reactors which range in size from 4 mm to 10 mm and are made of plastics such as polyethylene, polypropylene or expanded polystyrene whose specific gravity is one or just less than one.

Media are chosen for their properties of surface roughness and specific surface area (SSA), cost, durability and size distribution. Plastic media have been found to be most durable and least likely to break up. Media which do degrade can exit the reactor with the outflow or clog up the interstices causing short-circuiting of liquid.

In terms of size, the largest media will be used for carbonaceous oxidation as maximum void space is needed for rapid biofilm growth. Smaller media may be used for nitrification where less biofilm growth occurs and the reaction rate is much slower. A roughened surface ensures that all the biomass is not removed during backwash and that re-start is as rapid as possible. Smooth surfaces are acceptable in carbonaceous oxidation as maximum sludge removal is desirable. The smallest media used are for suspended solids removal where there is no aeration; the process is a physical filtration. The smaller media remove a larger proportion of solids. Smooth media are used in order to ensure maximum solids removal during backwash.

6.4.4 AERATION SYSTEM

Blowers and aeration equipment similar to that used in activated sludge are often used, although cheaper versions have been developed. Sunken media reactors have used lateral aeration pipes with fine to coarse sparge holes of 1-2 mm diameter with separate pipes for outflow collection and backwash water provision. Combined air/liquid laterals have been developed which provide aeration and liquid flow to and from the base of a reactor (Figure 6.7).

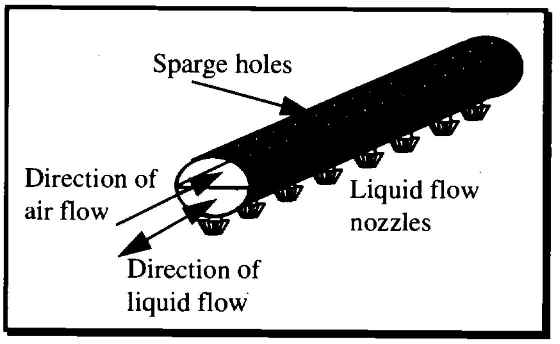


FIGURE 6.7 SPARGE PIPES FOR AERATION

Additional capacity is required in the aeration equipment to provide backwash air. Typically, this is provided by additional standby or dedicated air blowers although variable speed blowers are also used. The pipework must also be sized adequately to accommodate the increased pressure.

6.4.5 LOADING RATES

Loading rates are similar to or higher than conventional aeration plants:

- 0.25-2.0 kgBOD/m^3.day for carbonaceous oxidation (expressed in terms of m^3 total empty bed contact volume);
- 0.25-1.0 kgNH_3-N/m^3.day for nitrification;
- hydraulic loading rates up to a maximum for suspended solids removal processes of about 10 m/hr. More conventional rates are of the order of 1-4 m/hr. (*Calculated from: m^3 flow applied/hour per m^2 media bed surface area; m^3/m^2.hr = m/hr*).

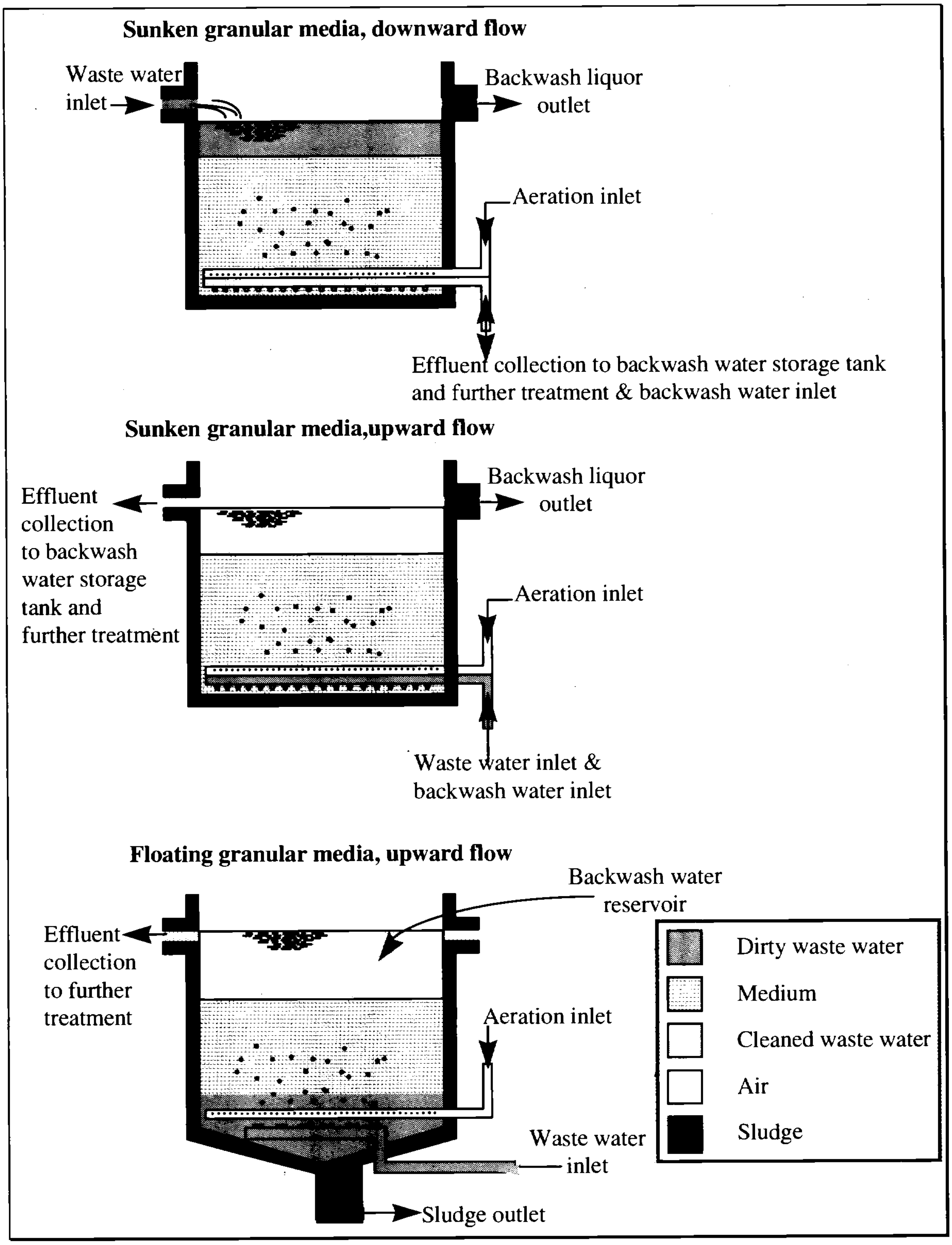


FIGURE 6.8 SUBMERGED BIOLOGICAL AERATED FILTERS

TABLE 6.3 UPFLOW OR DOWNFLOW SUBMERGED FILTERS
(Upton *et al*, 1993)

	Upflow submerged filters
Advantages	Good inflow distribution across the bottom of a bed. Reduced localised headloss build-up and increased possible flow velocities. More complete use of the media depth. Suspended solids become trapped throughout the full depth. Wash water reservoir sits above medium so no additional wash water tanks needed. Fewer odours. Off-gases are scrubbed by clean outflow at top of reactor. In downflow, air stripping of volatile compounds can occur with air passing through dirty waste water in the top of the tank. Research on pilot scale has claimed better reaction kinetics probably due to more efficient distribution of air and liquid and hence more effective use of reactor volume.
	Downflow submerged filters
Advantages	The media acts as a physical barrier to block any debris, such as rags, which could not be accessed at the base of an upflow system. Less intermixing or intergrading of granular media occurs. This allows for more successful stratification for nitrification. Smaller process air volumes and headlosses are claimed. Separate backwash water tanks mean a smaller depth of water above the aerators so smaller headlosses result. Media and inflow channels are more accessible for maintenance.

Some reactors combine a relatively low organic loading rate with nitrification while others require additional reactors operated in series in order to nitrify. Other downflow reactors use a raised aeration grid such that the bottom of the bed is unaerated and acts as a physical filter. Upflow systems with a raised aeration grid will allow denitrification if a carbon source is applied. Most biological submerged filters require a solids removal stage to remove any residual suspended solids from the outflow. Submerged gravel or sand filters are often used. These do not need to be as large as the biological reactors because of the higher hydraulic loading rates that are possible.

6.4.6 BACKWASH REQUIREMENTS / AIR SCOUR

Excessive bacterial slime growth (as in percolating filters) can cause clogging of the medium. Using tightly packed granular media, hydraulic erosion during normal operation does not occur so backwashing of the medium bed clears it of excessive growth. As biomass builds up on the medium and it becomes more clogged, the hydraulic head loss across the bed increases; it may completely block the bed in time. The increased head loss can be used as a trigger for backwash to take place. More usually, backwash takes place on a timed basis with headloss being used as an override in abnormal hydraulic or organic loads.

Variations in the sequence for backwashing granular media exist depending on the manufacturer and type of process but the basic sequence is as follows:

- inlet flow stops; the bed remains submerged;
- air flow is increased by 2-3 times to expand the medium and dislodge excessive attached or interstitial solids. This is called the air scour;
- backwash water is introduced (either upflow or downflow) and, combined with the air scour, washes the loosened solids from the reactor;
- air scour is stopped. Backwash water continues flushing out the bed;
- water scour stops and the medium settles back into place; and

- normal flow is re-introduced; on some processes the first flush of outflow needs to be recycled because of large concentrations of suspended solids. This is called the recovery period.

Reactor outflow is generally used for flushing the medium during backwash. It is stored in separate clean backwash water tanks or, in the case of some upflow reactors, above the medium (see Figure 6.8).

The backwash frequency will vary depending on the function of the filter and on the growth rate of the micro-organisms inside. Due to the high rate of biomass growth in reactors designed for carbonaceous oxidation, reactors will require backwashing at least once every 24 hours. Nitrifying reactors, because of the slower growth rate of nitrifying bacteria, will require backwashing at frequencies between weekly and monthly depending on the organic load. If the frequency of backwash of nitrifying reactors is too high, the nitrifying bacteria may be washed out; i.e. the rate of removal is greater than the growth rate. Solids removal reactors are backwashed at least daily and often more frequently depending on the solids load. The recovery period must not be longer than the backwash frequency.

Where carbonaceous BOD removal and nitrification are to be carried in one unit operation then a submerged aerated filter with a medium that will remain stratified during backwash should be used; i.e. the layers containing the heterotrophic and autotrophic bacteria should not become mixed up as the autotrophs will be unable to compete effectively against the heterotrophs. Such a medium will typically be a heavy granular sunken medium which expands but does not become mixed during the air and water scours. Structured media will also satisfy this function.

Although structured media reactors do not generally require frequent backwash, excessive biomass growth and grit settlement on the reactor floor may cause hydraulic blockages and short-circuiting to occur. On a monthly basis, scouring of the medium using high hydraulic loading rates will remove excess biomass and draining the liquid through purpose installed valves in the reactor floor will flush out any settled solids or grit. Similarly, moving bed biofilm reactors may require periodic removal of material settled on the floor.

6.4.7 OUTFLOW CHARACTERISTICS

High quality outflows are possible using submerged filters due to their intensity of operation and the concentration of biomass supported by the biological units. In filtration units, the tightly packed nature of the medium ensures an outflow which is low in suspended solids.

6.4.8 RELATIONSHIP WITH OTHER UNIT PROCESSES

While many submerged aerated filters have been applied as new plant incorporated with preliminary works, many have been used to extend the capacity of existing plants. Frequently where available land area does not permit expansion in conventional plant, submerged filters may achieve the expansion required in a smaller footprint. Some of the applications include:

- additional carbonaceous capacity operating in parallel with existing plant;
- additional nitrification capacity operating in series with existing plant, i.e. treating the outflow from existing plant;
- anoxic pre-treatment for denitrification and organic load reduction to downstream existing plant; and
- tertiary polishing or solids removal operating after secondary settlement.

6.4.9 DISSOLVED OXYGEN CONTROL

The operation of aerobic submerged filters may be adversely affected by a lack of dissolved oxygen. Thus, many smaller plants operate using a continuous minimum air flowrate with little regard for the resulting oversupply during periods of low flow or low organic loading. However, because of the cost of operating large blowers, larger plants may include airflow controls based on one of the following criteria:

- during periods of high flow, additional blower capacity is brought on line either by ramping up variable speed blowers or by starting extra units. The protocol can be governed either by flowmeters or by pre-programmed diurnal flow variations; or
- the DO in the tank is continuously measured and the blowers controlled accordingly. This technology is frequently used in activated sludge processes.

6.4.10 COMMON OPERATING PROBLEMS

6.4.10.1 Unscheduled backwashing

Submerged filters generally backwash at scheduled times in order to ensure consistency of operation. However, as discussed in section 6.4.6, if the headloss increases abnormally then an unscheduled backwash may override the system timer. Increased headloss across a filter bed may be caused by:

- an increased organic loading resulting in higher biomass growth rates;
- an increased hydraulic loading resulting in a greater resistance to flow across the medium bed; or
- a blockage of the medium or pipework.

Possible causes of a blockage may include sediment or grit buildup, rags, inefficient air or water scour or uneven distribution of flow between filters.

The difficulty in cleaning a submerged medium once it has become fouled by material such as rags, highlights the importance of fine screening of influent waste water where submerged filters are to be used.

6.4.10.2 Medium loss

Some medium loss takes place from almost every proprietary submerged filter system on the market. The designer or operator should assess:

- whether the manufacturer has quantified this?
- what is the acceptable loss of medium before replacement becomes necessary? and
- where does the lost medium go to and what effect will it have on other unit processes such as primary settlement tanks, pumps and other equipment? Will it be discharged with the plant outflow and affect the effluent quality?

Most media are lost during backwash and therefore end up in the waste sludge system. If the medium is buoyant it may end up floating on the surface of primary settlement tanks or sludge thickeners. If it is not buoyant, it may settle in pipes or tanks and cause blockages. If the medium settles in the primary sedimentation tank, it may cause damage to pumps or other equipment because of its gritty nature.

A medium may begin to break down as it approaches the end of its design life. During this period an increase in medium loss may be apparent either by observing the outflow or the level of medium in the tank (if possible).

6.4.10.3 Power failure

Many submerged filter plants are power dependent and in the event of a power failure will not operate. It is important in such events to have sufficient storage capacity (in the wet well for example) for action to be taken in order to avoid untreated effluent being discharged through overflows.

6.4.11 NUISANCE

The main sources of nuisance in submerged filter plants are odours and noise. Odours may result particularly from downflow filters (see Table 6.3) or from waste sludge storage tanks. Due to their compact size, it is relatively easy to cover these units and provide odour abatement processes. Noise nuisance results generally from the operation of aeration blowers. This can be controlled by use of acoustic enclosures.

7. NUTRIENT REMOVAL PROCESSES

7.1 DEFINITION OF NUTRIENT REMOVAL

In waste water treatment, the term 'nutrient' generally refers to compounds of nitrogen and phosphorus which are responsible for enrichment of water bodies and which cause eutrophication which detrimentally impacts on water resources. Nutrient removal involves reducing the concentrations of phosphorus and nitrogen in the waste water so as to prevent algal and other photosynthetic aquatic plant growth in the receiving waters. Basically, it is the conversion and removal of compounds containing nitrogen and phosphorus so as to avoid enrichment of water bodies. In the course of biological waste water treatment nutrients are taken up by micro-organisms. However, this is a relatively small amount when compared to the remainder which must be removed from waste waters where these are deemed to promote excessive enrichment of sensitive water bodies.

7.2 THE NEED FOR NUTRIENT REMOVAL

In the Environmental Protection Agency Act, 1992 (Urban Waste Water Treatment) Regulations, 1994, provision has been made for the definition of sensitive areas. Ten areas have been identified based on the sensitivity of receiving water bodies to nutrient enrichment and eutrophication and are listed in Appendix D. Article 5(6) of the UWWT Directive (91/271/EEC) requires that the identification of sensitive areas is reviewed at intervals of no more than four years.

Nutrients in the environment come from two major source types: point and diffuse. Urban waste water is generally collected and directed to a discharge point or to a treatment plant and thus the point of entry to the aquatic environment can be pinpointed and controlled. It is termed a point source. Diffuse sources may be characterised by run-off from agricultural or non-agricultural land. These are more difficult to control and reduce.

The following example from Randall *et al*, 1992, illustrates the effect of nutrients on the environment. *If 1 kg of phosphorus is completely assimilated by algae and used to manufacture new biomass (from photosynthesis and inorganic elements), biomass weighing 111 kg with a COD of 138 kg would be produced. This assumes that algae can be represented by* $C_{106}H_{263}O_{110}N_{16}P$. *Thus a discharge containing 6 mg/l P could potentially result in COD production in an equivalent volume of receiving water of 828 mg/l, more than double the COD in a typical waste water. Similarly, a discharge containing 30 mg/l N has the potential to produce a COD of 600 mg/l in an equivalent volume of water.* It is now well established that phosphorus and nitrogen are the principal nutrients controlling algal and rooted plant growth in water. In relation to plant needs, phosphorus is normally less abundant than nitrogen in freshwater and it is frequently the growth limiting factor regulating algal and plant development. In estuarine and coastal water, nitrogen is the growth limiting nutrient.

Within an urban waste water treatment plant nitrogen and phosphorus may also be removed from return liquors arising in sludge dewatering plants.

7.3 MECHANISM AND APPLICATION OF NITROGEN REMOVAL

7.3.1 PHYSICO-CHEMICAL NITROGEN REMOVAL

Physico-chemical methods of nitrogen removal have not been widely applied in waste water treatment because:

- they are generally more expensive to operate than biological treatment;
- they produce a poorer effluent quality than biological treatment; and
- they produce more sludge.

7.3.1.1 Air stripping of ammonia

As the pH increases, a greater proportion of ammonia converts from NH_4^+ to NH_3.

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

Therefore, if the pH of a waste water is increased and the liquid brought into contact with air, a gradient will exist across the gas/liquid interface and ammonia will be stripped to the air. Cooling or other simple towers may be used as contactors and lime or caustic soda for pH adjustment. The build-up of lime scale on the media of these units has been a major problem in their operation. The ammonia in the stripping air may be removed by two methods:

- by passing the gas through a filter for biological removal, or
- by passing the gas through a scrubber to re-dissolve the ammonia in water which can be treated separately to the main process stream.

7.3.1.2 Ion exchange

Zeolites have been found effective in many water, waste water and industrial applications as molecular filters which can distinguish molecules at the ionic level. For example, the natural zeolite clinoptilolite is selective for the ammonium ion in preference to other ions present in solution. A filtered waste water can be passed through a bed of zeolite to effect a 90-97% ammonium removal.

7.3.1.3 Breakpoint chlorination

By adding chlorine to a waste water, a stepwise reaction takes place which results in the conversion of ammonium to nitrogen gas.

$$NH_4^+ + 1.5HOCl \longrightarrow 0.5N_2 + 1.5H_2O + 2.5H^+ + 1.5Cl^-$$

A stoichiometric ratio of Cl_2:NH_3-N = 7.6:1 will achieve a 95-99% conversion to N_2. Subsequent dechlorination of the waste water stream may be required. Undesirable by-products may result from the chlorination process.

7.3.2 BIOLOGICAL NITRIFICATION AND DENITRIFICATION

The processes for biological nitrogen removal can be incorporated or retrofitted into both activated sludge and percolating filter plants. The overall mechanism follows the route of nitrification (oxidation of ammonia to nitrite and nitrate) and denitrification (reduction of nitrate sequentially to nitrite, nitric oxide, nitrous oxide and nitrogen).

Nitrification	**Denitrification**
Ammonia, NH_3	Nitrate, NO_3^-
↓	↓
Nitrite, NO_2^-	Nitrite, NO_2^-
↓	↓
Nitrate, NO_3^-	Nitric oxide, NO
	↓
	Nitrous oxide, N_2O
	↓
	Nitrogen, N_2

In modifying an existing plant for nitrification, up to 25% additional oxygenation and volumetric capacity may be required. On lowly loaded plants, nitrification can occur automatically due to the capacity remaining after carbonaceous oxidation. Their slower growth rate and susceptibility to shock loads and hydraulic washout mean that nitrifiers require more stable conditions and longer hydraulic and solids retention times than heterotrophic carbonaceous bacteria.

Denitrification is an anoxic process which takes place in the absence of dissolved oxygen. The nitrate and nitrite produced during nitrification become the oxygen source for heterotrophic bacteria which utilise the available BOD. In essence, what is required are: bacteria, oxidised nitrogen as the oxygen source and a carbon source.

In percolating filter processes, these conditions will be provided in a separate reactor which may precede or succeed the biofilters themselves. Conventionally, if the reactor precedes the biofilter, settled sewage is used as the carbon source and recirculated nitrified biofilter effluent (either settled or unsettled, depending on the nature of the reactor) provides the nitrate. This is termed pre-denitrification and is illustrated in Figure 7.1. If the reactor succeeds the biofilter (Figure 7.2), nitrified effluent again provides the nitrate but the carbon source is provided by dosing a carbon rich chemical such as methanol (CH_3OH). Such dosing processes are controlled to avoid excess methanol getting into the effluent stream, thereby increasing its BOD. Submerged unaerated reactors are generally used and good results have been achieved at high hydraulic and organic loading rates. Simultaneous nitrification and denitrification is possible on some proprietary submerged filters (see Figure 7.3). Sludge production is high when operated at high loading rates.

In the activated sludge process, denitrifying conditions are provided in a separate anoxic zone at the front end of a nitrifying plant. Organic carbon from the incoming waste water and nitrate provided in the RAS are utilised by the micro-organisms. Anoxic zones can occupy 25-40% of the total capacity of an activated sludge lane and can therefore provide significant savings in the energy required for aeration. In utilising the oxygen contained in the RAS to satisfy incoming BOD, the actual organic load carried forward to the aerated section of a plant is reduced. This allows for more complete treatment of an effluent or improved nitrification downstream. Anoxic zones may have the added benefit of improving the settleability of mixed liquor and of helping to control bulking and filamentous bacterial growth, particularly in plug flow tanks. Anoxic zones are low dissolved oxygen areas or tanks with weir or baffle overflows to the aeration lanes.

Mechanical mixers are generally required to keep the mixed liquor in suspension.

Biological denitrification processes generally recirculate nitrified effluent as a source of nitrate. This means that 100% removal can never be achieved. Only the nitrate contained in the recirculated stream will be removed; thus, referring to Figure 7.1, if the recycle ratio is 1:1, then a maximum 50% NO_3 removal is possible, i.e. only half of the flow is recirculated. If the recycle ratio is 3:1, then a 75% removal is possible. Obviously, the recycle ratio becomes limiting due to hydraulic constraints on the plant and allowances must be made for periods of high flow. As many plants are designed for a throughput of no more than 3 DWF, there are practical limitations on the amount of NO_3 removal possible.

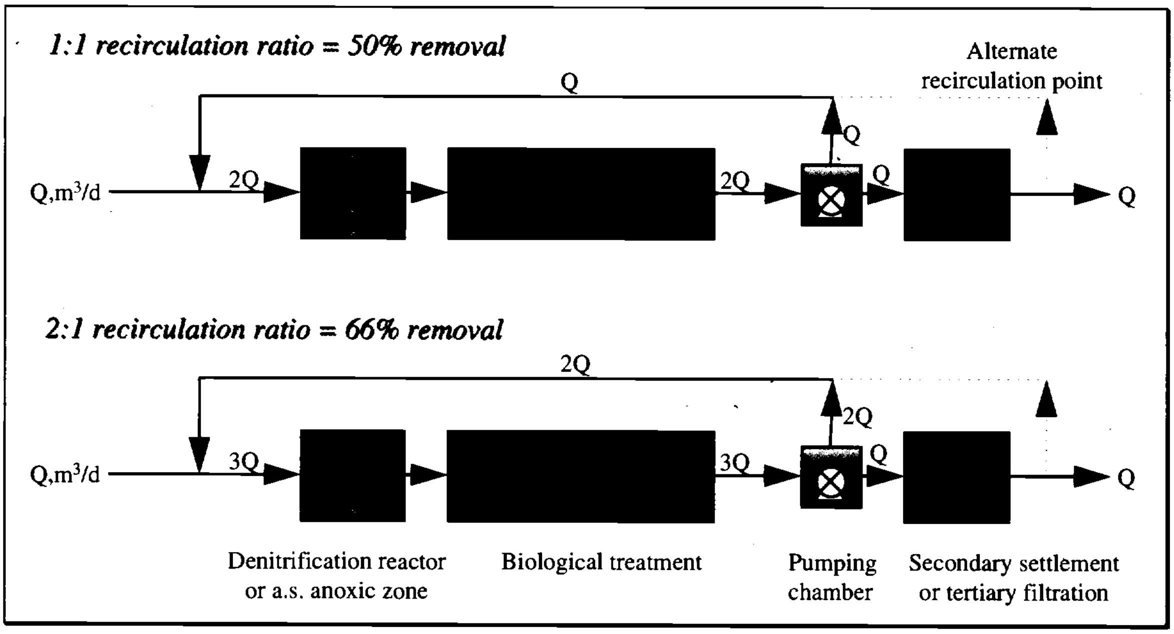


FIGURE 7.1 BIOLOGICAL PRE-DENITRIFICATION AND THE EFFECT OF RECIRCULATION RATIO

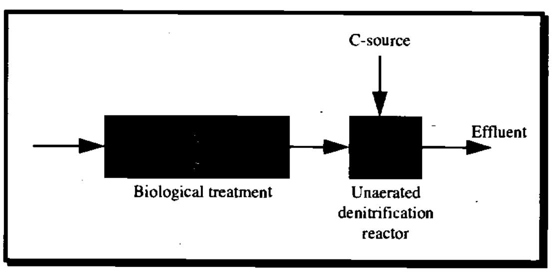


FIGURE 7.2 BIOLOGICAL POST-DENITRIFICATION

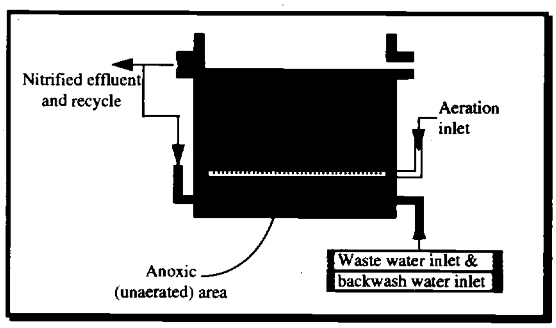


FIGURE 7.3 SIMULTANEOUS BIOLOGICAL NITRIFICATION AND DENITRIFICATION

7.4 MECHANISM AND APPLICATION OF PHOSPHORUS REMOVAL

7.4.1 CHEMICAL PHOSPHORUS REMOVAL

Phosphorus exists in three main forms in waste water; ortho-phosphate, polyphosphate and organic phosphate. During aerobic treatment, the latter two forms are converted to ortho-phosphate which is the easiest form to precipitate using chemical addition. Metal salts are generally used for the precipitation of phosphate according to the reaction:

$$M^{3+} + PO_4^{3-} \longrightarrow MPO_4$$

Sulphates and chlorides of ferric (Fe^{3+}), and ferrous (Fe^{2+}) iron and aluminium are most suitable (Table 7.1). Ferric sulphate has been commonly applied although ferrous sulphate is increasingly being used. The metal salt can be applied at a number of different points:

- prior to primary sedimentation;
- at the biological stage; or
- prior to the secondary clarification stage.

Figure 7.4 illustrates the most commonly used dosing locations. Effluent phosphate concentrations of 0.1 mg/l P are theoretically possible depending on the chemical used and on the dosing point, although a concentration of 0.2 mg/l is more likely to be achieved in practice.

TABLE 7.1 CHEMICAL PHOSPHORUS REMOVAL PERFORMANCE
(Day, 1995)

Mole ratio	Effluent mg/l P	Dosing point (see Figure 7.4)	Chemical precipitant
0.8	2 to 3	Simultaneous	Fe^{3+}
0.8			Al^{3+}
1.0		Pre	Al^{3+}
1.0	1 to 2	Simultaneous	Fe^{2+}, Al^{3+}
1.0		Pre	Al^{3+}
1.0		Post	Fe^{2+}
1.5	0.5 to 1	Simultaneous	Fe^{2+}, Al^{3+}
2.0		Pre	Al^{3+}
1.5		Post	Fe^{3+}

The Fe^{3+} oxidation state is the active form of the iron salts. Fe^{2+} must therefore be oxidised to Fe^{3+} before it becomes viable. Therefore, if Fe^{2+} is dosed into a primary settlement tank, it will gradually become oxidised as it passes through the treatment plant. Active Fe^{3+} is thus available after the biological stage to react with any newly available ortho-phosphate. This can avoid the need for expensive metering equipment and dosing of chemicals near an effluent discharge point. Chemical dosing immediately before a percolating filter plant may cause a buildup of insoluble precipitate on the surface of the filter bed which can cause ponding. Adequate hydraulic loading rates will reduce the effects of ponding.

Phosphorus removal chemicals can be corrosive and hazardous substances and due regard must be paid to the appropriate health and safety literature. Tanks for liquid storage must be constructed and bunded to the appropriate building regulations and chemical deliveries by contractors should be fully supervised.

Dosing pumps are generally of the adjustable diaphragm or peristaltic type and are themselves bunded or contained within the bounds of the tank bund.

A control system for chemical dosing may be required to ensure the process performs satisfactorily and to minimise overuse of the chemical. The control regime can use the following criteria:

- continuous constant dosing rate - based on an average influent load; attenuation of the load will take place in the treatment plant;
- timed constant dosing rate - e.g. for periods of known high flow/load;
- on-line feed-forward control - chemical dose is proportional to the measured flowrate or P concentration; and
- redox potential or feedback control - chemical dose is proportional to the measured redox or effluent P concentration; this needs empirical setup.

It must be remembered when dosing chemicals to waste waters to ensure that concentrations in the effluent stream do not significantly affect the receiving water. Any probes used will need to be maintained and calibrated at specified intervals.

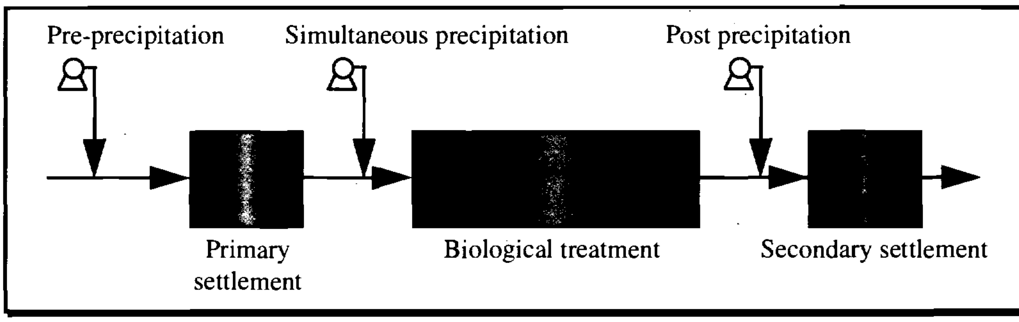


FIGURE 7.4 DOSING POINTS FOR THE CHEMICAL PRECIPITATION OF PHOSPHORUS

7.4.2 BIOLOGICAL PHOSPHORUS REMOVAL

Biological phosphorus removal is dependent mainly on the ability of the bacterium *Acinetobacter spp.* to release phosphate under anaerobic conditions and to absorb it under aerobic conditions. The role of this bacterium in the process has only recently become understood and its basic biochemistry is illustrated in Figure 7.5.

The mechanism of P removal by *Acinetobacter spp.* follows this sequence:

- under anaerobic conditions, readily biodegradable organic matter (i.e. BOD) becomes fermented to short chain fatty acids (SCFA). These are stored in the cell as poly-hydroxyl butyrates (PHB). This is fuelled from the energy released by the hydrolysis of stored poly-phosphates;
- under aerobic conditions the stored PHB is oxidised and energy is released allowing the assimilation of soluble ortho-phosphate;
- the ortho-phosphate is metabolised by the cell and excess quantities are stored in the cell as poly-phosphate. The storage of excess phosphate is known as 'luxury uptake' of P and it is this particular ability of the cell that is exploited in the nutrient removal process.

Thus, if the cell is cycled between anaerobic and aerobic zones in an activated sludge plant, P will be alternately released and taken up. Growth of the *Acinetobacter* population occurs as a result of organic matter utilisation and this excess must be removed as waste sludge. Phosphorus is thus removed from the waste water stream via the waste activated sludge. The ability of *Acinetobacter* to assimilate organic matter in the anaerobic zone gives it a competitive edge over non-facultative heterotrophic bacteria; therefore its population can grow to sufficient size to remove large amounts of P. Bacterial selection of this type is similar to that which may be used in controlling the growth of filamentous bacteria in bulking activated sludges.

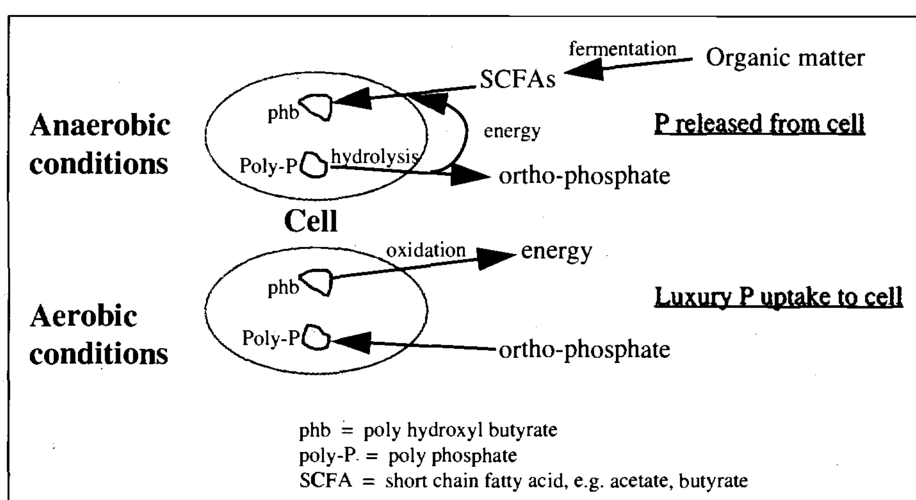


FIGURE 7.5 ILLUSTRATION OF CELL MECHANISM FOR P RELEASE AND LUXURY UPTAKE

A number of process conditions must be met to ensure successful P removal (Day, 1995) and these include:

- dissolved oxygen and nitrate must be excluded from the anaerobic zone;
- sufficient SCFA must be present to ensure there is sufficient PHB stored for use in the aerobic zone. Some weak waste waters are deficient and require the addition of SCFAs (typically as dosed chemicals like acetic acid or as septic primary sludge liquors which are generated either in sludge storage tanks or purpose built fermenters). Wet weather can dilute a normally strong waste water, so rainfall can upset P release. Temporary SCFA supplements may be required for such occasions;
- enough DO must remain in the settlement tank to ensure that the settled sludge remains aerobic and that P is not released to the liquid phase and hence to the outflow; and
- as the P is contained within the solid fraction, good solids capture is necessary in the secondary settling tank.

Under anaerobic conditions the phosphate contained in the waste activated sludge will be released; thus, on storage, the sludge must be kept aerobic. If the sludge is anaerobically digested, avoid returning P-rich supernatant liquors to the main process stream.

7.5 COMBINED BIOLOGICAL N AND P REMOVAL

Although some research has been carried out on biological nutrient removal in submerged filters, combined biological nutrient removal (BNR) is most viable at present in the activated sludge process. Thus a combination of the above techniques are applied. A number of patented variations of the activated sludge process are available as retrofits or as new plant. Some of these are illustrated below. The following outlines the function of each zone in the combined N & P removal plant:

- the role of the anaerobic zone is to provide an oxygen free zone for the generation of SCFAs and the release of ortho-phosphate;
- the anoxic zone ensures that nitrate is removed and prevents oxygenation of the anaerobic zone (where the anoxic zone precedes the anaerobic zone). The proportion of nitrate removed is dependent upon the recirculation ratio;
- the aerobic zone performs carbonaceous oxidation, nitrification and phosphorus uptake; and
- the clarifier, which must be kept aerobic, concentrates the mixed liquor and provides the return activated sludge and the waste activated sludge which contains the removed phosphorus.

Recycle ratios vary from process to process and will depend on local conditions and on empirically derived operating conditions and parameters and will generally be set up when a plant is commissioned.

The PhoStrip process (Figure 7.6), developed in the 1960s and 1970s, was the first combined N and P removal system. In this process, a sidestream (30-35%) of the return activated sludge is taken to an anaerobic 'stripper' tank where P is released into solution. The sludge, which is now P-free is recycled as normal to the aerobic zone where it readily absorbs more P. The P-rich supernatant is dosed with lime to form a calcium phosphate precipitate and this is settled out in the primary settlement tank. Thus, phosphorus is removed with the primary sludge. Nitrogen is removed by exposing the RAS to anoxic conditions before returning it to the aeration basin.

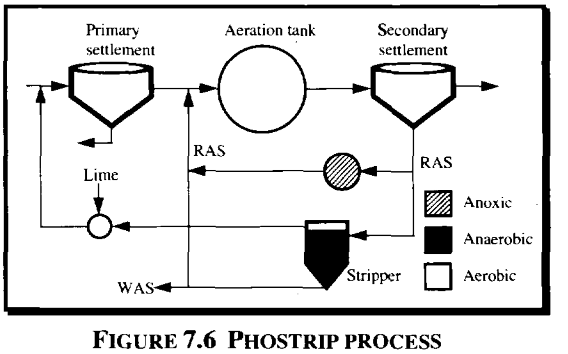


FIGURE 7.6 PHOSTRIP PROCESS

The Bardenpho process (Figure 7.7) began as a denitrifying reactor when it was observed that it removed large quantities of phosphorus. Improvements to the Bardenpho have added anaerobic zones and the result was the modified Phoredox or A^2/O process. A second anoxic zone was removed as denitrification rates were slow due to a lack of carbonaceous material. High recycle ratios of nitrified effluent from the aerobic zone to the anoxic zone ensure a minimal amount of nitrate is returned to the anaerobic zone thus minimising the amount of oxygen in the system and maximising the P release. The Bardenpho/Phoredox process requires a COD:Total N ratio greater than 10 to ensure complete denitrification and a COD:P ratio greater than 40 to maximise phosphorus removal.

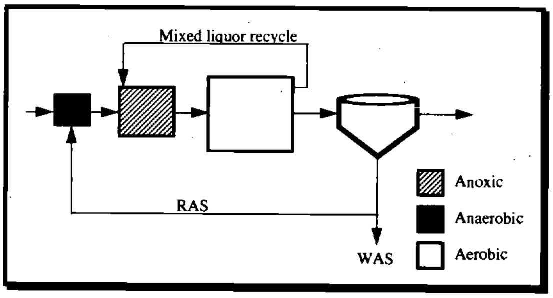


FIGURE 7.7 MODIFIED PHOREDOX, A^2/O, 3-STAGE BARDENPHO PROCESS

The UCT (University of Cape Town) process (Figure 7.8) protects the anaerobic zone fully from any nitrate contained in the return activated sludge. The nitrate rich RAS is returned to the anoxic zone where it is mixed with the mixed liquor recycle to remove all residual nitrate. Close control of the volume of mixed liquor recycle ensures good nitrate removal. When the anoxic zone effluent is recirculated to the anaerobic zone, it is nitrate free thus ensuring maximum P release. A multi-celled (at least 2 cells per zone) version of the UCT is marketed in the USA as the VIP (Virginia Initiative Plant).

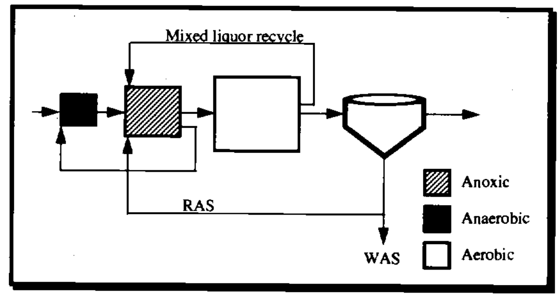


FIGURE 7.8 UCT, VIP PROCESS

Many new and retrofitted plants have used variable speed pumps and flexible piping to connect the process stages and to provide recycles. This provides for some flexibility of operation and for the best empirically derived treatment configuration to be used. Bench scale or pilot studies are advisable prior to applying BNR to ensure that the waste water is suitable.

TABLE 7.2 NUTRIENT REMOVAL PROCESS SELECTION AND APPLICATION

	Activated sludge	Percolating filter	RBC	Submerged filter
Biological nitrification	✔	✔	✔	✔
	Additional capacity or upgrades on separate units generally required			
Biological denitrification using sewage as C-source	✔	✔ separate reactor required with recirculation	✔ separate reactor required with recirculation	✔
Biological denitrification using external C-source	✔ unusual	✔ separate reactor required	✔ separate reactor required	✔
Chemical P precipitation	✔	✔	✔	✔
Biological P removal	✔	not applied	not usually applied	✔ complex - under development

8. DISINFECTION

8.1 INTRODUCTION

Disinfection of urban waste water is the destruction of disease bearing micro-organisms or pathogens. It is distinct from sterilisation which involves the complete destruction of all organisms in the liquid being treated. Disinfection has not been extensively practised in Europe to date; in the USA a large proportion of discharges are disinfected using chlorine. However, in order to comply with EU directives such as:

- the shellfish directive (79/923/EEC), as implemented by S.I. 200 of 1994, and
- the bathing water directive (76/160/EEC), as implemented by S.I. 155 of 1992 and S.I. 230 of 1996,

sanitary authorities may in future have to consider the use of disinfection.

Activated sludge and biofilm systems will disinfect the waste water to some degree but few achieve greater than 90% removal of pathogenic micro-organisms. For complete disinfection, further treatment is necessary. The pathogenic micro-organisms to be removed include faecal coliforms and streptococci, salmonella and enteric viruses.

The main techniques for the disinfection of urban waste water fall into three main categories:

- Chemical;
- Physical; and
- Irradiation.

Chemical disinfectants include chlorine, ozone and hydrogen peroxide. The factors influencing the performance of chemical disinfectants are the contact time, the efficiency of mixing, the type and concentration of chemicals used, the residual remaining, the pH and the concentration of interfering substances which may reduce the effectiveness of the disinfectant.

The principal physical methods rely on enhanced removal of solids and membrane technologies. Ultra-violet (UV) light is the principal method of irradiation used.

8.2 CHLORINE DISINFECTION

Chlorine is widely used in drinking water treatment for the disinfection of surface and groundwater. It is a strong oxidising agent and reacts with any organic matter present in the water. As a result of the large concentrations of organic matter in waste waters, higher doses are required (than in drinking water treatment) in order to achieve similar levels of disinfection. Chlorine may be applied in a number of forms such as chlorine gas, sodium hypochlorite or chlorine dioxide. On contact with water, elemental chlorine is hydrolysed and ionises to hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-). HOCl is by far the more potent disinfectant, therefore the lower the pH, the more effective is the process. Chlorine will also react rapidly with ammonia in the waste water to produce a series of chloramines in solution as follows:

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$$
(monochloramine)

$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$$
(dichloramine)

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$$
(nitrogen trichloride)

Monochloramine and dichloramine are the dominant species and are less potent disinfectants than hypochlorous acid. Gray (1989) quotes dosing rates ranging from 2 to 15 mg Cl_2/l, depending on how much treatment the waste water has received (that is, on how much organic matter is remaining), and contact times of 20-30 minutes.

Chlorination of treated urban waste water can result in the production of toxic compounds including trichloromethanes and chloramines that can have longterm adverse effects on the beneficial uses of the waters to which they are discharged. Dechlorination of discharges is possible but cost comparisons will be required due to additional process equipment and their associated costs.

8.3 OZONE DISINFECTION

Ozone gas (O_3) can be used as a disinfectant even though it does not leave a residual in the water being treated. It is a highly reactive oxidising agent and rapidly forms free radicals on reaction with water. It is generated on-site in ozone generators by passing dry air or oxygen through a high voltage electric field. The gas is bubbled through the water being treated and any remaining ozone in the off-gas is destroyed either catalytically using metal oxide catalysts or in a furnace heated to 300°C. Ozone reacts with organic matter in the waste water and this ozone demand must be satisfied before efficient disinfection commences. Disinfection is typically achieved within 5 minutes at dosage rates of 5-50 mg O_3/l, depending on the level of treatment received by the waste water (that is, on how much organic matter is remaining).

The advantages of ozone disinfection include:

- the elimination of odours;
- the oxidation of residual organic compounds;
- the 8-hour occupational exposure limit (OEL) of ozone in air is 0.1 ppm. The odour threshold of ozone has been reported at 0.02 ppm. This means that a person working near an ozone handling area should be able to smell ozone at concentrations far below the OEL; and
- ozone can be generated from air, making its supply dependent only upon a source of power.

The disadvantages of using ozone as a disinfectant include:

- the high cost of production; and
- the potential to cause localised air pollution.

8.4 ULTRA-VIOLET DISINFECTION

Ultra-violet light is produced by a special mercury discharge lamp. The effectiveness of UV radiation depends on the dose received by the micro-organisms and this depends on:

- the intensity of the radiation (the most effective wavelength is 254nm);
- the path length from the source to the micro-organisms;
- the contact time at the required dose; and
- the quality of the waste water (particularly with regard to turbidity).

Lamps are prone to interference from chemical constituents of the waste water such as ferric and hardness salts. Periodic cleaning of the lamps is therefore required.

8.5 MEMBRANE TECHNOLOGY

Membrane technology is an emerging technique for the removal of bacteria and viruses. The membrane pore size dictates the particle sizes which will be removed and will also influence the capital and operating costs. Table 8.1 details the uses of some types of membranes.

TABLE 8.1 MEMBRANE TYPE AND APPLICATION

Membrane type	Size (μm)	Suitable to remove
Microfiltration	0.1-1	bacteria and some viruses
Ultrafiltration	0.001-0.1	bacteria and viruses
Reverse osmosis	< 0.001	bacteria, viruses and inorganic ions

Operators should initially decide on the level of disinfection required and then examine the removal efficiencies of the various options. For example, microfiltration will remove most viruses and therefore the additional expense of ultrafiltration may not be justified.

9. HYDRAULICS OF A WASTE WATER TREATMENT PLANT

9.1 INTRODUCTION

Once the waste water treatment plant unit processes have been selected, of equal importance are the hydraulic gradients that drive the liquid flow through a plant. Properly designed hydraulics are important to ensure that:

- flow to unit processes are not exceeded during high flow periods;
- overflow of tanks and channels does not occur;
- sewer and outfall surcharge is prevented;
- interstage pumps are properly sized; and
- pipe velocities are adequate for self-cleansing thereby preventing deposition.

9.2 HEAD LOSSES

A fluid will flow through a section of pipe or channel only when a driving force is applied. This force is the pressure difference over that section of pipe or channel. Pressure is measured in terms of height of water, called the head, and is expressed in meters. In a gravity system the head is provided by the difference in level between the inlet and the outlet and is called the static head. In a pumped system the inlet is lower than the outlet and the required pumping head is produced by a pump. Head losses in a system are caused by flow being retarded by the effects of friction between the moving liquid and the walls of the pipe or channel and also by the presence of fittings, valves, flowmeters, constrictions, flow-splitters, etc. Thus, to ensure that flow is possible in a section of pipe or channel:

- in a gravity system, the difference in level must be large enough to accommodate all head losses;
- in a pumped system, the energy provided must be sufficient to overcome the difference in level plus all head losses.

Figure 9.1 illustrates the head to be overcome by different types of pumping systems.

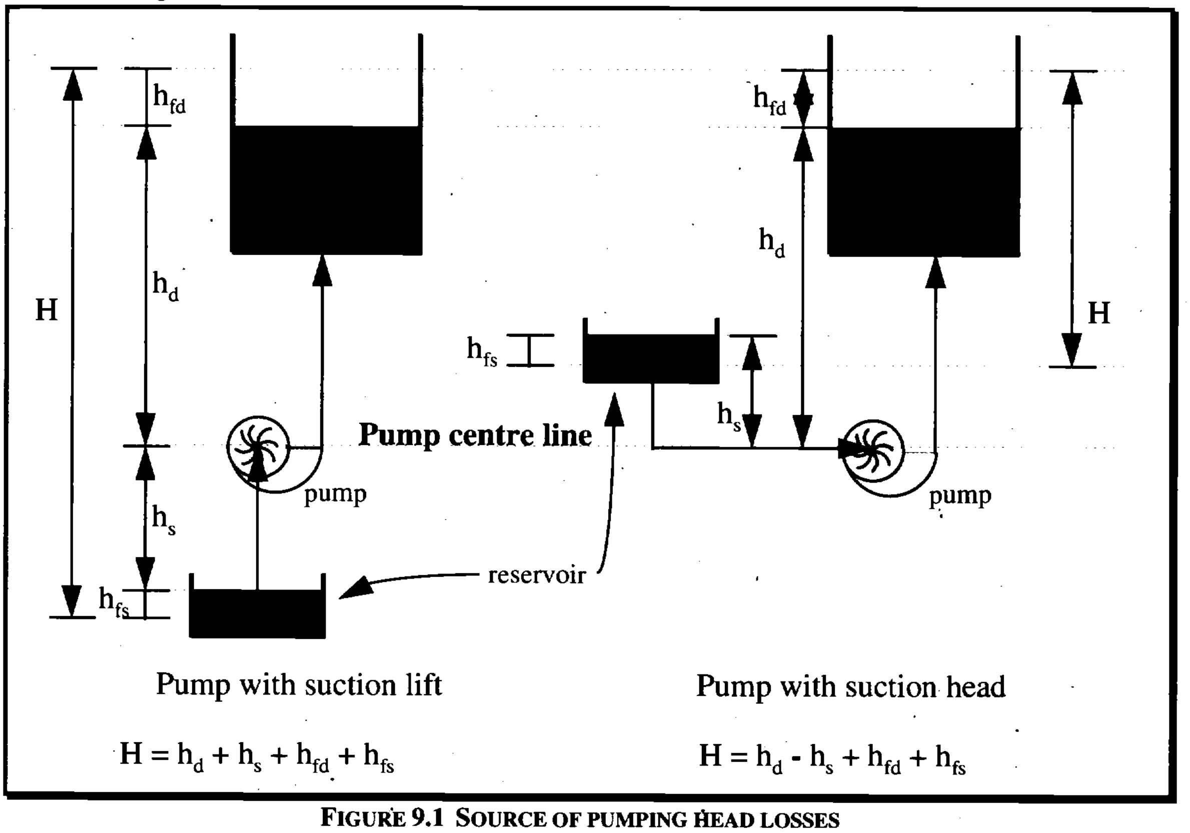


FIGURE 9.1 SOURCE OF PUMPING HEAD LOSSES
(New York SDEC, 1988)

H	is the total head of the system.
h_d	is the static discharge head which is the height of water standing above the pump.
h_s	is the static suction head or the height of liquid between the reservoir and the pump. With suction lift (when the source is below the centre line of the pump) this term is positive; with suction head (when the source is above the centre line of the pump) it is negative as it helps the pump.
h_{fd}	is head due to friction on the discharge side.
h_{fs}	is head due to friction on the suction side.

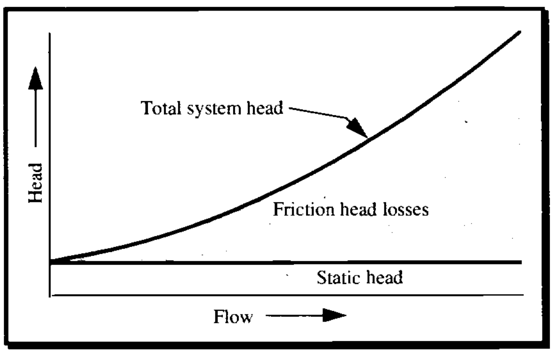


FIGURE 9.2 PUMP SYSTEM HEAD CURVE
(WPCF, 1990)

Figure 9.2 illustrates how the resistance to flow caused by static and friction head constitutes the total system head. Static head losses are independent of the liquid flow rate and are only changed by physically altering the system. Head loss due to friction however, increases with increasing flow rate. In a well sized system, friction losses will account for about 10% of the total losses.

In addition to the above losses, minor head losses occur as a liquid encounters the following:

- pipe fittings such as bends, valves, junctions and flowmeters;
- pipe and tank entrances and exits;
- flow splitting and flow combining chambers;
- peripheral weirs on settlement tanks, and
- channel obstructions such as weirs, flumes and penstocks.

Pipe fittings may be taken into account in the calculation of total head losses using a number of methods:

- as an empirically derived percentage increase in total head loss;
- using a nomograph to convert all fittings into equivalent theoretical straight pipe runs; or
- using empirically derived formulae which will calculate the actual head loss across each individual fitting. For details, reference should be made to standard texts on hydraulics.

9.3 HYDRAULIC PROFILES

A hydraulic profile maps out the hydraulic gradient line from the inlet of the waste water treatment plant to the outfall thus ensuring that hydraulic losses have been adequately accounted for. Depending on the unit processes and the inter-stage connections, different head losses will exist between the units. Typical losses are shown in Table 9.1; actual losses at a particular treatment plant will be highly site specific.

Many waste water treatment plants are constructed on sloping land to take advantage of topography. The hydraulic profile will indicate the height to which any return flows (such as return activated sludge) must be lifted to prevent interference with the hydraulics of the plant.

Figure 9.3 shows a hydraulic profile calculated for a plant with a maximum throughput of 15,000 m^3/d. In designing the hydraulics of a plant, a designer will start at either end and calculate the hydraulic drops or rises back to the opposite end taking all tanks, pipes, channels, pipe fittings, weirs, penstocks and other flow obstructions into account. Site topography can be altered by burying or raising process units; typically to provide sufficient head as far as the outfall. Most frequently, hydraulic analyses of waste water treatment plants are carried out using one of a number of software packages on the market.

TABLE 9.1 TYPICAL HEADLOSSES ACROSS VARIOUS TREATMENT UNITS

Treatment Unit	Headloss range, in metres, for plants of p.e.		
	500	2,000	20,000
Primary sedimentation	0.5-0.7	0.6-0.8	0.7-0.9
Aeration tank	0.7-1.0	0.8-1.1	0.9-1.2
Percolating filter - Low rate	3.0-4.0	3.0-5.0	4.0-6.0
- High rate, rock media	1.8-4.0	2.5-4.5	3.0-5.0
- High rate, plastic media	5.0-8.0	6.0-10.0	8.0-12.0
Secondary sedimentation	0.5-0.7	0.6-0.8	0.7-0.9

Qasim (1994) outlined the basic principles that must be considered when preparing a hydraulic profile through a plant and these are summarised as follows:

- profiles are prepared at peak flow (which accounts for the largest head loss through a treatment unit), average flow and minimum flow;
- profiles are prepared for all flow paths;
- the total head loss through connecting pipework, channels and attachments is the sum of the head losses due to entrance, exit contraction, enlargement, fittings, gates, valves and meters. The head loss over weirs and other hydraulic controls, the weir free-fall allowance and the head allowance for future expansions of the treatment facility should be included;

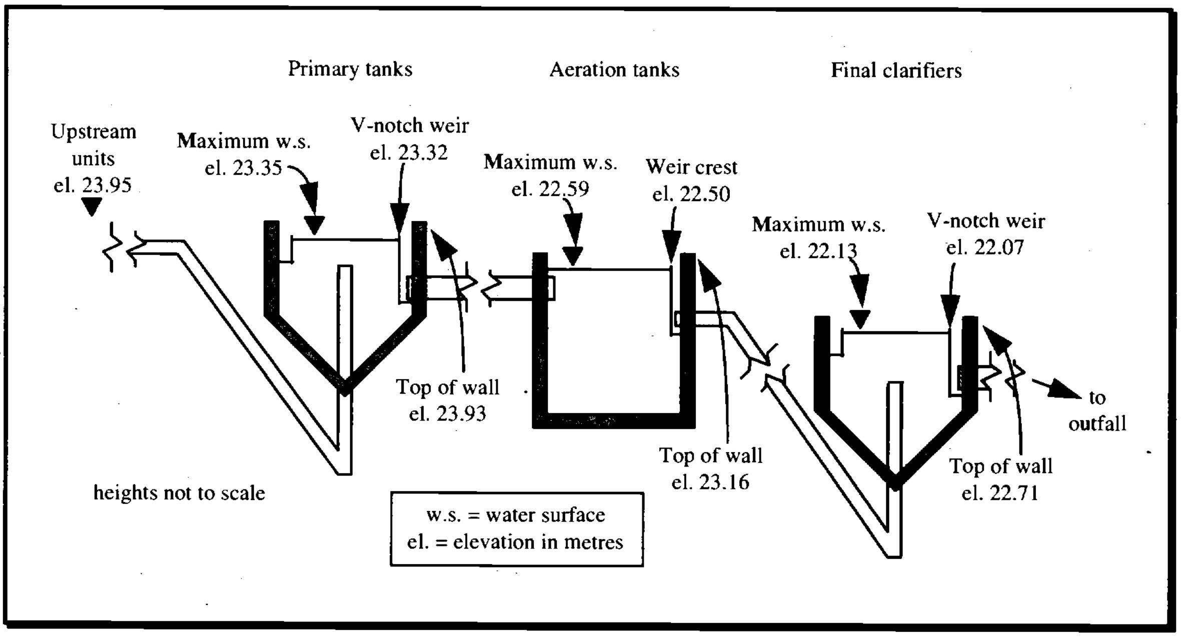


FIGURE 9.3 HYDRAULIC PROFILE FOR A SECONDARY WASTE WATER TREATMENT PLANT
(Metcalf & Eddy, 1991)

- the total head loss through a treatment plant is the sum of the head losses in the treatment units and in the connecting pipework and attachments;
- a minimum velocity (normally taken as 0.3m/s) in connecting piping and conduits should be maintained to ensure that solids do not settle out;
- friction losses in pressure conduits must be included;
- the maximum levels in the receiving water at the outfall must be established; and
- the depth and grade of open channel is kept in such a way that the water surface at the design flow corresponds to the hydraulic profile.

9.4 PUMPS

Pumps used in waste water treatment fall into two main categories: centrifugal and positive displacement. Centrifugal pumps are more commonly used in pumping waste water while positive displacement pumps are frequently used for pumping sludge.

Centrifugal pumps rely on the force imparted to a fluid by a rotating impeller to drive it towards the pump discharge. The size, speed and configuration of the impeller all have an influence on the amount of liquid a pump can handle. The characteristic pump curve (

Figure 9.5), which is produced by the manufacturer, is used when selecting a pump. It allows a pump to be selected based on the flowrate it is capable of achieving against a certain head of water at a certain efficiency with regard to power input per unit volume pumped. Most pumps have an optimum range where maximum flow is possible with an acceptable head loss and efficiency.

Centrifugal pumps can be operated in a dry well or submerged in a wet well. Submersible pumps are fully sealed against water ingress. Variable speed centrifugal pumps which use inverter drives are widely available and are used to vary impeller speed to change the flowrate. Variable speed control must take into account the need to attain self-cleansing velocities in the discharge pipes.

Archimedean screw pumps are used mainly for lifting raw waste water and for re-lifting return activated sludge.

Examples of positive displacement pumps are diaphragm, rotary lobe, piston or ram and progressive cavity pumps. Their operation is characterised by a cavity which cyclically operates as a suction and discharge chamber. Positive displacement pumps are often self-priming and some can be allowed to run dry for short periods of time. Macerators are often required upstream of these pumps in order to protect them from large objects that may block the pump. The volume that can be pumped is governed by the size of the pump and its speed of rotation. Positive displacement pumps are not usually submersible but can be operated using variable speed drives.

The flowrate of a pump can be checked by the following methods:

- install a flowmeter; or
- measure the time it takes to <u>fill</u> a vessel or a tank of known volume where all other inputs and outlets have been isolated. To ensure a constant fixed head on the pump, the inlet should discharge at or above the top water level of the vessel. What is being measured is the time it takes to fill or drain a known volume; (e.g. if it takes 5 minutes to fill 1000 litres, then the flowrate is 1000 litres/5 min or 3.33 l/s).

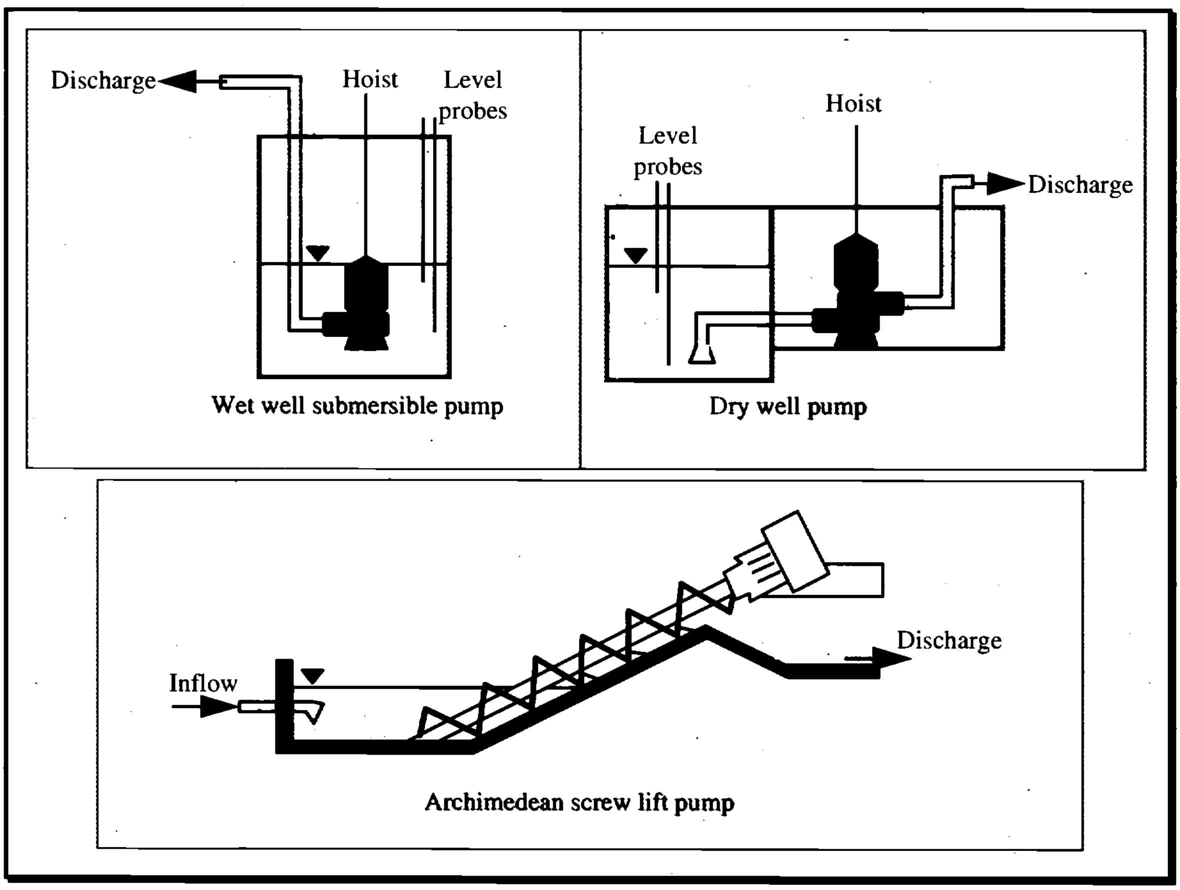


FIGURE 9.4 TYPES OF PUMPS AND APPLICATIONS

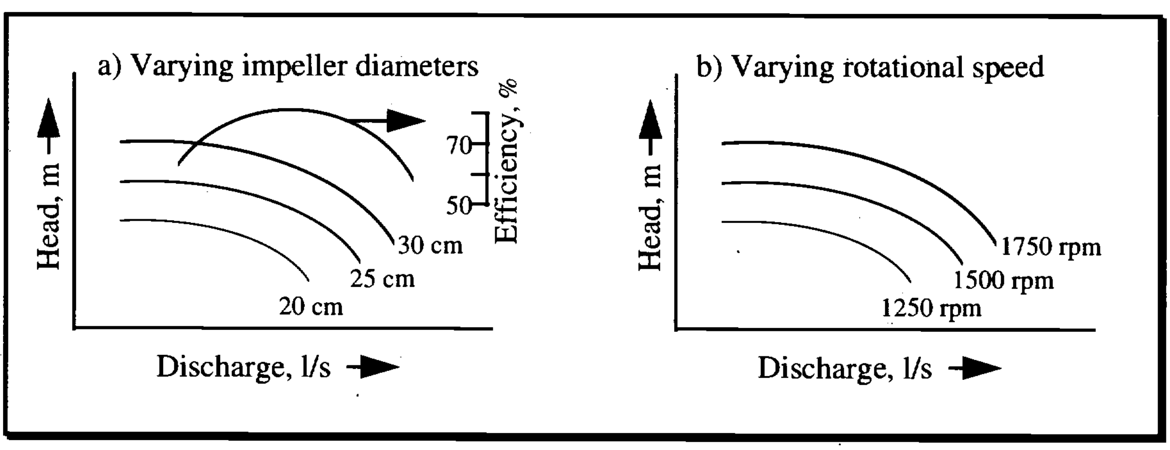


FIGURE 9.5 CENTRIFUGAL PUMP PERFORMANCE CURVES
(WPCF, 1990)

10. CONTROL OF NUISANCE

10.1 INTRODUCTION

The potential nuisances which may arise in connection with a waste water treatment plant are those which relate to:

- odour;
- noise;
- visual impact; and
- in the case of some biofilm processes, pests.

10.2 SOURCES OF NUISANCE

10.2.1 ODOURS

Odours arising from urban waste water treatment plants can be grouped into two classes, namely:

- reduced compounds such as hydrogen sulphide, and
- oxidised compounds such as aldehydes.

Noxious sulphur compounds are generated under anaerobic conditions, and their odour can be very noticeable even at low concentrations. Odour thresholds for some odorous gases which have been encountered at waste water treatment plants are illustrated in Table 10.1. The table also highlights the problem of detecting some of these compounds as many are perceived at levels below which they can be detected by modern instrumentation. Oxidised compounds result from the intermediate breakdown of carbohydrates, proteins and fats present in the waste water. These intermediate products are responsible for the "musty" odour associated with biological processes; however, given sufficient oxygen, they are eventually broken down to carbon dioxide and water. In general, when sufficient oxygen is available in secondary treatment works, hydrocarbons are broken down to alcohols, then to aldehydes and ketones, then to carboxy acids and finally to carbon dioxide and water.

Table 10.2 lists the more common odour generating processes in waste water treatment plants and ranks them in order of their potential for odour generation. Though odours can arise at the secondary treatment stage, the table shows that the greatest potential for odour generation is associated with preliminary treatment and with activities associated with sludge disposal and handling.

TABLE 10.1 ODOUR THRESHOLDS OF COMMON ODOROUS GASES

Compound	Odour threshold, ppm	Detection threshold, ppm
Acetaldehyde	0.004	-
Allyl mercaptan	0.00005	0.016
Ammonia	0.037	-
Hydrogen sulphide	0.00047	-
Ethyl mercaptan	0.00019	0.0026
Chlorophenol	0.01	0.01
Crotyl mercaptan	0.000029	0.0077
Dibutylamine	0.016	-
Ethylamine	0.83	-
Methylamine	0.021	-
Skatole	0.0012	0.223
Pyridine	0.0037	-

The potential sources of odours associated with primary settlement include:

- inadequate scum removal;
- infrequent removal of settled solids; and
- release of odorous gases (dissolved in the primary outflow) resulting from the discharge over the weir.

The potential sources of odours associated with biofilm processes include:

- insufficient oxygen;
- septic conditions as a result of hydraulic overloading or clogging;
- organic overload;
- inadequate wetting of the media;
- ponding; and
- inadequate ventilation (stagnant airflow).

TABLE 10.2 ODOUR POTENTIAL FROM WASTE WATER TREATMENT PROCESSES (WEF, 1995)

Process	Odour potential
Flow equalisation	High
Sludge handling	High
Sidestream returns	High
Pre-aeration	High
Screening	High
Grit removal	High
Primary settlement	High
Suspended growth systems	Low
Fixed film	Moderate
Chemical	High
Secondary settlement	Low
Tertiary filtration	Low
Sludge thickening and holding	High
Aerobic digestion	Moderate
Anaerobic digestion	Moderate
Thermal conditioning	High
Storage lagoons	High
Dewatering (vacuum, centrifuge, belt and filter press, drying beds, composting).	High

The potential sources of odours associated with activated sludge processes include:

- inadequate oxygen levels in the tank (major source);
- poor mixing of the mixed liquor; and
- wetting of the walls of the aeration tank.

The potential sources of odours associated with secondary settlement tanks include:

- the scum removal system; and
- the sludge removal system.

10.2.2 ODOUR CONTROL

It is not uncommon in areas where treatment plants are close to residential areas that primary settlement tanks are covered and the off-gases ducted to chemical and biological treatment units. These are discussed in detail in sections 7.3.1.1 and 7.3.1.2 of the Preliminary Treatment Manual. In summary, chemical oxidation of the odours can be achieved using ozone, potassium permanganate, peracetic acid and sodium hypochlorite. Biological oxidation is possible by passing the off-gases through beds of peat or compost where the microbial flora break them down.

Biological treatment processes are not generally a major source of odour. The control of odours from primary and biological treatment processes is commonly achieved by operational practices such as:

Primary settlement

- frequent cleaning of scum scrapers and pits thereby reducing the biological breakdown of grease and scum;
- frequent sludge withdrawal ensuring that solids residence times of 1 hour at average flow conditions are established;
- preventing septic conditions by reducing hydraulic retention times and increasing the frequency of settled solids scraping;
- reducing the turbulence at the weir overflow by reducing the height of the drop between the weir overflow and the channel; and
- constructing a wind barrier if wind is a problem.

Biofilm processes

- recirculation of outflow; and
- forced air circulation (upflow or downflow).

Activated sludge

- maintaining aerobic conditions in the aeration tank; and
- maintaining the velocity of the mixed liquor in the tank at a minimum of 0.15m/s.

Secondary settlement tanks

- similar controls to primary units except that withdrawal rates can be increased to 1.5 to 2 hours; cleaning is critical as odours can occur more quickly due to the mixed liquor being more biologically active.

10.2.3 SHORT TERM ODOUR PREVENTION

Masking agents can be used as a short term solution to an odour problem. These work by combining with the original odour and producing a total odour which is less objectionable. The impact of the masking agent is dependent on environmental conditions and is only suitable for low strength odour emissions. Care should be taken in using masking agents as in some cases the resultant total odour can be worse than the original odour.

10.3 NOISE

Noise is a pressure phenomenon and is defined as unwanted sound. At waste water treatment plants potential noise sources are mechanical equipment such as grit blowers, compactors, aeration equipment, scrapers, sludge removal pumps and sludge dewatering equipment.

The physical characteristics of noise from a waste water treatment plant which should be quantified in an assessment are the:

- level,
- temporal and
- quality

of the noise.

Noise monitoring equipment uses a filter to differentiate between sounds of different frequencies. Measuring equipment which reports results as dB(A) approximates the subjective human response to that noise. As a general rule of thumb a 10 dB(A) increase represents a doubling in loudness; for example, 60 dB(A) would be perceived to be twice as loud as 50 dB(A). When a sound pressure level is measured using the A-weighted network (i.e. dB(A)) the noise instrument analyses the sound in terms of the A-weighting curve (human response) and then gives a single figure in dB(A). In essence the sound level meter adjusts the level of individual frequency bands of noise to broadly correspond to the response of the human ear in determining the total noise level in dB(A). The adjustments which the instrument makes to compute the dB(A) value are illustrated in Table 10.3 which indicates that at low frequencies the human ear has a relatively low response. Sounds with frequencies around 3 kHz are going to be assessed subjectively as being much louder than sounds around 32 Hz even though the sounds may have the same sound pressure level.

TABLE 10.3 A-WEIGHTING ADJUSTMENTS

Octave band centre frequency, Hz	A-weighting adjustment, dB
63	-26
125	-16
250	-9
500	-3
1k	0
2k	+1
4k	+1
8k	-1

The following example illustrates the principle of obtaining an A-weighted sound pressure level from the frequency analysis of a machine.

The octave centre frequencies and measured sound pressure levels are given in columns 1 and 2 of Table 10.4. Column 3 gives the A-weighting network adjustment appropriate to each frequency (as mentioned in Table 10.3 above). Column 4 is the computed A-weighted corrections for each frequency.

The overall level in dB(A) of the machine noise is calculated from the equation for the addition of decibels, which in this case will be:

$$\text{Noise (at a receptor)} = 10\log_{10}[10^{50/10} + 10^{48/10} + \ldots 10^{45/10} + 10^{36/10}]$$

$$= 86.3\ dB(A)$$

When the machine noise is measured on a sound level meter with the A-weighting network selected, the conversion process would be carried out automatically and the meter would indicate a single reading of 86.3dB(A).

A noise measurement in dB(A) from a sound level meter does not give any information about the frequency or spectral components of the noise being measured. The temporal aspect of the sound refers to the assessment of noise over a given period; for example, is the noise transient or intermittent?

TABLE 10.4 CONVERSION OF OCTAVE LEVELS TO A-WEIGHTED LEVELS

Octave band centre frequency (Hz)	Measured sound pressure level (dB)	A-weighted adjustment (dB)	A-weighted pressure level (db(A))
(1)	(2)	(3)	(4)
63	76	-26	50
125	64	-16	48
250	82	-9	73
500	78	-3	75
1k	84	0	84
2k	80	+1	81
4k	44	+1	45
8k	27	-1	26

The quality of the noise refers to whether the noise is impulsive or abrupt in nature or whether it contains clearly audible tonal components such as hisses or whines.

For general acceptability, the noise level at noise sensitive locations should be within the following ranges:

Night: 35 - 45 dB(A)

Day: 45 - 55 dB(A)

It is important to note that any tonal or impulsive qualities detected during the measurement period normally attract a penalty, typically +5 dB(A) to the measured value. The quality of the noise can normally be assessed subjectively. However, in the event of dispute, frequency analysis can be carried out on the measured noise, to establish its tonal component. Impulsive noise is regarded as being a feature if there are audible, discrete and repeated noise events which are less than one second's duration. Monitoring of environmental noise arising from urban waste water treatment plants should be performed in accordance with the International Standard, ISO 1996: Acoustics and Measurement of Environment Noise.

10.3.1 NOISE CONTROL

The first step in the control of noise is the selection of low noise emission equipment where new plant is being purchased or existing plant is being replaced. Noise specification sheets normally exist for most equipment and the sound power level over a stated distance (normally one metre) should be noted. For the propagation of noise outdoors, the noise level at a receptor point decreases with distance from the source. For small sources such as fans, motors, pumps etc., the noise level can simply be calculated as follows:

$$SWL = SPL + 20 \text{ Log distance from source} + 8$$

Where:

SWL = Sound Power Level

SPL = Sound Pressure Level

Therefore, for an item of equipment whose reference distance is one metre:

$$SWL = SPL + 8$$

It should be noted that sound power is independent of its location, whereas the sound pressure depends on the distance from the source to the receptor. Other factors may effect the noise received such as acoustic screening and wind effects.

The second step in controlling noise should be the use of sound insulation, and this can be provided by the envelope of the building where the equipment is housed or through the use of equipment enclosures.

Thirdly, various noise treatments exist for external equipment and they include:

- barriers such as walls and landscaping which intercept the direct sound path between the noise source and the receiver;
- partial or complete enclosure;
- lagging or double wall construction; and
- attenuators or silencers.

Table 10.5 gives a range of approximate noise reduction possible for the various noise treatments.

TABLE 10.5 APPROXIMATE RANGE OF NOISE REDUCTION

Treatment method	**Achievable noise reduction, dB(A)**					
	5	**10**	**15**	**20**	**25**	**30**
Barrier	✔	✔	✔			
Partial enclosure	✔	✔				
Complete enclosure	✔	✔	✔	✔	✔	✔
Attenuators	✔	✔	✔	✔	✔	✔
Lagging	✔	✔	✔			

10.4 VISUAL IMPACT

Careful site selection and a good layout within the plant can contribute to minimising visual nuisance. Due regard should be given to cleanliness and operation to ensure that unsightly features are kept to a minimum. The environmental impact statement (if one was prepared) should be consulted to ensure that any mitigating measures proposed are implemented.

From an operational point of view the key issues on a treatment plant are:

- adequate landscaping;
- maintenance of a neat and tidy site;
- protection of exposed surfaces from splashing, lichen, algal or fungal growth;
- maintenance of site fencing and boundary screening in good condition;
- prevention of aerosols and foaming from the aeration tank; and
- regular painting of gates, doors and buildings.

10.5 PESTS

The fly *Psychoda* is the chief nuisance insect associated with some biofilm processes. These flies require an alternative wet and dry environment for growth and are normally associated with low rate systems. Controls include:

- increasing the recirculation rate which has the effect of washing the larvae off the media;
- on percolating filters, maintaining the gates of the distribution arm clear at all times; and
- applying an approved insecticide to the filter structures.

11. PRETREATMENT OF INDUSTRIAL WASTE

A significant number of industrial premises discharge waste to the public sewer for which a single media licence under the Water Pollution Acts (processed by local authorities) or an Integrated Pollution Control licence (processed by the EPA) is required.

The performance of the waste water treatment plant is dependent on the performance of micro-organisms and their metabolism can be dramatically affected by the presence of toxic material in the raw waste water. Toxic compounds such as heavy metals and biocides can inhibit the biological activity in the treatment plant. Table 11.1 lists some of the inhibitory levels reported for metals, inorganics and organic substances.

The fourth schedule of the Environmental Protection Agency Act, 1992 (Urban Waste Water Treatment) Regulations, 1994 (S.I. No 419 of 1994), requires that industrial waste water entering collecting systems and urban waste water treatment plants be subjected to such pretreatment as is required in order to:

- protect the health of staff working in collecting systems and treatment plants;
- ensure that collecting systems, waste water treatment plants and associated equipment are not damaged;
- ensure that the operation of a waste water treatment plant and the treatment of sludge are not impeded;
- ensure that discharges from treatment plants do not adversely affect the environment or prevent receiving waters from complying with other Community Directives; and
- ensure that sludge can be disposed of safely in an environmentally acceptable manner.

As mentioned in section 1.1 of this manual, safety procedures (acceptable to the Health and Safety Authority) should be adopted when operating urban waste water treatment plants and nothing in this manual should be construed as advice to the contrary. This advice is also applicable for work carried out on the collection system.

TABLE 11.1 REPORTED INHIBITION THRESHOLD LEVELS
(WEF, 1994)

Substance	Inhibition threshold for activated sludge, mg/l
Cadmium	1-10
Total Chromium	1-100
Chromium III	10-50
Chromium VI	1
Copper	1
Lead	0.1-5.0, 10-100
Nickel	1.0-2.5
Zinc	0.3-5.0
Arsenic	0.1
Mercury	0.1-1, 2.5 as Hg(II)
Silver	0.25-5.0
Cyanide	0.1-5
Ammonia	480
Iodine	10
Sulphide	25 - 30
Anthracene	500
Benzene	100-500, 125-500
2-Chlorophenol	5
Ethylbenzene	200
Pentachlorophenol	0.95, 50
Phenol	50-200, 200
Toluene	200
Surfactants	100-500

Potential problems from industrial waste water may be associated with hydraulic overloads, temperature extremes and with excessive amounts of:

- oil, fats and grease;
- acidic or alkaline wastes;
- suspended solids;
- inorganic or organic wastes;
- explosive and flammable materials; and
- waste water containing volatile, odorous, or corrosive gases.

Non-toxic materials such as oils, fats, grease and hair can affect the operation of plant and equipment. Where significant levels are present in an industrial discharge, pretreatment or monitoring equipment should be considered in order to control and monitor their discharge into the foul sewer.

Appendix C lists some of the toxic and non-toxic parameters that are commonly associated with various industrial sectors. All industrial waste discharging to the foul sewer should be fully characterised. In addition, where significant levels of toxicity are suspected, data on the respiration rate, algal and microbial inhibition potential should be obtained.

Table 11.2 lists the technologies which are commonly used to remove industrial pollutants prior to discharge to a sewer.

11.1 FLOW EQUALISATION

Licensing of industrial waste water discharges is complicated by the fact that raw materials and processes may change. Fluctuations may occur in the flowrate as well as in the type and concentration of the contaminants. Flow equalisation or balancing of the industrial waste water may therefore be advisable prior to entry to the foul sewer to avoid problems at the treatment plant later.

To assess whether this is required, the sanitary authority should obtain background information on the variability of the flow, pollutant levels and temperature (as appropriate).

The four basic methods for flow equalisation are:

alternating flow diversion, where the total flow from the process is collected in alternate tanks and allowed to equalise. While one tank is filling, another is being discharged;

intermittent flow diversion, where significant periodic variations in the discharge are diverted and subsequently allowed to bleed back into the process stream at a controlled rate;

TABLE 11.2 TECHNOLOGIES AVAILABLE FOR THE PRETREATMENT OF INDUSTRIAL DISCHARGES

Physical	Chemical	Biological
Carbon adsorption	Chemical oxidation	Activated sludge
Distillation	Chemical precipitation	Biofilm systems
Filtration	Chromium reduction	
Ion exchange	Coagulation	
Microfiltration and ultrafiltration	Cyanide destruction	
Reverse osmosis	Electrochemical oxidation	
Dissolved air flotation	Hydrolysis	
Flocculation	Neutralisation	
Oil and grease skimming		
Oil and water separation		
Sedimentation		
Steam stripping		
Solvent extraction		

completely mixed combined flow systems, where multiple streams are combined in order to reduce their variance. This assumes compatibility between the constituents in each stream; and

completely mixed flow system, where a completely mixed holding basin is employed and provides a constant discharge to the treatment plant.

The different designs are illustrated in Figure 11.1.

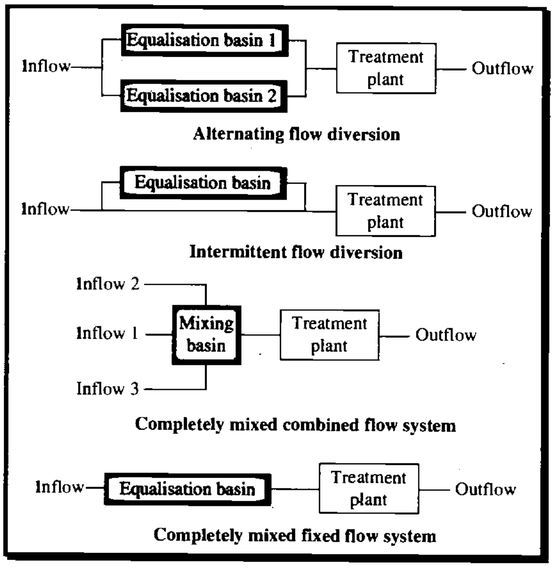


FIGURE 11.1 METHODS OF FLOW BALANCING (WEF, 1994)

11.2 FATS, OILS AND GREASE (FOG)

The term FOG includes materials of vegetable, animal and mineral origin. Pretreatment of FOG from industrial processes may be required to avoid blockages in the collection system, pumping stations and at the treatment plant.

The effect of FOG on the treatment system depends on the type of FOG present. Animal and vegetable oil tend to be broken down in the treatment system but oils of mineral origin typically degrade slowly. This slow degradation can affect the activity of micro-organisms at the plant by preventing the transfer of oxygen or slowing down the degradation of other organic material. FOG can affect the operation of monitoring equipment such as dissolved oxygen probes, pH probes and other instrumentation required to effectively control the process.

The simplest form of removal of FOG is gravity separation. This may be appropriate for waste water emanating from restaurants, hotels and petrol stations. Other techniques include dissolved air flotation, centrifugation, filtration, biological removal and ultrafiltration. There is wide scope for the reuse of FOG which has been recovered by gravity settlement. For example, FOG recovered from restaurants can be purified and reused as animal feed.

11.3 pH NEUTRALISATION

A strongly acidic or alkaline waste may seriously affect the collection system as well as the treatment process, therefore neutralisation prior to entry to the collection system may be required.

The most common bases used to neutralise acidic wastes are lime (which may come in the form of high-calcium hydrated lime, calcium oxide, dolomitic quicklime, dolomitic hydrate, high-calcium limestone, dolomitic limestone, calcium carbide and calcium hydroxide), caustic soda (sodium hydroxide), sodium bicarbonate, sodium carbonate and magnesium hydroxide. Acids used to neutralise alkaline wastes include sulphuric acid, carbon dioxide (as carbonic acid), hydrochloric acid and nitric acid.

11.4 HEAVY METALS

The primary effect of heavy metals on the treatment process is decreased biological activity of the micro-organisms. The toxicity of individual metals varies and certain metals become more toxic when combined with others. Also, certain metals can combine with organic compounds and cause mutagenicity (changing of the genetic makeup) and/or teratogenicity (abnormal tissue development in embryos).

High levels of heavy metals in waste water may prohibit sludge from being used in agriculture.

Though technologies exist for the removal of heavy metals from waste water, industry should be encouraged to recover as much as is economically viable. Recovery systems include evaporation, reverse osmosis, electrodialysis, electrolytic recovery and ion exchange.

11.5 ORGANIC CONSTITUENTS

Industrial wastes can contain high levels of organic matter and/or low levels of nutrients and may require some form of treatment prior to discharge to the collection system. As a guide, Appendix B lists the waste water characteristics from the main industrial categories.

Many pretreatment systems are available which will protect a waste water treatment plant from, for example, shock loads. The selection of the pretreatment option will depend on:

- waste water characteristics - flow and chemical composition;
- pretreatment limits imposed in either a single media licence or an integrated pollution control licence;
- site constraints; and
- BATNEEC (best available technology not entailing excessive cost).

Some of the options available are listed in Table 11.3.

TABLE 11.3 PRETREATMENT OPTIONS FOR SELECTED DISCHARGES (WEF, 1994)

Industry	Typical pretreatment technologies
Food processing, dairies	Equalisation, biological treatment, removal of whey
Meat, poultry, and fish	Screening, gravity separation, flotation, coagulation/precipitation, biological treatment
Fruit and vegetable	Screening, equalisation, gravity separation, neutralisation, biological treatment, coagulation/precipitation
Breweries and distilleries	Screening, centrifugation, biological treatment
Pharmaceuticals	Equalisation, neutralisation, coagulation, solvent extraction, gravity separation, biological treatment
Organic chemicals	Gravity separation, flotation, equalisation, neutralisation, coagulation, oxidation, biological treatment, adsorption
Plastics and resins	Gravity separation, flotation, equalisation, chemical oxidation, solvent extraction, adsorption, biological treatment
Leather tanning and finishing	Screening, gravity separation, flotation, coagulation, neutralisation, biological treatment

12. MANAGEMENT AND CONTROL

The primary function of an urban waste water treatment plant is to treat waste water in a consistent and reliable manner in order to meet required standards. It is the responsibility of management to ensure that a satisfactory quality of outflow is achieved at a reasonable cost. A management system should be developed to ensure that the treatment objectives are achieved.

The management system should address:

- organisation and responsibilities of personnel involved in operating the treatment plant;
- quantification of the environmental effects of the treatment plant;
- operational control of the treatment plant;
- documentation and maintenance records of the treatment plant;
- audits of the plant;
- preventative maintenance;
- routine servicing;
- emergency response;
- equipment replacement;
- quantification of inflow to the plant; and
- monitoring programme and frequency of analysis.

12.1 MANAGEMENT SYSTEM AND AUDIT SCHEME

A schematic of a management and audit scheme is illustrated in Figure 12.1.

12.2 INITIAL ENVIRONMENTAL REVIEW

The initial environmental review would:

- examine the current policy and practices at the plant;
- assess current performance; and
- make a list of recommendations including, objectives, plans and timescales.

This exercise should be repeated on at least an annual basis to assess the performance of the plant.

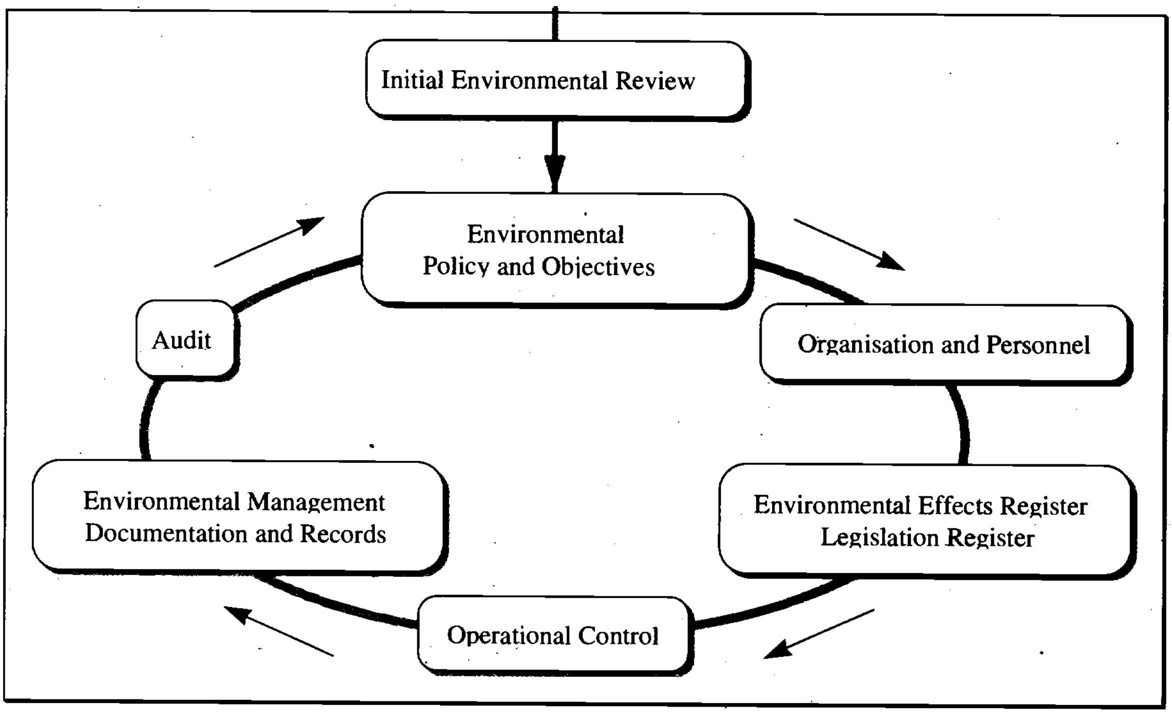


FIGURE 12.1 MANAGEMENT SYSTEM OF A WASTE WATER TREATMENT PLANT

12.3 ENVIRONMENTAL POLICY AND OBJECTIVES

The environmental policy and objectives of the sanitary authority will establish the policy for the treatment plant. For agglomerations which fall within the UWWT Regulations a significant aspect of this policy will already be prescribed. The goal is a comprehensive set of objectives and targets involving all participants (County Manager, County Engineer, Senior Executive Engineer/Chemist, Executive Engineer/Chemist, Assistant Engineer/Chemist, Staff Officer, Technician, Caretaker etc.). The objectives and targets must be clear and achievable. They must be budgeted for and an annual budget should be prepared.

12.4 ORGANISATION AND PERSONNEL

The organisational structure and responsibilities of each individual should be written down. Procedures for identifying training needs and allocation of sufficient resources to allow training needs to be fulfilled should be established. Appropriate training should be provided for all personnel. Records of all staff training and qualifications should be maintained.

12.5 ENVIRONMENTAL EFFECTS REGISTER

The environmental effects register will provide a basis for analysing and documenting the environmental effects of the waste water treatment plant and communicating these effects to relevant parties. These entries could include analysis of inflow, outflow, receiving water upstream, downstream, etc. together with information on sludge treatment, reuse and disposal.

12.6 OPERATIONAL CONTROL

The operational controls are a set of documented practices, procedures and systems to ensure that the activities of the plant operator which have an impact on the waste water treatment plant performance are carried out in accordance with specified procedures. This would typically be achieved under three sub-sections:

- control procedures to ensure activities take place within parameter limits;
- verification, measurement and testing to ensure that the control procedures are effective; and
- corrective actions to be taken to change the control parameters when failures occur.

12.7 ENVIRONMENTAL MANAGEMENT DOCUMENTATION AND RECORDS

The environmental management documentation and records will cover a wide range of topics to provide the necessary evidence of compliance with the specified standards, i.e. the records required by:

- management; and
- legislation (in particular the discharge standards set in the UWWT Regulations).

The records will also assist the operator in demonstrating the extent to which the objectives and targets for the plant have been achieved.

12.8 THE AUDIT

The objective of an audit (either internal or external) is to evaluate the plant performance. This involves two factors:

- measurement of the standards achieved; and
- measurement of the effectiveness of the system or management process which have been used.

12.9 SECTOR REPORTS

The sector reports refer to the data to be submitted to the EPA to assist in producing the national reports on urban waste water treatment as required.

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GLOSSARY

Activated sludge. A flocculent microbial mass of bacteria, protozoa and other micro-organisms with a significant proportion of inert debris, produced when sewage is continuously aerated.

Adsorption. A surface phenomenon involving the adhesion of molecules to interfaces with which they are brought into contact.

Aerator. A mechanical device used for dissolving oxygen in water. The oxygen is generally supplied for use by aerobic micro-organisms.

Aerobic. A condition in which elementary oxygen is available and utilised in the free form by bacteria.

Anaerobic. A condition in which oxygen is not available in the form of dissolved oxygen or nitrate/nitrite.

Anoxic. A condition in which oxygen is available in the form of oxidised inorganic compounds such as nitrate, nitrite and sulphate.

Bacteria. Micro-organisms, of simple structure and very small size (average 1 µm diameter); typically unicellular rods or rounded cells (cocci), occasionally filamentous.

Baffle. Used to check eddies and promote a more uniform flow through a tank. A scum baffle is used for retaining scum.

Biofilm. A layer of micro-organisms and their products attached to a support medium.

Biological (aerated) filter. See **Submerged filter**.

Biological oxygen demand. The BOD is a measure of the rate at which micro-organisms use dissolved oxygen in the bacterial breakdown of organic matter (food) under aerobic conditions. The **BOD_5 test** indicates the organic strength of a waste water and is determined by measuring the dissolved oxygen concentration before and after the incubation of a sample at 20°C for five days in the dark. An inhibitor may be added to prevent nitrification from occurring.

Biomass. The total weight of activated sludge or biological film.

Biotower. A configuration of percolating filter using a high loading rate designed for the removal of the easily biodegradable BOD. May be constructed of structured bales of plastic media stacked up to 12 m in height.

Bulking. The inability of an activated sludge to settle causing it to float on the settlement tank surface or to be carried over with the outflow.

Carbonaceous oxidation. The oxidation of carbon based compounds ultimately to CO_2 and H_2O; generally quantified by the Biological Oxygen Demand (BOD) parameter.

Chemical oxygen demand. COD is a measure of the amount of oxygen consumed from a chemical oxidising agent under controlled conditions. The COD is generally greater than the BOD as the chemical oxidising agent will often oxidise more compounds than is possible under biological conditions.

Ciliates. A class of protozoans distinguished by short-hairs on all or part of their bodies.

Clarifier or settling tank or sedimentation tank. A solids-liquid separation stage used in primary and secondary treatment in which heavier material sinks to the bottom and lighter material floats to the water surface.

Consolidation. The squeezing out of water held between flocs or particles caused by the weight of further settlement of particles above.

Conventional aeration. An activated sludge process whereby the waste water is subjected to periods of aeration of 5-14 hours at F/M ratios between 0.2 and 0.5; the mixed liquor is returned at rates similar to the incoming flow with the object of removing BOD and sometimes nitrogen.

Denitrification. The reduction of nitrate to molecular nitrogen (N_2) under anoxic conditions. The nitrate is used as an oxygen source by heterotrophic bacteria in the absence of molecular oxygen. A source of carbon must be added.

Dry solids content (of sludge). The weight of dry solids per unit weight of sludge, expressed as a percentage or as mg/kg. Also used to express the quantity of biomass produced per quantity of BOD removed (kg dry solids produced per kg BOD removed)

Dry-weather flow (DWF). When the sewage flow is mainly domestic in character, the average daily flow to the treatment works during seven consecutive days without rain (excluding a period which includes public or local holidays) following seven days during which the rainfall did not exceed 0.25 mm on any one day. With an industrial sewage the dry-weather flow should be based on the flows during five working days if production is limited to that period. Preferably, the flows during two periods in the year, one in the summer and one in the winter, should be averaged to obtain the average dry-weather flow.

Effluent. As applied to sewage treatment, a liquid which flows out of a process or system, but more particularly the domestic or industrial wastewater, treated to a greater or lesser extent, which flows out of a section of the treatment plant, or from the treatment works as a whole.

Endogenous respiration or **cryptic growth**. A stage in bacterial growth where dead bacterial cells are consumed in the absence of other organic substrates.

Erosion. The removal of attached biofilm growth by the washing action of a flow of liquid. Used in biofilm processes to control the thickness of biofilm on the medium.

Eutrophication. The over enrichment of a water body by nutrients such as nitrate and phosphate causing, amongst other things, excessive plant growth and oxygen depletion.

Extended aeration. An activated sludge process whereby the waste water is subjected to prolonged aeration at F/M ratios less than 0.15; the mixed liquor is returned at a high rate with the aim of bringing about considerable oxidation and aerobic digestion of the organic matter in the activated sludge.

Filamentous bacteria. Organisms that grow in a thread or filamentous form. Common types are *thiothrix* and *actinomycetes*. A common cause of sludge bulking in the activated sludge process.

Food to micro-organism (F/M) ratio. A measure of the amount of food available to micro-organisms in an activated sludge process. Expressed in terms of the BOD loading against the mass of micro-organisms.

$$\frac{\text{Food}}{\text{Microorganisms}} = \frac{\text{kg BOD / day}}{\text{kg MLSS}}$$

The F/M ratio indicates the mode of operation of an activated sludge process.

Foul sewer. A sewer conveying sewage, i.e. wastewater of domestic or industrial origin, excluding rainwater or surface water.

Grease. In sewage treatment, grease includes fats, oils, waxes, free fatty acids, calcium and magnesium soaps, mineral oils, and other non-fatty materials. The type of solvent used for its extraction should be stated.

Grease trap. A receptacle designed to collect and retain grease and fatty substances in kitchen wastes or in an industrial wastewater and installed in the drainage system between the point of production and the sewer.

Grit. The heavy mineral matter in sewage, such as silt, sand, gravel, cinders, ashes, metal and glass. It is abrasive in character and may vary in composition seasonally. Soil originating from vegetable washing and preparation is also classified as grit.

Head. The *total head* against which a pump is to deliver is made up of the static head, plus friction head, plus velocity head. The *static head* is the actual lift, from the minimum level of the liquid in the wet well to the point of discharge. The *friction head* is the energy lost by friction in the suction and the delivery pipes, including losses at bends and obstructions. The *velocity head* is the energy per unit weight of liquid being pumped due to its velocity.

Humus tank. A secondary settlement stage succeeding the percolating filter process. Named after the nature of the humus solids separated.

Hydraulic load. The volumetric flow in relation to the hydraulic capacity of the collecting system or treatment plant.

Imhoff tank. A primary settlement tank incorporating an integral sludge storage tank. Not normally constructed nowadays.

Longitudinal mixing. The back-mixing of liquid in the opposing direction to the main flow as it moves through a pipe or vessel.

Metabolism. The utilisation by micro-organisms of nutrients (organic matter, compounds of nitrogen and phosphorus, inorganic matter, trace elements) necessary to sustain life and to proliferate.

Milligrams per litre (mg/l). Used for expressing concentration of impurities in a wastewater or effluent. In SI units the equivalent is gm/m^3.

Mixed liquor suspended solids. The suspension of bacterial flocs or solids in an activated sludge plant which firstly adsorb and then metabolise organic matter.

Nitrification. The sequential oxidation of ammonia and ammonium firstly to nitrite and then to nitrate by the autotrophic bacteria *Nitrosomonas* and *Nitrobacter*.

Nutrients. Compounds (typically of nitrogen and phosphorus) which cause enrichment of water bodies when present in sufficient concentrations. Enrichment causes eutrophication.

Organic load. The mass of organic polluting matter discharging from a sewer expressed as kg organic matter per m^3 of flow.

Outfall. The site of discharge of a liquid from a pipe. Applied particularly to the point at which a sewer or the effluent from a treatment plant discharges into a receiving water.

Outflow. The effluent from a sewer or treatment plant discharged to a water body via an outfall.

Percolating filter. A biological waste water treatment method using an immobile support medium for the growth of a bacterial slime that consumes organic matter under aerobic conditions.

Photosynthesis. A mechanism by which plants synthesise materials (mainly carbohydrates) from carbon dioxide, water and inorganic salts using sunlight as a source of energy. Oxygen is also produced.

Plug flow. A configuration of activated sludge plant whereby there is (theoretically) no longitudinal mixing between influent and effluent flows. A pipe/channel length to width ratio of at least 12:1 is normally required.

Pollutant. A material or compound which has a detrimental effect on the environment (aquatic, air or land)

Pollution. The impairment of the suitability of water for some considered purpose.

Ponding. The blockage of the interstices between the medium on a percolating filter caused by the excessive growth of bacterial slime. The term is also applied to the effect of a blockage caused by inert substances applied to a bed.

Population equivalent. The volume and strength of a waste water expressed in terms of an equivalent population, assuming a production of 0.060 kg BOD per capita per day; the population equivalent of a waste water is therefore calculated using the relationship:

$$\text{Population Equivalent (p.e.)} = \frac{BOD_5(mg/l) \text{ x flow}(m^3/day)}{0.060 \text{ x } 10^3}$$

Preliminary treatment. The removal or disintegration of gross solids in sewage and the removal of grit. Also sometimes the removal of oil and grease from sewage, prior to sedimentation.

Pretreatment. The treatment which an industrial wastewater receives at the source before discharge into the public sewer. Pretreatment of a sludge refers to conditioning before dewatering.

Primary treatment. The first major stage of treatment following preliminary treatment in a sewage works, usually involving removal of settleable solids.

Protozoa. A group of motile microscopic animals (usually single celled and aerobic) that sometimes cluster into colonies and often consume as an energy source.

Receiving water. A body of water, flowing or otherwise, such as a stream, river, lake, estuary or sea into which an outfall discharges.

Recirculation. The re-introduction of treated effluent to a treatment stage with the objective of reducing the concentration of pollutants in incoming waste water in order to protect the process from overloading or clogging due to excessive biomass growth or from toxicity.

Return activated sludge (RAS). Closing the activated sludge loop by drawing bacterial floc from secondary settlement tanks to be mixed with incoming waste water. The waste water provides the food for the bacteria.

Return liquors. Water separated in sludge dewatering processes which is typically high organic strength and is returned to the main treatment plant inlet.

Rotating biological contactor. An attached growth biofilm process using rotating support media. Typically used in small schemes and package plants.

Rotifers. Microscopic animals characterised by short hairs on their end.

Scum. A layer of fats, oils, grease and soaps together with particles of plastic and sludge which floats on the surface of settlement tanks or digesters.

Scum baffle. A plate or board which dips below the surface of sedimentation tanks to prevent scum flowing out with the effluent. Also termed a 'scum board'.

Septic. A condition produced by lack of dissolved oxygen and oxidised nitrogen (nitrate or nitrite). Putrefaction can occur.

Septic tank. A waste water treatment system whereby the settlement of heavy material and flotation of lighter material occurs in a tank. The liquid overflow is then distributed over a percolation area for dispersion in the natural environment. Septic tanks are sometimes used as precursors to small scale biological waste water treatment systems. They are desludged 2-4 times per year.

Settlement. A physical solid-liquid separation process in which solid particles sink when the velocity of flow decreases below a critical value. Can be aided by using chemicals to coagulate and flocculate the solid particles to increase their density.

Sludge age. The total mass of sludge contained in an activated sludge aeration and settlement tank divided by the total mass of sludge wasted daily, including suspended solids discharged with the outflow.

Sound power and sound pressure. A sound source radiates power and this results in a sound pressure. Sound power is the cause and sound pressure is the result. Sound power is independent of the environment in which it is located. The sound pressure which we hear is dependent on the distance from the sources and the acoustic environment (or sound field) in which the sound waves are present.

Submerged filter. A submerged fixed film biological waste water treatment system developed mainly within the last fifteen years with claims for low footprint and high treatment intensities.

Substrate. A (food) substance that becomes changed by enzymes during a bacteriological process. In waste water treatment processes, it normally comprises the soluble biodegradable organic fraction of the waste water.

Surcharge. A condition where flow backs up in a pipe or channel due to a lack of hydraulic capacity downstream.

Telemetry. A system of remote monitoring of plant and equipment using radio links and central control rooms. Particularly valuable for alarm situations.

Trickling filter. See **Percolating filter**.

Waste activated sludge (WAS). A portion of the sludge drawn from the secondary settlement tank which is wasted due to the continuous growth of new micro-organisms during the activated sludge process. Used to control the MLSS in the aeration tank at the required concentration.

APPENDICES

APPENDIX A: STANDARD FORMS

This appendix provides examples of the forms which operators are encouraged to use to standardise sampling and reporting. Those included are:

- sample analysis report form;
- sampling monitoring sheet;
- dilution scheme for BOD; and
- laboratory sheet for biochemical oxygen demand (BOD_5).

SAMPLE ANALYSIS REPORT FORM

SAMPLE ANALYSIS REPORT FORM	Name and address of laboratory:			
Report to:			Date of report:	
Sample/s from:				
Sample/s taken by:			Sampling date:	
Received at	Hours: / /		By:	
Laboratory No:				
Sample Description				
Sample Time				
BOD mg/l O_2				
COD mg/l O_2				
Suspended Solids mg/l				
MLSS mg/l				
Temperature °C				
Ammonia mg/l N				
Total Nitrogen mg/l N				
Total Phosphorus mg/l P				
Comments:			Signed: --------------------------------------- (Printed Name of analyst)	

SAMPLE MONITORING SHEET

EFFLUENT SAMPLING SHEET	Name and Address of Laboratory:	
Name of Plant:		
Laboratory No:		
Container Marking:		
Sample Description:		
Sampling Location:		
Temperature °C:		
Sample taken by:		
Person contacted :		
GRAB SAMPLES:		
Sampling date:	Sample Time:	
FLOW MEASUREMENT		
V-notch Angle ° :	Head (cm) :	
Weir Width (cm):	Head (cm) :	
Flume Width (cm):	Head (cm) :	
Meter reading	Units	

COMPOSITE SAMPLE

	Date	Time	Flow meter reading	Units
Start				
Finish				

COMMENTS:

BOD DILUTION SCHEME

Dilution Factor	BOD range	ml of sample	To (ml)	Dilution No. 1	ml of dilution No.1	To (ml)	Dilution No. 2
1:2	4 - 12	250	500	1:2			
1:3	6 - 18	150	450	1:3			
1:4	8 - 24	125	500	1:4			
1:5	10 - 30	100	500	1:5			
1:10	20 - 60	50	500	1:10			
1:15	30 - 90	30	450	1:15			
1:20	40 - 120	25	500	1:20			
1:25	50 - 150	20	500	1:25			
1:30	60 - 180	15	450	1:30			
1:40	80 - 240	25	1000	1:40			
1:50	100 - 300	20	1000	1:50			
1:100	200 - 600	25	250	1:10	50	500	1:10

LABORATORY SHEET FOR BIOCHEMICAL OXYGEN DEMAND (BOD)

Laboratory sheet for Biochemical Oxygen Demand						
	Date	Time	Analyst		Incubator temperature (°C)	
On						
Off						
Laboratory No.	Salinity (%)	Dilution	DO_o mg/l O_2	DO_5 mg/l O_2	DO_6 mg/l O_2	BOD mg/l O_2
Duplicate Sample No.						
Dilution water Blank	N/A*	N/A*				
Deionised water Blank	N/A*	N/A*				
QC Standard**	N/A*	1/50				

*N/A - Not applicable

** Dry reagent grade glucose and reagent grade glutamic acid at 103°C for 1 hour. Add 0.150g glucose and 0.150g glutamic acid to distilled water and dilute to 1 litre (BOD estimated @ 198± 0.5 mg/l). Prepare freshly before use and dilute 10 ml to 500 ml with dilution water for use as QC standard. Acceptable level for duplicate samples = ± 25%.

APPENDIX B: INDUSTRIAL WASTE WATER CHARACTERISTICS

Industry	Flow	BOD	Total Suspended Solids	COD	pH	Nitrogen	Phosphorus
Meat products	Intermittent	High - extremely high	High	High - extremely high	Neutral	Present	Present
Milk handling	Intermittent	Average - high	Low - average	Average - high	Acid- alkaline	Adequate	Present
Cheese products	Intermittent	Extremely high	Average - extremely high	Extremely high	Acid - alkaline	Deficient	Present
Alcoholic Beverages	Intermittent	High - extremely	Low - high	High - extremely high	Alkaline	Deficient	Deficient
Soft drinks	Intermittent	Average - high	Low - high	Average - high		Deficient	Present
Textiles	Intermittent - continuous	High	High	High	alkaline	Deficient	Present
Tanning and finishing	Intermittent	Extremely high	Extremely high	Extremely high	Acid - alkaline	Adequate	Deficient
Metal finishing	Continuous - variable	Low	Average - high	Low	Acidic	Present	Present
Fruit and vegetables	Intermittent	Average - extremely high	Average - extremely high	Average - extremely high	Acid - alkaline	Deficient	Deficient
Paper and allied products	Continuous	Average - extremely high	Low - high	Low - high	Neutral (mech. pulping)	Deficient	Deficient
Pharmaceutical products	Continuous - intermittent	High	Low - high	High	Acid - alkaline	Deficient	Deficient
Plastics and resins	Continuous - variable	Average - high	Low - high	Average - high	Acid - alkaline		

APPENDIX C: INDUSTRIAL DISCHARGES

Parameters other than BOD, COD, Total Phosphorus, Total Nitrogen, pH, and Ammonia which may be present in an industrial discharge and which may affect the operation of secondary treatment plant.

RENDERING OF ANIMAL BY-PRODUCTS

- Oils, Fats and Grease
- Mineral Oil (Interceptor)

MANUFACTURE OF FISH MEAL AND FISH OIL

- Oils, Fats and Grease
- Mineral Oil (Interceptor)

BREWING, DISTILLING AND MALTING

- Oils, Fats and Grease
- Mineral Oil (Interceptor)

MANUFACTURE OF DAIRY PRODUCTS

- Oils, Fats and Grease
- Mineral Oil (Interceptor)
- Mineral Oil (Biological Treatment)

MANUFACTURE OF COATING MATERIALS

- Oil
- Organohalogens
- Zinc
- Chromium VI
- Total Chromium
- EC list 1 (76/464/EEC)

TREATMENT OR PROTECTION OF WOOD WITH PRESERVATIVES

- EC list 1 (76/464/EEC)
- Chromium VI
- Total Chromium
- Organohalogens
- Phenols
- Arsenic
- Mineral Oil (Interceptor)
- Mineral Oil (Biological Treatment)
- Oils, Fats and Grease

ROASTING, SINTERING OR CALCINING OF METALLIC ORES (PRINCIPALLY LEAD, ZINC, IRON ORE)

- Cadmium
- Mineral oil
- Mercury
- Lead
- Zinc
- Copper
- Nickel
- Chromium VI
- Total Chromium

PRODUCTION, RECOVERY OR PROCESSING OF NON FERROUS METALS, THEIR COMPOUNDS OR OTHER ALLOYS

- Mineral oil
- Cadmium
- Mercury
- EC list 1 (76/464/EEC)
- Nickel
- Silver
- Lead
- Chromium VI
- Total Chromium
- Tin
- Zinc
- Copper

METAL MINING AND MINERAL QUARRYING

- Oils, Fats and Grease
- Mineral Oil (Interceptor)
- Mineral Oil (Effluent)
- Thallium

OPERATIONS INVOLVING COATING WITH ORGANO-TIN COMPOUNDS

- EC List 1 (76/464/EEC)
- Organo-Tin
- Copper
- Mineral Oil
- Metals

COARSE CERAMICS INCLUDING REFRACTORY BRICKS, STONEWARE PIPES, FACING AND FLOOR BRICKS AND ROOF TILES

- Mineral Oil
- Sulphide
- Fluoride

MELTING OR PRODUCTION OF IRON OR STEEL

- Mineral Oil
- Cadmium
- Mercury
- EC List 1(76/464/EEC)
- Lead
- Zinc
- Chromium VI
- Total Chromium
- Nickel

PRODUCTION, RECOVERY, PROCESSING OR USE OF FERROUS METALS IN FOUNDRIES

- Mineral Oil
- Phenols
- Cadmium
- Mercury
- EC List 1(76/464/EEC)
- Other parameters depending on Resins and Binders

MANUFACTURE OF CHEMICALS (INCLUDING OLEFINS AND THEIR DERIVATIVES, ORGANIC OR ORGANO-METALLIC, INORGANIC, FERTILISERS, PESTICIDES, PHARMACEUTICAL, VETERINARY, INTERMEDIATES, GLUES, BONDING AGENTS, VITAMINS INVOLVING HEAVY METALS)

- Oils, Fats, and Grease
- Organohalogens
- Phenols
- Cyanide
- Mercury
- Tin
- Lead
- Chromium VI
- Total Chromium
- Cadmium
- Zinc
- Copper
- Mineral Oil (Interceptor)
- Mineral Oil (Biological treatment)
- EC List 1 (76/464/EEC)
- Benzene, Toluene and Xylene
- Genetically Modified Organisms (S.I. No. 345 of 1994)

FELLMONGERING OF HIDES AND TANNING OF LEATHER

- Oils, Fats and Grease
- Mineral Oil (Interceptor)
- EC List 1 (76/464/EEC)
- Chromium VI
- Total Chromium
- Sulphide
- Phenols

DYEING, TREATMENT OR FINISHING OF FIBRES OR TEXTILES

- Oils, Fats and Grease
- Organohalogens
- Phenols
- Mercury
- Nickel
- Cobalt
- Lead
- EC List 1 (76/464/EEC)
- Chromium VI
- Total Chromium
- Arsenic
- Cadmium

- Zinc
- Copper
- Mineral Oil (Interceptors)
- Mineral Oil (Biological treatment)
- Organochlorine pesticides
- Benzene, Toluene and Xylene
- Mothproofing agents (as Cl)
- Organophosphorus pesticides
- Aldrin, Dieldrin, Endrin, Isodrin
- Sulphide

SLAUGHTERING

- Oils, Fats and Grease
- Mineral Oil (Interceptor)

MANUFACTURE OF SYNTHETIC FIBRES

- Oils, Fats and Grease
- Mineral Oil (Interceptor)
- Phenols
- Cyanide
- Mineral Oil (Biological treatment)

PROCESSING OF ASBESTOS OR MANUFACTURE OR PROCESSING OF ASBESTOS BASED PRODUCTS MANUFACTURE OF GLASS FIBRE OR MINERAL FIBRES, AND PRODUCTION OF GLASS

- Mineral Oil (Biological treatment)
- Phenols
- Lead
- Arsenic
- Fluoride
- EC List 1 (76/464/EEC)

MANUFACTURE OF INTEGRATED CIRCUITS AND PRINTED CIRCUIT BOARDS

- Oils, Fats and Grease
- Mineral Oil (Interceptor)
- Chromium VI
- Total Chromium
- Arsenic
- Fluoride
- Copper
- Tin
- Lead

ELECTROPLATING

- Oils, Fats and Grease
- Mineral Oil (Interceptor)
- Mineral Oil (Effluent treatment)
- Organohalogens
- Phenols
- Mercury
- Nickel
- Silver
- Lead
- Chromium VI
- Total Chromium
- Cadmium
- Tin
- Zinc
- Copper
- EC List 1 (76/464/EEC)
- Cyanide

MANUFACTURE OF VEGETABLE AND ANIMAL OILS AND FATS

- Oils, Fats and Grease
- Mineral Oil (Interceptor)
- Mineral Oil (Biological treatment)

PROCESSING OF IRON AND STEEL IN FORGES, DRAWING PLANTS AND ROLLING MILLS

- Oils, Fats and Grease
- Lead
- Nickel
- Zinc
- Chromium VI
- Total Chromium
- Copper
- Mineral Oil

APPENDIX D: SENSITIVE AREAS

Ten areas are designated as sensitive in the the Urban Waste Water Treatment Regulations. Article 5(6) of the Urban Waste Water Treatment Directive (91/271/EEC) requires that the identification of sensitive areas is reviewed at intervals of no more than four years.

River Boyne Co. Meath	6.5 km section downstream of sewage treatment works outfall at Blackcastle, Navan, Co. Meath.
River Camlin Co. Longford	From sewage treatment works at Longford to entry into the River Shannon.
River Castlebar Co. Mayo	Downstream of sewage treatment works outfall at Knockthomas to entry into Lough Cullin.
River Liffey	Downstream of Osberstown sewage treatment works to Leixlip reservoir, Co. Kildare.
River Nenagh Co. Tipperary	Downstream of sewage treatment works outfall in Nenagh to entry into Lough Derg.
River Tullamore Co. Offaly	0.5 km section downstream of sewage treatment works outfall in Tullamore.
Lough Derg on the River Shannon	Whole lake.
Lough Leane Co. Kerry	Whole lake.
Lough Oughter Co. Cavan	Whole lake.
Lough Ree on the River Shannon	Whole lake.

APPENDIX E: MICROSCOPY EXAMINATION FORM

Date: ______________________ Time: __________ AM/PM

By: ______________________ Temperature __________ °C

Sample Location: ____

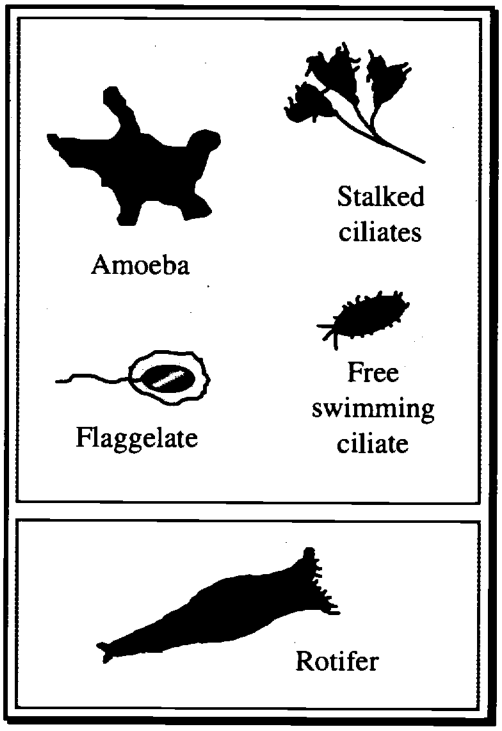
Micro-organism Group	Slide No. 1	Slide No. 2	Slide No. 3	Total
Amoebae				
Flagellates				
Free swimming ciliates				
Stalked ciliates				
Rotifers				
Worms				

Relative predominance

1 ______________________

2 ______________________

3 ______________________



Method

1. Record the date, time, temperature, and sample location.
2. Examine a minimum of three slides per sample with one drop of mixed liquor per slide.
3. Randomly scan each slide and count the number of each type of micro-organism.
4. Determine the number from each group and assess predominance.

USER COMMENT FORM

NOTE: Completed comments to be forwarded to: The Environmental Management and Planning Division, Environmental Protection Agency, Ardcavan, Wexford

Document Title: **Waste Water Treatment Manuals - Primary, secondary and tertiary treatment**

CONTENTS:

STYLE:

INFORMATION:

SUGGESTIONS FOR FUTURE EDITIONS:

NAME...ORGANISATION...

ADDRESS...

DATE .... PHONE .... FAX....................................

SELECTED EPA PUBLICATIONS

Urban Waste Water Discharges in Ireland: A Report for 1994-1995 (1997)	£10
Handbook on Urban Wastewater Treatment. *(1996)*	£15
National Waste Database - *Report for 1995. (1996)*	£15
Waste Catalogue and Hazardous Waste List. *(1996)*	£5
Municipal Waste Characterisation. *(1996)*	£5
Landfill Manual *Investigations for Landfills. (1995)*	£15
Landfill Manual *Landfill Monitoring. (1995)*	£15
State of the Environment Report in Ireland. *(1996)*	£30
The Quality of Drinking Water in Ireland *A Report for the Year 1995 and a Review of the Period 1993-1995. (1997)*	£15
Water Treatment Manual *Filtration. (1995)*	£15
Waste Water Treatment Manual *Preliminary Treatment. (1995)*	£15
Dioxins in the Irish Environment *An assessment based on levels in cows' milk. (1996)*	£5
Lough Ree *An Investigation of Eutrophication and its Causes*	£20
Pesticides in Drinking Water *Results of a Preliminary Survey Dec '94-Dec '95*	£5
Smoke & Sulphur Dioxide *A Summary of Results from Local AuthorityMonitoring Networks (1996)*	£2

A full list of publications is available on request (see below).

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ENVIRONMENTAL PROTECTION AGENCY

ESTABLISHMENT

The Environmental Protection Agency Act, 1992, was enacted on 23 April, 1992 and under this legislation the Agency was formally established on 26 July, 1993.

RESPONSIBILITIES

The Agency has a wide range of statutory duties and powers under the Act. The main responsibilities of the Agency include the following:

- the licensing and regulation of large/complex industrial and other processes with significant polluting potential, on the basis of integrated pollution control (IPC) and the application of best available technologies for this purpose;
- the monitoring of environmental quality, including the establishment of databases to which the public will have access, and the publication of periodic reports on the state of the environment;
- advising public authorities in respect of environmental functions and assisting local authorities in the performance of their environmental protection functions;
- the promotion of environmentally sound practices through, for example, the encouragement of the use of environmental audits, the establishment of an eco-labelling scheme, the setting of environmental quality objectives and the issuing of codes of practice on matters affecting the environment;
- the promotion and co-ordination of environmental research;
- the licensing and regulation of all significant waste recovery activities, including landfills and the preparation and updating periodically of a national hazardous waste plan for implementation by other bodies;
- preparation and implementation of a national hydrometric programme for the collection, analysis and publication of information on the levels, volumes and flows of water in rivers, lakes and groundwaters; and
- generally overseeing the performance by local authorities of their statutory environmental protection functions.

STATUS

The Agency is an independent public body. Its sponsor in Government is the Department of the Environment. Independent is assured through the selection procedures for the Director General and Directors and the freedom, as provided in the legislation, to act on its own initiative. The assignment, under the legislation, of direct responsibility for a wide range of functions underpins this independence. Under the legislation, it is a specific offence to attempt to influence the Agency, or anyone acting on its behalf, in an improper manner.

ORGANISATION

The Agency's headquarters are located in Wexford and it operates five regional inspectorates, located in Dublin, Cork, Kilkenny, Castlebar and Monaghan.

MANAGEMENT

The Agency is managed by a full-time Executive board consisting of a Director General and four Directors. The Executive Board is appointed by the Government following detailed procedures laid down in the Act.

ADVISORY COMMITTEE

The Agency is assisted by an Advisory Committee of twelve members. The members are appointed by the Minister for the Environment and are selected mainly from those nominated by organisations with an interest in environmental and developmental matters. The Committee has been given a wide range of advisory functions under the Act, both in relation to the Agency and to the Minister.

ORC