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ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshaoil

WASTEWATER TREATMENT MANUALS

TREATMENT SYSTEMS for SMALL COMMUNITIES, BUSINESS, LEISURE CENTRES AND HOTELS

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 disposal and recovery activities, including landfills and the preparation and periodic updating of a national hazardous waste plan for implementation by other bodies;

- implementing a system of permitting for the control of VOC emissions resulting from the storage of significant quantities of petrol at terminals;

- implementing and enforcing the GMO Regulations for the contained use and deliberate release of GMOs into the environment;

- 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 and Local Government. Independence 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 is 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 Local Government 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.

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TREATMENT SYSTEMS FOR SMALL COMMUNITIES,
BUSINESS, LEISURE CENTRES AND HOTELS
(P.E. 10 - 500)

Published by the Environmental Protection Agency, Ireland.

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and Mr. Gerard O'Leary, (EPA).

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Mr. Frank Gleeson	Sligo Co. Co., representing the County and City Engineers' Association
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Mr. Gerard O'Leary	EPA
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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 ".

The purpose of this manual is to provide guidance in the selection, operation and maintenance of small wastewater treatment systems (i.e. for population equivalents between 10 - 500). Other manuals in the series on *Preliminary Treatment, Primary, Secondary and Tertiary Treatment, Treatment systems for single houses and Characterisation of industrial wastewaters* should be consulted. The Agency hopes that it will provide practical guidance to those involved in plant selection, 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 attached User Comment Form.

List of Abbreviations

°C	degrees Celsius
Agency	Environmental Protection Agency
BAF	biofilm aerated filters
BOD	biochemical oxygen demand
BOD_5	five-day biochemical oxygen demand
COD	chemical oxygen demand
d	day
DO	dissolved oxygen
DWF	dry weather flow
EPA	Environmental Protection Agency
EQO	environmental quality objective
EQS	environmental quality standard
F/M	food to microorganism ratio
FOG	fats, oils and grease
FWS	free-water surface
g	gram
h	hour
kg	kilogram
l	litre
m	metre
m/s	metres per second
mg	milligram
MLSS	mixed liquor suspended solids
mm	millimetre
p.e.	population equivalent
PFSC	percolating filter solids contact process
RAS	return activated sludge
RBC	rotating biological contactors
s	second
S.I.	statutory instrument
SBR	sequencing batch reactor
SFS	sub-surface flow system
SS	suspended solids
SVI	sludge volume index
TSS	total suspended solids
UWWT	urban wastewater treatment
WAS	waste activated sludge

1. INTRODUCTION TO SMALL WASTEWATER TREATMENT SYSTEMS

1.1 GENERAL

In Ireland, the wastewater from over one third of the population is treated in small scale treatment systems. These wastewater treatment systems - located mainly in rural areas - include over 350,000 septic tank systems for single houses, and over 450 systems treating wastewater from population equivalents greater than a single house population.

There are many systems available for the treatment of wastewater from small communities. All small wastewater treatment systems should be designed to:

- treat the wastewater;
- comply with public health standards;
- avoid unpleasant odours and sights, both on and off the site;
- enable the receiving "waters" to fulfill their designated beneficial uses; and
- comply with legal requirements, which include the EPA Act, 1992, Waste Management Act, 1996 and the Water Pollution Acts 1970 - 1990.

In order to examine the current position relating to on-site systems and to establish guidelines for future use, a research project was put out to tender in March 1995. The title of the R&D project was "Small scale wastewater treatment systems". The Department of Civil Engineering, NUI, Galway was awarded the contract for this project, which was undertaken as part of the Environmental Monitoring, R&D sub-programme of the Operational Programme for Environmental Services,1994-1999 and was part financed by the European Regional Development Fund. The sub-programme is administered on behalf of the Department of the Environment by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research.

As part of the research study, forty systems were initially examined, and later twelve systems were selected for monitoring. The main conclusions from the study were:

- all treatment systems - including wastewater collection systems - should be designed, constructed, commissioned and operated in accordance with national and international standards and guidelines;
- all work relating to the installation of small scale wastewater treatment systems should be supervised and certified by indemnified professionals;
- checks should be carried out by the local authorities on all aspects of small scale wastewater treatment systems including site suitability tests;
- sludge and grease storage and handling should be taken into account in the selection of a wastewater treatment system ; and
- bonding schemes should be introduced to facilitate private developments such as housing estates with private wastewater treatment schemes.

1.2 LEGISLATION

1.2.1 The Environmental Protection Agency Act, 1992 (Urban Waste Water Treatment) Regulations, 1994 (S.I. 419 of 1994)

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

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

The Regulation require agglomerations with a p.e. of less than or equal to 2,000, which discharge to freshwater to have "appropriate treatment" by the year 2005. Appropriate treatment is defined in the Regulations as "treatment of urban waste water by any process and/or disposal system which after discharge allows the receiving waters to meet the relevant quality objectives and relevant provisions of the Directive and of other Community Directives".

1.2.2 Water Pollution Acts, 1977 - 1990

The discharge of any trade effluent means (any effluent from any works, apparatus, plant or drainage pipe used for the disposal to waters or to a sewer of any liquid (whether treated or untreated), ...discharged from premises used for carrying on any trade or industry) or sewage effluent to "waters" requires an Effluent Discharge licence which is granted by the relevant local authority under the Water Pollution Acts.

There is a general prohibition in relation to water pollution in the above act; it is an offence to cause or permit the entry of "polluting matter" to "waters[1]".

"Polluting matter" is defined in the Acts as ....any substance........the entry or discharge of which into any waters is liable to render those or any other waters.........................harmful or detrimental to public health or to domestic...........or recreational uses.

1.2.3 The Waste Management Act, 1996

Section 22(1) of the Waste Management Act, 1996 requires local authorities to prepare a waste management plan. The plan (which should include sludges from treatment plants) must take into account *"the prevention, minimisation, collection, recovery and disposal of non-hazardous waste within its functional area"*:

The use of sewage sludge in agriculture is regulated under the Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998, (S.I. 148 of 1998). A person using sewage sludge in agriculture must *inter alia* ensure that *"the quality of soil, of surface water and of groundwater is not impaired"*.

1.2.4 The Building Regulations, 1991

The Building Regulations, which came into operation in June, 1992, apply to new buildings and to extensions, material alterations, and certain changes of use of existing buildings, and apply across all local authority areas, replacing Building Bye-laws which were operated in the larger urban authority areas. In order to assist designers, constructors and installers, the Department of the Environment has published Technical Guidance Documents (TGDs) for each part of the First Schedule to the Regulations. The parts which are chiefly relevant to small wastewater treatment systems include:

Part A: Structure;

Part C: Site preparation and resistance to moisture;

Part D: Materials and Workmanship;

Part H: Drainage and Waste Disposal.

1.3 THE PUBLIC HEALTH (IRELAND) ACT, 1878

The Public Health (Ireland) Act, 1878 is frequently used to abate nuisance caused by the accumulation of raw or treated sewage. The Act prohibits the discharge of sewage or filthy water into any natural stream or watercourse, or into any canal, pond or lake unless the discharge is freed from all excrementitious or foul or noxious matter. The Act allows for a statutory nuisance to exist where a pool, gutter, watercourse, privy, urinal, cesspool, drain or ashpit is so foul or in such a state as to be a nuisance or injurious to health.

1.4 FISHERIES ACTS, 1959-1990

Section 171(1) of the 1959 Act provides that any person who *"throws, empties, permits or causes to fall into any water any deleterious matter, shall...........be guilty of an offense"*.

Deleterious matter is defined as *"any substance (including explosive liquid or gas) the entry or discharge of which into any waters is liable to render those or any other waters poisonous or injurious to fish, spawning grounds or the food of any fish or to injure fish in their value as human food, or to impair the usefulness of the bed and soil of any waters as spawning grounds or their capacity to produce the food of fish"*.

1.5 ENVIRONMENTAL PROTECTION AGENCY, ACT, 1992

Section 60 allows the Agency to publish criteria and procedures for the operation and maintenance of wastewater treatment plants for the purposes of environmental protection. The Agency is also required under the Act (Section 61) to publish reports on the quality of effluents being discharged from plant, sewers or drainage pipes which are under the control of local authorities and to make recommendations as it considers necessary.

The remainder of this manual sets out criteria and

[1] includes any (or any part of) river, stream, lake, canal, reservoir, aquifer, pond, watercourse or any inland waters, whether natural or artificial.

procedures for the design and operation of small wastewater treatment systems which the Agency considers to be appropriate for the protection of the environment.

Chapter 3 sets out *inter alia* the selection factors which should be taken into account when choosing a small wastewater treatment system for a small community, business or leisure centre. Chapter 4 gives design details for primary and secondary treatment tanks. Chapters 5 and 6 give detailed information about the different biofilm and suspended growth systems, while Chapter 7 discusses the installation, management and control for such systems.

As mentioned in the preface, other wastewater treatment manuals in the series should be consulted for a discussion on related topics and in some cases a detailed discussion on the scientific background to some of the technologies outlined in this manual. In particular, the manual on preliminary treatment discusses screening, grit removal, oils, greases and fats. The manual on primary, secondary and tertiary treatment discusses in greater detail biofilm (attached growth) and suspended growth systems. The manual on the characterisation of industrial wastewaters stresses the importance of characterising a wastewater stream in advance of designing a wastewater treatment system. A methodology for carrying out this characterisation is set out in the manual.

For small treatment systems where the disposal of the treated wastewater to ground is being considered, the manual on treatment systems for single houses is of particular relevance. In this latter manual a methodology for characterising a site, which includes a desk study and on-site assessment is set out. The site characterisation should be completed to determine the suitability or otherwise of the site for discharging treated wastewater to ground.

2. WASTEWATER FLOWS AND LOADINGS

2.1 OVERVIEW OF SMALL SCALE WASTEWATER TREATMENT

Wastewater treatment can involve physical, chemical or biological processes or combinations of these processes depending on the required wastewater standard. A schematic layout of a typical biological wastewater treatment system is shown in Figure 1:

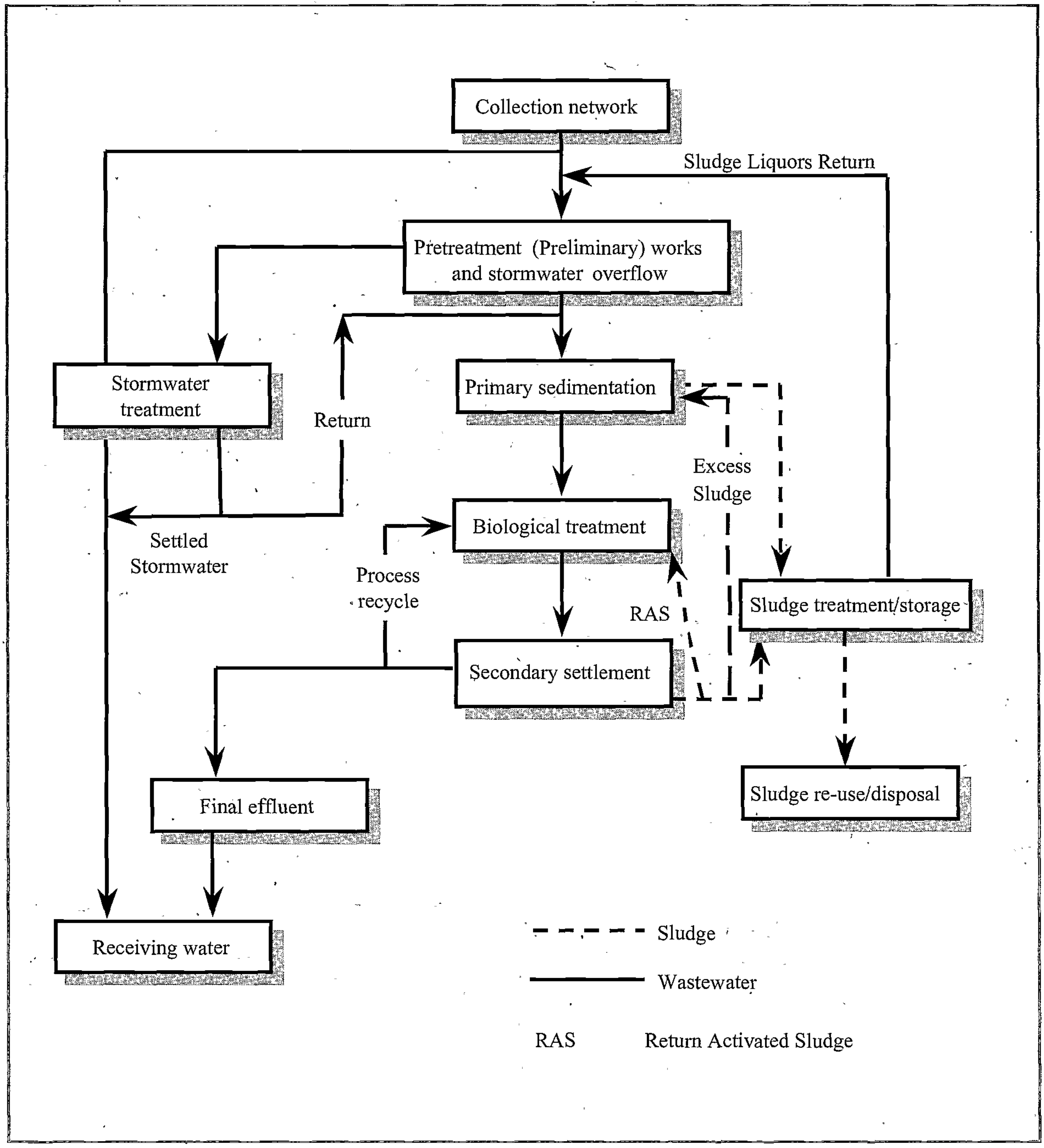

FIGURE 1: SMALL WASTEWATER TREATMENT SYSTEM

The first stage of wastewater treatment takes place in the preliminary treatment units where materials such as oils, fats, grease, grit, rags and large solids are removed.

Primary settlement is required in advance of biofilm (attached growth) and conventional activated sludge systems. Radial or horizontal flow tanks are normally employed to reduce the velocity of flow of the wastewater such that a proportion of suspended matter settles out.

Biological treatment of wastewaters takes place in biofilm 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.

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

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

2.2 WASTEWATER FLOWS

Flow rates and wastewater characteristics discharged to small scale treatment systems may differ significantly. Per capita flowrates can vary from less than 50 litres/day for a camping site up to 300 litres/day for an affluent high amenity residential area. Knowledge of the expected wastewater flowrates and characteristics is therefore essential for the design of these systems.

Measurements should be made over a representative time period to accurately determine the flowrates and characteristics of the particular wastewater. If these measurements cannot be carried out, other methods of assessing the wastewater parameters should be adopted. These methods could include comparisons with similar systems elsewhere. In any event, it is essential to critically assess *all* design parameters.

The daily average flow in a mainly domestic wastewater treatment system, measured during a period of 7 dry days following a period of 7 days during which the rainfall did not exceed 0.25 mm on any one day, is called the dry weather flow (DWF). In the absence of flow measurements, the DWF is calculated from the product of the population equivalent (p.e.) and the per capita wastewater flow. A value for the per capita wastewater flow which has been used in the past is 225 litres/day. In recent studies carried out by Dublin Corporation and Galway Corporation, the average per capita *water consumption* was found to be between 130 and 150 litres/day. **The true value for *wastewater flow* per capita will vary upwards from the 130-150 litres/day range, depending on the amount of infiltration into the system and other factors; however, it is now thought that the true *per capita wastewater flow* is somewhat less than the 225 litres/day that has been used in the past and a figure of 180 litres/day is suggested.** In small scale systems, flows greatly in excess of the DWF are common, making it necessary to consider peak flows and the variations of wastewater flow; these flow variations can occur during a day, week or may be seasonal.

The nature of the sewerage system is one of the major factors which influences the flows and characteristics of the wastewater. A sewerage system can be:

- a separate system that contains foul wastewater only;
- a combined system that contains both foul wastewater and surface water; or
- an intermediate system that has a fraction of the surface water combined with the foul wastewater.

2.2.1 Separate Sewerage Systems

The pattern of small flows at night and large flows in the morning and evening, is common in a separate sewerage system. A diurnal flow diagram from a typical separate sewerage system is shown in Figure 2. The short sewer lengths associated with small scale treatment systems provide little flow balancing and as a result, peak flows in excess of 3 DWF can regularly occur. In a separate sewerage system, no provision for overflow should be made; instead all flows should pass through the treatment system. It is common to design the system for 6 DWF while at the same time allowing all flow to pass through the system. In order to cater for peak flows, the provision of flow balancing facilities should be considered. It is generally simpler to treat wastewaters from a separate system.

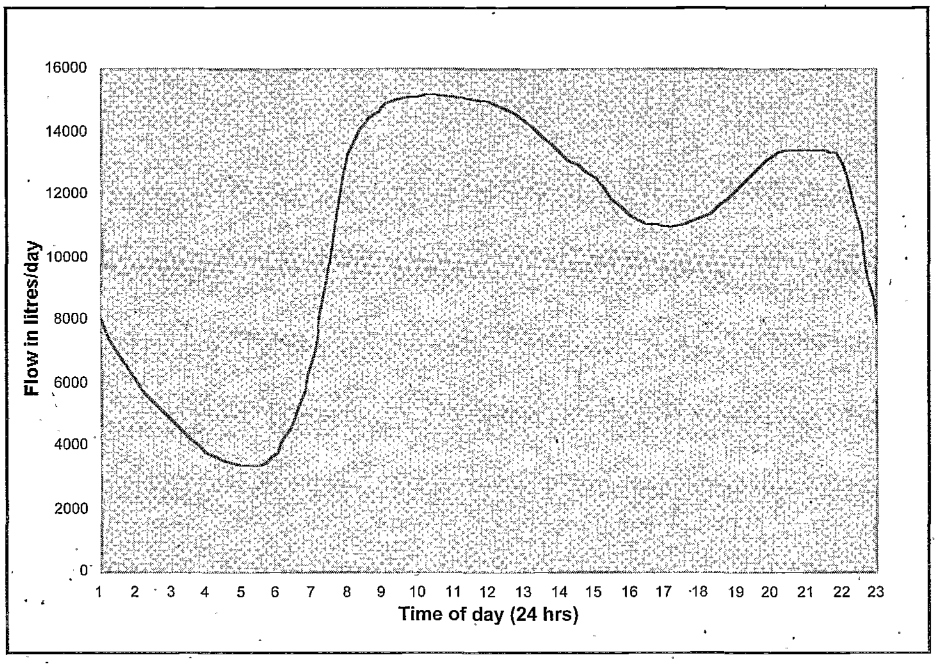

FIGURE 2 TYPICAL FLOW VARIATION FROM A SEPARATE SYSTEM

2.2.2 Combined Sewerage Systems

The inclusion of surface waters with foul wastewater will result in high wastewater flows at times of heavy rainfall when flows well in excess of 3 DWF are highly probable. Complete treatment for the entire flows under storm conditions is neither desirable nor practicable at small works. Prolonged high wastewater flows could cause failure of biological treatment systems by washing beneficial microorganisms out of the system. Overflow weirs are sometimes used to limit the wastewater flow through the treatment system. Flows in excess of 7.5 DWF can be discharged directly provided that there is no adverse impact on the receiving water. Screening of the overflow may, as a minimum, be required to prevent gross solids affecting the aesthetic quality of the receiving waterbody. Detailed consideration should be given to the problems associated with the treatment of wastewaters discharged to combined sewerage systems.

2.2.3 Annual Variations in Wastewater Flows

Annual variations in domestic wastewater flows can occur at treatment systems where there is an influx of visitors for certain periods or there are seasonal industries. These variations in flow can cause operational problems especially where there are little or no wastewater flows in the systems for long periods of the year. The treatment system needs to be able to withstand shock loads and to treat the maximum flows during busy periods. The system should also be capable of functioning at low flows. In some situations, it may be necessary to have a modular treatment system such that part of the system can be taken out of commission during low flows. In some cases it may be unwise to shut down a mechanical treatment system such as an RBC during the off-season, as this may lead to excessive stress or torque on start up due to uneven build up of sludge on the discs. At the design stage, detailed consideration should be given to the problems associated with the treatment of wastewaters with large annual flow variations.

2.3 WASTEWATER CHARACTERISTICS

In order to design a wastewater treatment system it is necessary to examine the characteristics of the wastewater to be treated. The extent of the examination will depend on the type of treatment proposed, which, in turn, depends on the effluent standards required. The more important domestic wastewater characteristics include, organic matter (BOD), total suspended solids, total nitrogen, total phosphorus, pathogenic organisms, and grease.

Inflow wastewater data from twelve small scale treatment systems in Ireland are presented in Table 1 and Table 2 (domestic and restaurant/hotel sources respectively); these systems were tested as part of the EPA research study. Samples were taken at about two and half hour intervals. There was evidence of infiltration flow into some of these systems.

TABLE 1: INFLOW WASTEWATER CHARACTERISTICS* FROM EPA STUDY (DOMESTIC SOURCES)

Parameter	Mean	Standard Deviation
SS	163	136
BOD_5	168	127
COD	389	310
O-PO_4	7.1	4.2
Total-N	40.6	19.0
NH_3-N	31.5	15.6
NO_3-N	0.25	0.41
NO_2-N	0.04	0.06
pH	7.5	0.5
Total-coli	1 x 10^8	2 x 10^8
E-coli	4 x 10^7	5 x 10^7

* all results in mg/l, except bacterial counts which are expressed in colony forming units, CFU per 100 ml

TABLE 2: INFLOW WASTEWATER CHARACTERISTICS* FROM EPA STUDY (TREATMENT SYSTEMS SERVING HOTELS/RESTAURANTS)

Parameter	Mean	Standard Deviation
SS	293	238
BOD_5	470	455
COD	888	860
O-PO_4	8.21	4.95
Total-N	55.0	40.7
NH_3-N	45.6	36.5
NO_3-N	0.27	0.58
NO_2-N	0.04	0.08
pH	7.37	0.64
Total-coli	1 x 10^8	1 x 10^8
E-coli	9 x 10^7	1 x 10^8

* all results in mg/l, except bacterial counts which are expressed in colony forming units, CFU per 100 ml

2.4 SUBSTRATE LOADINGS

The BOD_5 loading rate is an important parameter in the design of all biological wastewater treatment systems. The unit per capita or population equivalent (p.e.) is used to express industrial, institutional and agricultural wastewaters in terms of domestic loadings. The EPA Act, 1992, (Urban Waste Water Treatment Regulations, 1994) define one population equivalent (p.e.) as 60 g BOD_5 per day, calculated on the basis of the maximum average weekly load entering the treatment system during the year. It should be noted that:

- BS 6297 : 1983, uses a BOD loading rate of 60 g per person per day and this is equivalent to 1 p.e.;
- DIN 4261, also uses 60 g BOD per person per day; however, if physical treatment such as primary settlement has been installed upstream, the figure of 40 g BOD_5 per person per day can be used; and
- US EPA recommends a BOD loading rate of between 35 to 50 g per person per day.

Household garbage grinders can increase the BOD_5 loading rate by up to 30% and because these appliances are becoming more popular their use is an important consideration.

2.5 WASTEWATER CHARACTERISATION

To ensure the proper design of a wastewater treatment system for a small community, business, leisure centre or hotel, all relevant details pertaining to the discharge should be collected prior to designing the treatment system. A form which will assist the gathering of this information is set out in Appendix A. Where no data can be obtained (e.g. a new activity), the information listed in Table 3 below may be used to complete the form.

Table 3: recommended wastewater loading rates from commercial premises

Situation	Source	Flow litres/day per person	BOD_5 grams/day per person
Industrial	Office and/or factory without canteen	30	20
	Office and/or factory with canteen Open industrial site e.g. quarry (excluding canteen)	60 40	30 25
Schools	Non-residential with cooking on-site	60	30
	Non-residential with no canteen	40	20
	Boarding school: (I) residents (II) day staff (includes mid-day meal)	 180 60	 60 30
Hotels	Guests	250	75
	Guests (no meals)	180	45
	Resident staff	180	60
	Day staff	60	30
	Conference	40	20
	Restaurant full meals: (I) luxury catering (II) prepared catering (III) snack bars (IV) function rooms incl. Buffets (V) fast food	 25 15 10 10 10	 25 15 10 10 10
Pubs and clubs	Residents	200	60
	Day staff	60	30
	Bar drinkers	10	10
	Bar meals	10	10
Amenity sites	Restaurants	15	15
	Function rooms	10	10
	Toilet blocks (per use)	5	10
	Toilet Blocks (long stay car parks)	10	15
	Golf clubs	20	10
	Squash, with club house	25	15
	Swimming	10	10
	Football Club	30	20
	Caravan Sites (I) Touring (II) Static not serviced (III) Static fully serviced (IV) Tent sites	 50 75 150 50	 35 35 55 35
Hospitals	Residential elderly people	250	60
	Residential elderly people plus nursing	300	65
	Nursing homes (convalescent)	350	75

3. TREATMENT SYSTEM SELECTION & DESIGN

3.1 GENERAL

There are many suitable types of systems for treating wastewaters from small communities, businesses and leisure centres. The appropriateness of a given wastewater treatment system will depend largely on the physical characteristics of the site, the nature of the wastewater to be treated and the capabilities of those responsible for management of the treatment system.

In general, small scale wastewater treatment systems should have the following characteristics:

- the ability to treat the wastewater to the specified standard;
- be robust (capable of dealing with specified load variations);
- be economical to construct and operate;
- be simple to maintain; and
- be reliable.

Items to be considered in the design of small scale wastewater treatment systems are described below. Details, where given, should be used as a guide to best current practice. Other design values can be used where it can be demonstrated that the specified wastewater standards can be achieved.

3.2 WASTEWATER COLLECTION SYSTEM

All collection systems should be designed and constructed in accordance with recognised standards or codes of practice (e.g. British Standard 8005: Sewerage and the Building Regulations, 1991, I.S./EN 588-1:1997 Fibre-cement pipes for sewers and drains - Part 1: Pipes, joints and fittings for gravity systems; I.S./EN 752-1:1996 Drain and sewer systems outside buildings - Part 1: Generalities and definitions; I.S./EN 752-2:1997 Drain and sewer systems outside buildings - Part 2: Performance requirements; I.S./EN 752-3: 1997 Drain and sewer systems outside buildings - Part 3: Planning, I.S./EN 1091:1997 Vacuum sewerage systems outside buildings). Separate collection systems should be used where possible.

3.3 HYDRAULICS

During early planning and design stages, a critical consideration is the determination of maximum flow to be accommodated through the system (see section 2.2). This maximum flow determines the sizing of pipework and head losses to be provided between each stage of the plant. Hydraulic profile is the graphical representation of the hydraulic grade line through the plant. The elevations of treatment units and piping are adjusted to give adequate hydraulic gradient to ensure gravity flows. It is important that attention is given at the design stage to the hydraulic profile. Otherwise, the system may later encounter serious operational problems due to insufficient gradient between units. Head losses through a treatment unit include, head losses at the inflow structure, head losses at the outflow structure, head losses through the unit, and miscellaneous and free-fall surface allowance. For a more detailed discussion on hydraulic design reference should be made to the Agency publications on *Preliminary Treatment* (Chapter 2) and Primary, *Secondary and Tertiary Treatment* (Chapter 9).

3.4 MECHANICAL AND ELECTRICAL SERVICES

All electrical fittings should be housed and wired in accordance with the Register of Electrical Contractors of Ireland (RECI) rules and the Electrotechnical Council of Ireland Regulations.

3.5 TELEMETRY

Telemetry can be used for the remote interrogation of a process plant, for the control of equipment and the monitoring of control parameters. For a small treatment system where the cost of continuous human presence for control and monitoring purposes would be excessive, consideration should be given to its use. Telemetry links to key personnel are important as incidents arising at small treatment systems 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 telemetric 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.

3.6 SELECTION FACTORS

The factors that influence the selection of a particular type of wastewater treatment system include:

- the ability to treat the expected load to the required standard;
- accreditation of the product;
- additional costs prior to commissioning;
- annual running cost;
- capital cost;
- construction requirements prior to delivery of components;
- delivery or construction time;
- design criteria (including the minimum loading the system can accept);
- distance to nearest habitation;
- durability;
- ease of inspection;
- ease of operation;
- environmental impact;
- expected operating life of the system;
- experience in use of similar systems;
- final wastewater discharge location;
- fly and odour nuisance;
- guarantees;
- head loss through system;
- health, safety and welfare considerations;
- installation and commissioning agreements;
- maintenance service available/provided;
- means of desludging;
- noise levels;
- recommendations from owners of similar systems;
- recommended daily, weekly and annual maintenance requirements;
- regulatory requirements;
- resilience to shock and noxious loadings;
- restart difficulties;
- risk of environmental pollution;
- robustness;
- safety of the installation;
- seasonal factors;
- site requirements;
- sludge production and frequency of desludging;
- sludge storage in system;
- start up time and procedure;
- type of wastewater collection system; and
- visual impact.

Even though most of the factors listed above require little explanation, the following observations in relation to the selection of a proposed wastewater treatment system should be taken into consideration:

- information should be obtained from users on the operational performance of systems similar to the proposed system. In addition, where a system has been tested using internationally accepted testing procedures (e.g. CEN standard), reports from these tests should be reviewed. Information on the quality of the final discharge (BOD, TSS, temperature, microorganisms) and power consumption of the system should be examined;

- the total costs of the proposed system, including the capital, running and maintenance costs must be considered;
- the system should be designed and constructed to a high standard;
- the individual components of the proposed system should be robust;
- the proposed system should be easy to operate and inspect;
- sludge handling and storage requirements should be closely examined;
- the system should require infrequent and simple maintenance;
- the environmental impact of the proposed system should be assessed;
- it should be easy to carry out flow monitoring and sampling on the proposed system; and
- the health, safety and welfare of all personnel should be considered in relation to the proposed treatment system.

3.7 PUMPING

Pumps for small scale wastewater treatment systems must be selected and sited with full knowledge of their capabilities. Pumps to pump sewage should have an output of at least 5 litres/sec. (70 gals/min) to minimise blockages, and connect to a 100 mm minimum diameter rising main. Flow velocities greater than 0.75 metres/sec should be provided.

The pumps can be operated either manually or automatically, and the most usual automatic actuation method is by float switches or a programmed time switching sequence.

Adequate space should be provided in fixed pump installations to ensure pump maintenance can be carried out. It should be noted that for submersible pump sumps, the pumps are lifted to the surface for maintenance.

Equation 1 below is a useful formula for checking the adequacy of pump sumps. Adequate depth should be provided in the pump sump to protect submersible motors.

$$Vu = \frac{0.9 \times Qp}{Z} \text{ cubic metres} \qquad \textbf{EQUATION 1}$$

where Vu = useful volume of pump sump (m^3)
Qp = Discharge (l/sec)
Z = Starting frequency per hour (6 - 15 starts - normal range, typically 10 is used)

Flow velocities of about 0.75 m/s in a 100 mm diameter pipe should be sufficient to prevent solids in the wastewater from settling out.

Larger diameters and higher velocities of between 1.5 m/s and 2.5 m/s are essential where raw sludge is to be pumped, in order to avoid the rapid increase in resistance to flow which occurs below a velocity of 1.2 m/s. The pipe friction increases with a decrease in sludge moisture content. The pipe-friction factor - as compared with resistance values for clean water - has a value of about 2.5 for a sludge moisture content of 96 %.

Anaerobic conditions should be avoided as these may lead to corrosive gases being produced which could shorten the pump life considerably. If such conditions are likely to occur then consideration should be given to air injection into the sump, and the rising main.

In general, it is advisable to supply the pump maker with drawings of the installation and application before selecting a pump, and deciding on a final method of installation.

In most cases, pumps require regular inspection. Valves and apertures may require cleaning out, but these are readily accessible and do not present any problems. A seal failure, which should be an unlikely event, may lead to pump replacement. Standby pumping capacity should always be provided. Pumps incorporating macerators should be used where no screening facilities are installed.

3.8 SLUDGE PRODUCTION AND TREATMENT

Treatment and disposal of sludge generated from small scale wastewater treatment systems is a

TABLE 4: RECOMMENDED MINIMUM DISTANCES FROM TREATMENT SYSTEMS

System size p.e.	Approximate number of houses served	Distance from existing development (m)
10 - 40	2 - 10	28
41 - 60	11 - 15	31
61 - 80	16 - 20	34
81 - 100	21 - 25	37
101 - 120	26 - 30	40
121 - 140	31 - 35	43
141 - 160	36 - 40	46
> 161	> 41	50

significant problem. Sludge production can range up to about 0.085 kg dry matter per person per day. Sludge handling can account for up to 50 % of the cost of operating a wastewater treatment system. At a minimum, agricultural use of sludge requires the sludge be pre-treated; this pre-treatment can include aerobic digestion, anaerobic digestion, lime stabilisation, long-term storage, composting or drying. It is likely that most of the sludge produced at small treatment systems will be processed at regional or county sludge treatment centres. With the Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998 in mind, and in accordance with the Waste Management Act, 1996, local authorities (as mentioned earlier) will be required to produce Waste Management Plans, which should make provision for sewage sludge.

For most sludge management schemes a sludge holding tank with a volumetric capacity to accommodate about 30 days' production of waste sludge should be provided. If sludge holding tanks are used, they should be aerated to prevent septic conditions; this aeration can also reduce the solids content by up to 30 %. Odour emissions from sludge holding tanks can be a problem, but can be controlled by simple gas biofilters of soil or peat.

3.9 SITE SUITABILITY AND SECURITY

A geotechnical investigation should be carried out to find out if the ground conditions at the chosen site are suitable for the construction or installation of the proposed wastewater treatment system. The maximum height to which the water-table rises should be established.

There should be a buffer zone around wastewater treatment systems. Table 4 above sets out recommended minimum distances which should be used as a guide to avoiding odour and noise nuisance from a wastewater treatment system. In addition, for a system size > 81 p.e., at least 30 metres of the distance specified in Table 4 should be in the possession of the operator of the treatment system. Residential developments should not occur within the buffer zone except in exceptional circumstances and in no case should residential development be undertaken within the distance outlined in Table 4. The minimum distances in Table 4 above may need to be increased where the treatment system is particularly noisy and/or prone to odours.

For security reasons a good quality fence should be erected to prevent unwanted access. Relevant standards which should be consulted include: I.S. 310: 1980 Chain Link Fencing; I.S. 252: 1982 Post and Rail Fences - Concrete; I.S. 177: 1980 Anti-Intruder Concrete Fence Posts.

3.10 STRUCTURAL DESIGN AND CONSTRUCTION

There are four basic types of structures in a typical wastewater treatment works. These are:

- water or liquid retaining structures;
- machine and equipment foundations;
- protective housings and storage buildings; and
- conduits and interconnecting pipework.

In the case of prefabricated package systems, the design and construction of a foundation slab for the system, and the selection and laying of conduits and pipework may be the main problems to be dealt with.

For an in situ constructed system, all the four basic types of structures listed above may have to be designed and built.

Concrete tanks should be constructed in accordance with BS8007: *Code of Practice for Design of Concrete Structures for Retaining Aqueous Liquids.*

3.11 DISPOSAL OF TREATED WASTEWATER

In the selection of a wastewater treatment system, it is essential to consider the disposal of the treated wastewater. Where the wastewater is being discharged to surface waters or to ground waters, the characteristics and the uses of the receiving water should be established so that the impact of the wastewater can be assessed. Discharges may require a licence under the Local Government (Water Pollution) Acts, 1977 - 1990, depending on the volume of discharge and on the discharge point. The degree of wastewater treatment should be determined by the required quality of the receiving water taking dilution into account.

Of the commonly used treatment systems, only filters, such as soil, sand and peat filters, have the capability to remove large numbers of coliforms from the final wastewater. It should be pointed out that although filter systems can reduce coliform counts by up to 99.9 %, there can be coliform concentrations of 10^5/100 ml remaining in the final wastewater. To evaluate the impact of a wastewater treatment system on the receiving water the following should be consulted:

- Freshwater Fish Directive (78/659/EEC) as implemented by S.I. 293 of 1988;
- Shellfish Directive (79/923/EEC) as implemented by S.I. 200 of 1994;
- Bathing Water Directive (76/160/EEC) as implemented by S.I. 155 of 1992 and S.I 230 of 1996;
- Surface Water Directive (75/440/EEC) as implemented by S.I. 294 of 1989;
- Groundwater Directive (80/68/EEC) as implemented by S.I. 271 of 1992 and S.I. 184 of 1996;
- The relevant Water Quality Management Plan;
- Memorandum No.1: Technical Committee on Effluent and Water Quality Standards;
- EPA, 1996: Handbook on Implementation (of the UWWT Regulations) for Sanitary Authorities;
- Any relevant environmental water quality objectives;
- DELG: Managing Ireland's Rivers and Lakes - A Catchment based Strategy Against Eutrophication; and
- EPA, 1998: Environmental Quality Objectives and Environmental Quality Standards: The Aquatic Environment A Discussion Document.

Where it is proposed to discharge the treated wastewater to ground a site characterisation should be carried out. The site characterisation form, contained in the manual on treatment systems for single houses should be completed. The general guidelines set out in that manual should be followed for discharges to ground. A discharge licence will however be required in accordance with S. I. 41 of 1999 for direct discharges to groundwater.

3.12 OPERATION AND MAINTENANCE

The maintenance required at a wastewater treatment system depends on the type of collection system, the treatment process and the nature of the wastewater treated. It is essential that regular maintenance is carried out.

Septic tanks require little attention other than inspection for blockages and desludging (at least once per year); desludging should be carried out efficiently since septic tank sludges are malodorous. Maintenance of settlement tanks should include: regular desludging, cleaning of weirs and baffles, checking of mechanical equipment and flushing of pipes. Solids should be removed from screens, grit channels and storm tanks on a regular basis. Hotels, restaurants and leisure facilities can produce wastewaters with a high fat content which are difficult to treat biologically.

In activated sludge systems, aeration equipment must be checked and maintained regularly. Standby equipment which is fixed or easily installed as a replacement may be necessary to ensure the operation of the process is continued. Air diffusers need to be examined, cleaned and have speedy lift out manifolds or alternatively have at least a two stream flow so that flow is channelled through one stream while the other is maintained. Surface aerators usually require mechanical maintenance, lubrication, adjustment and replacement. The sludge return system must also be maintained.

Trickling filter distributors should be maintained to ensure optimum treatment.

The bearings in a rotating biological contactor system must be lubricated. If the shaft stops rotating, care must be taken on restart to avoid excessive torque on the drive shaft due to biofilm imbalance. This imbalance can be reduced by turning the contactors by hand to ensure that all the media is wetted.

In general, all motors should be checked for overheating.

Records of all activities at the wastewater treatment, such as desludging, should be kept in a log book or diary at the site with copies of the records lodged at an administrative centre.

Grease can cause difficulty in a wastewater treatment system. Among other problems, grease can coat biofilms so that they are not able to function properly. Where grease is used in large quantities, it is essential to install a grease trap in the wastewater collection system and to maintain it. It is advisable that the grease trap should be located at a strategic location where any problems associated with the trap will be immediately noticed and rectified.

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

3.13 MONITORING

The treatment system should be designed so that sampling of the inflow and outflow is practicable. The design should also permit easy assess to most parts of the treatment system without dismantling any fixed components. The equipment necessary to carry out a sampling programme includes: a fixed or portable sampling device, a data logger, a flow measuring device and a power supply. Further details on monitoring treatment systems is contained in the Agency publication *The Environmental Protection Agency Act, 1992. [Urban Waste Water Treatment] Regulations, 1994: A Handbook on Implementation for Sanitary Authorities.*

The sludge levels in the settlement tanks should be monitored on a regular basis; there are portable devices which facilitate this. Records should be maintained of the sludge levels in the tanks to allow optimisation of desludging operations and to avoid overflow of sludges into biological zones where treatment efficiencies can be affected.

4. PRIMARY AND SECONDARY SETTLEMENT

4.1 PRIMARY SETTLEMENT

Primary settlement tanks are used to settle out solids. In smaller systems they reduce the loading on subsequent biological treatment stages. Where screening is not employed they remove material which would interfere with or inhibit subsequent treatment stages. Primary settlement tanks should not be designed with only settlement in mind; they also need to be designed to provide adequate sludge storage. Tanks should be desludged on a regular basis.

4.1.1 Conventional primary settlement tanks

Conventional primary settlement tanks can be either horizontal flow or upward flow type tanks.

Upward flow tanks are more costly to construct but can facilitate desludging. In hopper bottomed tanks an angle of 60° is often employed but may be increased to prevent sludge accumulation. A maximum upward flow velocity of 0.9 m/h is recommended. The minimum surface area of the tank may be calculated from the formula (based on a dry weather flow of 180 *l* per person):

$$A = \frac{1}{10} P^{0.85} \qquad \textbf{EQUATION 2}$$

where:

A = minimum surface area (m^2) of the tank; and
P = design population

The minimum vertical side-wall height between the hopper top and Top Water Level (TWL) is 400mm. A detention period of 12 hours at dry weather flow should not be exceeded.

Horizontal tanks should have a length approximately three times its width and a liquid depth of about 1500 mm. The gradient of the floor should be about 1:10. Twin tanks to facilitate desludging is recommended, a decanting valve about 300 mm above inlet floor level and a weir type final outlet.

The capacity of horizontal tanks may be calculated from the formula, again based on a dry weather flow of 180 *l* per person;

$$C = 180\, P^{0.85} \qquad \textbf{EQUATION 3}$$

where;

C = gross capacity of the tank (*l*); and
P = design population

4.1.2 Septic tanks

The volume required for sludge storage is the determining factor in sizing the septic tank and this sizing depends on the potential occupancy of the dwelling which can be estimated from the number of persons. The tank capacity may be designed from the following formula, assuming that desludging is carried out at not more than 12-monthly intervals:

$$C = 180.P + 2000 \qquad \textbf{EQUATION 4}$$

where:

C = the capacity of the tank (l) with a minimum capacity of 2720 *l* (2.72 m^3)
P = the design population

When household garbage grinders are installed, additional sludge solids are discharged with the sewage and the capacity of the septic tank should be increased by 70 litres for each person.

A two chamber septic tank is required. The depth from top water level to the floor of the tank should be a minimum of 1 m. Baffles in the form of T-pipes should be provided at the inlet and outlets of the tank. The baffles should extend 150 mm above the liquid level and down to a depth of 450 mm into the liquid. The inlet invert should be about 75 mm higher than the outlet invert to prevent stranding of solids in the inlet pipeline. The inlet and outlet baffles should extend about 150 mm above the liquid level, but should not extend to the roof of the tank.

Manholes must be provided in the roof of each chamber to allow for inspection and desludging. These should be a minimum size of 600 mm x 600 mm.

Inlet and discharge pipelines to and from the septic tank should have an internal diameter of not less than 100 mm. They should be designed and constructed such that they are capable of being easily inspected, maintained and repaired at all times. A manhole on the inlet must also be provided for rodding the drain to the tank. This manhole should be within one metre of the tank.

For detailed discussion on septic tanks reference

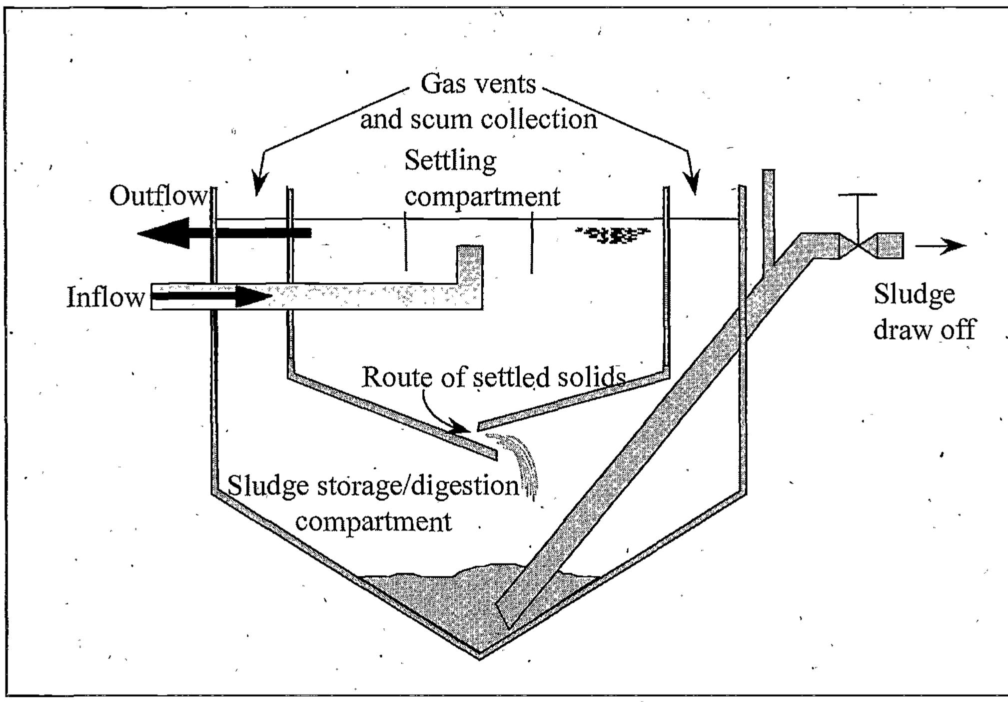

FIGURE 3: TRANSVERSE SECTION OF AN IMHOFF TANK

should be made to the manual on *Treatment Systems for Single Houses.*

4.1.3 Imhoff tanks

In an Imhoff tank the settlement of solids occurs in the upper compartment, with some sludge digestion taking place in the lower compartment. A lip at the bottom of the settlement compartment prevents solids from re-entering this compartment. Imhoff tanks are deeper than septic tanks (see Figure 3).

The level of treatment provided is similar to that of a properly maintained septic tank. The availability of other systems, coupled with the necessity of deep excavations has led to a decrease in popularity for the Imhoff tank.

Typical design figures for Imhoff tanks are shown in Table 5 below:

TABLE 5: DESIGN CRITERIA FOR AN IMHOFF TANK

Design parameter	**value**
Detention time	2-4 h
Length to width ratio	2:1 - 5:1
Tank depth	~10 m
Volume of digestion section	57 - 100 *l* per capita

4.2 SECONDARY SETTLEMENT

Secondary settlement tanks (clarifiers) are installed following secondary treatment to settle out biomass cells which are produced during secondary treatment. In activated sludge systems, this settled sludge needs to be continuously returned to the aeration tank, with some of the sludge being wasted periodically from the system. As is the case with primary settlement tanks, secondary settlement tanks may be either *upward flow or horizontal flow tanks.*

4.2.1 Upward flow secondary settlement tanks

The surface area of upward flow secondary tanks should not be less than:

$$A = \frac{3}{40}P^{0.85}$$ **EQUATION 5**

where;

A is the minimum area (m^2) of the tank at the top of the hopper; and
P is the design population (based on 180 *l* per capita per day)

The side-wall height should not be less than 400 mm. Sludge should be accumulated in the bottom two-thirds of the hopper.

The tanks may be rectangular or circular. If rectangular, the hopper bottom tank should slope at 60° to the horizontal to facilitate sludge deposition. Sludge is drawn off hydrostatically from the bottom of the hopper. If circular, the tank bottom should slope at a minimum of 10° to the horizontal; and sludge swept to a central draw off hopper with a radial bridge sweeper. Alternatively, the circular tank could be constructed with a conical hopper with a slope of 60° to the horizontal.

4.2.2 Horizontal flow, secondary settlement tanks

For determining tank capacity, the following formula is recommended:

$$C = 135.P^{0.85} \qquad \textbf{EQUATION 6}$$

where:

C = gross capacity of the tank (*l*); and
P = design population

Use of this formula will give detention periods of less than 9 h at dry weather flow, where the design population is greater than 100 persons. It is also recommended that the area of the tank should not be less than that given for upward flow secondary settlement tanks.

5. BIOFILM (ATTACHED GROWTH) SYSTEMS

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 microorganisms necessary to treat the applied wastewater. In biofilm systems, the biological process is usually preceded by primary settlement to remove gross settleable solids which may interfere with oxygen transfer to the microorganisms, block the filter media or result in high solids yields.

Some primary settlement tanks have a long sludge storage time, such as in a septic tank; others have a short storage time, such as in a package system. It is essential that adequate sludge storage is provided in the primary tank and that it is desludged regularly so that sludge does not flow into the biological zone. In biofilm systems with secondary settlement, the secondary sludge should be returned to the primary tank to avoid problems associated with sludge flotation caused by denitrification. Careful consideration should be given to the selection of sludge storage facilities in biofilm systems, and to the logistics of sludge handling. By using a fluid lifting device - such as a pump - in the primary settlement tank, it is possible to maintain a balanced flow through the biological zone and avoid shock loadings; these shock loadings may cause a deterioration in final wastewater quality.

The main biofilm systems include: constructed wetlands, intermittent aerobic filters, percolating filters, rotating biological contactors and submerged filters. For a more detailed discussion on Biofilm systems, reference should be made to chapter 6 of the manual on *Primary, Secondary and Tertiary Treatment*, published by the Agency.

5.1 CONSTRUCTED WETLANDS

5.1.1 Description

Wetlands are lands where the water table is near the ground surface for enough of the year to maintain saturated soil conditions and promote vegetation. Constructed wetlands are specifically designed to treat wastewater.

Normally, constructed wetland systems are used to treat wastewaters from primary settlement tanks and secondary settlement tanks. Constructed wetlands are sometimes used to treat landfill leachates, agricultural wastewaters, industrial wastewaters, mining wastewaters, storm water and sludges. Typical arrangements are shown in Figure 4.

The two different types of constructed wetlands are characterised by the flow path of the water through the system. In the first type, called the horizontal-flow wetland, the wastewater is fed in at the inlet zone and flows in a horizontal direction through a bed of media until it reaches the outlet zone. The media can consist of soil, gravel or waste material. If the surface of the wastewater is at, or above, the surface of the wetland media, the system is called a free-water surface (FWS) horizontal-flow wetland. Horizontal-flow wetlands have been built 0.6 m deep at the inlet end with the outlet end being deeper to fit in with the selected slope (usually 1%). The reasoning behind the 0.6 m depth is that this is the maximum depth that to which *Phragmites* will grow.

If the surface of the wastewater is below the surface of the wetland media, the system is called a sub-surface (SFS) horizontal flow wetland (Figure 5). In the second type, called the vertical-flow wetland, the wastewater is dosed uniformly over, and intermittently onto the media, and gradually drains vertically to a drainage network at the base of the media; as the wastewater drains vertically, air re-enters the pores in the media (Figure 6). The media used in the vertical-flow wetland can consist of 80 mm layer of sand on top of layers of different sized gravels of a total thickness of about 400 mm (Cooper et al., 1996).

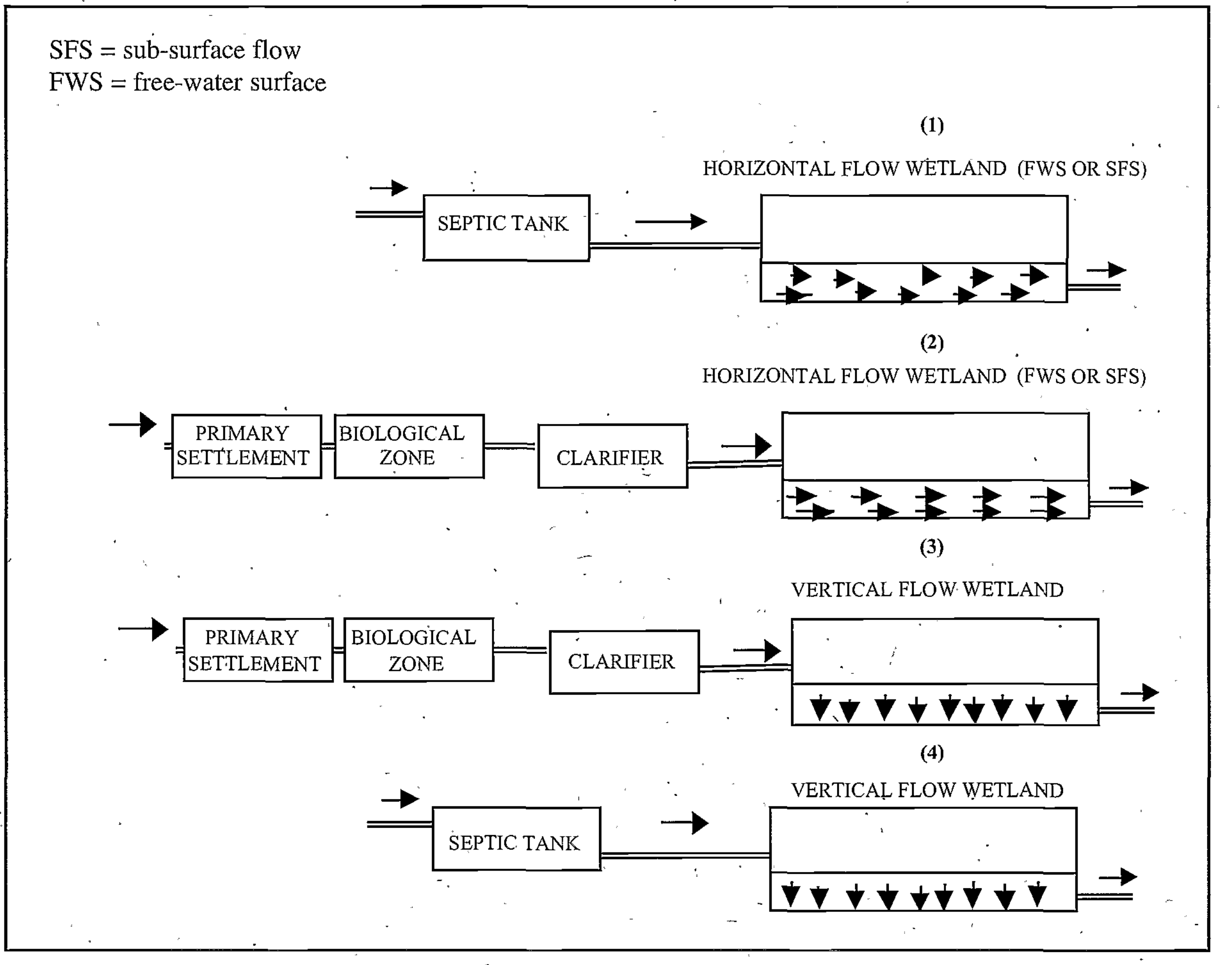

FIGURE 4: VARIOUS ARRANGEMENTS OF CONSTRUCTED WETLANDS

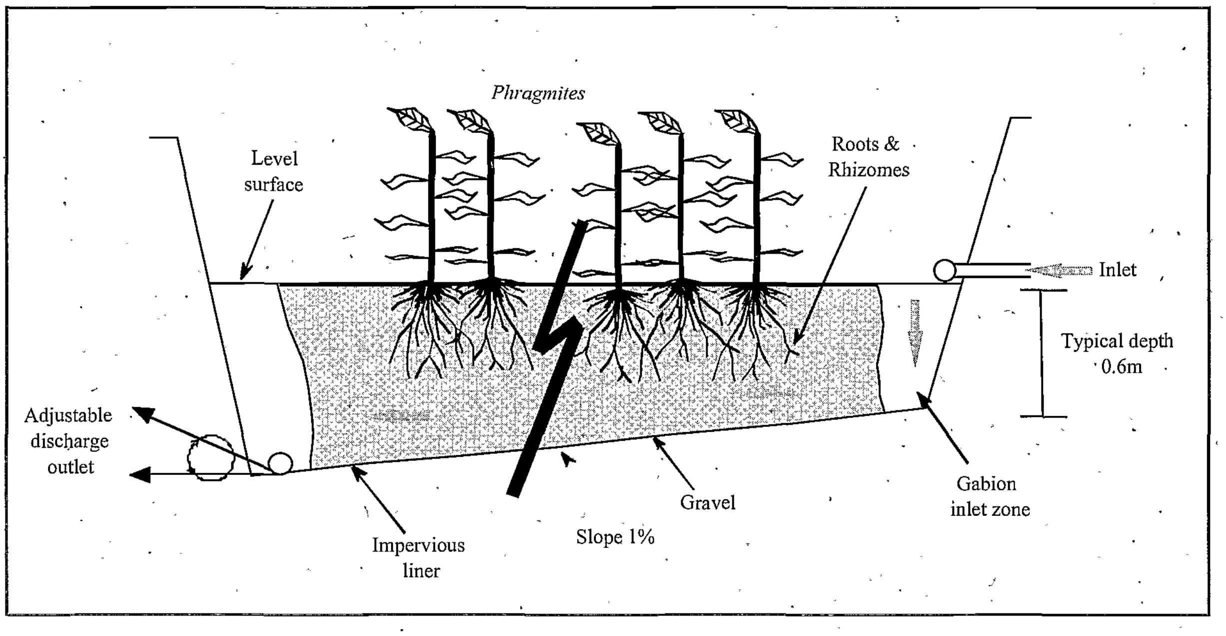

FIGURE 5: SUB-SURFACE HORIZONTAL FLOW WETLAND

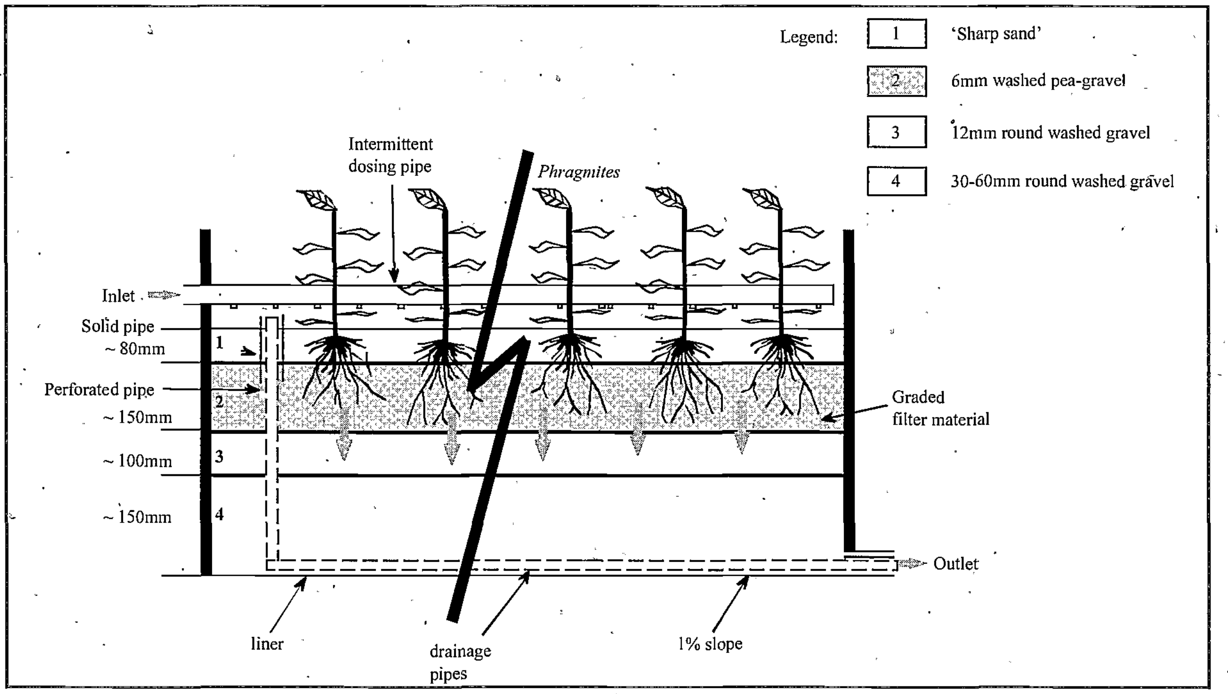

Figure 6: Vertical flow constructed wetland

Phragmites australis (the common reed) is commonly used in constructed wetlands and it facilitates some oxygen transfer from the atmosphere to the roots. A barrier is provided beneath the bed of all constructed wetlands to prevent groundwater contamination; barrier materials include compacted clays and synthetic membrane liners.

5.1.2 Applicability

Since the mid-1980s the use of constructed wetlands for treating wastewaters from small communities has become accepted practice in Europe, North America and Australia.

In some parts of Europe, constructed wetlands are mainly used to provide secondary treatment of domestic wastewater from small communities, whereas in North America, Australia and in Britain, their main use is for the tertiary treatment of wastewaters from towns and cities.

5.1.3 Advantages/Disadvantages

The advantages of constructed wetlands include:

- low construction and running costs;
- easy management;
- excellent reduction of biochemical oxygen demand (BOD_5) and suspended solids (SS) from all primary settlement tank wastewaters, including imhoff and septic tanks;
- maximum growth occurs during late spring and summer when the receiving water provides least dilution;
- evaporation takes place during the months when the receiving water provides least dilution;
- secondary benefits in terms of wildlife habitat enhancement; and
- useful as a backup in the event of failure of a secondary treatment system with mechanical aeration devices.

The disadvantages of constructed wetlands include:

- lack of agreed design criteria;
- systems remain unproven for other than BOD_5 and SS removal. There is some removal of Total Nitrogen and Total Phosphorus but this is low. Removal of faecal and total coliforms is unreliable;
- large land area required for treating inflow from primary settlement tanks;
- weed control is a problem;
- concern about disease vectors and odours;

- difficulty in achieving uniform distribution of flow at inlet; and
- replacement of the bed is required after 10-15 years.

5.1.4 Design Criteria

For horizontal-flow constructed wetlands, the areal requirement for BOD_5 removal in the secondary treatment of domestic wastewater from a primary settlement tank is influenced by the influent BOD and the desired final quality of the wastewater and can be computed using the formula below (Cooper et al, 1996).

$$A_h = Q_d (LnC_o - LnC_t) / k_{BOD}$$

where:

A_h = surface area of the bed, in m^2

Q_d = daily average flowrate, in m^3 / day

C_o = daily average BOD of the influent, mg/l

C_t = daily average BOD of wastewater, mg/l

k_{BOD} = rate constant and 0.1 m/d is used

The areal requirement is generally about $5m^2$/p.e.; in tertiary treatment with or without storm overflow, it is about 1 m^2 /p.e.; and in the treatment of storm wastewater overflow, it is about 0.5 m^2/ p.e. The depth of the bed is about 0.6 m at the inlet end with the outlet end being deeper to allow for a 0.5% - 2% slope on the base of the wetland. The width of the constructed wetland can be calculated from the following equation:

$$A_c = Q_s /(K_f (dh/ds))$$

where:

A_c = the cross-sectional area perpendicular to the flow, (m^2)

Q_s = the average flowrate of the wastewater (m^3/s)

K_f = the hydraulic conductivity for the fully-developed bed, (m/s)

dh/ds = the slope of the base of the bed, (m/m)

The European Design and Operation Guidelines (1990) recommend a soil with a hydraulic conductivity value of $1x10^{-3}$ m/s. All media should be washed before placement. Severn Trent Water Company uses the slope of the base of the bed as the hydraulic gradient and sets this at 5 % for its tertiary treatment systems.

For vertical-flow constructed wetlands (Cooper et al., 1996), the areal requirement for BOD_5 removal in the secondary treatment of domestic wastewater is about 1 m^2/ p.e., and for BOD_5 removal followed by nitrification, it is about 2 m^2/p.e. and in the treatment of storm wastewater overflow, it is about 0.5 m^2/ p.e. The depth of the bed is usually between 0.5 m and 0.8 m in depth. At least two stages of vertical-flow constructed wetlands are recommended.

5.1.5 Costs

The capital costs should provide for the following:

- land and fencing;
- earthworks;
- liner;
- planting;
- gabions or other structures for stabilising the inlet and outlet ends of the wetland;
- fill media;
- pipework and fittings; and
- settlement tanks.

Wetlands in series are more desirable than one large wetland. This would also allow diversion pipework to be put in place to allow wetlands to be by-passed if the need arose.

5.1.6 Operation and Maintenance

Constructed wetlands should be inspected weekly. Flow distribution should be carefully examined. Sidewalls should be maintained. Rabbits, weeds and plant diseases can cause damage to the reeds. Solids from the wastewater will reduce the pore space in the media especially at the inlet end of a horizontal-flow wetland making it necessary to replace some of the media after a period of time.

5.1.7 Monitoring

Vegetation growth, flows and wastewater should be monitored. Special attention should be given to the flow distribution in the wetland to prevent channelling.

5.1.8 Construction

Media for the constructed wetlands should be rounded and washed. Use of gabions at the inlet ensures construction stability and can facilitate good distribution of flow.

5.1.9 Treatment residues

Harvesting of the vegetation would increase the removal of nutrients but would lead to increased operation and maintenance costs, and harvested reed disposal problems.

5.1.10 Special considerations

In properly designed and constructed wetlands, good BOD_5 and suspended solids removal can be expected. Nitrification can take place if BOD_5 removal is complete, but additional media are required. Denitrification of nitrates may occur in anoxic zones in the presence of biodegradable organic substrates. Phosphate may be precipitated if the wetland media contain metal cations; as the exchange capacity of the media is used up, precipitation will reduce. Microorganism concentrations can decrease during flow through wetlands by mechanisms which include filtration.

5.2 INTERMITTENT AEROBIC FILTERS

5.2.1 Description

Intermittent filters are used for both individual houses and small communities. The media used in the filters include sand, peat and plastic material. They consist of one or more beds of granular media - typically graded sand - 0.6 m to 0.9 m in depth, which are underlain with collection drains or polishing filters. Wastewater from a primary settlement tank is intermittently applied to the surface of the bed and it flows vertically through the media where it is treated (Figure 7). The filter media are nearly always unsaturated and are vented to the atmosphere such that an aerobic environment is maintained in the media. The wastewater from the filter is collected in the drains at the bottom of the bed.

Three types of intermittent filters are commonly used: soil covered, open and recirculating filters. Soil covered intermittent filters may be constructed underground and overground. The latter two are commonly referred to as mound systems. When buried or part buried intermittent sand filters are constructed, a hole of suitable size is excavated in the soil. In permeable soils with a high watertable and in gravelly soils (excessive permeability) the filter must be lined on the base and sides with an impervious liner. In impervious clays and silts the intermittent filter can be placed directly in the hole after all surface waters are intercepted. Mound systems are part or totally overground and are of similar construction to bunded intermittent filters. Inflow distribution piping is embedded in gravel or crushed stone placed on top of the filter media. A geotextile fabric is placed over the pipe bedding material and the remaining excavation is covered with soil. The gravel about the inflow pipes and wastewater drainage pipes may be vented above the ground surface to ensure aerobic conditions in the filter media. Open sand filters may be exposed or covered with removable lids. In the recirculating sand filter, a portion of the filtrate is recycled with the inflow through the filter media.

Peat filters consist of 0.5 - 1.0 m of peat underlain with collection drains. Following sedimentation in a primary settlement tank the effluent is distributed over the surface of the peat. It moves through the media where pollutants are removed. Particulate material may be added to the surface to facilitate effluent distribution. This may be covered by a further layer of peat to eliminate odours. The media must be free draining allowing for maintenance of an aerobic environment. As there is no production of excess secondary sludge there is no requirement for secondary settlement. Peat filter systems can be open or roofed. Wastewater may be recycled to facilitate some denitrification.

Intermittent filters operate as aerobic biofilm reactors capable of consistently producing high quality wastewater. The treatment processes in a filter include biochemical reactions, physical filtration and chemical adsorption. It is possible to achieve full carbonaceous oxidation and nitrification if the filter is properly designed. Some denitrification can be achieved in recirculating filters. Phosphate may be precipitated if the filter media contain metal cations; as the exchange capacity of the media is used up, precipitation will reduce. Faecal coliform removal is less efficient in recirculating filters than in single pass filters. However, even in recirculating filters, 99 % - 99.9 % removal rates can be achieved.

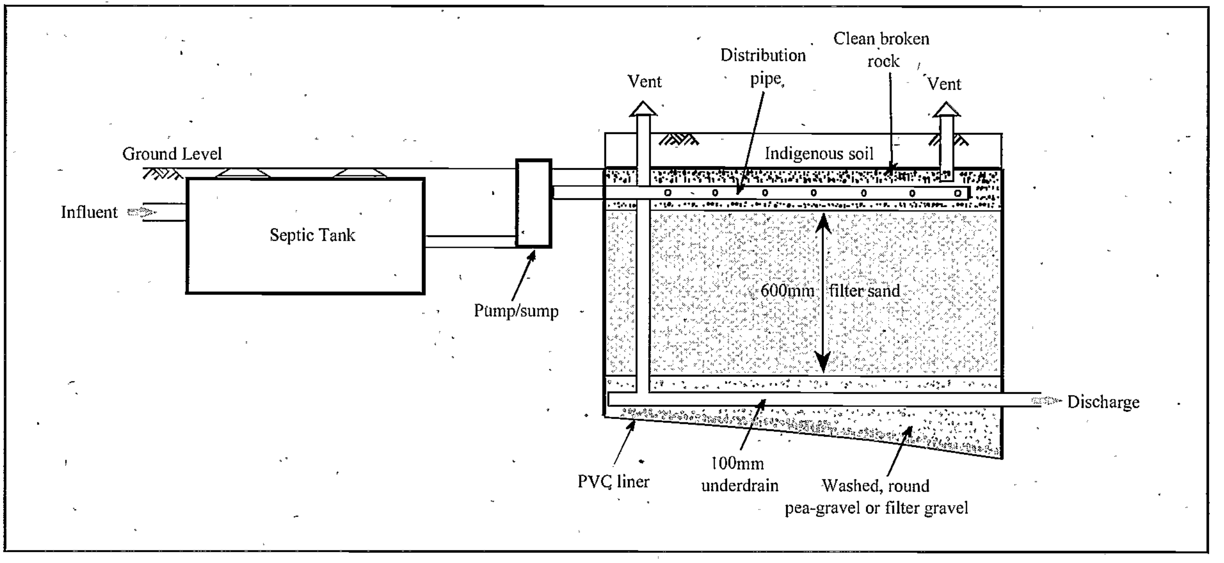

FIGURE 7: INTERMITTENT SAND FILTER SYSTEM (SECTION THROUGH FILTER)

5.2.2 Applicability

Intermittent filters have been shown to be an advanced method of secondary wastewater treatment since the late 1800s. Peat systems specifically have been used in the U.S. since the 1970s in Canada from the early 1980s and Ireland and the UK since the late 1980s. Intermittent filters are well suited to rural communities, small businesses and individual residences. Their use can be limited by land availability and capital cost. They are easy to operate and require personnel with minimum skills.

5.2.3 Advantages/Disadvantages

The advantages of Intermittent filters include:

- low construction and running costs;
- easy management;
- high quality wastewaters; and
- the treatment process is extremely stable.

The disadvantages of such filters include:

- the filter system may require relatively large land area;
- pumping is required to distribute the septic tank effluent on the media;
- pumping may be required for final wastewater disposal;
- odours can occur from open filter systems;
- media are required to be replaced;
- necessity to avoid grease or oil coating the biofilm; and
- suitable filter media may not be available locally.

5.2.4 Design Criteria

Primary settlement (such as that provided by a septic tank) is required before application of the wastewater onto intermittent filters; the primary settlement tanks should be sized to cater for the population equivalent to be served and the required sludge storage.

Sand is the most commonly used medium in the United States of America and is defined by its effective size and its uniformity coefficient. By reducing the effective size of the filter media, the quality of effluent wastewater will increase; this increase in quality will be at the expense of a lower hydraulic loading rate and a higher maintenance rate. Hydraulic loading rates vary with the characteristics of the media, the type of filter design, and the wastewater strength. The design criteria for intermittent sand filters are given in Table 6.

Wastewater must be applied uniformly to the filter surface at time intervals that enable the wastewater to drain through the filter completely, thus allowing sufficient aeration of the media to effect aerobic treatment. Standby filters are recommended.

TABLE 6: DESIGN CRITERIA FOR INTERMITTENT SAND FILTERS

Design Factor	Buried	Open	Recirculating
Pre-treatment	----------------------Minimum of Sedimentation---------------		
Media Specifications			
Effective size (mm)	0.7-1.0	0.4-1.0	1.0-1.5
Uniformity coefficient	<4.0	<4.0	<4.0
Depth (m)	0.6-0.9	0.6-0.9	0.6-0.9
Hydraulic loading (l/m².d)	40-60	50-100	120-200 (forward flow)
Dosing frequency	2-4/d	1-4/d	5-10min/30min
Recirculation ratio	NA	NA	3:1 - 5:1

(US EPA, 1992)[2]

The hydraulic loading rate on peat filters varies depending on the type of peat employed. Commercial peat filters are presently designed at hydraulic loading rates in excess of 100 l/m².d.

5.2.5 Costs

The capital costs should provide for the following:

- land and fencing;
- earthworks;
- liner;
- cover;
- fill media;
- pipework and fittings;
- primary settlement tanks; and
- pumps and sumps.

5.2.6 Operation and Maintenance

Operation and maintenance tasks include filter surface maintenance, dosing equipment servicing, and inflow and final wastewater monitoring. If the operational infiltration rates fall below the hydraulic loading rate - this could be due to high biofilm growth on the surface of the sand - the filter should be rested or its surface removed. Buried filters, which have the lowest loading, are designed to operate without maintenance.

5.2.7 Monitoring

Flows and wastewater should be monitored. The infiltration rate should be compared with the hydraulic loading rate to establish if the filter needs maintenance.

5.2.8 Construction

Media for the filters should be placed in lifts and should be homogeneous. The dosing system should provide uniform distribution of wastewater on the filter surface. The underdrain system should be installed carefully in accordance with proper design practice. If the system is being roofed then the retaining walls and roof must be designed for wind and snow loads. In unroofed systems, precautions must be taken to avoid excessive growth of weeds etc., which may affect the efficiency of the distribution of the effluent.

5.2.9 Treatment residues

If the surface of the filter becomes blocked, it will be necessary to remove the top layer of media and clean or replace it.

5.3 PERCOLATING FILTERS

5.3.1 Description

A conventional percolating filter system includes preliminary treatment, primary settlement, aerobic biological treatment in the percolating filter reactor and secondary settlement. In the percolating filter reactor, wastewater from the primary settlement tank is distributed intermittently over biofilms which are attached to inert media consisting of rock or plastic; the microorganisms in the biofilm treat the substrate matter in the wastewater. In circular filters, a rotating-arm distributor, consisting of arms extending from the central axis of the filter towards its outer edge, is provided to distribute the wastewater over the media, as shown in Figure 8.

[2] US EPA (1992). Manual: Wastewater Treatment/Disposal for Small Communities. U.S. Environmental Protection Agency Office of Research and Development, Cincinnati, Ohio. pp110.

Portions of the biofilm slough off periodically and are settled out in the secondary settlement tank. It is essential that the pores in the filter media are well ventilated to ensure aerobic conditions. The conventional percolating filter system is easy to operate.

In the past, some problems were experienced with the conventional percolating filter reactor wastewater, which contained finely divided particulate matter with poor settling properties. Modifications have been developed to overcome the performance limitations of the original process. These include high rate processes and percolating filter solids contact (PFSC) (Figure 9). High rate processes can employ continuous recirculation of wastewater through the filter at 50 % to 300 % of the inflow, and the use of plastic media with a high surface area per unit volume. In the PFSC process, discharge from the percolating filter is contacted with return sludge from the secondary settlement tank in a small aerated tank. This allows flocculation and agglomeration of the percolating filter fines, improving suspended solids and associated BOD_5 removal in the secondary settlement tank.

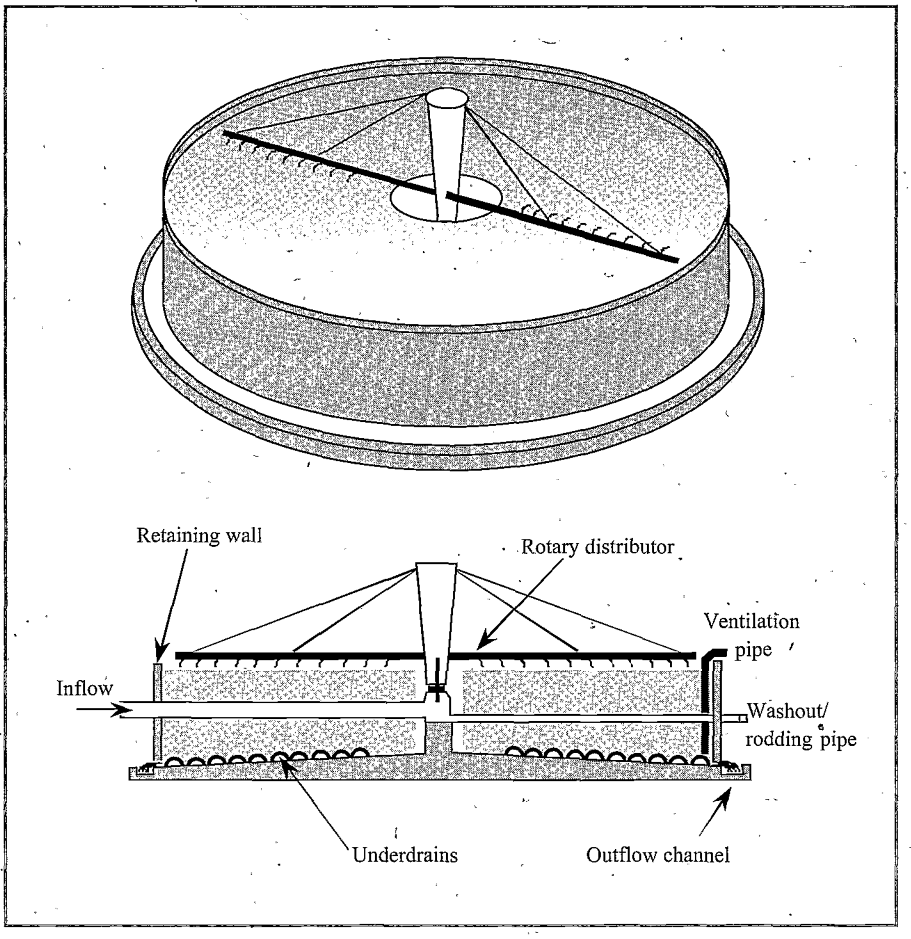

FIGURE 8: CONVENTIONAL PERCOLATING FILTER

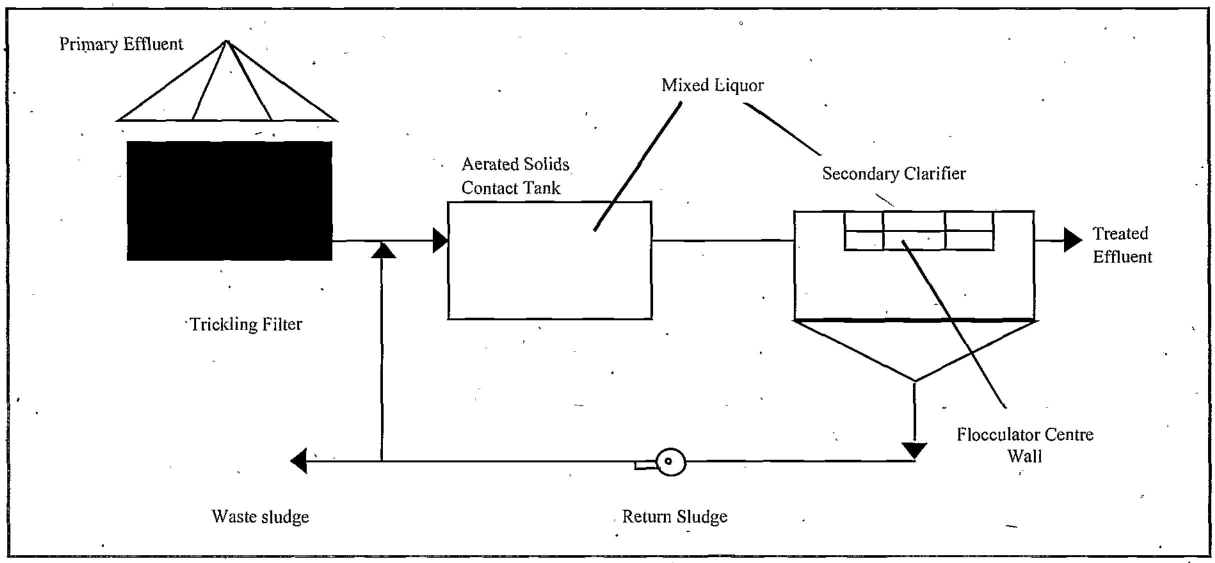

FIGURE 9: PERCOLATING FILTER SOLIDS CONTACT PROCESS

5.3.2 Applicability

Conventional percolating filter systems using stone media are rarely constructed now. However, many such plants are still in operation, having been constructed to treat wastewater from both small and large communities. In other countries, some of these systems have been upgraded to the percolating filter solids contact process to improve performance, whilst maintaining simplicity of operation. The high rate system is also used as a roughing filter to reduce the organic loadings of high strength wastewater before it undergoes further biological treatment.

5.3.3 Advantages/Disadvantages

The advantages of the percolating filter solids contact process include:

- applicable for new plants or upgrading existing percolating filter systems;
- relatively simple process;
- high quality final effluent;
- low cost and reliable upgrading technique for percolating filters;
- the treatment process is extremely stable; and
- nitrification can be achieved.

The disadvantages of the percolating filter solids contact process include:

- primary settlement tank or imhoff tank is needed to prevent clogging of nozzles and reduce the load;
- pumping is required;
- odour and fly nuisances can occur;
- buffer distance around the system should be at least 60 m; and
- moderately high operation and maintenance requirements; skilled operator necessary.

5.3.4 Design Criteria

Available design criteria for the percolating filter system including the PFSC process are summarised in Table 7. It is essential to establish favourable conditions in the solids contact tank and secondary settlement tank to promote good coagulation. Fine bubble diffusers are typically used in the contact tank to provide sufficient dissolved oxygen and gentle mixing without excessive turbulence that might shear the developed floc. Systems should be equipped with an alarm system to alert personnel of mechanical failure.

5.3.5 Costs

Use of the PFSC process is an economical way of upgrading an existing percolating filter system.

5.3.6 Operation and Maintenance

Operation and maintenance requirements for a PFSC facility are relatively high due to the need for skilled and regular operator supervision and the complexity

TABLE 7: DESIGN CRITERIA FOR THE PERCOLATING FILTER PROCESS

Parameter	Percolating Filters	
	Low Rate	High Rate
Hydraulic loading ($m^3/m^2.d$)	0.93 - 3.74	9.35 - 37.4
BOD_5 loading ($kg/m^3.d$)	0.08 - 0.4	0.48 - 0.96
Recirculation ratio	0	0.5 - 3
Media depth (m)	1.8 - 2.4	1.2 - 1.8
	Solids Contact/Aeration Tank	
	Low Rate	High Rate
Detention time (hr)	0.3 - 1.5	6 - 12
Solids retention time (days)	0.5 - 2.0	>6
MLSS (mg/l)	700 - 3000	1500 - 3500
Dissolved oxygen (DO) (mg/l)	1.5 - 3.5	2.0 - 4.0
	Secondary Clarifier	
Overflow rate based on total area ($m^3/m^2.d$)	12 - 20	
Sidewater depth (m)	4.5 - 5.5	
Flocculator centrewell (% of total area)	5 - 16	

of the system.

The treated wastewater should be recirculated during periods of low inflow to ensure that the media remains wet.

5.3.7 Monitoring

Flows and wastewater characteristics should be monitored. Operational monitoring generally includes mixed liquor suspended solids (MLSS), solids contact aeration basin DO, pH, sludge settleability, inflow, percolating filter recirculation flow, return sludge flow and sludge wasting rate.

5.3.8 Construction

Media for the filters should be placed in lifts and should be homogeneous. The dosing system should provide uniform distribution of wastewater onto the filter surface. The underdrain system should be installed carefully in accordance with the manufacturer's instructions.

5.3.9 Treatment residues

Grit and screenings must be removed and disposed of promptly otherwise they may become putrescent. Secondary sludge may be blended with primary sludge in the primary tank. Sludge may be removed from the system as a liquid or may be dewatered by mechanical devices and hauled away.

5.4 ROTATING BIOLOGICAL CONTACTORS

5.4.1 Description

A rotating biological contactor system consists of a primary settlement tank, a rotating biological contactor zone and a secondary settlement tank (Figure 10); screens are sometimes used to remove large solids from the inflow. The system is similar to the conventional percolating filter system except that there may not be a need to pump the wastewater from the primary settlement tank to the biological reactor. In the usual RBC design, plastic media are assembled on a horizontal shaft - usually as vertical discs - in the form of a cylinder that can be up to 4 m. diameter and 7 m long. The shaft is rotated at 1-10 revolutions per minute; the assemblage is placed in a bulk fluid tank containing wastewater, and the media are immersed to a depth of about 40% of their diameter. The rotation of the assemblage ensures that the media are alternately in air and wastewater resulting in the development of a biofilm. The peripheral speed limitation to 0.3 m/sec. is required to avoid stripping the biomass and the disk spacing in the inlet zone area should be designed to prevent the bridging of gaps between surfaces.

Though plastic is the most common, other materials such as expanded metal, GRP, uPVC and high density polystyrene foam may be used.

Oxygen moves into the biofilm when it is in the air. Oxygen may move into or out of the biofilm when it is in the wastewater; this depends, in part, on the

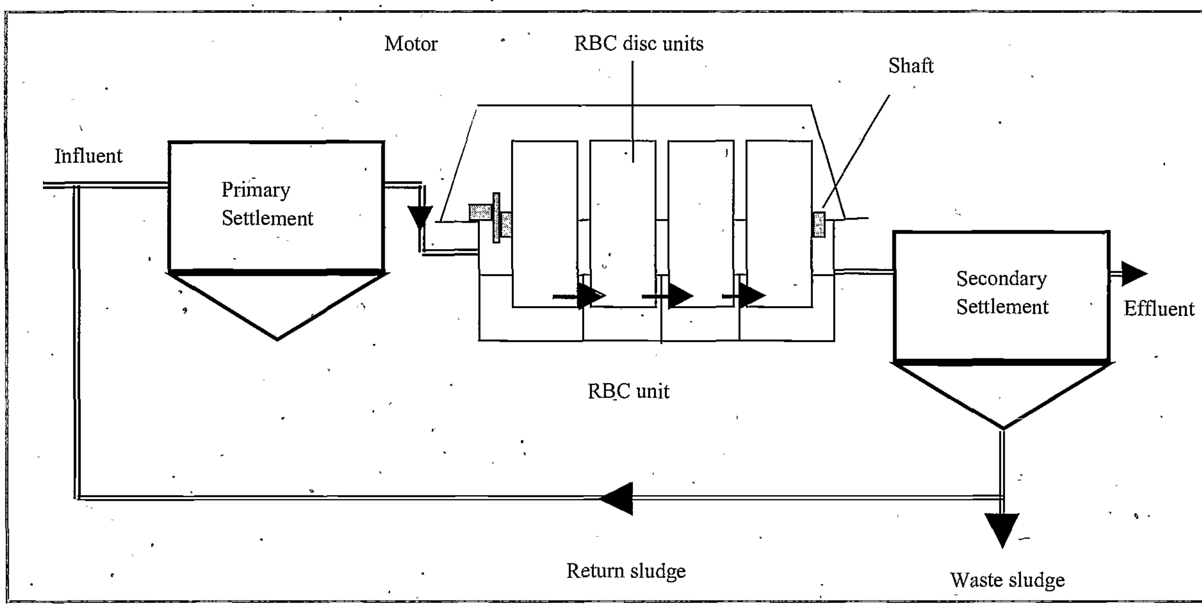

FIGURE 10: ROTATING BIOLOGICAL CONTACTOR TREATMENT SYSTEM

relative concentrations of oxygen in the wastewater and biofilm. The speed of rotation of the RBC is usually limited to a peripheral speed of 0.30 m/sec. and the biological reactor tank is divided into a number of stages for enhanced performance. When the overall flow of wastewater is parallel to the shaft, the biofilm will reduce in thickness from the inflow end to the wastewater end. Carbonaceous oxidation will occur at the inlet end, and if there are sufficient media, nitrification will then occur further along the shaft. The sludge from the secondary settlement tank is usually pumped to the primary settlement tank for storage; problems have arisen with sludge rising in the primary settlement tank due to the selection of unsuitable pumps. A cover is needed to protect the biofilm from heavy rain, frost and snow, and for safety. There are a number of variations of the RBC system which differ, mainly, in the way that the plastic media are assembled on the moving support structure.

5.4.2 Applicability

The RBC system is a well developed technology and has been regularly used for small communities. Since the biofilm is attached to the plastic media, there is not normally a requirement to recycle sludge from the secondary settlement tank to the biological zone. As a result, the level of operator skill required for an RBC system is less than that required for an activated sludge system. During shock loading, the microorganisms are not flushed from the system since they are contained in the biofilm. Great care should be taken to ensure that grease and oil do not enter the system, as these contaminants may cover the biofilm and severely limit the movement of oxygen and substrate into the biofilm.

The covers for the RBCs should be robust and should be locked to prevent interference and possible accidents occurring. There should be an alarm system to indicate when the RBC is out of commission. It is important to restart an RBC as soon as possible after stopping, in order to prevent the biofilm above the wastewater surface drying out and causing a large torque on the drive shaft. Oversize motors are sometimes used to take the extra torque required on start-up after a breakdown. It is also important that the sludge holding capacity of the system is sufficient to meet the requirements of the sludge management system; if sludge overflows from the primary settlement tank into the biological zone there will be a deterioration in the quality of wastewater leaving the system. Constructed wetlands are used on some sites to polish wastewater from RBC systems.

In Switzerland, RBC units have been added to existing secondary treatment systems to provide nitrification; since very little solids are synthesised in the nitrification process, additional settlement tanks may not be required. Denitrification can also be effected using RBCs by totally submerging a contactor under the surface of the wastewater and thus creating an anoxic zone; if inflow from the primary settlement tank is mixed with wastewater containing nitrate from the nitrification tank in this anoxic zone, denitrification will occur. The degree of denitrification depends on the flow of nitrified wastewater into the anoxic zone. Denitrification can also be achieved by recycling the secondary effluent back through the primary settlement tank.

5.4.3 Advantages and disadvantages

The advantages of an RBC system include:

- low maintenance;
- ability to function under conditions of shock loading;
- low running costs;
- low noise levels;
- no fly nuisance;
- low operator skill;
- low head loss through the system; and
- possibility of nitrification and denitrification.

The disadvantages of an RBC system include:

- some commissioning problems may occur;
- package systems may have small sludge storage volume which could lead to overloading of the biofilm;
- structural damage can be expensive;
- the plastic media must be sheltered;
- necessary to avoid grease or oil coating on biofilm; and
- pumps may be necessary to move sludge from the secondary to the primary settlement tank .

5.4.4 Design criteria

Primary settlement is required before the RBC stage; the primary settlement tanks should be sized to cater for the population equivalent to be served, and the required sludge storage. It is essential that sludge should not be allowed to build up in the primary settlement tank and overflow into the RBC zone causing overloading.

The loading on the rotating surfaces in the biological zone should not exceed 5 g BOD_5 per m^2 per day of settled wastewater or 7.5 g BOD_5 per m^2 per day of raw wastewater entering the whole system in order to meet a 25:35 mg/l (BOD_5: suspended solids) standard. The loading rate onto the first stage of the RBC unit should be restricted to prevent odour problems. Additional surface area of 15% should apply for each 2.8°C below a design wastewater temperature of 13°C. Adequate storage for sludge should be provided in the tank.

Nitrification rates of about 1.46 g NH_4-N/m^2.d have been quoted for RBC systems. This area must be provided in addition to the area for carbonaceous oxidation.

The sludge from RBCs can be filamentous, which may settle slowly. It is suggested that the weir overflow rate in the secondary settlement tank should be less than 100 m^3/m.d.

5.4.5 Costs

The capital costs will depend on whether the system is constructed in situ or whether it is prefabricated off-site. A prefabricated unit may be very capital cost effective but may impose increased running costs; however, running costs will be relatively low compared to other systems. A small sludge storage capacity will necessitate frequent desludging. A telemetry system should be installed to indicate if the RBC is working or not; prompt restarting of the system reduces the risk of major structural damage.

The capital costs should provide for the following:

- land and fencing;
- earthworks;
- RBC unit;
- pipework and fittings;
- primary and secondary settlement tanks; and
- pumps.

5.4.6 Operation and maintenance

Operation and maintenance tasks include cleaning channels, periodic desludging, lubrication and general inspection. Sludge levels in the primary settlement tank should not be allowed to rise and cause problems in the biological zone. Sludge pumping from the secondary to the primary sedimentation tanks should be carefully controlled. The required frequency of visits to RBC systems is between once and three times per week, compared with at least three times per week for extended-aeration systems.

To avoid damage to the unit, maintenance and cleaning procedures should be in place to cater for situations where the unit is out of operation for more than 24 hours. Overload protection of the motor and manual restart after an electrical failure should be provided. All pumps should have thermal overload protection.

5.4.7 Monitoring

Monitoring requirements may include system inflow and final wastewater flows, suspended solids concentrations and substrate concentrations. Operational monitoring generally includes RBC basin dissolved oxygen (DO) levels, pH, sludge settleability, sludge flow from secondary to primary settlement tank and sludge wasting rate. If the RBC is overloaded, there will be odour problems at the inlet end of the biological zone.

5.4.8 Construction

Specifications should be drawn up by experienced professionals for the construction work and for the components in the system. Covers to the RBC process should be robust and have a long life, as uncovered rotating equipment can be extremely dangerous.

5.4.9 Treatment residues

Sludge must be removed and processed at regular intervals.

5.5 VARIATIONS ON THE MOVING BIOFILM PROCESS

One variation on the moving biofilm process consists of a fibre glass drum with a number of curved channels, through which the wastewater flows when the drum is rotated in the wastewater. The wastewater flows alternately from the perimeter to the centre of the drum and then from the centre of the drum back to the perimeter, as it makes its way from the inlet end to the outlet end of the drum. The drum can be used to increase the head of the wastewater between the inlet end and outlet end of the contactor.

A second variation consists of repeatedly moving plastic media with a high surface area up and down in wastewater. Carbonaceous oxidation and nitrification can be effected by alternately immersing the media in, and lifting them out of, the wastewater. Denitrification can occur by limiting the movement of the media so that they are submerged in the wastewater at all times.

A third variation on the moving bed biofilm process consists of moving small plastic elements around a reactor using diffused air or a mixer, depending on whether aerobic conditions or anoxic conditions are required. This system has been developed in the past decade in Norway.

5.6 SUBMERGED FILTERS

5.6.1 Description

A biofilm aerated filter (BAF) system is a relatively new technology and normally consists of a primary settlement tank, an aerated submerged biofilm filter and, possibly, a secondary settlement tank (Figure 11); screens are sometimes used to remove large solids from the inflow. The system is similar to the conventional percolating filter system except that the media are submerged and forced aeration is applied. The BAF reactor can operate in an upflow, downflow or horizontal flow manner. There is little active sloughing of the biofilm, so periodic backwashing may be necessary - depending on the type of media used - to prevent the unit from clogging due to excessive biomass growth.

The media can consist of large plastic structured modules (150 to 500 m^2/m^3 surface area), plastic granules (4 to 10 mm size), or natural granular material (2 to 10 mm size); the structured media with low surface area may not require backwashing. Media with larger pore spaces should be used for carbonaceous oxidation - thick biofilms are synthesised during this process - in order to avoid clogging; the biofilms synthesised by nitrification are quite thin and should not cause clogging problems. Physical filtration can occur along with any biological reactions as the wastewater flows through the media.

It is essential that some of the biofilm remains after the backwashing process is complete in order to initiate rapid microorganism growth once the normal operating mode is recommenced. Care must be taken to prevent granular media from leaving the reactor in the upflow type BAF reactor. Denitrification can take place if aeration of the media is eliminated and an anoxic zone is created; the anoxic zone is usually placed immediately after the primary settlement tank and receives both the wastewater from the primary tank and the returned nitrified wastewater. Denitrification, carbonaceous oxidation and nitrification can take place in tanks in series or in a single tank if it is properly designed.

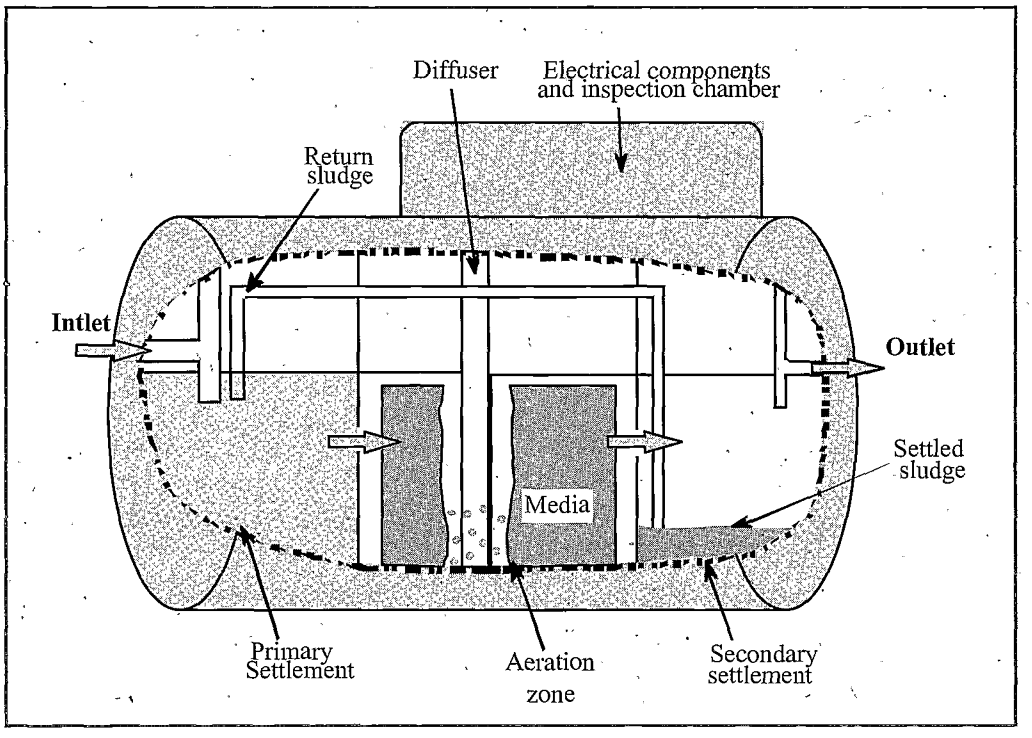

FIGURE 11: SUBMERGED AERATED FILTER

5.6.2 Applicability

The BAF system has been used to treat wastewater from small communities. Since the biofilm is attached to the plastic media, there is not normally a requirement to recycle sludge from the secondary settlement tank to the biological zone. As a result, the level of operator skill required for an BAF system is less than that required for an activated sludge system. During shock loading, the microorganisms are not flushed from the system since they are contained in the biofilm. Great care should be taken to ensure that grease and oil do not enter the system, as these contaminants may cover the biofilm and severely limit the movement of oxygen into the biofilm reducing its effectiveness.

5.6.3 Advantages and disadvantages

The advantages of the BAF system include:

- ability to function under conditions of shock loading;
- physical filtration can occur;
- low noise levels;
- no fly nuisance; and
- possibility of nitrification and denitrification.

The disadvantages of the BAF system include:

- backwashing may be necessary to prevent clogging;
- pumps and compressor are usually required;
- granular media may leave the reactor;
- possibility of foaming;
- the necessity for sludge disposal and treatment;
- disposal of the backwash waters;
- complex control system if scouring and backwash of the filter is required; and
- it is important to avoid grease or oil coating on biofilm.

5.6.4 Design criteria

Primary settlement and/or fine screening may be required before the BAF stage; the primary settlement tanks should be sized to cater for the population equivalent to be served, and the required sludge storage. It is essential that sludge should not be allowed to build up in the primary settlement tank and overflow into the BAF zone causing overloading.

It may be necessary in some cases to provide flow balancing to ensure satisfactory hydraulic loading rates. For submerged biofilm aerated filters using large modules of structured plastic media with a known surface area, the loadings for RBCs could be used for design purposes. The loading on the media surfaces in the biological zone should not exceed 5 g BOD_5 per m^2 per day of settled wastewater or 7.5 g BOD_5 per m^2 per day of raw wastewater entering the whole system in order to meet a 25:35 mg/l (BOD_5:SS) standard.

Nitrification rates of about 1.46 g NH_4-N per m^2.d have been quoted for RBC systems and these could also be applicable for BAF systems.

5.6.5 Costs

The capital costs will depend on whether the system is constructed in situ or whether it is prefabricated off-site. A prefabricated unit may be very capital cost effective but may impose increased running costs: a small sludge storage capacity will necessitate frequent desludging. A telemetry system should be installed to indicate if the BAF is working or not.

The capital costings should provide for the following:

- land and fencing;
- earthworks;
- BAF unit;
- pipework and fittings;
- media;
- primary and secondary settlement tanks;
- pumps and compressor;
- control system; and
- backwash tank.

5.6.6 Operation and maintenance

Operation and maintenance tasks include cleaning channels, periodic desludging, lubrication and general inspection. Sludge levels in the primary settlement tank should not be allowed to rise and cause problems in the biological zone. Sludge pumping from the secondary to the primary sedimentation tanks should be carefully controlled. Backwashing should be operated properly and no media should leave the BAF reactor.

5.6.7 Monitoring

Monitoring requirements may include system inflow and wastewater flows, suspended solids concentrations and substrate concentrations. Operational monitoring generally includes BAF reactor DOs, pH, sludge settleability, sludge flow from secondary to primary settlement tank and backwashing.

5.6.8 Construction

Precise specifications should be drawn up for the construction work and for the components in the system.

5.6.9 Treatment residues

Sludge and backwash water must be removed and processed at regular intervals.

6. SUSPENDED GROWTH SYSTEMS

The activated sludge process (or suspended growth system as it is commonly referred to now) was developed in England in 1914 and was so named because it involved the production of an activated mass of microorganisms capable of aerobically stabilising the organic matter of the wastewater. Like the biofilm systems, the suspended growth system is a biological contact process where bacteria, fungi, protozoa and small organisms such as rotifers and nematode worms are commonly found. The bacteria are the most important group of microorganisms for they are the ones responsible for the structural and functional activity of the activated sludge floc.

The suspended growth systems are 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. In suspended growth systems, the biological process may or may not be preceded by primary settlement. The conventional activated sludge system has primary settlement whereas the extended-aeration system has not. Primary settlement can take place in a tank with a long sludge storage time, such as a septic tank, or in a tank with a short storage time, such as in a package system. It is essential that the primary tank is desludged regularly so that sludge does not move into the biological zone. In suspended growth systems with secondary settlement, some of the secondary sludge must be returned to the biological reactor to maintain an adequate population of microorganisms. Excess sludge should be wasted to storage to avoid problems associated with sludge flotation due to denitrification and to maintain the correct mixed liquor suspended solids; this storage could take place in the primary tank. Careful consideration should be given to the selection of sludge storage facilities in suspended growth systems, and the logistics of sludge handling.

Suspended growth systems include conventional activated sludge, extended-aeration, oxidation ditches (a variation of the extended aeration process) and sequencing batch reactors. Conventional activated sludge systems are not normally employed to treat wastewater from small communities, primarily because they require frequent skilled attention and other variations of the process generate less sludge for disposal. Because of the difficulty of handling, storing and disposing of primary sludge, the use of primary settlement should be avoided in the design of small suspended growth systems.

For a more detailed discussion on suspended growth processes reference should be made to chapter 5 of the Manual on *Primary Secondary and Tertiary Treatment*, published by the Agency.

6.1 EXTENDED-AERATION ACTIVATED SLUDGE

6.1.1 Description

This system is characterised by low loading rates and long hydraulic retention times (HRT) between 20 - 30 hours and solids retention times of between 20 and 30 days. Because of the low loading rates, the system operates in the endogenous respiration phase of the microbial growth cycle, resulting in partial oxidation of biological solids. Some extended-aeration systems operate in completely mixed mode while other systems approximate to a plug-flow mode.

Properly designed and operated extended-aeration systems can be expected to produce a wastewater with BOD_5 and SS levels less than 30 mg/l, 90 % of the time and less than 20 mg/l, 50% of the time. A flow diagram of the system is shown in Figure 12.

An extended-aeration system typically consists of coarse screening or maceration, aeration using air diffusers or mechanical aerators, secondary settlement with surface skimming and return sludge pumping. Excess sludge may be wasted to an aerobic stabilisation tank.

6.1.2 Applicability

Extended-aeration systems are widely used. Some systems are constructed in situ in concrete, while package systems - fabricated in steel, plastic or fibre glass - are rapidly assembled on site. Most systems discharge to surface waters, although they have been used for treatment prior to land application or even subsurface disposal.

Extended-aeration systems are considered to be a fully developed technology, having been in use since the 1950s.

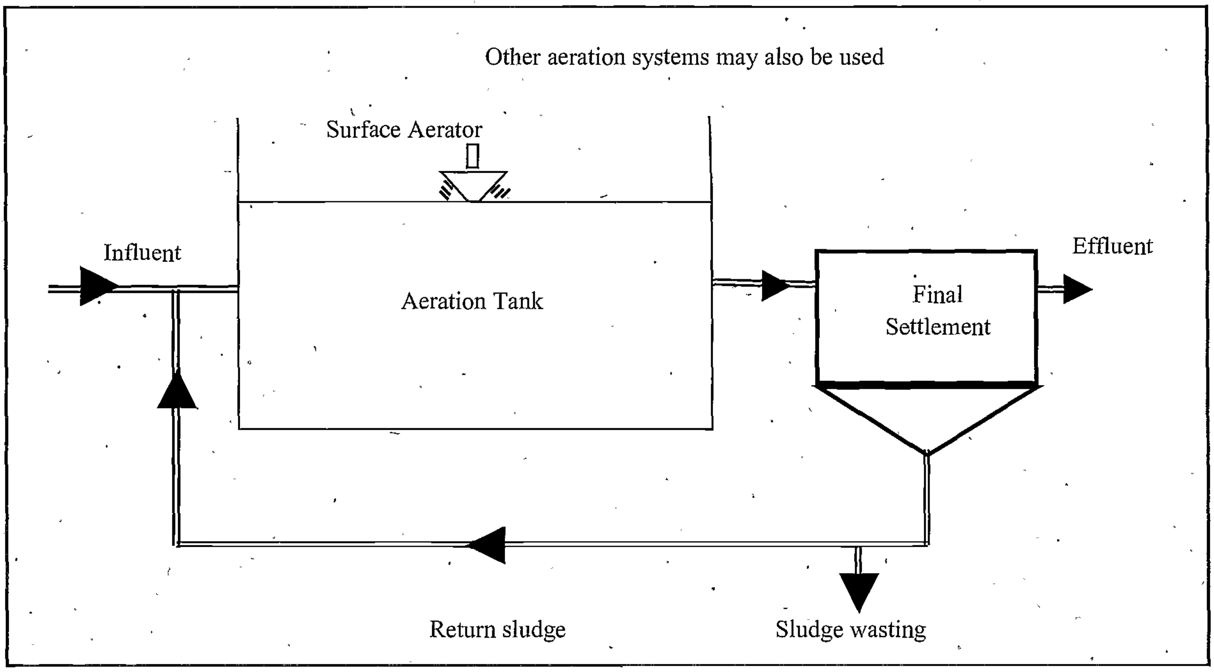

FIGURE 12: EXTENDED-AERATION SYSTEM

6.1.3 Advantages and disadvantages

The advantages of extended-aeration systems include:

- relatively low initial cost;
- lowest sludge production of any activated sludge system;
- high quality wastewater achievable;
- pre-engineered package systems quickly installed with minimal site preparation;
- favourable reliability with sufficient operator attention;
- relatively minimal land requirements;
- nitrification can occur; and
- moderate shock loadings can be handled with minimal problems.

The disadvantages of extended-aeration systems include:

- high power consumption compared to some filter systems;
- high operation and maintenance requirements compared to filter systems,
- skilled operators are necessary;
- poor quality wastewaters could be discharged from the secondary settlement tanks during periods of high flow variations and poor operator control;
- possibility of poor settleability of mixed liquor suspended solids due to the formation of "pinpoint" floc;
- potential for rising sludge due to denitrification in secondary settlement tank in warmer months;
- blower noise, aerosols, and sludge handling odour potential highlight need for careful sludge management; and
- dewatering of extended- aeration sludge is comparatively difficult.

6.1.4 Design criteria

The volume of the aeration tank should be based on the BOD loading and is generally in the range 0.25 - 0.3 kg BOD/m^3.d. Hydraulic retention time should be between 20 and 30 hours depending on the strength of the inflow and the degree of treatment required. Maximum daily loading should be between 0.05 to 0.15 kg BOD_5/d. kg MLSS, and the concentration of the MLSS should be maintained between 2000 mg/l and 6000mg/l.

Design criteria for the extended aeration process are given in Table 8.

TABLE 8: DESIGN CRITERIA FOR THE EXTENDED AERATION PROCESS

Parameter	Range
MLSS (mg/l)	2,000 - 6,000
F/M (g BOD_5/d per g MLSS)	0.05 - 0.15
Aeration detention time (hr) (based DWF)	20-30
Solids retention time (days)	20-30
Recycle ratio (R)	0.5-1.5
Volatile fraction of MLSS	0.6-0.7
Channel velocity (m/s)	≥ 0.305

With mechanically aerated systems, the aerator should be capable of providing a minimum of 2 g oxygen per g of BOD_5 applied for carbonaceous removal, additional oxygen is required when nitrification. In a diffused air system, the air compressor should be capable of producing up to 17 m^3 of air per day per head of population at a 2 m depth of water; the required treatment volume per day per head of population depends on bubble size and depth of immersion (Table 9).

The surface loading rate (flow per unit area) in the secondary settlement tank should not exceed 22 $m^3/m^2.d$. In other words, the upward flow velocity of 0.9 m/hr in the secondary settlement tank should not be exceeded (based on 6 DWF). The secondary tank should be conservatively designed to handle high MLSS and poor settleability of the biological solids. Since there is no primary settlement, it is advisable that secondary settlement tanks are equipped with surface skimming devices to remove grease and floating solids.

The extended aeration process can sometimes incorporate a contact tank upstream of the aeration zone to allow mixing of return sludge and influent. This tank would be equipped with subsurface mixers. Nitrification may be achieved by recirculating mixed liquor from the aeration zone to this tank at a rate of 4 DWF.

The service life of the equipment will depend on maintenance but should range up to 20 years. Notwithstanding table 4, buffer zones of about 60 m are required to cater for noises and odours. An alarm system (i.e. telemetry) should be installed to indicate malfunction.

6.1.5 Costs

Prefabricated package systems are generally less costly than custom designed systems employing in situ concrete tanks.

Energy consumption for an extended-aeration system is high relative to other mechanical treatment alternatives.

6.1.6 Operation and Maintenance

Operation and maintenance requirements for an extended-aeration facility are high because of the general complexity of the equipment, and the need for skilled and regular operator supervision.

6.1.7 Monitoring

Monitoring requirements may include system inflow and wastewater flows, suspended solids concentrations and substrate concentrations. Operational monitoring should include MLSS, aeration tank DO, pH, sludge settleability, alkalinity, return sludge flow, and sludge wastage rate.

6.1.8 Treatment residues

Grit will accumulate in the aeration tank, if there is

TABLE 9: AIR SUPPLY FOR EXTENDED-AERATION SYSTEMS

	Bubble size (mm)	Depth of aerator (m)	Air supply per day per capita (m^3)
Coarse bubbles	8	2	16.8
		3	12.0
		3.5	9.5
Fine bubbles	2 to 4	2	8.4
		3	6.0
		3.5	4.8

(BS 6297)

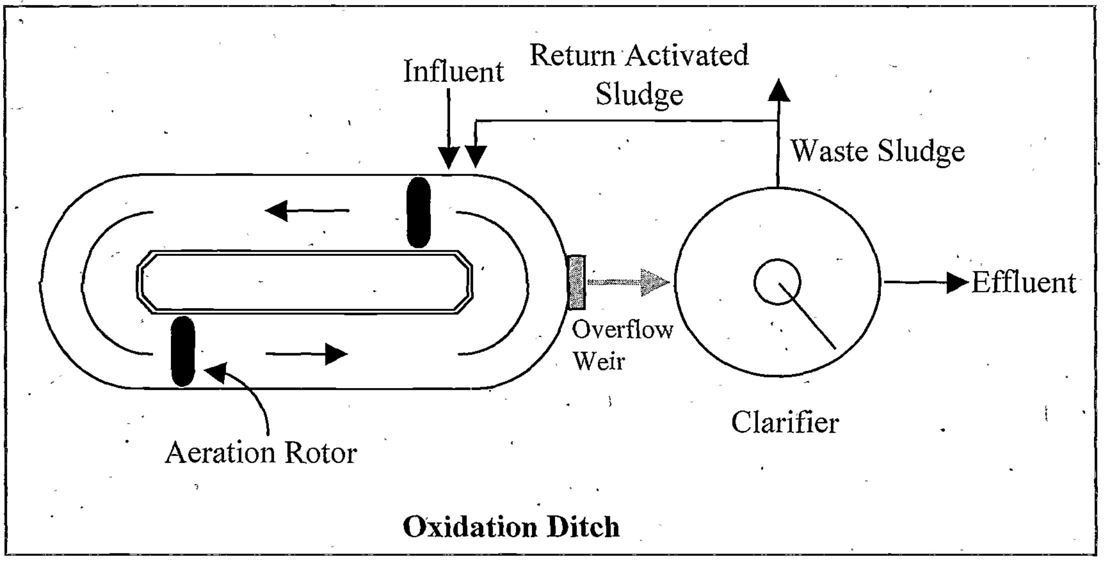

FIGURE 13: OXIDATION DITCH SYSTEM (OVAL SHAPE)

no separate grit chamber provided; eventually the aeration tank will have to be drained and cleaned.

Due to the long solids retention time, waste sludge production is less than for a conventional activated sludge system. Sludge may be wasted to a sludge holding tank.

6.2 DIFFERENT CONFIGURATIONS OF THE ACTIVATED SLUDGE PROCESS

6.2.1 Oxidation ditch

A specialised configuration of the activated sludge process, the oxidation-ditch system consists of coarse screening, grit removal, aerated channels and secondary settlement. Primary settlement is rarely used.

The oxidation ditch system is a closed-loop variation of the activated sludge process and is most commonly operated in the extended aeration mode, the details of which have been described above. This system is characterised by low loading rates and long hydraulic retention times of between 20 - 30 hours and solids retention times of between 10 and 20 days. A horizontally mounted rotating device transfers oxygen to the wastewater and also keeps it moving around the loop (Figure 13).

A single channel, 1.0 m to 3.0 m in depth is typically used. Depths of up to 5 m can be used in ditch type carousel units with vertical shaft aerators. The construction materials include concrete, steel and earthwork. Where earthwork is used, a liner for the channel may be required and a rigid liner should be provided to at least 4.5 m downstream of the aeration device. For more detailed design of oxidation ditches refer to Table 8.

A variation of the oxidation ditch has a secondary settlement tank placed in the ditch channel to provide a quiescent settling zone with solids returned back to the ditch through slots at the bottom of the secondary tank. These systems eliminate the need for separate secondary settlement tanks and return sludge pumping. However, the settled sludge may be dilute, there may be a lack of operational flexibility in adjusting sludge return rates, and there may be a need to increase mixing to overcome the headloss that results from the restriction of flow around the secondary settlement tank.

The oxidation ditch is capable of producing a very high quality wastewater. It can be used for nitrogen removal by having aerobic zones for nitrification and anoxic zones for denitrification in the ditch.

Operation and maintenance requirements for oxidation ditch systems are high because of the general complexity of the equipment, and the need for skilled and regular operator supervision. The aerators and scrapers on clarifers account for the major portion of the mechanical problems. These problems include loss of "teeth" on the aerators, corrosion, and failure of bearings, seals and couplings.

6.3 SEQUENCING BATCH REACTOR

6.3.1 Description

The sequencing batch reactor (SBR) process is a form of activated sludge treatment in which aeration,

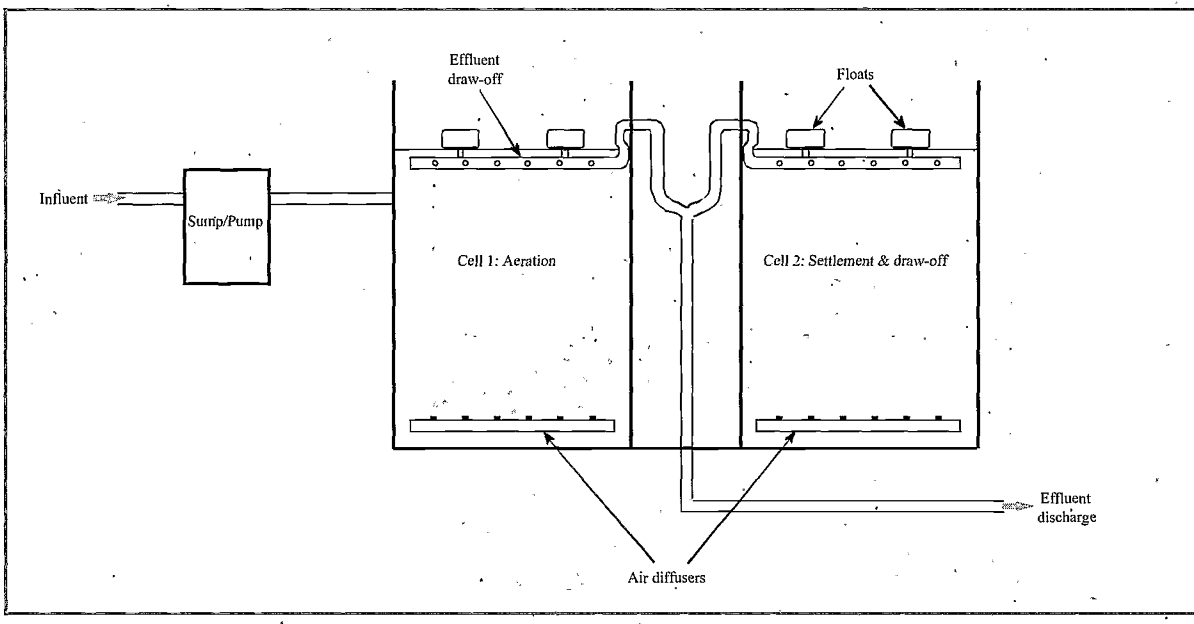

FIGURE 14: TYPICAL SEQUENCING BATCH REACTOR

settlement, and decanting can occur in a single reactor. Most SBRs consist of two or more reactor tanks. The process employs a five-stage cycle: fill, react, settle, empty and rest. Wastewater enters the reactor during the fill stage; it is aerobically treated in the react stage; the biomass settles in the settle stage; the supernatant is decanted during the empty stage; sludge is withdrawn from the reactor during the rest stage; and the cycle commences again with a new fill stage. When one reactor has been filled with inflow - at the end of the fill stage - the inflow is then diverted into the next reactor, and its cycle commences.

A typical SBR process consists of screening, grit removal and SBR cycling. There is usually no primary settlement. A typical SBR is shown in Figure 14.

Critical components of an SBR system include the aeration/mixing process, the decant process, and the control process.

SBR systems are capable of producing a high-quality wastewater. SBRs are also capable of both biological and phosphorus removal, which is accomplished by proper reactor sizing and selection of stage lengths and aeration times to achieve the desired distribution of anoxic, anaerobic and aerobic conditions. Sludge wasting is accomplished by wasting either aerated MLSS or settled sludge. Often submersible pumps are used to waste solids.

6.3.2 Applicability

Since the SBR system provides batch treatment of wastewater, it can accommodate wide variations in flow rates that are typically associated with small communities. The SBR system requires less operator attention than most alternatives. Process control is usually provided by a programmable logic controller (PLC), which along with associated software is provided by manufacturers. Programs are typically developed and modified by the vendor to suit the intended application. The SBR technology is well established in other countries.

6.3.3 Advantages/Disadvantages

The advantages of SBR systems include:

- reliability;
- ideally suited for wide flow variations;
- high quality wastewater achievable;
- requires less operator attention than most other mechanical systems;
- high operational flexibility which can be used for nitrification; and
- denitrification and phosphorus removal.

The disadvantages of SBR systems include:

- complex control system;
- skilled operator necessary;

TABLE 10: DESIGN CRITERIA FOR THE SBR PROCESS

Parameter	Range
Total tank volume	0.5 - 2.0 times average daily flow
Number of tanks	Typically 2 or more
Tank depth (m)	3.0 - 6.0
F/M	0.04 - 0.2
SRT (days)	20 - 40
Aeration system	Sized to deliver sufficient oxygen during aerated fill and react stage; O_2 requirements similar to conventional activated sludge (with nitrification as required)
Cycle times (hr)	4-12 (typical)

(US EPA, 1992)

- pumps and valves are used; and
- problems have been reported with emptying phase.

6.3.4 Design Criteria

Design criteria for the SBR process are summarised in Table 10.

6.3.5 Costs

SBR systems are likely to be cost-competitive with other mechanical wastewater treatment systems. The absence of an external secondary settlement tank and return sludge pumping system offers potential savings in construction costs. Also, there is usually no primary settlement tank. Energy consumption is expected to be similar to extended-aeration systems but greater than a percolating filter solids contact system.

6.3.6 Operation and Maintenance

Operating SBR systems have shown excellent reliability and relatively low maintenance. However, SBR systems require skilled operators. Operation and maintenance requirements include:

- wastewater quality monitoring;
- operation analysis (e.g. MLSS, DO, settleability);
- cleaning of screens, weirs, decant mechanisms, diffusers, and other components;
- adjustment of cycle times as required to optimise performance;
- regular wasting of solids;
- sludge dewatering and disposal;
- administration and recordkeeping;
- maintenance;
- blowers, mechanical aerators or mixing pumps;
- waste sludge pumps;
- electrical equipment;
- mechanical dewatering equipment; and
- laboratory equipment such as pH, DO meters, chemicals.

6.3.7 Monitoring

Monitoring requirements may include system inflow and final wastewater flows, suspended solids concentrations and substrate concentrations. Operational monitoring should include MLSS, reactor DO, pH, sludge settleability, alkalinity, return sludge flow, and sludge wastage rate.

6.3.8 Treatment residues

Grit will accumulate in the reactor tank, if there is no separate grit chamber provided; eventually the aeration tank will have to be drained and cleaned.

Due to the long solids retention time, waste sludge production is less than for a conventional activated sludge system. Sludge may be wasted to a sludge holding tank.

6.3.9 Membrane bioreactors

Membrane technology in the treatment of wastewater is an emerging technology. It is being combined with biological unit processes, especially suspended growth processes to separate activated sludge and treated wastewater. In such applications, the membrane separation process acts as a substitute for the secondary settlement tank. Several names have been used to describe the process, such as membrane reactors, membrane separation bioreactor and the membrane separation activated sludge process.

Membranes can reject various substances ranging from inorganic ions to suspended solids according to the types of membranes applied (see Figure 15). In comparison with the conventional activated sludge process, such systems produces an effluent with low suspended solids and have the capacity to produce a bacteria-free treated effluent. It enables complete sludge retention, can be operated at high MLSS and it minimises excess sludge production. The disadvantages include high energy consumption and membrane fouling.

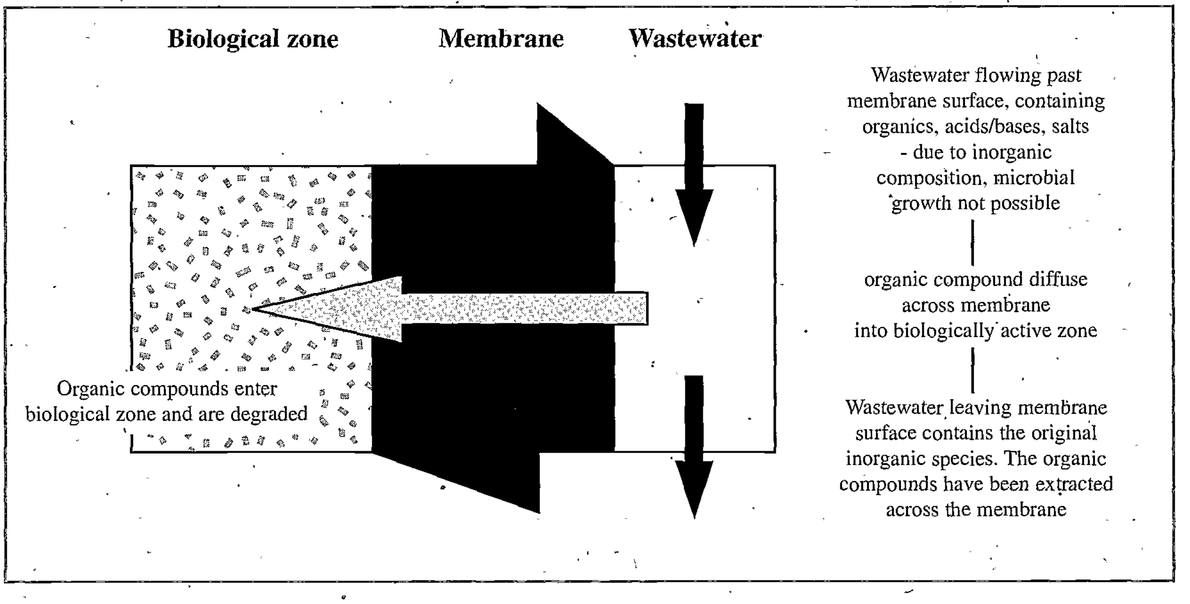

FIGURE 15: THE MODE OF ACTION OF EXTRACTIVE MEMBRANES

7. INSTALLATION, MANAGEMENT AND CONTROL OF SMALL TREATMENT SYSTEMS

7.1 INSTALLATION AND COMMISSIONING

The proper installation of small scale wastewater treatment systems is crucial so that they can function efficiently. Many long term problems can be addressed at the installation stage. The following points should be noted in relation to installation of small scale systems:

- there should be good access on site for all machinery;
- prefabricated packaged systems normally require a concrete slab to be constructed prior to delivery. This should be designed to a relevant standard such as BS 8110 and should be capable of supporting the packaged system when full of wastewater;
- ground conditions should be suitable for all construction operations;
- backfilling around prefabricated tanks should be carried out in accordance with the manufacturer's specifications;
- precautions should be taken so that flotation of tanks does not occur either during construction or subsequent to commissioning of the treatment system;
- where possible, inlet and outlet pipes should be built into walls during construction, with a flexible joint located externally within 200 mm of the wall;
- during installation there should be a safe supply of electricity to the site; care must be taken to protect all wires against damage by construction traffic;
- in the case of percolating filter systems, the media should be placed with care, in accordance with the manufacturer's specifications; damage to the media will result in a loss of performance of the treatment system;
- prior to delivery of prefabricated package systems, all pipes should be laid accurately to facilitate connection to the prefabricated system;
- there should be a proper supply of water on site during construction;
- provision should be made during construction for the entry of sludge removal tankers onto the site; it should be possible for these tankers to position themselves quite close to the relevant tanks or sludge drawoff points;
- care must be taken not to install prefabricated tanks 'back-to-front';
- in all cases the operator of the system should ensure that all works are inspected and are in proper order prior to commissioning; installation should be supervised by a chartered engineer; and
- certification of proper installation should be supplied by a suitably qualified person.

7.2 MANAGEMENT AND CONTROL

During the construction stage or during start-up, the long-term management of the system should be planned. Unlike larger wastewater treatment systems, staff involved in operating a small system may not be allocated full-time and may have to operate a number of facilities. However, the allocation of staff time to a small system should match the requirements of the system, to ensure that a good quality outflow is achieved.

For advice on the operation and maintenance of treatment systems, reference should be made to:

- the manufacturers' and suppliers' manuals of operation;
- the sanitary services operators training programmes developed and implemented by the Tipperary (N.R.) County Council/FAS training group; and
- textbooks and manuals.

To ensure that a satisfactory quality effluent is achieved at a reasonable cost a management system approach should be developed and operated. The management system outlined below is identical to that outlined in the EPA manual *Primary, Secondary and Tertiary Treatment of Wastewater.*

The management system should address:

- organisation and responsibilities of personnel involved in operating small wastewater treatment systems;
- quantification of the environmental effects of the treatment system;
- operational control of the treatment system (Appendix D provides a check list of some of the operational procedures);
- documentation and maintenance records of the treatment system;
- audits of the system;
- preventative maintenance;
- emergency response;
- equipment replacement;
- quantification of inflow to the system; and
- monitoring programme and frequency of analysis.

7.3 MANAGEMENT SYSTEM AND AUDIT SCHEME

The basic premise of an Environmental Management System is the achievement of continuous, and quantifiable improvement in performance. It requires that objectives be established and that an audit scheme, which is used to determine the performance of the treatment system be put in place. A schematic of a management and audit scheme is illustrated in Figure 16.

7.3.1 initial environmental review

The initial environmental review would:

- examine the current policy and practices for the treatment system(s) or proposed system(s);
- 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 system.

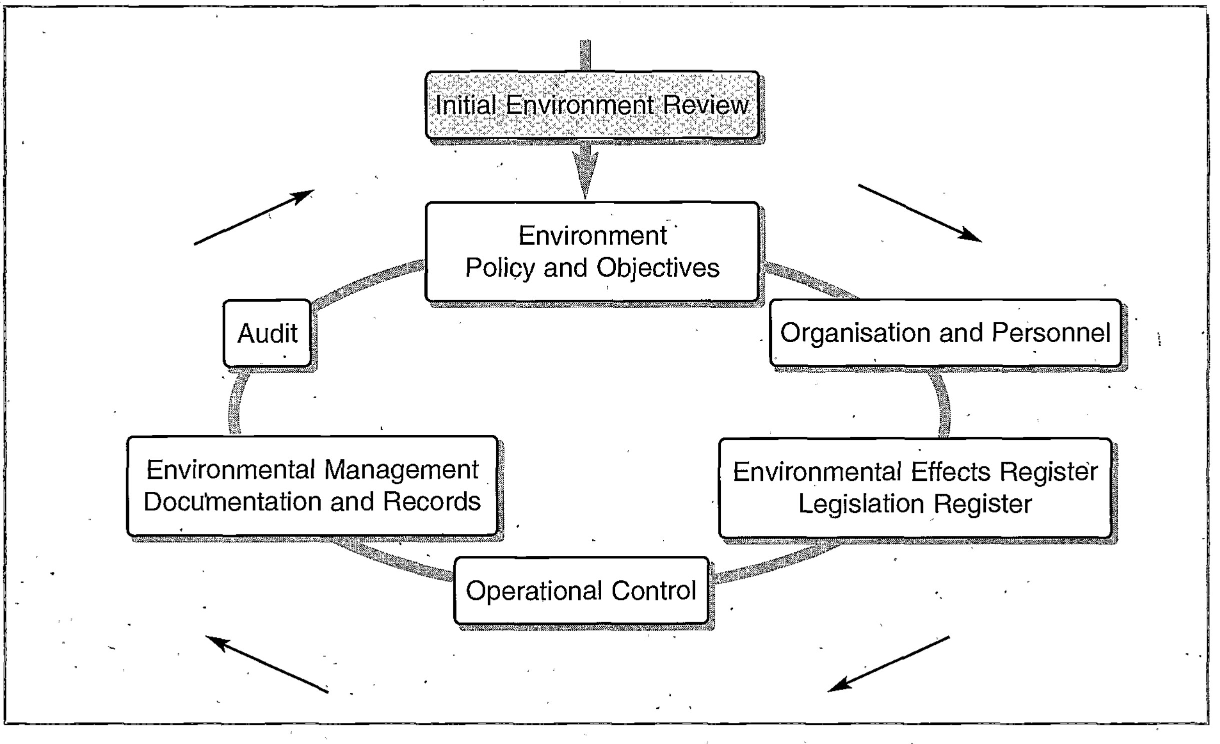

FIGURE 16: MANAGEMENT SYSTEM FOR SMALL WASTEWATER TREATMENT SYSTEMS

7.3.2 Environmental policy and objectives

The environmental policy and objectives of the relevant sanitary authority will establish the policy for the treatment system. The goal is a comprehensive set of objectives and targets involving all participants. The objectives and targets must be clear and achievable. They must be budgeted for and an annual budget should be prepared.

7.3.3 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.

7.3.4 Environmental Effects Register

The environmental effects register will provide a basis for analysing and documenting the environmental effects of the wastewater treatment system 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.

7.3.5 Operational Controls

The operational controls are a set of documented practices, procedures and systems to ensure that the activities of the system operator which have an impact on the wastewater treatment system 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.

7.3.6 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.

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

7.3.7 The audit

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

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

REFERENCES AND FURTHER READING

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GLOSSARY

Activated sludge system. A wastewater treatment system which includes biological treatment by an active suspension of microorganisms.

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

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 only available in the form of oxidised inorganic compounds such as nitrate, nitrite and sulphate.

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

Biofilm. A layer of microorganisms and their products attached to a support medium.

Biofilm aerated filter. This wastewater treatment system normally consists of a primary settlement tank, an aerated submerged biofilm filter and, possibly, a secondary settlement tank. The system is similar to the conventional percolating filter system except that the media are submerged and forced aeration is applied.

Biochemical oxygen demand (BOD). BOD is a measure of the amount of dissolved oxygen used by microorganisms in the bacterial breakdown of organic matter (food) under aerobic conditions. The BOD_5 test indicates the organic strength of a wastewater 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.

Carbonaceous oxidation. The synthesis of cells by heterotrophic bacteria under aerobic conditions resulting in the breakdown of organic matter.

Chemical oxygen demand (COD). 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_5 as the chemical oxidising agent will often oxidise more compounds than is possible under biological conditions.

Combined system. A sewerage system where foul and surface wastewater are conveyed together in the same collection system.

Conventional activated sludge system. A wastewater treatment system which consists of primary settlement, biological treatment using an aerated activated sludge process and secondary settlement.

Denitrification. The conversion of nitrate to nitrogen gas and water using suitable heterotrophic bacteria under anoxic conditions.

Dry weather flow. 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.

Extended-aeration system. An activated sludge process where the sludge age is extended with the aim of reducing the amount of organic solids produced. This normally has no primary settlement.

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

Mixed liquor. Mixture of wastewater and activated sludge undergoing treatment in an activated sludge system.

Mixed liquor suspended solids. Concentration of suspended solids in the mixed liquor.

Nitrification. The conversion of ammonia to nitrate using autotrophic bacteria under aerobic conditions.

Non-package system. A small wastewater treatment system which is not prefabricated in a factory, but is constructed on-site.

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

Oxidation ditch system. A wastewater treatment system which is an activated sludge process where the wastewater is treated aerobically along a ditch. The system does not normally have primary settlement.

Package system. A prefabricated factory-built wastewater treatment unit.

Peat filter system. A wastewater treatment system which includes primary settlement, biological treatment and filtration in a suitable peat medium.

Percolating filter system. A wastewater treatment system which consists of primary settlement and biological treatment achieved by distributing the settled liquid onto a suitable inert medium, followed by secondary settlement.

Population equivalent. A population equivalent of 1 (1 p.e.) means the organic biodegradable load having a five-day biochemical oxygen demand (BOD_5) of 60g of oxygen per day. Loads to the treatment system shall be calculated on the basis of the maximum average weekly load entering the treatment system during the year, excluding unusual situations such as those due to heavy rain.

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

Pre-treatment. The treatment which an industrial wastewater receives at the source before discharge into the public sewer. Pre-treatment 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.

Rotating biological contactor (RBC). The contactor consists of inert plastic modules mounted in the form of a cylinder on a horizontal rotating shaft. Biological wastewater treatment is effected by biofilms which attach to the modules. The biological contactor is normally preceded by primary settlement and followed by secondary settlement.

Rotifers. Microscopic animals characterised by short hairs.

Sand filter system. A wastewater treatment system which includes primary settlement, followed by biological treatment and filtration in a suitable sand medium.

Separate system. A sewerage system where foul and surface wastewater have separate collection systems.

Septic tank system. A wastewater treatment system which includes a septic tank, providing mainly primary treatment, followed by a filter system, which provides secondary treatment.

Sequencing batch reactor (SBR). A wastewater treatment system in which aeration, settlement and decanting occur in one or more tanks, with several cycles over a 24 hr period.

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

Urban Wastewater. This means domestic wastewater or the mixture of domestic wastewater with industrial wastewater and/or rain water.

APPENDIX A: WASTEWATER CHARACTERISATION FORM

Type of activity (hotel, restaurant etc.): ________________________________

List sources of wastewater (no. of kitchens, no. of toilets, no. of bedrooms, no of meals, swimming pools, no. of large functions, no. of floor washings etc.) :

____

____

____

Quantity of disinfection chemicals used on the premises: litres/day litres/week

List and quantities of other raw materials used on-site:

Emission Details:

Volume to be emitted			
Normal/day	m^3 /d	Maximum/day	m^3 /d
Maximum rate/hour	m^3 /hr		

(iii) Period or periods during which emissions are made, or are to be made, including daily or seasonal variations (start-up /shutdown to be included):

Periods of Emission (avg.) _______ min/hr _______ hr/day _______ day/week

Parameter	Prior to pre-treatment			
	Max. hourly average (mg/l)*	Max. daily average (mg/l)	kg/day	kg/week
BOD				
COD				
TSS				
Temperature (°C)				
pH				
Total Nitrogen				
Total Phosphorus				
Detergents				
Grease				

* except temperature

APPENDIX B: LABORATORY EQUIPMENT AND REPORT FORMS

The following equipment should be available at a central facility where routine monitoring for BOD_5, COD, TSS, NH_3, NO_3, P and general microscopic analysis can be performed:

- analytical balance;
- oven and incubator (20°C);
- desiccator;
- filter papers, filtration apparatus and vacuum pump;
- portable 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; BOD seed;
- COD kit;
- homogeniser;
- wash and reagent bottles;
- pipettes, graduated cylinders and Imhoff cone;
- microscope;
- fridge;
- fume hood;
- pH meter (and probes for NH_3-N and NO_3-N);
- thermometer;
- general laboratory apparatus and media for bacterial counts; and
- distilled de-ionised water.

Standard forms which operators are encouraged to use to standardise sampling and reporting for wastewater treatment systems are included hereafter. These include:

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

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_5 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				
Coliforms /100 ml				
Comments:			Signed: ------------------------------ (Printed Name of analyst)	

SAMPLE MONITORING SHEET

WASTEWATER SAMPLING SHEET	Name and address of laboratory:
Name of System:	
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$_5$ 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_5)

Laboratory sheet for Biochemical Oxygen Demand

	Date	Time	Analyst		Incubator temperature (°C)	
On						
Off						
Laboratory No.	Salinity – (%)	Dilution	DO_0 mg/l O_2	DO_5 mg/l O_2	DO_6 mg/l O_2	BOD_5 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*	N/A*				

*N/A - Not applicable

** As a check on certain sources of error, a glucose/glutamic acid solution should be analysed in accordance with standard reference procedures

MICROSCOPY EXAMINATION FORM

Date: ______________________ Time: ________ AM/PM

By: ______________________ Temperature ________ °C

Sample Location: ______________________

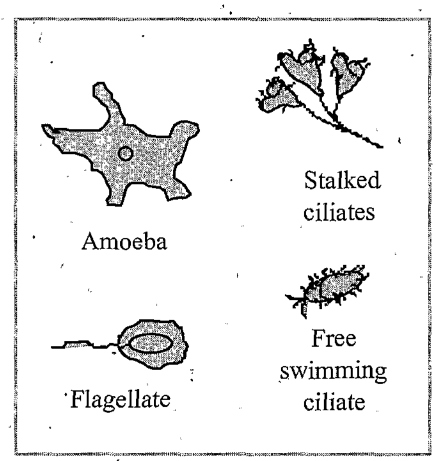
Microorganism Group	Slide No. 1	Slide No. 2	Slide No. 3	Total
Amoebae				
Flagellates				
Free swimming ciliates				
Stalked ciliates				
Rotifers				
Worms				

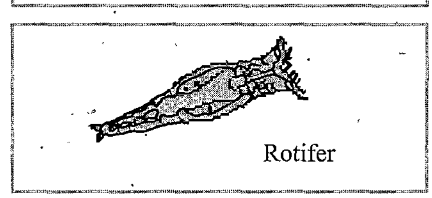
Relative predominance

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 microorganism.
4. Determine the number from each group and assess predominance.

APPENDIX C: DESIGN EXAMPLES

Design examples are given on the following pages for a population of 245 persons. **These examples are for illustration purposes only.** In the design of a wastewater treatment system, a large number of considerations should be taken into account.

These considerations could include the following:

- type of wastewater collection system (separate, combined or partially separate);
- peak flows (multiple of DWF used);
- infiltration;
- origin of wastewater;
- site location and ground conditions;
- power supply;
- head loss through the proposed site; and
- required final wastewater quality.

A number of treatment systems are considered in the design examples, without prejudice to other systems. The systems used in the design examples are:

- a percolating filter;
- a rotating biological contactor;
- a constructed wetland; and
- an extended-aeration system;

Other systems for which design data can be similarly obtained include:

- an oxidation-ditch system;
- a sequencing batch reactor; and
- a biofilm aerated filter.

The numbers in parentheses (200/180) adjust equations to take account of the flow of 200 l/population equivalent in comparison with the flow of 180 l/population equivalent used in BS 6297.

Allowances should be made for infiltration into any system and for peak flows. A flow balancing system can be used to ensure that the hydraulic load on the biological system does not exceed its capacity.

DESIGN EXAMPLE FOR A PERCOLATING FILTER

Population: 245 persons
Wastewater Volume/day: 200 l/person.day
BOD_5 loading: 0.06 kg/person.day
Final Wastewater Standards: BOD_5 of 25 mg/l and Suspended Solids of 35 mg/l

Type of sewerage collection system: Separate with no infiltration and balanced flow.

The proposed system consists of three elements:

- primary settlement;
- percolating filter; and
- secondary settlement.

(i) Primary Settlement - Horizontal Flow Settlement Tank or Septic Tank

<u>Horizontal Flow Settlement Tank</u>

The capacity of the primary settlement tank is calculated from:

Capacity = $200. P^{0.85} / 1000 = 21.5\ m^3$

where P is the population equivalent

The surface area can be calculated from;

Area = $(1/10).(200/ 180).P^{0.85} = 11.93\ m^2$

This tank could be a single tank with its floor sloping up at 1:10 from a depth of 2.1 m at the inlet end to 1.5m at the outlet end.

Two smaller tanks could also be used in parallel with their floors sloping up at 1:10 to a depth of 1.5 m at the outlet end.

The sludge from these tanks must be desludged on a regular basis to prevent movement of sludge into the biological zone.

Normally the length of these tanks is about three times the width. The maximum weir overflow rate of 200 m^3/m.day should not be exceeded. If flow splitting occurs it should be carried out as described in BS: 6297.

<u>Septic Tank</u>

The following equation for estimating the capacity of the septic tank is recommended for general use:

Capacity = $(200.P+2000) / 1000 = 51\ m^3$

For populations in excess of 100 persons, two tanks, each with two compartments, should be constructed. The first compartment should be able to contain 2/3 of the capacity of the tank and the second compartment 1/3 of the capacity of the tank. There should be a minimum tank depth of 1.5 m. The first compartment should have a floor slope of 1:4. This design assumes that the septic tank will be desludged at not more than 12-monthly intervals.

(ii) Percolating Filter

The volume of the filter media can be calculated from the following equation:
Volume of media = 1.5. $P^{0.83}$ = 144 m^3
Assuming a depth of 1.8 m, the required volume can be readily obtained by using one filter tank of 10.5 m diameter or two filter tanks, each of 7.5 metres diameter.

(iii) Horizontal Flow Secondary Settlement Tank

The surface area of this tank should not be less than:
Area = (3/40).(200/ 180).$P^{0.85}$ = 8.95 m^2

The capacity of the tank can be calculated from the following equation:

Capacity = 135.(200/180).$P^{0.85}$ = 16102 litres = 16.1 m^3

Note:

Some percolating filter systems may be upgraded by the use of high surface area plastic media and the installation of an aerated solids contact tank.

DESIGN EXAMPLE FOR A ROTATING BIOLOGICAL CONTACTOR*

Population: 245 persons
Wastewater Volume: 200 l/person.day
BOD_5 loading: 0.06 kg/person.day
Type of sewerage collection system: Separate with no infiltration with balanced flow
Final Wastewater Standards: BOD_5 of 25 mg/l and Suspended Solids of 35 mg/l

This system consists of three elements:

(i) Primary Settlement
(ii) Rotating Biological Contactor
(iii) Secondary Settlement

(i) Primary Settlement - Horizontal Flow Settlement Tank or Septic Tank

Horizontal Flow Settlement Tank

The following formula is recommended for calculating the capacity of the primary settlement tank:

Capacity = 200. $P^{0.85}$ / 1000 = 21.5 m^3

where P is the population equivalent

The surface area can be calculated from the following equation:

Area = (1/10).(200/ 180).$P^{0.85}$ = 11.93 m^2

This tank could be a single tank with its floor sloping up at 1:10 from a depth of 2.1 m at the inlet end to 1.5m at the outlet end.

Two smaller tanks could also be used in parallel with their floors sloping up at 1:10 to a depth of 1.5 m at the outlet end.

Normally the length of these tanks is about three times the width. The maximum weir overflow rate of 200 m^3/m.day should not be exceeded.

The sludge from these tanks must be desludged on a regular basis to prevent movement of sludge into the aeration zone.

*** A biofilm aerated system could be designed on the same basis**

Septic Tanks

The following equation for estimating the capacity of the septic tank is recommended for general use:

Capacity = (200.P +2000) / 1000 = 51 m^3

For populations in excess of 100 persons, two tanks, each with two compartments, should be constructed. The first compartment should be able to contain 2/3 of the capacity of the tank and the second compartment 1/3 of the capacity of the tank. There should be a minimum tank depth of 1.5 m. The first compartment should have a floor slope of 1:4. This design assumes that the septic tank will be desludged at not more than 12-monthly intervals.

(ii) Rotating Biological Contactor

The surface area of the contactor should not have a loading greater than 5 g BOD_5 per m^2 per day of settled sewage or 7.5 g BOD_5 per m^2 per day of raw sewage entering the system. On the basis of the raw sewage loading, the following contactor area is required:

Area = (245).(60)/ 7.5 m^2 =1960 m^2

This area could be provided by 320 discs, each of 2.0 m diameter. It is recommended to arrange these discs in a number of discrete chambers in series to eliminate by-pass flow.

(iii) Horizontal Flow Secondary Settlement Tank

The surface area of this tank should not be less than:

Area = (3/40).(200/ 180).$P^{0.85}$ = 8.95 m^2

The capacity of the tank can be calculated from the following equation:

Capacity = 135.(200/180).$P^{0.85}$ = 16102 litres = 16.1 m^3

Allowances should be made for infiltration into any system and for peak flows. A balancing flow system can ensure that the biological system is not overloaded at any time.

DESIGN EXAMPLE FOR A HORIZONTAL-FLOW CONSTRUCTED WETLAND FOR SECONDARY TREATMENT

Population: 245 persons
Wastewater Volume/day: 200 l/person.day
BOD_5 loading: 0.06 kg/person.day

Type of sewerage collection system: Separate with no infiltration and balanced flow
Final Wastewater Standards: BOD_5 of 25 mg/l and Suspended Solids of 35 mg/l

This system consists of two processes:

(i) Primary Settlement
(ii) Horizontal-Flow Constructed Wetland

(iii) Primary Settlement - Horizontal Flow Settlement Tank or Septic Tank

Horizontal Flow Settlement Tank

The following formula is recommended for calculating the capacity of the primary settlement tank:

Capacity = $200. P^{0.85} / 1000 = 21.5$ m^3

where P is the population equivalent

The surface area can be calculated from the following equation:

Area = $(1/10).(200/ 180).P^{0.85} = 11.93$ m^2

This tank could be a single tank with its floor sloping up at 1:10 from a depth of 2.1 m at the inlet end up to 1.5 m at the outlet end.

Two smaller tanks could also be used in parallel with their floors sloping up at 1:10 to a depth of 1.5 m at the outlet end.

Normally the length of these tanks is about three times the width. The maximum weir overflow rate of 200 m^3/m.day should not be exceeded. If flow splitting occurs it should be carried out as described in BS: 6297.

The sludge from these tanks must be desludged on a regular basis to prevent movement of sludge into the biological zone.

Septic Tanks

The following equation for estimating the capacity of the septic tank is recommended for general use:

Capacity = $(200.P + 2000) / 1000 = 51$ m^3

For populations in excess of 100 persons, two tanks, each with two compartments, should be constructed. The first compartment should be able to contain 2/3 of the capacity of the tank and the second compartment 1/3 of the capacity of the tank. There should be a minimum tank depth of 1.5 m. The first compartment should have a floor slope of 1:4. This design assumes that the septic tank will be desludged at not more than 12-monthly intervals.

(ii) Horizontal-Flow Constructed Wetland

The surface land area (A_h) can be calculated from the following equation:

$A_h = Q_d(\text{Ln } C_o - \text{Ln } C_t) / k_{BOD}$

where:

Q_d = Flow per day, calculated as 49 m^3/d

C_o = Constructed Wetland inflow BOD_5 of 210 mg/l assuming 70% of the BOD_5 has been removed in the primary sedimentation stage

C_t = the final wastewater BOD_5 of 20 mg/l

k_{BOD} = 0.1/day

A_h **= 1152 m²**

Using the Darcy equation

$A_c = Q_s/(k_f.\ dh/ds)$

where:

A_c is the required inlet cross-sectional area

Q_s is the flow per day, calculated as $5.67 \times 10^{-4} m^3/s$

k_f is the hydraulic conductivity of media with a value of 1×10^{-3}m/s and it is assumed that this value will be maintained during the working life of the wetland.
dh/ds is the hydraulic gradient selected at 2%

A_c **= 28.4 m²**

Using **a depth of 0.6 m**, the constructed wetland is **47.3m** wide and **24.4m** long. With a bed base slope of 2%, it can be shown that there is an adequate hydraulic gradient.

Great care should be taken to ensure that there is a uniform distribution of wastewater throughout the constructed wetland.

DESIGN EXAMPLE FOR AN EXTENDED-AERATION SYSTEM

Population: 245 persons
Wastewater Volume/day: 200 l/person.day
BOD_5 loading: 0.06 kg/person.day
Final Wastewater Standards: BOD_5 of 25 mg/l and Suspended Solids of 35 mg/l

Type of sewerage collection system: Separate with no infiltration and balanced flow

This system consists of two processes:

(i) Biological Aeration Process
(ii) Secondary Settlement

Taking an F/M ratio of 0.075 and a MLSS of 3,500 mg/l. The Sludge mass in the aeration tank will be 196 kg:

i.e $\dfrac{14.7 \text{ kg BOD/d}}{0.075 \text{ kg BOD/kg MLSS/day}}$

The volume in the aeration basin should then be 56 m³, i.e. $\dfrac{196 \text{ kg}}{3.5 \text{ kg /m}^3}$

Retention time should be at least 20 hours and up to 30 hrs may be provided depending on the strength of wastewater and standard of final wastewater required. The volume of 56 m³ provides a retention time of about 27 hrs. The BOD loading is 0.3 kgBOD/m³.d which is within the desired range.

The aeration capacity should be at least 2 g oxygen per g BOD applied.

(ii) Horizontal Flow Secondary Settlement Tank

The surface area of this tank should not be less than:

Area = (3/40).(200/ 180).$P^{0.85}$ = 8.95 m^2

The capacity of the tank can be calculated from the following equation:

Capacity = 135.(200/180).$P^{0.85}$ = 16102 litres = 16.1 m^3

The numbers in the brackets (200/180) adjust the above equations to take account of the daily flow of 200 l/population equivalent in comparison with the flow of 180 l/population equivalent used in BS 6297. A surface loading rate of 22 m^3/m^2.d should not be exceeded in the secondary settlement tank.

Allowances should be made for infiltration into any system and for peak flows.

DESIGN EXAMPLE FOR AN INTERMITTENT SAND FILTER

The example chosen is a 4-bedroomed residence with an unsuitable percolation area. The following conditions are assumed :

Average occupancy	=	4 persons/d
Flow	=	180 l/p.e.
Peaking factor	=	3
Size of septic tank	=	3 m^3
Sand filter application rate	=	40 $l/m^2/d$
Frequency of dosing /d	=	4/d
Distribution orifice size	=	3.0 mm
Orifice discharge head	=	1.5 m

Step 1. Determine the size of sand filter required :

Total flow = 4 x 0.18 m^3/d = 0.72 m^3/d
Area of sand filter = 0.72/0.04 m^2 = 18 m^2
Selected dimensions of sand filter = 4 m x 4.5 m

Step 2. Proposed layout of sand filter and wastewater distribution system

Spacing between distribution pipes and orifices = 0.6 m

Layout of sand filter and distribution system is shown in Figure 17. As shown there are 12 laterals spaced at 0.6 m, each being 2.1 m long. Each lateral has 4 orifices spaced at 0.6 m centres. As a first trial, try a 25 mm distribution pipe.

Step 3. Determine the flow and rate of discharge in each lateral

Flow rate discharged per dose = 0.72 m^3/d /4 = 0.18 m^3/dose
Flow rate/lateral = 0.18 m^3/dose/12 laterals = 0.015 m^3/lateral.dose

Determine the flow rate in each lateral : the flow in the lateral orifice is

$q_n = 4.7 \times 10^4 \times C \times D^2 \times (2 \times g \times h_n)^{0.5}$ l/minute

where q_n = flow through the last orifice in a lateral

4.7×10^4 = conversion factor to convert m^3/s to l/minute, multiplied by $\pi/4$

C = orifice discharge co-efficient = 0.61 for holes drilled in the field

D = diameter of orifice (m) = 0.003 m

g = acceleration due to gravity (9.81 m/s)

h_n = head on orifice n (m) = 1.5 m

q_n = 1.40 l/minute

total flowrate into each lateral with 4 orifices = 4 x 1.40 l/minute

= 5.6 l/lateral. minute

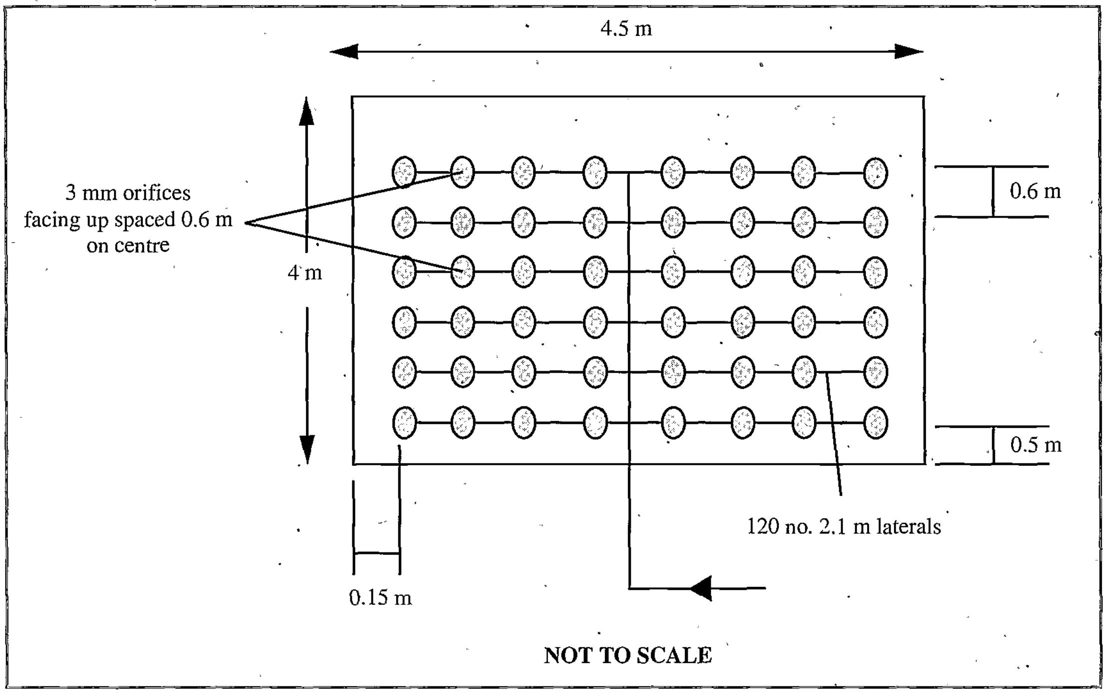


FIGURE 17: LAYOUT OF DISTRIBUTION PIPES ON AN INTERMITTENT SAND FILTER

Step 4. Check the flow distribution at peak flow

Peak flow essentially will not affect the computed headloss values. It will only affect the length of time the dosing pump is on. At average flow the dosing pump will be operating for

$$0.015\ m^3/\text{lateral.dose}/\ 0.0056\ m^3/\text{lateral.min} = 2.67\ \text{minutes}$$

At peak flow rate the pump will operate for about 8 minutes each time the filter is dosed.

Comment : The maximum flow rate to an intermittent sand filter serving a single house should not exceed 100 l/minute (Metcalf and Eddy, 1991, p 1070). A pump should be selected to provide the required flow rate with a minimum head of 1.5 m at the orifices. Higher pressures of up to 9 m head do not usually cause problems. The difference in discharge between the first and the last orifice in each lateral should be calculated to check that this difference is acceptable.

APPENDIX D: OPERATION AND MAINTENANCE

OPERATION AND MAINTENANCE OF EXTENDED-AERATION AND OXIDATION DITCH SYSTEMS

Extended-aeration systems tend to require skilled personnel to ensure proper operation. This is necessary due to the control required for proper sludge return and sludge wasting. Much of the operation of these systems involves visual inspection on a regular basis; however, the carrying out of some vital measurements will ensure good performance. Site visits vary depending on the size of the system but generally range from one hour, three times per week, to full time caretaking.

The following operation and maintenance requirements apply to extended aeration systems:

Daily

- make general observation to ensure proper operation of equipment;
- remove floating sludge on clarifier if present and clean clarifier weir;
- check dissolved oxygen readings for unusual values;
- perform simple cone test to give sludge settleability; and
- record hours of operation of individual processes.

Weekly (twice weekly if possible)

- adjust sludge return rate and air injection rate as necessary;
- carry out Sludge Volume Index (S.V.I.) test (see below);
- alternate duty/standby motors/pumps;
- clean and calibrate dissolved oxygen probes;
- waste sludge as necessary; and
- carry out chemical tests as appropriate (COD, phosphates etc.).

Monthly

- inspect aerators/blowers and maintain as necessary;
- inspect and maintain inflow and sludge return pumps;
- inspect and maintain electrical equipment; and
- stop aerator (if mechanical), examine for trapped debris.

The most important controls available in relation to extended-aeration systems are:

- DO level - by adjusting immersion or speed of aerators or air diffusers;
- MLSS level - maintain the correct MLSS by adjustment of sludge wasting rate;

- Sludge Volume Index (SVI) - the importance of the SVI test needs to be stressed as it gives valuable information on sludge settleability and it indicates if sludge needs to be wasted.

To obtain a value for the sludge volume index, two measurements must be made. Firstly, sludge settleability is calculated by taking one litre of well mixed sludge from the aeration tank and allowing it to settle in a graduated cylinder (not an Imhoff cone). The level of the interface between the settled sludge and the liquid is noted after 30 minutes, and this is recorded in *ml/l*. Secondly a MLSS value must be obtained. This value is obtained from the mass of dry solids in a known volume of wastewater retained on a glass fibre filter paper after a period of at least 2 hours. This quantity is expressed in mg/l and varies typically between 2000 mg/l and 8000 mg/l. The S.V.I. is expressed as follows ;

$$\text{Sludge Volume Index (ml/g)} = \frac{\text{settled volume of sludge after 30 mins (ml/l)} \times 1000}{\text{M.L.S.S. (mg/l)}}$$

Typical values range from 50 ml/g to 150 ml/g with the optimum lying around 100 ml/g. If the value is at the upper end of the range then the sludge is said to bulk; conversely, if the value is too low then the sludge concentration may be too high and desludging may be required.

A simple cone test using an Imhoff cone may be carried out every day, but these results must be used with caution and will only show up sudden changes in sludge characteristics.

OPERATION AND MAINTENANCE OF ROTATING BIOLOGICAL CONTACTORS (RBC) AND PERCOLATING FILTERS

Although these systems are quite different, the operation and maintenance of both system types are similar. The following operation and maintenance requirements apply to these systems:

Daily (if possible)

- examine blockage by rags etc., if system has no screening;
- make general inspection of system operation noting any noises from mechanical plant;
- rake screens, if applicable; and
- remove floating sludge from final clarifier surface.

Weekly

- examine and record biofilm appearance (colour and thickness), grey/black could indicate lack of oxygen, beige/brown indicates carbonaceous oxidation- reddish brown indicates nitrification;
- clean distributor openings (in percolating filter systems);
- return sludge from clarifier to primary settlement tank;
- examine surface of percolating filter for ponding;
- grease all bearings; and
- carry out chemical tests as appropriate (BOD, COD, phosphates etc.).

Monthly

- inspect shaft and bearings in RBC system;

- inspect and maintain inflow and sludge return pumps;
- inspect and maintain electrical equipment; and
- check oil levels in motors.

In general, RBCs and percolating filter systems require less operation and maintenance hours per week than extended-aeration systems; neglecting the checks above will result in poor system performance and could lead to mechanical breakdown.

OPERATION AND MAINTENANCE OF SEQUENCING BATCH REACTORS

These incorporate all phases of the treatment process in one reactor and are operated on a cyclical basis, often incorporating several cycles in one day. The phases are operated in the following sequence: fill/aeration; aeration; settlement; decanting. They are high technology systems and are generally only used above 100 population equivalent. Equipment includes pumps, aeration plant (compressor/blower or mechanical aerators), decanting equipment and sludge drawoff plant. Although they are high technology systems, they do not require sludge return and as such their operation is simpler than extended-aeration systems.

The following O&M requirements apply to sequencing batch reactors:

Daily

- make general observation and ensure proper operation of equipment;
- perform simple cone test to give sludge settleability (during aeration phase); and
- record hours of operation of individual processes.

Weekly

- check oil level of blowers if applicable;
- grease all bearings;
- carry out S.V.I. test;
- alternate duty/standby motors/pumps; and
- carry out chemical tests as appropriate (COD, phosphates etc.).

Monthly

- adjust cycle times to optimise performance;
- stop aerator (if mechanical) and examine for trapped debris;
- inspect and maintain electrical equipment; and
- waste sludge as necessary (generally when MLSS exceeds 4500-5000 mg/l).

OPERATION AND MAINTENANCE OF CONSTRUCTED WETLANDS

There are two types of constructed wetlands; horizontal flow and vertical flow wetlands. The horizontal flow wetlands can be subdivided into two categories:

- free water surface wetlands (FWS); and
- subsurface flow system wetlands (SFS).

Wetlands can be used for secondary treatment, tertiary treatment, storm water treatment or other applications. Wetlands, which are used for secondary treatment, are generally chosen for their low cost/low maintenance requirements. There is an ongoing debate as to whether reeds should be harvested to remove nutrients from the system; removal of reeds involves extra time and cost.

The following operation and maintenance requirements apply to constructed wetlands:

Start up/initial growth period

- control rabbit nuisance by periodically flooding wetland (SFS systems); and
- control weeds.

Weekly

- examine distribution pipes and channels for blockages (especially in secondary wetlands); and
- carry out chemical tests as appropriate.

Monthly

- clean out all distribution openings/notches;
- lower adjustable outlet level to flush out pipes; and
- desludge primary/septic tank as necessary (for secondary wetlands).

USER COMMENT FORM

NOTE: Completed comments to be forwarded to: The Environmental Management and Planning Division, Environmental Protection Agency, P.O. Box 3000, Johnstown Castle Estate, Co. Wexford.

Document Title: **WASTEWATER TREATMENT MANUALS**
TREATMENT SYSTEMS for SMALL COMMUNITIES, BUSINESS, LEISURE CENTRES AND HOTELS

CONTENTS:

STYLE:

INFORMATION:

SUGGESTIONS FOR FUTURE EDITIONS:

NAME .... ORGANISATION ....

ADDRESS ....

DATE .... PHONE .... FAX ....

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL

Bunú
Achtaíodh an tAcht fán nGníomhaireacht um Chaomhnú Comhshaoil ar an 23ú lá d'Aibreán, 1992 agus faoin reachtaíocht seo bunaíodh an Ghníomhaireacht go hoifigiúil ar an 26ú lá d'Iúil, 1993.

Cúraimí
Tá réimse leathan de dhualgais reachtúla ar an nGníomhaireacht agus de chumhachtaí reachtúla aici faoin Acht. Tá na nithe seo a leanas san áireamh i bpríomhfhreagrachtaí na Gníomhaireachta:

- ceadúnú agus rialáil próiseas mór/ilchasta tionsclaíoch agus próiseas eile a d'fhéadfadh a bheith an-truaillitheach, ar bhonn rialú comhtháite ar thruailliú (Integrated Pollution Control-IPC) agus cur chun feidhme na dteicneolaíochtaí is fearr atá ar fáil chun na críche sin;
- faireachán a dhéanamh ar cháilíocht comhshaoil, lena n-áiritear bunachair sonraí a chur ar bun a mbeidh rochtain ag an bpobal orthu, agus foilsiú tuarascálacha treimhsiula ar staid an chomhshaoil;
- comhairle a chur ar údaráis phoiblí maidir le feidhmeanna comhshaoil agus cuidiú le húdaráis áitiúla a bhfeidhmeannas caomhnaithe a chomhlíonadh;
- cleachtais atá fónta ó thaobh an chomhshaoil de a chur chun cinn, mar shampla, trí úsáid iniúchtaí comhshaoil a spreagadh, scéim éicilipéadaithe a bhunú, cuspóirí cáilíochta comhshaoil a leagan síos agus cóid chleachtais a eisiúint maidir le nithe a théann i bhfeidhm ar an gcomhshaol;
- taighde comhshaoil a chur chun cinn agus a chomhordú;
- gach gníomhaíocht thábhachtach diúscartha agus aisghabhála dramhaíola, lena n-áirítear líontaí talún, a cheadúnú agus a rialáil agus plean náisiúnta um dhramháil ghuaiseach, a bheidh le cur i ngníomh ag comhlachtaí eile, a ullmhú agus a thabhairt cothrom le dáta go tréimhsiúil;
- córas a fheidhmiú a chuirfidh ar ár gcumas astúcháin COS (Comhdhúiligh Orgánacha Sho-ghalaithe) a rialú de réir mar a thagann siad chun de bharr cáinníochtaí suntasacha peitril a bheith á stóráil i dteirminéil;
- na rialúcháin OMG (Orgánaigh a Mionathraíodh go Géiniteach) a fheidhmiú agus a ghníomhú maidir le húsáid shrianta a leithéad seo d'orgánaigh agus iad a scaoileadh d'aon turas isteach sa timpeallacht;
- clár hidriméadach náisiúnta a ullmhú agus a chur i ngníomh chun faisnéis maidir le leibhéil, toirteanna agus sruthanna uisce in aibhneacha, i lochanna agus i screamhuiscí a bhailiú, a anailisiú agus a fhoilsiú; agus
- maoirseacht i gcoitinne a dhéanamh ar chomhlíonadh a bhfeidhmeanna reachtúla caomhnaithe comhshaoil ag údarás áitiúla.

Stádas
Is eagras poiblí neamhspleách í an Ghníomhaireacht. Is í an Roinn Comhshaoil agus Rialtais Áitiúil an coimirceoir rialtais atá aici. Cinntítear a neamhspleáchas trí na modhanna a úsaidtear chun an tArd-Stiúrthóir agus na Stiúrthóirí a roghnú, agus trid an tsaoirse a dhearbhaíonn an reachtaíocht di gníomhú ar a conlán féin. Tá freagracht dhíreach faoin reachtaíocht aici as réimse leathan feidhmeannas agus cuireann sé seo taca breise lena neamhspleáchas. Faoin reachtaíocht, is coir é iarracht a dhéanamh dul i gcion go míchuí ar an nGníomhaireacht nó ar aon duine atá ag gníomhú thar a ceann.

Eagrú
Tá ceanncheathrú na Gníomhaireachta lonnaithe i Loch Garman agus tá cúig fhoireann chigireachta aici, atá lonnaithe i mBaile Átha Cliath, Corcaigh, Cill Chainnigh, Caisleán an Bharraigh agus Muineachán.

Bainistíocht
Riarann Bord Feidhmiúcháin lánaimseartha an Ghníomhaireacht. Tá Ard-Stiúrthóir agus ceathrar Stiúrthóirí ar an mBord. Ceapann an Rialtas an Bord Feidhmi úcháin de réir mionrialacha atá leagtha síos san Acht.

Coiste Comhairleach
Tugann Coiste Comhairleach ar a bhfuil dáréag ball cunamh don Ghníomhaireacht. Ceapann an tAire Comhshaoil agus Rialtais Áitiúil na baill agus roghnaítear iad, den chuid is mó, ó dhaoine a ainmníonn eagraíochtaí a bhfuil suim acu i gcúrsai comhshaoil nó forbartha.Tá réimse fairsing feidhmeannas comhairleach ag an gCoiste faoin Acht, i leith na Gníomhaireachta agus i leith an Aire araon.