TREATMENT OPTIONS

Introduction

Sewers transport wastes but do not eliminate them. Wastewater that is discharged to a water course or used for irrigation needs to be treated to ensure that there is neither harm to the environment nor a risk to the health of the people who come into contact with the wastewater.

Most ‘conventional’ sewage treatment systems are concerned with the first. They are designed to remove visually offensive solids, organic material and suspended solids, all of which are likely to affect the quality of the receiving watercourse. Suspended solids may also block drip irrigation systems. When wastewater is used for irrigation, either directly or indirectly following withdrawal from a receiving watercourse, it is also important to consider the need to reduce pathogen levels. In general, the longer the retention time in the treatment facility, the greater the pathogen removal.

Sewage treatment options fall into two broad categories: aerobic treatment and anaerobic treatment. Both rely on micro-organisms, particularly bacteria, those required for aerobic treatment need oxygen while those that facilitate anaerobic treatment do not. Most conventional treatment processes are aerobic but anaerobic systems have some advantages. The key features of aerobic and anaerobic treatment are summarised in the table below.

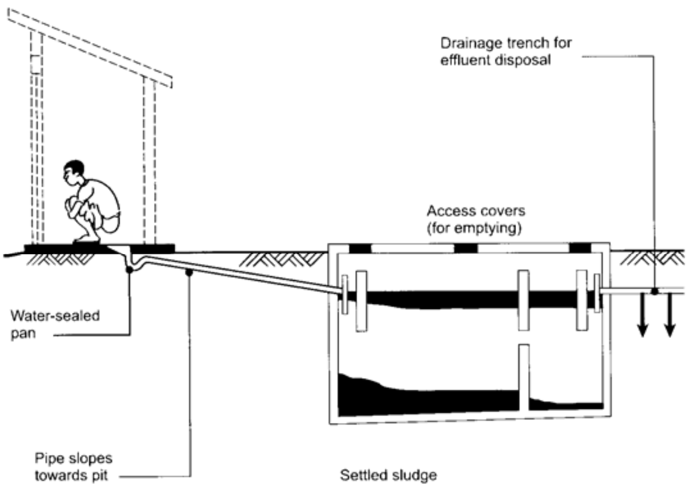
Aerobic	Anaerobic
Need land (From about 0.06sq m. per person for activated sludge up to 3 sq.m per person and more for facultative ponds and constructed wetlands	Require very little land
More intensive forms of treatment (activated sludge and extended aeration) require energy.	No energy requirement – indeed can be net producers of energy
Can remove 90% or more of organic load	Typically remove 40 – 70% of organic load and may need to be supported by secondary aerobic treatment
Systems with long retention (ponds and constructed wetlands) can achieve WHO guidelines for pathogen levels in effluent	Generally poor pathogen removal
Systems with longer retention (ponds and constructed wetlands) deal well with fluctuations in flow and organic load	Sensitive to variations in flow and loading.
Higher sludge production than anaerobic systems	Produce low volumes of well-stabilised sludge
Can smell, particularly if overloaded	Need to be enclosed to avoid smell problems

Not all treatment options are suitable for decentralised use. Anaerobic and aerobic options that are likely to be viable in a decentralised context are considered in the following pages.

ANAEROBIC TREATMENT OPTIONS

Septic tanks

What is it? Septic tanks are the simplest form of anaerobic technology. They hold solids in a watertight tank, where anaerobic digestion takes place, reducing sludge volume significantly The oxygen demand of the effluent is also reduced, typically by between 40 and 70%, depending on temperature, the layout and whether or not the septic tank is desludged once it is full. Septic tanks normally consist of two compartments, the first about twice the length of the first. They are covered to ensure that smells do not escape.



When and where to use it? To serve single households, groups of houses and institutions such as schools and hotels. The normal practice is to discharge septic tank effluent to a leach pit or soakaway, which may be difficult in densely populated areas. Where existing septic tanks discharge to open drains, it may be appropriate to retain them for primary treatment, transporting their effluent to the secondary treatment site in sewers.

Advantages Septic tanks are simple. They require infrequent desludging and provide basic sewage treatment.

Disadvantages Septic tanks are expensive compared to leach pits and more centralised systems. Their performance deteriorates significantly if desludging is neglected. The sludge produced must be treated.

In many countries, it is standard practice to discharge the effluent from septic tanks to open drains. This creates potential hazards for people coming into contact with the drains and usually means that the effluent is discharged untreated to fields or a watercourse.

Technical requirements Septic tanks are normally rectangular in shape with two compartments, as shown in the illustration. Providing two chambers reduces carry through of solids as most settle out in the first chamber. Providing tees at the inlet and outlet from the tank further reduces the possibility of carry-through of solids.

Space must be provided for settlement of solids, solids digestion and storage of digested solids. Household septic tanks are often designed for 24 hours retention plus the volume required for sludge storage.

More information See **http://pubs.caes.uga.edu/caespubs/pubcd/c819-2w.html** for a comprehensive introduction to septic tank design and construction. A good source of information on various anaerobic options, including but not restricted to septic tanks is http://www.irc.nl/page/22812.

BAFFLED REACTOR

What is it? A baffled reactor consists of a compartment similar to the first compartment in a septic tank, followed by a number (typically four or more) of added narrow compartments. The flow is introduced to the bottom of each compartment and then flows vertically to an outlet near the water surface, from where a baffle wall or pipe directs it to the bottom of the next compartment. This means that the flow is forced to flow through the sludge at the bottom of each compartment and this enhances biological activity, leading to increased BOD removal. The last chamber may have a filter in its upper part to prevent solid particles from escaping with the outflow.

When to use it? Baffled reactors work best at a fairly small scale since the width of the baffled compartment should not normally exceed about 75 cm when wastewater is introduced at one side of the chamber and 160cm when it enters the compartment through a centrally located pipe. So, baffled reactors are best used at the local or neighbourhood level. They might be used to achieve a slightly higher discharge standard, typically around 80 mg/l BOD_5, which could not be achieved with a conventional septic tank. Baffled reactors also provide an option for primary treatment, reducing the load to be dealt with aerobically and hence the space required for secondary aerobic treatment.

Advantages Baffled reactors are almost as simple as septic tanks. They need no special construction skills and require little maintenance. Some commentators suggest that they rarely if ever need to be desludged if grit is removed upstream of the tank.

Disadvantages Like all anaerobic systems, baffled reactors take several months after start-up to achieve full treatment efficiency. They are sensitive to variations in flow, which may wash out the sludge in the reactors, causing pollution and reducing subsequent performance. They do not remove pathogens

Technical features and requirements Like septic tanks, baffled reactors are likely to be built with a mass concrete base, rendered brick walls and a reinforced concrete roof. Access covers should be left in the roof to allow access for desludging. The last compartment may be filled with stone and operate as an upward flow anaerobic filter. BORDA provide a design for a tank with dimensions of about 10 metres by 2.5 metres by 2 metres deep, designed for a design flow of 25^3m /day. This would typically serve a population of 250-400, depending on the average per-capita water consumption. BORDA also report performance in the range range 65-90% COD removal (70-95% BOD removal).

More information http://www.nu.ac.za/abr/ gives information on the use of baffled reactors in low-income communities in South Africa. For information on systems in Vietnam, see ttp://www.sandec.ch/Wastewater/Documents/VietAnh_Morel_Luebeck_2003.pdf. A general introduction to anaerobic treatment methods, including baffled reactors is available at **http://www2.gtz.de/ecosan/download/Bangalore03-Kraemer.PDF**. Note that this is a rather large file (2.4Mb)

UPFLOW ANAEROBIC FILTER

What is it? An anaerobic filter is similar in layout to a baffled reactor and operates in a similar way. An initial settling chamber, with the same dimensions as a standard septic tank chamber, is followed by a number of narrow compartments. As with the baffled reactor, the flow passes over a weir at the downstream end of the first chamber and is then directed to the bottom of the next chamber. This chamber and those that follow it are filled with filter material so that they act as filters to the anaerobic wastewater that passes up through them. This allows the treatment of non-settleable and dissolved solids.

When to use it? Anaerobic filters can be used in similar circumstances to baffled reactors. Indeed some designs are hybrid designs, incorporating perhaps three baffled upflow compartments followed by one compartment containing filter media. Like baffled reactors upflow anaerobic filters have mainly been used for small, local installations.

Advantages As with septic tanks and baffled reactors, the advantage of upflow anaerobic filters lies in their simplicity. Like baffled reactors, they can be net providers rather than users of energy.

Disadvantages The disadvantages of upflow anaerobic filters are the same as those of other anaerobic systems. They take several months to reach full treatment efficiency and are susceptible to variations in both flow and load. They do not greatly reduce pathogens and are unlikely to reduce oxygen demand by more than about 85%, which may sometimes leave the effluent BOD or COD above that allowed in national discharge standards.

Technical features and requirements Anaerobic filters may be operated as up flow or down flow systems. The former are normally preferred because they have a lower risk of washing out active bacteria. The filter material may be cinder (5 – 15cm in diameter) or stones (5 – 10cm in diameter). The more irregular the filter media, the better. Organic load limits are typically in the range 4 – 5 kg COD/m^3/day. In theory, the anaerobic filters should be backwashed from time to time or the filter media should be washed but it seems that this is rarely done in practice, despite which filters continue to produce reasonable results

More information For information on how an upward-flow anaerobic filter can be combined with aerobic treatment methods to produce a high quality effluent, see http://www.ci.austin.tx.us/wri/treat12.htm. (This system uses trickling filters for secondary treatment but constructed wetlands or ponds could also be used). Some of the references already given for other anaerobic systems also include information on anaerobic filters.

ANAEROBIC WASTE STABILISATION PONDS

What is it? Anaerobic waste stabilisation ponds are open anaerobic reactors. Solids settle to the bottom of the pond, where they are digested anaerobically. Anaerobic digestion is a two stage process involving two sets of anaerobic bacteria. Complex organics are initially broken down into volatile organic compounds and methanagic bacteria further break these down into carbon dioxide and gas.

When to use it? Use anaerobic ponds either to reduce the strength of an effluent prior to secondary treatment in facultative and maturation ponds or as a means of providing primary treatment, perhaps as a first stage in moving towards full treatment of sewage. Because they are open, anaerobic ponds will smell and they should therefore not be located close to houses. Some authorities suggest a minimum distance of 1000 metres from the nearest house but a separation of 500 metres and even less may be appropriate.

Advantages Anaerobic waste stabilisation ponds are simple to both construct and operate. They are relatively inexpensive and can be used on a larger scale than baffled reactors and upward flow anaerobic filters.

Disadvantages As with other anaerobic treatment options, anaerobic ponds take time to reach full treatment efficiency. The restrictions on location near to houses and the requirement for a minimum depth of at least 3 metres means that they may be more appropriate for use in larger schemes.

Technical features and requirements Ponds are normally rectangular basins, ideally with a length to with ratio of about 3 to 1. The depth should be at least 3 metres and ideally 4 metres. The sides are normally sloped at 1:2 internally and 1:3 externally, with the inner slope lined with concrete or bricks. Provision must be made for periodic desludging. This may take the form of a ramp, down which a vehicle or animal-drawn cart can be backed once the pond has been dewatered. Another option is to provide a float-mounted sludge pump that can periodically pump sludge into a drying bed. A well-designed pond may achieve up to about 60% BOD/COD removal in warm conditions. Hydraulic retention time should not exceed 2 days and may be one day for temperatures higher than 20^{o}C and BOD of up to 300 mg/l.

More information See http://www.irc.nl/page/8237 for a general introduction to WSPs, including anaerobic ponds. Other general introductions to WSPs include Arthur, J.P; *Notes on the Design and Operation of Waste Stabilisation Ponds in Warm Climates of Developing Countries,* World Bank Technical Paper 7, and Mara, D.D., Alabaster, G.P., Pearson, H.W. and Mills, S.W. (1992). *Waste Stabilization Ponds: A Design Manual for Eastern Africa.* Lagoon Technology International. Leeds, England. See http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/theses/penavaron/penavaron.html for more specific information on high-rate anaerobic ponds.

UPWARD FLOW ANAEROBIC SLUDGE BLANKET REACTOR (UASB)

What is it? The UASB is basically a rectangular tank, similar to a septic tank but deeper, phase separators - sloping plates that act to separate gas from liquid. Sludge collects and digests in the lower part of the tank while gas is collected and released at the top of the reactor. The key operational feature of the UASB is the sludge blanket – the layer of active sludge that is maintained in the lower part of the UASB, below the phase separators. Wastewater has to pass through this layer and is treated as it passes through.

When to use it? UASBs should only be considered for larger schemes, serving whole districts and/or small towns rather than individual neighbourhoods. Consider their use if land is in short supply, power is expensive or unreliable and suitable management systems can be identified.

Advantages UASBs have the same advantages as the other anaerobic technologies mentioned earlier. They can be used on a fairly large scale and are thus suitable for district/zone and town level schemes.

Disadvantages UASBs suffer from the disadvantages already identified for other anaerobic treatment methods – slow start-up time and, to a greater extent than other treatment methods, susceptibility to changes in flow, which destabilise the sludge blanket. There is some evidence, from schemes in India, that corrosion of system components, particularly the phase separators can shorten the life of facilities and lead to poor performance.

Technical features and requirements Hydraulic retention time at peak flow should normally be about 6 hours for tropical and sub-tropical regions. This needs to be increased to 12-14 hours for temperatures of 10-12 degrees centigrade. For reactor volumes exceeding approximately 1000 cubic metres, it is beneficial to build systems consisting of more than one unit. Reactors can be circular in plan but this is only economic when there is only one unit.

More information For general introductions to UASBs see http://www.uasb.org/ and http://www.waterandwastewater.com/www_services/ask_tom_archive/methods_for_uasb_reactor_design.htm

AEROBIC TREATMENT OPTIONS

Facultative and maturation waste stabilisation ponds

What are they? Facultative ponds are large shallow ponds that retain sewage and allow treatment by a combination of aerobic and anaerobic processes. Treatment takes place as a result of a combination of physical and biological processes, which can be quite complex. Maturation ponds are smaller ponds that are placed in series following facultative ponds. They can plan an important role in reducing pathogen concentrations to safe levels.

When to use them Consider using waste stabilisation ponds when land is available, there is a need to achieve a good reduction in pathogen levels and there is a probability that the sewage inflow will occasionally include large quantities of stormwater run-off. Land take can be reduced by about a third by providing anaerobic WSPs ahead of the facultative ponds.

Advantages Waste stabilisation ponds are simple and their long retention time means that they are robust and can deal with fluctuations in . A WSP system with a retention time of at least 22 days is the only treatment system considered by WHO to achieve the effluent standard required for unrestricted irrigation.

Disadvantages The obvious disadvantage of WSPs is their high land take, which varies depending on sewage strength and temperature but is likely to be in the range 3 – 5m^2 per person. Their high land take means that they are unlikely to be a viable option where land is either expensive or in short supply.

Technical features and requirements Facultative ponds are normally between 1.5 and 1.8 metres deep. Most are rectangular in shape although this is not essential, provided that the ratio of length to breadth is greater than about 2:1. The sides normally slope and the base and sides of ponds do not have to be lined, other than providing lining for about half a meter above and below the pond water level to prevent erosion due to wave action. The inlet and outlet arrangements can be simple although the outlet should incorporate a baffle at top water level to prevent loss of floating solids.

More information The first three references already given in the page on anaerobic WSPs provide information on facultative and maturation ponds. Web-based design guides for India and the Mediterranean region are available at two Leeds University web sites - http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/india.html And http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/med/medman.html. Each can be used for regions with similar climatic conditions to those in the region that it covers.

CONSTRUCTED WETLANDS

What are they? Constructed wetlands are artificial reed beds through which wastewater is allowed to flow under gravity. Phragmites reeds are commonly used but other plants, including bulrushes and cattails, are also used. Purification takes place through a variety of natural chemical, physical and biological processes, including sedimentation, precipitation, adsorbation, assimilation from the plants and microbic activity. Flow may be either horizontal or vertical and, in the case of horizontal flow wetlands, may be either above or below the surface. Most constructed wetlands in developing countries are of the horizontal sub-surface flow type. Above-surface designs are generally avoided because they create problems with mosquitoes.

When to use them? Consider the use of constructed wetlands when there is a need for a better quality effluent than can be achieved by purely anaerobic treatment. Constructed wetlands need land, typically 3 -5 m^2 per person if the constructed wetland is to treat a full-strength sewage. For this reason, it will often be better to use them as a secondary treatment option after primary anaerobic treatment.

Advantages Constructed wetlands are a relatively simple technology, with limited maintenance needs. They can achieve good BOD/COD reduction and can remove some pathogens. .

Disadvantages Their relatively high land take means that constructed wetlands can only be used when land is available. They are more complicated than WSPs and so have greater management requirements. Given the siConstructed wetlands have similar land requirements to waste stabilisation ponds .

Technical features and requirements Horizontal flow beds are normally constructed using a gravel medium, into which the reeds are planted. Wastewater has to be pre-treated to remove gross solids and is then introduced at one end of the filter and allowed to flow to the other end. To prevent percolation of wastewater into the ground, the bottom of the filter should be sealed. The gravel should normally be round and uniform, preferably with diameters in the range 8 - 16mm. Filters do become clogged over time and can be partially unclogged by resting them for several months. This, of course, has consequences for the amount of land required for the filter.

More information To access an introduction to constructed wetlands, giving links to individual chapters, go to http://www.wetlands.org/pubs&/ConstructedWetlands.htm.

DUCKWEED PONDS AND OTHER AQUATIC PLANT SYSTEMS

What are they? Duckweeds, known botanically as lemnaceae , are a family of small plants that float in still or slow-moving water in all but the coldest regions in the World. Duckweed. Their growth is very rapid. *Lemna sp..* the most common form of duckweed, can double in frond numbers and therefore in area covered in four days and it is believed that duckweed can grow 30% faster than water hyacinth, another aquatic plant that can be used in wastewater treatment. Treatment with duckweed is simple. Duckweed plants are introduced into shallow ponds, similar to facultative waste stabilisation ponds, through which the wastewater to be treated passes. As the duckweed grows, it is harvested and can be used to feed either fish or poultry.

When to use them? Duckweed systems require as much land as waste stabilisation ponds. This means that they should only be considered where land is available and there is realistic hope that the duckweed produced can be put to some commercial use. In practice, there are likely to be relatively few conditions in which these conditions will be met.

Advantages The main advantage of duckweed systems over simple waste stabilisation pond systems lies in their production of duckweed, which has an economic value. This advantage will only be realised if systems are in place to harvest and reuse the duckweed.

Disadvantages Like waste stabilisation pond systems, duckweed systems require a large amount of land. Insect breeding is likely to become a problem if they are not properly managed.

Techical features and requirements The United States Environmental Protection Agency states that duckweed ponds can be designed using the conventional design procedures for facultative ponds. In a well-managed plant, performance in respect of the removal of BOD_{5},, SS, and nitrogen should exceed that of a facultative pond. Duckweed production from nutrient-rich wastewater may be in the range 10-40 tonnes of dry matter/year. Growth may be adversely affected by very high and/or very low temperatures and by high light intensity. The latter point suggests that ponds function best when located in shaded areas. Duckweed is difficult to dry and decomposes rapidly once harvested. So, the full economic benefits of duckweed production will only be realised if adequate management arrangements are in place.

More information http://www.epa.gov/owow/wetlands/pdf/design.pdf, page 49 onwards, contains more information on duckweed systems in the context of the United States.

MANAGEMENT OPTIONS FOR WASTEWATER IRRIGATION

While treatment of wastewater prior to its use in irrigation is always desirable, it will often be difficult to provide the level of treatment required by the WHO Guidelines. (22 days in a WSP system for unrestricted irrigation and around 11 days retention in a WSP system or equivalent for restricted irrigation). This page provides brief notes on some of the other management options that can be used, either as stand-alone measures or, more beneficially, in conjunction with other management measures.

Wastewater application methods Contamination of crops and risks to farm workers vary depending on the method used to apply irrigation water. The most hazardous option is spray irrigation, followed by general inundation of the area to be irrigated. Ridge and furrow irrigation reduces risks to some extent but the best irrigation option from a health point of view is drip irrigation from pipes laid along the ground. Drip irrigation is also advantageous in that it minimises the amount of irrigation water required.

Drip irrigation systems discharge water through small holes and this means that they will only be viable if pre-treatment is provided to remove solids. This pre-treatment might be by septic tanks or simple pond systems.

Irrigation timing Health risks to users can be reduced by stopping irrigation two weeks before crops are harvested. However, this option does not protect the health of farm workers.

Choice of crops The dangers to consumers will be negligible if wastewater is only used to irrigate crops that are cooked before eating. However, this will not reduce the risks to farm workers. In practice, it may be difficult to persuade farmers to forego high value salad crops.

Use of protective clothing In theory, health risks to workers will be reduced if they are issues with and use protective clothing such as rubber gloves and waterproof shoes. In practice, workers may be reluctant to use protective clothing, because it is hot and restricts their movement.

Further information A good general discussion of the options for wastewater use is available at http://web.idrc.ca/es/ev-68345-201-1-DO_TOPIC.html. This is one chapter in a book on irrigated agriculture that is available on line. Go to http://web.idrc.ca/es/ev-31595-201-1-DO_TOPIC.html to see the chapter headings and gain access for the whole book.