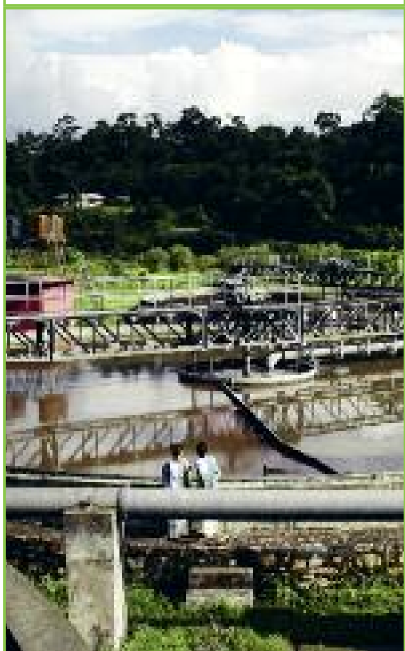
(Semi-) Centralized Treatment

T

This section describes the technologies that can be used for the treatment of faecal sludge and blackwater. These treatment technologies are designed to accommodate increased volumes of flow and provide, in most cases, improved removal of nutrients, organics and pathogens than household-centered storage technologies.



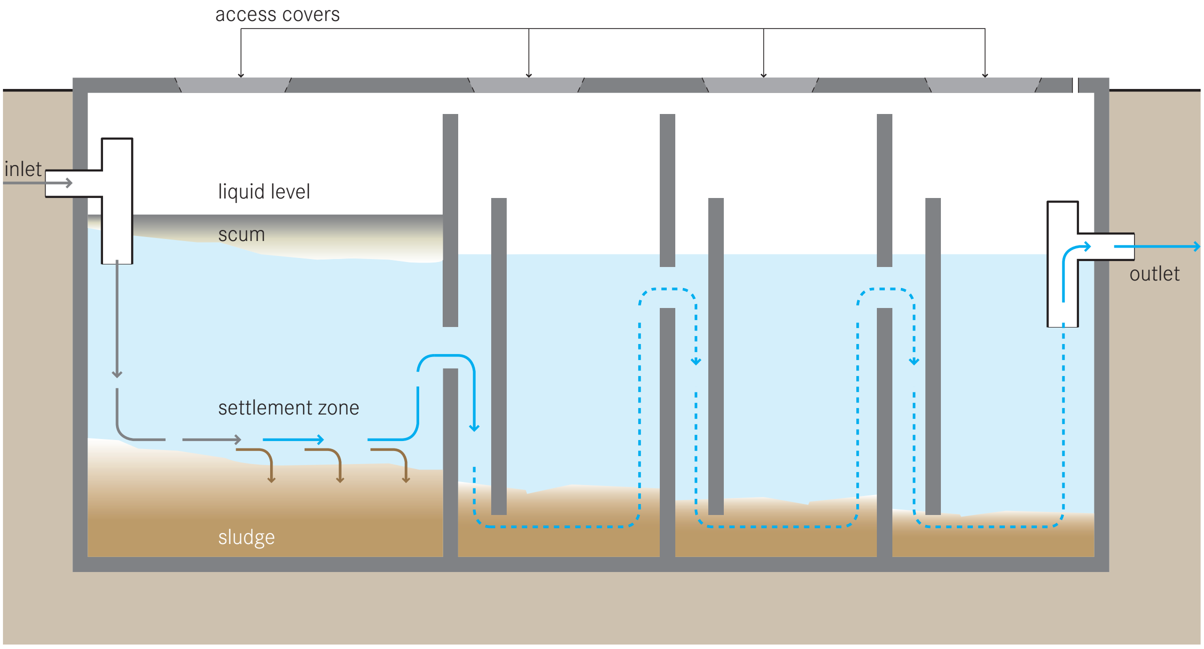
T

T.1 Anaerobic Baffled Reactor (ABR)

Applicable to: **System 7**

T.1

Application Level	Management Level	
★★ Household	★★ Household	**Inputs:** Blackwater, Greywater
★★ Neighbourhood	★★ Shared	
City	★★ Public	**Outputs:** Faecal Sludge, Effluent



An Anaerobic Baffled Reactor (ABR) is an improved septic tank because of the series of baffles over which the incoming wastewater is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment.

The majority of settleable solids are removed in the sedimentation chamber at the beginning of the ABR, which typically represents 50% of the total volume. The up-flow chambers provide additional removal and digestion of organic matter: BOD may be reduced by up to 90%, which is far superior to that of a conventional septic tank. As sludge is accumulating, desludging is required every 2 to 3 years. Critical design parameters include a hydraulic retention time (HRT) between 48 to 72 hours, up-flow velocity of the wastewater less than 0.6 m/h and the number of up-flow chambers (2 to 3).

Adequacy This technology is easily adaptable and can be applied at the household level or for a small neighbourhood (refer to Technology Information Sheet S10: Anaerobic Baffled Reactor for information about applying an ABR at the household level).

A (semi-) centralized ABR is appropriate when there is an already existing Conveyance technology, such as a Solids-Free Sewer (C5). This technology is also appropriate for areas where land may be limited since the tank is installed underground and requires a small area. It should not be installed where there is a high groundwater table as infiltration will affect the treatment efficiency and contaminate the groundwater.
This technology can be efficiently designed for a daily inflow of up to 200,000 L/day. The ABR will not operate at full capacity for several months after installation because of the long start up time required for the anaerobic digestion of the sludge. Therefore, the ABR technology should not be used when the need for a treatment system is immediate.
Because the ABR must be emptied regularly, a vacuum truck should be able to access the location.
ABRs can be installed in every type of climate although the efficiency will be affected in colder climates.

Health Aspects/Acceptance Although the removal of pathogens is not high, the ABR is contained so users do not come in contact with any of the wastewater or disease causing pathogens. Effluent and sludge

must be handled with care as they contain high levels of pathogenic organisms.
To prevent the release of potentially harmful gases, the tank should be vented.

Maintenance ABR tanks should be checked to ensure that they are watertight and the levels of the scum and sludge should be monitored to ensure that the tank is functioning well. Because of the delicate ecology, care should be taken not to discharge harsh chemicals into the ABR.
The sludge should be removed annually using a vacuum truck to ensure proper functioning of the ABR.

Pros & Cons:

+ Resistant to organic and hydraulic shock loads
+ No electrical energy required
+ Greywater can be managed concurrently
+ Can be built and repaired with locally available materials
+ Long service life
+ No real problems with flies or odours if used correctly
+ High reduction of organics
+ Moderate capital costs, moderate operating costs depending on emptying; can be low cost depending on number of users
- Requires constant source of water
- Effluent requires secondary treatment and/or appropriate discharge
- Low reduction pathogens
- Requires expert design and construction
- Pre-treatment is required to prevent clogging

References

_ Bachmann, A., Beard, VL. and McCarty, PL. (1985). Performance Characteristics of the Anaerobic Baffled Reactor. *Water Research* 19 (1): 99–106.

_ Foxon, KM., et al. (2004). The anaerobic baffled reactor (ABR): An appropriate technology for on-site sanitation. *Water SA* 30 (5) (Special edition). Available: www.wrc.org.za

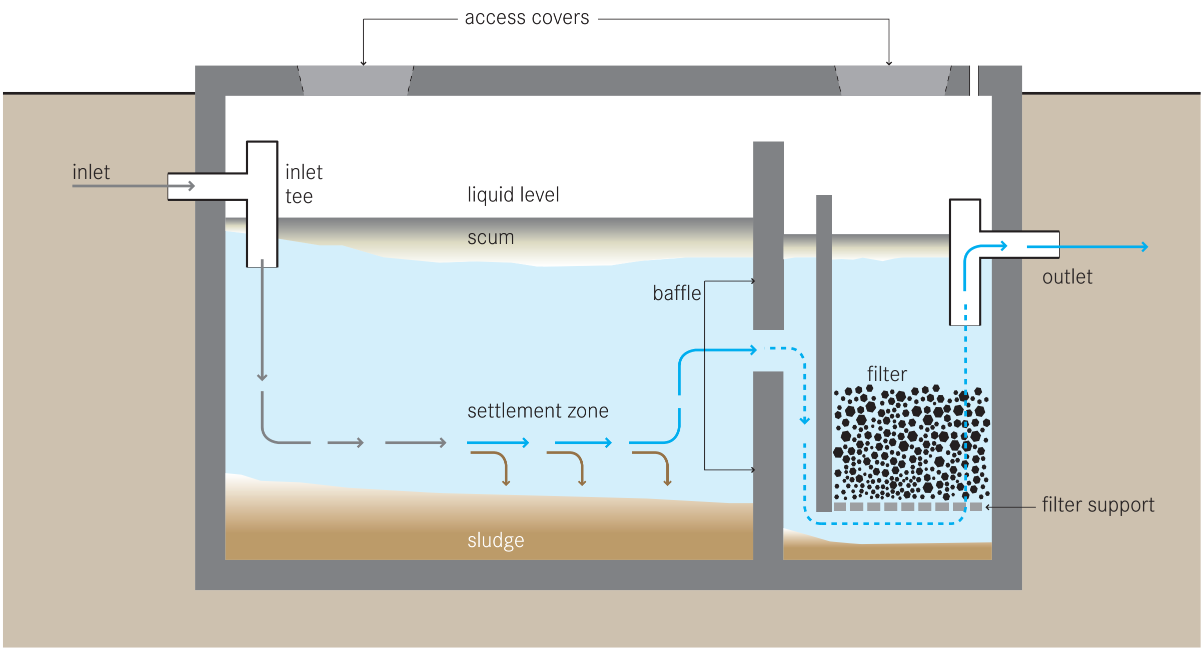
_ Sasse, L. (1998). *DEWATS: Decentralised Wastewater Treatment in Developing Countries.* BORDA, Bremen Overseas Research and Development Association, Bremen, Germany. (Design summary including and Excel®-based design program.)

T.2 Anaerobic Filter

Applicable to: **System 7**

T.2

Application Level	**Management Level**	**Inputs:** Blackwater, Greywater **Outputs:** Faecal Sludge, Effluent
★★ Household	★★ Household	
★★ Neighbourhood	★★ Shared	
City	★★ Public	



An Anaerobic Filter is a fixed-bed biological reactor. As wastewater flows through the filter, particles are trapped and organic matter is degraded by the biomass that is attached to the filter material.

This technology consists of a sedimentation tank or septic tank (refer to Technology Information Sheet S9: Septic Tank) followed by one to three filter chambers. Filter material commonly used includes gravel, crushed rocks, cinder, or specially formed plastic pieces. Typical filter material sizes range from 12 to 55 mm in diameter. Ideally, the material will provide between 90 to 300 m^2 of surface area per 1 m^3 of reactor volume. By providing a large surface area for the bacterial mass, there is increased contact between the organic matter and the active biomass that effectively degrades it.
The Anaerobic Filter can be operated in either upflow or downflow mode. The upflow mode is recommended because there is less risk that the fixed biomass will be washed out. The water level should cover the filter media by at least 0.3 m to guarantee an even flow regime. Pre-treatment is essential to remove settleable solids and garbage which may clog the filter.

Studies have shown that the HRT is the most important design parameter influencing filter performance. An HRT of 0.5 to 1.5 days is a typical and recommended. A maximum surface-loading (i.e. flow per area) rate of 2.8 m/d has proven to be suitable. Suspended solids and BOD removal can be as high as 85% to 90% but is typically between 50% and 80%. Nitrogen removal is limited and normally does not exceed 15% in terms of total nitrogen (TN).

Adequacy This technology is easily adaptable and can be applied at the household level or a small neighbourhood (refer to Technology Information Sheet S11: Anaerobic Filter for information about applying an Anaerobic Filter at the household level).
An Anaerobic Filter can be designed for a single house or a group of houses that are using a lot of water for clothes washing, showering, and toilet flushing. It is only appropriate if water use is high ensuring that the supply of wastewater is constant.
The Anaerobic Filter will not operate at full capacity for six to nine months after installation because of the long start up time required for the anaerobic biomass to stabilize. Therefore, the Anaerobic Filter technology should

not be used when the need for a treatment system is immediate. Once working at full capacity it is a stable technology that requires little attention.
The Anaerobic Filter should be watertight but it should still not be constructed in areas with high groundwater tables or where there is frequent flooding.
Depending on land availability and the hydraulic gradient of the sewer, the Anaerobic Filter can be built above or below ground. It can be installed in every type of climate, although the efficiency will be affected in colder climates.

Health Aspects/Acceptance Because the Anaerobic Filter is underground, users should not come in contact with the influent or effluent. Infectious organisms are not sufficiently removed, so the effluent should be further treated or discharged properly. The effluent, despite treatment, will still have a strong odour and care should be taken to design and locate the facility such that odours do not bother community members.
To prevent the release of potentially harmful gases, the Anaerobic Filters should be vented.
The desludging of the filter is hazardous and appropriate safety precautions should be taken.

Maintenance Active bacteria must be added to start up the Anaerobic Filter. The active bacteria can come from sludge from a septic tank that has been sprayed onto the filter material. The flow should be gradually increased over time, and the filter should be working at maximum capacity within six to nine months.
With time, the solids will clog the pores of the filter. As well, the growing bacterial mass will become too thick and will break off and clog pores. A sedimentation tank before the filter is required to prevent the majority of settleable solids from entering the unit. Some clogging increases the ability of the filter to retain solids. When the efficiency of the filter decreases, it must be cleaned. Running the system in reverse mode to dislodge accumulated biomass and particles cleans the filters. Alternatively, the filter material can be removed and cleaned.

Pros & Cons:

+ Resistant to organic and hydraulic shock loads
+ No electrical energy required
+ Can be built and repaired with locally available materials
+ Long service life
+ No real problems with flies or odours if used correctly
+ Moderate capital costs, moderate operating costs depending on emptying; can be lowered depending on the number of users
+ High reduction of BOD and solids
- Requires constant source of water
- Effluent requires secondary treatment and/or appropriate discharge
- Low reduction pathogens and nutrients
- Requires expert design and construction
- Long start up time

References

_ Morel, A. and Diener, S. (2006). *Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighbourhoods.* Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland.
(Short summary including case studies, page 28.)

_ Polprasert, C. and Rajput, V.S. (1982). *Environmental Sanitation Reviews: Septic Tank and Septic Systems.* Environmental Sanitation Information Center, AIT, Bangkok, Thailand. pp 68–74. (Short design summary.)

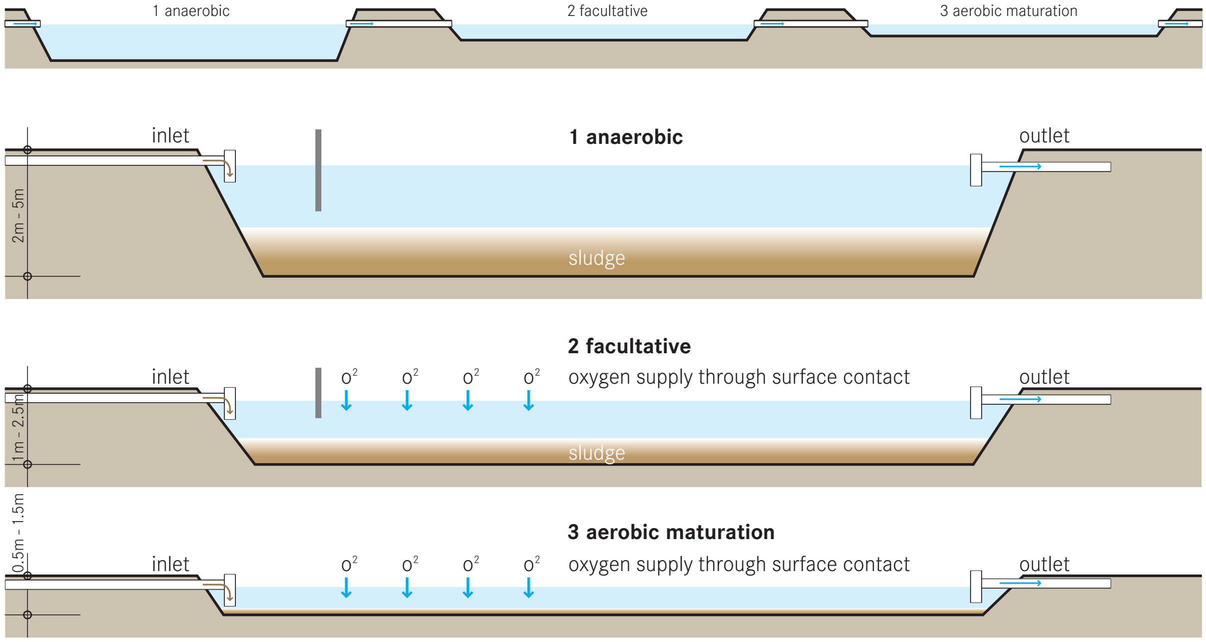
_ Sasse, L. (1998). *DEWATS: Decentralised Wastewater Treatment in Developing Countries.* BORDA, Bremen Overseas Research and Development Association, Bremen, Germany.
(Design summary including Excel-based design program.)

_ von Sperlin, M. and de Lemos Chernicharo, C.A. (2005). *Biological Wastewater Treatment in Warm Climate Regions. Volume One*. IWA, London. pp 728–804.
(Detailed design instructions.)

_ Vigneswaran, S., et al. (1986). *Environmental Sanitation Reviews: Anaerobic Wastewater Treatment-Attached growth and sludge blanket process.* Environmental Sanitation Information Center, AIT, Bangkok, Thailand.
(Design criteria and diagrams in Chapter 2.)

T.3	**Waste Stabilization Ponds (WSP)**	Applicable to: **System 1, 5, 6, 7, 8**	T.3

Application Level	**Management Level**	
☐ Household	☐ Household	**Inputs:** Blackwater, Greywater
☐★ Neighbourhood	☐★ Shared	
☐★★ City	☐★★ Public	**Outputs:** Faecal Sludge, Effluent



Waste Stabilization Ponds (WSPs) are large, man-made water bodies. The ponds are filled with waste-water that is then treated by naturally occurring processes. The ponds can be used individually, or linked in a series for improved treatment. There are three types of ponds, (1) anaerobic, (2) facultative and (3) aerobic (maturation), each with different treatment and design characteristics.

For the most effective treatment, WSPs should be linked in a series of three of more with effluent being transferred from the anaerobic pond to the facultative pond and finally the aerobic pond. The anaerobic pond reduces solids and BOD as a pre-treatment stage. The pond is a fairly deep man-made lake where the entire depth of the pond is anaerobic. Anaerobic ponds are built to a depth of 2 to 5 m and have a relatively short detention time of 1 to 7 days. The actual design will de-pend on the wastewater characteristics and the loading; a comprehensive design manual should be consulted for all types of WSPs. Anaerobic bacteria convert organ-ic carbon into methane and in the process, remove up to 60% of the BOD. Anaerobic ponds are capable of treating strong wastewaters.

In a series of WSPs the effluent from the anaerobic pond is transferred to the facultative pond, where further BOD is removed. A facultative pond is shallower than an anaer-obic pond and both aerobic and anaerobic processes occur within the pond. The top layer of the pond receives oxygen from natural diffusion, wind mixing and algae-driven photosynthesis. The lower layer is deprived of oxy-gen and becomes anoxic or anaerobic. Settleable solids accumulate and are digested on the bottom of the pond. The aerobic and anaerobic organisms work together to achieve BOD reductions of up to 75%. The pond should be constructed to a depth of 1 to 2.5 m and have a deten-tion time between 5 to 30 days.
Following the anaerobic and the facultative ponds can be any number of aerobic (maturation) ponds to achieve a highly polished effluent. An aerobic pond is commonly referred to as a maturation, polishing, or finishing pond because it is usually the last step in a series of ponds and provides the final level of treatment. It is the shallowest of the ponds, usually constructed to a depth between 0.5 to 1.5 m deep to ensure that the sunlight penetrates the full depth for photosynthesis. Because photosynthesis is driven by sunlight, the dissolved oxygen levels are high-est during the day and drop off at night. Whereas anaer-

obic and facultative ponds are designed for BOD removal, maturation ponds are designed for pathogen removal. Dissolved oxygen in the lake is provided by natural wind mixing and by photosynthetic algae that release oxygen into the water. If used in combination with algae and/or fish harvesting, this type of pond is effective at removing the majority of nitrogen and phosphorus from the effluent.

To prevent leaching, the ponds should have a liner. The liner can be clay, asphalt, compacted earth, or another impervious material. To protect the pond from runoff and erosion, a protective berm should be constructed around the pond using the excavated material.

Adequacy WSPs are among the most common and efficient methods of wastewater treatment around the world. They are especially appropriate for rural communities that have large, open unused lands, away from homes and public spaces. They are not appropriate for very dense or urban areas.

WSPs work in most climates, but are most efficient in warm, sunny climates. In the case of cold climates, the retention times and loading rates can be adjusted so that efficient treatment can be achieved.

Health Aspects/Acceptance Although effluent from aerobic ponds is generally low in pathogens, the ponds should in no way be used for recreation or as a direct source of water for consumption or domestic use.

Upgrading Ideally, several aerobic ponds can be built in series to provide a high level of pathogen removal. A final aquaculture pond can be used to generate income and supply a locally grown food source.

Maintenance To prevent scum formation, excess solids and garbage from entering the ponds, pre-treatment (with grease traps) is essential to maintain the ponds. The pond must be desludged once every 10 to 20 years. A fence should be installed to ensure that people and animals stay out of the area and excess garbage does not enter the ponds. Rodents may invade the berm and cause damage to the liner. Raising the water level should prompt rodents to evacuate the berm.

Care should be taken to ensure that plant material does not fall into the ponds. Vegetation or macrophytes that are present in the pond should be removed as it may provide a breeding habitat for mosquitoes and prevent light from penetrating the water column.

Pros & Cons:

+ High reduction in pathogens
+ Can be built and repaired with locally available materials
+ Construction can provide short-term employment to local labourers
+ Low operating cost
+ No electrical energy required
+ No real problems with flies or odours if designed correctly
- Requires expert design and supervision
- Variable capital cost depending on the price of land
- Requires large land area
- Effluent/sludge requires secondary treatment and/or appropriate discharge

References

_ Arthur, J.P. (1983). *Notes on the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries.* The World Bank+ UNDP, Washington.

_ Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems.* WCB and McGraw-Hill, New York, USA.

_ Mara, D.D. and Pearson, H. (1998). *Design Manual for Waste Stabilization Ponds in Mediterranean Countries.* Lagoon Technology International Ltd., Leeds, England.

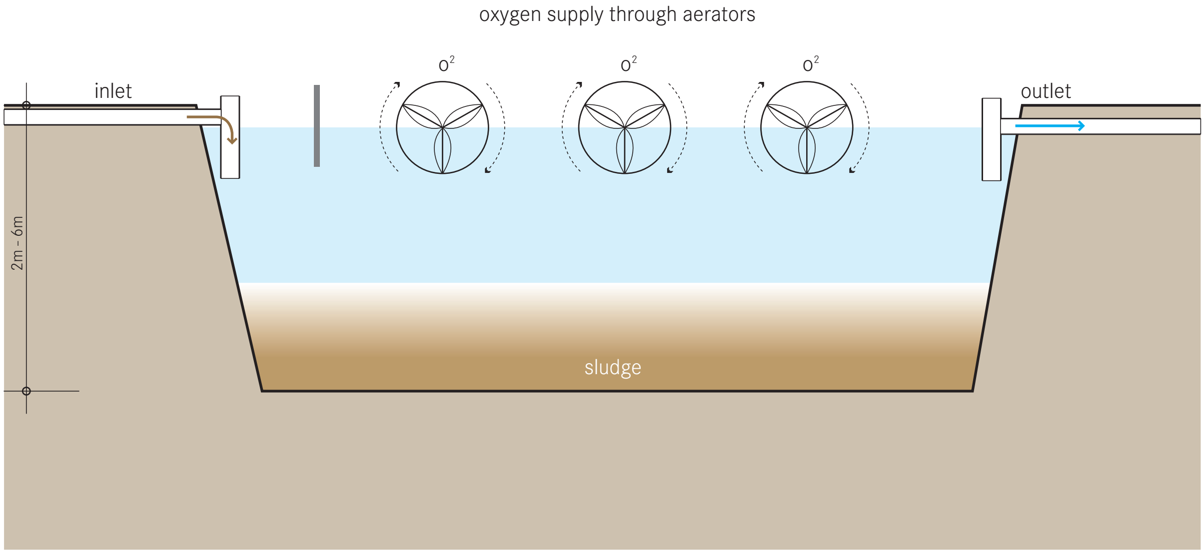
_ Mara, D.D. (1997). *Design Manual for Waste Stabilization Ponds in India.* Lagoon Technology International Ltd., Leeds, England.

_ Sasse, L. (1998). *DEWATS: Decentralised Wastewater Treatment in Developing Countries.* BORDA, Bremen Overseas Research and Development Association, Bremen, Germany.
(Detailed description and Excel ® Spreadsheet codes for design.)

_ von Sperlin, M. and de Lemos Chernicharo, C.A. (2005). *Biological Wastewater Treatment in Warm Climate Regions. Volume One.* IWA, London. pp 495–656.

T.4	Aerated Pond	Applicable to: **System 1, 5, 6, 7, 8**

Application Level	**Management Level**	**Inputs:** Blackwater, Greywater
Household	Household	
★ Neighbourhood	★ Shared	
★★ City	★★ Public	**Outputs:** Faecal Sludge, Effluent



An Aerated Pond is a large, outdoor, mixed aerobic reactor. Mechanical aerators provide oxygen and keep the aerobic organisms suspended and mixed with the water to achieve a high rate of organic degradation and nutrient removal.

Increased mixing and aeration from the mechanical units means that the ponds can be deeper and can tolerate much higher organic loads than a maturation pond. The increased aeration allows for increased degradation and increased pathogen removal. As well, because oxygen is introduced by the mechanical units and not by light-driven photosynthesis, the ponds can function in more northern climates. Influent should be screened and pre-treated to remove garbage and coarse particles that could interfere with the aerators.
Because the aeration units mix the pond, a subsequent settling tank is required to separate the effluent from the solids.
The smaller area requirement (compared to a maturation pond) means that it is appropriate for both rural, and peri-urban environments.
The pond should be built to a depth of 2 to 5 m and should have a detention time of 3 to 20 days.

To prevent leaching, the pond should have a liner. The liner can be clay, asphalt, compacted earth, or another impervious material. Using the fill that is excavated, a protective berm should be built around the pond to protect it from runoff and erosion.

Adequacy A mechanically aerated pond can efficiently handle high concentration influent and can reduce pathogen levels significantly. It is especially important that electricity service is uninterrupted and that replacement parts are available to prevent extended downtimes that may cause the pond to turn anaerobic.
Aerated lagoons can function in a larger range of climates than WSPs. They are most appropriate for regions with large areas of inexpensive lands that are away from homes and businesses.

Health Aspects/Acceptance The pond is a large expanse of pathogenic wastewater; care must be taken to ensure that no one comes in contact with, or goes into the water.
The aeration units can be dangerous to humans and animals. Fences, signage, or other measures should be taken to prevent entry to the area.

Maintenance A permanent skilled staff is required to repair and maintain aeration machinery. The pond must be desludged once every 2 to 5 years.
Care should be taken to ensure that the pond is not used as a garbage dump, especially considering the damage that could be done to the aeration equipment.

Pros & Cons:

+ Good resistance against shock loading
+ High reduction in pathogens
+ Construction can provide short-term employment to local labourers
+ Requires large land area
+ No real problems with insects or odours if designed correctly
- Effluent/sludge requires secondary treatment and/or appropriate discharge
- Requires expert design and construction supervision
- Requires full time operation and maintenance by skilled personnel
- Not all parts and materials may be available locally
- Constant source of electricity is required
- Moderate-high capital and variable operating costs depending on the price of land, electricity

References

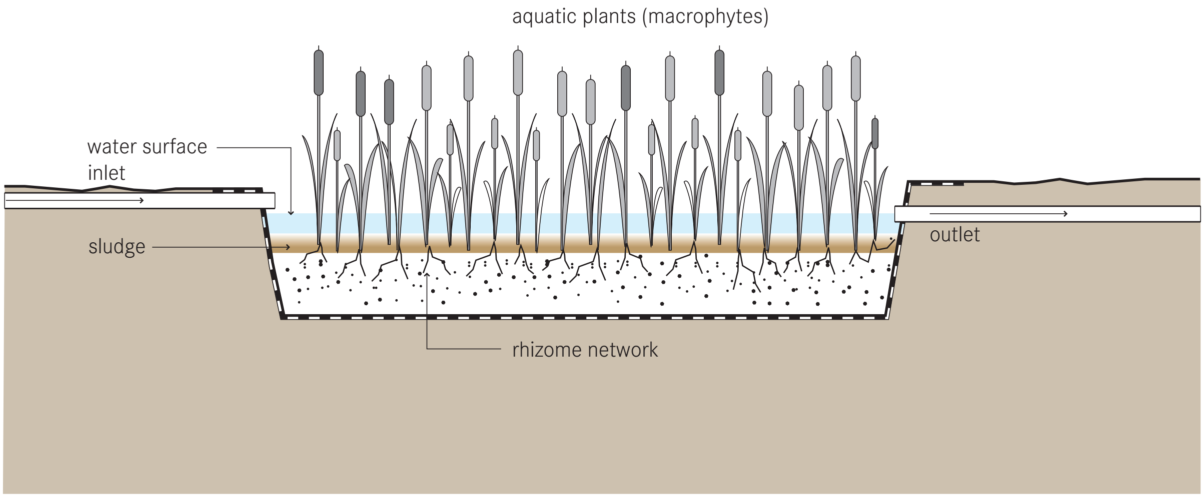
_ Arthur, JP. (1983). *Notes on the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries.* The World Bank + UNDP, Washington.
(Notes on applicability and effectiveness.)

_ Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems.*
WCB and McGraw-Hill, New York, USA. pp 527–558.
(Comprehensive summary chapter.)

_ Tchobanoglous, G., Burton, FL. and Stensel, HD. (2003).
Wastewater Engineering: Treatment and Reuse, 4th Edition.
Metcalf & Eddy, New York. pp 840–85.
(Detailed design and example problems.)

T.5	Free-Water Surface Constructed Wetland	Applicable to: System 1, 5, 6, 7, 8

Application Level	Management Level	Inputs / Outputs
★ Household	★ Household	**Inputs:** Blackwater, Greywater
★★ Neighbourhood	★★ Shared	
★★ City	★★ Public	**Outputs:** Effluent



A Free-Water Surface Constructed Wetland is a series of flooded channels that aims to replicate the naturally occurring processes of a natural wetland, marsh or swamp. As water slowly flows through the wetland, particles settle, pathogens are destroyed, and organisms and plants utilize the nutrients.

Unlike The Horizontal Subsurface Flow Constructed Wetland (T6), the Free-Water Surface Constructed Wetland allows water to flow above ground, exposed to the atmosphere and direct sunlight. The channel or basin is lined with an impermeable barrier (clay or geo-textile) covered with rocks, gravel and soil and planted with native vegetation (e.g. cattails, reeds and/or rushes). The wetland is flooded with wastewater to a depth of 10 to 45 cm above ground level. As the water slowly flows through the wetland, simultaneous physical, chemical and biological processes filter solids, degrade organics and remove nutrients from the wastewater.

Raw blackwater should be pretreated to prevent the excess accumulation of solids and garbage. Once in the pond, the heavier sediment particles settle out, also removing nutrients that are attached to particles. Plants, and the communities of microorganisms that they support (on the stems and roots), take up nutrients like nitrogen and phosphorus. Chemical reactions may cause other elements to precipitate out of the wastewater. Pathogens are removed from the water by natural decay, predation from higher organisms, sedimentation and UV irradiation.

Although the soil layer below the water is anaerobic, the plant roots exude (release) oxygen into the area immediately surrounding the root hairs, thus creating an environment for complex biological and chemical activity.

The efficiency of the Free-Water Surface Constructed Wetland also depends on how well the water is distributed at the inlet. Wastewater can be input to the wetland using weirs or by drilling holes in a distribution pipe to allow it to enter in even spaced intervals.

Adequacy Free-Water Surface Constructed Wetlands can achieve high removals of suspended solids and moderate removal of pathogens, nutrients and other pollutants such as heavy metals. Shade from plants and protection from wind mixing limit the dissolved oxygen in the water, therefore, this technology is only appropriate for low strength wastewater. Usually this requires

that Free-Water Surface Constructed Wetlands are only appropriate when they follow some type of primary treatment to lower the BOD.
Depending on the volume of water, and therefore the size, wetlands can be appropriate for small sections of urban areas or more appropriate for peri-urban and rural communities. This is a good treatment technology for communities that have a primary treatment facility (e.g. Septic Tanks (S9)). Where land is cheap and available, it is a good option as long as the community is organized enough to thoroughly plan and maintain the wetland for the duration of its life.
This technology is best suited to warm climates but can be designed to tolerate some freezing and periods of low biological activity.

Health Aspects/Acceptance The open surface can act as a potential breeding ground for mosquitoes. However, good design and maintenance can prevent this.
The Free-Water Surface Constructed Wetlands are generally aesthetically pleasing, especially when they are integrated into pre-existing natural areas.
Care should be taken to prevent people from coming in contact with the effluent because of the potential for disease transmission and the risk of drowning in deeper waters.

Maintenance Regular maintenance should ensure that water is not short-circuiting, or backing up because of fallen branches, garbage, or beaver dams blocking the wetland outlet. Vegetation may have to be cut back or thinned out periodically.

Pros & Cons:
+ Aesthetically pleasing and provides animal habitat
+ High reduction in BOD and solids; moderate pathogen removal
+ Can be built and repaired with locally available materials
+ Construction can provide short-term employment to local labourers
+ No electrical energy required
+ No real problems with flies or odours if used correctly
- May facilitate mosquito breeding
- Long start up time to work at full capacity
- Requires large land area
- Requires expert design and supervision
- Moderate capital cost depending on land, liner, etc.; low operating costs

References

_ Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems.* WCB and McGraw-Hill, New York, USA. pp 582–599. (Comprehensive summary chapter including solved problems.)

_ Mara, DD. (2003). *Domestic wastewater treatment in developing countries.* Earthscan, London, UK. pp 85–187.

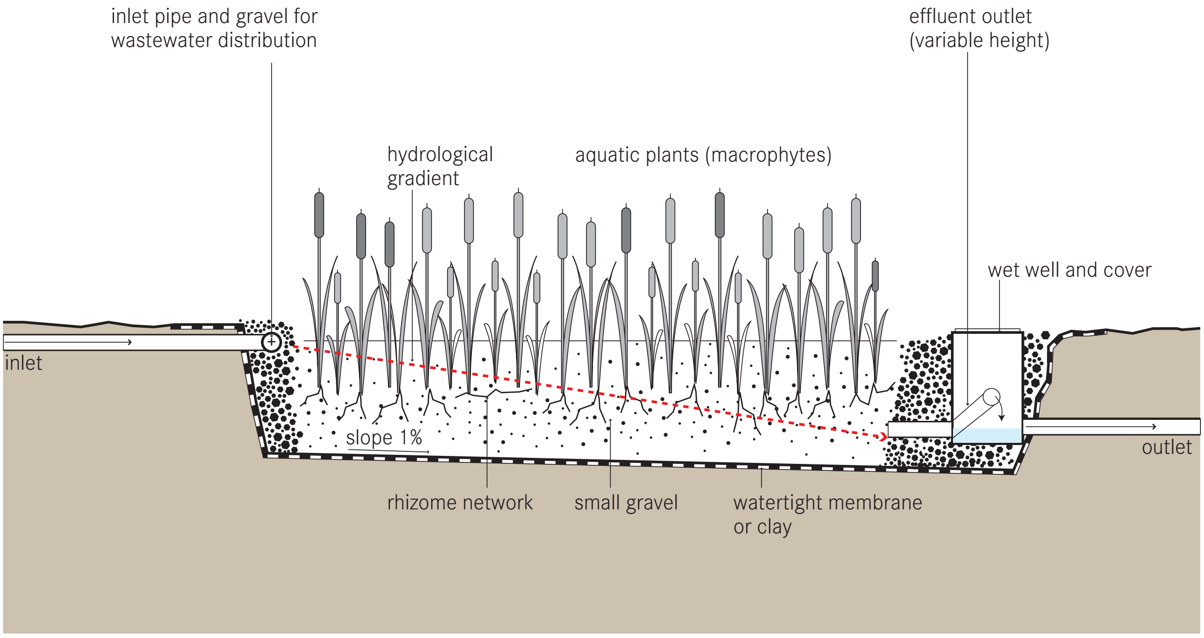
_ Poh-Eng, L. and Polprasert, C. (1998). *Constructed Wetlands for Wastewater Treatment and Resource Recovery.* Environmental Sanitation Information Center, AIT, Bangkok, Thailand.

_ Polprasert, C., et al. (2001). *Wastewater Treatment II, Natural Systems for Wastewater Management.* IHE Delft, The Netherlands. Chapter 6.

_ QLD DNR (2000). *Guidelines for using free water surface constructed wetlands to treat municipal sewage.* Queensland Government, Department of Natural Resources, Brisbane, Australia.
Available: www.epa.qld.gov.au

T.6	Horizontal Subsurface Flow Constructed Wetland	Applicable to: **System 1, 5, 6, 7**

Application Level	**Management Level**	**Inputs:** Blackwater, Greywater
★ Household	★ Household	
★★ Neighbourhood	★★ Shared	
★ City	★★ Public	**Outputs:** Effluent



A Horizontal Subsurface Flow Constructed Wetland is a large gravel and sand-filled channel that is planted with aquatic vegetation. As wastewater flows horizontally through the channel, the filter material filters out particles and microorganisms degrade organics.

The water level in a Horizontal Subsurface Flow Constructed Wetland is maintained at 5 to 15 cm below the surface to ensure subsurface flow. The bed should be wide and shallow so that the flow path of the water is maximized. A wide inlet zone should be used to evenly distribute the flow. Pre-treatment is essential to prevent clogging and ensure efficient treatment.

The bed should be lined with an impermeable liner (clay or geotextile) to prevent leaching. Small, round, evenly sized gravel (3–32 mm in diameter) is most commonly used to fill the bed to a depth of 0.5 to 1 m. To limit clogging, the gravel should be clean and free of fines. Sand is also acceptable, but is more prone to clogging. In recent years, alternative filter materials such as PET have been successfully used.

The removal efficiency of the wetland is a function of the surface area (length multiplied by width), while the cross-sectional area (width multiplied by depth) determines the maximum possible flow. A well-designed inlet that allows for even distribution is important to prevent short-circuiting. The outlet should be variable so that the water surface can be adjusted to optimize treatment performance.

The filter media acts as both a filter for removing solids, a fixed surface upon which bacteria can attach, and a base for the vegetation. Although facultative and anaerobic bacteria degrade most organics, the vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics as well. The plant roots play an important role in maintaining the permeability of the filter.

Any plant with deep, wide roots that can grow in the wet, nutrient-rich environment is appropriate. Phragmites australis (reed) is a common choice because it forms horizontal rhizomes that penetrate the entire filter depth. Pathogen removal is accomplished by natural decay, predation by higher organisms, and sedimentation.

Adequacy Clogging is a common problem and therefore the influent should be well settled with primary treatment before flowing into the wetland. This technology is not appropriate for untreated domestic waste-

water (i.e. blackwater). This is a good treatment for communities that have primary treatment (e.g. Septic Tanks (S9) or WSPs (T3)) but are looking to achieve a higher quality effluent. This is a good option where land is cheap and available, although the wetland will require maintenance for the duration of its life.
Depending on the volume of water, and therefore the size, this type of wetland can be appropriate for small sections of urban areas, peri-urban and rural communities. They can also be designed for single households.
Horizontal Subsurface Flow Constructed Wetlands are best suited for warm climates but they can be designed to tolerate some freezing and periods of low biological activity.

Health Aspects/Acceptance The risk of mosquito breeding is reduced since there is no standing water compared to the risk associated with Free-Water Surface Constructed Wetlands (T5). The wetland is aesthetically pleasing and can be integrated into wild areas or parklands.

Maintenance With time, the gravel will clog with accumulated solids and bacterial film. The filter material will require replacement every 8 to 15 or more years. Maintenance activities should focus on ensuring that primary treatment is effective at reducing the concentration of solids in the wastewater before it enters the wetland. Maintenance should also ensure that trees do not grow in the area as the roots can harm the liner.

Pros & Cons:
+ Requires less space than a Free-Water Surface Constructed Wetland
+ High reduction in BOD, suspended solids and pathogens
+ Does not have the mosquito problems of the Free-Water Surface Constructed Wetland (T5)
+ Can be built and repaired with locally available materials
+ Construction can provide short-term employment to local labourers
+ No electrical energy required
- Requires expert design and supervision
- Moderate capital cost depending on land, liner, fill, etc.; low operating costs
- Pre-treatment is required to prevent clogging

References

_ Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems.* WCB and McGraw-Hill, New York, USA. pp 599–609. (Comprehensive summary chapter including solved problems.)

_ Mara, DD. (2003). *Domestic wastewater treatment in developing countries.* Earthscan, London. pp 85–187.

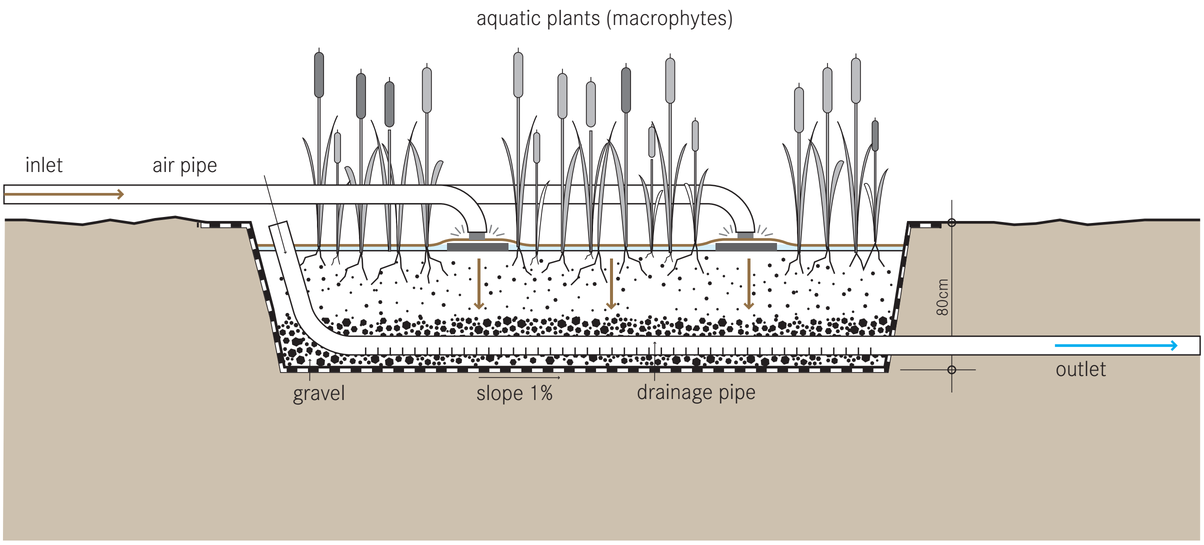
_ Poh-Eng, L. and Polprasert, C. (1998). *Constructed Wetlands for Wastewater Treatment and Resource Recovery.* Environmental Sanitation Information Center, AIT, Bangkok, Thailand.

_ Polprasert, C., et al. (2001). *Wastewater Treatment II, Natural Systems for Wastewater Management.* Lectur Notes, IHE Delft, The Netherlands. Chapter 6.

_ Reed, SC. (1993). *Subsurface Flow Constructed Wetlands For Wastewater Treatment, A Technology Assessment.* United States Environmental Protection Agency, USA. Available: www.epa.gov (Comprehensive design manual.)

T.7	Vertical Flow Constructed Wetland	Applicable to: System 1, 5, 6, 7, 8

Application Level	Management Level	Inputs / Outputs
★ Household	★ Household	**Inputs:** Blackwater, Greywater
★★ Neighbourhood	★ Shared	
★★ City	★★ Public	**Outputs:** Effluent



A Vertical Flow Constructed Wetland is a filter bed that is planted with aquatic plants. Wastewater is poured or dosed onto the wetland surface from above using a mechanical dosing system. The water flows vertically down through the filter matrix. The important difference between a vertical and horizontal wetland is not simply the direction of the flow path, but rather the aerobic conditions.

By dosing the wetland intermittently (four to ten times a day), the filter goes through stages of being saturated and unsaturated, and accordingly, different phases of aerobic and anaerobic conditions. The frequency of dosing should be timed such that the previous dose of wastewater has time to percolate through the filter bed so that oxygen has time to diffuse through the media and fill the void spaces.

The Vertical Flow Constructed Wetland can be designed as a shallow excavation or as an above ground construction. Each filter should have an impermeable liner and an effluent collection system. Vertical Flow Constructed Wetlands are most commonly designed to treat wastewater that has undergone primary treatment. Structurally, there is a layer of gravel for drainage (a minimum of 20 cm), followed by layers of either sand and gravel (for settled effluent) or sand and fine gravel (for raw wastewater).

The filter media acts as both a filter for removing solids, a fixed surface upon which bacteria can attach and a base for the vegetation. The top layer is planted and the vegetation is allowed to develop deep, wide roots which permeate the filter media.

Depending on the climate, Phragmites australis, Typha cattails or Echinochloa Pyramidalis are common options. The vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics. However, the primary role of vegetation is to maintain permeability in the filter and provide habitat for microorganisms.

During a flush phase, the wastewater percolates down through the unsaturated bed and is filtered by the sand/gravel matrix. Nutrients and organic material are absorbed and degraded by the dense microbial populations attached to the surface of the filter media and the roots. By forcing the organisms into a starvation phase between dosing phases, excessive biomass growth can be decreased and porosity increased. A drainage network at the base collects the effluent. The design and

size of the wetland is dependent on hydraulic and organic loads.
Pathogen removal is accomplished by natural decay, predation by higher organisms, and sedimentation.

Adequacy Clogging is a common problem. Therefore, the influent should be well settled with primary treatment before flowing into the wetland. This technology is not appropriate for untreated domestic wastewater (i.e. blackwater).
This is a good treatment for communities that have primary treatment (e.g. Septic Tanks (S9) or WSPs (T3)) but are looking to achieve a higher quality effluent. This is a good option where land is cheap and available, although the wetland will require maintenance for the duration of its life.
There are many complex processes at work, and accordingly, there is a significant reduction in BOD, solids and pathogens. In many cases, the effluent will be adequate for discharge without further treatment. Because of the mechanical dosing system, this technology is most appropriate for communities with trained maintenance staff, constant power supply, and spare parts.
Vertical Flow Constructed Wetlands are best suited to warm climates but can be designed to tolerate some freezing and periods of low biological activity.

Health Aspects/Acceptance The risk of mosquito breeding is low since there is no standing water. The system is generally aesthetic and can be integrated into wild areas or parklands. Care should be taken to ensure that people do not come in contact with the influent because of the risk of infection.

Maintenance With time, the gravel will become clogged with accumulated solids and bacterial film. The material may have to be replaced every 8 to 15 or more years.
Maintenance activities should focus on ensuring that primary treatment effectively lowers organics and solids concentrations before entering the wetland. Testing may be required to determine the suitability of locally available plants with the specific wastewater. The vertical system requires more maintenance and technical expertise than other wetland technologies.

Pros & Cons:

+ Does not have the mosquito problems of the Free-Water Surface Constructed Wetland
+ Less clogging than in a Horizontal Flow Constructed Wetland
+ Requires less space than a Free-Water Surface Constructed Wetland
+ High reduction in BOD, suspended solids and pathogens
+ Construction can provide short-term employment to local labourers
+ Constant source of electrical energy required
- Not all parts and materials may be available locally
- Requires expert design and supervision
- Moderate capital cost depending on land, liner, fill, etc.; low operating costs
- Pre-treatment is required to prevent clogging
- Dosing system requires more complex engineering

References

_ Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems.* WCB and McGraw-Hill, New York, USA. pp 599–609. (Comprehensive summary chapter including solved problems.)

_ Mara, D.D. (2003). *Domestic wastewater treatment in developing countries.* London, Earthscan, pp 85–187.

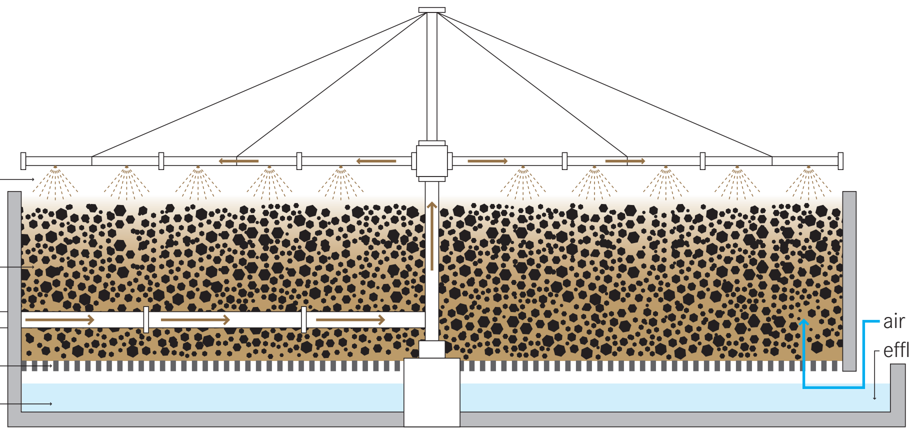
_ Poh-Eng, L. and Polprasert, C. (1998). *Constructed Wetlands for Wastewater Treatment and Resource Recovery.* Environmental Sanitation Information Center, AIT, Bangkok, Thailand.

_ Polprasert, C., et al. (2001). *Wastewater Treatment II, Natural Systems for Wastewater Management.* Lecture Notes. IHE Delft, The Netherlands. Chapter 6.

_ Reed, S.C. (1993). *Subsurface Flow Constructed Wetlands For Wastewater Treatment, A Technology Assessment.* United States Environmental Protection Agency, USA. Available: www.epa.gov (Comprehensive design manual.)

T.8	Trickling Filter	Applicable to: **System 1, 5, 6, 7, 8**

Application Level	Management Level	Inputs / Outputs
Household	Household	**Inputs:** Blackwater, Greywater
★ Neighbourhood	Shared	
★★ City	★★ Public	**Outputs:** Sludge, Effluent



A Trickling Filter is a fixed bed, biological filter that operates under (mostly) aerobic conditions. Pre-settled wastewater is 'trickled' or sprayed over the filter. As the water migrates through the pores of the filter, organics are degraded by the biomass covering the filter material.

The Trickling Filter is filled with a high specific surface-area material such as rocks, gravel, shredded PVC bottles, or special pre-formed filter material. A material with a specific surface area between 30 and 900 m^2/m^3 is desirable. Pre-treatment is essential to prevent clogging and to ensure efficient treatment. The pre-treated wastewater is 'trickled' over the surface of the filter. Organisms that grow in a thin biofilm over the surface of the media oxidize the organic load in the wastewater to carbon dioxide and water while generating new biomass.

The incoming wastewater is sprayed over the filter with the use of a rotating sprinkler. In this way, the filter media goes through cycles of being dosed and exposed to air. However, oxygen is depleted within the biomass and the inner layers may be anoxic or anaerobic.

The filter is usually 1 to 3 m deep but filters packed with lighter plastic filling can be up to 12 m deep. The ideal filter material has a high surface to volume ratio, is light, durable and allows air to circulate. Whenever it is available, crushed rock or gravel is the cheapest option. The particles should be uniform such that 95 % of the particles have a diameter between 7 and 10 cm.

Both ends of the filter are ventilated to allow oxygen to travel the length of the filter. A perforated slab that allows the effluent and excess sludge to be collected supports the bottom of the filter.

With time, the biomass will grow thick and the attached layer will be deprived of oxygen; it will enter an endogenous state, will lose its ability to stay attached and will slough off. High-rate loading conditions will also cause sloughing. The collected effluent should be clarified in a settling tank to remove any biomass that may have dislodged from the filter. The hydraulic and nutrient loading rate (i.e. how much wastewater can be applied to the filter) is determined based on the characteristics of the wastewater, the type of filter media, the ambient temperature, and the discharge requirements.

Adequacy This technology can only be used following primary clarification since high solids loading will cause the filter to clog. A skilled operator is required to

monitor and repair the filter and the pump in case of problems. A low-energy (gravity) trickling system can be designed, but in general, a continuous supply of power and wastewater is required.
Compared to other technologies (e.g. WSPs), trickling filters are compact, although they are still are best suited for peri-urban or large, rural settlements.
Trickling Filters can be built in almost all environments, although special adaptations for cold climates are required.

Health Aspects/Acceptance The odour and fly problems require that the filter be built away from homes and businesses. There must be appropriate measures taken for pre-treatment, effluent discharge and solids treatment, all of which can still pose health risks.

Maintenance The sludge that accumulates on the filter must be periodically washed away to prevent clogging. High hydraulic loading rates can be used to flush the filter.
The packing must be kept moist. This may be problematic at night when the water flow is reduced or when there are power failures.

Pros & Cons:
+ Can be operated at a range of organic and hydraulic loading rates
+ Small land area required compared to Constructed Wetlands
- High capital costs and moderate operating costs
- Requires expert design and construction
- Requires constant source of electricity and constant wastewater flow
- Flies and odours are often problematic
- Not all parts and materials may be available locally
- Pre-treatment is required to prevent clogging
- Dosing system requires more complex engineering

References

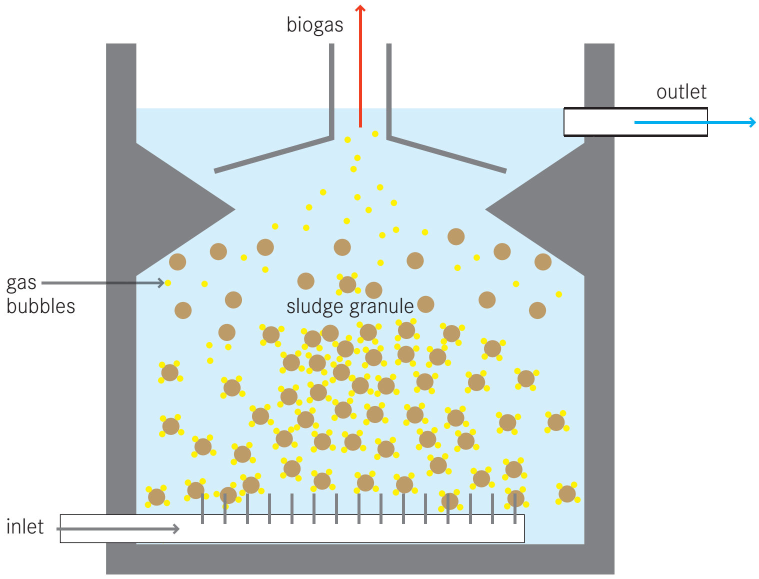
_ U.S. EPA (2000). *Wastewater Technology Fact Sheet-Trickling Filters, 832-F-00-014.* US Environmental Protection Agency, Washington.
Available: www.epa.gov
(Design summary including tips for trouble shooting.)

_ Sasse, L. (1998). *DEWATS: Decentralised Wastewater Treatment in Developing Countries.* BORDA, Bremen Overseas Research and Development Association, Bremen, Germany.
(Provides a short description of the technology.)

_ Tchobanoglous, G., Burton, F.L. and Stensel, H.D. (2003). *Wastewater Engineering: Treatment and Reuse, 4th Edition.* Metcalf & Eddy, New York. pp 890–930 .
(Detailed description and example calculations.)

T.9	Upflow Anaerobic Sludge Blanket Reactor (UASB)	Applicable to: **System 1, 5, 6, 7, 8**

Application Level	**Management Level**	**Inputs:** Blackwater, Greywater
Household	Household	**Outputs:** Treated Sludge, Effluent, Biogas
★ Neighbourhood	Shared	
★★ City	★★ Public	



The Upflow Anaerobic Sludge Blanket Reactor (UASB) is a single tank process. Wastewater enters the reactor from the bottom, and flows upward. A suspended sludge blanket filters and treats the wastewater as the wastewater flows through it.

The sludge blanket is comprised of microbial granules, i.e. small agglomerations (0.5 to 2 mm in diameter) of microorganisms that, because of their weight, resist being washed out in the upflow. The microorganisms in the sludge layer degrade organic compounds. As a result, gases (methane and carbon dioxide) are released. The rising bubbles mix the sludge without the assistance of any mechanical parts. Sloped walls deflect material that reaches the top of the tank downwards. The clarified effluent is extracted from the top of the tank in an area above the sloped walls.

After several weeks of use, larger granules of sludge form which in turn act as filters for smaller particles as the effluent rises through the cushion of sludge. Because of the upflow regime, granule-forming organisms are preferentially accumulated as the others are washed out.

The gas that rises to the top is collected in a gas collection dome and can be used as energy (biogas). An upflow velocity of 0.6 to 0.9 m/h must be maintained to keep the sludge blanket in suspension.

Adequacy A UASB is not appropriate for small or rural communities without a constant water supply or electricity. A skilled operator is required to monitor and repair the reactor and the pump in case of problems. Although the technology is simple to design and build, it is not well proven for domestic wastewater, although new research is promising.

The UASB reactor has the potential to produce higher quality effluent than septic tanks (S9), and can do so in a smaller reactor volume. Although it is a well-established process for large-scale industrial wastewater treatment processes, its application to domestic sewage is still relatively new. Typically it is used for brewery, distillery, food processing and pulp and paper waste since the process can typically remove 85% to 90% of Chemical Oxygen Demand (COD). Where the influent is low strength, the reactor may not work properly. Temperature will also affect performance.

Health Aspects/Acceptance UASB is a centralized treatment technology that must be operated and maintained by professionals. As with all wastewater processes, operators should take proper health and safety measures while working in the plant.

Maintenance Desludging is infrequent and only excess sludge is removed once every 2 to 3 years.
A permanent operator is required to control and monitor the dosing pump.

Pros & Cons:

+ High reduction in organics
+ Can withstand high organic loading rates (up to 10 kg BOD/m^3/d) and high hydraulic loading rates
+ Low production sludge (and thus, infrequent desludging required)
+ Biogas can be used for energy (but usually requires scrubbing first)
- Difficult to maintain proper hydraulic conditions (upflow and settling rate must be balanced)
- Long start up time
- Treatment may be unstable with variable hydraulic and organic loads
- Constant source of electricity is required
- Not all parts and materials may be available locally
- Requires expert design and construction supervision

References

_ Crites, R. and Tchobanoglous, G. (1998). *Small and decentralized wastewater management systems.* WCB and McGraw-Hill, New York, USA. (Short overview.)

_ Lettinga, G., Roersma, R. and Grin, P. (1983). Anaerobic Treatment of Raw Domestic Sewage at Ambient Temperatures Using a Granular Bed UASB Reactor *Biotechnology and Bioengineering* 25 (7): 1701–1723. (The first paper describing the process.)

_ Sasse, L. (1998). *DEWATS: Decentralised Wastewater Treatment in Developing Countries.* BORDA, Bremen Overseas Research and Development Association, Bremen, Germany. (Short overview.)

_ von Sperlin, M. and de Lemos Chernicharo, C.A. (2005). *Biological Wastewater Treatment in Warm Climate Regions. Volume One.* IWA, London, pp 741–804. (Detailed design information)

_ Tare, V. and Nema, A. (n.d). *UASB Technology-expectations and reality.* United Nations Asian and Pacific Centre for Agricultural Engineering and Machinery. Available: http://unapcaem.org (Assessment of UASB installations in India.)

_ Vigneswaran, S., et al. (1986). *Environmental Sanitation Reviews: Anaerobic Wastewater Treatment- Attached growth and sludge blanket process.* Environmental Sanitation Information Center, AIT, Bangkok, Thailand. (Chapter 5 provides a good technical overview.)

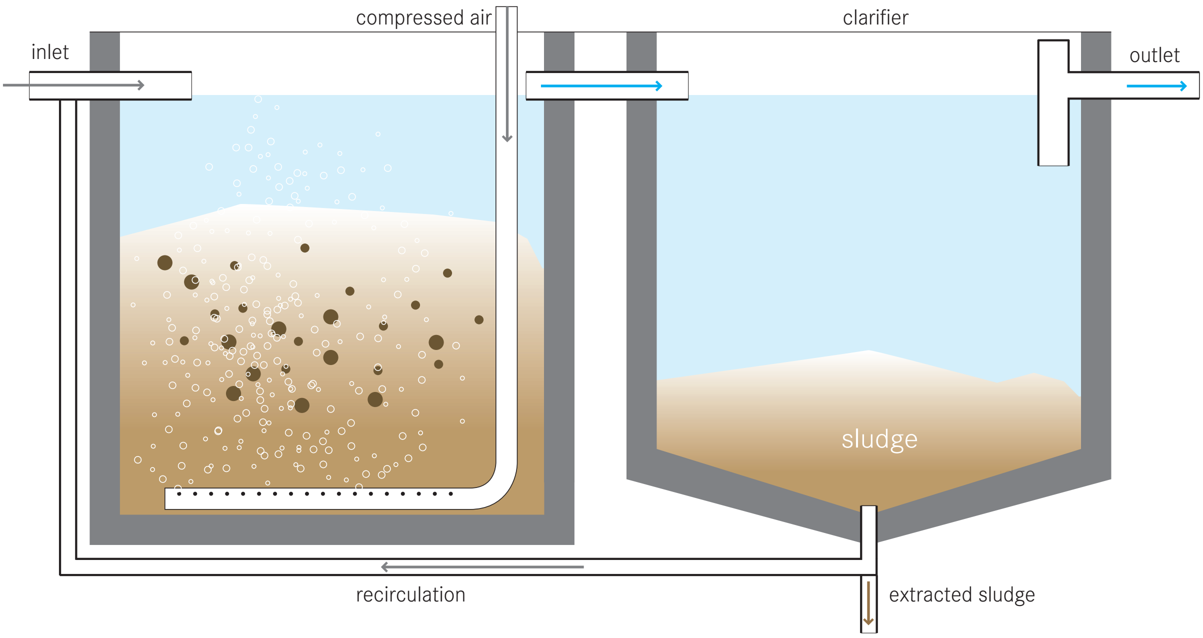
T.10	Activated Sludge	Applicable to: **System 1, 5, 6, 7**	T.10

Application Level
- Household
- ★ Neighbourhood
- ★★ City

Management Level
- Household
- Shared
- ★★ Public

Inputs: Blackwater, Greywater

Outputs: Treated Sludge, Effluent



Activated Sludge is a multi-chamber reactor unit that makes use of (mostly) aerobic microorganisms to degrade organics in wastewater and to produce a high-quality effluent. To maintain aerobic conditions and to the keep the active biomass suspended, a constant and well-timed supply of oxygen is required.

Different configurations of the Activated Sludge process can be employed to ensure that the wastewater is mixed and aerated (with either air or pure oxygen) in an aeration tank. The microorganisms oxidize the organic carbon in the wastewater to produce new cells, carbon dioxide and water. Although aerobic bacteria are the most common organisms, aerobic, anaerobic, and/or nitrifying bacteria along with higher organisms can be present. The exact composition depends on the reactor design, environment, and wastewater characteristics. During aeration and mixing, the bacteria form small clusters, or flocs. When the aeration stops, the mixture is transferred to a secondary clarifier where the flocs are allowed to settle out and the effluent moves on for further treatment or discharge. The sludge is then recycled back to the aeration tank, where the process is repeated.

To achieve specific effluent goals for BOD, nitrogen and phosphorus, different adaptations and modifications have been made to the basic Activated Sludge design. Aerobic conditions, nutrient-specific organisms (especially for phosphorus), recycle design and carbon dosing, among others, have successfully allowed Activated Sludge processes to achieve high treatment efficiencies.

Adequacy Activated Sludge is only appropriate for a centralized treatment facility with a well-trained staff, constant electricity and a highly developed centralized management system to ensure that the facility is operated and maintained correctly.

Activated Sludge processes are one part of a complex treatment system. They are used following primary treatment (that removes settleable solids) and before a final polishing step. The biological processes that occur are effective at removing soluble, colloidal and particulate organic materials for biological nitrification and denitrification and for biological phosphorus removal. This technology is effective for the treatment of large volumes of flows: 10,000 to 1,000,000 people.

Highly trained staff is required for maintenance and trouble-shooting. The design must be based on an accu-

rate estimation of the wastewater composition and volume. Treatment efficiency can be severely compromised if the plant is under- or over- designed.
An Activated Sludge process is appropriate for almost every climate.

Health Aspects/Acceptance Because of space requirements, Centralized treatment facilities are generally located away from the densely populated areas that they serve. Although the effluent produced is of high quality, it still poses a health risk and should not be handled directly.

Maintenance The mechanical equipment (mixers, aerators and pumps) must be maintained constantly. As well, the influent and effluent must be monitored constantly to ensure that there are no abnormalities that could kill the active biomass and to ensure that detrimental organisms have not developed that could impair the process (e.g. filamentous bacteria).

Pros & Cons:
+ Good resistance against shock loading
+ Can be operated at a range of organic and hydraulic loading rates
+ High reduction of BOD and pathogens (up to 99%)
+ Can be modified to meet specific discharge limits
- Prone to complicated chemical and microbiological problems
- Effluent might require further treatment/ disinfection before discharge
- Not all parts and materials may be available locally
- Requires expert design and supervision
- High Capital cost; high operation cost
- Constant source of electricity is required
- Effluent and sludge require secondary treatment and/or appropriate discharge

References

_ Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems.* WCB and McGraw-Hill, New York, USA. pp 451–504. (Comprehensive summary including solved problems.)

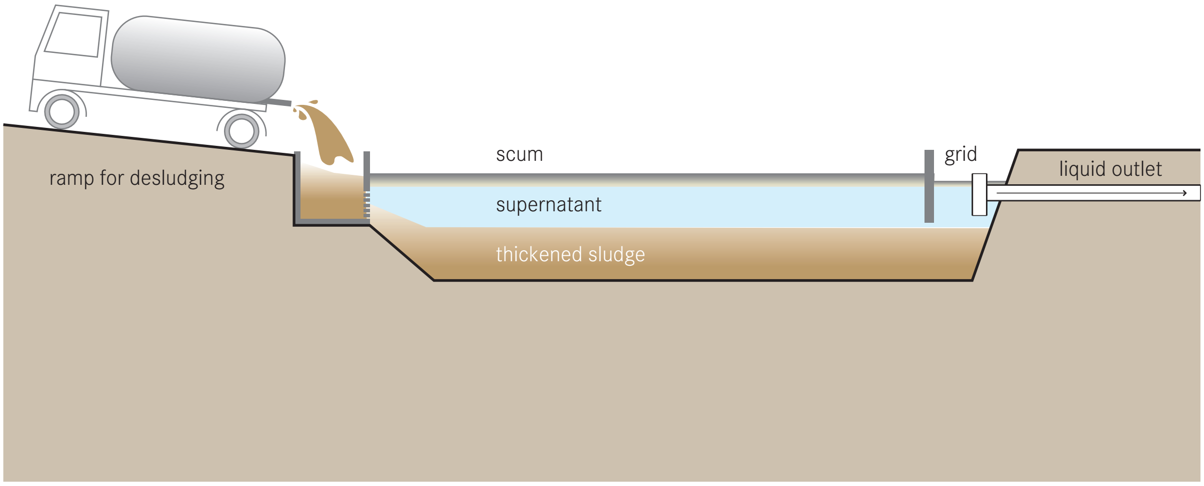
_ Ludwig, HF. and Mohit, K. (2000). Appropriate technology for municipal sewerage/Excreta management in developing countries, Thailand case study. *The Environmentalist* 20(3): 215–219. (Assessment of the appropriateness of Activated Sludge for Thailand.)

_ von Sperling, M. and de Lemos Chernicharo, CA. (2005). *Biological Wastewater Treatment in Warm Climate Regions, Volume Two.* IWA, London.

_ Tchobanoglous, G., Burton, FL. and Stensel, HD. (2003). *Wastewater Engineering: Treatment and Reuse, 4th Edition.* Metcalf & Eddy, New York.

T.11	**Sedimentation/Thickening Ponds**	Applicable to: **System 1, 5, 6, 7, 8**	**T.11**

Application Level	**Management Level**	
Household	Household	**Inputs:** Faecal Sludge
★ Neighbourhood	Shared	
★★ City	★★ Public	**Outputs:** Faecal Sludge, Effluent



Sedimentation or Thickening Ponds are simple settling ponds that allow the sludge to thicken and dewater. The effluent is removed and treated, while the thickened sludge can be treated in a subsequent technology.

Faecal sludge is not a uniform product and therefore, its treatment must be specific to the characteristics of the specific sludge. In general, there are two types of faecal sludges: high strength (originating from latrines and unsewered public toilets) and low strength (originating from Septic Tanks (S9)). High strength sludge is still rich in organics and has not undergone significant degradation, which makes it difficult to dewater. Low strength sludge has undergone significant anaerobic degradation and is more easily dewatered.

In order to be properly dried, high strength sludges must first be stabilized. Allowing the high strength sludge to degrade anaerobically in Settling/Thickening Ponds can do this. The same type of pond can be used to thicken low strength sludge, although it undergoes less degradation and requires more time to settle. The degradation process may actually hinder the settling of low strength sludge because the gases produced bubble up and re-suspend the solids. To achieve maximum efficiency, the loading and resting period should not exceed 4 to 5 weeks, although much longer cycles are common. When a 4-week loading, and 4-week resting cycle is used, total solids (TS) can be increased to 14% (depending on the initial concentration).

As the sludge settles and digests, the supernatant must be decanted and treated separately. The thickened sludge can then go on to be dried or composted further.

Adequacy Settling/Thickening Ponds are appropriate where there is inexpensive, available space that is far from homes and businesses; it should be on the edge of the community.

The sludge is not hygienized and requires further treatment before disposal. Ideally this technology should be coupled with an onsite Drying (T13) or Co-Composting (T14) facility to generate a hygienic product.

Trained staff for operation and maintenance is required to ensure proper functioning.

This is a low-cost option that can be installed in most hot and temperate climates. Excessive rain may prevent the sludge from properly settling and thickening.

Health Aspects/Acceptance The incoming sludge is pathogenic, so workers should be equipped with proper protection (boots, gloves, and clothing). The thickened sludge is also infectious, although it is easier to handle and less prone to splashing and spraying.
The pond may cause a nuisance for nearby residents due to bad odours and the presence of flies. Therefore, the pond should be located sufficiently away from urban centres.

Maintenance Maintenance is an important aspect of a well-functioning pond, although it is not intensive. The discharging area must be maintained and kept clean to reduce the potential for disease transmission and nuisance (flies and odours). Grit, sand, and solid waste that are discharged along with the sludge must be removed.
The thickened sludge must be removed mechanically (front end loader or specialized equipment) when the sludge has thickened sufficiently.

Pros & Cons:

+ Can be built and repaired with locally available materials
+ Low capital cost; low operating cost
+ Potential for local job creation and income generation
+ No electrical energy required
- Requires large land area
- Odours and flies are normally noticeable
- Long storage times
- Requires front-end loader for monthly desludging
- Requires expert design and operation

References

_ Heinss, U., Larmie, SA. and Strauss, M. (1999). *Characteristics of Faecal Sludges and their Solids-Liquid Separation.* Eawag/Sandec Report, Dübendorf, Switzerland. Available: www.sandec.ch

_ Heinss, U., Larmie, SA. and Strauss, M. (1998). *Solids Separation and Pond Systems for the Treatment of Faecal Sludges in the Tropics-Lessons Learnt and Reccomendations for Preliminary Design. Second Edition.* Eawag/Sandec Report 05/98, Dübendorf, Switzerland. Available: www.sandec.ch

_ Montangero, A. and Strauss, M. (2002). *Faecal Sludge Treatment.* Lecture Notes, IHE Delft. Available: www.sandec.ch

T.12 Unplanted Drying Beds

Applicable to:
System 1, 5, 6, 7, 8

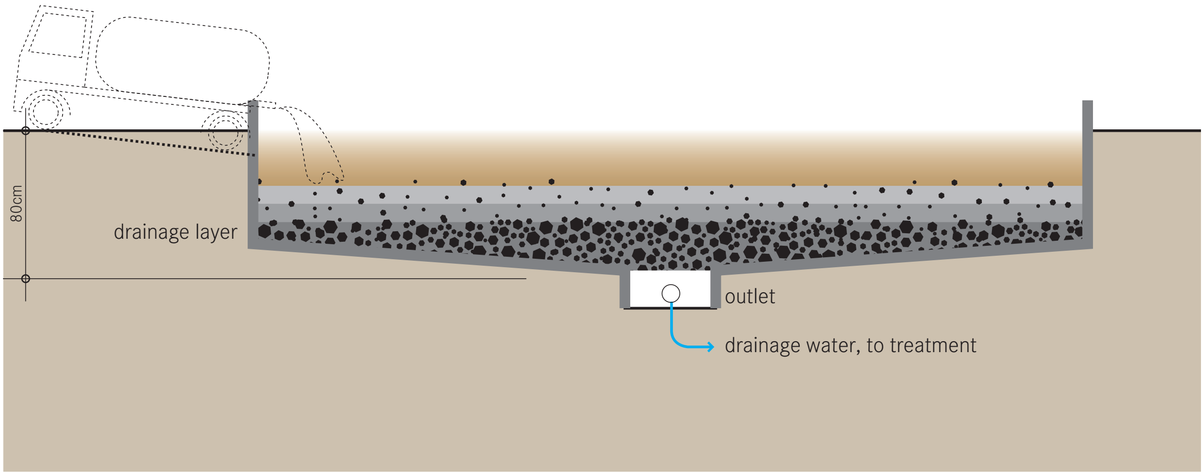
T.12

Application Level
- Household
- ★ Neighbourhood
- ★★ City

Management Level
- Household
- Shared
- ★★ Public

Inputs: Faecal Sludge

Outputs: Faecal Sludge, Effluent



An Unplanted Drying Bed is a simple, permeable bed that, when loaded with sludge, collects percolated leachate and allows the sludge to dry by evaporation. Approximately 50% to 80% of the sludge volume drains off as liquid. The sludge however, is not stabilized or treated.

The bottom of the drying bed is lined with perforated pipes that drain away the leachate. On top of the pipes are layers of sand and gravel that support the sludge and allow the liquid to infiltrate and collect in the pipe.
The sludge should be loaded to approximately 200 kg TS/m^2 and it should not be applied in layers that are too thick (maximum 20 cm), or the sludge will not dry effectively. The final moisture content after 10 to 15 days of drying should be approximately 60%. A splash plate should be used to prevent erosion of the sand layer and to allow the even distribution of the sludge.
When the sludge is dried, it must be separated from the sand layer and disposed of. The effluent that is collected in the drainage pipes must also be treated properly. The top sand layer should be 25 to 30 cm thick as some sand will be lost each time the sludge is manually removed.

Adequacy Sludge drying is an effective way of decreasing the volume of sludge, which is especially important when it requires transportation elsewhere for direct use, Co-Composting (T 14), or disposal. The technology is not effective at stabilizing the organic fraction or decreasing the pathogenic content.
Sludge drying beds are appropriate for small to medium communities with populations up to 100,000 people and there is inexpensive, available space that is far from homes and businesses. It is best suited to rural and peri-urban areas. If it is designed to service urban areas, it should be on the edge of the community.
The sludge is not hygienized and requires further treatment before disposal. Ideally this technology should be coupled with a Co-Composting (T 14) facility to generate a hygienic product.
Trained staff for operation and maintenance is required to ensure proper functioning.
This is a low-cost option that can be installed in most hot and temperate climates. Excessive rain may prevent the sludge from properly settling and thickening.

Health Aspects/Acceptance The incoming sludge is pathogenic, so workers should be equipped with proper protection (boots, gloves, and clothing). The thickened sludge is also infectious, although it is easier to handle and less prone to splashing and spraying.
The pond may cause a nuisance for nearby residents due to bad odours and the presence of flies. Therefore, the pond should be located sufficiently away from urban centres.

Maintenance The Unplanted Drying Bed should be designed with maintenance in mind; access for humans and trucks to pump in the sludge and remove the dried sludge should be taken into consideration.
Dried sludge must be removed every 10 to 15 days. The discharge area must be kept clean and the effluent drains should be flushed regularly. Sand must be replaced when the layer gets thin.

Pros & Cons:
+ Can be built and repaired with locally available materials
+ Moderate Capital Cost; low operating Cost
+ Potential for local job creation and income generation
+ No electrical energy required
- Requires large land area
- Odours and flies are normally noticeable
- Long storage times
- Requires expert design and operation
- Labour intensive removal
- Leachate requires secondary treatment

References

_ Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems.* WCB and McGraw-Hill, New York, USA.

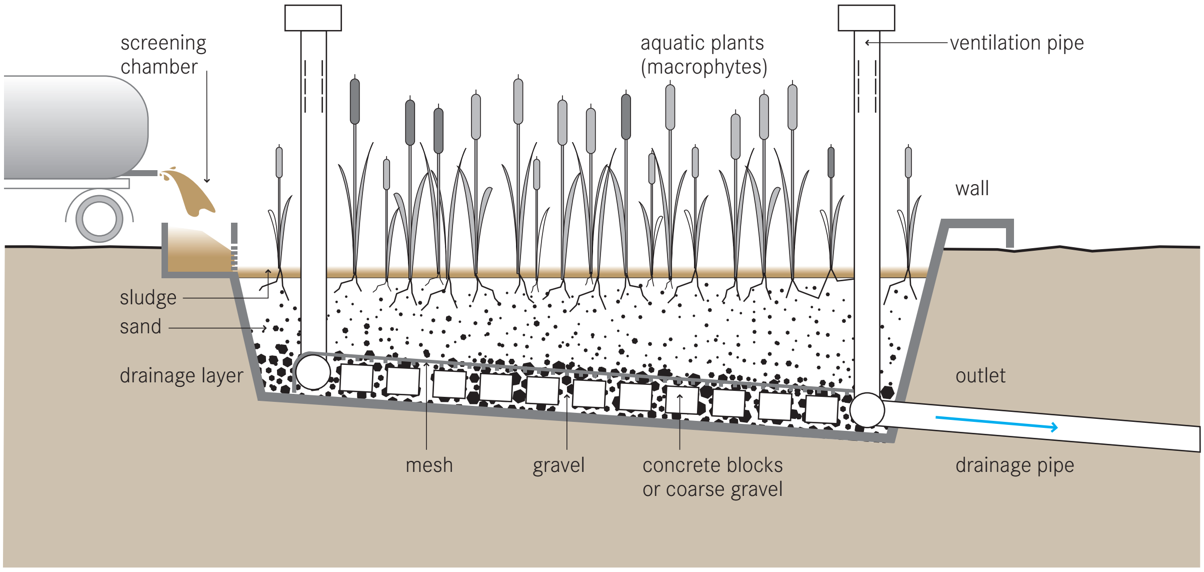
_ Heinss, U. and Koottatep, T. (1998). *Use of Reed Beds for Faecal Sludge Dewatering – A Synopsis of Reviewed Literature and Interim Results of Pilot Investigations with Septage Treatment in Bangkok, Thailand.* UEEM Program Report, AIT/EAWAG, Dübendorf, Switzerland. (Comparison to planted drying beds.)

_ Montangero, A. and Strauss, M. (2002). *Faecal Sludge Treatment.* Lecture Notes, IHE Delft. Available: www.sandec.ch

_ Tchobanoglous, G., Burton, F.L. and Stensel, H.D. (2003). *Wastewater Engineering: Treatment and Reuse, 4th Edition.* Metcalf & Eddy, New York.

T.13	**Planted Drying Beds**	Applicable to: **System 1, 5, 6, 7, 8**

Application Level	**Management Level**	**Inputs:** Faecal Sludge
Household	Household	**Outputs:** Treated Sludge, Effluent, Forage
★ Neighbourhood	Shared	
★★ City	★★ Public	



A Planted Drying Bed is similar to an Unplanted Drying Bed (T12) with the benefit of increased transpiration. The key feature is that the filters do not need to be desludged after each feeding/drying cycle. Fresh sludge can be applied directly onto the previous layer; it is the plants and their root systems that maintain the porosity of the filter.

This technology has the benefit of dewatering as well as stabilizing the sludge. Also, the roots of the plants create pathways through the thickening sludge to allow water to escape more easily.
The appearance of the bed is similar to a Vertical Flow Constructed Wetland (T7). The beds are filled with sand and gravel to support the vegetation. Instead of effluent, sludge is applied to the surface and the filtrate flows down through the subsurface to collect in drains.
A general design for layering the bed is: (1) 250mm of coarse gravel (grain diameter of 20mm); (2) 250mm of fine gravel (grain diameter of 5 mm); and (3) 100–150mm of sand. Free space (1m) should be left above the top of the sand layer to account for about 3 to 5 years of accumulation.

When the bed is constructed, the plants should be planted evenly and allowed to establish themselves before the sludge is applied. Echinochloa pyramidalis, Cattails or Phragmites are suitable plants depending on the climate.
Sludge should be applied in layers between 75 to 100mm and should be reapplied every 3 to 7 days depending on the sludge characteristics, the environment and operating constraints. Sludge application rates of up to 250kg/m^2/year have been reported.
The sludge can be removed after 2 to 3 years (although the degree of hygienization will vary with climate) and used for agriculture.

Adequacy This is an effective technology at decreasing sludge volume (down to 50%) through decomposition and drying, which is especially important when the sludge needs to be transported elsewhere for direct use, Co-Composting (T14), or disposal.
Planted drying beds are appropriate for small to medium communities with populations up to 100,000 people. It should be located on the edge of the community. The sludge is not hygienized and requires further treat-

ment before disposal. Ideally this technology should be coupled with a Co-Composting (T14) facility to generate a hygienic product.
Trained staff for operation and maintenance is required to ensure proper functioning.

Health Aspects/Acceptance Because of the pleasing aesthetics, there should be few problems with acceptance, especially if located away dense housing.
Faecal sludge is hazardous and anyone working with it should wear protective clothing, boots and gloves.

Maintenance The drains must be maintained and the effluent must be properly collected and disposed of. The plants should be periodically thinned and/or harvested.

Pros & Cons:
+ Can handle high loading
+ Fruit or forage growing can generate income
+ Can be built and repaired with locally available materials
+ Low capital cost; low operating cost
+ Potential for local job creation and income generation
+ No electrical energy required
– Requires large land area
– Odours and flies are normally noticeable
– Long storage times
– Requires expert design and operation
– Labour intensive removal
– Leachate requires secondary treatment

References

_ Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems.* WCB and McGraw-Hill, New York, USA.

_ Heinss, U. and Koottatep, T. (1998). *Use of Reed Beds for Faecal Sludge Dewatering - A Synopsis of Reviewed Literature and Interim Results of Pilot Investigations with Septage Treatment in Bangkok, Thailand.* UEEM Program Report , AIT/EAWAG, Dübendorf, Switzerland. Available: www.sandec.ch

_ Koottatep, T., et al. (2004). Treatment of septage in constructed wetlands in tropical climate – Lessons learnt after seven years of operation. *Water Science & Technology,* 51(9): 119–126. Available: www.sandec.ch

_ Montangero, A. and Strauss, M. (2002). *Faecal Sludge Treatment.* Lecture Notes, IHE Delft. Available: www.sandec.ch

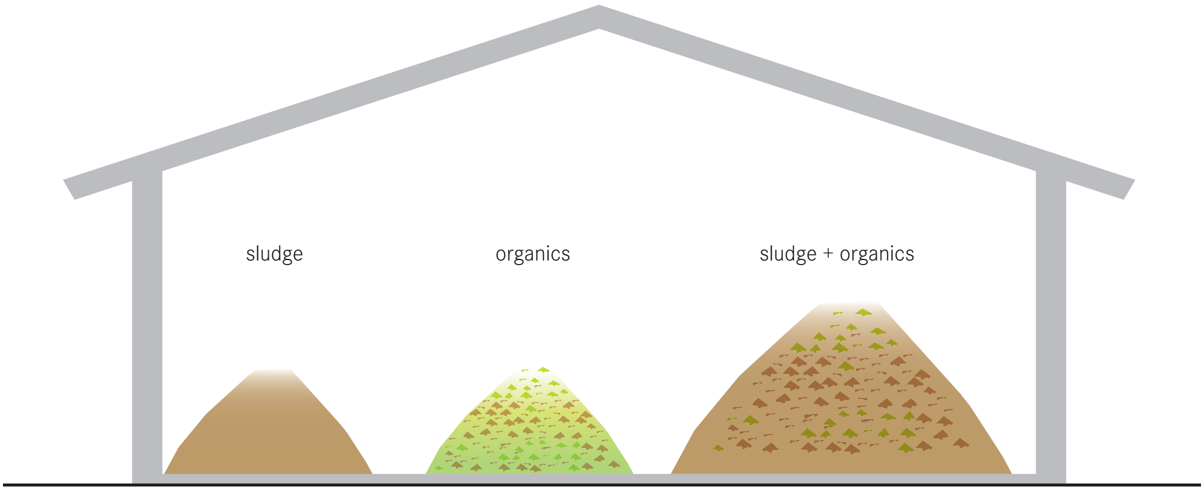
_ Tchobanoglous, G., Burton, F.L. and Stensel, H.D. (2003). *Wastewater Engineering: Treatment and Reuse, 4th Edition.* Metcalf & Eddy, New York, pp 1578.

_ Kengne Noumsi, I.M. (2008). *Potentials of Sludge drying beds vegetated with Cyperus papyrus L. and Echinochloa pyramidalis (Lam.) Hitchc. & Chase for faecal Sludge treatment in tropical regions.* [PhD dissertation]. Yaounde (Cameroon): University of Yaounde. Available: www.nccr-north-south.unibe.ch

T.14 | # Co-Composting

Applicable to:
System 1, 5, 6, 7, 8

Application Level	**Management Level**	**Inputs:** Faecal Sludge, Organics
Household	Household	
★ Neighbourhood	★ Shared	
★★ City	★★ Public	**Outputs:** Compost/EcoHumus



Co-Composting is the controlled aerobic degradation of organics using more than one feedstock (Faecal sludge and Organic solid waste). Faecal sludge has a high moisture and nitrogen content while biodegradable solid waste is high in organic carbon and has good bulking properties (i.e. it allows air to flow and circulate). By combining the two, the benefits of each can be used to optimize the process and the product.

For dewatered sludges, a ratio of 1:2 to 1:3 of dewatered sludge to solid waste should be used. Liquid sludges should be used at a ratio of 1:5 to 1:10 of liquid sludge to solid waste.

There are two types of Co-Composting designs: open and in-vessel. In open composting, the mixed material (sludge and solid waste) is piled into long heaps called windrows and left to decompose. Windrow piles are turned periodically to provide oxygen and ensure that all parts of the pile are subjected to the same heat treatment. Windrow piles should be at least 1 m high, and should be insulated with compost or soil to promote an even distribution of heat inside the pile. Depending on the climate and available space, the facility may be covered to prevent excess evaporation and protection from rain.

In-vessel composting requires controlled moisture and air supply, as well as mechanical mixing. Therefore, it is not generally appropriate for decentralized facilities.

Although the composting process seems like a simple, passive technology, a well-working facility requires careful planning and design to avoid failure.

Adequacy A Co-Composting facility is only appropriate when there is an available source of well-sorted biodegradable solid waste. Mixed solid waste with plastics and garbage must first be sorted. When done carefully, Co-Composting can produce a clean, pleasant, beneficial product that is safe to touch and work with. It is a good way to reduce the pathogen load in sludge.

Depending on the climate (rainfall, temperature and wind) the Co-Composting facility can be built to accommodate the conditions. Since moisture plays an important role in the composting process, covered facilities are especially recommended where there is heavy rainfall. The facility should be located close to the sources of organic waste and faecal sludge (to minimize transport) but to minimize nuisances, it should not be too close to homes and businesses.

A well-trained staff is necessary for the operation and maintenance of the facility.

Health Aspects/Acceptance Although the finished compost can be safely handled, care should be taken when handling the faecal sludge. Workers should wear protective clothing and appropriate respiratory equipment if the material is found to be dusty.

Upgrading Robust grinders for shredding large pieces of solid waste (i.e. small branches and coconut shells) and pile turners help to optimize the process, reduce manual labour, and ensure a more homogenous end product.

Maintenance The mixture must be carefully designed so that it has the proper C:N ratio, moisture and oxygen content. If facilities exist, it would be useful to monitor helminth egg inactivation as a proxy measure of sterilization. Maintenance staff must carefully monitor the quality of the input materials, keep track of the inflows, outflows, turning schedules, and maturing times to ensure a high quality product. Manual turning must be done periodically with either a front-end loader or by hand. Forced aeration systems must be carefully controlled and monitored.

Pros & Cons:

+ Easy to set up and maintain with appropriate training
+ Provides a valuable resource that can improve local agriculture and food production
+ High removal of helminth eggs possible (< 1 egg viable egg/g TS)
+ Can be built and repaired with locally available materials
+ Low capital cost; low operating cost
+ Potential for local job creation and income generation
+ No electrical energy required
- Long storage times
- Requires expert design and operation
- Labour intensive
- Requires large land area (that is well located)

References

_ Cofie, O., et al. (2006). Solid–liquid separation of faecal Sludge using drying beds in Ghana: Implications for nutrient recycling in urban agriculture. *Water Research* 40(1): 75–82.

_ Koné, D., et al. (2007). Helminth eggs inactivation efficiency by faecal Sludge dewatering and co-composting in tropical climates. *Water Research* 41(19): 4397–4402.

_ Obeng, LA. and Wright, FW. (1987). *Integrated Resource Recover. The Co-Composting of Domestic Sold and Human Wastes.* The World Bank + UNDP, Washington.

_ Shuval, HI., et al. (1981). *Appropriate Technology for Water Supply and Sanitation; Night-soil Composting. UNDP/WB Contribution to the IDWSSD.* The World Bank, Washington.

The following reports can all be found in the Faecal Sludge Co-Composting section of the Sandec Website: www.sandec.ch

_ Montangero, A., et al. (2002). *Co-composting of Faecal Sludge and Soil Waste.* Sandec/IWMI, Dübendorf, Switzerland.

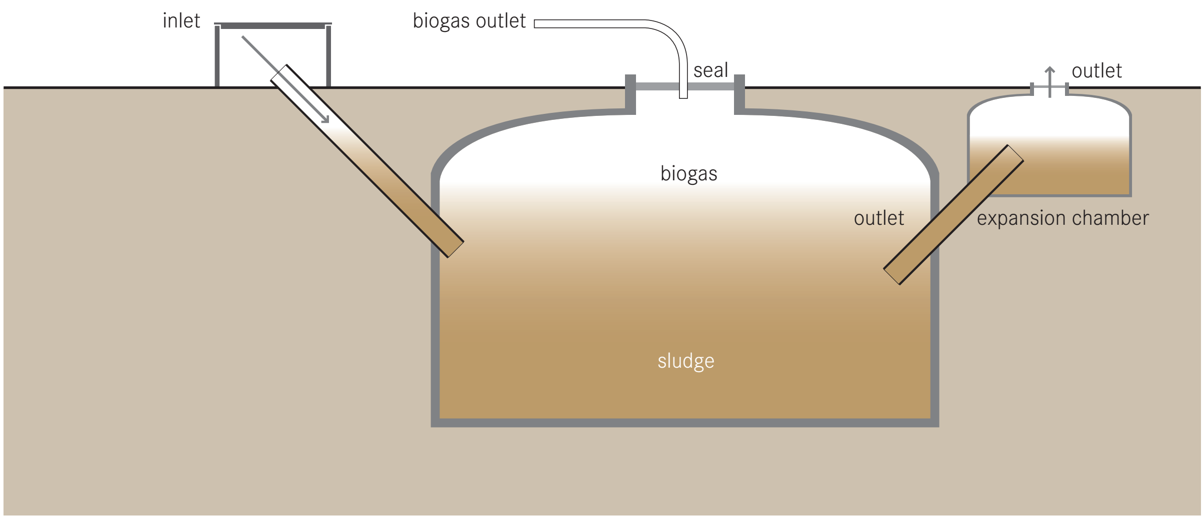
_ Strauss, M., et al. (2003). *Co-composting of Faecal Sludge and Municipal Organic Waste- A Literature and State-of-Knowledge Review.* Sandec/IMWI, Dübendorf, Switzerland.

_ Drescher. S., Zurbrügg, C., Enayetullah, I. and Singha, MAD. (2006). *Decentralised Composting for Cities of Low- and Middle-Income Countries - A User's Manual.* Eawag/Sandec and Waste Concern, Dhaka.

T.15 Anaerobic Biogas Reactor

Applicable to:
System 1, 5, 6, 7, 8

Application Level	Management Level	Inputs / Outputs
★★ Household	★★ Household	**Inputs:** Faecal Sludge, Blackwater, Organics
★★ Neighbourhood	★★ Shared	**Outputs:** Treated Sludge, Effluent, Biogas
★★ City	★★ Public	



An Anaerobic Biogas Reactor is an anaerobic treatment technology that produces (a) a digested slurry to be used as a soil amendment and (b) biogas which can be used for energy. Biogas is a mix of methane, carbon dioxide and other trace gases that can be easily converted to electricity, light and heat.

An Anaerobic Biogas Reactor is a chamber or vault that facilitates the anaerobic degradation of blackwater, sludge, and/or biodegradable waste. It also facilitates the separation and collection of the biogas that is produced. The tanks can be built above or below ground. Prefabricated tanks or brick-constructed chambers can be built depending on space, resources and the volume of waste generated.

The hydraulic retention time (HRT) in the reactor should a minimum of 15 days in hot climates and 25 days in temperate climates. For highly pathogenic inputs, a HRT of 60 days should be considered. Normally, Anaerobic Biogas Reactors are not heated, but to ensure pathogen destruction (i.e. a sustained temperature over 50° C) the reactor should be heated (although in practice, this is only found in the most industrialized countries).

Once waste products enter the digestion chamber, gases are formed through fermentation. The gas forms in the sludge but collects at the top of the reactor, mixing the slurry as it rises. Biogas Reactors can be built as fixed dome or floating dome reactors. In the fixed dome reactor the volume of the reactor is constant. As gas is generated it exerts a pressure and displaces the slurry into an expansion chamber. When the gas is removed, the slurry will flow back down into the digestion chamber. The pressure generated can be used to transport the biogas through pipes. In a floating dome reactor, the dome will rise and fall with the production and withdrawal of gas. Alternatively, the dome can expand (like a balloon).

Most often Biogas Reactors are directly connected to indoor (private or public) toilets with an additional access point for organic materials. At the household level, reactors can be made out of plastic containers or bricks and can be built behind the house or buried underground. Sizes can vary from 1,000 L for a single family up to 100,000 L for institutional or public toilet applications.

The slurry that is produced is rich in organics and nutrients, but almost odourless and partly disinfected (complete pathogen destruction would require thermophilic conditions). Often, a Biogas Reactor is used as an alternative to a conventional septic tank, since it offers a similar level of treatment, but with the added benefit of energy capture. Depending on the design and the inputs, the reactor should be emptied once every 6 months to 10 years.

Adequacy This technology is easily adaptable and can be applied at the household level or a small neighbourhood (refer to Technology Information Sheet S12: Anaerobic Biogas Reactor for information about applying an Anaerobic Biogas Reactor at the household level).
Biogas reactors are best used for concentrated products (i.e. rich in organic material). If they are installed at a public toilet, for example, and the sludge is too dilute, additional organic waste (e.g. from the market) can be added to improve the efficiency. Because they are compact and can be built underground, biodigestors are appropriate for dense housing areas or public institutions that generate a lot of sludge, but where space is limited.
To minimize distribution losses, the reactors should be installed close to where the gas can be used.
Biogas reactors are less appropriate for colder climates as gas production is not economically feasible below 15°C.

Health Aspects/Acceptance The digested slurry is not completely sanitized and still carries a risk of infection. There are also dangers associated with the flammable gases that, if mismanaged could be harmful to human health.

Maintenance The Anaerobic Biogas Reactor must be well built and gas tight for safety. If the reactor is properly designed, repairs should be minimal. To start the reactor, active sludge (e.g. from a septic tank) should be used as a seed. The tank is essentially self-mixing, but it should be manually stirred once a week to prevent uneven reactions.
Gas equipment should be cleaned carefully and regularly so that corrosion and leaks are prevented.
Grit and sand that has settled to the bottom should be removed once every year. Capital costs for gas transmission infrastructure can increase the project cost. Depending on the quality of the output, the gas transmission capital costs can be offset by long-term energy savings.

Pros & Cons:

+ Generation of a renewable, valuable energy source
+ Low capital costs; low operating costs
+ Underground construction minimizes land use
+ Long life span
+ Can be built and repaired with locally available materials
+ Low capital cost; low operating cost
+ No electrical energy required
- Requires expert design and skilled construction
- Gas production below 15°C, is not longer economically feasible
- Digested sludge and effluent still requires further treatment

References

_ Food and Agriculture Organization (FAO) (1996). *Biogas Technology: A Training Manual for Extension.* Consolidated Management Services, Kathmandu.
Available: www.fao.org

_ ISAT (1998). *Biogas Digest Vols. I-IV.* ISAT and GTZ, Germany.
Available:www.gtz.de

_ Koottatep, S., Ompont, M. and Joo Hwa, T. (2004). *Biogas: A GP Option For Community Development.* Asian Productivity Organization, Japan.
Available: www.apo-tokyo.org

_ Rose, GD. (1999). *Community-Based Technologies for Domestic Wastewater Treatment and Reuse: options for urban agriculture.* IDRC, Ottawa. pp 29–32.
Available: http://idrinfo.idrc.ca

_ Sasse, L. (1998). *DEWATS: Decentralised Wastewater Treatment in Developing Countries.* BORDA, Bremen Overseas Research and Development Association, Bremen, Germany.