Onsite Wastewater Treatment Systems Technology Fact Sheet 5

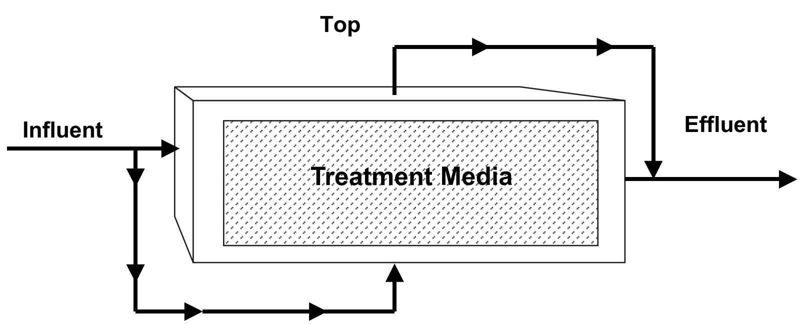
Vegetated Submerged Beds and Other High-Specific-Surface Anaerobic Reactors

Description

A high-specific-surface anaerobic reactor (figure 1) is any tank or cavity filled with solid media through which wastewater flows with a high hydraulic retention time (HRT). In onsite treatment the two primary types are vegetated submerged beds (VSBs) and anaerobic upflow filters (AUFs). The first is characterized by horizontal flow and prolific growth of macrophytes on the surface. The second comes in a variety of forms from upflow sludge blanket systems and fixed media anaerobic filters to partially fluidized beds of fine media. Both have long HRTs, produce anaerobic effluents, generally treat either high-strength or minimally pretreated wastewater, and usually require some form of posttreatment to meet surface discharge or water reuse requirements.

The primary removal mechanisms in all of these systems are physical, that is, floculation, sedimentation, and adsorption. Anaerobic biological reactions are extremely slow and do not have a significant impact on soluble BOD until HRTs become quite long. Some toxic organic compounds may be reduced through these mechanisms and chemical precipitation (e.g., sulfides) at shorter HRTs.

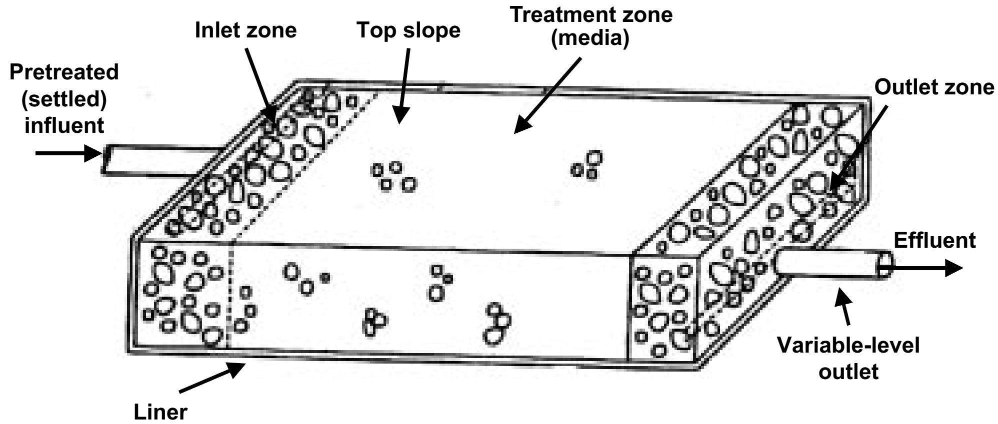
Figure 1. Generic high-specific surface anaerobic reactor

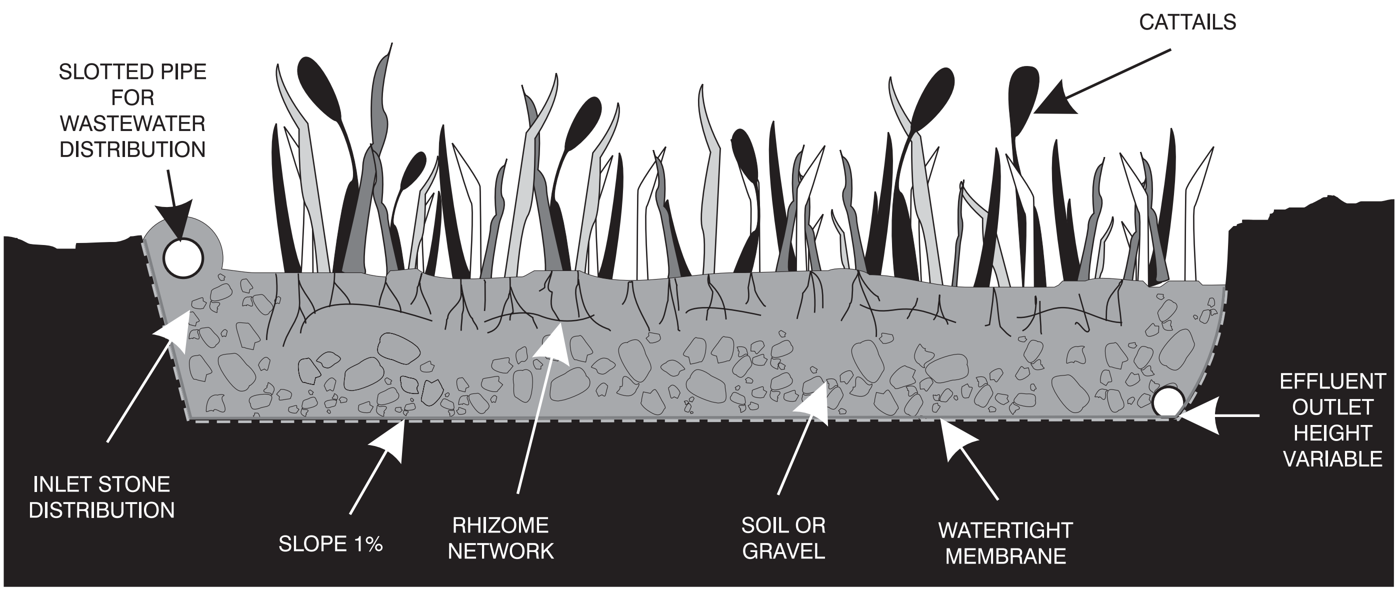


VSBs, as shown in figure 2, usually follow a septic tank and remove most of the suspended and larger colloidal particles, BOD, organic forms of nitrogen, and other particles. Although they are frequently identified as subsurface constructed wetlands, they do not fit the strict definition of a constructed wetland.

Three types of AUFs can be used as pretreatment devices for high-strength wastewater and some onsite pretreatment applications in the United States. They are in shown in figures 3, 4, and 5. Figure 3, with a rock medium, is the most typical U.S. application.

Figure 2. Elements of a vegetated submerged bed (VSB) system





Source: Toms Creek Project, VA.

Figure 3. Schematic of the upflow anaerobic filter process

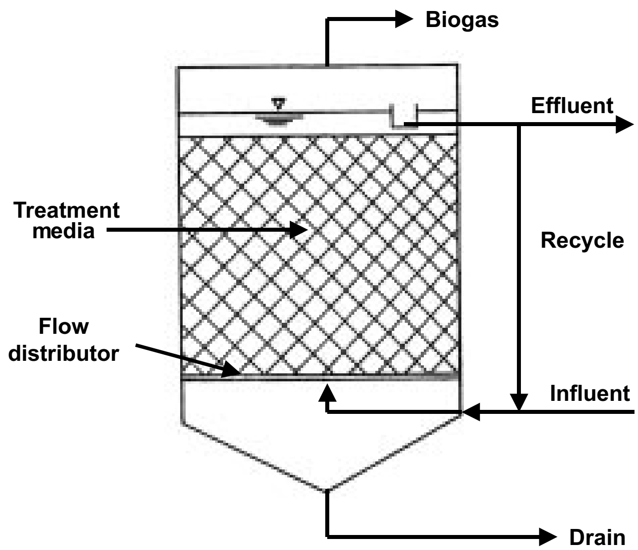


Figure 4. Schematic of the upflow anaerobic sludge blanket process

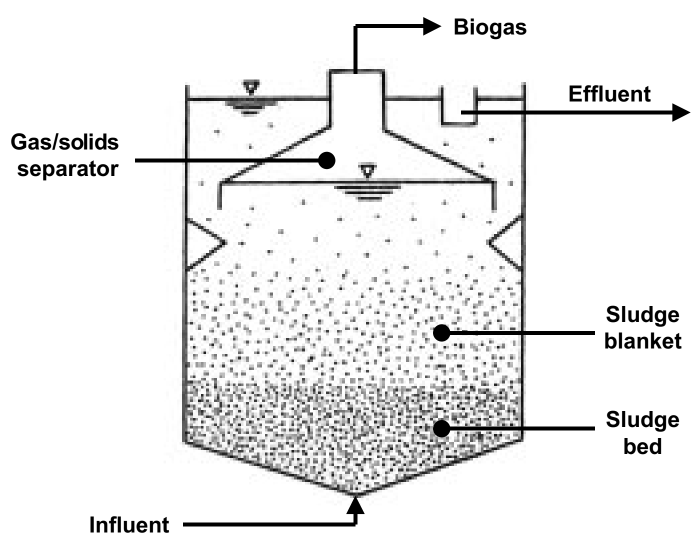
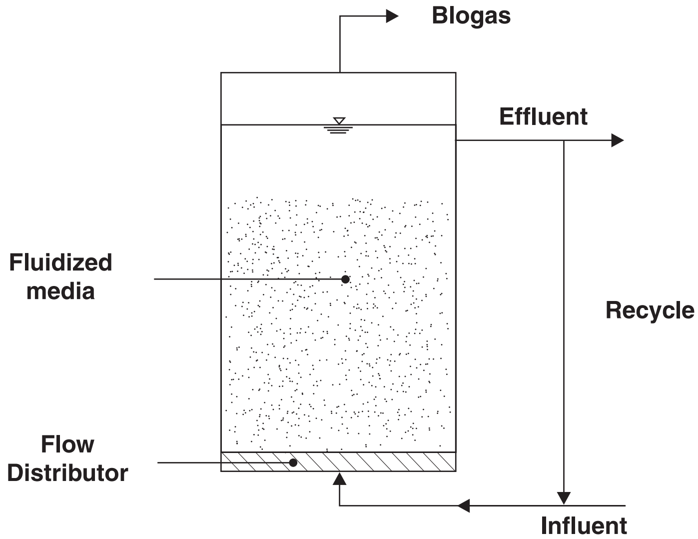


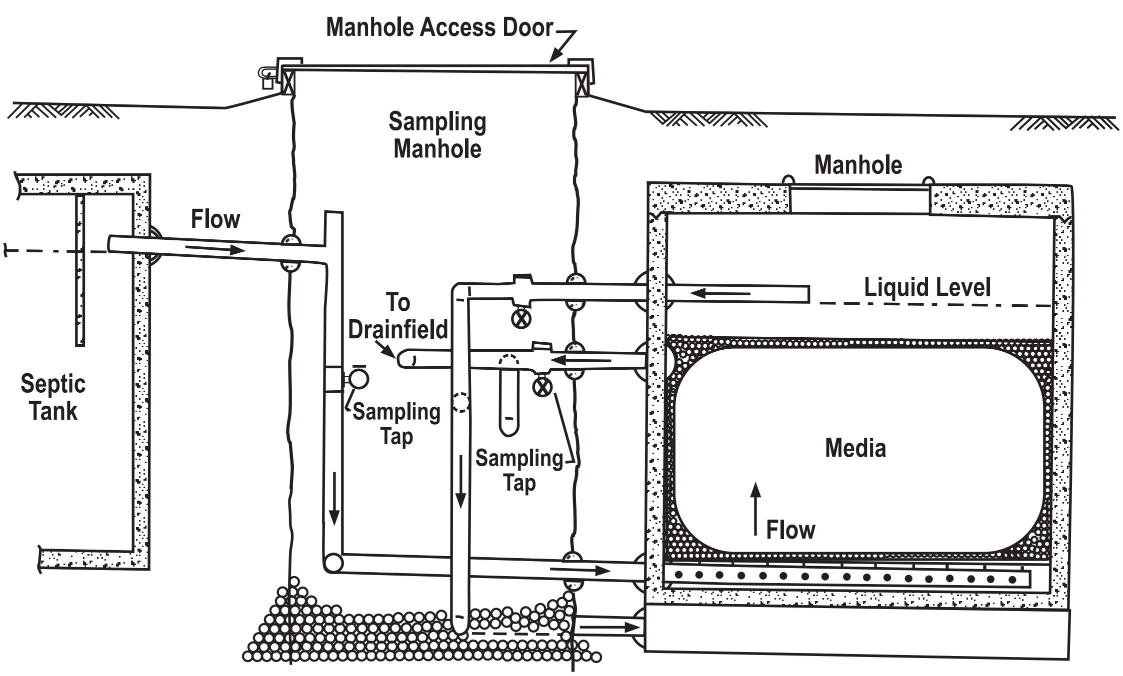
Figure 5. Schematic of the anaerobic fluidized bed process



Typical applications

AUFs are widely used in hot climates where domestic wastewaters are several times higher in strength than U.S. wastewaters. These systems can reduce high BOD and TSS to levels that can be readily treated by typical aerobic processes such as suspended and fixed growth aerobic units or recirculating/intermittent media filters. International literature contains numerous references to the three types of AUFs and their valuable contributions to water pollution abatement. Anaerobic rock upflow filters (figure 6) are also used to lower septic tank effluent BOD and TSS concentrations prior to discharge to the subsurface wastewater infiltration system (SWIS).

Figure 6. Anaerobic upflow filter



VSBs are extremely popular in the United States because of their aesthetic features and their ability to meet basic (secondary) effluent standards when treating septic tank effluent. Until recently they were purported to be capable of nitrification and nutrient removal at economically competitive HRTs. Since they are largely anaerobic, this would be biochemically impossible. However, they are fully capable of meeting secondary BOD and TSS standards. They are also sometimes used before a SWIS and can meet the same effluent TSS and BOD standards as aerobic units (Technology Fact Sheets 1, 2, and 3). VSBs can be considered as pretreatment units regarding SWIS design requirements. They do not, however, remove more than 2 logs of fecal coliform and would likely require disinfection for direct surface discharge. They also require some form of aeration to meet effluent standards for dissolved oxygen (DO). These VSBs will capture rainfall and snowmelt, effluent standards for requiring adjustment to designs of SWIS following these units.

Both VSBs and AUFs are being used in rural areas in combination with aerobic processes to remove significant amounts of nitrogen through denitrification. These processes are included in the nutrient removal fact sheets.

Design assumptions

VSB design guidance for small communities is provided in table 1. In the first few months of operation, excellent phosphorus removal will occur until the rock medium becomes saturated with phosphorus and breakthrough occurs. (Note: USEPA guidance on design of VSBs can be found in *Manual: Constructed Wetlands Treatment of Municipal Wastewater*, posted at **http://www.epa.gov/ordntrnt/ord/nrmrl/pubs/2001/wetlands/625r99010.pdf**)

Except for the anaerobic upflow rock filter, AUFs are rarely employed for U.S. onsite applications. Since the primary purpose of these systems is to improve the BOD and TSS of septic tank effluent, they are essentially physical processes. Therefore, they must be designed to maximize their flocculation and sedimentation functions. Limited field studies

Table 1. Summary of VSB design guidance

Pretreatment [a]	Objective
Surface area	Based on desired effluent quality and areal loading rates as follows:
BOD	6 g/m^2-d (53.5 lb/ac-d) to attain 30 mg/L effluent
TSS	1.6 g/m^2-d (14.3 lb/ac-d) to attain 20 mg/L effluent
TKN	20 g/m^2-d (178 lb/ac-d) to attain 30 mg/L effluent
TP	Use another treatment process in conjunction with VSB VSBs not recommended for phosphorus removal
Depth	
Media (typical)	0.5–0.6 m (20–24 in)
Water (typical)	0.4–0.5 m (16–20 in)
Length	Minimum of 15 m (49 ft.)
Width	As calculated
Bottom slope	0–1%
Top slope	Level or nearly level
Hydraulic conductivity	
First 30% of length	1% of clean K
Last 70% of length	10% of clean K
Media	All media should be washed clean of fines and debris; more uniform rounded media will generally have more void spaces; media should be resistant to crushing or breakage.
Inlet zone (1st 2 m [6.5 ft])	40–80 mm (1.5–3.0 in)
Treatment zone	20–30 mm (3/4–1 in) use clean K = 100,000, if actual K not known
Outlet zone (last 1 m [3.3 ft])	40–80 mm (1.5–3.0 in)
Planting media (top 10 cm [4 in])	5–20 mm (1/4–3/4 in)
Miscellaneous	Use adjustable outlet control device with capability to flood and drain system and sizing of VSB and SWIS (if used) must include a water balance analysis

[a] *Use after primary sedimentation (e.g., septic tank, Imhoff tank, primary clarifier); not recommended for use after ponds because of problems with algae.*

indicate that successful removal of particulate BOD and TSS could be obtained with an average HRT between 16 and 24 hours, rounded media size of 1 to 2 inches or greater, and a means of periodically draining excess accumulated solids from the bottom of the unit. At higher temperatures, some partial digestion of accumulated organic solids occurs. This liquefaction may by accompanied by gas production. The amount and makeup of that gas depend on pH, wastewater constituents (e.g., protein, lipids, carbohydrates), sulfate, alkalinity, and other constituents.

Performance

VSB systems can treat septic tank effluent to a BOD of 20 to 30 mg/L, depending on the organic loading rate chosen. The VSB effluent TSS is almost always less than 30 mg/L. Some removal of all constituents (e.g., heavy metals, organic nitrogen and organic phosphorus, pesticides, and other toxic organics) can also be expected. Over and above these removals, there will be some small percentage of dissolved organic removal owing to anaerobic biological activity.

Rock AUFs after septic tanks have not been widely studied, but they appear to remove TSS by as much as 55 percent from septic tank effluent, while removing a similar percent of the BOD. Actual removals will depend on the specific fractions of particulate, colloidal, and soluble matter in the septic tank effluent. Little soluble or fine particulate removal is likely. Both systems will remove pathogens, with VSBs capable of removing from 1 to 3 logs (design average = 2 logs), while AUF removal is estimated to be closer to 1 log because of shorter HRTs.

Management needs

All of these anaerobic systems are passive in nature and require minimal O/M activity. AUF units may be constructed aboveground, but they usually are below the ground surface to provide insulation and protect against severe climatic conditions. The solid medium can be a coarse gravel or one of many commercially available synthetic media that will not easily clog with biomass. Access to inlet and outlet systems should be provided for purposes of cleaning and servicing. An easily accessible means to drain the unit and an effective alarm system should be provided.

VSB units are generally aesthetically pleasing additions to the landscape if sufficient area is available for their application. It is estimated that fewer than 4 hours per year will be required for O/M tasks, which will involve inspecting the system and making any adjustments required. Therefore, until more information becomes available, a site visit schedule of three to four times a year is suggested.

Residuals generate in VSB systems at a slow rate. Although the system inlet where most solids accumulate can be excavated or piped for high-pressure removal, it is more likely that a replacement system would be built after the service life of the original system ends.

AUF units will require periodic flushing of accumulated solids and inspection of inlet and outlet systems. If solids are allowed to accumulate, the filter may clog or release high solids “events” to the SWIS. This will clog the infiltrative surface or the distribution system. Therefore, a site visit schedule of three to four times per year is suggested until more information becomes available. This would entail from 6 to 8 hours per year of labor. Disposal and transport of excess solids will require similar management to septage.

Risk management issues

VSB systems can usually handle the flow variations likely to occur from residential sources, as well as toxic shock loads and power outages. Reed and colleagues (1995) proposed some models to support the view that insulation provided by dead vegetation (litter) on the surface should aid these systems during typical winters in northern climates. The potential for odor is low for properly sized systems.

AUF systems should also accommodate typical flow variations, toxic shocks, and power outages. They should be insulated from cold weather. AUFs are inherently odor and corrosion generators, so corrosion-resistant materials should be employed. Odor (hydrogen sulfide) production may require the use of an odor-control system (e.g., soil filters) to deodorize off-gases.

Costs

VSB systems for onsite application will cost about $20 per square foot (USEPA, 1999). Almost half of that cost is for the media, while excavation, liner, plants, control structures, and piping make up the rest. Operation and maintenance costs would run less than $100 per year if these services are professionally provided.

AUF systems are likely to cost about $1,000 to $1,500 per house, primarily related to the cost of the tank and related containment features. O/M costs would run around $200 per year, including solids transport as required.

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