Anaerobic and anoxic treatment processes are characterized by the absence of free oxygen from the treatment process. Many of the aerobic treatment systems described in other sections of this report utilize anoxic or anaerobic stages to accomplish specific treatment objectives. Anaerobic treatment processes are typically used for the treatment of waste that has a high concentration of biodegradable organic material. Anoxic and anaerobic processes do not require the input of oxygen, which is typically an energy intensive process in aerobic systems.

5-1 Anoxic systems

Anoxic processes are typically used for the removal of nitrogen from wastewater. The process of biological nitrogen removal is known as denitrification. Denitrification requires that nitrogen be first converted to nitrate, which typically occurs in an aerobic treatment process such as a trickling filter or aerated suspended growth system. The nitrified water is then exposed to an environment without free oxygen. Organisms in this anoxic system use the nitrate as an electron acceptor and release nitrogen in the form of nitrogen gas or nitrogen oxides. A readily biodegradable carbon source is also needed for efficient denitrification processes to occur. It should be noted that sulfate can also be used as an electron acceptor, resulting in the formation of hydrogen sulfide.

Anoxic attached growth reactors

The basic form of the anoxic attached growth reactor is a submerged basin filled with a support medium and, in some cases, carbon source. Anoxic upflow rock filters have been used for nitrogen removal from nitrified wastewater. Nitrified wastewater flows into the bottom of the filter and is mixed with the carbon source as it flows up through the fixed packing. The organic matter is septic tank effluent is the most common carbon source used because of its availability; however, methanol or an alternate compound (e.g., soap) may also be used to supply carbon.

Anoxic suspended growth reactors

The suspended growth reactor is simply a tank in which nitrified wastewater is mixed with a carbon source, typically septic tank effluent. In some cases, nitrified wastewater is discharged back to the primary treatment stage, such as a septic tank, for denitrification. Nearly all of the suspended growth treatment systems and multi-pass trickling biofilter systems make use of an anoxic stage, through recycle of the aerobic stage effluent, to accomplish denitrification.

Anoxic processes that are coupled with aerobic systems are discussed with the respective aerobic process in Chaps. 6, 7, and 8.

5-1.1 AWT Anoxic Filter

Category	Advanced treatment
Technology	Continuous flow, anoxic attached growth
Input	Secondary effluent (nitrified wastewater), carbon source
Function	Denitrification
Applications	Individual, community, and institutional systems

Background

The AWT Anoxic Filter is a biological reactor with a fixed packing for attached growth of denitrifying organisms. The primarily use of this technology is for the removal of nitrogen from wastewater.

Description of process

Nitrified process water flows into the anoxic reactor and is combined with a supplemental carbon source, typically a dilute methanol solution. Chemical is metered by calibration with an electrical signal from the feed pump. Treatment process includes devices for flow monitoring, float switches, and alarms. Effluent from the anoxic reactor is treated in a septic tank for solids removal before being discharged.

Performance
Expected nitrogen removal to below 10 mg/L total nitrogen.

Operation and maintenance
Carbon source will need to be replenished periodically. Pumps and other electrical/mechanical devices will need to be inspected regularly.

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5-1.2 Nitrex™ Trickling Biofilters

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Nitrified wastewater
Function	Primarily denitrification
Applications	Removal of nitrate for wastewater, agricultural runoff, and landfill leachate

Background
The Nitrex filter was developed at the University of Waterloo and is effective for the removal of nitrate from wastewater. The unit is filled with a proprietary wood byproduct mixture that promotes nitrogen removal. Typically the units are single-pass and do not require pumping.

Description of process
Wastewater containing nitrate, such as nitrified wastewater, agricultural runoff, and landfill leachate, is applied to the surface of the Nitrex filter. As the wastewater moves through the organic medium, microbial reduction of the nitrate nitrogen (denitrification) occurs. The bed must remain submerged for this to occur due to the anaerobic nature of this reaction.

System footprint
A typical system will have a surface area of 60 to 75 ft^2. System is typically buried to take advantage of gravity flow. Influent should be a nitrified wastewater, such as sand filter or other aerobic treatment effluent.

Advantages
Near complete removal of nitrogen from wastewater. Passive process with low energy and maintenance requirements.

Disadvantages
Requires aerobic pretreatment.

Performance
Manufacturer claims near complete removal of nitrate nitrogen. With adequate upstream aerobic process (e.g., trickling biofilter, aerated treatment process), total nitrogen removal is expected to be greater than 95%. Other effluent constituent concentrations are not known.

Operation and maintenance
Relatively low maintenance needs; however, media may need to be replaced over time.

Power and control
Can be operated with or without pumps depending on specific site characteristics and design. Annual power usage expected to range from negligible (no pump/control) to 50 kWh.

Cost
System for treatment of residential wastewater expected to cost from $1500 to 2000, not including shipping and installation costs.

Contact

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E wroberts@sciborg.uwaterloo.ca
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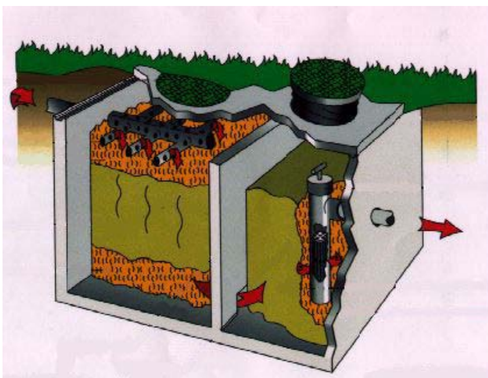

Figure 5-1
Diagram of Nitrex unit (left) and installation of a Nitrex unit to receive effluent from a sand biofilter (right). (Adapted from Wastewater Science, Inc.)

5-1.3 Rock Denitrification Tank

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Nitrified wastewater, carbon source
Function	Denitrification
Applications	Removal of nitrate for wastewater

Background/description of process
The rock tank is used in combination with a sand filter or other nitrifying treatment system. The nitrified wastewater flows into the tank with a submerged packing, typically an aggregate media such as rock. A carbon source is added to the system to stimulate denitrification.

System footprint
The anoxic rock tanks are typically designed with a 1 to 3 day hydraulic retention time.

Advantages
Depending on the carbon source used, nitrogen removal ranging from 30 to 100% can be achieved.

Disadvantages
Requires aerobic pretreatment for proper operation.

Performance
A research study by Lamb *et al*. (1990) found that the denitrification process was affected by the carbon source used, see Table 5-1.

Table 5-1
Summary of reported rock denitrification tank performance (Lamb *et al*., 1990)

Carbon source added to rock tank	Carbon source to sand filter effluent ratio	C:N ratio in rock tank	Mean denitrification, %
Septic tank effluent	1 to 4	0.7 to 1	25
Methanol	1 to 2,000	4 to 1	99
Ethanol	1 to 7,000	2 to 1	99

Operation and maintenance
The system for distribution of the external carbon source will require additional monitoring and maintenance compared to the passive system. The carbon source will need to be replenished periodically.

Power and control
Typically, a peristaltic pump is used to deliver the carbon source into the anoxic tank.

References and other resources
Lamb B.E., A.J. Gold, G.W. Loomis, and C.G. McKiel (1990) Nitrogen Removal for Onsite Sewage Disposal: A Recirculating Sand Filter/Rock Tank Design, *Transactions of the ASAE*, Vol. 33, No. 2, pp. 525-531.

Sandy A.T., W.A. Sack, and S.P. Dix (1987) Enhanced Nitrogen Removal Using a Modified Recirculating Sand Filter (RSF^2), *Proceeding of the Fifth National Symposium on Individual and Small Community Sewage Systems,* American Society of Agricultural Engineers, St Joseph, MI.

Sikora L.J., and D.R. Keeney (1976) Denitrification of Septic Tank Effluent, *Journal of the Water Pollution Control Federation*, Vol. 48, pp. 2018-2025.

5-4 RUCK® SYSTEMS INC.

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems, commercial

Background
The RUCK system utilizes the natural distribution of wastewater constituents to promote denitrification activity. RUCK systems are in use at residential and commercial sites in the United States and other countries.

Description of process
The RUCK system requires separate plumbing for collection of the greywater and blackwater. In the standard system, greywater is used as the carbon source for denitrification of the blackwater. To obtain nitrification, the blackwater is processed in a standard septic tank followed by a trickling biofilter. Greywater sources are collected in a separate septic tank for solids separation.

Because greywater typically has a high concentration of carbon and low concentrations of nitrogen, and blackwater processed in the trickling biofilter has a low concentration of carbon and a high concentration of nitrate, combining these two wastewater streams results in the transformation of nitrate into nitrogen gas. Diagrams of the RUCK system are shown in Figs. 5-2 and 5-3.

The denitrification step occurs in a separate anoxic biofilter, where the two wastewater streams are combined and allowed to percolate into the soil. For commercial and residential systems that have insufficient carbon for denitrification, a supplemental carbon source (typically a specially formulated soap) is added to the nitrified blackwater.

System footprint

Typical system will have a surface area of 300 to 400 ft^2.

Advantages

There is a potential for high nitrogen removal. The system is relatively simple to operate and maintain. Most of the materials needed for construction are locally available.

Disadvantages

The system performance is highly dependent on user activities. Retrofit of existing systems is more difficult because of the need to separate greywater and blackwater. There may be space limitations because of the large area needed for installation of all system components.

Performance

The RUCK systems have demonstrated excellent nitrogen removal. Due to the variation in household wastewater constituent concentrations, the specific performance of any particular system is variable. Systems receiving wastewater from clusters of homes or small communities have resulted in more stable performance due to an averaging effect and overall reduction in concentration peaks. Additional performance specifications from representative research studies are presented in Table 5-2.

Table 5-2

Selected representative studies of RUCK system performance

Parameter	Unit	Location of study		
		Florida[b]	Massachusetts[b]	Vermont[c]
Description of system		Residential	Residential	Residential
System performance[a]				
COD	mg/L	n/a	n/a	
BOD_5	mg/L	12 (95%)	30 (75%)	48
TSS	mg/L	10	30 (75%)	63
TN	mg/L	12 (75%)	8 (90%)	6
NO_3-N	mg/L	11	3	0.35
NH_3-N	mg/L		5	3.5
TP	mg/L	3 (66%)		3.5
Fecal coliform	CFU/100 mL		5000 (3)	

[a] Performance reported as average effluent concentration with average removal in parentheses, where applicable.
[b] Typical values from individual home systems; performance is dependent on water usage.
[c] Average of effluent from system serving cluster of 8 homes.

Operation and maintenance
Operation and maintenance requirements are similar to those for standard biofilter systems. For systems that use a supplemental carbon source, the carbon source will need to be replenished occasionally and the supply pump will need maintenance as required or specified by manufacturer. Systems should be inspected regularly for ponding of wastewater on the biofilter surface (or otherwise reduced infiltrative capacity) due to clogging. Correct pump and control system operation should be confirmed. The replenishment of the external carbon source may also be necessary.

Power and control
The basic system design is passive and does not require the use of pumps. Control, pumping, and monitoring systems can be used as for other systems.

Cost
An estimated cost of $7,000 to 9,000 includes capital and installation costs for the RUCK components only (does not include standard septic system).

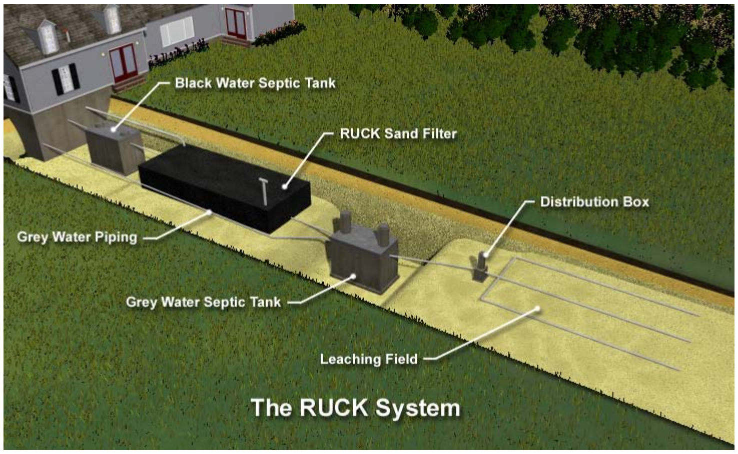

Figure 5-2
Diagram of residential RUCK system. (Adapted from Innovative RUCK Systems, Inc.)

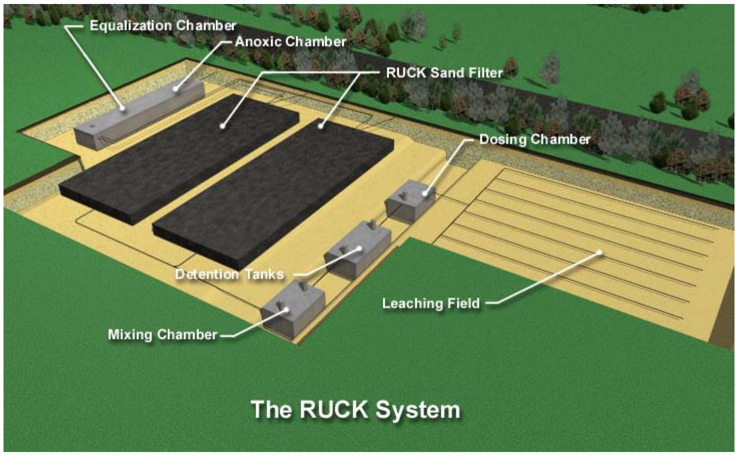

Figure 5-3
Diagram of commercial RUCK system. (Adapted from Innovative RUCK Systems, Inc.)

Contact

RUCK Systems. Inc.
149 Browns Rd.
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Fax (860) 456-0803
Web www.rucksystems.com
RUCK Systems provides proprietary system design to authorized professional engineers.

Innovative RUCK Systems
200 Main St, Room 201
Falmouth, MA 02540
Phone (508) 548-3564
Web www.irucks.com
IRUCKS provides designs for RUCK Systems under license from RUCK Systems, Inc.

Model description

System design is available from an authorized professional engineer. Most materials needed are available locally, other components are available from the manufacturer. Biofilter media can generally be obtained from site location.

References and other resources

Laak, R., and M.A. Parese (1981) Denitrification of Blackwater with Greywater, *Journal of Environmental Engineering*, American Society of Civil Engineers, Vol. 7, No. EE3, pp. 581-591.

5-2 Anaerobic systems

Anaerobic processes are used for treating wastewater with high concentrations of biodegradable organic materials, such as concentrated domestic wastewater, biosolids, animal manure slurry, and food processing wastes. There are many types of anaerobic processes available, including the following:

- Anaerobic continuous flow stirred tank reactor – A suspended growth mixed anaerobic digestion process where all anaerobic biochemical reactions are occurring in the same reactor.
- Anaerobic plug-flow reactor – A reactor with a high length to width ratio where influent wastewater enters one end, flows through the reactor, and exits the opposite end. All anaerobic reactions occur in the same reactor.
- Upflow anaerobic sludge blanket (UASB) reactor – Influent wastewater is discharged into the bottom of a reactor and flows upwards through a layer of naturally forming sludge pellets.
- Anaerobic sequencing batch reactor – A batch reaction process where influent wastewater sequentially undergoes anaerobic treatment, clarification, and discharge.
- Anaerobic biofilter (fixed media packing) – A fixed packing submerged biofilter, typically operated in the upflow mode and operated at higher loading rates than suspended growth systems.
- Anaerobic fluidized bed – Attached growth anaerobic process where the influent wastewater enters the bottom of the reactor under sufficient pressure to expand the packing and cause liquefaction.
- Anaerobic mixed biofilm reactor – A reactor similar to a continuous flow stirred tank reactor with the addition of suspended media for fixed film anaerobic organisms.
- Staged anaerobic processes – Anaerobic reactors operated in series for improved process control.
- Phased anaerobic processes – Anaerobic reactors operated in a way that separates the biochemical reactions of hydrolysis/acidogenesis and methanogenesis for improved methane production and process control.

Additional details on these processes may be found in Speece (1996). All of these processes make use of anaerobic biochemical reactions for the removal of organic material and the mineralization of nutrients. The three biochemical reactions that characterize anaerobic processes are:

- Hydrolysis – enzyme mediated transformation of complex organic compounds into simple compounds.

- > Acidogenesis – Bacterial conversion of simple compounds into substrates for methanogenesis (acetate, formate, hydrogen, carbon dioxide).
- > Methanogenesis – Bacterial conversion of methanogenic substrates into methane and carbon dioxide.

The methanogenesis process is more sensitive to changes in pH and the presence of toxic compounds than aerobic treatment systems. Because of the sensitivity of the anaerobic bacteria to environmental variables, these processes are often used on a larger scale with more process monitoring and control. In some cases, methane, also known as biogas, may be captured for the recovery of energy. Biogas production and wastewater stabilization through anaerobic digestion may be a feasible option for applications that produce sufficient amounts of organic waste.

References

Speece, R. (1996) *Anaerobic Biotechnology for Industrial Wastewaters*, Archae Press, Nashville, TN.

5-2.1 Glendon Biofilter™

Category	Secondary treatment
Technology	Anaerobic upflow/trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Anaerobic digestion, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background

The Glendon Biofilter was developed in Washington State and has been used extensively in areas that have poor soils and high groundwater conditions. The process is known for its high quality treatment and relative low maintenance needs.

Description of process

The components of the Glendon Biofilter are a standard septic tank, a pump tank, an upflow sand filter process, and an aerobic capillary flow process. Septic tank effluent is collected in a pump tank and metered in small doses (on demand) to the anaerobic upflow biofilter unit. After moving upward through the bed of sand, the wastewater spills over the rim of the anaerobic reactor and then moves downward through the surrounding medium for aerobic treatment. The process is shown in Fig. 5-4.

System footprint

Requires about 200 ft^2 for treatment unit and surrounding soil adsorption area.

Advantages

Excellent treatment performance. Adaptable to sites that have restrictions for other types of treatment systems, such as areas with high groundwater. Low maintenance and energy usage. Does not require subsequent soil distribution system.

Disadvantages

Treatment system leaves mounded area on property (may be landscaped).

Performance

Process design is based on meeting treatment standards set by Washington State of BOD_5 and TSS less than 10 mg/L, and fecal coliform bacteria less than 200 CFU/100 mL. Specific performance data has not been obtained, but may be available from manufacturer.

Operation and maintenance

System maintenance is performed by a certified technician. System includes one pump, high water alarm, and control panel. Electrical components will need to be monitored to confirm that the system is operating correctly. Excessive water use or pump failure will result in activation of the high water alarm. The system incorporates a septic tank that will require periodic servicing for solids removal.

Power and control
Relatively passive process, which uses one pump (110 Volt electric pump), control panel, and high water alarm. The expected annual power usage ranges from 50 to 150 kWh.

Cost
The estimate includes capital and installation costs for biofilter component only is $5,000 to 8,000.

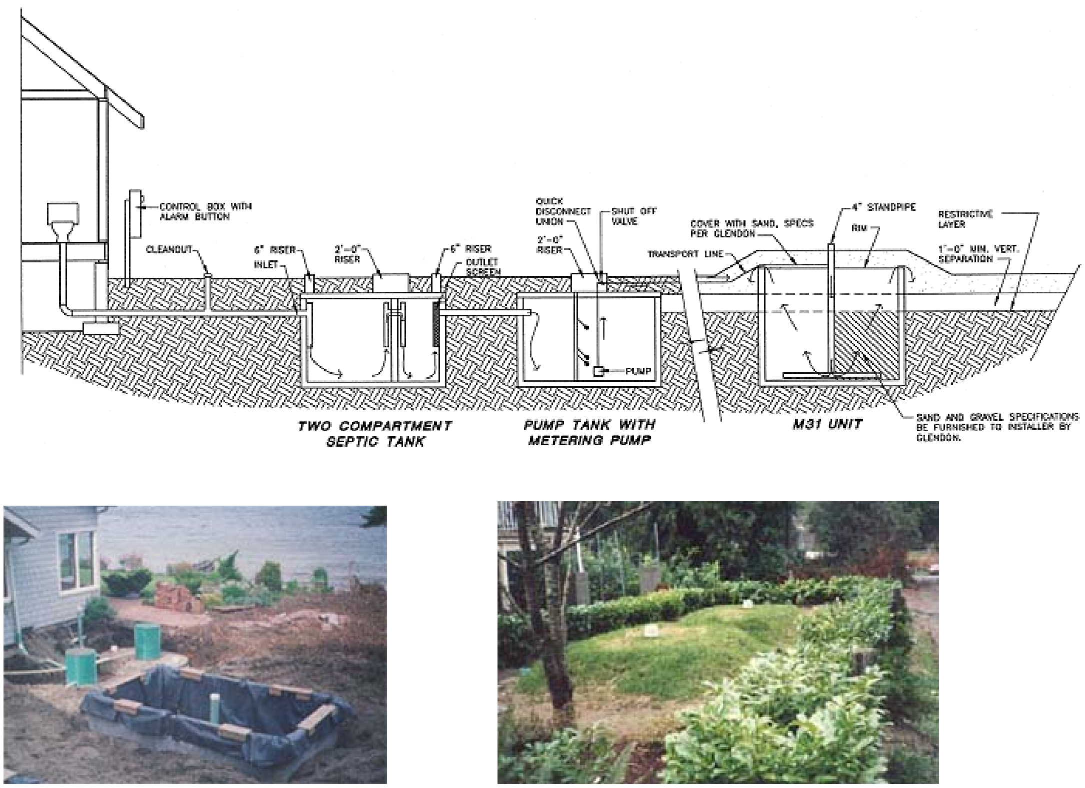

Figure 5-4

A diagram of the Glendon Biofilter system (top), the installation of a Glendon Biofilter (bottom left), and a completed system at a residence (bottom right). (Adapted from Glendon Biofilter Technologies, Inc.)

Contact
Glendon Biofilter Technologies, Inc.
25448 Port Gamble Rd. N.E.
Poulsbo, WA 98370
Phone (360) 297-7066
Fax (360) 297-8479
E info@glendon.com
Web www.glendon.com
Model description
M3 (240 to 480 gpd)
M31 (90 to 528 gpd)

Manufacturer support

Two year warranty on treatment system, one year warranty for the pump and timer.

5-2.2 Upflow Anaerobic Sludge Blanket (UASB) Reactor

Category	Secondary treatment
Technology	Anaerobic upflow biofilter
Input	Untreated waste/wastewater, septic tank effluent
Function	Anaerobic digestion, pathogen reduction
Applications	Community wastewater, agricultural and industrial wastes

Background/description of process

The UASB reactor was developed in the Netherlands (Lettinga *et al*., 1980) and is widely used in Europe and South America. The wastewater flows in the bottom of the anaerobic reactor and through a layer of naturally forming, dense biological sludge granules. The sludge particles range in size from flocculants to granules with a diameter of 0.25 in. Gases formed in the digestion process generate mixing action and promote granule formation in the sludge layer. The methane gas is captured in a reservoir at the top of the reactor and may be used for energy reclamation. The process is shown in Fig. 5-5.

System footprint

For an individual residence, a UASB reactor receiving septic tank effluent would have a volume between 35 and 70 ft^3. Additional arrangements for biogas management would also be needed.

Advantages

Anaerobic systems do not require aeration, which is typically a significant cost for aerated systems. The amount of sludge produced is less than that produced by a comparable aerobic systems.

Disadvantages

There is a potential for odors associated with anaerobic digestion. The treatment process is more sensitive to the presence of toxic compounds and changes in temperature than aerobic systems. Minimal nutrient removal occurs without the application of a subsequent treatment process.

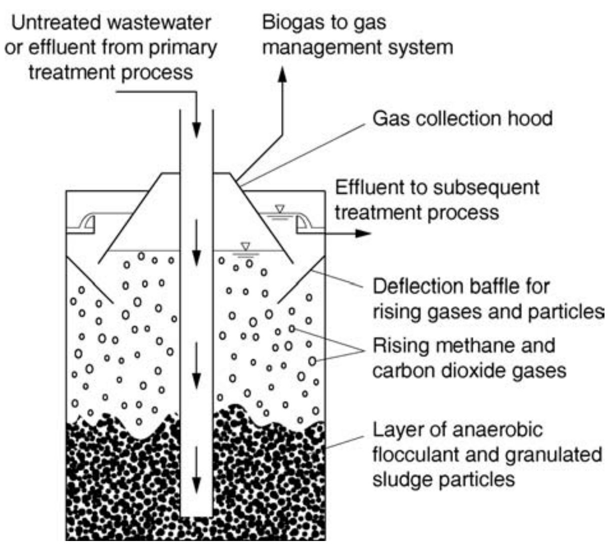

Figure 5-5

Diagram of the UASB treatment process.

Performance

Anaerobic processes are effective at COD removal from concentrated waste streams, typically 60 to 90 percent COD removal; however, these systems mineralize nutrients and thus do not remove them from the water phase. Anaerobic systems are suited for nutrient recovery applications, such as through agricultural reclamation. If nutrient removal is the objective, subsequent treatment will be needed. In cool climates, performance may be similar to a septic tank.

Operation and maintenance

Process monitoring is important to ensure that the pH is within the required range of 6.6 to 7.6, particularly if methane recovery is to be considered. Periodic sludge removal may be necessary.

Power and control

Aeration is not needed for anaerobic systems.

References

Lettinga, G.A., A.F.M. van Velsen, S.W. Hobma, W.J. de Zeeuw, and A. Klapwijk (1980) Use of the Upflow Sludge Blanket (USB) Reactor Concept for Biological Wastewater Treatment, *Biotechnology and Bioengineering*, Vol. 22, pp. 699-734.

Zeeman, G., and G.A. Lettinga (1999) The Role of Anaerobic Digestion of Domestic Sewage in Closing the Water and Nutrient Cycle at the Community Level, *Water Science and Technology*, Vol. 39, No. 5, pp. 187-194.