

PRINCIPLES OF PRETREATMENT SYSTEMS FOR  
ON-SITE WASTE DISPOSAL

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## PRINCIPLES OF PRETREATMENT SYSTEMS FOR ON-SITE WASTE DISPOSAL

By

James C. Converse\*

January, 1992

On-site wastewater systems, using soil absorption treatment and disposal, have been used for many years for homes or commercial establishments which are not connected to a community wastewater treatment system.

Individual on-site systems, commonly known as septic systems, consist of several components: collection, pretreatment, treatment and disposal. This paper will discuss pretreatment units as they relate to on-site waste treatment and disposal.

A pretreatment unit is essential for on-site systems as it pretreats the wastewater before it reaches the soil system for final treatment and disposal. For surface discharge the pretreatment unit serves as both the pretreatment and treatment system, except for disinfection, providing an effluent that should meet surface discharge criteria. There are essentially two classes of pretreatment units; anaerobic and aerobic. Sometimes both of these units are used in combination.

The purpose of this paper is to provide information on the pretreatment concepts, practices and alternatives. This paper is not inclusive and additional information must be sought for design purposes. A list of definitions is included to assist those unfamiliar with the terms (Appendix).

### ANAEROBIC PRETREATMENT UNITS

Most all anaerobic pretreatment units for on-site treatment and disposal systems have been the septic tank and will likely continue to be or it will be used in combination with other pretreatment units. This discussion centers on the basic principles and adaptations that may affect septic tank performance.

Recently there has been interest in anaerobic upflow filters which are processing units that follow a septic tank. The purpose of the anaerobic upflow filter is to improve the septic tank effluent by reducing the BOD and total suspended solids prior to final treatment and disposal with the intent of downsizing the treatment unit that may follow. However, there is limited data available on such units.

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The use of product and company names in this document is for illustrative purposes and does not constitute endorsement of the product or company.

## A. Septic Tank Unit

### 1. Principle of Operation:

- a. Solids settling and flotation.
- b. Liquefaction of solids - converting settleable solids into suspended and dissolved solids.
- c. Anaerobic environment (no oxygen present).

### 2. Tank Configuration

- a. Must promote quiescent settling so most suspended solids settle or float (Fig. A-1).
- b. Tanks with larger surface areas and shallower depth (max. 3.5 ft of liquid depth) are preferred as larger surface area increases surge storage capacity resulting in a smaller rise of the surface area, slower discharge rate and a reduced exit velocity.
- c. Double compartment tanks with 2/3 and 1/3 volume ratio (Fig. A-2). Equal size compartments can cause flow oscillation between compartments which is not a problem with tanks in series.
- d. Several tanks in series especially for restaurant waste. Too much septic tank volume may promote new cell growth adding flocculent type solids. However there is no data available to indicate that this may occur.
- e. When pumping wastes into septic tank:
  1. the flow rate must be low to minimize disturbance in the tank and resuspend settled material. Although no data is available, flow rates of less than 10 gpm are recommended.
  2. the volume of waste discharged to the tank must be small so as not to create large velocities and displace a large quantity of waste. Although no data is available, less than 10 gallons per pumping cycle is recommended.
  3. two tanks in series is recommended each with inlet and outlet baffles.

### 3. Effluent Quality

- a. Typical effluent quality from septic tanks under proper operating conditions is: (EPA, 1980)

BOD <sub>5</sub>	125 - 150 mg/L
Total suspended solids	50 - 100 mg/L
Total nitrogen	45 - 50 mg N/L
Fecal coliform counts	10 <sup>5</sup> - 10 <sup>6</sup> MPN/100 ml

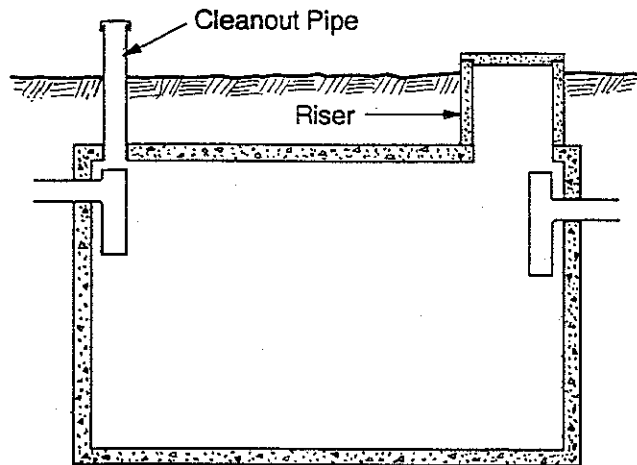


Fig. A-1 Cross section of a single compartment tank showing baffle location.

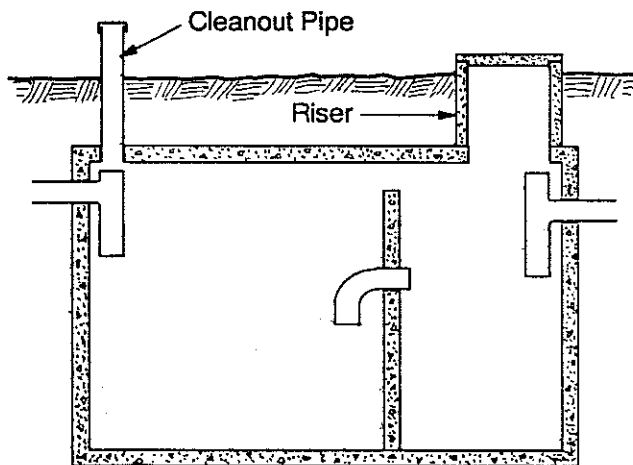


Fig. A-2 Cross section of a double compartment tank showing baffle location with compartments volume ratios of 2/3 to 1/3.

b. Nitrogen is in the form of organic nitrogen and ammonia ( $\text{NH}_3$ ) and ammonium ( $\text{NH}_4^+$ ).

c. Effluent is odorous (septic) and turbid.

4. Inlet baffle

a. Directs flow downward to dissipate energy and minimize disturbance of scum and settleable solids.

b. Types consist of 4" PVC tee or other suitable-sized baffle that can be cleaned out from above (Fig. A-1).

c. Need 4" cleanout to above ground surface.

## 5. Outlet baffle

- a. Retains scum in tank.
- b. Has large enough surface area to minimize disturbance due to exit velocity through baffle which should be lower than the solids settling velocity. For example a 6" baffle provides an exit velocity of  $\frac{2}{3}$  that of a 4" baffle for the same flow rate in gpm.
- c. May have gas deflection capabilities to deflect solids carried upward by gas bubbles into baffle outlet. The impact of gas deflection baffles is questionable because of the relatively small area of the baffle to the tank area. However, they can be built into the baffle with minimal cost. Gas deflection baffles:
  1. may consist of two 4" diameter tees with lower tee ends cut at slight angle (Fig A-3).
  2. may consist of a 4" tee and a 4" long sweep elbow with end cut at slight angle (Fig. A-4).
  3. may be commercially available units connected to tank wall with gas deflection units incorporated.
- d. Must be able to retain non-floaters and non-settleable solids such as plastic, diaper liners, towelette wipes, cigarette butts. Most current baffles will not retain such objects in the tank. Such devices may consist of:
  1. a horizontal plate filter (e.g. Zabel Industries Inc.) which is the baffle (Fig. A-5).
  2. an effluent screen ( $\frac{1}{8}$ " open mesh screen) (e.g. Orenco Systems Inc.). The screen is the baffle in the septic tank or the septic tank can have one of the above baffles with the filter placed around the pump or siphon in a dose chamber (Fig. A-6 and A-7).
- e. Should have a 24 - 30" diameter riser placed above the outlet baffle instead of the inlet baffle for easy servicing and inspection. Riser should come to above ground surface for easy access for inspection.

## 6. Tank Integrity

- a. In high water table sites, infiltration can add ground water to system. Leaks occur around the tank cover, infiltration through concrete wall due to poor quality concrete, joints in riser and at the riser/cover joint. Frost action may break joint. Consider the following:
  1. Good sealant at joints for concrete risers.
  2. Ribbed PVC riser epoxyed into special groove in septic tank top (e.g. Orenco Systems Inc., Fig. A-6).

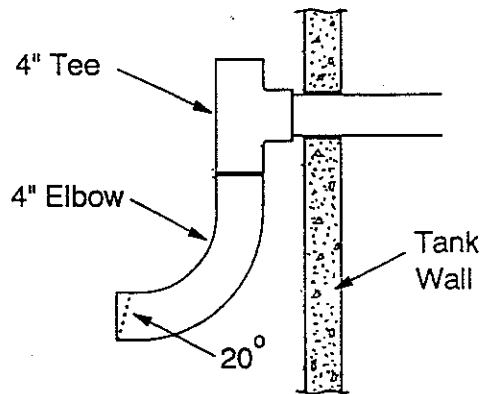


Fig. A-3 Cross section of a gas deflection baffle utilizing a 4" PVC tee and elbow with a 20 degree angle cut on the elbow.

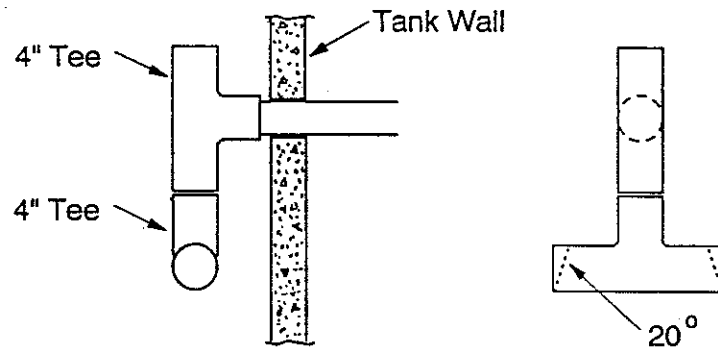


Fig. A-4 Cross section of a gas deflection baffle utilizing two 4" PVC tees with a 20 degree angle cuts on the lower tee.

3. Backfill around riser with pea gravel to keep frost action from breaking joint.

b. Provide an adequate sand base for the tank.

c. Provide a quality concrete tank with adequate reinforcing and quality concrete that is engineered for the site.

d. Provide for tank flotation in high water table situations.

#### 7. Maintenance of tanks

a. Proper pumping schedule reduces solids carry over into the soil absorption unit.

b. Regular pumping of the septic tank on a 3 to 4 year basis or more often if excessive solids accumulation occurs such as from restaurants.







Fig. A-7     An effluent screen surrounding a pump or siphon in a dose chamber. The screen is 1/8 in. mesh polyethylene with a fiber glass bottom. It comes in various diameters and heights. It does not replace the outlet baffle such as a 4" tee in the septic tank (Orengo Systems Inc.).

- c. Proper maintenance of baffles and filters.
- d. Encourage owners not to use strong cleaning compounds; especially those that have VOCs
- e. Enzymes and compounds that claim to facilitate septic tank performance should not be used. If compounds enhance the conversion of solids to gases they may be appropriate. If they enhance the liquefaction of the settled or floating solids (conversion to dissolved and suspended solids) then they must not be used as it adds BOD and suspended solids to the final treatment unit.
- f. Garbage grinders are not compatible with on-site systems. If garbage grinders are installed, enlarge septic tank and pump tank more often.

## B. Anaerobic Upflow Filters

### 1. Description

Anaerobic upflow filters consist of a liquid-tight tank normally filled with rock or other aggregate materials. Influent is introduced through a distribution system at the bottom of the tank with the liquid moving upward and exiting the tank near the top. Somewhat uniform distribution of influent is required to minimize short circulating of liquid through the aggregate. Limited field experience exists.

### 2. Principle of Operation and Performance

- a. The aggregate provides an attachment area for the microflora to grow.
- b. As the liquid passes upward through the aggregate the microflora convert the dissolved and suspended solids to water, gas and other cells.
- c. Effluent quality exiting the unit should have lower BOD and suspended solids. BOD<sub>5</sub> and total suspended solids reductions of 40-60% and 25-50%, respectively, with half day retention times are reported in the literature (Andreakakis, 1987; Viraraghavan and Kent, 1984 and 1986, Venhuizen, 1991),
- d. Higher hydraulic loading rates on the downstream treatment systems such as sand filters or soil absorption systems are possible with lower BOD and suspended solid wastewaters. Soil hydraulic loading rates must be considered.

### 3. Design

Upflow filters are not a very common component in residential on-site systems especially in the upper Midwest. Caution must be exercised when designing and implementing such a system until further investigations are undertaken. Thus these design comments and concepts are based on limited literature and field data.

- a. Upflow filters can be incorporated into an on-site system:
  1. by using a large single tank with one or two septic tank compartments followed by an upflow filter compartment (Fig A-8).
  2. by using a one or two compartment septic tank followed by a separate upflow filter tank (Fig. A-9).
- b. The minimum septic tank size is limited by code requirements, i.e. 1000 gallons for a 3 bedroom home.

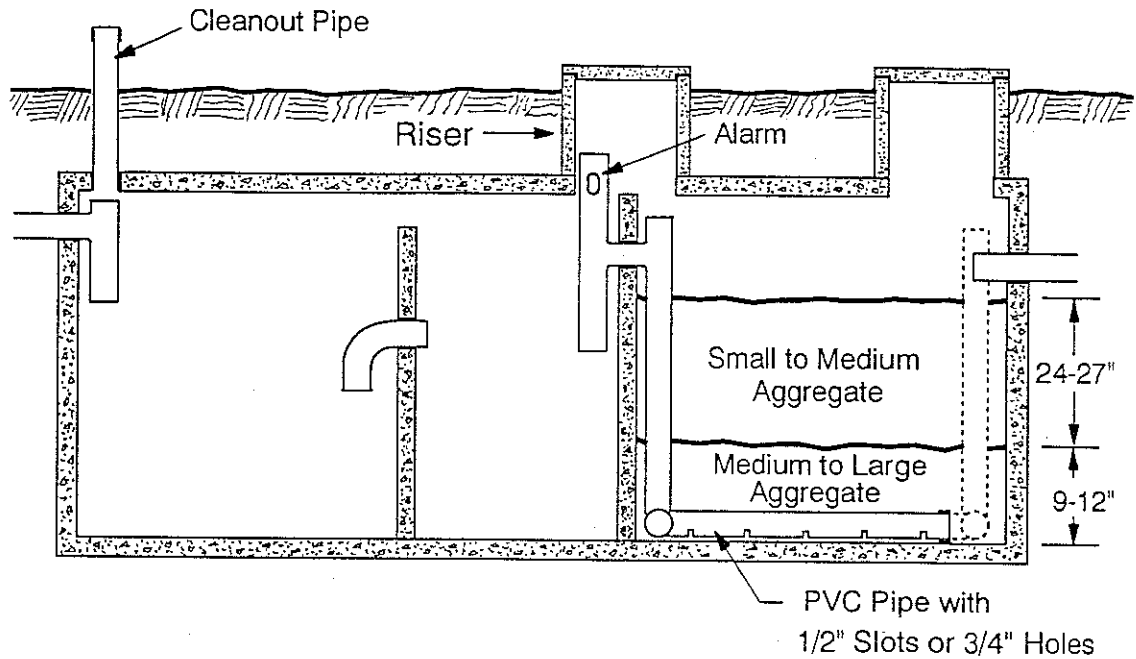


Fig. A-8 Cross section of a two compartment septic tank with an upflow filter. The dashed portion may be desired to assist in backflushing.

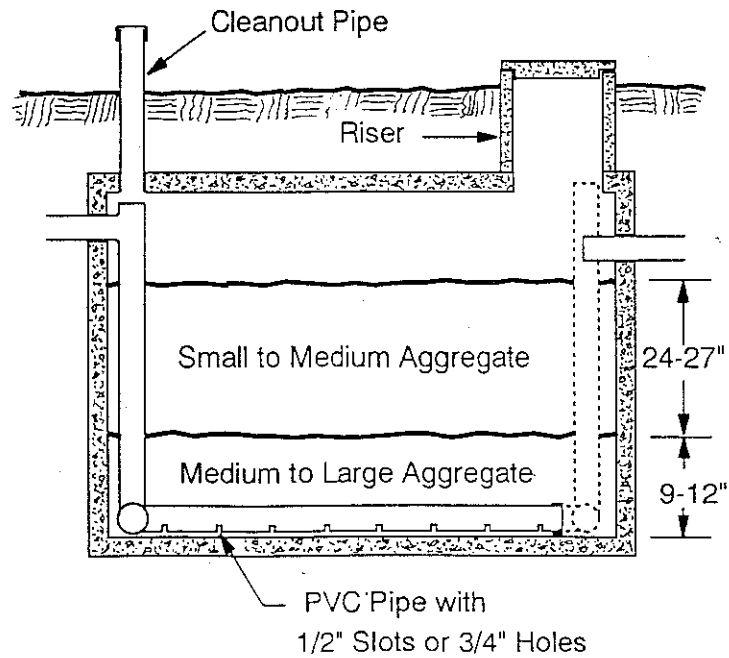


Fig. A-9 Cross section of a separate upflow filter. The dashed portion may be desired to assist in backflushing. A single compartment or double compartment septic tank proceeds the filter.

c. For a separate upflow filter for a 3 bedroom home:

1. Use a 750 gallon septic tank designed to be filled with aggregate.
2. Place a perforated plastic pipe network on the floor connected to a vertical pipe connected to the inlet tee baffle with an opening upward. The perforated pipe must support the aggregate. Use 4" diameter PVC pipe with 3/4 in. diameter holes located at 4:00 and 8:00 o'clock spaced every 4-6 in. or 1/2 in. wide slots 1 1/2 in. deep cut every 4-6 inches apart on the bottom side of the pipe. Use a header with 4 laterals spaced equally across the tank bottom with end caps (Fig. A-10).
3. Place a medium to large clean aggregate to a depth of approximately 9-12 in. surrounding the distribution pipe. This coarser aggregate should facilitate distribution of the effluent across the bottom of the tank. Place approximately 24-27 in. of small to medium clean aggregate on top of the medium to large aggregate. Too fine an aggregate may cause greater head loss and backing up of the effluent but the finer aggregate will provide more aggregate surface area for bacterial growth. Experience will determine the best aggregate to use.
4. The top of the aggregate should stop 2-3 in. below the invert of the tank outlet. Do not provide a baffle on the outlet edge but a liquid collection system on the surface of the aggregate may be needed to minimize short circuiting.
5. Place a 4 or 6 in. vertical outlet in the tank top above the inlet tee and vertical pipe so a suction hose from the pumper truck can be lowered into it.

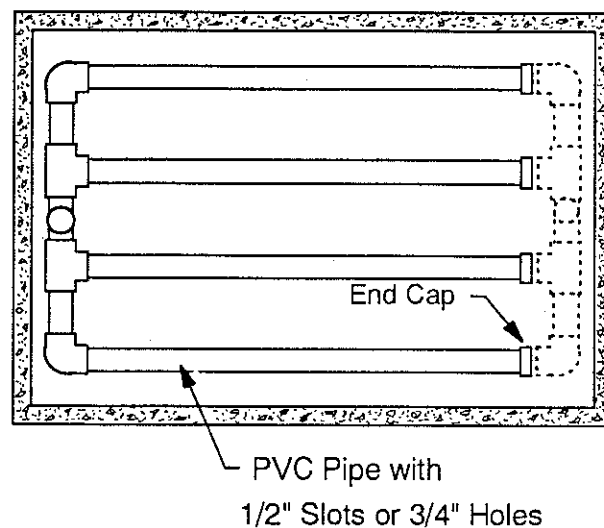


Fig. A-10

Plan view of an upflow filter showing the bottom distribution system. The dashed portion may be desired to assist in backflushing.

6. Place the 24-30 in. diameter riser over the outlet to above the ground surface.
7. The vertical distance between the inlet and outlet inverts may have to be increased to accommodate the head loss through the aggregate. Allow for driving heads of several inches .
8. A surge volume must be provided in the septic tank for large flows as the aggregate will dampen the flow rate and cause the liquid level of the septic tank to rise higher than normal.
9. The head space in the septic tank could be used provided the outlet baffle is extended upward into the riser to avoid scum from flowing into the upflow filter. This can be done easily with an extension on the top of a 4" PVC tee baffle. (Fig. A-7)
10. An alarm system, similar to that used in pump chambers, could be installed in the vertical riser of the outlet tee baffle of the septic tank to protect the home from wastewater backing up into it.
11. An alternate to the alarm system is to connect the ends of the distribution laterals with a 4" collector pipe which is connected to a vertical open ended pipe extending several inches into the riser but ending at or below the hydraulic grade line of the septic tank inlet. (Fig. A-8 and Fig. A-9). This approach will allow the distribution system to be flushed easier.

#### 4. Maintenance

- a. Backflushing the filter when the septic tank is pumped is advisable or more often if the driving head becomes too great.
- c. Backflushing is accomplished by adding water to the top of the filter and sucking out the liquid through the vertical inlet pipe connected to the distribution pipes, using a pumper truck. Cleaning water quantities added to the filter will probably have to be at a rate greater than can be added by a garden hose.

## AEROBIC PRETREATMENT UNITS

Aerobic pretreatment units utilize aerobic bacteria in the treatment process. Oxygen is mechanically or naturally added to the system to maintain aerobic conditions. Aerobic treatment can be categorized as suspended media or fixed media.

Aerobic units, activated sludge units, extended aeration units or package treatment units are suspended media units. Air is pumped into the system to provide for a transfer of oxygen from the air to the liquid as dissolved oxygen. The system operates as a totally mixed reactor with the air providing the mixing.

Rock or sand filters are fixed media units. Effluent is applied to the top of the filter intermittently and moves downward through the media. The treatment processes consist of filtration by the media and absorption of the organic matter by the microflora living on the media. As the effluent moves downward it draws air into the pore space maintaining aerobic conditions.

Rotating biological disk units can also be considered a fixed media unit as the bacteria attach themselves to the rotating disks which are partially submerged in a pool of effluent.

### A. Suspended Media (Aerobic Units)

#### 1. Principle of Operation

- a. Most of the organic matter is converted to carbon dioxide, water and new organic matter in the form of biomass cells.

Organic matter(BOD) + oxygen + aerobic bacteria = water + CO<sub>2</sub> + new biomass cells.

- b. The conversion process is much faster and more complete under aerobic conditions than under anaerobic conditions with the accumulation of many more new cells known as sludge.
- c. Extended aeration, in which the bacterial cells consume other bacterial cells, reduces the amount of waste sludge produced.
- d. The biomass in the mixed reactor are settled or filtered out of the effluent stream leaving a effluent low in BOD and suspended solids, with most of the nitrogen in the nitrate form.
- f. Suspended media systems are quite sensitive and can be easily upset with the addition of toxic chemicals or rapid and large changes in the loading rates. During these times it is not unusual for the units to foam and froth. Seeding the unit at start-up will bring the system to stability earlier. BOD and suspended solids concentrations during upset periods will likely increase resulting in a poorer quality effluent.

## 2. Design

- a. These systems are rather complex with considerable engineering in the design of the system. It is more than just injecting air into a tank of waste. There are two types of units; batch or draw and fill and continuous or intermittent.
- b. The batch unit fills and aerates during the day and evening with solids settling and discharge during the late night or early morning (Fig. B-1).
- c. The continuous (intermittent) flow systems has a constant mixed liquor volume. When a volume of influent enters the unit an equal volume of effluent exits the unit. There are several manufacturers of these units each employing different methods of adding air and clarifying the effluent. Two such units are shown in Fig B-2 and B-3.
- c. Only National Sanitation Foundation tested and approved units should be used. Two such systems have been approved for use in Wisconsin at this time (i.e. Multi-Flo Inc. and Jet Inc.). However, there are several other units approved by NSF. The NSF testing is very rigorous.
- c. Manufacturer's recommendations must be followed when installing these aerobic units.
- d. A trash trap (small septic tank) should be installed upstream of the unit. This trash trap removes large and undesirable solids such as plastics, diapers and sanitary napkins which may cause pump clogging. Some units already have a trash trap incorporated in the design (Fig. B-3).
- e. A filter, such as fabric socks or other type of filter, retains the solids in the tank (Fig. B-2). Other units may have a settling clarifier (Fig. B-3). An upflow rock filter or another type of filter may follow these units as the clarifiers are not very effective with bulking sludges (sludges that have a tendency to float instead of settle). This phenomena will occur at times and not at other times.
- f. It is difficult to determine how heavily the system will be loaded. It is desirable to oversize the system to make sure extended aeration takes place so as to minimize the pumping of the tank so often. If the system is not in the extended aeration mode, excessive sludge will be generated requiring frequent pumping to remove the sludge.
- g. Air pumps operate continuously. Some pumps are submerged while others are located above the liquid level. Depending on the size of the unit, energy consumption will approach or exceed 10 KWH per day (similar to refrigerator) for a 3 bedroom home.
- h. Noise must be considered in locating the unit on the premise. Some units are quieter than others.



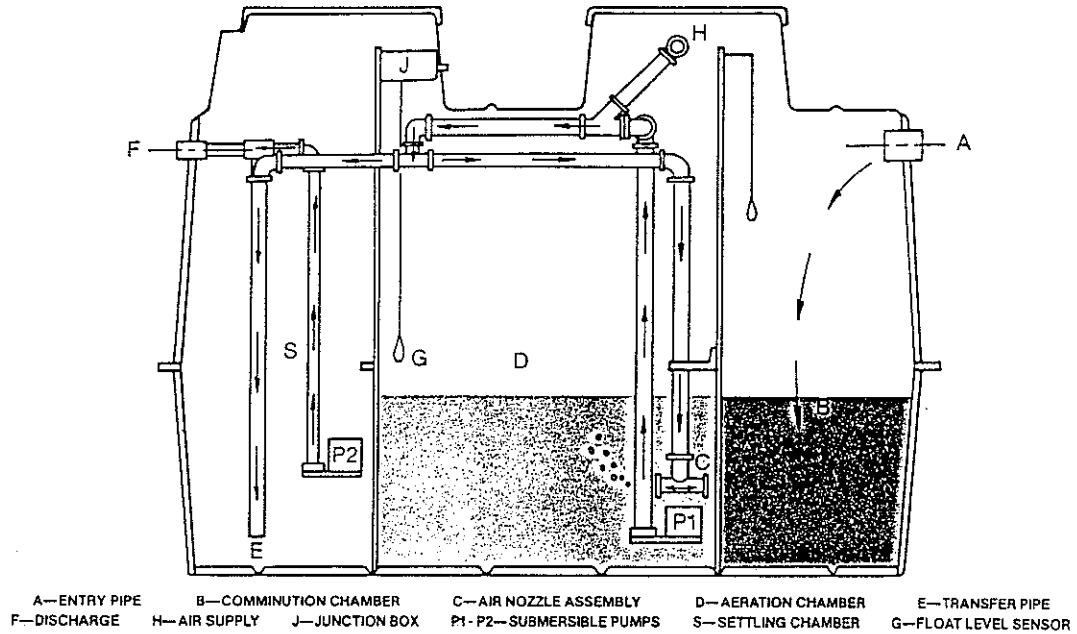


Fig. B-1 A cross section of a batch (draw and fill) aerobic unit (Gromaglass Corp.)

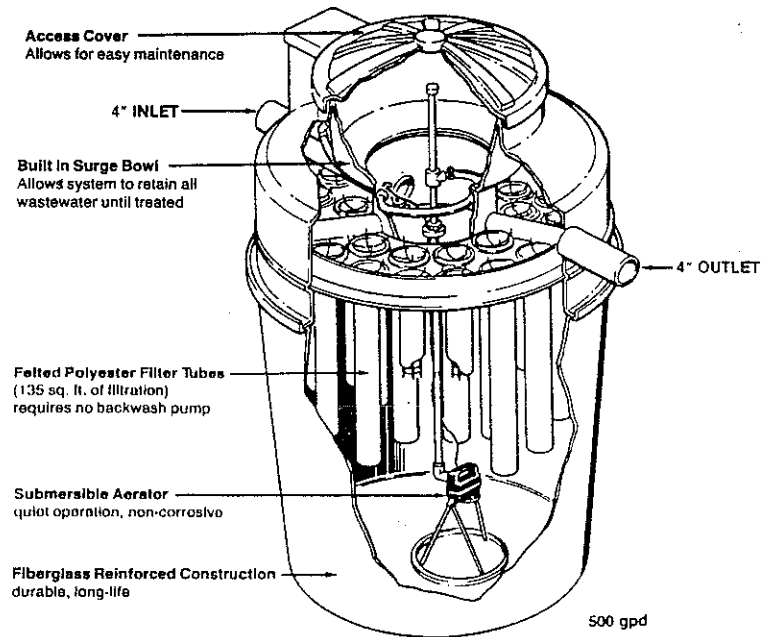


Fig. B-2 A cut away view of continuous (intermittent) flow aerobic unit utilizing filter tubes to separate the effluent from the mixed liquor. (Multi-Flo Inc.).

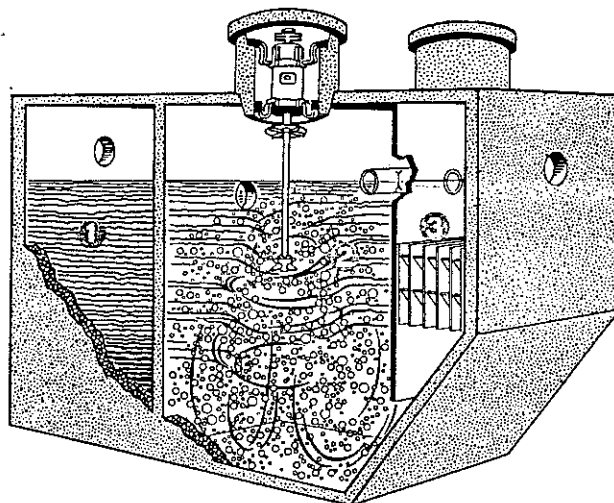


Fig. B-3 A cut away view of a continuous flow (intermittent) aerobic unit utilizing primary treatment, aeration, and settling compartments. For class 1 quality effluent flows through an upflow rock filter which is not shown (Jet Inc.).

### 3. Effluent Quality

- a. Typical effluent quality from aerobic units under proper operating conditions:

BOD <sub>5</sub>	5 - 10 mg/L
Total suspended solids	10 - 20 mg/L
Total nitrogen	30 <sup>2</sup> - 45 <sup>3</sup> mg N/L
Fecal coliform counts	10 <sup>2</sup> - 10 <sup>3</sup> MPN/100 ml

- b. Nitrogen is primarily in the nitrate form ( $\text{NO}_3^-$ ) with a small amount of organic and ammonia (normally less than 2-3 mg N/L).
- c. Effluent should be non odorous and clear.

### 4. Maintenance

- a. Aerobic units do require pumping to remove the accumulated sludge every one to two years depending upon rate of sludge production.
- b. Semi-annual or annual routine maintenance by a professional is necessary thus requiring an annual fee structure or some other financial structure to insure proper maintenance.

## B. Fixed Media (Sand or Rock Filters)

### 1. Principle of Operation

- a. Most of the organic matter is converted to carbon dioxide, water and new organic matter in the form of biomass cells.

Organic matter(BOD) + oxygen + aerobic bacteria = water + CO<sub>2</sub> + new biomass cells.

- b. A septic tank is required up-stream to remove the settleable solids.
- c. The sand filter is considered a passive system while aerobic units are an active system.
- d. Sand filters are more stable than aerobic units.
- e. Sand filters do not accumulate as much sludge as an anaerobic unit.

### 2. Effluent Quality

- a. Typical effluent quality from sand filters under proper operating conditions:

BOD <sub>5</sub>	5 - 10 mg/L
Total suspended solids	10 - 20 mg/L
Total nitrogen	30 - 45 mg N/L
Fecal coliform counts	10 <sup>2</sup> - 10 <sup>3</sup> MPN/100 ml

- b. Nitrogen is primarily in the nitrate form (NO<sub>3</sub><sup>-</sup>) with a small amount of organic and ammonia (normally less than 2-3 mg N/L).
- c. Effluent is non-odorous and clear.

### 3. Design

- a. Sand filters can be designed as single pass buried filter, single pass free access or as recirculating sand filters. All are intermittently loaded (Figs. B-4, B-5, B-6 and B-7).
- b. Sand filters can be open bottomed or they are sealed in which the effluent flows out by gravity or is pumped out (Fig. B-4). Normally no portion of the sand filter is submerged or remains saturated. Open bottomed filters are for sites where depth to limiting conditions allow additional unsaturated soil treatment.
- c. Sizing of the single pass filter is dependent upon:
  1. strength of the wastewater with higher strength wastes requiring lower loading rates and larger units. Anaerobic upflow filter effluent may allow higher loading rates than septic tank effluent because of the reduced BOD and total suspended solids.

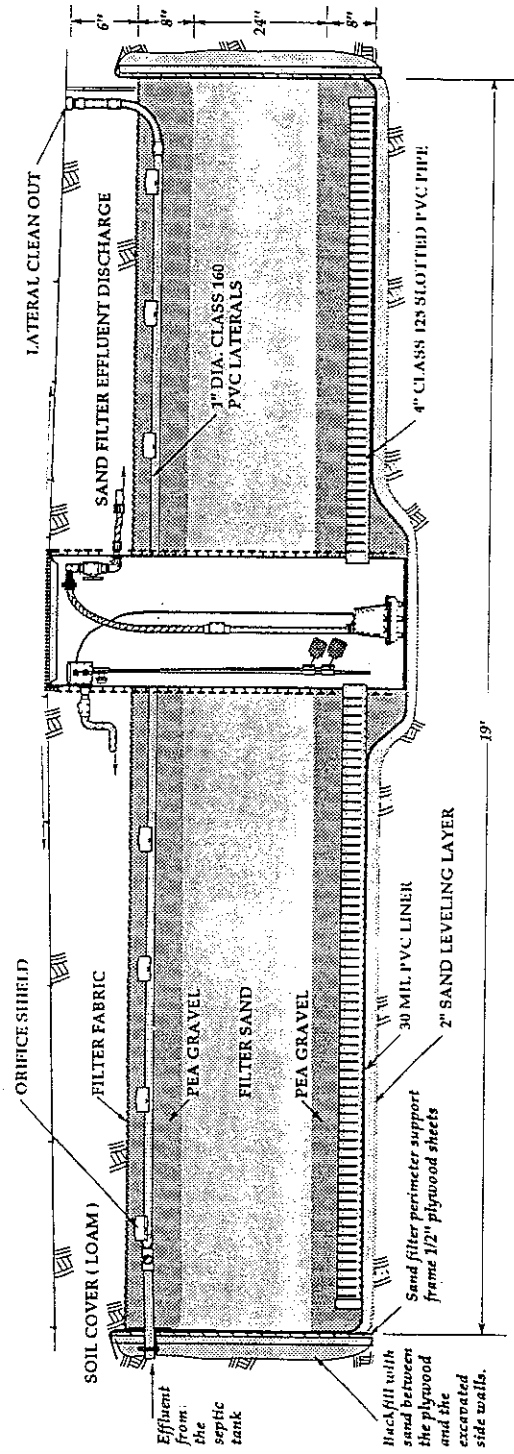
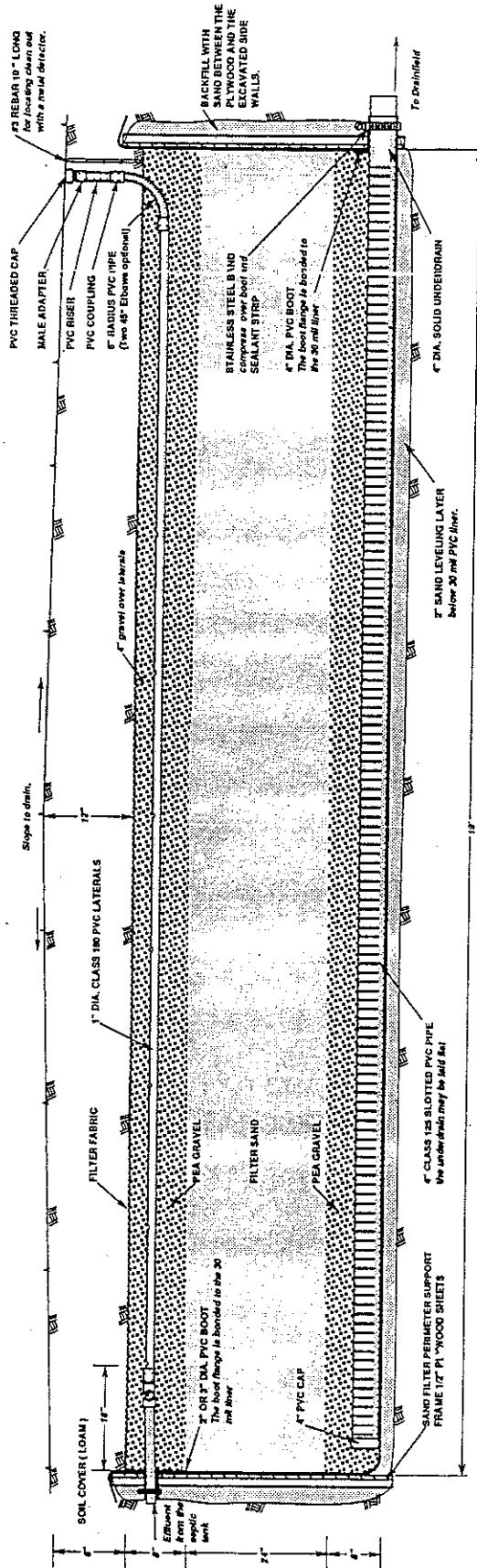


Fig. B-4 Cross section of a single pass buried sand filter using a 30 mil liner with pressure distribution with holes upward. Laterals must drain after each dose or holes should be located downward. Top figure shows gravity flow and bottom figure showing a pump located in the filter (Orencia Systems Inc.).

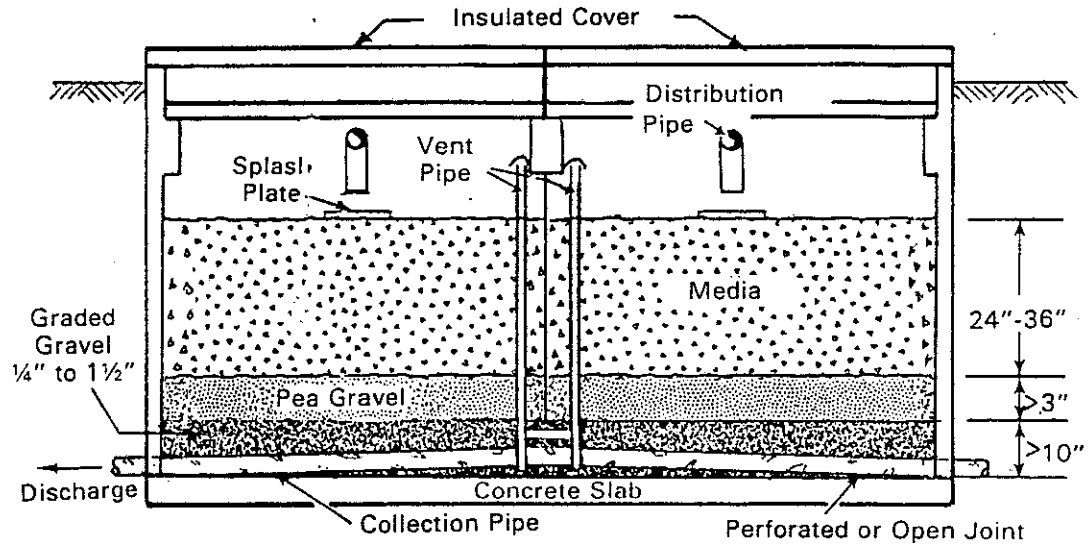


Fig. B-5 Cross section of a single pass free access sand filter utilizing two compartments with a splash plate. A more uniform application such as a spray nozzle or pressure distribution with deflectors is desired. (EPA, 1980).

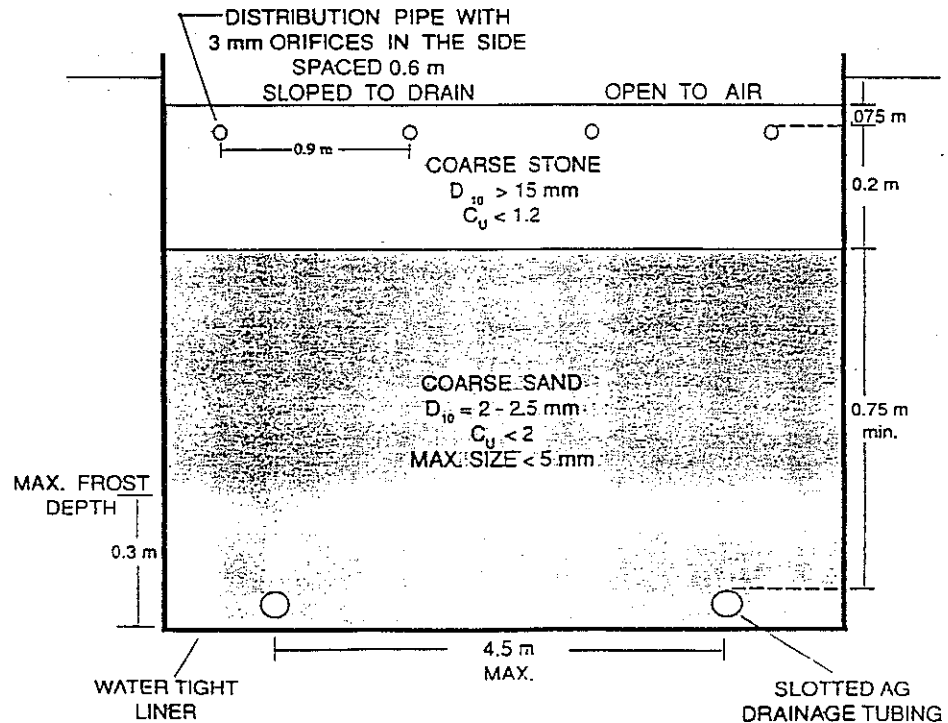


Fig. B-6 Cross section of a free access sand filter recommended for cold weather with pressure distribution pipe located in the aggregate placed on the sand surface. Sand specifications listed are for recirculating sand filters. If single pass is utilized then the sand size should be smaller (Loudon et al., 1989).

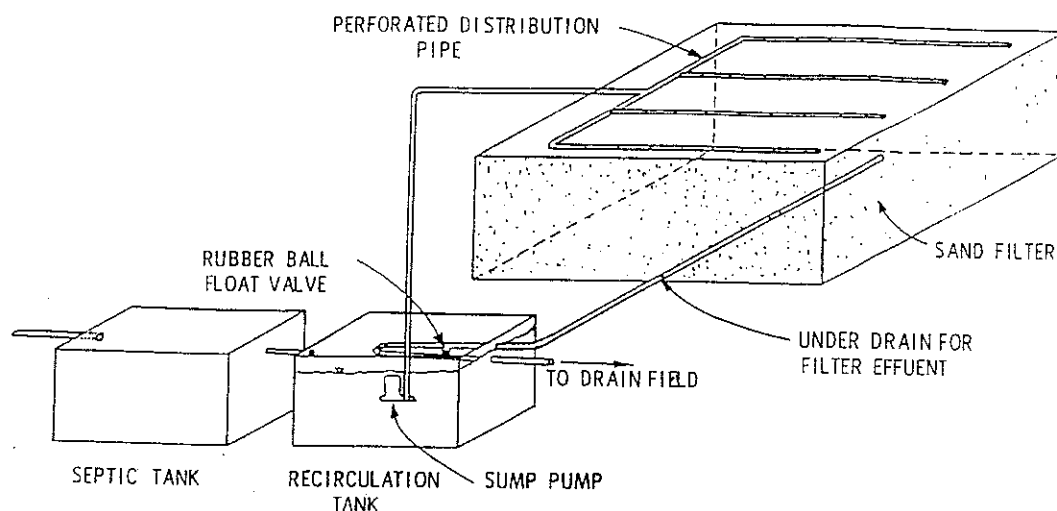


Fig. B-7 Schematic of a recirculating sand filter for cold climates with cross section of sand shown in Fig. B-6 (Loudon et al., 1989).

2. effective size and uniformity coefficient of the sand. In general, the coarser sand will require less maintenance and clog less frequently but will produce an effluent with higher BOD and suspended solids. It can also be loaded at a higher rate than the finer sands. The following table gives the design values from the literature using domestic waste septic tank effluent. For wastes with higher BOD and suspended solids adjustments must be made.

Type	Loading Rate gpd/ft <sup>2</sup>	Effective Size mm	Uniformity Coefficient -
Buried	1.0	0.5 - 1.0	3.5 - 4.0
Free Access	2.0 - 5.0	0.35- 1.0	3.5 - 4.0
Recirculating	3.0 - 5.0**	0.3 - 1.5*	3.5 - 4.0*

\*Another source recommends that effective size and uniformity coefficient be 2.0-2.5 mm and <2, respectively, for cold regions. \*\*Forward flow loading rate.

On-going research in sand filters indicates that sand quality greatly affects performance and maintenance. These new research findings will give better design criteria for sand size, sand depth and loading rates.

- d. For recirculating sand filters a recirculation rate of  $2^{3-5}$  is recommended. For a forward loading rate of 3.0 gpd/ft<sup>2</sup> and a recirculating rate of 4, the actual loading rate is 12 gpd/ft<sup>2</sup>. Effective sand size is usually larger for recirculating than single pass filters.

- e. Pressure distribution of effluent over the filter is essential.
  - 1. For cold weather free access filters, the pressure distribution unit is placed in 6" of aggregate which is placed on the surface of the sand (Fig. B-6).
  - 2. For free access filters, without rock cover, use some type of spray nozzles that spread the waste over the surface.
  - 3. A uniform application is desired for better performance of the filter. Smaller diameter orifices and closer spacing is desired.

#### 4. Maintenance

- a. Free access filters may require the removal of a clogging mat on the surface of the sand. The surface may need to be periodically raked and plant growth will need to be removed. Properly designed and operated units may not develop a clogging mat.
- b. Normal pump maintenance will be required.

### C. Fixed Media (Rotating Biological Contactor)

#### 1. Principle of Operation

- a. Most of the organic matter is converted to carbon dioxide, water and new organic matter in the form of biomass cells.  
  
$$\text{Organic matter(BOD)} + \text{oxygen} + \text{aerobic bacteria} = \text{water} + \text{CO}_2 + \text{new biomass cells.}$$
- b. A septic tank is required up-stream to remove the settleable solids.
- c. The disks rotate slowly with a portion of the disk submerged in the septic tank effluent. The biological growth is attached to the disks (Fig. B-8).
- d. During the submerged portion of the cycle, the bacteria come in contact with the organic material (BOD) in the effluent and during the air exposed portion of the cycle, oxygen is diffused into the biological mat maintaining aerobic conditions.

#### 2. Design

- a. These systems are quite complex and require considerable engineering. Manufacturer's specifications must be followed.
- b. The unit must be housed in some type of enclosure to assure above freezing conditions.

### 3. Effluent Quality

- a. Limited data is for on-site home size systems.
- b. Based on one study for a home size system the typical effluent quality was 35 mg/L of COD and 20 mg/L of total suspended solids. Removal efficiencies were 70-90% COD removal and 60-70% removal total suspended solids (Jacques et al., 1991).
- c. Removal rates and effluent quality was influenced by the loading rate and rotational speed.

### 4. Maintenance

- a. Semi-annual or annual routine maintenance by a professional is necessary thus requiring an annual fee structure or some other financial structure to insure proper maintenance.
- b. Periodical pumping of the septic tank and accumulated biomass (sludge) is necessary.

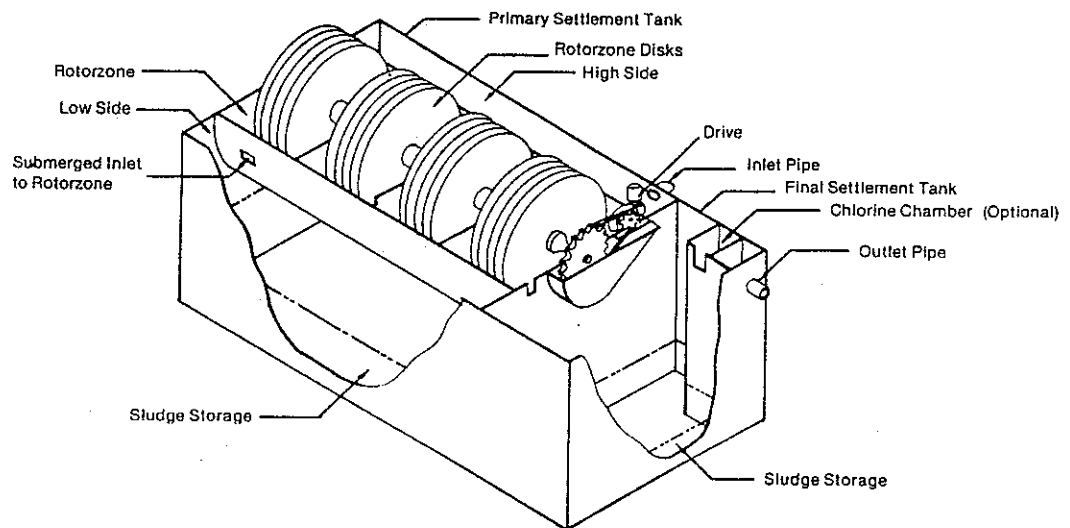


Fig. B-8 Schematic of a rotating biological contactor (CSM Rotordisk, Inc.).



## NITROGEN REMOVAL SYSTEMS

Typical nitrogen concentrations in the pretreated effluent from septic tanks, upflow filters, aerobic units and sand filters ranges from 30-50 mg N/L, being quite variable from system to system. The drinking water standard for nitrogen is 10 mg N/L. Thus, the effluent entering the soil absorption system does not meet this standard. If the standard is to be met, the soil absorption system must be able treat and remove the nitrogen to acceptable levels before the effluent enters the ground water. Research indicates that on-site systems do not adequately treat the nitrogen and thus contribute excessive nitrogen to the ground water at levels above the 10 mg N/L in sandy soils (Walker, et al. 1973). In structured soils the impact may be less but recent research indicates that the levels may still be above the 10 mg N/L (Converse, et. al, 1991). A number of nitrogen removal systems have been suggested but there is not much field performance data available (Whitmyer et al., 1991).

### A. Nitrogen Species

1. Nitrogen in nature is present in the forms of nitrogen gas, organic nitrogen, ammonium, nitrite and nitrate.
2. Nitrogen gas makes up 78% of the atmosphere.
3. Organic nitrogen is found in organic matter especially proteins and excreted in feces and urine.
4. Ammonium ( $\text{NH}_4^+$ ) is an ion found in aqueous solutions while ammonia ( $\text{NH}_3$ ) is a dissolved gas found in aqueous solutions or as a gas in the atmosphere. The pH of the solution dictates the ratio of the ammonium to ammonia in aqueous solutions. The higher the pH the greater the proportion of ammonia. When ammonia is noted in this publication it includes both species. Ammonia is excreted in the urine.
4. Nitrite ( $\text{NO}_2^-$ ) is an ion found in aqueous solutions. If nitrite is present in the solution, it is usually included as part of the nitrate as it is relatively unstable and easily converted to nitrate.
5. Nitrate ( $\text{NO}_3^-$ ) is an ion found in aqueous solutions.
  - a. Nitrate can be reported as both nitrate ( $\text{NO}_3^-$  in mg/L) or nitrate nitrogen ( $\text{NO}_3^-$  mg N/L or mg/L of N). Nitrate concentrations are 4.5 times as great as nitrate nitrogen concentrations. Thus drinking water standards are reported as 10 mg N/L as nitrate nitrogen (also as  $\text{NO}_3^-$ -N) or 45 mg/L of nitrate (also as  $\text{NO}_3^-$ ).
  - b. Nitrate nitrogen is the species normally reported in drinking water but ammonia may also be present under certain anaerobic circumstances.
6. Nitrogen conversion from one species to another is as follows:
  - a. organic nitrogen is converted to ammonium/ammonia by bacterial action either under anaerobic conditions such as in the septic tank or under aerobic conditions such as in aerobic units. Some organic nitrogen will exit these tanks in bacterial cells and other organic material.

- b. ammonium/ammonia is converted to nitrite then to nitrate by nitrifying bacteria under aerobic conditions which occurs in aerobic units, sand filters and beneath the soil absorption system.
- c. Nitrates are converted to nitrogen gas by denitrifying bacteria if anaerobic conditions and a source of carbon is present. This can occur beneath the soil absorption system or in tanks.
- d. The conversion to nitrate is sensitive to temperature with less conversion at lower temperatures.

## B. Nitrogen Removal Methods

### 1. Dilution of Wastes

- a. NR140 code is based on concentration (mg/L) and not mass loading.
- b. dilution is an acceptable means of meeting the groundwater standards.
- c. Ten gallons of effluent with a nitrate concentration of 50 mg N/L will have a nitrate concentration of 10 mg N/L if diluted to 50 gallons, thus meeting ground water standards at the point of application.
- d. Large quantities of dilution water added to the on-site system to meet the nitrate standards may cause hydraulic failure of the soil absorption system. Systems 5 times larger than current code requirements would be required for similar loading rates in  $\text{gpd/ft}^2$ .
- e. Groundwater dilution may not be an acceptable method for meeting drinking water standards:
  - 1. because effluent plumes form beneath the soil absorption system due to non-uniform distribution of effluent in the system and to the non-homogeneity of the soil beneath the system.
  - 2. because ground water mixing cannot be counted on as an effective method of dilution.
  - 3. but proper orientation on the landscape and pressure distribution to spread the effluent along the groundwater contour will enhance the dilution in the groundwater.

### 2. Separation of Wastes

- a. Approximately 75-80% of the nitrogen found in residential wastewater is in the black waters (toilet wastes) and the remainder in the grey waters (sink, bath, washing).
- b. Thus if waste components were segregated into the black and grey water components with the black waters stored in a holding tank and hauled to a treatment system and the grey waters treated in the on-site system, approximately 75-80% of the nitrogen would be removed and not impact upon the ground water (Fig. C-1).

- c. Assuming 75% of the nitrogen is in the black water and the nitrogen concentration is 45 mg N/L in the combined waste, the nitrogen concentration in the grey water would be approximately 12 mg N/L. With some loss occurring in the treatment system, this approach would likely meet ground water standards.
- e. Utilizing low flow toilets will minimize the hauling of the black water but community treatment systems would have to accept this wastewater.
- f. The majority of the nitrogen in this waste would be converted to nitrate in the treatment plant and be conveyed with the effluent to final disposal in surface waters or ground waters. Thus it is still in the environment but at a different location.

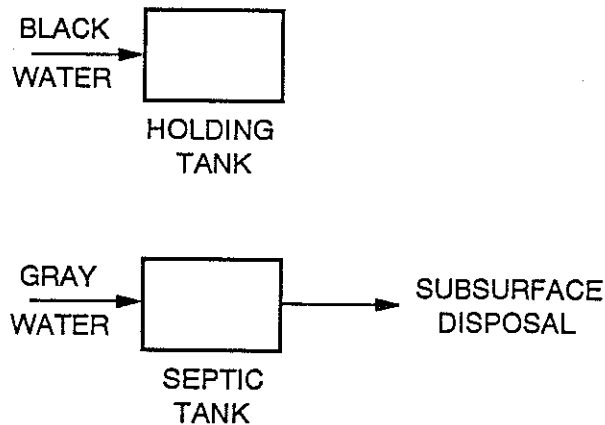


Fig. C-1 Flow diagram of a system segregating the black waters from the grey waters and hauling the black waters off site.

### 3. Ion Exchange

- a. Ion exchange resins may be developed for ammonium or nitrate ion removal from the wastewater using similar principles as currently employed in water softeners (Fig. C-2).
- b. When the resin is exhausted the cartridge is replaced with a regenerated cartridge and the exhausted cartridge is taken to a processing plant for regeneration. Proper disposal of the ammonium and nitrate is done at the plant.
- c. This technology has not been perfected yet and in all likelihood the wastewater would have to be highly pretreated with the nitrogen in the ammonium or nitrate form prior to entering the cartridge.

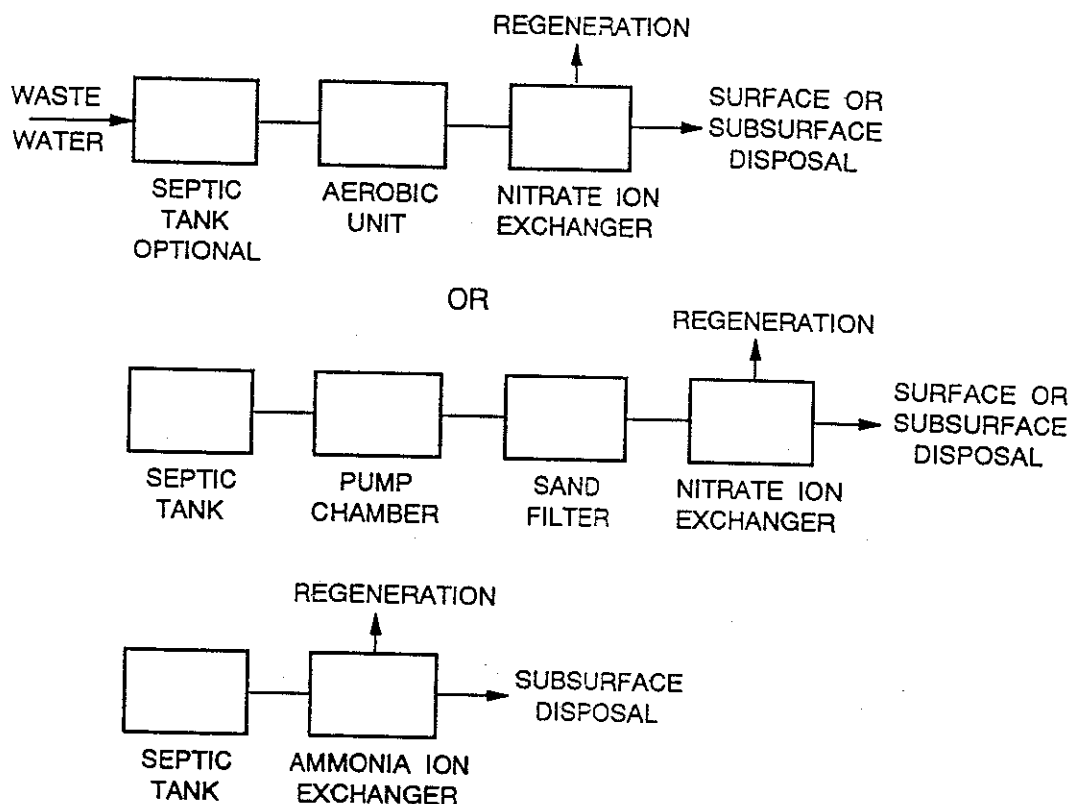


Fig. C-2 Flow diagram of a ion exchange system utilizing cation or anion exchange for ammonia or nitrate nitrogen removal.

#### 4. Denitrification

##### a. Principle of Operation

1. Denitrification is a biological process in which bacteria convert nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) to nitrogen gas as the bacteria use the oxygen molecule as an electron acceptor.
2. For denitrifying bacteria to function they must have an anaerobic environment with a source of carbon which serves as a food (energy source, BOD).
3. In the process of converting the nitrogen to nitrates with sand filters or aerobic units, most of the carbon source (BOD) is consumed by the bacteria.
4. Most any readily available organic matter will suffice as a carbon source such as ethanol, methanol or sewage. However, it must be easily added to the system in controlled amounts so as not to increase the BOD of the final effluent significantly. In some systems the nitrified effluent is returned to the septic tank so as to use the incoming sewage as the carbon source.

b. Types of Systems

1. Recirculating Sand Filter

- a. The system consists of a septic tank, a recirculation tank and a sand filter (Fig. C-3).
- b. The septic tank effluent enters the recirculating tank and it is intermittently pumped to the sand filter where the BOD and suspended solids are removed and the nitrogen converted to nitrate.
- c. Either all of the sand filter effluent flows into the recirculation tank or a portion of it is diverted to final treatment and disposal. The amount diverted depends on the desired recirculation rate to the sand filter. If a recirculation rate of 4 is desired, then 25% of the flow is diverted.

If it all flows into the recirculation tank, a diverter valve (floating ball in a basket) closes, diverting the sand filter effluent to final treatment and disposal.

- d. The recirculation tank contains the septic tank effluent which is anaerobic and the BOD and suspended solids serve as a carbon source for the bacteria to convert the nitrate to nitrogen gas.
- e. Depending on the operating conditions, this system removes approximately 50-70% of the total nitrogen. If the septic tank effluent contained 45 mg/L of nitrogen and a 70% removal rate is achieved, the final effluent stream would have a nitrate nitrogen concentration of approximately 15 to 22 mg N/L.

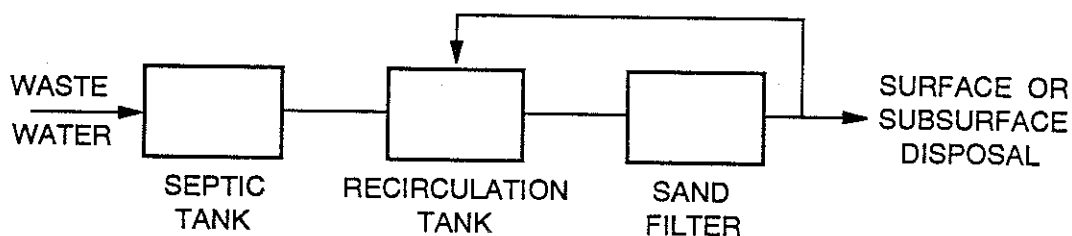


Fig. C-3 Flow diagram of a recirculating sand filter for nitrogen removal.

3. Recirculating Sand Filter - Anaerobic Upflow Filter

- a. The system consists of a septic tank, upflow filter and a recirculating sand filter (Fig. C-4).

- b. The septic tank effluent enters the upflow filter where additional BOD and suspended solids and additional organic nitrogen is converted to ammonia.
- c. The upflow filter effluent is intermittently pumped to the recirculating sand filter where the BOD and suspended solids are further removed and the nitrogen converted to nitrate. A portion of the effluent is recycled to the upflow filter with the remainder going to final treatment and disposal.
- d. The bacteria in the anaerobic upflow filter convert the nitrate to nitrogen gas. The carbon source is the BOD and suspended solids in the septic tank effluent.
- e. Nitrogen removals of 50 -70% are possible.

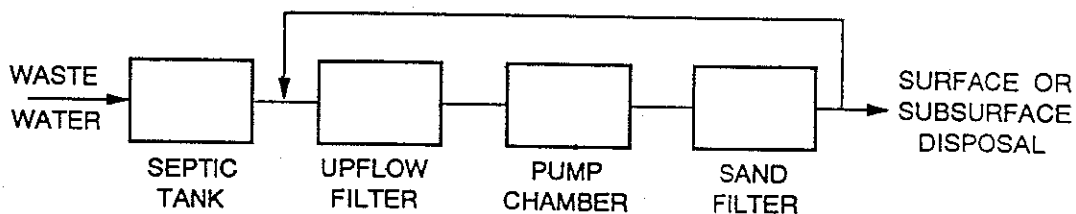


Fig. C-4 Flow diagram of a recirculating sand filter with an upflow filter for nitrogen removal.

#### 4. Aerobic Unit - Carbon Source Addition - Anaerobic Upflow Filter

- a. A septic tank may be installed upstream of the aerobic unit (Fig. C-5)
- b. The aerobic unit removes the BOD and suspended solids and converts the organic nitrogen and ammonia to nitrate.
- c. A prescribed amount of ethanol or methanol is added to the effluent stream to provide a carbon source for the bacteria. The ethanol also provides sufficient BOD to convert the aerobic stream to anaerobic conditions.
- d. The effluent flows to a upflow anaerobic rock filter with several days detention time for the nitrate to be converted to nitrogen gas.

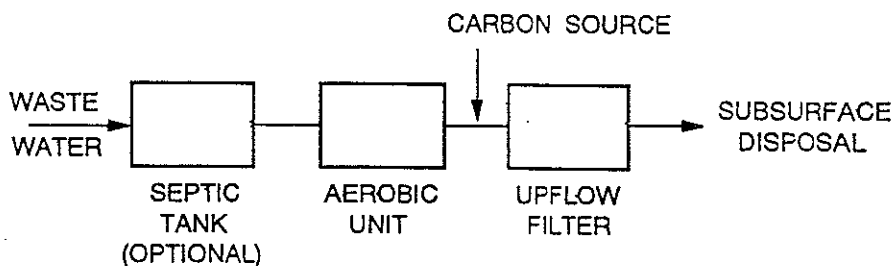


Fig. C-5 Flow diagram using an aerobic unit, carbon source and upflow filter for nitrogen removal.

5. Segregation - Septic Tank - Sand Filter - Recombination (Ruck System)

- a. The wastewater at the home is segregated into the black water and the grey water with separate streams exiting the building (Fig. C-6).
- b. The black water passes through a septic tank and a sand filter where the nitrogen is converted to nitrate.
- c. The grey water passes through a separate septic tank.
- d. The sand filter effluent flows into the grey water septic tank. The septic tank is anaerobic and the grey water BOD and organic matter serve as the carbon source for the bacteria to convert the nitrate to nitrogen gas.
- e. Nitrogen removals of 40 - 60% have been achieved. The 25% in the grey water stream will not be removed as it is not in the nitrate form.

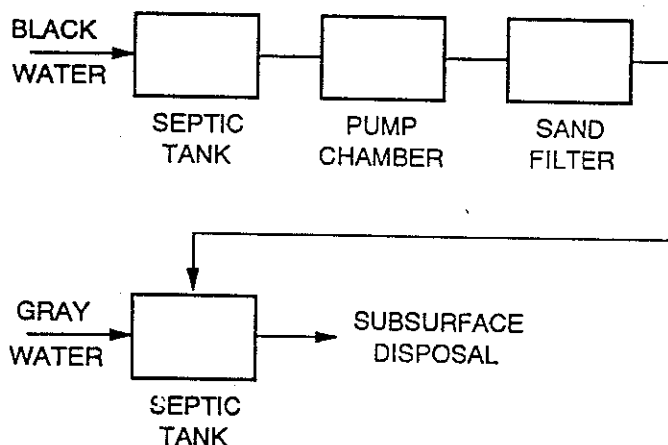


Fig. C-6 Flow diagram segregating the black waters from the grey waters, nitrifying the nitrogen in the sand filter and using the carbon in the grey water for denitrifying. This process is known as the Ruck system.

## 6. Septic tank - Peat Filter

- a. The system consists of a septic tank and a peat filter (Fig. C-7).
- b. The peat filter is similar in design to a sand filter with an underdrain and designed so the bottom portion of the filter is submerged.
- c. Septic tank effluent is applied to the peat filter. As it moves down through the unsaturated peat filter the BOD and suspended solids are removed and the nitrogen converted to nitrate.
- d. The nitrified effluent enters the submerged portion of the peat filter where anaerobic conditions exist. The peat serves as the carbon source along with the BOD still existing in the wastewater.
- e. Nitrogen removal rates of 50 to 60% have been reported.

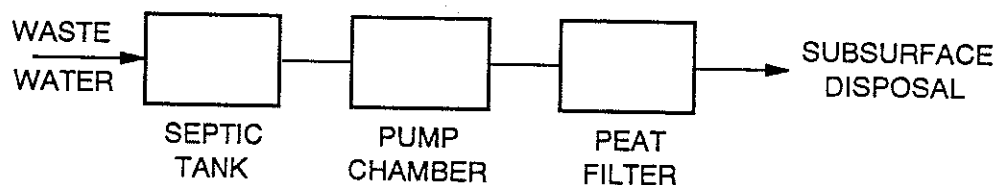


Fig. C-7 Flow diagram using a septic tank and peat filter for nitrogen removal.

## 7. Mound and Constructed Wetlands

- a. The system consists of a septic tank, pump chamber, mound and constructed wetland (Fig C-8).
- b. The septic tank effluent enters the mound where the BOD and suspended solids are removed and the nitrogen is converted to nitrates.
- c. An impervious barrier is placed in the basal area of the mound. As the effluent moves through the mound, it is directed downslope to the constructed wetlands.



- d. The effluent moves into the constructed wetlands. The nitrogen is denitrified or consumed by the plants.
- e. This is a relatively new concept and only limited data is available.

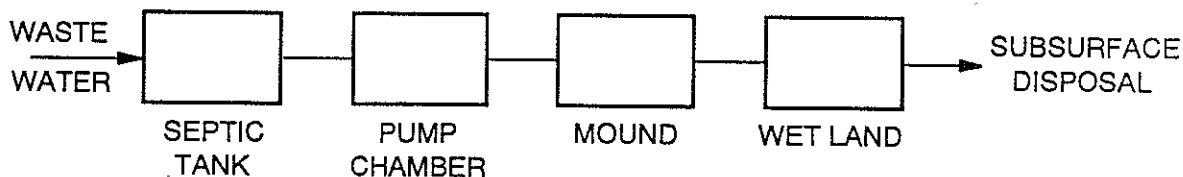


Fig. C-8 Flow diagram using a mound to nitrify the nitrogen and a constructed wetland to denitrify or utilize the nitrogen.

#### C. General Comments on Nitrogen Removal Systems

1. Nitrogen removal systems for on-site wastewater disposal systems is relatively new with very little design and performance data available.
2. Additional research and demonstration must be undertaken before these system can be installed as reliable systems in removing nitrogen from the waste stream.
3. Prior to implementation of nitrogen removal systems, a mandatory management and maintenance system must be in place.

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3. Multi-Flo Waste Treatment Systems Inc. 2324 East River Road, Dayton, OH 45439.
4. CMS Rotodisk Inc. 5266 General Rd. Unit 12, Mississauga, Ont. Canada L4W 1Z7.
5. Zabel Industries International, Ltd. 3600 Chamberlain Lane, Suite 612, Louisville, KY 40241.
6. Cromaglass Corporation, Williamsport, Pennsylvania, 17701.

APPENDIX

GLOSSARY OF TERMS  
for  
On-Site Wastewater Treatment

- adsorption: The increased concentration of molecules or ions at a surface, including exchangeable cations and anions on soil particles.
- anaerobic: (1) The absence of molecular oxygen. (2) Growing in the absence of molecular oxygen (such as anaerobic bacteria.)
- ammonification: The conversion of organic nitrogen to ammonium or ammonia by bacterial action. Ammonia ( $\text{NH}_3$ ) and ammonium ( $\text{NH}_4^+$ ) are both present with ammonium as the ion form and ammonia the gaseous form. In solution the ratio of ammonia to ammonium is Ph dependent.
- biochemical oxygen demand (BOD): Measure of the concentration of organic impurities in wastewater. The amount of oxygen required by bacteria while stabilizing organic matter under aerobic conditions, expressed in mg/l, is determined entirely by the availability of material in the wastewater to be used as a biological food, and by the amount of oxygen utilized by the microorganisms during oxidation.
- chemical oxygen demand (COD): A measure of the oxygen equivalent of that portion of organic matter that is susceptible to oxidation by a strong chemical oxidizing agent.
- coliform-group bacteria: A group of bacteria predominantly inhabiting the intestines of man or animal, but also occasionally found elsewhere. Used as an indicator of human fecal contamination. Both total & fecal coliforms comprise this group of bacteria with fecal coliforms of primary concern for on-site systems. For water supply both total and fecal coliforms are evaluated.
- denitrification: The biological reduction of nitrate or nitrite to gaseous molecular nitrogen or an oxide of nitrogen.
- digestion: The biological decomposition of organic matter in sludge, resulting in partial gasification, liquefaction, and mineralization.
- disinfection: Killing pathogenic microbes on or in a material without necessarily sterilizing it.
- dissolved oxygen (DO): The oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter (mg/l), parts per million (ppm), or in percent of saturation.
- dissolved solids: Solids dissolved in water or sewage that are deposits if the water is evaporated.

- effluent: Sewage, water, or other liquid, partially or completely treated or in its natural state, flowing out of a reservoir, basin, or treatment plant.
- intermittent filter: A natural or artificial bed of sand or other fine-grained material to the surface of which wastewater is applied intermittently in flooding doses and through which it passes: opportunity is given for filtration and maintenance of an aerobic condition.
- influent: Sewage, water, or other liquid, partially or completely treated or in its natural state, flowing out of a reservoir, basin, or treatment plant.
- nitrification: The biochemical oxidation of ammonium to nitrate. The process is done under aerobic conditions.
- organic nitrogen: Nitrogen combined in organic molecules such as proteins and amino acids.
- pathogenic: Causing disease. "Pathogenic" is also used to designate microbes which commonly cause infectious diseases, as opposed to those which do so uncommonly or never.
- suspended solids: Solids physically suspended in water, sewage, or other liquids. The quantity of material deposited when a quantity of water, sewage, or liquid is filtered through a designated filter in a Gooch crucible.
- total solids: The solids in water, sewage, or other liquids; includes suspended and dissolved solids; all material remaining as residue after all the water has been evaporated.