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SMALL SCALE WASTE MANAGEMENT PROJECT

Nitrogen Removal Systems for On-site Waste Disposal

by

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January, 1996

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NITROGEN REMOVAL SYSTEMS FOR ON-SITE WASTE DISPOSAL

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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 to 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 (NH_4^+) is an ion found in aqueous solutions while ammonia (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.

5. Nitrite (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.

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6. Nitrate (NO_3^-) is an ion found in aqueous solutions.

   a. Nitrate can be reported as both nitrate (NO_3^- in mg/L) or nitrate nitrogen (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 NO_3^- -N) or 45 mg/L or nitrate (also as NO_3^-).

   b. Nitrate nitrogen is the species normally reported in drinking water but ammonia may also be present under certain anaerobic circumstances.

7. 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 are present. This can occur beneath the soil absorption system or in tanks.

   d. The conversion to nitrate is sensitive to temperature with slower conversion at lower temperatures, especially when temperatures get below 5°C.

B. Nitrogen Removal Methods

1. Dilution of Wastes

   a. NR140 code is based on concentration (mg N/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 five times larger than current code requirements would be required for similar loading rates in 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. If waste components were segregated into the black and grey water components with the black waters stored in a holding tank and hauled to an off-site 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. 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.

d. Utilizing low flow toilets will minimize the hauling of the black water but community treatment systems would have to accept this wastewater.

e. 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.

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. 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

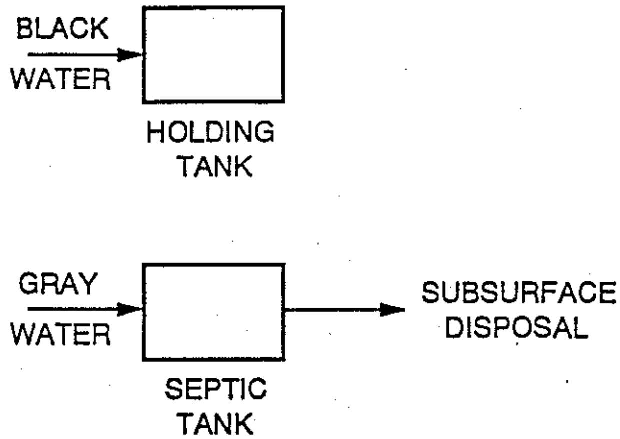

Fig. 1. Flow diagram of a system segregating the black waters from the grey waters and hauling the black waters off site.

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.

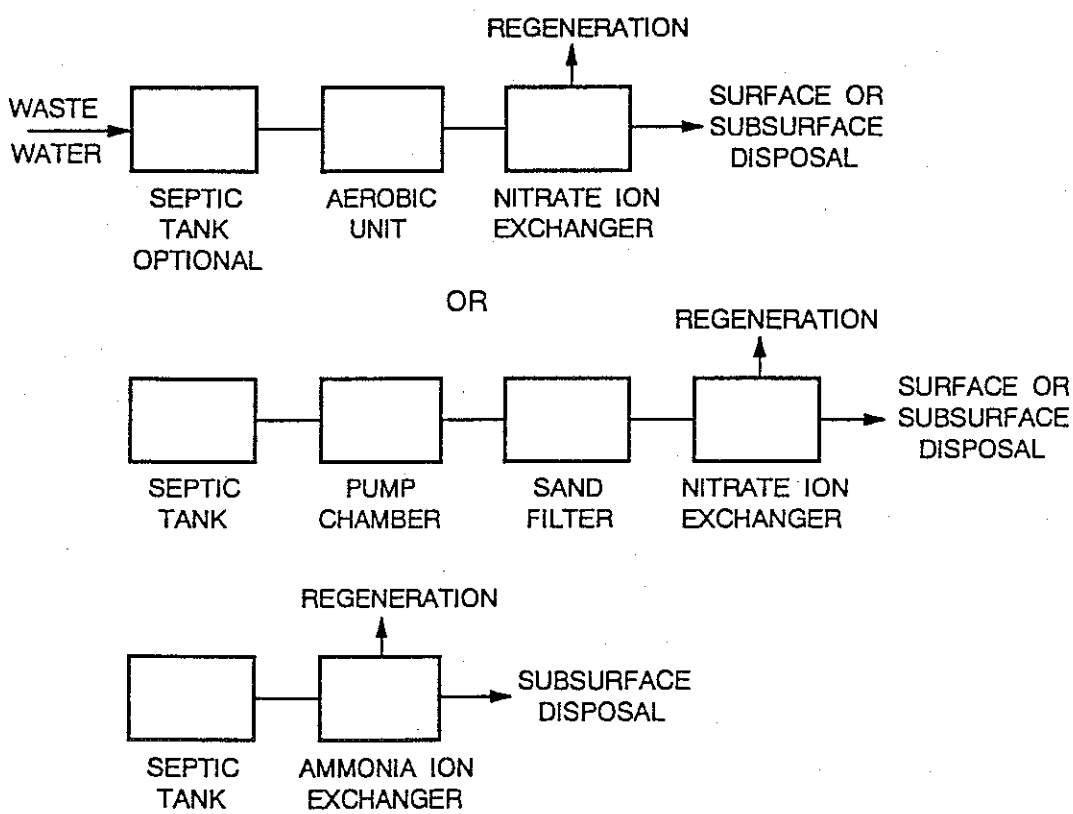

Fig. 2. Flow diagram of an ion exchange system utilizing cation or anion exchange for ammonia or nitrate nitrogen removal.

4. Denitrification

a. Principle of Operation

1. Denitrification is a biological process in which bacteria convert nitrate nitrogen (NO_3 - N) to nitrogen gas.

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 nitrate with sand filters or aerobic units, most of the carbon source (BOD) is consumed by the bacteria.

4. Most any readily availability 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 significantly increase the BOD of the final effluent. 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. 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 20% 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. The recirculation rate will vary depending upon the flow rate from the septic tank to the recirculation tank. Low flow rates will have a high recirculating rate and large flows will have low recirculating rates.

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. High recirculating rates may cause aerobic conditions in the recirculating tank thus reducing the ability to denitrify the effluent in the recirculating tank.

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 50-70% removal rate is achieved, the final effluent stream would have a nitrate nitrogen concentration of approximately 15 to 22 mg N/L.

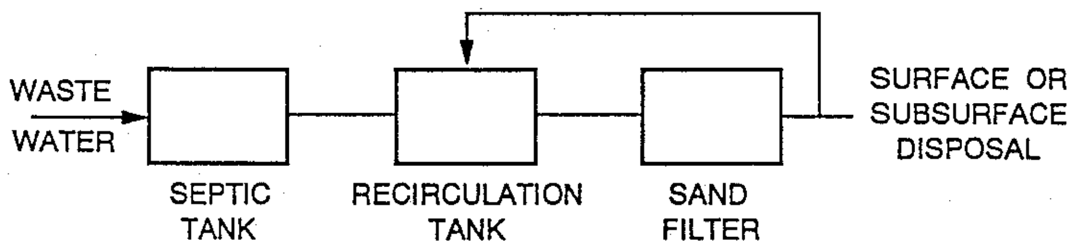

Fig. 3. Flow diagram of a recirculating sand filter for nitrogen removal.

3. Recirculating Sand Filter - Anaerobic Upflow Filter

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

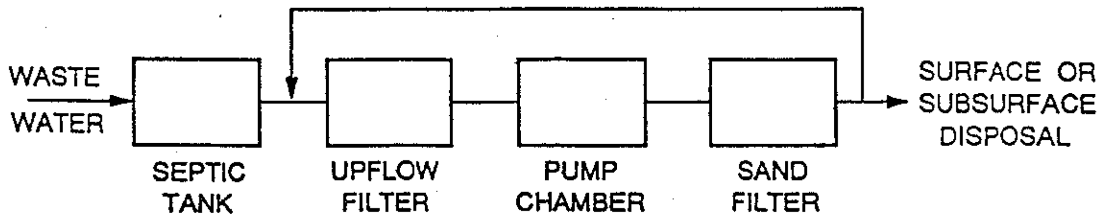

Fig. 4. Flow diagram of a recirculating sand filter with an upflow filter for nitrogen removal.

4. Recirculating Sand Filter - Septic Tank

   a. System consists of a septic tank, pump chamber and sand filter (Fig. 5).

   b. The septic tank effluent flows to a pump chamber where it is intermittently pumped to the sand filter. The sand filter effluent flows through a diverter valve where a portion of it flows to the septic tank inlet and the remainder flows to final treatment and disposal. The septic tank provides the anaerobic environment and the food (BOD) for the bacteria to convert the nitrate to nitrogen gas.

   c. This system is very similar to the system shown in Fig. 4. The sand filter will need to be larger as the BOD loading will be greater without the anaerobic upflow filter. However, there will be more food available in the septic tank than in the anaerobic filter. In both cases, the recirculation rate must not cause the septic tank or anaerobic upflow filter to become aerobic.

   d. Nitrogen removal should be similar to system shown in Fig. 4.

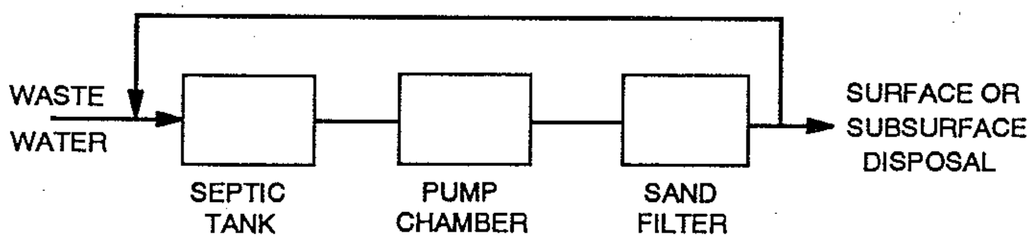

Fig. 5. Flow diagram of a recirculating sand filter with recirculation through the septic tank.

5. Aerobic Unit - Carbon Source Addition - Anaerobic Upflow Filter

   a. A septic tank may be installed upstream of the aerobic unit (Fig. 6).

   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 an upflow anaerobic rock filter with several days detention time for the nitrate to be converted to nitrogen gas.

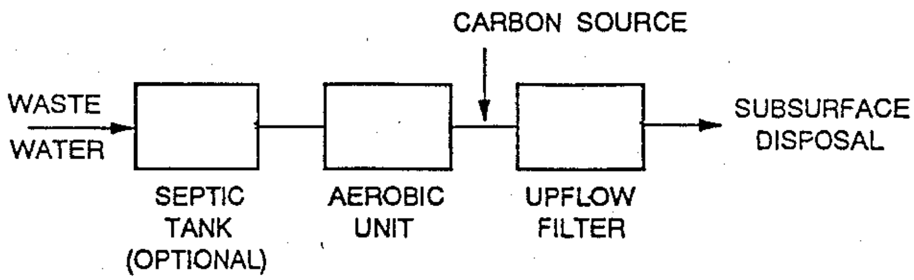

Fig. 6. Flow diagram using an aerobic unit, carbon source and upflow filter for nitrogen removal.

6. 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. 7).

   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.

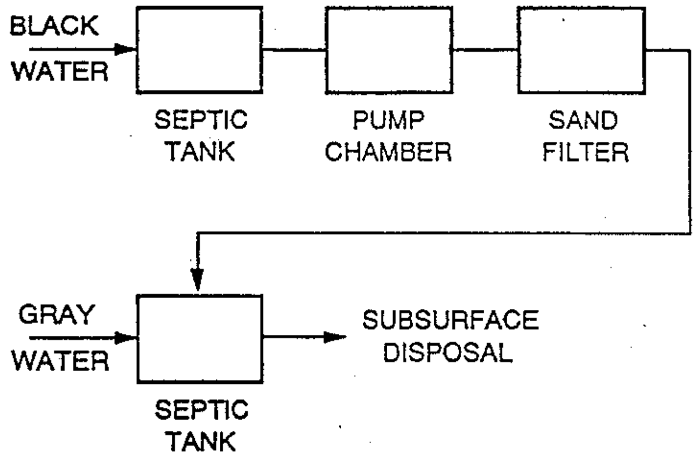

Fig. 7. Flow diagram segregating the black waters from the grey waters, nitrifying the nitrogen in the sand filter and using the carbon in the grey water for denitrifying. This process is known as the Ruck system. (Laak, 1986)

7. Septic Tank - Peat Filter

   a. The system consists of a septic tank and a peat filter (Fig. 8).

   b. The peat filter is similar in design to a sand filter with an under drain 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.

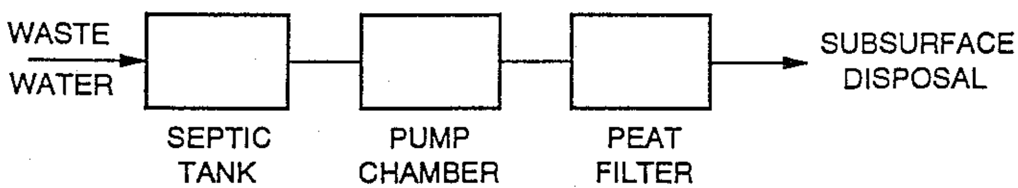

Fig 8. Flow diagram using a septic tank and peat filter for nitrogen removal.

8. Mound and Constructed Wetlands

   a. The system consists of a septic tank, pump chamber, mound and constructed wetland (Fig. 9). Other variations exist such as a septic tank and constructed wetland with gravity flow.

   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 down slope 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.

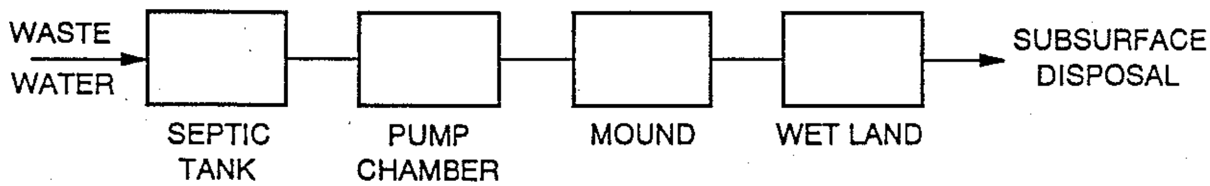

Fig. 9 Flow diagram using a mound to nitrify the nitrogen and a constructed wetland to denitrify or utilize the nitrogen.

REFERENCES

1. Converse, J.C., M.E. Kean, E.J. Tyler and J.O. Peterson. 1991. Bacterial and nutrient removal in Wisconsin at-grade on-site systems.. In: On-site Wastewater Treatment. Proceedings of the Sixth National Symposium on Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI.

2. Laak, R. 1986. Wastewater engineering design for unsewered areas, 2nd ed. Technomic Publishing Co., Inc. Lancaster, PA.

3. Walker, W.G., J. Bouma, D.R. Keeney and P.G. Olcott. 1973. Nitrogen transformation during subsurface disposal of septic tank effluent in sands. II Groundwater Quality. J. Environmental Quality 2:521-525.

4. Whitmyer, R.W., R.A. Apfel, R.J. Otis and R.L. Meyer. 1991. Overview of individual on-site nitrogen removal systems. In: On-site Wastewater Treatment. Proceedings of the Sixth National Symposium on Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI.