8-4 ON-SITE DISPOSAL SYSTEMS

In less densely populated areas where lot sizes are large and houses are spaced widely apart, it is often more economical to treat human waste on site, rather than use a sewer system to collect the waste and treat it at a centralized location. On-site systems are generally small and may serve individual homes, small housing developments (clusters), or isolated commercial establishments, such as small hotels or restaurants. In the United States, about 25 percent of the population is served by on-site wastewater systems. In some states as much as 50 percent of the population utilize on-site systems within rural and suburban communities (U.S. EPA, 1997). As many people choose to move to rural and outer suburban areas, the number of decentralized systems is increasing. It is estimated that as much as 40 percent of new housing construction is taking place in areas that are not connected to municipal sewers.

Alternative On-Site Treatment and Disposal Systems with Water

Septic Tanks and Absorption Fields. About 85 to 90 percent of on-site wastewater disposal systems are conventional septic systems. A conventional septic system consists of three parts: the *septic tank*, a distribution box, and an absorption field (also called a leach or drain or tile field) (see Figure 8-1). The septic tank and tile field are a unit. Neither part will function as intended without the other.

The main function of the septic tank (Figure 8-2) is to remove large particles and grease that would otherwise clog the tile field. Heavy solids settle to the bottom, where they undergo biological decomposition. Grease floats to the surface and is trapped. It is only slightly decomposed.

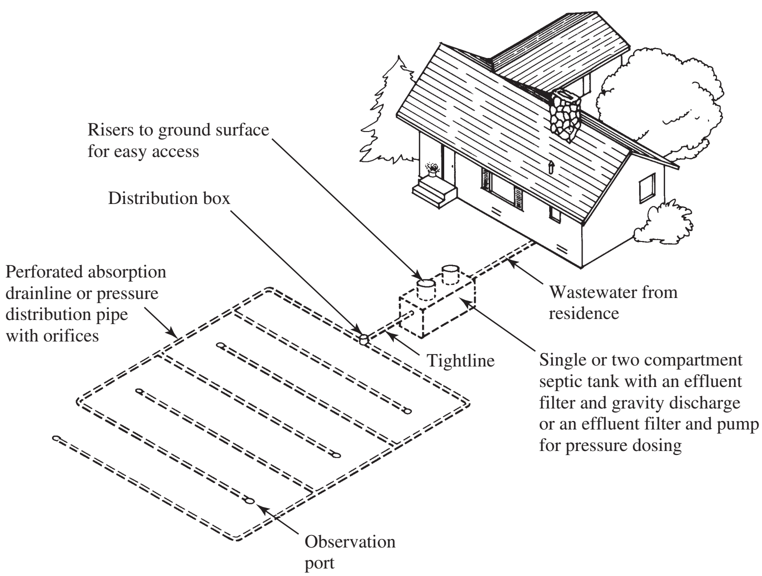


FIGURE 8-1
Schematic of a conventional septic system. (*Source:* Crites and Tchobanoglous, 1998.)

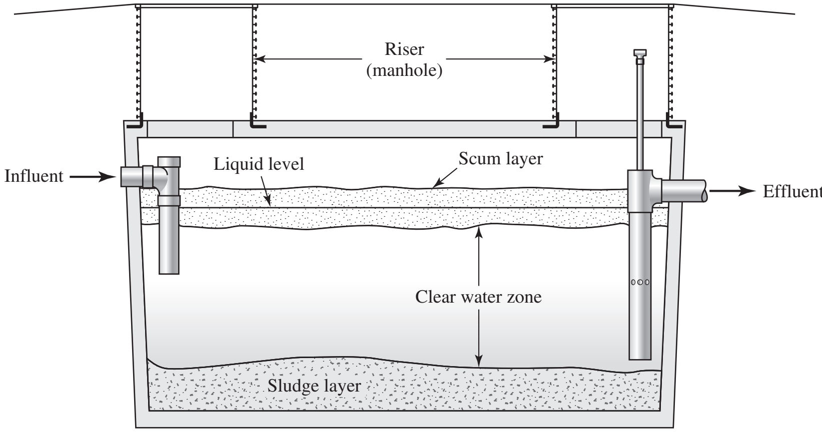


FIGURE 8-2
Definition sketch for the sludge, clear water, and scum zones that form in a septic tank.
(*Source:* Crites and Tchobanoglous, 1998.)

The size of the tank depends on the expected wastewater flow. The tank should be large enough that the holding time for water in a septic tank is a least 24 hours. For individual homes the following guidelines can be used: 3 m^3 tank minimum; 4 m^3 for a three-bedroom house; 5 m^3 for a four-bedroom house and 6 m^3 for a five-bedroom house.

Bacterial action in the tank helps to degrade the organic matter in the wastewater. The BOD_5 of the wastewater is also reduced by the separation of the solids from the liquid. For domestic systems, the BOD_5 of the influent is typically 210 mg/L. The septic tank effluent has a BOD_5 of about 180 mg/L without an effluent filter and about 130 mg/L if an effluent filter is used in the system. Usually the BOD_5 limit to allow wastewater to be discharged to surface waters is 20 mg/L or less, so the BOD_5 of a septic effluent is too high to allow for surface water discharge. However, as further treatment occurs in the soil, absorption fields can be used to safely dispose of the partially treated septic tank effluent. A distribution box is used to distribute the septic tank effluent throughout the absorption field. The absorption field usually consists of a series of trenches that contain perforated PVC pipes that are about 10 cm diameter. The pipes placed over a 15-cm-deep layer of drainrock and then buried with an additional layer of drainrock. The drainrock is covered building fabric or building paper (which helps to prevent the migration of fines into the drainrock) and finally the trench is filled with native soil (Figure 8-3). The trenches should be separated by a distance of at least 2 meters.

When the system is operational, bacteria produce a slime layer at the bottom of the trench. This layer is commonly called the clogging mat. The clogging mat creates a barrier that slows the movement of water into the surrounding soil. This allows the flow in the surrounding soil to remain unsaturated, which allows air to move through the soil. This maintains aerobic conditions, which are essential to obtain proper treatment of the effluent.

The size of the absorption area depends upon the wastewater flow and the permeability of the surrounding soil. The permeability of the soil is determined by a percolation (or *perc*) test. The perc test is conducted by digging a hole of a prescribed size, filling it

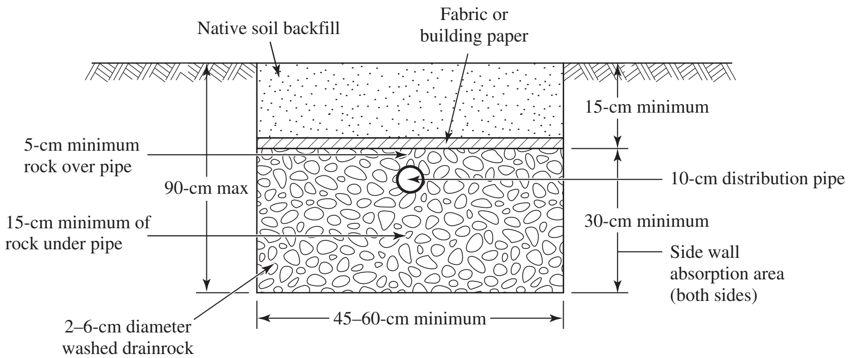


FIGURE 8-3
Typical cross section through conventional absorption trench. (*Source:* Crites and Tchobanoglous, 1998.)

with water and measuring the rate at which the water percolates into the soil. An alternative, and preferred, method for determining the suitability of the soil is to dig a trench in the area proposed for the tile field and visually inspect it. The inspector looks for unsuitable soil (clay, for example) and the presence of mottled (discolored) soil. Mottled soil indicates that the groundwater table has, at some point in time, risen to a level which would interfere with the operation of the tile field and, perhaps more important, bring the groundwater into direct contact with sewage. The information in Table 8-1 is then used to determine the size of the tile field.

Further limitations on the use of a septic-tank tile-field system usually include the following:

1. The tile field must be located more than 30 m from any well, surface water, footing drain, or storm drain.
2. The tile field must be located at least 3 m from any property line.
3. The minimum distance between the bottom of the absorption trench and the groundwater table or any impermeable layer must not be less than 1.25 m.

TABLE 8-1
Maximum acceptable application rates for tile fields

Soil texture and structure	Percolation rate mm/h	Percolation rate min/mm	Maximum acceptable application rate, m^3 of vol/m^2 area
Coarse and medium sand	≥150	<0.40	0.04
Fine and loamy sand	75–150	0.40–0.80	0.03
Sandy loam	50–75	0.80–1.20	0.02
Loam and sandy clay	35–50	1.20–1.71	0.01
Loams	<35	>1.71	Not permitted
Clays, silts, muck, peat, marl	≪35	≫1.71	Not permitted

4. The earth cover placed over the absorption tile must not be less than 0.3 m nor more than 0.6 m deep.
5. A clean aggregate graded between 12 and 36 mm must be placed around the tile pipe. It must be a minimum of 50 mm above the pipe and 150 mm below the pipe, with a total depth of not less than 300 mm.

Most states limit septic tank/tile field installation to facilities producing less than 40 m^3/d of wastewater. This limits their use to single-family residences, small apartments, freeway rest areas, parks, and isolated commercial establishments.

Example 8-1. Peter and Pam Piper are considering the purchase of a plot of land on which to build a retirement home. According to their water bills for the past 5 years, their average daily water consumption is about 0.4 m^3. What size septic tank and tile field should they expect to put on the lot if it perks at 1.00 min/mm?

Solution. If the septic tank must provide a detention time of 24 h, then its volume should be

$$V = 0.4 \text{ m}^3/\text{d} \times 1 \text{ d} = 0.4 \text{ m}^3$$

However, the minimum recommended volume is 4.0 m^3. Good septic tank design practice calls for length to width ($1/w$) ratios greater than 2 to 1 and a minimum liquid depth of about 1.2 m. For these criteria and a 4.0 m^3 volume, the liquid surface area would be

$$A_s = \frac{4.0 \text{ m}^3}{1.2 \text{ m}} = 3.33 \text{ m}^2$$

If we choose a width of 1.15 m and a length of 3 m, we will have a well-sized tank of 4.14 m^3 and a $1/w$ ratio of 2.61 to 1.

From Table 8-7 we find that a perk rate of 1.00 min/mm will allow an application rate of 0.02 m^3/m^2 of trench. The bottom area of trench should then be about

$$\text{A} = \frac{0.4 \text{ m}^3}{0.02 \text{ m}^3/\text{m}^2} = 20.0 \text{ m}^2$$

One trench 1.0 m wide and 20.0 m long would meet the requirements; however, our preference is to use a 0.6-m trench width and three trenches about 12 m in length.

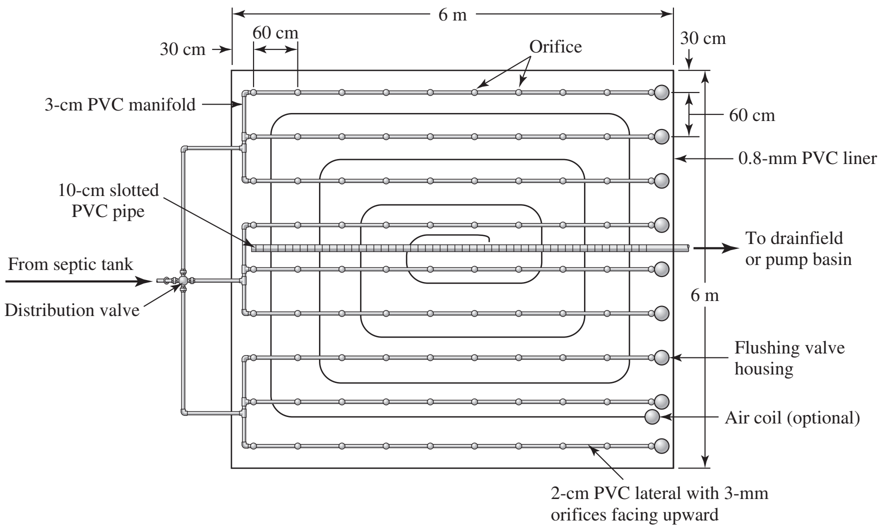
Most septic systems will fail eventually. The normal lifetime of an absorption field is 20 to 30 years. After that time the soil around the field becomes clogged with organic matter and the system will not operate properly. Many factors can cause the system to fail prematurely. Roots can block pipes or the pipes may be crushed if a vehicle is driven over the field. The system may also fail if the absorption field is hydraulically overloaded or if substances that are toxic to soil bacteria, such as solvents, paints, pesticides or softener salt are disposed of down the drain. However, the most common reason for premature failure is improper maintenance. Because the rate of biodegradation in septic tanks is slow, the solids that settle in the tank tend to accumulate over time. If these solids are not removed, the clear water zone between the sludge layer and the scum layer becomes too small. This leads to an increased carryover of solids to the absorption field. If too many solids reach the absorption field, then it can become clogged, resulting in premature failure of the field. To prevent the accumulation of too much sludge and scum in a septic tank, they should be periodically removed. The rate of accumulation of sludge depends on the usage of the system. It is suggested that the level of sludge in the tank be checked annually, though usually a domestic system will need to be pumped out only once every 2 or 3 years.

Septic Tank and Absorption Field Modifications. As mentioned above, often the reason for the failure of absorption fields in poorly drained soils is that the growth of the clogging mat is excessive. Reduction of the BOD of the wastewater can reduce the rate of growth of the mat. Two types of treatment systems that are commonly used to reduce the wastewater BOD are aerobic treatment systems and sand filters.

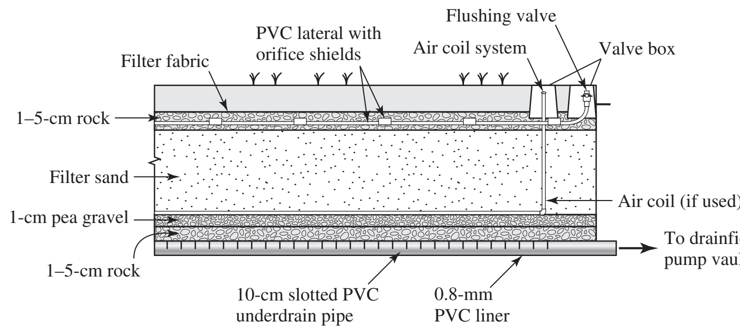
Aerobic Systems. A wide range of aerobic treatment systems are available. The common feature of these units is that they use some mechanism to inject or circulate air inside the treatment tank. If sufficient air is introduced, then aerobic conditions can be achieved in the wastewater. As aerobic degradation is rapid, good removal of BOD can be achieved under these conditions. This reduces the rate of growth of the clogging mat and extends the life of the absorption field.

Sand Filter Systems. The sand filter is also an aerobic treatment system. The components of a typical sand filter are illustrated in Figure 8-4. The filter consists of a bed of granular material (usually sand, but other materials such as anthracite can be used). The surface of the bed is intermittently dosed with wastewater that percolates through the sand to the bottom of the filter. The sand bed is dosed anywhere from 12 to 72 times per day. The size of the dose should be such that the sand bed does not become saturated. This allows the wastewater to flow as a thin film around the sand particles, so good contact between the wastewater and the air can be achieved. Sand filters may be single-pass or multipass. Single-pass sand filters are commonly called intermittent sand filters (ISFs). In a single-pass system the wastewater is collected in the underdrain and passed onto an absorption field or other disposal system. In a multipass system a portion of the treated wastewater is recycled back through the sand bed. Recirculation dilutes the wastewater coming from the septic tank. By diluting the strength of the effluent, higher application rates can be used. Recirculating sand filters take up 3 to 5 times less area than single-pass sand filters. Also, better nitrogen removal is achieved in recirculating sand filters because of nitrification/denitrification (see Chapter 5).

Dosing Systems. Another solution to the clogging problem can be to replace the conventional absorption trenches with a disposal system that is less prone to failure. In a conventional absorption field the effluent flows by gravity into the trenches. The gravity system may be replaced by a dosing system, similar to that used in a sand filter. This helps to maintain unsaturated conditions in the soil surrounding the trench.



(*a*) Plan view



(*b*) Typical cross section

FIGURE 8-4
Schematic of modern intermittent sand filter: (*a*) plan view and (*b*) typical cross section. (Courtesy Orenco Systems, Inc.)

Shallow Absorption Fields. In these systems the distribution piping is often covered with large half pipe rather than gravel. The trenches are only about 0.25 m deep. Better treatment can be achieved, as the upper soil layers have a higher concentration of microbes.

On-Site Treatment/Disposal Systems for Unfavorable Site Conditions

Where site conditions are unfavorable for conventional septic systems, alternative treatment/disposal systems may be required. Among the limitations that might preclude the installation of a conventional system are: high groundwater tables, shallow limiting layers of bed rock, very slowly or rapidly permeable soils, close proximity to surface water, and small lot size.

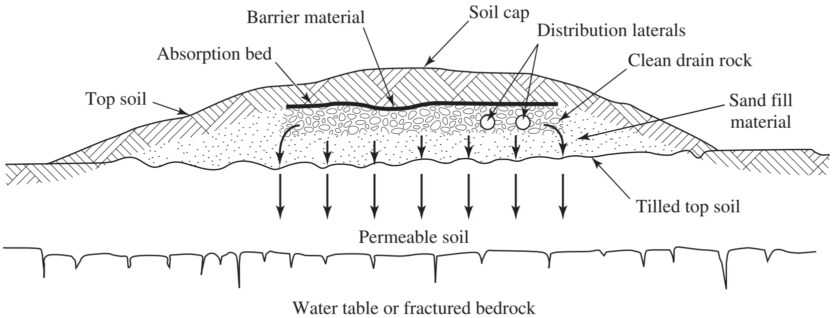


FIGURE 8-5
Typical cross section through mound effluent disposal system. (*Source:* Crites and Tchobanoglous, 1998.)

Mound Systems. Mounds were first developed at the North Dakota Agricultural College in the 1940s. They were known as NODAK systems. The components of a typical mound system are illustrated in Figure 8-5. Mounds are both treatment and disposal systems, as the effluent from the mound percolates directly into the native soil. The design overcomes certain site restrictions such as slowly permeable soils, shallow permeable soils over porous bedrock, and permeable soils with high water tables. A mound system is a pressure-dosed absorption system that is elevated above the natural soil surface. Effluent from the septic tank is pumped or siphoned to the elevated absorption area and distributed through a piping network located in the coarse aggregate at the top of the mound. The effluent then passes through the aggregate and infiltrates the sand fill. Treatment occurs in the sand and in the fill below the sand bed. As the water percolates downward, it spreads out over a large area. The size of the mound must be such that area of native soil under the mound, called the *basal area,* is large enough that wastewater does not seep out of the base or sides of the mound. During construction of mound systems, special attention should be given to ensuring that the basal area of the system is properly scarified, and that compaction of the basal area by earthmoving equipment is minimal. Compaction of the top layer of the soil can greatly reduce the rate of infiltration into the soil.

Barriered-Landscape Water-Renovation System (BLWRS). In the summer of 1969, Dr. A. Earl Erickson demonstrated the efficacy of utilizing a BLWRS (pronounced “blowers,” like “flowers”) to denitrify water containing 100 mg/L of nitrate. Subsequently, he and his associates demonstrated that the BLWRS could be used to renovate both dairy cow and swine feedlot wastewater (Table 8-2) (Erickson et al., 1974). The system is, of course, equally applicable to domestic wastewater.

The BLWRS differs from the NODAK mound system in that the mound of soil is underlain by an impervious water barrier (Figure 8-6*a* and *b*). As the renovated water passes beyond the edge of the barrier, it may be collected in drains or be allowed to recharge the aquifer. The mound is constructed of a fine sand. The dimensions of the BLWRS depend on the soil texture and expected wastewater application rates. A 0.15-m layer of topsoil is used to cover the sand. A water-hardy grass (quack grass

TABLE 8-2
BLWRS wastewater renovation efficiencies

	Average influent concentration, mg/L	Average effluent concentration, mg/L	Efficiency, %
Swine waste[a]			
BOD_5	1,131	8.9	98.3
P	18	0.02	99.9
Suspended solids	3,000	Nil	~100.0
TKN	937	187.4	80.0
Dairy waste[b]			
BOD_5	1,637.0	18.9	98.8
P	38.5	0.22	99.4
Suspended solids	4,400.0	Nil	~100
TKN	917.0	27.5	97.0

[a]Average application rate of 15 mm/d for 503 d.
[b]Average application rate of 8.8 mm/d for 450 d.
Source: Erickson et al., 1974.

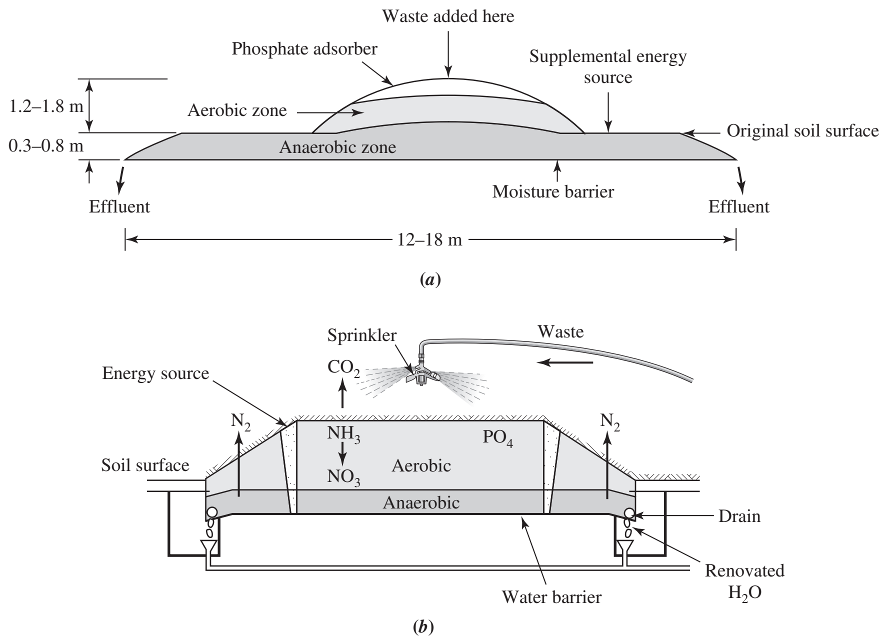


FIGURE 8-6
(*a*) Common dimensions of barriered landscape water-renovation system (BLWRS); (*b*) water chemistry change in a BLWRS.

or volunteer weed cover) must be established on the surface and banks to maintain the soil's permeability and stability.

The wastewater is spread on the top of the mound by a sprinkler. As the wastewater percolates down, the organic particles are filtered out and remain on the surface. The particles are oxidized by soil microorganisms. The soluble organic compounds and other ions move into the aerobic soil zone. Most of the soluble organic matter is oxidized by bacteria in the highly active aerobic soil. The phosphate ions are held on the clay fraction of the soil and sand bed. (Iron slag and/or limestone can be used to enhance the phosphorus adsorption capacity.) The ammonium ions are held on the soil until they are nitrified to nitrate. The downward movement of the nitrified water is stopped by the barrier. The water then is forced to move laterally through the anoxic layer. Denitrification occurs as the waste passes out of the carbon source.

The BLWRS must be operated in a cyclic fashion to allow the soil microorganisms time to degrade the waste and to maintain aerobic conditions in the soil. Application rates between 9 and 18 mm of wastewater per day may be used, provided that the BLWRS is "rested" for one-third of the time. The physical conditions of the soil govern the application rates. Ponding on the surface indicates excessive application rates.

Other On-Site Treatment/Disposal Options

Constructed wetlands can be used for on-site wastewater treatment/disposal. The use of these systems is more common in warmer climates. In arid areas, evapotranspiration (ET) beds are an alternative to conventional absorption beds. In an evapotranspiration system, water tolerant vegetation is planted in a shallow sand bed. The plant roots draw the water up through the sand and it is evaporated or transpired to the atmosphere.

Treated domestic wastewater can be reused. However, because of the risks posed by pathogens in the water, the reuse of domestic wastewater in on-site systems is not common. Some alternatives for reuse are drip irrigation and toilet flushing.

Alternative On-Site Treatment/Disposal Systems without Water

In areas away from population centers, such as national or state parks, remote roadside rest areas or vacation, there may be no reliable water supply. The absence of a water supply or water scarcity may preclude the use of flush toilets. In this case, other systems for the disposal of human waste need to be considered. Commonly used systems are the pit privy and vault, chemical and composting toilets. Vault, chemical, and composting toilets are closed systems, so there is "zero" discharge from these systems on site. The waste produced is collected and disposed of elsewhere. For this reason, these systems may also be used in environmentally sensitive areas where the discharge of wastewater may be environmentally unacceptable.

The Pit Privy. Although most modern environmental engineering and science texts would skip this subject, the mere existence of 10,000 of these or their modern equivalent in the United States is just too much for us to ignore. Furthermore, the facts of the matter are that junior engineers and environmental scientists are the most likely candidates for designing, erecting, operating, dismantling, and closing the beasts.

Figure 8-7 provides most of the information you will ever want to know about the construction of an outhouse. The slab is usually poured over flat ground on top of roofing paper. The riser hole is formed with 12-gauge galvanized iron. Once the slab has set, it is lifted into place over the pit. The concrete is a 1:2:3 mix, that is, one part portland cement, two parts sand, and three parts gravel less than 25 mm in diameter.

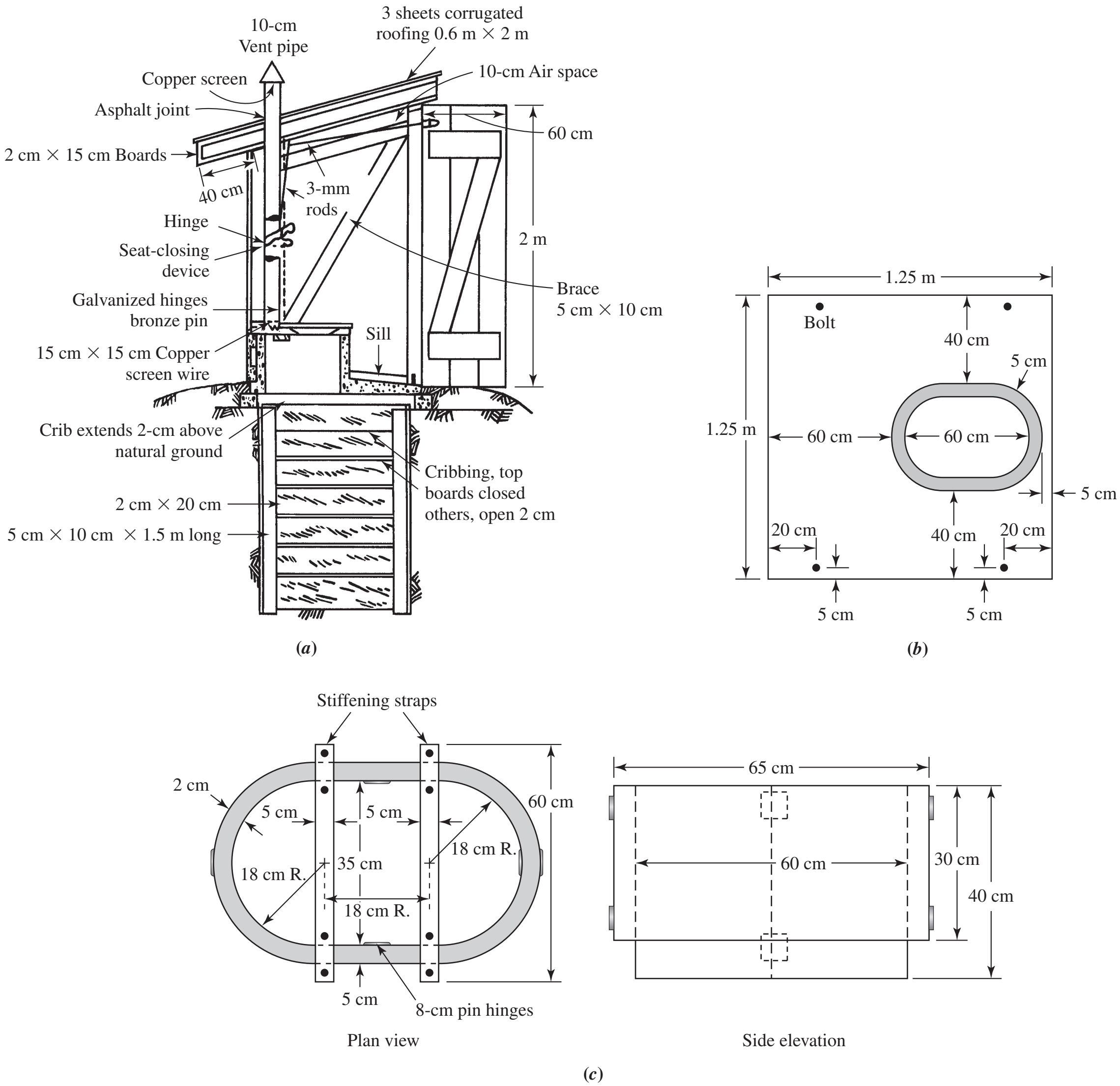


FIGURE 8-7

Construction details of the pit privy: (*a*) cross section; (*b*) plan of concrete slab; and (*c*) details of riser form. (*Source:* Ehlers, V. M., and E. W. Steel, 1943.)

The principle of operation of the pit privy is that the liquid materials percolate into the soil through the cribbing and the solids "dry out." A pit of the dimensions shown in Figure 8-7 should last a family of four about 10 years. Rainwater is to be prevented from entering the pit. A cup of kerosene at weekly intervals discourages mosquito breeding, and odors can be reduced by the use of a cup of hydrated lime. Unfortunately, the lime also slows the decomposition of paper, so its use is not encouraged. Disinfectants should never be used.

The Vault Toilet. This is the modern version of the pit privy. Its construction is the same as that of the pit privy with the exception that the pit is formed as a watertight vault. A special truck (fondly called a "honey wagon") is used to pump out the vault at regular intervals. Because of the liquefying action of the bacteria and biological decomposition in the liquid (rather than in the soil as occurs with the pit privy), vault toilets are much more odiferous than the old pit privies. Many masking agents (perfumes) and disinfectants are available to mitigate the stench. Unfortunately, most of them have unpleasant odors themselves. If electricity is at hand, an ozone generator, set to vent into the gas space above the waste, will perform near-miracles in odor reduction.

The Chemical Toilet. The airplane toilet, the coach-bus toilet, and the self-contained toilets of recreation vehicles are all versions of the chemical toilet. The essence of the system is a strong disinfectant chemical used to carry the waste to a holding tank and render it inoffensive until it can be pumped from the holding tank. While these vehicular systems are quite effective, the chemical must be selected with an eye toward its impact on the treatment system that ultimately must receive it. The chemical toilet has not found wide acceptance in permanent installations. This is because of the cost of the chemical and the impracticality of maintenance.

The Composting Toilet. A composting toilet consists of a large tank located directly below the toilet room. Wastes enter the tank through a large-diameter chute that connects to the toilet. No water is used for the toilet, but a bulking agent (such as wood shavings) is added to improve liquid drainage and aeration. A small fan draws air through the tank and up the vent pipe to ensure adequate oxygen for decomposition and odorless operation. The liquid in the waste is evaporated, leaving a compost. The finished compost can be removed from the lower end of the tank about once each year. It can be used as a fertilizer. Power requirements for the system are very low, so if power from an electrical grid is not available, the electrical requirements can be met from an independent generating system, such as a photovoltaic system.