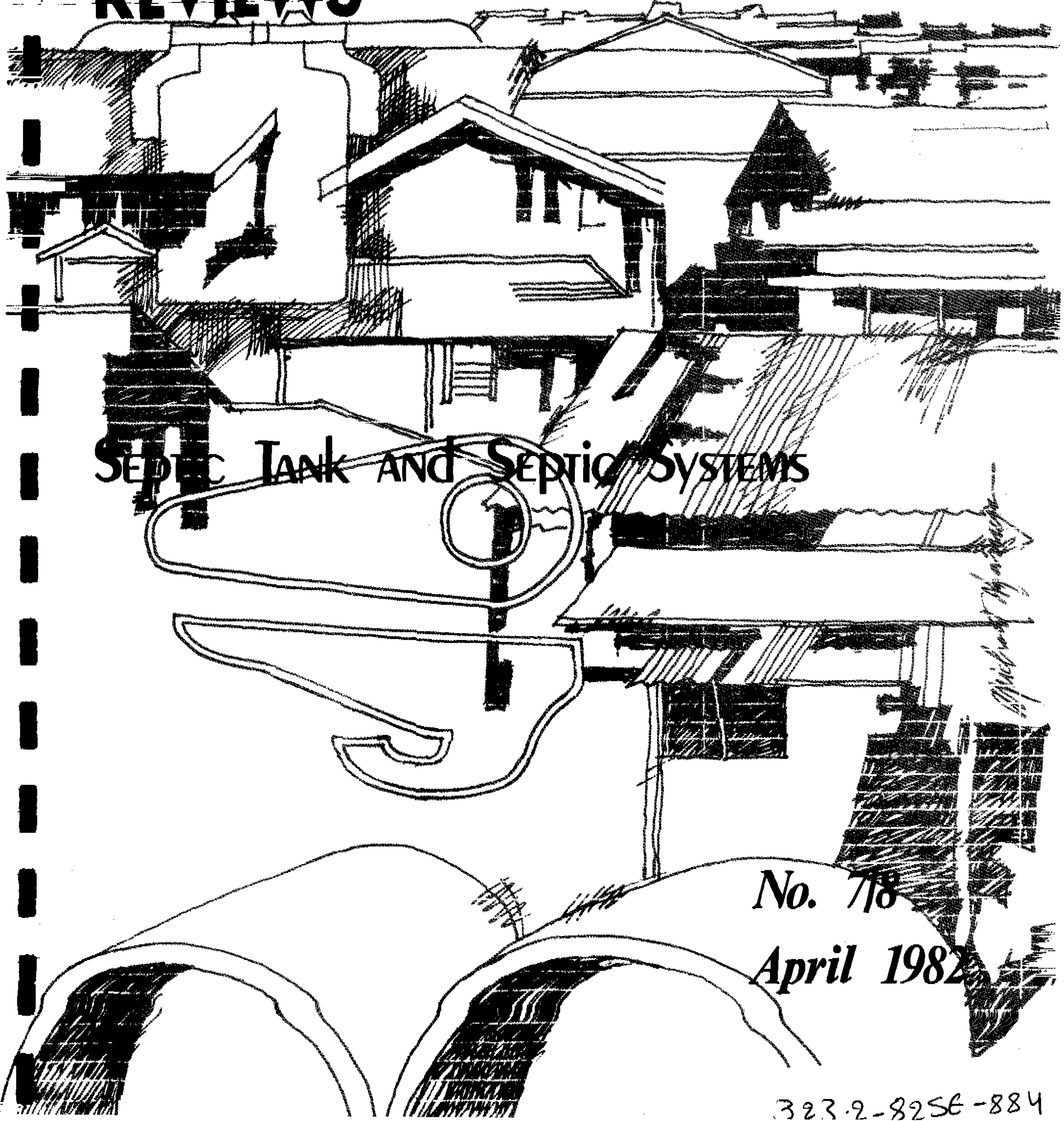
ISSN 0125-5088

ENVIRONMENTAL SANITATION REVIEWS



SEPTIC TANK AND SEPTIC SYSTEMS

No. 7/8
April 1982

Environmental Sanitation Reviews

No. 7/8, April 1982

ENVIRONMENTAL SANITATION INFORMATION CENTER
ASIAN INSTITUTE OF TECHNOLOGY
P.O. BOX 2754
BANGKOK, THAILAND

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ACKNOWLEDGEMENTS

ENSIC gratefully acknowledges the financial support it receives from the **International Development Research Centre (IDRC)** *of Canada and the* **Asian Institute of Technology (AIT).**

It is also indebted to the **AIT Regional Computer Center (RCC)** *for the use of its computer facilities.*

SEPTIC TANK AND SEPTIC SYSTEMS

by

ENSIC Review Committee on Septic Systems

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ENVIRONMENTAL SANITATION INFORMATION CENTER

BANGKOK, THAILAND

APRIL, 1982

CONTENTS

GLOSSARY OF TECHNICAL TERMS

Absorption - The process by which one substance is taken into and included within another substance, as in the absorption of water by soil or nutrients by plants.

Absorption Trench - A trench not over 91 cm (36 in.) in width with a minimum of 30.5 cm (12 in.) of clean, coarse aggregate and a distribution pipe, and covered with a minimum of 30.5 cm (12 in.) of earth cover.

Adsorption - The increased concentration of molecules or ions at a surface, including exchangeable cations and anions on soil particles.

Aerobic - 1. Having molecular oxygen as a part of the environment. 2. growing or occuring only in the presence of molecular oxygen, such as aerobic organisms.

Anaerobic - 1. The absence of molecular oxygen 2. Growing in the absence of molecular oxygen, such as anaerobic bacteria.

Anaerobic Contact Process - An anaerobic waste treatment process in which the micro-organisms responsible for waste stabilization are removed from the treated effluent by sedimentation or other means, and held in or returned to the process to enhance the rate of treatment.

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 biological food, and by the amount of oxygen utilized by the micro-organisms during oxidation.

Blackwater - Liquid and solid human body wastes and the carriage water generated through toilet usage.

Capillary Attraction - A liquid movement over, or retention by, a solid surface, due to the interaction of adhesive and adhesive forces.

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 occassionally found elsewhere. Used as an indicator of fecal contamination.

Colloids - Finely divided suspended matter which will not settle, and apparently dissolved matter which may be transformed into suspended matter by contact with solid surfaces or precipitated by chemical treatment.

Crust - A surface layer on soils that is much more compact, hard, and brittle when dry, than the material immediately beneath it.

Denitrification - The biochemical reduction of nitrate or nitrite to gaseous molecular nitrogen or an oxidized form 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.

Effective Size - That size of sand of which 10 percent by weight is smaller.

Effluent - Sewage, water or other liquid, partially or completely treated or in its natural state, flowing out of a basin or treatment plant.

Electric Conductivity - The ability of a solution to transmit an electric currrent - an ability closely related to the concentration of ions in the solution.

Evapotranspiration - The combined loss of water from a given area, and during a specified period of time, by evaporation from the soil surface and by transpiration from plants.

Evapotranspiration System Evapotranspiration systems combine moisture evaporation from the surface and transpiration by plants.

Eutrophic - A term applied to water that has a concentration of nutrients optimal, for plant or animal growth.

Fragipan - Dense and brittle pan or layer in soils that owe their hardness mainly to extreme density or compactness rather than high clay content or cementation.

Fine Texture - The texture exhibited by soils having clay as a part of their textural class name

Ground Water - Water that fills all the unblocked pores of underlying material below the water table, which is the upper limit of saturation.

Greywater - Wastewater generated by water using fixtures and appliances, excluding the toilet and possibly the garbage disposal.

Heavy Soil - A soil with a high content of the fine separates, such as clay.

Hydraulic Conductivity - As applied to soils - the ability of the soil to transmit water in liquid form through pores.

Impervious - Resistant to penetration by fluids or by roots.

Individual Sewage Disposal System - A single system of sewage treatment and disposal facilities serving only a single lot.

Infiltration - The downward entry of water into the soil.

Infiltration Rate - A soil characteristic determining or describing the rate at which water moves through the soil water interface. It measures the ability of a soil to accept water.

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 the maintenance of an aerobic condition.

Intermittent Sand Filter - This consists of a holding tank and an open sand filter.

Leaching - The removal of materials in solution from the soil.

Lysimeter - A device for measuring percolation and leaching losses from a column of soil under controlled conditions.

Manifold - A pipe fitting with numerous branches to convey liquids between a large pipe and several smaller pipes, or to permit choice of diverting flow from one of several sources or to one of several discharge points.

Marsh - Periodically wet or continually flooded areas with the surface not deeply submerged. Covered dominantly with sedges, cattails, rushes, or other hydrophytic plants.

Medium Texture - The texture exhibited by very fine sandy loams, loams, silt loams, and silts.

Mineralization - The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Mottling - Spots or blotches of different color or shades of color interspersed with the dominant color.

Nitrification - The biochemical oxidation of ammonium to nitrate.

Organic Nitrogen - Nitrogen combined in organic molecules such as proteins, amino acids etc.

Paddled Soil - Dense, massive soil artificially compacted when wet and having no regular structure. The condition commonly results from the tillage of a clay soil when it is wet.

Particle Size Distribution - The amounts of the various soil separates in a soil sample, usually expressed as weight percentage.

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.

Ped - A unit of soil structure such as an aggregate, crumb, prism, block, or granule, formed by natural processes.

Perched Water Table - The upper limit or surface of a small body of water above the main water table. The water is retained in its elevated position by an impervious stratum and may form a limited source of water supply.

Percolating Filter - A type of trickling filter.

Percolation - The flow or trickling of a liquid downward through a contact or filtering medium. The liquid may or may not fill the pores of the medium.

Percolation Rate - The rate at which water moves through the soil once it has passed the interface. It measures the ability of a soil to transport water.

Permeability of Soil - The ease with which liquid passes through a bulk mass of soil or a layer of soil.

Plains - Land forms whose predominating feature is flatness or low inclination; generally applied to topographic features which cannot properly be described as benches or terraces.

Porosity - The volume percentage of the total bulk not occupied by solid particles.

Sand Filter Trenches - A system of trenches, consisting of a perforated pipe or drain tile surrounded by clean, coarse aggregate containing an intermediate layer of sand as filtering material and provided with an underdrain for carrying off the filtered sewage.

Seepage Bed - A trench or bed exceeding 91 cm (36 in.) in width containing a minimum of 30.5 cm (12 in.) of clean, coarse aggregate and a system of distribution piping through which treated sewage may seep into the surrounding soil.

Seepage Pit - A covered pit with lining designed to permit treated sewage to seep into the surrounding soil.

Septic Tank - A Water-tight, covered receptacle designed and constructed to receive the discharge of sewage from a building sewer, separate solids from liquid, digest organic matter and store digested solids through a period of detention, and allow the clarified liquids to discharge for final disposal.

Serial Distribution - A series of absorption trenches, seepage pits, or seepage beds so arranged that each is forced to pond to utilize the total effective absorption area before the liquid flows into the succeeding component.

Settleable Solids - That matters in wastewater which will not stay in suspension during a preselected settling period but either settles to the bottom or floats to the top.

Slope - Deviation of a plane surface from the horizontal.

Sludge - The accumulated, settled solid deposited from sewage and containing more or less water to form a semi-liquid mass.

Sludge Clear Space - The distance between the top of the sludge and the bottom of the outlet device.

Soakaways - A soakaway is basically a pit or a trench filled with stones or given a lining through which water can seep. It simply allows the waste water to filter into the ground and disperse.

Soil Absorption Field - A system of absorption trenches.

Soil Absorption System - Any system that utilizes the soil for subsequent absorption of the treated sewage; such as an absorption trench, a seepage bed, or a seepage pit.

Soil Map - A map showing the distribution of soil types or other soil mapping units in relation to the prominent physical and cultural features of the earth's surface.

Soil Morphology - The physical constitution, particularly the structural properties, of a soil profile as exhibited by the kinds, thickness, and arrangement of the horizons in the profile, and by the texture, structure, consistence, and porosity of each horizon.

Soil Separates - Groups of mineral particles separated on the basis of a range in size. The principal separates are sand, silt and clay.

Soil Survey - The systematic examination, description, classification, and mapping of soils in an area.

Soil Texture - The relative proportions of the various soil separates in a soil.

Soil Water Tension - The expression, in positive terms, of the negative hydraulic pressure of soil water.

Standard Absorption Trench - A trench 30.5 cm (12 in.) to 91 cm (36 in.) in width containing 30.5 cm (12 in.) of clean, coarse aggregate and a distribution pipe, covered with a minimum of 30.5 cm (12 in.) of earth cover.

Steady State A condition in which the rate of change of parameters of interest in describing a process is 0; i.e., $dc/dt = 0$.

Subsurface Sand Filters - A wide bed, consisting of a number of lines of perforated pipe or drain tile surrounded by clean coarse aggregate, containing an intermediate layer of sand as filtering material, and provided with a system of underdrains for carrying off the filtered sewage.

Subsurface Sewage Disposal System - A system for the treatment and disposal of domestic sewage by means of a septic tank and a soil absorption system.

Tight Soil - A compact, relatively impervious and tenacious soil (or subsoil), which may or may not be plastic.

Top Soil - The layer of soil moved in cultivation.

Total Solids - The solids in water, sewage, or other liquids; includes suspended and dissolved solids; all material remaining as residue after water has been evaporated.

Total Kjeldahl Nitrogen (TKN) - An analytical method for determining total organic nitrogen and ammonia.

Tertiary Treatment - Treatment to remove traces of organic matter causing a biochemical oxygen demand that were passed through from the secondary treatment process.

Uniformity Coefficient - A coefficient obtained by dividing that size of sand of which 60 percent by weight is smaller, or 10 percent by weight is smaller.

Unsaturated Flow - The movement of water in a soil which is not filled to capacity with water.

Water Table - The upper surface of ground water, or that level below which the soil is saturated with water, and the hydraulic pressure is zero.

Environmental Sanitation Reviews, No. 7&8, April 1982

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SEPTIC TANK AND SEPTIC SYSTEMS

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by

ENSIC Review Committee on Septic Systems

C. Polprasert
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D. Donaldson
T. Viraraghavan

1. INTRODUCTION

Safe disposal of wastewater from single family dwellings not connected to a central sewerage system is a complex and serious problem. Such wastewaters contain many undesirable and potentially dangerous substances. Pathogenic bacteria and viruses that cause diseases such as typhoid fever, dysentry, gastro-enteritis, cholera, poliomyelitis and several parasitic infections are often carried with the wastewater. Putrescible organic matter, toxic chemicals and nutrients (i.e. nitrogen and phosphorus compounds) are also found in wastewater which can create nuisances and lead to the deterioration of the environment.

For a prosperous city with an ample water supply, a water carried sewerage system discharging into a sewage treatment plant can satisfy all the requirements for safe and nuisance-free wastewater disposal. However, according to Figure 1, sewers are available only to a small proportion of the urban population in the developing countries. The number of people without sewers is increasing, mainly because the population growth exceeds the provision of new sewer connections. Another estimate by the World Health Organization (WHO) (51) indicates that in the developing countries, public sewers in cities reach 70 percent of the urban population; while in rural areas, only 8 percent have a disposal system, and others have no system at all.

In low density residential areas throughout the world, septic tanks are the most common means of providing water carried sanitation where there is no municipal sewerage system. For the residential dwellings existing in a variety of forms, such as single and multiple family households, apartment houses, cottages or resort residences, isolated villages and hamlets, a well designed septic tank with an effective effluent disposal system has virtually all the advantages of a sewer connection.

It is well established that a properly designed septic tank

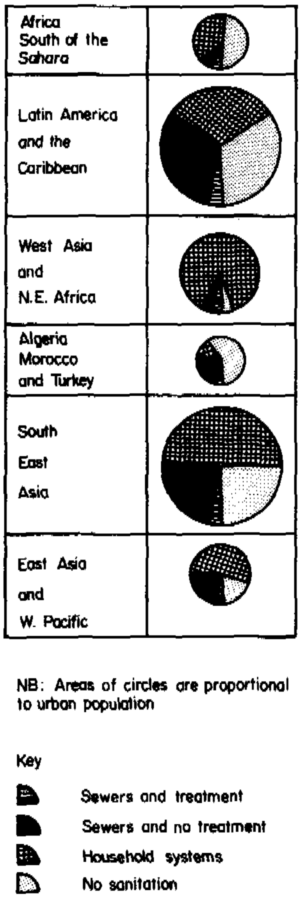


Figure I Urban Sanitation in Developing Countries (43)

performs efficiently in the removal of settleable matter and its settleable biochemical oxygen demand (BOD) components. However, the effluent from a septic tank still contains high pathogenic bacteria, BOD, nitrogen and phosphorus which prohibit its discharge into any water course or on land. The subsurface soil absorption system is widely recommended to overcome the problem of septic tank effluent disposal wherever site conditions are suitable and does not pose any threat to the ground water quality. The conventional method of sub-surface soil disposal of septic tank effluent cannot be applied in shallow soil over creviced bed rock and in sites with a high ground water table. In these problem soils, other alternatives such as intermittent sand filters, mound systems, evapotranspiration beds and anaerobic filters have been proposed.

This paper presents a state-of-the-art review on the septic tank and septic systems. Information on design and functional aspects, and environmental effects of septic tank systems are presented. In addition, some important research needs as reported in the literature are pinpointed. It should be noted that this review paper contains neither standards nor rules and regulations pertaining to septic tank and septic systems. The design information presented herein is intended as technical guidance. It is hoped that this review will serve as a basic source of information to those, besides academicians, who are actively involved in the field.

2. WASTEWATER CHARACTERISTICS

2.1 Wastewater Flow

The effective management of any wastewater flow requires a reasonably accurate knowledge of its quantity and quality. This is particularly true for wastewater flows from houses and rural residential dwellings where individual water use patterns create an intermittent flow of wastewater that can vary widely in volume and degrees of pollution. The total amount of water used per person per day (pd) varies with the economic level of the community and the individual household. It also depends on the availability of water, local affluence and habits. Generally in rural areas the range is between 10-40 l/pd, whereas in urban areas, water consumption rate may go up to 300 l/pd (319). Septic tanks dealing only with flow from the toilet receive 50 l/pd if each person flushes the pan each time it is used. However, in developing countries where water is in short supply or the householder is charged on the metered quantity, the pan may not be flushed every time the toilet is used, and the flow may be 20 l/pd or less. In cases where a septic tank receives all the domestic wastewater, this is likely to be about 90 percent of the water consumption, apart from that used for garden watering (43). WAGNER and LANOIX (157) reported that a sewage flow of less than 100 l/pd (26 gal/pd) may be expected in most rural areas of the world. Furthermore, in the absence of local information, wastewater flow of 120 l/pd is a reasonable figure (154) if there is a continuous supply of water.

2.2 Wastewater Composition

Based on the concentration of its various components, wastewater may be classified as strong, medium, or weak. Typical composition of medium strength domestic wastewater, as reported in the literature, is presented in Table 1. In using this table it must be remembered that the composition of the wastewater fluctuates with time as, individual water-using activities occur intermittently and contribute varying quantities of pollutants. Hence the data presented in the table should serve as a guide rather than a basis for design. The characteristics of the wastewater can be influenced by several factors. Primary influences are the characteristics of the plumbing fixtures and appliances present as well as their frequency of use. In addition to this, the characteristics of the residing family in terms of number of family members, age levels, and mobility are important as is the overalll socioeconomic status of the family. VIRARAGHAVAN (388) reported that, though the use of synthetic detergents is not common in India, the phosphorus content in the sewage is similar to the north American values, i.e. 10-15 mg/l, because the wastewater contribution/water used by each person is about 30% less than that of the North American usage. VANKEECK (274) reported that the average total suspended solids (TSS) entering an individual septic tank is about 150 mg/l, whereas 5-day biochemical oxygen demand (BOD) usually ranges from 150 to 325 mg/l (277).

Most of the flow from a single house to a septic tank is the water used for transporting solid excreta and for cleaning the water closet (WC) bowl. Solids in the tanks are usually derived from excreta, cleaning material and, from bathing, laundry and kitchen

Table 1: Approximate Composition of Medium Strength Domestic Wastewater (187, 236, 194, 195, 196, 215, 200, 169)

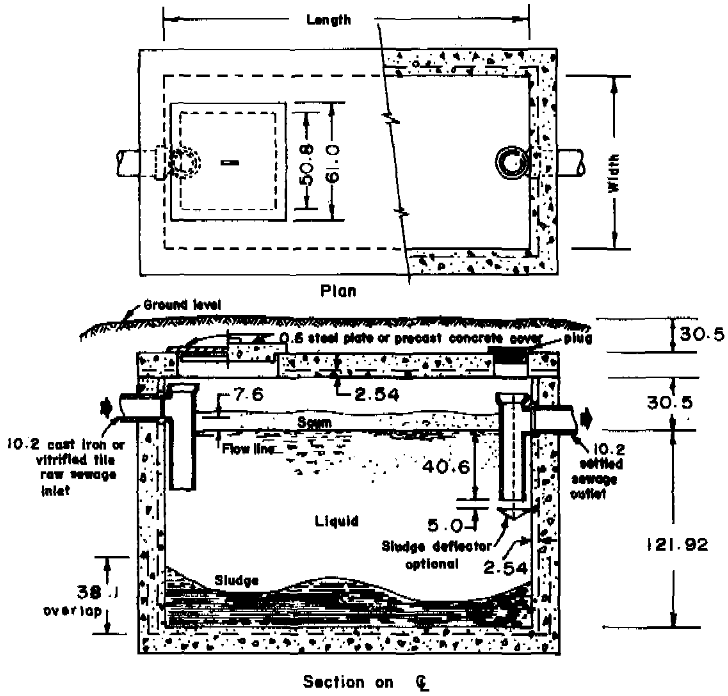
Parameter	Value mg/l, except as noted
pH, Units	6.5 to 7.0
Dissolved Oxygen	0 to 3
Biochemical Oxygen Demand	220
Chemical Oxygen Demand	610
Total Organic Carbon	240
Total Phosphorus	30
Phosphates	10
MBAS	23
Total Solids	700
Total Suspended Solids	300
Total Dissolved Solids	400
Total Nitrogen	35
Kjeldahl Nitrogen	35
Ammonia Nitrogen	25
Organic Nitrogen	10
Nitrate	0
Nitrite	0
Boron	0.25
Sodium	55
Potassium	11
Magnesium	5
Calcium	11
Zinc	5
Copper	11
Lead	0.20
Nickel	0.01
Mercury	0.07
Chromium	0.04
Sulfate	20
Chlorides	45
Grease	100
Alkalinity as $CaCO_3$	120
Coliforms - Total Coliform/100ml	25×10^5
- Fecal Coliform/100ml	3×10^5
Temperature, (°c)	37

wastes. The solids consist of both organic and inorganic matter in solution or in suspension. The organic matter includes carbohydrates and proteins from faeces and food scraps. Inorganic matter includes salt and sand.

3. DESCRIPTION OF A SEPTIC TANK

The septic tank is an outgrowth of the cesspool and the sedimentation basin. The first device which approaches the septic tank as known today was patented in France in 1881 by M. Mouras. It was called the "Mouras Automatic Scavenger" and described as "a mysterious contrivance consisting of a vault hermetically closed by a hydraulic seal. By a mysterious operation, and one which reveals an entirely novel principle, it rapidly transforms all the excrementitious matters it receives into a homogenous liquid, only slightly turbid, and holds all the solid matter in suspension in the form of scarcely visible filaments. The vault is self-emptying and continuous in workings."

A septic tank is a buried, watertight receptacle designed and constructed to receive wastewater from a home, to separate solids from the liquid, to provide limited digestion of organic matter, to store solids, and to allow the clarified liquid to discharge for further treatment and disposal. Settleable solids and partially decomposed sludge settle to the bottom of the tank and accumulate. A scum of light weight material (including fats and greases) rises to the top. The partially clarified liquid is allowed to flow through an outlet structure just below the floating scum layer. This partially clarified liquid can be disposed of through soil absorption systems, soil mounds, evaporation beds or anaerobic filters depending upon the site conditions. The essential components of a septic tank are shown in Figure 2.



Plan

Section on ℄

All dimentions in centimetres

Figure 2 Schematic Details of a Septic Tank (275)

3.1 Processes within the Septic Tank

Although a septic tank is simply a sedimentation basin with no moving parts or added chemicals, the processes occuring in the tank are complex, and interact with each other. The most important processes are discussed below.

3.1.1 Separation of Suspended Solids

This is a purely mechanical process and results in the formation of three distinct layers in the septic tank (Figure 2): a layer of sludge on the bottom, a floating layer of scum on top, and a relatively clear layer of liquor in the middle. Very fine particles called colloids initially stay in suspension, but later these particles coagulate to form larger particles which may fall or rise depending on their density. Coagulation is assisted by gases and particles of digested sludge rising through the liquid.

3.1.2 Digestion of Sludge and Scum

Organic matter in the sludge, as well as in the scum, is degraded by anaerobic bacteria. As a result of bacterial action, volatile acids are formed at first and eventually are converted mostly to water, carbon dioxide and methane. The formation of gases in the sludge layer causes irregular floatation of sludge flocs, which resettle after the release of the gases at the surface. Sludge at the bottom of the tank is compacted, becoming denser due to the weight of the liquid and the top layers of sludge.

3.1.3 Stabilization of the Liquid

During their retention in the tank, organic materials remaining in the liquid are stabilized by anaerobic bacteria, which break down complex substances into simpler ones, in a process similar to the one described in 3.1.2.

3.1.4 Growth of Micro-organisms

Many kinds of micro-organisms grow, reproduce and die in the tank. Most are attached to organic matter and so separated out with the solids. Some, accustomed to living in the human intestine, suffer in the adverse environment of the tank. Some are themselves heavy and sink to the sludge layer. There is an overall reduction in the number of micro-organisms, but a large number of viruses, bacteria, protozoa and helminths can be present in the effluent, the sludge and the scum.

4. PERFORMANCE OF A SEPTIC TANK

The settleable solids in sewage settle out and are retained in the septic tank (268), and others float in the scum layer. Tables 2 & 3 give respectively the average composition of septic tank effluent and percent removal efficiency of the septic tank. The effluent is generally high in BOD, bacteria, organic and ammoniacal nitrogen and phosphorus (104, 66). Reduction in BOD of 25-50 percent has been observed (75, 321). The high reduction in BOD and TSS can be obtained by prolonging the retention time. PHADKE et al. (131) reported about 80 percent removal of both BOD and TSS by providing a nearly 20-day retention period in the tank. However, in practice this long retention time may not be practicable. BRANDES (30, 31) studied the quality of effluents from septic tanks treating grey water and black water. He found that without increasing the volume of the septic tank, the efficiency of the blackwater treatment was improved by prolonging the retention time through discharging the grey water to a separate treatment disposal system. In the test of six small septic tanks dosed intermittently with municipal sewage to provide a retention time of about 30 hours, BABBIT and BAUMANN (33) reported the efficiencies of these tanks as listed in Table 4. All tanks were dosed on a similar basis in a fixed laboratory type situation without major flow variation. Figures 3, 4 and 5 show respectively the levels of

Table 2: Average Composition of Septic Tank Effluent (115, 275, 276, 119, 30, 22, 11, 23)

Parameter	Value mg/l, except as noted
Total Suspended Soilds, mg/l	40 - 74
Vol. Susp. Solids	36 - 60
BOD_5	90 - 130
Dissolved Oxygen	0
pH	70 - 81
Alkalinity	300 - 400
Organic Nitrogen	5.4 - 10
Nitrite - Nitrogen (NO_2- N)	0.003 - 16.2
Nitrate - Nitrogen (NO_3- N)	0.11 - 0.15
Ammonical Nitrogen (NH_3- N)	14 - 25
Phosphate as P	20
Potassium (K)	10 - 15
Sodium (Na)	10.0
Sulphates	50
Chloride	43 - 70
Coliform bacteria/100ml.	1.01×10^6 - 2×10^8

Table 3: Septic Tank Effluent Concentrations and Percent Removed (187, 236, 200, 81, 219, 290, 186)

Parameter	Value mg/l, except as noted	Percent Removed
pH, Units	7.1	--
Dissolved Oxygen	0	--
Biochemical Oxygen Demand	160	27
Chemical Oxygen Demand	323	47
Total Organic carbon	129	46
Total Phosphorus	18	40
Phosphates	34	240 increase
MBAS	7.6	67
Total Solids	378	46
Total Suspended Solids	90	70
Total Nitrogen as N	32	8
Ammonia Nitrogen	27	8 increase
Organic Nitrogen	8	20
Nitrate	0.14	increase
Nitrite	0.061	increase
Chlorides	95	111 increase
Alkalinity	390	225 increase
Coliforms - Total coliforms	10^5/100 ml	--
- Fecal coliforms	10^5/100 ml	--

Table 4: Performance of Six Small Septic Tanks Dosed with Municipal Sewage, 27 - 34 Hours Detention (33)

Test	Units	Raw Sewage	Septic Tank					
			1	2	3	4	5	6
Suspended Solids	mg/l	267	55	63	46	85	40	79
Settleable Solids	ml/l	8.05	0.45	0.07	0.08	0.83	0.09	1.79
BOD_5	mg/l	301	63	103	70	91	84	104

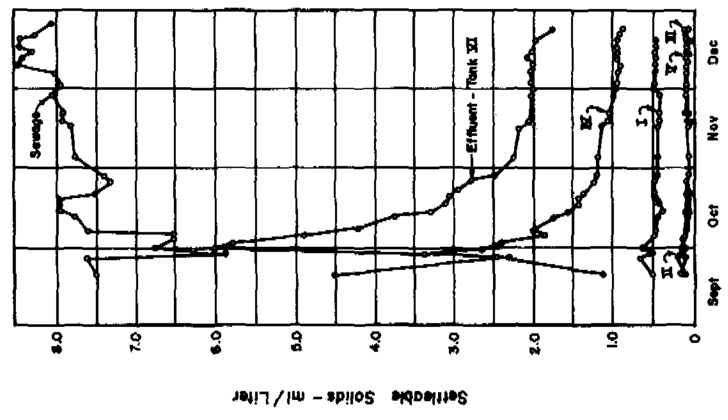


Fig.3 Average Settleable Solids in Effluents of Six Septic Tanks (33)

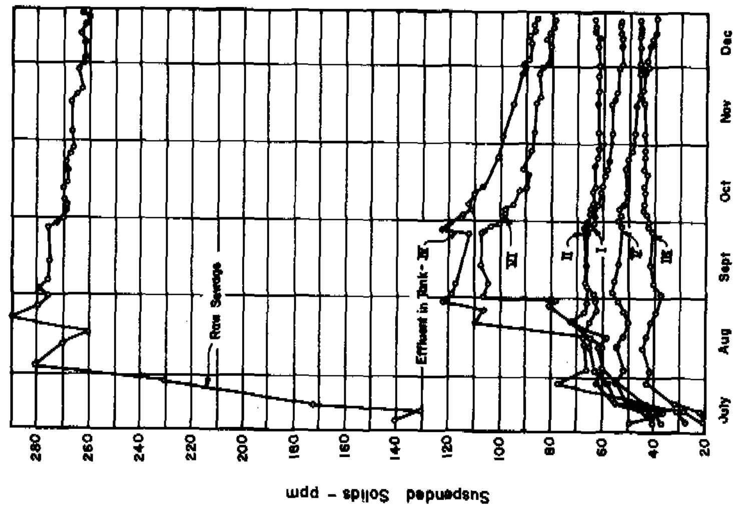


Fig.4 Average Suspended Solids in Effluents of Six Septic Tanks (33)

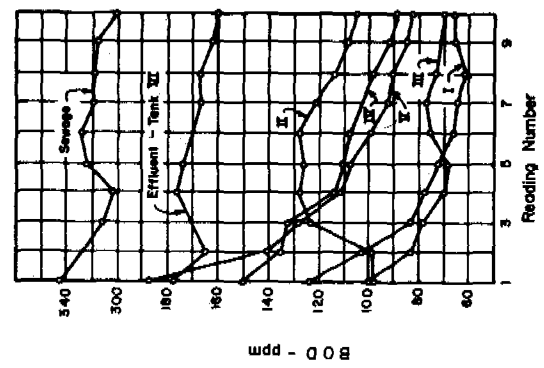


Figure 5 Average BOD in Effluents of Six Septic Tanks (33)

settleable solids, suspended solids and BOD of the influent and effluents from each tank. Figure 3 indicates that the settleable solids in the effluents from tanks not having baffles (I, IV and VI) are significantly greater than those tanks incorporating baffles in their design. It can be seen from Figures 4 and 5 that after a period of acclimatization, these three tanks provided both the best suspended solids removal and BOD removal. The performance of tanks 1 and 3 appeared to have reached a peak, but the performance of other tanks was still improving.

The performance of a septic tank depends to a great extent on the retention time. When wastewater stands quiescent or moves at a very low velocity the suspended matter and the solids settle out gradually, with the heaviest portion settling first. After prolonged standing, a part of the suspended colloidal matter may settle down gradually through coagulation due to physical contact or changes in composition of the sewage, and eventually a part of the dissolved colloidal matter may be precipitated similarly. The effect of the retention time on the efficiency of solid separation is illustrated in Figure 6.

Other factors, apart from the retention time, which affect the performance of the septic tank are: ambient temperature, the nature of the influent wastewater, the organic matter content in the wastewater, and the position of the inlet and the outlet in the septic tank. The digestion of sludge and scum depends on the microbial population and the temperature. Sludge and scum decompose more slowly at lower temperatures (76, 193). Digestion is accelerated by an increase in temperature up to about 35 degrees Celsius, (43).

It is a well established fact for a sedimentation process that quiescent conditions are required, while for efficient digestion thorough mixing is useful. When the flow into the tank comes in surges, these surges disturb the whole liquid, especially in small tanks (Figure 7). In addition, the temperature of the incoming wastewater may be different from that of the liquid in the tank, which further disturbs the liquid. In a septic tank, disturbance due to surges can be reduced by using a longer inlet drain pipe (Figure 8). CLEMESHA (140) reported that the hanging scum board at the inlet improved the performance of septic tanks. However, STEPHENSON (160) who reported common defects in design and construction of septic tanks, illustrated that tanks should not be provided with hanging baffles because these hanging baffles will affect the sedimentation and digestion process in the tank (Figure 9E). LUDWIG (87) suggested that the installation of a mechanical mixer in the primary chamber of a two-compartment tank would speed up the anaerobic digestion and thus enhance the performance of the septic tank.

5. DESIGN AND CONSTRUCTION OF A SEPTIC TANK

5.1 Design Objectives of a Septic Tank

The primary purpose of a septic tank is to receive and treat the raw household wastewater in order to provide a satisfactory effluent for disposal into the ground or by other means. A septic tank must be designed to ensure removal of almost all settleable solids and as high a degree as possible of anaerobic decomposition of the colloidal and soluble organic solids. To accomplish this, the tank must provide the following:

1. A volume of liquid sufficient for a 24-hour liquor retention time at maximum sludge depth and scum accumulation (40).

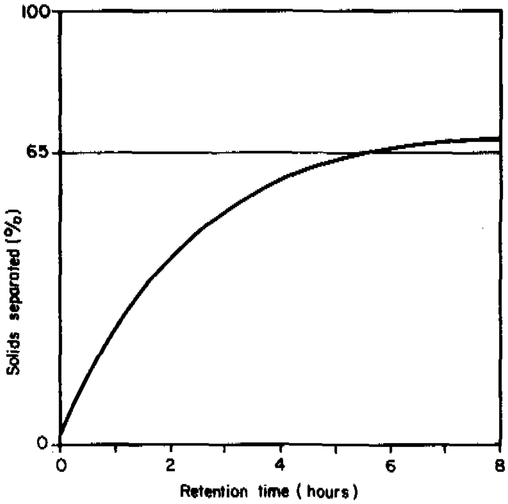


Figure 6 Typical Relationship between Solids Separation and Time of Retention of Sewage in Tank (43)

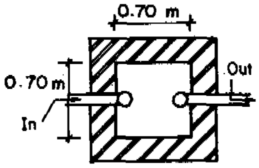


Figure 7 Tank which is too small to be efficient (160)

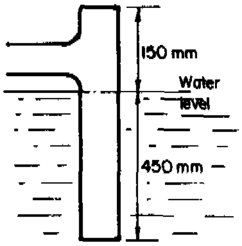
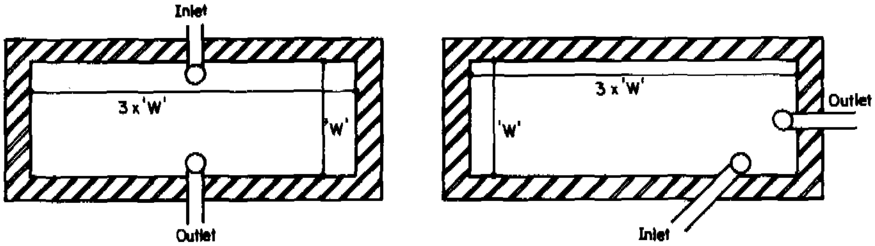
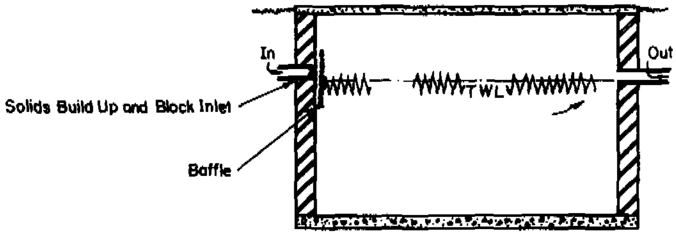


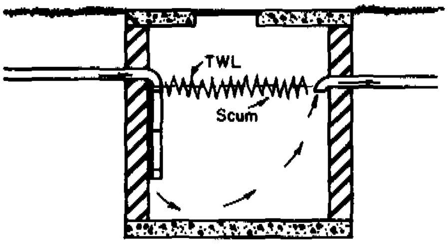
Figure 8 Simple Inlet to Septic Tank (43)



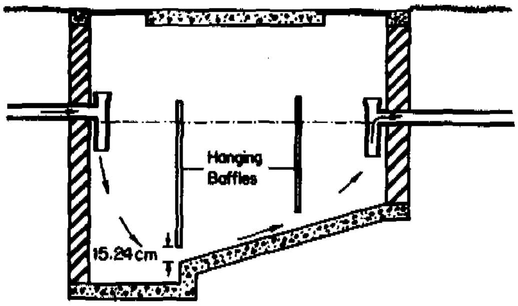
A and B Typical Examples of Tanks with Poorly Placed Inlets and Outlet



C : Poor Inlet and Outlet



D : Tank with Inlet too Deep



E : Tank Fitted with Hanging Baffles;
Sludge is Washed Straight Through.

Figure 9 Common Defects in Design of Septic Tanks (160)

2. Proper placement of inlet and outlet devices and adequate sludge and scum storage space to prevent the discharge of sludge or scum in the effluent.

3. Since the digestion process is anaerobic, no direct ventilation is necessary. However, provision should be made for the escape of the gases produced in the tank.

5.2 Septic Tank Sizing

The capacity of a septic tank should make provision for liquid retention, as well as for storage of sludge and scum between cleaning. There is a diversity of opinion regarding the liquid retention time and frequency of cleaning. It is normally considered that liquid retention time should not be less than 24 hours (40). The extent to which provision should be made for the storage of sludge and scum will depend on the frequency of cleaning. The frequency of cleaning depends on the rate of sludge and scum accumulation and this in turn depends on many factors, such as liquid retention time, ambient temperature, the materials used for anal cleaning and the volume of wastewater. Hence, there is a great diversity regarding the rate of sludge and scum accumulation per person.

There are various formulae, codes and standards which relate the capacity of the tank to the number of bedrooms per home, the number of users and the average daily flow of sewage. The required minimum liquid capacities of tanks based on the number of bedrooms and the number of users are presented in Tables 5 and 6, respectively. The septic tank standards for single houses used in different countries are shown in Table 7. Figure 10 shows the relationships between capacity and the number of people served, for some widely used standards. It can be seen from this figure that there is a great variation in capacities suggested. The formula used in the British Standard Code of Practice (183) gives the capacity, in litres, c as $c = 180\ P+2000$, where P is the contributing population. In the USPHS. manual (137), the capacity of a household septic tank is related to the number of bedrooms, and that of institutional tanks to the sewage flow rate. For developing countries, the number of users or the average daily flow rate is the most appropriate criteria for sizing a septic tank. The Indian system (38) allows for the rate of sewage flow, the rate of sludge accumulation, the frequency of sludge removal and the effect of surge due to simultaneous discharge from sanitary fixtures.

The effective capacity of a septic tank, expressed in litres, can also be calculated by the following general equation (43):

$$C = A+P\ (rq+ns) \qquad (1)$$

where A is a constant, P is the number of persons contributing to the tank, r is the minimum retention time (in days) for sewage in the tank just before desludging is carried out, q is the sewage flow in litres per person per day, n is the number of years between desludging, and s is the rate of sludge accumulation in litres per person per year.

In the British Code of Practice (183), 'A' is given as 2000 litres and the term (rq+ns) equals 180 litres.

The retention time r is often taken as one day (184, 185, 263, 159). CAMPBELL and MARA (1) recommended that the size of the septic tank should be based on a 3-day retention time at start up which is

Table 5: Required Capacities of Septic Tanks Based on Number of Bedrooms (10, 23, 100, 137, 159, 372)

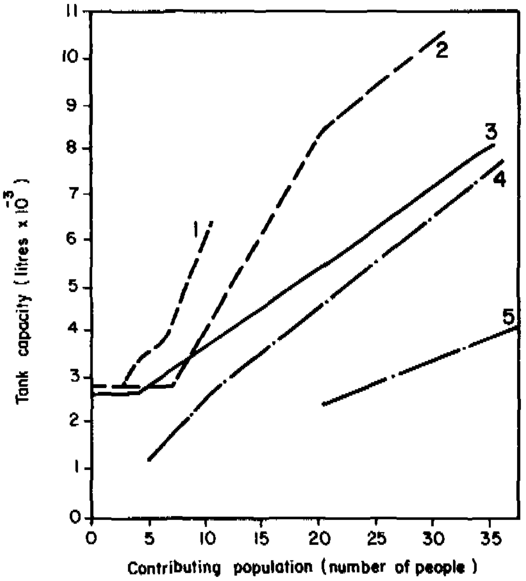
Number of Bedrooms	Nominal Liquid Capacity of Tank, m^3	Equivalent Capacity per Bedrooms, m^3
2 or less	2.84	1.42
3	3.41	1.14
4	3.79 - 4.16	0.95 - 1.04
5	4.92	0.98
6	5.67	0.94

Table 6: Required Capacities of Septic Tanks Based on Number of Persons Served (157, 261, 262, 275)

Number of Bedrooms	Nominal Liquid Capacity of Tank, m^3	Equivalent Capacity of Tank per Person, m^3
1		0.05
4	1.89	0.47
6	2.27	0.37
8	2.84	0.35
10	3.41	0.34
12	4.16	0.34
14	4.92	0.35
16	5.68	0.35

Table 7: Septic Tank Standards for Single Houses, World Health Organization 1953 (274).

Country	Minimum Liquid Capacity, m^3	Compartment	Detention (days)
Belgium	1.25	2	2
Finland	1.02	1 - 2	1 - 2
France	1.70 - 2.27	1 - 3	5 - 10
Germany	2.46	3	5 - 10
Great Britain	2.46	1 or 2	2 - 4
Greece	2.38	2	-
Italy	-	3	3
Switzerland	3.33	3	3 - 4
U.S.A.	1.90	2	2 - 3



Key

1. US Manual of Septic Tank Practice
   - private house assuming 1½ persons per bedroom
2. US Manual of Septic Tank Practice
   - institutional tank, single family dwellings, flow 21.2 m^3/day (75 gal/day)
3. British Standard Code of Practice CP 302:1972
4. Indian Standard Code of Practice for design and construction of septic tanks - 2 year cleaning interval
5. Indian Standard Code of Practice for design and construction of septic tanks – 6 months cleaning interval

Figure 10 Minimum Recommended Tank Capacities (43) equivalent to a 24-hour retention just prior to desludging. However, JONES (280) stated that septic tanks are normally designed on the basis of 283.8 l (75 gal) of sewage per capita per day and a theoretical detention time of 48 to 72 hours. Furthermore, theoretical detention times determined from various recommended loadings and clear space requirements ranged from 12 hours for a 3785 l (1000 gal) tank to 21 hours for a 2840 l (750 gal) tank (29).

In the Indian code, the sludge accumulation rate, s, is taken as 77 litres per person per year (38). Measurements in the United States (159) on 205 septic tanks gave the average rate of accumulation as shown in Figure 11, and this rate is also used in the South African guide (148).

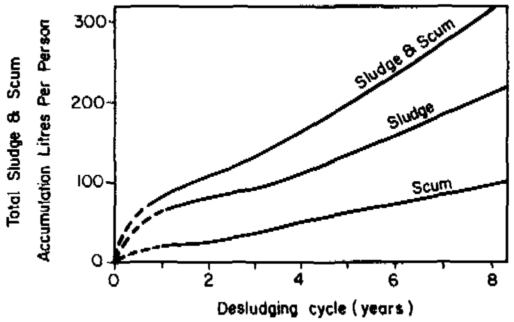


Figure11 Rate of Accumulation of Sludge and Scum in 205 Septic Tanks in U.S.A (159)

The capacity of a septic tank can easily be calculated by assuming that sludge and scum are removed when they occupy two-thirds of the capacity, and the retention time is never less than a day. In this case, the required capacity is three times the total daily sewage flow, multiplied by the retention time,

or $C = 3 Prq$.

There are several methods for calculating the required tank capacity. However, most of the available methods are not applicable for developing countries (such as the method based on the number of bedrooms in a home, i.e. two person/bedroom). PICKFORD (43) presented a detailed method of calculating the required capacity considering local variations, as described below.

As the tank has to accommodate both solids (sludge and scum) and liquids, there are three stages in the calculation.

1. Calculate the capacity needed for sludge and scum storage:

$A = Pnfs$ litres

where, A is the required sludge storage capacity, P is the number of people expected to contribute to the tank, n is the number of years between desludging (assumed as 3 years if no other information is available), f is a factor which is related to the ambient temperature as described in Tables 8 and 9, S is the rate of sludge and scum

Table 8: Values of Sizing Factor 'f' for Stated Desludging Intervals and Temperatures (43)

Number of Years between De-Sludging	Ambient Temperature		
	More Than 20°C Throughout Year	More Than 10°C Throughout Year	Less Than 10°C During Winter Time
1	1.3	1.5	2.5
2	1.0	1.15	1.5
3	1.0	1.0	1.27
4	1.0	1.0	1.15
5	1.0	1.0	1.06
6 or more	1.0	1.0	1.0

Table 9: Rate of Sludge Accumulation 'S' in Litres (43)

Material Used for Anal Cleansing	Water Closet or Latrine Wastes Only	Household Sullage in Addition to Waste
Water, soft paper	25	40
Leaves, hard paper	40	55
Sand, stone, earth	55	70

accumulation, C, in litres per year, which depends upon the materials used for anal cleansing as well as upon the volume of wastewater received by the tank (Table 9).

2. Calculate the capacity needed for liquid retention:

$$B = Prq \text{ litres}$$

where B is the required liquid retention capacity and q is the average flow, l/pd. The average sewage flow 'q' may be determined by measuring sewage flows for a given period, but this is seldom feasible, particularly in rural areas. If no local information is available for q, the following values can be assumed:

(i) 120 l/pd if water is continuously available at good pressure and the house has several fittings (i.e. WC, bath or shower, sink etc.), all of which are connected to the water supply and the septic tank.

(ii) 50 l/pd if water is continuously available at good pressure, but only to a compound tap, and domestic wastewater goes to the tank.

(iii) 40 l/pd if water is continuously available at good pressure and the WC alone is connected to the water supply and the septic tank. (If water is not available all the time, or pressure is sometimes low, multiply the given value by the proportion of the day during which it is normally available).

(iv) 20 l/pd if water is obtained from a nearby stand-pipe.

(v) 5 l/pd if water is obtained from a public standpipe, well or other source and only the minimum water is used to clean the latrine.

(vi) If it is certain that the water supply will improve during the next few years, the value of q should be based on the expected water supply.

3. <u>Calculate the total capacity</u>

Having made the separate calculations of the capacities needed for storage of solids and liquid, then the total capacity required is the sum of the two, i.e.,

$$C = A+B$$

unless B is less than half of A, the minimum capacity of the tank should be:

$$C = 1.5 A$$

Thus, the minimum capacity for proper functioning of the tank can be determined. In the case of small tanks, the size is often determined by other considerations (e.g., the width of the tank should not be less than 60 cm if a man is to work inside, either to build or to maintain it).

5.3 Shape and Dimensions of the Tank

The shape of the tank influences the velocity of sewage flowing through the tank, the depth of sludge accumulation and the presence or absence of a stagnant pocket of liquid. If the tank is too deep, then the other dimensions will also be too small, and a direct sewage current from inlet to outlet will occur, thereby shortening the detention time. Conversely, if the tank is too shallow, the sludge clear space will be too small and the effective cross section will be unduly reduced (150, 157).

A very deep tank reduces the surface area and thus causes reduction in the sedimentation efficiency (154), although for a tank of given capacity and depth, the shape of the tank is relatively unimportant (148). Both shallow and deep tanks function equally well, provided there is no sacrifice in capacity or surface area (100) (Figure 7). However, tanks with greater surface area and shallow depth are preferred, because increased liquid surface area increases surge storage capacity. These surges of flow through the tank diminish as the surface area increases. This allows a longer time for separation of the sludge and scum that are mixed by turbulance resulting from the influent surge.

A rectangular septic tank has been reported to be better than a square septic tank, while long narrow tanks are most satisfactory (154). Tanks of cylindrical shape, made of sewer pipe of ample size are reported to be satisfactory and, in some cases, less costly to install (135). A rectangular shape for a single compartment tank is most favoured with a length three times its width; the depth is usually 1.22-1.83 m (177). CHOI (39) observed 47 percent and 43 percent BOD removal in rectangular and circular tanks, respectively, thus indicating the superiority of the rectangular tank. A few typical shapes of tank are shown in Figure 12.

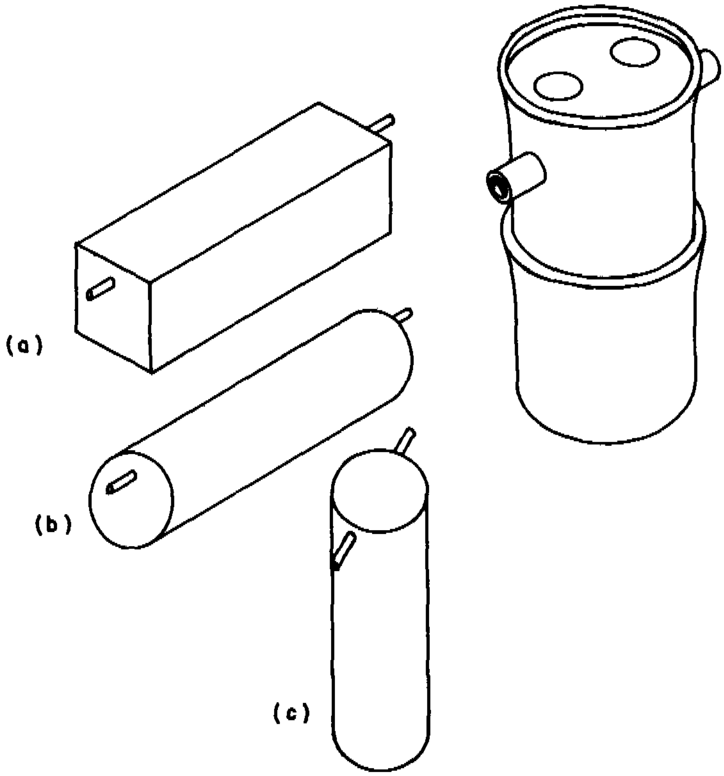


Figure 12 Typical Shapes of Septic Tank

5.4 Compartmentation

The experimental investigations on septic tank compartmentation are well reported (199, 370). A single compartment tank usually provides acceptable performance (137, 148) but a two-compartment tank is reported to be better than a single compartment tank of equal capacity for the removal of BOD, suspended solids and organic colloids (100, 147, 8, 135, 363, 162). One of the reasons for this is the trapping action of the second compartment (100). Two compartment tanks are particularly important where the population is less than 100 (178) and the subsurface soil absorption field is installed in very dense soil (277). Moreover, the hourly and daily flows from the home can vary greatly. During high flow periods, higher solids concentrations are discharged with septic tank effluent. Well-designed two compartment tanks can reduce the effect of peak hourly loads.

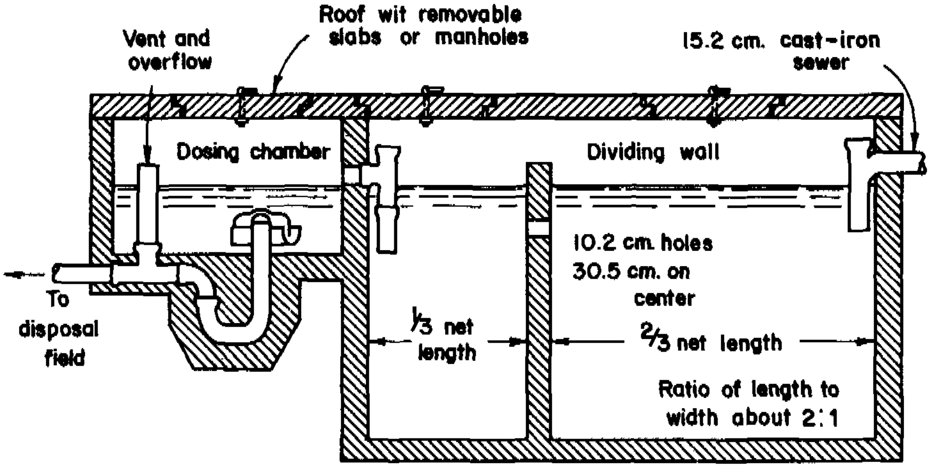


Figure 13 Two - Compartment Septic Tank with Dosing Chamber (193)

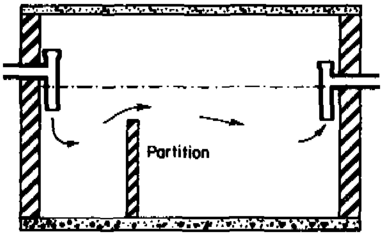


Figure 14 Example of Poor Compartmentation (160)

The large compartment, holding at least two thirds of the sewage should be situated immediately after the inlet, as shown in Figure 13. The liquid capacity of the first compartment should not be less than that of the second compartment, as it would result in large flows, disrupting the sludge contained in the first compartment and causing it to be washed over into the second compartment (Figure 14) (160). In addition a partition such as that shown in Figure 14 should be carried to at least 15.2 cm (6 in.) above the top water level to ensure little disturbance of the scum build up. The flow of liquid from the first compartment to the second compartment is best achieved through horizontal slots. The slots should be made below the scum level and above the sludge.

Some investigators have stated that the benefit of dividing a septic tank into more than two compartments is insignificant (135, 148). However, PEEL (150) reported that the multicompartment tank provides better BOD removal efficiency. Furthermore, a three compartment septic tank used in China showed a high parasitic ova removal efficiency (138).

5.5 Inlet and Outlet Devices

The design and location of inlet and outlet devices have considerable influence on tank operation. Sewage should enter the septic tank without causing much disturbance to the sedimentation process and the outflow of a septic tank should carry only minimal concentrations of settleable solids. Higher solids concentrations can occur if:

1. The inlet turbulence in a single-compartment tank causes mixing of the sludge with the liquor in the clear space.
2. The rise velocity of the water in the vertical leg of the outlet tee resuspends previously captured solids.
3. The rising gases produced by anaerobic digestion interfere with particle settling and resuspended previously captured solids, which then are lost in the effluent.

The above problems can occur if the inlet and outlet are poorly designed and improperly placed, as illustrated in Figure 9. The inlet to a septic tank should be designed to dissipate the energy of the incoming water, to minimize turbulence, and to prevent short-circuiting. The inlet should preferably be either a sanitary tee, an elbow, or a specially designed inlet device (similar to the outlet shown in Figure 2). The invert radius in a tee helps dissipate energy in the transition from horizontal to vertical flow, and prevents dripping - which at the proper frequency can amplify water surface oscillations and increase intercompartmental mixing. The vertical leg of the inlet tee should extend below the liquid surface. This minimizes induced turbulence by dissipating as much energy in the inlet as possible.

In order to limit the action of surge flows from flushing water closets and unplugged baths and sinks, the pipe to the septic tank should not be less than 10 cm in diameter, and the gradient not steeper than 1.5% for the last 10 metres. The inlet tee juction diameter should not be less than the inlet pipe (i.e. not less than 10 cm); the top limb should rise at least 15 cm above the water level, and the bottom limb should extend about 45 cm below the water level, as shown in Figure 8 (43).

The outlet structure's ability to retain sludge and scum in a septic tank is a major factor in overall tank performance. The outlet of a septic tank can be a tee or a baffle. The outlets for septic tanks are usually made with a tee-junction (Figure 2). It should be placed in such a way that the bottom of the horizontal leg is below the level of the inlet pipe. The bottom of the pipe is called the invert, the main function of which is to fix the water level in the tank. As with the inlet tee-junction, the vertical leg must extend above the top and bottom of the scum layer, as shown in Figure 15. Liquid must be discharged from the liquid zone between the scum and the sludge. An alternative to the outlet tee is a guard plate made of ferrocement or asbestos cement, as illustrated in Figure 16.

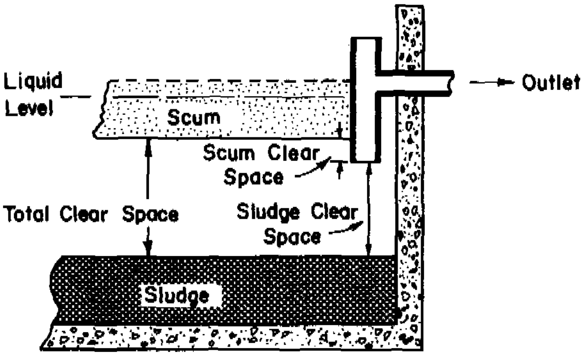


Figure 15 Septic Tank Scum and Sludge Clear Spaces (40)

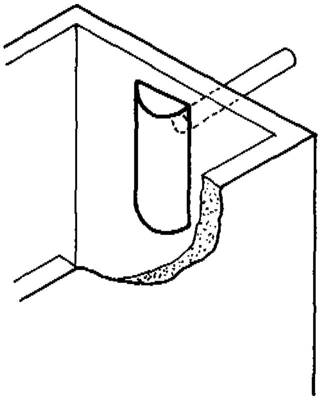


Figure 16 Simple Outlet from Septic Tank (148)

In the case of small tanks, surge in the tank results in increased outflow, although the surge is attenuated by passage through the tank. However, with rapid discharge, there is a danger that the upward movement of the liquid will drag the sludge with it. Apart from this, rising gases in either small or big tanks may disturb sludge settling. BAUMANN and BABBIT (102) recommended the addition of a gas-deflection baffle under the rising leg of the discharge outlet to prevent gas disturbance of the liquor to be discharged. This baffle can take many forms and is described in Figure 17B as a sludge deflector. Figure 17 shows several schematic diagrams of methods used to include gas deflection devices in septic tanks.

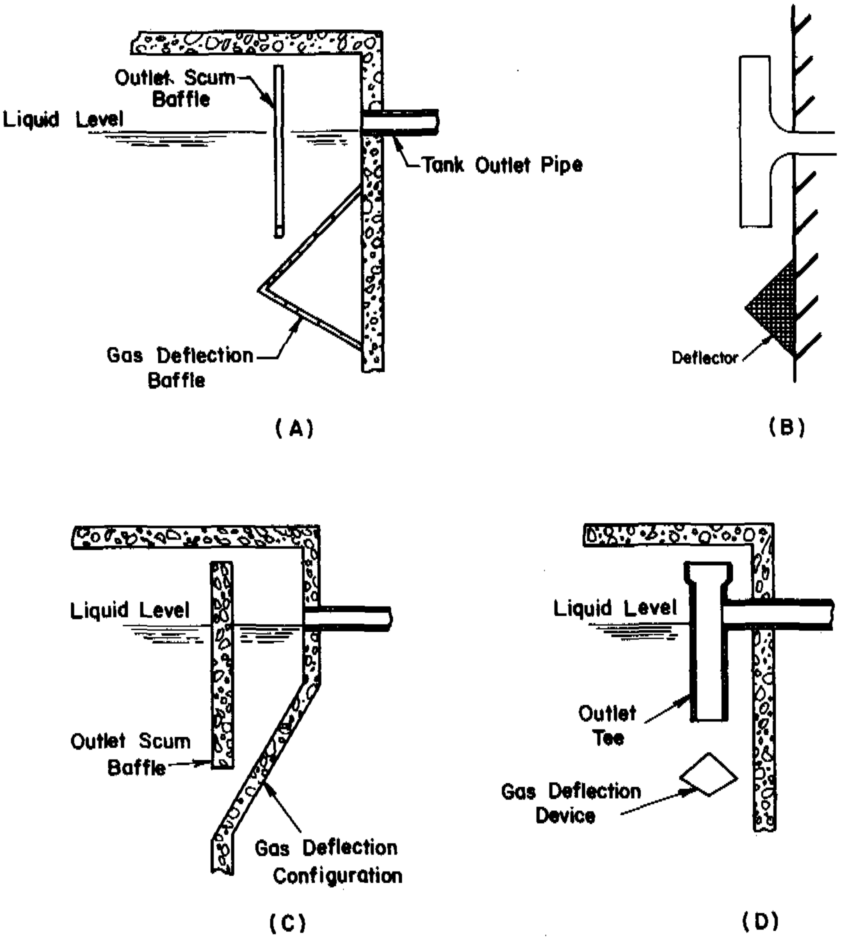


Figure 17 Typical Septic Tank Outlet Structures to Minimize Suspended Solids in Discharge (52)

5.6 Grease Traps

A U.S. Government publication (78) indicated that a grease trap is neither needed nor recommended for normal septic tank systems because it clogs easily and thus frequent cleaning is required. At the same time, in order to protect the soil absorption system, grease traps are commonly used in the separate system of disposal on the waste pipe from the kitchen, with the objective of removing grease and fat (Figure 18).

5.7 Ventilation

Digestion of the sludge, and to a lesser extent the scum, produces gases such as methane, carbon dioxide and some other foul-smelling gases, and hence some form of ventilation is necessary for the tank. In household systems, gases escape from the tank

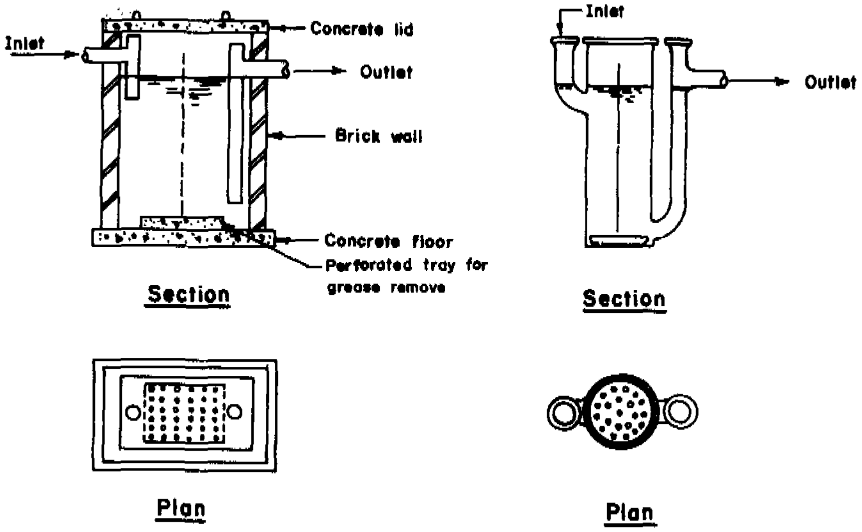


Figure 18 Typical Grease Traps (148)

through the upper limb of the inlet tee. Another method is to provide a ventilation pipe for the tank itself.

5.8 Access and Inspection

In order to facilitate access and provide a means to inspect the inside of the septic tank, manholes should be provided. Manholes are usually placed over both the inlet and the outlet to permit cleaning behind the baffle. The manhole cover should extend above the actual septic tank to a height of not more than 15 cm below the finished grade (264).

5.9 Construction Materials

Septic tanks must be watertight, structurally durable and stable. As a construction material, reinforced concrete adequately meets these requirements. The walls of the septic tank should have a thickness of 8 to 10 cm, and the tank should be sealed for watertightness after installation with two coats of bituminous coating. Proper care must be taken to seal around the inlet and discharge pipes with a bonding compound that will adhere both to concrete and to the inlet and outlet pipe.

Steel is another material that has been used for septic tanks. Steel tanks should be coated with either bituminous or coaltar coating. However, despite a corrosion-resistant coating, tanks deteriorate at the liquid level. Moreover, compared with steel tanks, concrete tanks provide better insulation in cold climate (75).

Other materials include polyethylene and fiberglass. Plastic and fiberglass tanks are very light, easily transported, and resistant to corrosion and decay. A typical proprietary septic tank, made from fiberglass reinforced plastic is shown in Figure 19.

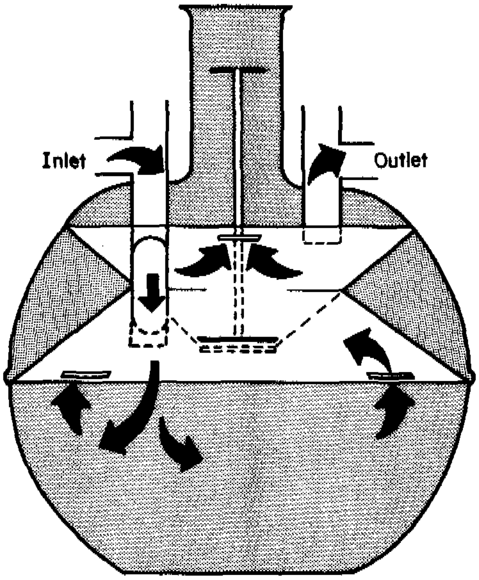


Figure 19 Typical Proprietary Septic Tank, Made from Glass - Fibre Reinforced Plastic (43)

5.10 Installation Procedures

The most important requirement of installation is that the tank should be placed on a level grade and at a depth that provides adequate gravity flow from the home and matches the invert elevation of the house sewer. The tank should be placed on undisturbed soil so that settling does not occur. If the excavation is dug too deep, it should be backfilled to the proper elevation with sand to provide an adequate bedding for the tank. Tank performance can be impaired if a level position is not maintained, because the inlet and outlet structures will not function properly. During the installation of septic tanks, the following points should be considered (264):

1. Cast iron inlet and outlet structures should be used in disturbed soil areas where tank settling may occur.
2. The tank should be placed so that the manhole is slightly below the grade to prevent accidential entry.
3. The tank should be placed in an area with easy access to alleviate pump-out problems.
4. During installation, any damage to the watertight coating should be repaired. After installation, the tank should be tested for watertightness by filling it with water.
5. Care should be taken with installation in areas with large rocks to prevent undue localized stresses.
6. Baffles, tee, and elbows should be made of durable and

corrosion-proof materials. Fiberglass or acid-resistant concrete baffle materials are the most suitable.

5.11 Operation and Maintenance

One of the major advantages of the septic tank is that it has no moving parts and, therefore, needs very little routine maintenance. The only maintenance necessary for a well constructed and properly used septic tank is the removal of surplus sludge and scum to leave a clear central zone for liquor. One cause of septic tank problems involves a failure to pump out the sludge solids when necessary. As the sludge depth increases, the effective liquid volume and retention time decrease. When this occurs, sludge scouring increases, treatment efficiency falls off, and eventually more solids escape through the outlet. The only way to prevent this hazard is by periodic pumping of the tank.

The scum and sludge accumulations in a septic tank should be inspected once or twice a year. When a tank is inspected, the depth of sludge and scum should be measured in the vicinity of the outlet baffle. The tank should be cleaned whenever: (1) the bottom of the scum layer is within 7.6 cm (3 in.) of the bottom of the outlet device; or (2) the sludge level is within 20-32 cm (8 in.) of the bottom of the outlet device (137).

Scum can be measured with a stick to which a weighted flap has been hinged, or with any device that can be used to feel out the bottom of the scum mat. The stick is forced through the mat, the hinged flap falls into a horizontal position, and the stick is raised until resistance from the bottom of the scum results. With the same tool, the distance to the bottom of the outlet device can be determined (Figure 20).

A long stick wrapped with rough, while toweling and lowered to the bottom of the tank will show the depth of the sludge and the liquid depth of the tank. The stick should be lowered behind the outlet device to avoid contact with scum particles. After several minutes, if the stick is carefully removed, the sludge line can be distinguished by sludge particles clinging to the toweling (Figure 20). The most satisfactory method of sludge removal is to use a tanker lorry equipped with a pump and a flexible suction hose. Cleaning of the tank can also be carried out by using some kind of draw-off pipe, as shown in Figure 21. When a tanker lorry or draw-off pipe are not available, it is usual to dig out the sludge with a long handled shovel, and to remove it in buckets or tins.

A septic tank should not be completely cleaned. Some old sludge (about 5-10 liters) should be left at the bottom to ensure that digestion continues. Known as seeding, it improves the efficiency of the septic tank (21, 154).

6. DISPOSAL OF SEPTIC TANK EFFLUENT

The effluent from a septic tank is an obnoxious liquor containing pathogenic microorganisms and high BOD which should not be discharged into a public water-course or on land. Further treatment or other means of disposal are required. Where site conditions are suitable and do not pose any threat to groundwater quality, subsurface soil absorption is usually the best method for septic tank effluent disposal for single system dwellings because of its simplicity,

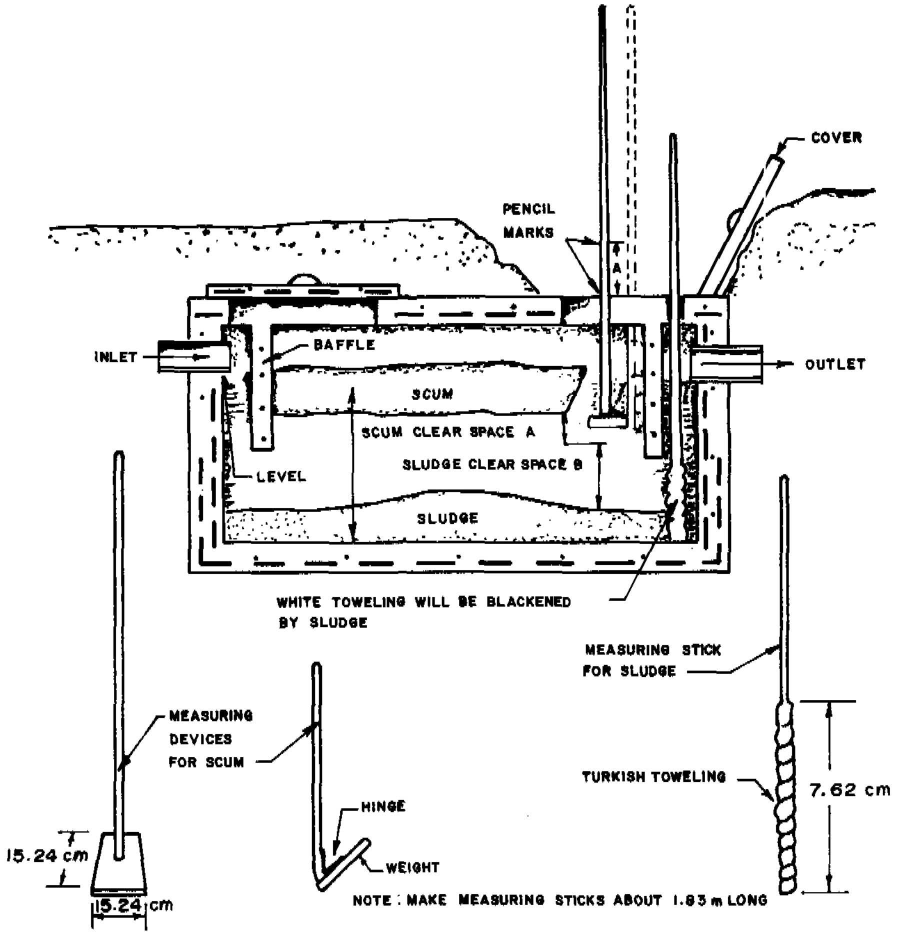


Figure 20 Devices for measuring sludge and scum (137)

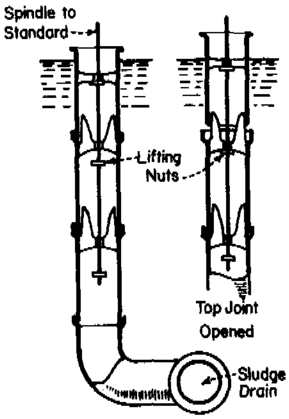


Figure 21 Draw-off pipe for septic tank sludge

durability, and low cost.

Sites which are characterized by low permeable soil, high ground water conditions, shallow depth to bedrock and steep land slopes, preclude the subsurface soil absorption system, and consequently other alternatives of effluent disposal need to be investigated.

6.1 The Subsurface Soil Absorption System.

The most common method of on-site liquid waste disposal is the conventional soil absorption system. It consists of two components: a septic tank, used to provide partial treatment of the raw wastewater and the soil absorption field or pit where final treatment and disposal of septic tank effluent takes place (Figure 22). Both are installed below the ground surface.

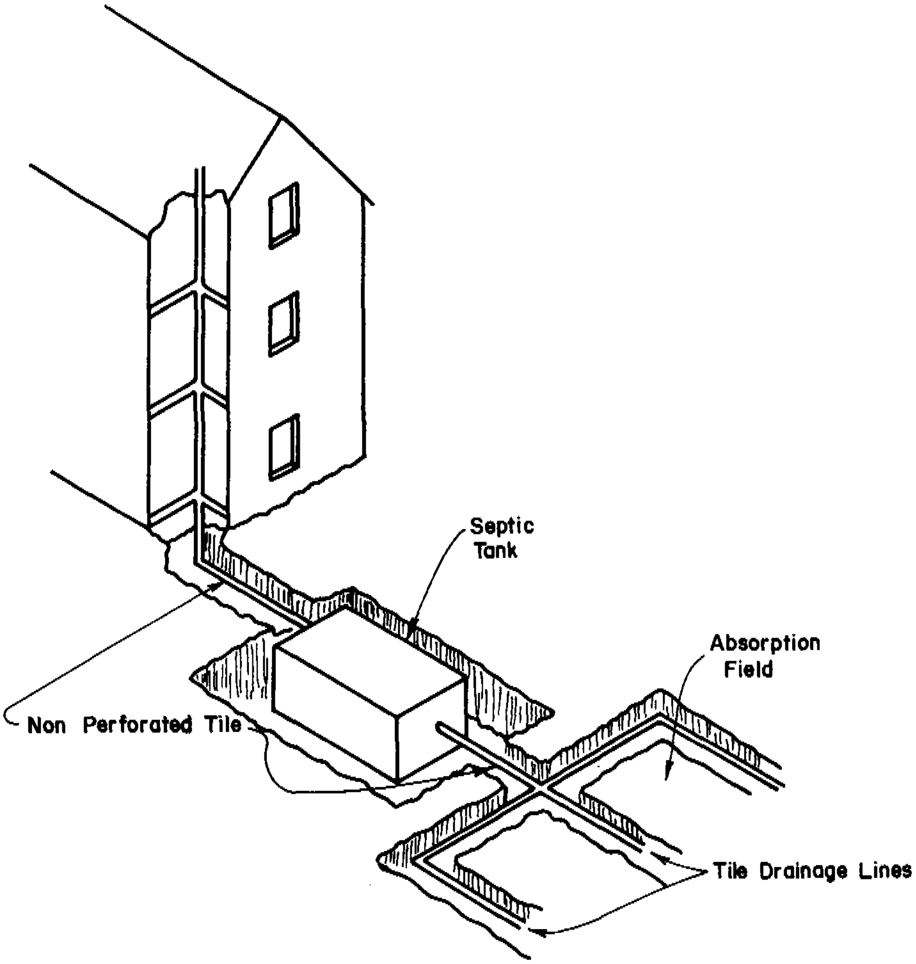


Figure22 Typical On-Site System (174)

GOEHRING and CARR (163) strongly recommend the use of the conventional soil absorption system (septic tank system) as a viable means of domestic wastewater treatment in situations where public sewers are expensive. They also describe how conventional land use and public policy decisions drive up the already high costs of wastewater treatment.

6.1.1 *Site Selection for Subsurface Soil Absorption Systems.*

The performance of the soil absorption systems depends on the ability of the soil to accept liquid, absorb viruses, strain out bacteria and filter the wastes. A proper site evaluation requires accurate measurement of the soil permeability, the degree of slope, the position of the water table, the soil depth, and the depth of bedrock or other impermeable material (166). PARKER et al. (136) have reviewed the site conditions required for soil absorption systems, the evaluation procedures, and the control that should be instituted to ensure proper site evaluation. OTIS (86), and WARKENTIN and HARWARD (96), have presented procedures of site evaluation for a soil absorption field. SCHWAB et al. (26) have proposed the following guidelines for selecting the site:

(a) soil permeability should be moderate to rapid and the soil percolation rate should generally be 24 minutes per cm (60 minutes/ in.) or less,

(b) the groundwater level during the wettest season should be at least 1.22 m (4 ft) below the bottom of the trenches in a subsurface soil absorption field and 1.22 m below the pit floor in a field using seepage pits;

(c) rock formations or other impervious layers should be more than 1.22 m below the bottom of trenches, seepage bed and pit floor;

(d) trenches and seepage beds are difficult to lay out and construct on slopes steeper than 15 percent;

(e) the site for an absorption field should not be within 15.24 m (50 ft) of a stream or other water body;

(f) a soil adsorption system should never be installed in an area subject to flooding; and

(g) an area in which different kinds of soils are present within short distances and differ greatly in their absorption capacity may not be suitable for the installation of a soil absorption field. The following list summarizes the site characteristics and tests that must be determined (373):

Site Characteristics	Site tests
1. Soil type and thickness	Test pit or auger hole.
2. Highest seasonal water table elevation	Test pit in spring, monitored well, soil mottling
3. Hydraulic Conductivity	
a) for soil interface area	Percolation test, crust test, undisturbed sample, pumped hole tests

b) for seepage analysis	Crust test, undisturbed samples, pumped hole tests

The potential to treat and dispose of wastewater through the soil absorption systems depends on the characteristics of the area. Therefore, a site evaluation should be done in a systematic manner to ensure that the information collected is useful and sufficient. A suggested procedure for a site evaluation with respect to the subsurface soil disposal system is briefly discussed below.

6.1.1.1 Topography

Any site evaluation should determine significant topographic features such as slope, ditches, natural drains, rivers etc. as well as the location of existing wells and disposal systems.

6.1.1.2 Landscape Position

The landscape position and land form for each suitable area should be noted. Figure 23 can be used as a guide for identifying landscape position. This information is useful in estimating surface and subsurface drainage patterns. For example, hill tops and side slopes can be expected to have good surface and subsurface drainage, while depressions and foot slopes are more likely to be poorly drained.

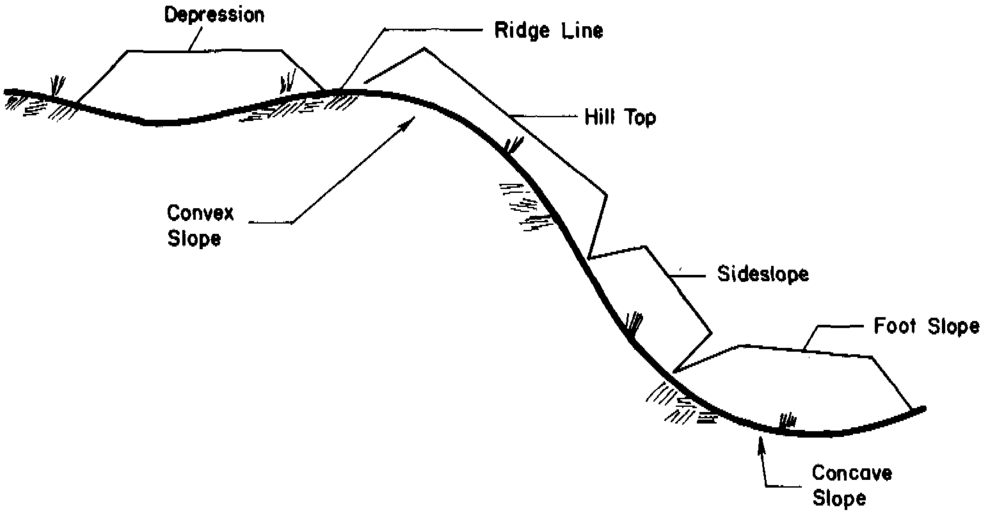


Figure 23 Landscape Positions (316)

6.1.1.3 Slope

Slope must be considered when evaluating a site for the subsurface soil absorption system. The type of slope indicates the expected surface drainage problems. Moreover, for correct location and design of the system, slopes can be used because they can help carry effluent away from the area of the septic tank system. In an area with shallow sandy soil over clay, the slope will help in the overall operation of the system. However, sufficient borings are necessary to ensure that there is a sufficient area of sandy soil to preclude seepage out to the ground surface. In areas of clay soil, the slope works against the successful operation of the system because seepage will tend to come to the ground surface.

6.1.1.4 Soil Texture

Soil is the medium for the subsurface treatment system, and the quality of treatment depends primarily on the soil type and length of travel by the effluent. Soil texture is one of the most important physical properties of soil because of its close relationship to pore size, pore size distribution, and pore continuity. Soil texture refers to the relative proportions of sand, silt and clay. The higher the percentage of clay and silt, the slower the permeability of the soil. The textural properties of the soil can be determined easily in the field by its feel and appearance, as presented in Table 10.

6.1.1.5 Soil Structure

Soil structure has a significant influence on the soil's acceptance and transmission of water. Soil structure is the arrangement of primary soil particles (sand silt, clay, minerals and organic material) into compound particles or aggregates, called peds, that are separated by surfaces of weakness. These surfaces of weakness upon planer pores between the peds, are often seen as cracks in the soil. These planer pores can greatly modify the influence of soil texture on water movement. Well-structured soils with large voids between peds will transmit water more rapidly than structureless soils of the same texture. This rapid transmission will occur particularly if the soil has become dry before water is added. Fine-textured, massive soils (soils with little structure) have very slow percolation rates. Examples of common kinds of structure that will be encountered are shown in Figure 24 and described below (264).

1. Granular or crumb - excellent for permeability, normally 0.31 to 0.63 cm in size.

2. Blocky - chunks of soil, 0.63 - 1.9 cm in size with smooth exterior that are good for permeability and more typically associated with loam-clayloam texture.

3. Platy - 0.31 to 0.63 cm thick horizontal plates that are poor in permeability because of the horizontal layer restricting the vertical movement of the water, can reduce permeability 20-fold and can be associated with almost all soil textures.

4. Massive - lack of structure, which means the soil is poor for permeability. This is normally associated with loam-clay soil texture.

6.1.1.6 Groundwater Level

The elevation of the water table determines the direction in which the water in an aquifer will flow. This is an important consideration because direction of flow in part controls the distance a system can be located from nearby discharge areas.

A final groundwater characteristic that should be evaluated, before a particular site can be selected, is the seasonal height of the local water table. The presence of a natural water table near the ground indicates that the ground cannot absorb the natural inflow and would have difficulty absorbing additional inflow from a septic tank.

Table 10: Textural Properties of Mineral Soils (264)

Soil Class	Feeling and Appearance	
	Dry Soil	**Moist Soil**
Sand	Loose, single grains which feel gritty. Squeezed in the hand, the soil mass falls apart when the pressure is released.	Suqueezed in the hand, it forms a cast which crumbles when touched. Does not form a ribbon between thumb and forefinger.
Sandy Loam	Aggregates easily crushed; very faint velvety feeling initially but with continued rubbing the gritty feeling of sand soon dominates.	Forms a cast which bears careful handling without breaking. Does not form a ribbon between thumb and forefinger.
Loam	Aggregates are crushed under moderate pressure; clods can be quite firm. When pulverized, loam has velvety feel that becomes gritty with continued rubbing. Casts bear careful handling.	Cast can be handled quite freely without breaking. Very slight tendency to ribbon between thumb and forefinger. Rubbed surface is rough.
Silt Loam	Aggregates are firm but may be crushed under moderate pressure. Clods are firm to hard. Smooth, flour-like feel dominates when soil is pulverized.	Cast can be freely handled without breaking. Slight tendency to ribbon between thumb and forefinger. Rubbed surface has a broken or rippled appearance.
Clay Loam	Very firm aggregates and hard clods that strongly resist crushing by hand. when pulverized, the soil takes on a somewhat gritty feeling due to the harshness of the very small aggregates which persist.	Cast can bear much handling without breaking. Pinched between the thumb and forefinger, it forms a ribbon whose surface tends to feel slightly gritty when dampened and rubbed. Soil is plastic, sticky and puddles easily.
Clay	Aggregates are hard; clods are extremely hard and strongly resist crushing by hand. When pulverized, it has a grit-like texture due to the harshness of numerous very small aggregates which persist.	Casts can bear considerable handling without breaking. Forms a flexible ribbon between thumb and forefinger and retains its plasticity when elongated. Rubbed surface has a very smooth, satin feeling. Sticky when wet and easily puddled.

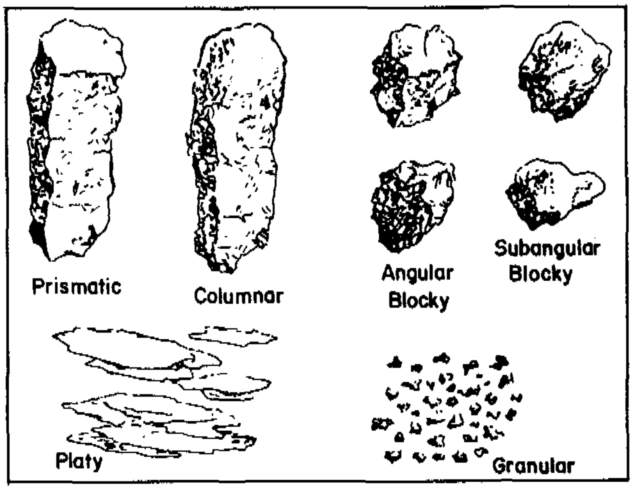


Figure 24 Types of Soil Structure (264)

The exact depth of the water table that will provide sufficient hydraulic gradient in the soil to carry the effluent away from the distribution system depends on the hydraulic conductivity, the thickness of the soil, and the slope. The highest seasonal elevation of the water table must be known to determine the hydraulic capacity of a system under the worst conditions (199).

Ground water tables fluctuate in response to changing weather conditions. Soil mottling is reported to indicate the presence of a seasonal high water table (134). Soil mottles, which are spots of contrasting greyish and reddish color when present in a disposal profile are considered unsuitable for on-site subsurface soil disposal of septic tank effluent, if the assumed saturation with water occurs within 90 cm below the bottom of the seepage field or bed (114, 259).

Soil mottles are usually brown, black, red, yellow or gray in color. If a soil horizon has a background of light brown with spots of red and gray, the red and gray spots are the soil mottles. The brown and yellow (brightly colored) mottles are commonly called high chroma. The gray mottles (dull colored) are called low chroma. VEPRAKAS and BOUMA (18) used the scanning electron microscope to determine the iron and manganese concentrations of soil mottles as related to the background material of a soil profile. They found that red mottles were rich in iron relative to the background material. BLOOMFIELD (375) used acid ammonium oxalate to extract iron from mottles and the surrounding soil material. He found that mottles contain as much as four times the concentration of iron as did the whole soil. The waterlogging conditions of soil can be traced using Mn or Fe as indicators. Studies have shown that Mn compounds are reduced before Fe compounds upon water logging of soils while the reverse sequence applied for oxidation upon aeration (224, 283, 286, 284, 285). Mottles with chromas of two or less are assumed to indicate saturation of the soil with water during certain periods of the year (282). Distinction of different types of mottles in terms of globules, cutans, quasicutans, and neocutans has been shown to be quite helpful to fully realize the potential of the soil mottling phenomena in the predicted hydraulic soil conditions (283, 286).

Examination of deeper soils is necessary. In cases where deeper soil shows the absence of mottling below the mottled horizon, the site may be considered suitable for the installation of a soil absorption system (98, 255). VEPRAKAS et al. (98) reported that low chroma mottling inside the beds is not necessarily associated with long periods of saturation within the entire horizon. A general description of the process of mottle formation as given in the Wisconsin Soil Texture Manual (376) is discussed below.

"The chemical reactions that cause soil mottles to form are complex. Mottle formation includes both chemical and biological reactions. The chain of events that result in the formation of soil mottles is as follows. With temperature above 40 Celsius degrees, 2 basic types of bacteria are the agents which decompose or oxidize organic matter in the soil. Aerobic bacteria are the primary agents as long as there is some air in the soil. As infiltrating water and/or a rise in groundwater completely fills all the air spaces and the soil becomes saturated, air and gaseous free oxygen are excluded, dissolved oxygen is depleted and anaerobic bacteria become the primary decomposers. They utilize insoluble manganese and iron compounds for respiration instead of oxygen. In the chemical reactions that occur, soluble compounds of manganese and iron are formed from the otherwise insoluble oxide and hydroxide compounds, and begin to flow with the soil solution. Because this action removes iron, a color reduction occurs in those areas tending to turn them gray or white. When these compounds again encounter oxygen in aerated pores, they recombine with oxygen to form yellow and rust colored concentrations. Manganese compounds are reoxidized and form black concentrations."

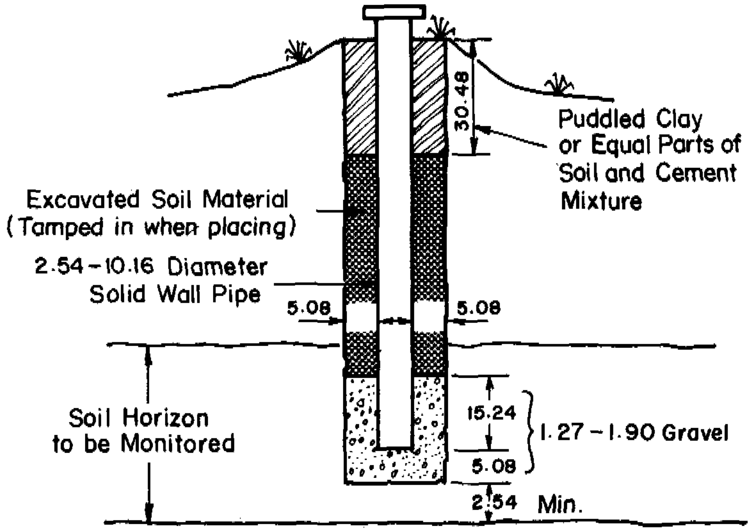
Seasonally saturated soils can also be detected by digging observation wells designed as shown in Figure 25. The well should be placed in, but should not be extended through, the horizon that is to be monitored. More than one well in each horizon that may become seasonally saturated is desirable. The wells are monitored over a normal wet season by observing the presence and duration of water in the well. If water remains in the well for several days, the water elevation is measured and assumed to be the elevation of the seasonally saturated soil horizon.

6.1.1.7 Soil Permeability Measurements

The most widely used indicator of soil permeability is the percolation test, which measures the ability of soils to absorb water. A well established method for determining the percolative capacity of soils has been notified (259, 137). One of the methods of making percolation tests is shown in Figure 26, and detailed test procedure is presented in Table 11.

The length of time required for percolation tests depends on the types of soil. Fine textured soils require longer presoaking than coarse textured soils to obtain steady infiltration rates (16). MOKMA (371) reported that percolation tests should be made in soils which have been presoaked for a minimum period of eight to twenty four hours. Numerous investigators have emphasized the importance of continuing percolation tests for sewage absorption systems until the water seeps away at a constant rate, or until a degree of consistency is obtained in the results (118, 367, 328, 7).

Most engineers agree that the leaching area required for a sewage absorption system can be determined by percolation tests (185, 215, 216). MACHMEIR (146) presented a method to run a percolation test for the determination of a required trench bottom area to absorb septic tank effluent. He also described the methods of measurement and



All measurements in centimetres

Figure 25 Typical Observation Well for Determining Soil Saturation.

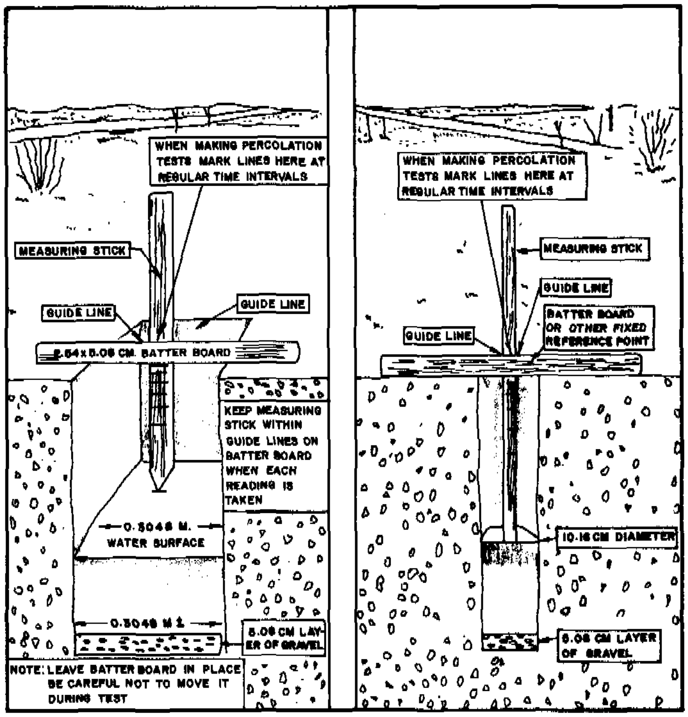


Figure 26 Methods of Making Percolation Test (368)

Table 11. Falling Head Percolation Test Procedure (264)

1. Number and Location of Tests

   Commonly a minimum of three percolation tests are performed within the area proposed for an absorption system. They are spaced uniformly throughout the area. If soil conditions are highly variable, more tests may be required.

2. Preparation of Test Hole

   The diameter of each test hole is 15.24 cm (6 in.), dug or bored to the proposed depths at the absorption systems or to the most limiting soil horizon. To expose a natural soil surface, the sides of the hole are scratched with a sharp pointed instrument and the loose material is removed from the bottom of the test hole. Two inches of 1.27 to 1.91 cm (1/2 to 3/4 in.) gravel are placed in the hole to protect the bottom from scouring action when the water is added.

3. Soaking Period

   The hole is carefully filled with at least 30.48 cm (12 in.) of clear water. This depth of water should be maintained for at least 4 hr and preferably overnight if clay soils are present. A funnel with an attached hose or similar device may be used to prevent water from washing down the sides of the hole. Automatic siphons or float valves may be employed to automatically maintain the water level during the soaking period. It is extremely important that the soil be allowed to soak for a sufficiently long period of time to allow the soil to swell if accurate results are to be obtained.

   In sandy soils with little or no clay, soaking is not necessary. If after filling the hole twice with 30.48 cm (12 in.) of water, the water seeps completely away in less than ten minutes, the test can proceed immediately.

4. Measurement of the Percolation Rate

   Except for sandy soils, percolation rate measurements are made 15 hr but no more than 30 hr after the soaking period began. Any soil that sloughed into the hole during the soaking period is removed and the water level is adjusted to 15.24 cm (6 in.) above the gravel or 20.32 cm (8 in.) above the bottom of the hole. At no time during the test is the water level allowed to rise more than 15.24 cm (6 in.) above the gravel.

   Immediately after adjustment, the water level is measured from a fixed reference point to the nearest 0.16 cm (1/6 in.) at 30 min intervals. The test is continued until two successive water level drops do not vary by more than 0.16 cm (1/6 in.) At least three measurements are made.

   In sandy soils or soils in which the first 15.24 cm (6 in.) of water added after the soaking period seeps away in less than 30 min, water level measurements are made at 10 min intervals for a 1-hour period. The last water level drop is used to calculate the percolation rate.

5. The percolation rate is calculated for each test hole by dividing the time interval used between measurements by the magnitude of the last water level drop. This calculation results in a percolation rate in terms of min/cm. To determine the percolation rate for the area, the rates obtained from each hole are averaged. (If tests in the area vary by more than 7.87 min/cm (20 min/in.), variations in soil type are indicated. Under these circumstances, percolation rates should not be averaged.

   Example : If the last measured drop in water level after 30 min is 1.59 cm (5/8 in.), the percolation rate = (30 min)/(1.59 cm) = 18.87 min/cm, or
   = (30min)/(5/8 in.) = 48 min/in.

calculation for percolation rates. KIKER (287, 367) presented empirical formulaea to calculate the area required for the sewage absorption field.

The percolation test is based on the assumption that the ability of a soil to absorb sewage effluents over a prolonged period of time may be predicted from its initial ability to absorb clear water (73). The rate of water flow from a hole depends on the hydraulic conductivity of the soil, the shape of the hole, and the depth to the water content of the soil surrounding the hole (6, 7). ALLISON (298) has stated that the migration of fines, as well as the ion exchange phenomena, will lead to a reduction of the rate at which even clear water enters a soil after the initial wetting period. CHRISTIANSON (299) has shown that the period of increased permeability results from the removal of entrapped air by liquid in the percolating waters. The subsequent long period of decreasing permeability due to microbial activity is reported by ALLISON (300). Occasional changes in both the test procedure and in the sewage loading rates have occured from time to time (91, 158). FREDERICK (301) proposed a modification of Ryon's test involving a formula instead of a curve for relating percolation rate to soil loading.

The percolation test is influenced by soil characteristics and environmental factors, and the variability caused by these factors reduces the reliability of the standard percolation test results (269, 25). The use of a percolation test for sizing a soil absorption system relies on the empirical relationship between the measured percolation rate and the actual loading rate. The variability and empirical characters of percolation tests have been adequately examined (89). Tests run in the same soil vary by as much as 50 percent (251, 6, 166). WINNEBERGER et al. (73) have discussed both the theoretical and practical aspects of percolation tests and concluded that the percolation test is an uncertain guide to leaching field design. Similarly BOUMA et al. (28) have demonstrated that the capacity of soils to accept, conduct and purify effluent cannot be expressed simply by percolation tests or by hydraulic conductivities at saturation.

The capacity of soils to accept and conduct liquid can be expressed adequately by considering hydraulic conductivity data, which can be used to calculate real flow rates into the soil by monitoring soil moisture contents adjacent to the seepage field (89). The hydraulic conductivity is defined in soil physics as a one dimensional flow rate through a unit area at a unit hydraulic gradient (253). To measure the unsaturated hydraulic conductivity of soil, a new test called the "crust test" has been developed (231, 251, 221, 253, 254, 224). A schematic diagram of the crust test procedure is shown in Figure 27. This test is now widely applied to Wisconsin soils for adequately sizing systems (14).

In addition to percolation tests and crust tests, more soil physical techniques, such as tensiometry, are applied to soils adjacent to seepage systems in the field to determine the performance characteristics. VIRARAGHAVAN and WARNOCK (50) described the method of installation and use of zero-tension lysimeters to obtain percolates from an experimental septic tile bed. A perspective view of the zero-tension lysimeter is shown in Figure 28.

The use of soil classification and description schemes, and soil maps of the soil survey program of the U.S. Department of Agriculture, Soil Conservation Service, can be very helpful in predicting soil hydraulic properties (88). The soil classification and description schemes, and soil maps, present a comprehensive taxonomic

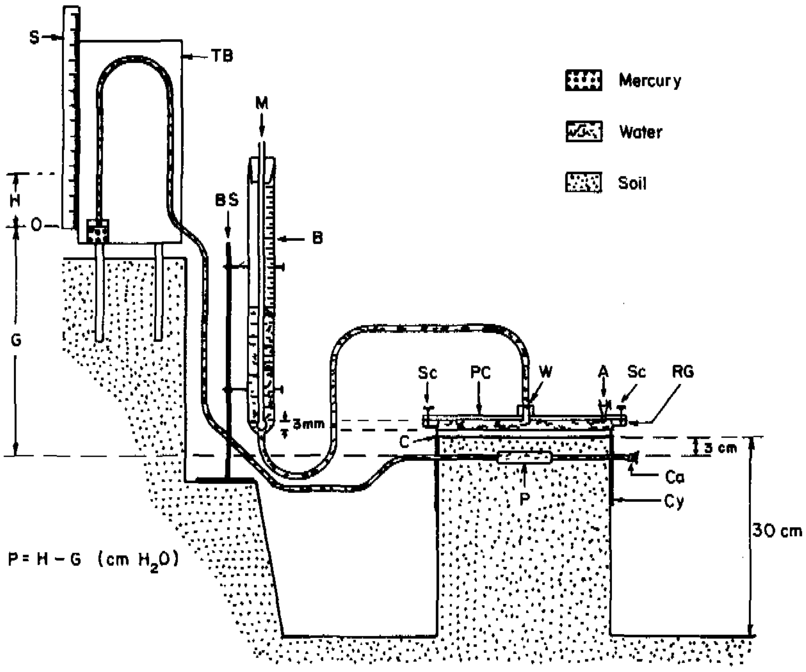


Figure 27 Schematic Diagram of the Crust Test Procedure (253)

(TB = manometer board, S = scale, B = burette, BS = burette stand, M = marriot device, Cy = metal cylinder, C = crust, PC = plastic cover, Sc = wing nut, W = water inlet, A = air breeder, RG = rubber gasket, Ca = cap, P = porous cup, O = zero mercury level, H = height mercury level above zero level, G = distance between porous cup level and zero mercury level)

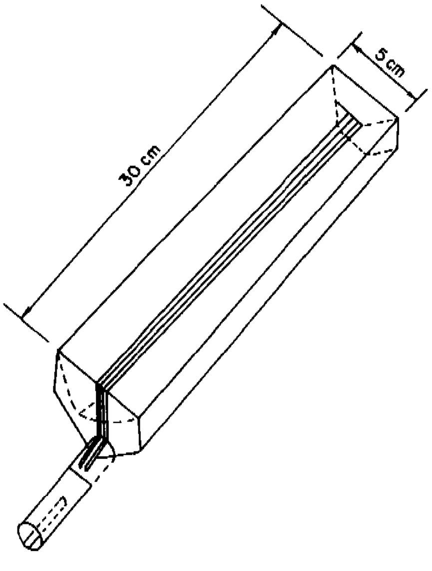


Figure 28 Perspective View of the Zero - Tension Lysimeter (50)

classification system of soils to serve the purposes of soil survey. Classes in this system are defined in terms of observable and measurable properties selected primarily to group soils of similar genesis. Much information exists about the physical, chemical, and mineralogical properties of soils as they relate to soil behavior under defined systems of soil management. This information is available at various levels of generation in the soil classification system. The hydraulic conductivity of natural soil materials can be estimated by a trained soil surveyor on the basis of detailed morphological characterization (357, 222, 362). Moreover, the variability of the hydraulic conductivity is reported to be lower than the value generally assumed on the basis of quite variable percolation test results (88). A comparison of percolation test data with soil survey information (84) has showed that soil survey interpretations can be a useful tool for soil absorption field design. MORRIS et al. (329), WITWER (330) and SEGLIN (84) found a very good correlation between the permeability obtained by interpretation of soil maps and the percolation tests made by the Health Department.

6.1.2 Location of the Septic Tank and Disposal Fields

Septic tanks should be located where they cannot cause contamination of any wells, springs, or other source of water supply. Underground contamination may travel in any direction and for considerable distances, unless filtered effectively. Underground pollution usually moves in the same general direction as the normal movement of the ground water in the locality. Ground water moves in the direction of the slope or gradient of the water table. In general, the water table follows the general contour of the ground surface. For this reason, septic tanks should be located downhill from wells or springs. Sewage from disposal systems occasionally contaminate wells having higher surface elevations. It is necessary, therefore, to rely upon horizontal as well as vertical distances for protection. Tanks should never be closer than 15.2 m (50 ft) from any source of water supply (137).

The septic tank should not be located within 1.52 m (5 ft) of any building, as structural damage may result during construction, or seepage may enter the basement. The tank should not be located in swampy areas, nor in areas subject to flooding. In general, the tank should be located where the largest possible area will be available for the disposal field. Consideration should also be given to the location from the standpoint of cleaning and maintenance. Where public sewers may possibly be installed at a future date, provision should be made in the household plumbing system for connection to such a sewer.

The soil absorption systems are suitable mainly for areas where the population density is strictly limited and soil conditions are suitable for effective absorption (270). Soil absorption systems do not function adequately in densely populated areas, where the soil-water interface is too close to the surface (98). The location of the disposal field, up to a certain extent, depends on the soil type, i.e., the clay, silt and sand content, because of the variation of these constituents in the filtration and absorption efficiency of pollutants. Table 12 gives the horizontal distance for the location of components of a sewage disposal system.

6.1.3 Design of Subsurface Soil Absorption Systems

Three types of soil treatment units commonly used are: 1) absorption trenches; 2) absorption beds (seepage beds); and 3) absorption pits (seepage pits). The use of these units strictly depends on the suitability of soil, and each design has some advantages and disadvantages which are shown in Table 13.

Table 12: Location of Septic Tank and its Components (137, 145) (Horizontal Distance in Meter)

Source of Water Supply	Building Sewer	Septic Tank	Disposal Field and Seepage Bed	Seepage Pit
Water or suction line	15.24	15.24	30.48	30.48
Water supply line	3.048	3.048	7.62	15.24
Stream	15.24	15.24	15.24	15.24
Dwelling	-	1.524	6.098	6.098
Property line	-	3.048	1.524	3.048
Habitate building	-	7.62	710.668	-

Critical site factors include soil profile characteristics and permeability, soil depth over water tables or bedrock, slope, and the size of an acceptable area. Where the soil is at least moderately permeable and remains unsaturated several metres below the system throughout the year, trenches or beds may be used. Trenches and beds are excavations of relatively large areas that generally rely on the upper soil horizons to absorb the wastewater through the bottom and sidewalls of the excavation. Absorption pits (seepage pits) are deep excavations designed primarily for lateral absorption of the wastewater through the bottom and sidewalls of the excavation. However, these pits can be used only where the groundwater table is below the bottom of the pit.

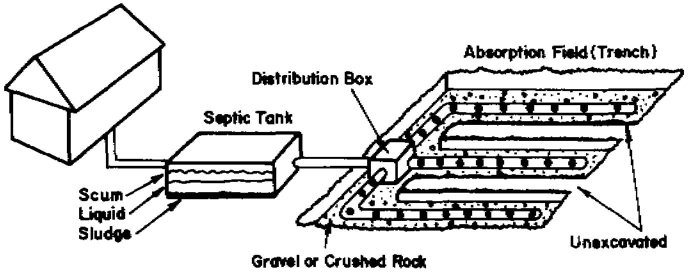
IMPEY (145) proposed four methods: trench drain, soakage pit, agricultural drains and seepage terrace, and discussed design aspects and suitability of soil for each system. OTIS et al. (79, 188) reviewed the design and construction of conventional soil absorption trenches and beds, including the sizing of the infiltrative surface, the geometry of the surface, and the design of gravity, dosing and pressure distribution networks. PLEWS (144) reviewed the literature on techniques for sizing drain-field systems and pointed out that volume is a significant variable in sizing the drainfield. KIKER (210, 287) presented the empirical relationship to calculate the leaching area required in a properly constructed sewage absorption field. LAAK et al. (5) presented a rational basis for septic tank system design.

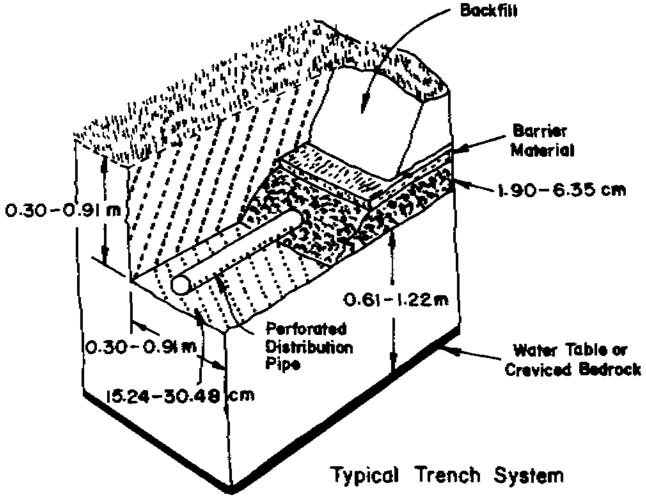
6.1.3.1 Design of Absorption Trenches and Absorption Beds

Trenches are shallow, level excavations, usually 0.3 to 1.5 m (1 to 5 ft) deep and 0.3 to 0.9 m (1 to 3 ft) wide. The bottom is filled with 15 cm (6 in) or more of washed crushed rocks or gravel over which a single line of perforated pipe is placed (137) (Figure 29). Additional rocks may be placed over the pipe and the rocks are covered with a suitable semipermeable barrier to prevent the backfill from

Table 13. Comparison of Individual Home Treatment/Disposal System

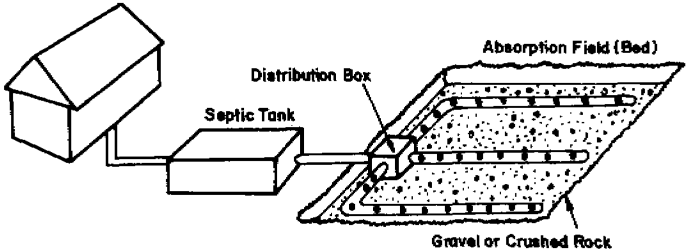
Type of System	Principle of Operation	Operation and Maintenance Requirement	Advantages	Disadvantages
Septic Tank/Absorption Field System	Generated waste-water is settled and allowed to percolate through the soil. The settled solids are stabilized by anaerobic digestion.	Insignificant. The septic tanks have to be pumped out once every 1 to 3 years.	1. Least costly of all currently approved disposal methods. 2. Requires little maintenance. 3. Provides effective and reliable treatment. 4. No mechanical moving parts.	1. Soil texture and structure must be suitable. 2. Cannot be used in high ground water or shallow bed rock areas. 3. Cannot be located near wells and surface waters. 4. Susceptible to soil clogging.
Septic Tank/ Absorption Beds	Similar to above	Insignificant	1. Can be used where lot sizes are too small for absorption (leach) trenches. 2. Maintenance costs are minimal.	Similar to above
Septic Tank/ Absorption Pits	Similar to above	Insignificant	1. Least costly of all approved systems. 2. Other advantages are similar to absorption field system.	Similar to above

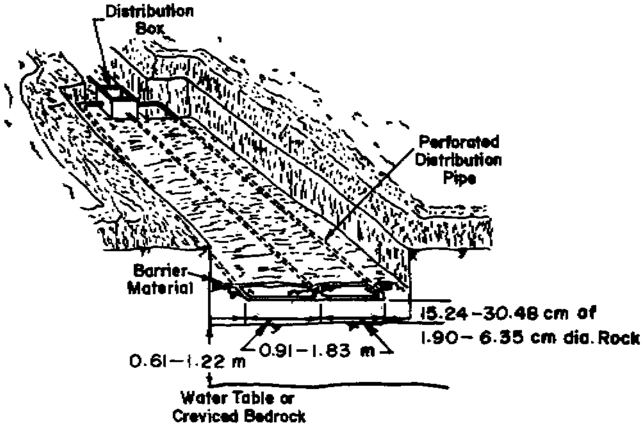




Typical Trench System

Figure 29 Septic Tank with Absorption Trench





Typical Bed System

Figure 30 Septic Tank with Absorption Bed penetrating the rock. The conventional soil absorption field consists of two or more flat-bottom absorption trenches, measuring a maximum of 30.48 m (100 ft) long, but shorter trenches of 18.29 cm (60 ft) or less are preferred. Deep narrow trenches are preferable to wide shallow trenches because the former provide more sidewall area, through which the bulk of the effluent enters the soil after the bottom becomes clogged (148).

The amount of absorption area required in the absorption field depends on the percolation rate of the soil and the daily wastewater flow. An infiltrative rate obtained from percolation tests can be used to estimate the absorption area required. Other methods, such as the crust test, a soil survey interpretation, and KIKER's formula (210, 287) are also reported to be useful for sizing, and for the construction aspects of the absorption field. A detailed description on the design and construction aspects of an absorption field is well documented (137, 148, 10, 159).

Absorption beds (seepage bed) differ from trenches in that they are wider than 0.91 m (3 ft) and may contain more than one line of distribution piping (Figure 30). Thus, the bottoms of the beds are the principal infiltrative surfaces. There are three main elements of an absorption bed: (1). absorption surface, (2) rockfill or packing material, and (3) the distribution system. The total absorption area required for an absorption bed may be calculated by estimating the daily wastewater flow and percolation rate. It has been demonstrated that the empirical relationship between the percolation test and the bottom area required for trenches is applicable for absorption beds. A mottled subsoil overlying permanently unsaturated sand is considered unsuitable for a subsurface absorption system. VEPRAKAS et al. (18) pointed out that a seepage bed for septic tank effluent disposal in the underlying unsaturated sand can be constructed, following excavation of the silt layer, because the lateral flow of the water from the mottled silt next to the excavation into the bed is typically insignificant.

(a) Infiltrative Surface

Since the performance of the absorption field for septic tank effluent treatment is based on the infiltrative capacity of the soil, the infiltrative capacity of the soil should be sized on the basis of the expected hydraulic conductivity of the clogging mat and the estimated daily wastewater flow. However, waste flows from single homes are intermittent and subject to wide fluctuations (Section 2.1).

It may not be possible to furnish direct measurement of the septic tank effluent infiltration rate through a mature clogging mat in a specific soil prior to design. However, experience with operating subsurface soil absorption systems has shown that design loadings can sometimes be correlated with soil texture (137, 377, 79, 378), as illustrated in Table 14.

Data presented in Table 14 are meant only as a guide because soil texture and measured percolation rates may not always be correlated as indicated, due to differences in structure, clay mineral content and bulk densities. Conventional trench or bed designs should not be used for rapidly permeable soils with percolation rates lesser than 0.4 min/cm (1 min/in) (378) because these rapidly permeable soils may not provide the necessary treatment of septic tank effluent to protect the ground water quality. Nevertheless, this problem may be solved by replacing the native soil with a suitably thick layer of loamy sand or

Table 14. Recommended Rates of Wastewater Application for Trench and Bed Bottom Areas (377, 79, 378).

Soil Texture	Percolation Rate, min/cm	Application Rate[1] m^3/m^2-day
Gravel, coarse sand	<0.39	Not suitable[2]
Coarse to medium sand	0.39 - 1.96	0.049
Fine sand, loamy sand	2.36 - 5.90	0.032
Sandy loam, loam	6.30 - 11.81	0.024
Loam, porous, silt loam	12.20 - 23.62	0.018
Silty clay loam, clay loam[3]	24.01 - 47.24	0.001

[1] Rates based on septic tank effluent from a domestic waste source. A factor of safety may be desirable for wastes of significantly different character.

[2] Soils with percolation rates <0.39 min/cm can be used if the soil is replaced with a suitably thick (<0.61 m layer of loamy sand or sand).

[3] Soils without expendable clays.

sand textured soils to obtain a desirable permeability.

Conventional trench or bed designs should also be avoided in soils with percolation rates greater than 24 min/cm (60 min/in), for the simple reason that these soils can easily be smeared and compacted during construction, thus reducing the soil's infiltration rate to as little as half the determined rate (79). Trench systems may be used in less permeable soils with percolation rates as high as 47 min/cm (120 min/in) but great care needs to be exercised during construction.

(b) Sidewall Versus Bottom Area Absorption

A soil absorption system has two infiltrative surfaces; the horizontal bottom of the trench or bed and the vertical side walls. When the bottom area begins to clog, the waste effluent ponds in the system and the side wall begin to absorb liquid (148, 28). In some soils the sidewall may become the more significant infiltrative surface as clogging continues (67, 73).

Absorption systems should be designed to maximize the most significant infiltrative surface. The infiltrative surface can be maximized by considering sidewalls as a reserve capacity but the bottom area should be sized to absorb the entire estimated daily flow.

In humid regions where percolating rainwater reduces the adsorption potential along the sidewall, shallow trench systems are suggested (377). The bottom area is the principal infiltrative surface in these systems. Shallow trenches are often the best because the upper soil horizons are ususally more permeable and consequently greater evapo-transpiration can occur. In dry climates, the side wall area may be used to a greater extent. The bottom area may be reduced as the sidewall area is increased.

Absorption beds, instead of trenches, are often preferred because the former usually require less total land area and are less costly to construct. However, trenches are generally more desirable (377,378, 79, 67, 263). Trenches can provide up to five times more sidewall area than beds for identical bottom areas.

(c) Distribution of Liquid Over the Infiltrative Surface

Localized overloading of septic tank effluent on the soil often occurs because of poor distribution. This may diminish the infiltration of the effluent, even in highly permeable soils and may accelerate clogging in slowly permeable soils. Uniform application of the wastewater over the infiltrative surface is usually beneficial.

Absorption systems with uniform distribution and dosing are not necesary in all types of soil to eliminate poor purification and soil clogging, but sand and weakly structured sandy loams and loams would benefit most (13). Uniform distribution aids in reducing clogging by simultaneously applying equal or less liquid than the soil is able to accept to the entire infiltrative surface (12).

Liquid flow by gravity is the most common method of distributing waste effluent over the infiltrative surface of the soil absorption field. However, such a system does not provide uniform distribution because the liquid trickles out of the holes nearest to the point of inlet and at the points of lowest elevation. Altering the orientation of the holes or changing the slopes of the pipe does not improve distribution significantaly (13).

Uniform distribution can be achieved by designing networks of small-diameter pipes with small holes in such a way that the entire pipe network fills before much liquid passes out the holes (13, 59, 12, 257). This system is called pressure distribution.

Absorption fields in sandy soils with pressure distribution have shown no evidence of clogging after 4 years of operation (13), while fields in sand with conventional gravity distribution begin to clog after 6 months of operation (231).

(d) Dosing

The determination of soil capacity to accept a certain liquid load is essential. The loading capacity of an absorption system is determined by the following factors (85):

1. The effective area of interface between the soil and liquid vertical surfaces are probably more effective than horizontal surfaces because (a) soil permeability is greater in the horizontal plane than in the vertical direction and (b) bottom areas are usually covered with a thicker sludge blanket than are sidewall areas.

2. The permeability, porosity and homogeneity of the soil.

3. The geometry or shape of the system.

4. The hydraulic arrangement for loading of different components of the absorption field.

Periodic dosing of large volumes of effluent on the field improves distribution and provides an opportunity for the soil to drain between applications. Drainage exposes the infiltrative surface to air, which reduces clogging of the soil (67, 73, 12). The performance of a tile field on sloping ground can be improved by loading individual trenches in series, rather than by conventionally arranging trenches which are dosed laterally in parallel sequence (278).

(e) Porous Media

The function of the porous media placed below and around the distribution pipe is four-fold. Its primary purposes are to support the distribution pipe and to provide a media through which the effluent can flow from the distribution pipe to reach the bottom and sidewall infiltration areas. The second function is to provide storage of peak wastewater flows. Thirdly, the media dissipates any energy that the incoming wastewater may have which could erode the infiltrative surface. Finally, the media supports the sidewall of the excavation and prevents it from collapsing.

Gravel or crushed rock is usually used as the porous media, though other durable porous materials may be suitable. The suggested gravel or rock size is 1.8 to 6.4 cm (3/4 to 2-1/2 in) in diameter. Smaller sizes are preferred because masking of the infiltrative surface by the rock is reduced (67).

(f) Construction Practices

Probably the frequent occurrence of an early failure of soil absorption systems is due to poor construction techniques. The rapid absorption of waste effluent by the soil requires maintenance of open pores at the infiltrative surface. The pores are often sealed during construction by compaction, by smearing or puddling of the soil by excavation equipment. Failure of the soil absorption system can be minimized by considering the following recommendations (74, 114):

1. Work should be done in clay soil only when the moisture content is low. If the soil forms a wire instead of breaking apart while attempting to roll it between the hands, then it is too wet.

2. Excavating equipment should not be driven on the surface of the absorption system. Trenches rather than bed construction is preferable in clay soils because equipment can straddle the trench.

3. Shallow systems should be constructed to place the infiltrative surface in more permeable horizons and to enhance evapo-transpiration. This is particularly beneficial in clay soils because they are generally wetter for longer periods, especially at greater depths.

4. Compacted surface should be removed. Compaction may extend as deep as 20.3 cm (8 in.). This requires hand spading to expose a fresh infiltrative surface.

5. Work should be scheduled only when the infiltrative surface can be covered in one day because wind blown silt or rain drop impact can clog the soil.

(g) Backfilling

Once the infiltrative surface is properly prepared, the backfilling operations must be done carefully to avoid any damage to the soil.

1. The gravel or crushed rock used as the porous media is laid in by a backhoe or front-end loader.

2. The distribution pipes are covered with a minimum of 5 cm (2 in) of gravel or rock to retard root growth and to stabilize the pipe before backfilling.

3. The gravel or rock is covered with untreated building paper, marsh hay or straw to prevent the unconsolidated soil cover from entering the media.

4. The backfill material should be similar to the natural soil and no more permeable. It should be mounded above the natural grade to allow for settling and to channel runoff from the system. BROWN and THOMAS (55) found that common Bermuda grass planted over absorption trenches constructed in the same soils could remove from 45 to 89 percent of the nitrogen in sandy loam and clay soils respectively, if harvested and removed.

(h) Operation and Maintenance

Once installed, a subsurface soil absorption system requires little or no attention as long as the septic tank effluent discharged into it is nearly free from settleable solids, greases, fats, and oils. This condition can be met by proper maintenance of the septic tank.

6.1.3.2 Design of an Absorption Pit

Absorption pits or dry wells are deep excavations used for subsurface disposal of septic tank effluent. Covered porous-walled chambers are placed in the excavation and surrounded by ground or crushed rock (Fig 31). Effluent enters the chamber where it is stored until it seeps out through the chamber wall and infiltrates the side wall of the excavation.

Absorption pits are generally discouraged by many local regulatory agencies in favour of trench or bed systems. However, absorption pits have been shown to be an acceptable method of disposal for small wastewater flows (91). Absorption pits, as with all absorption systems, are restricted for use where there is a likelihood of contaminating ground waters or where adequate absorption beds or trenches can be provided. Maintaining sufficient separation between the bottom of the absorption pit and the high water table is a particularly important consideration for protection of ground water quality. In view of this, the pit excavation should be terminated 1.22 m above the ground water table (137).

Absorption pits are recommended as an alternative when absorption fields are impracticable, and where the top 0.91 or 1.22 m of soil is underlaid with porous sand or fine gravel, and the surface conditions are suitable for pit installations. The capacity of an absorption pit can be computed on the basis of percolation tests made in each vertical stratum penetrated. The design and construction considerations for absorption pits have been reported (148, 137). HICKEY and DUNCAN (75) have suggested the construction of a narrow trench rather than a rectangular pit as an alternate method for obtaining the required wall absorption area in an absorption pit. In some cases, where impervious soils are underlaid with porous sand or fine gravel, absorption pits may offer the cheapest and the best solution to disposal problems (210). BENDIXEN et al. (168) stated that the absorption pit is a feasible device for introducing septic tank

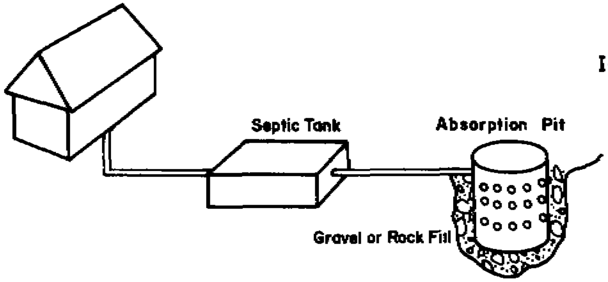
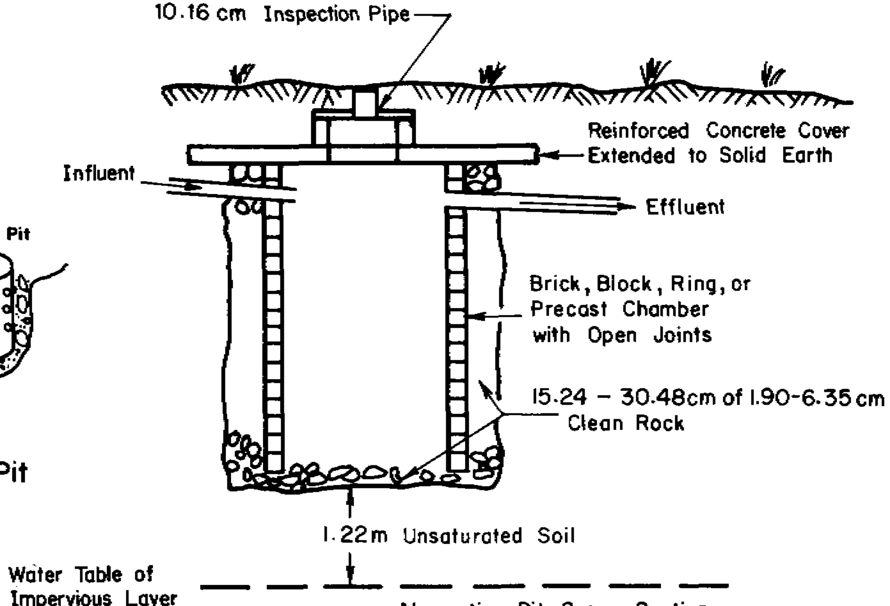


Figure 31 Septic Tank with Absorption Pit



Absorption Pit Cross Section

effluent from single family residences into the soil in special situations where the pervious soil is deep, or an impervious upper layer is underlaid by a porous media. They also presented practical design criteria for absorption pits, based on providing a sufficient area so that a reasonable period of satisfactory service is obtained with a minimal total expenditure for initial upkeep and replacement costs.

(a) Sizing the Infiltrative Surface

As the dominant infiltration surface of an absorption pit is its side wall, the depth and diameter of the pit is determined from the percolation rate and thickness of each soil layer exposed by the excavation. A weighted average of the percolation test results, i.e. the sum of the thickness times the percolation rate of each layer divided by the total thickness, is used. Soil layers with percolation rates greater than 12 min/cm (30 min/in) are excluded from this computation (137).

(b) System layout

Absorption pits may be of any diameter or depth provided they are structurally sound and can be constructed without seriously damaging the soil. Typically, absorption pits are 1.8 to 3.6 m (6 to 12 ft) in diameter and 3 to 6 m (10 to 20 ft) deep, but pits 0.5 m (18 in) in diameter and 12 m (40 ft) deep have been constructed (212). When more than one pit is required, a separation distance from sidewall to sidewall equal to 3 times the diameter of the largest pit should be maintained (137).

(c) Construction

Pits may be dug with conventional excavating equipment or with power augers. Particular care must be exercised to ensure that the soils are not too wet before starting construction.

Precast concrete absorption chambers may be used, or the chambers may be constructed out of clay, concrete brick, or ferrocement blocks or rings. The rings must have notches in them to provide for seepage. About 15 to 30 cm of clean gravel, or 1.8 to 6.4 cm crushed rock, is placed at the bottom of the excavation prior to placement or construction of the chamber. This provides a firm foundation for the chamber and prevents bottom soil from being removed if the pit is pumped.

Covers of suitable strength to support the soil overlay and any anticipated loads are placed over the chamber and extend at least 30 cm beyond the excavation. Access to the pit for inspection purposes can be provided by a manhole. If a manhole is used, it should be covered with 15 to 30 cm of soil. An inspection pipe can extend to the ground surface. A non corrosive, watertight cap can be used with the inspection pipe.

(d) Maintenance

A well-designed and constructed absorption pit requires almost no routine maintenance. If a failure should occur, it can be remedied by pumping and resting the pit.

6.1.4 Failures of Subsurface Soil Absorption Systems

The causes of failure can be complex, resulting from poor siting, poor design, poor construction, poor maintenance, hydraulic overloading, or a combination of these factors. To determine the most appropriate method of rehabilitation, the cause of failure needs to be determined.

The failure of the subsurface absorption system occurs when the soil surrounding the seepage area stops adequate purification of septic tank effluent. The system may fail hydraulically due to soil clogging, or it may fail to purify the effluent because of unsuitable soil material (26).

In an investigation of eight systems in silty soils, six major problems have been identified, which may occur from the time of the initial site evaluation to construction (250):

1. poor site evaluation by the installer;
2. failure of the regulatory agency to reject applications with poor siting or design;
3. design specifications not followed during construction;
4. poor construction procedures followed by the installer;
5. mistakes overlooked during the site evaluation by the regulatory agency; and
6. system overloading due to increased effluent volume following installation.

The failure of systems has also been reported as being due to enforcement problems (41). Two studies in Connecticut showed that about 70 percent of the failure were caused by seasonal high groundwater (197, 198). Studies on the aspects of soil absorption failure and methods of prevention are well documented (68, 69, 70, 71, 72, 73). These researchers have observed that soil clogging is a surface phenomena and the depth of penetration depends upon the size of the pores in the medium. Generally it occurs within the top one or two cm of any soil, which is enough to pose a problem in absorption systems.

It is essential to determine the failure frequency before isolating the cause. Failure may occur occasionally or continuously. Occasional failure may be characterized by occasional seepage on the ground surface, sluggish drains, or pluming backups. These may occur due to heavy rainfall. Continuous failure can have similar symptoms but on a continuous basis. However, some systems may seriously contaminate the ground water with no surface manifestations of failure. These failures are detected by ground water sampling.

SAXTON (317) developed a computer model to predict the expected number of failures of each category for the next 20 years, and this can be used as an input for presenting calculations, estimating sanitarian work loads and predicting water quality. The model was calibrated with 10 years of existing data on septic system failures. MITCHELL (172) conducted experiments to correct the failure of septic tank-absorption systems by relatively inexpensive changes in absorption field design. An absorption field with an addition of 12 in. of gravel passing a sieve number 4 with a uniformity co-efficient (CU) of 30 and an effective size of 0.4 mm, would provide COD removal of 90 percent. COREY et al. (60) studied the effect of water softner wastes on the permeability of soil absorption fields. They concluded that the inclusion of the softener waste is not detrimental, but its exclusion could be more harmful.

Some of important methods for correcting failures of soil absorption are shown in Figure 32.

The results reported by numerous investigators indicate that the

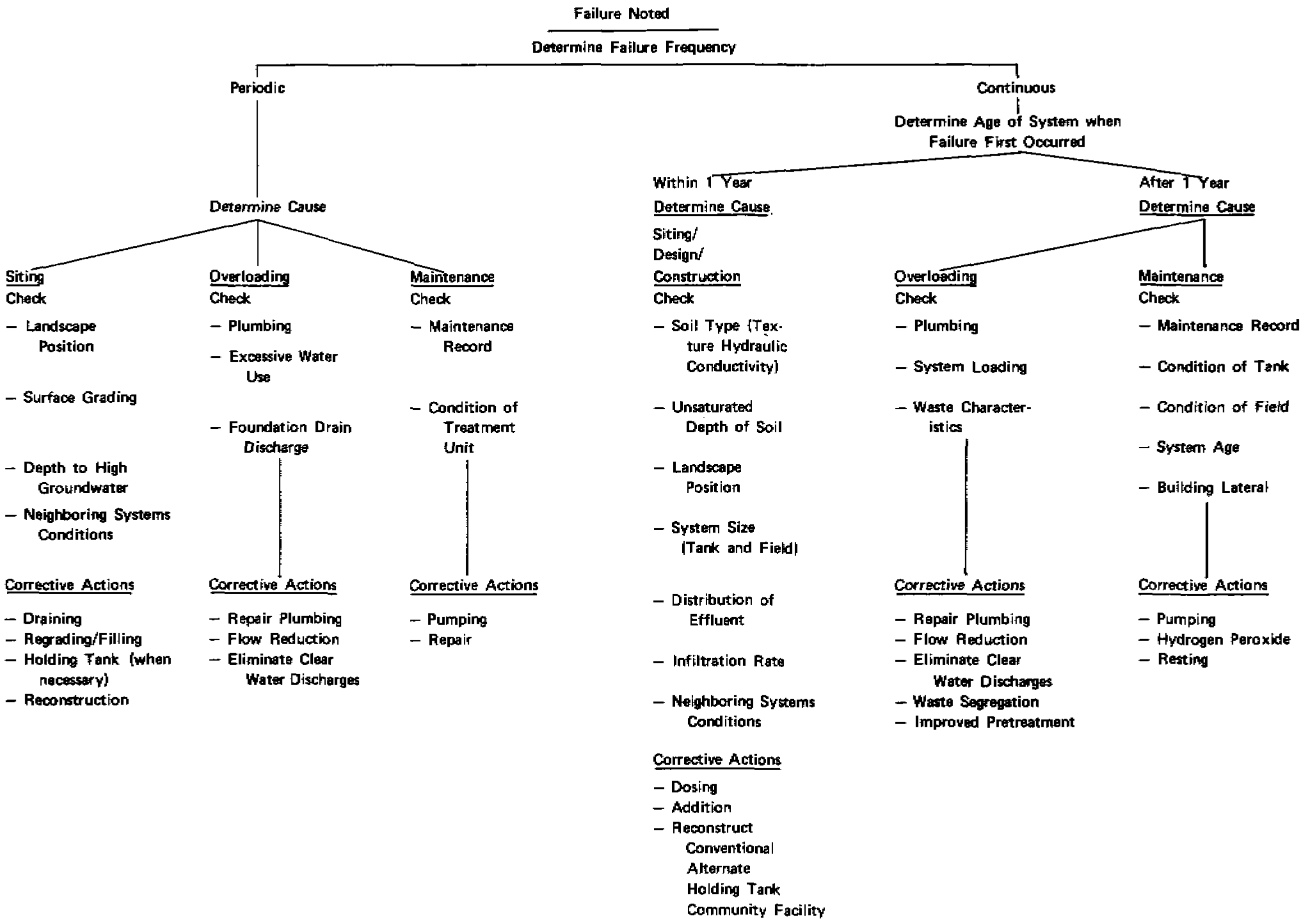


Figure 32 Methods of Soil Absorption Field Rehabilitation

physical and biological mechanisms are the primary causes of soil clogging in an absorption field, rather than smearing and compaction during construction (67, 94, 231, 232, 97, 300, 233, 234, 235, 236, 237, 238, 239, 240, 241, 95). BENDIXEN (232, 267) suggested three possible categories of soil clogging:

(a) physical plugging of soil pores by solid particles in the effluent;
(b) biological plugging of soil pores by fecal organisms and their by-products, or by destruction of the soil structure through biological activity; and
(c) chemical plugging of the soil pores by the swelling of soil particles.

ALISON (298) and McGAUHEY and WINNEBERGER (67) pointed out that even clean water will lead to clogging eventually by the ion exchange effect and the migration of fine soil. JONES and TAYLOR (94) presented data to support chemical clogging by water.

Clogging usually seems to start near the inlet of the absorption system and progress down the length of the bed or trench (231, 71). The progressive clogging of the infiltrative surfaces of subsurface absorption systems is shown in Figure 33.

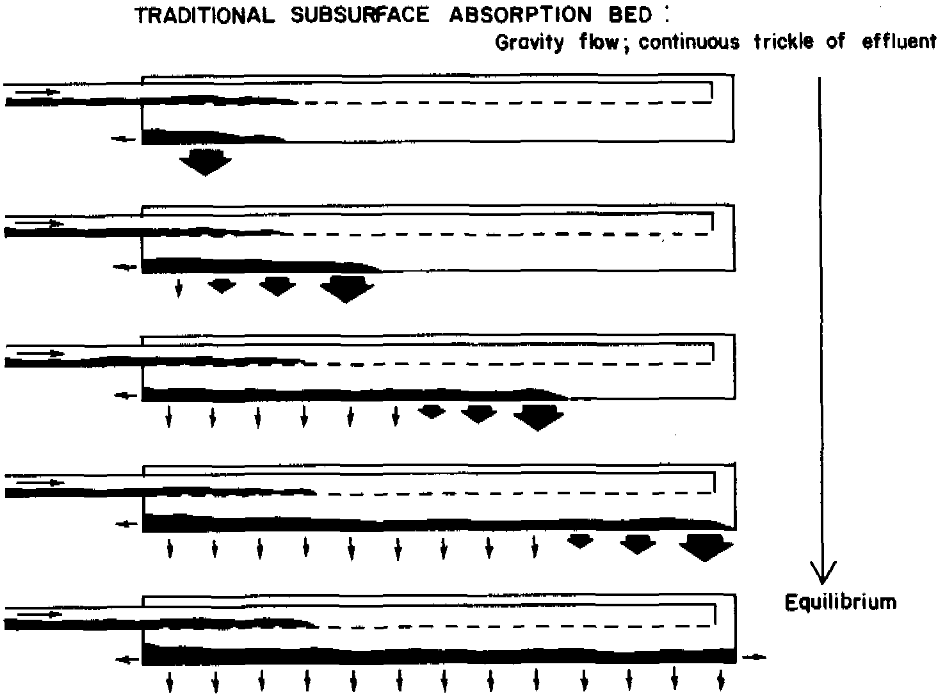


Figure 33 Progressive Clogging of the Infiltrative Surfaces of Subsurface Absorption Systems (231)

THOMAS et al. (234) have shown that anaerobic conditions stimulate clogging, in which the accumulation of materials in the soil pores leads to the formation of ferrous sulfide, which mechanically clogs the pores and impedes the liquid penetration (70, 71, 67). Although LAAK (236) determined that this is not an important contributor to infiltration rate reduction, VIRARAGHAVAN (42) and MAGDOFF (4) have demonstrated that the reduction in soil permeability is due to microbial clogging rather than to ferrous sulphate clogging. WEIBEL et al. (40) have found that effluent containing ground garbage (a high carbon source) caused faster clogging than effluent without this material.

The clogging which leads towards the failure of a system can be reduced by periodic dosing (67, 73, 12). Trenches or beds which are ponded due to a loss of the infiltration capacity of the soil could be recovered by allowing the ponded surface to drain and rest (260).

6.2 Alternatives for the Disposal of Septic Tank Effluent

A septic tank with a conventional soil absorption system continues to be an acceptable means of sewage disposal wherever soil conditions are suitable for its installation. In soils having unfavourable properties for soil absorption and purification of liquid wastes, such as slowly permeable soils or soils with bedrock or a high groundwater level, conventional subsurface soil disposal of septic tank effluent is not recommended (89, 114, 90, 151, 259). Several alternatives, such as sand filters, mounds, evapo-transpiration beds (ET beds) and anaerobic upflow filters, are now available which provide environmentally safe and effective treatment/disposal.

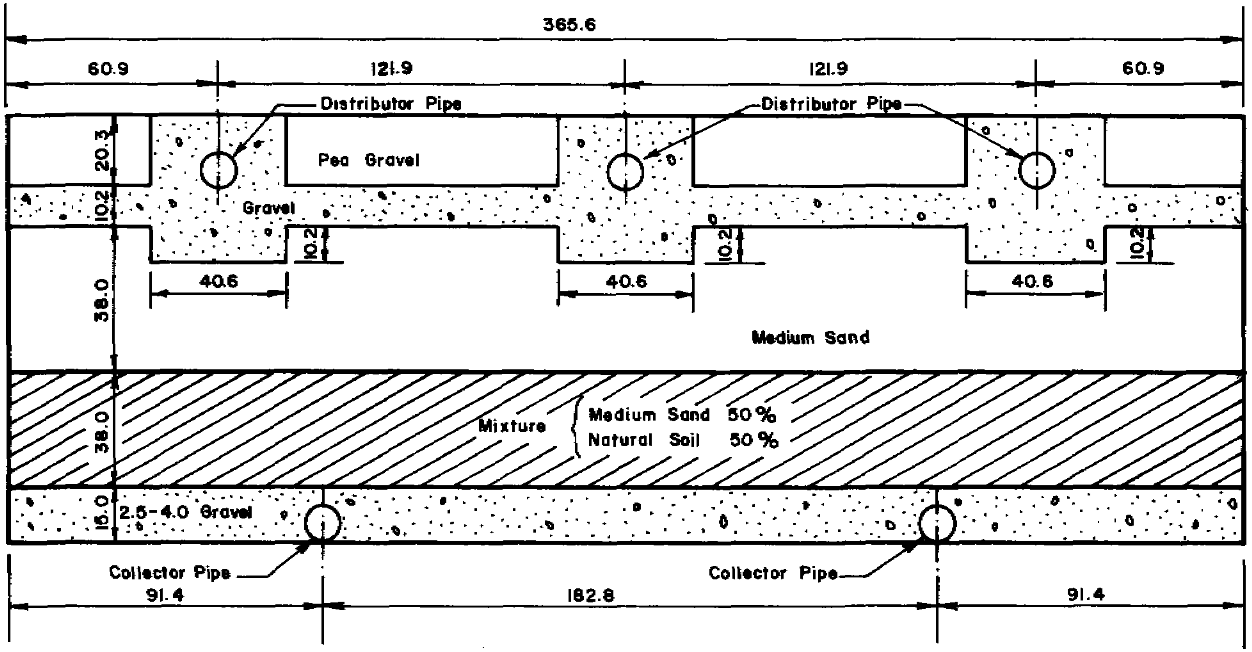
6.2.1 Septic Tank-Sand Filter Systems

In areas where conditions for the installation of conventional absorption fields are not favorable, a sand filter may provide a satisfactory alternative of septic tank effluent treatment (126, 127) (Figure 34).

HINES et al. (23) have described three alternative sand filter systems for on-site applications. Design criteria, performance, operation and maintenance requirements are described. SAVER et al. (152) have presented the result of field studies conducted with an on-site intermittent sand filter following the septic tanks or aerobic units.

Intermittent sand filters are beds of granular materials placed 61 to 91 cm (24 to 36 in) deep and underlain by graded gravel and collecting tile. Wastewater is applied intermittently to the surface of the bed through distribution pipes or troughs. Uniform distribution is normally obtained by dosing so as to flood the entire surface of the bed.

Filters may be designed to provide free access, called open filters, or may be buried in the ground, called buried filters. The mechanisms of purification of intermittent sand filters are complex. Filters provide physical straining and sedimentation of solid materials within the media. Chemical sorption also plays a role in the removal of some materials. However, successful treatment of wastewaters is dependent upon the biochemical transformations occuring within the filter. Without the assimilation of filtered and sorbed materials by biological growth within the filter, the process may fail



All Measurements in Centimetres, Filter Sand D_{10} = 0.24 mm

Figure 34 Section of Filter Bed with Medium Sand and Natural Soil from Site (126) to operate properly.

Intermittent sand filtration is well adapted to onsite disposal. Its size is limited by land availability. The process is applicable to single homes and clusters of dwellings. Site constraints should not limit the applicability of intermittent sand filters, although odors from open filters receiving septic tank effluent may require isolation of the process from dwellings.

6.2.1.1 Parameters Important in Septic Tank-Sand Filter Design

The percent reduction of pollutants from wastewater by an intermittent sand filter is dependent upon the following factors: (1) the type and biodegradability of wastewater applied to the filter, (2) the environmental conditions within the filter, and (3) the design characteristics of the filter.

Reaeration and temperature are two of the most important environmental conditions that affect the degree of wastewater purification through an intermittent sand filter. Availability of oxygen within the pores allows for the aerobic decomposition of the wastewater. Temperature directly affects the rate of microbial growth, chemical reactions and absorption mechanisms.

Proper selection of process design variables also affects the degree of purification of wastewater by intermittent filters. A brief description of these variables is presented below.

(a) Depth of Media

Depths of intermittent sand filters were initially designed to be 1.2 to 3 m; however, it was observed later that most of the purification of wastewater occurred within the top 23 to 30 cm of the bed (380). Additional bed depth did not improve the wastewater purification to a significant degree. The use of shallow filter beds helps to keep the cost of installation low. Deeper beds tend to produce a more consistent effluent quality, and they are not affected severely by rainfall (133).

(b) Media Size

The effectiveness of the filter media depends upon its effective size and the uniformity of the grains. The size and uniformity of filter media are expressed respectively in terms of their "effective size" and "uniformity coefficient". The effective size is the size of the grain, in millimeters, such that 10% by weight are smaller. The uniformity coefficient is the ratio of a grain size having 60% by weight finer than itself to a size havings 10% finer than itself. The effective size of the granular media has a profound effect on the quantity of wastewater that may be filtered, the rate of filtration, the penetration depth of particulate matter, and the quality of the filter effluent. Granular media that are too coarse lower the retention time of the applied wastewater through the filter to a point where adequate biological decomposition is not attained. Too fine media limits the quantity of wastewater that may be successfully filtered, and may lead to early filter clogging. This is due to the low hydraulic capacity and the existence of capilary saturation, which are characteristics of fine materials. METCALF and EDDY (196) recommended that not more than 1% of the media be finer than 0.13 mm. Many suggested values for the effective size and uniformity coefficient are available in the literature (137, 128, 207). Table 15 summarizes some of the effective size and uniformity coefficients of sand filters.

Table 15: Effective Size and Uniformity Co-efficient of Sand Filter.

Effective Size (mm)	Uniformity Co-efficient	References
0.3 to 0.6	Not greater than 3.5	(128)
0.25 to 0.50	" " " 4.0	(130)
0.35 to 0.50	" " " 3.0	(129)
0.24 to 2.5	1.2 to 3.9	(127)
0.14	1.99	(99, 242)

Granular media other than sand have been used, notably anthracite, garnet, activated carbon and mineral tailings. The media selected should be durable and insoluble in water.

Shapes of individual media grains include round, oval, and angular configurations. Purification of wastewater infiltrating through granular media is dependent upon the adsorption and oxidation of organic matter in the wastewater. To a limited extent, this is dependent on the shape of the grain. However, it is more dependent on the size distribution of the grains, which is characterized by the uniformity coefficient.

The placement of different sizes of grains throughout the filter bed is another important design consideration. In a bed having fine media layers placed above coarse layers, the downward attraction of wastewater is not as great, due to the lower amount of cohesion of the water in the larger pores (380). The coarse media will not draw the water out of the fine media, thereby causing the bottom layers of the fine material to remain saturated with water. This saturated zone acts as a water seal, limits oxidation, promotes clogging, and reduces the action of the filter to a mere straining mechanism. The use of media with a uniformity coefficient of less than 4.0 minimizes this problem.

(c) Hydraulic Loading Rate

The hydraulic loading rate may be defined as the volume of liquid applied to the surface area of the sand filter over a designated length of time. Hydraulic loading is normally expressed as cu.m/sq.m-d or gal/sq.ft-d. Values of recommended loading rates for intermittent sand filtration vary throughout the literature and depend upon the effective size of sand and the type of wastewater. Based on both laboratory and field experiments, SAVER (32) recommended a hydraulic loading rate of 0.2 cu.m/sq.m-d (5 gal/sq.ft-d) for determining the required surface area for sand filters. DUCHINSIT (141) suggested that the loading of 10 liters per day per running metre of irrigation network can be safely applied on biologically matured filtration beds. The time periods of loading and resting depend upon the effective size of the sand (32).

(d) Organic Loading Rate

The organic loading rate may be defined as the amount of soluble and insoluble organic matter applied per unit volume of filter bed over a designed length of time. Organic loading rates are not often reported in the literature. However, early investigators found that the performance of sand filters was dependent upon the accumulation of stable organic material in the filter bed (380,219). To account for this, suggested hydraulic loading rates are often given for a particular type of wastewater. Allowable loading rates can be increased with the higher degree of sewage pretreatment. A strict relationship establishing an organic loading rate has not yet been clearly defined in the literature.

6.2.1.2 Performance of a Sand-Filter

The removal efficiency of a sand filter is reported to increase with the age and maturity of the filter (152). CHOUDHARY (127) reported an average 90 percent reduction of BOD and suspended solids, and approximately 30 percent phosphorus. The phosphorus removal was increased over 70 percent after the addition of red mud to the filter beds. BRANDES et al. (293) in their study on removal of pollutants from domestic wastewater by underdrained soil filters have shown the effect of hydraulic loading on bacterial removal. BRANDES (30) almost achieved a complete removal of total and fecal coliform organisms from household wastewater. Less than 500/100 ml of total coliform organisms and less than 30/100 ml of fecal coliform organisms were observed in the final effluent from a sand filter. An experiment was conducted to determine the effectiveness of Salmonella removal from septic tank effluent using subsurface filtration beds. Results revealed that effluent from the filter did not cause contamination of the groundwater.

The disinfection of sand filtered effluents using tablet-feed calcium hypochlorite or ultraviolet irradiation was reported by SAVER and BOYLE (116). Excellent results were observed during the field tests performed over 7- to 78-month periods.

The design of soil filters should enable a maximum possible run-off from the filter surface to reduce the infiltration of water from atmospheric precipitation. Higher sun exposure and evapo-transpiration are advantageous to sand filter operation (133). The sand filter system cannot work efficiently for long periods without proper maintenance. The system often fails due to reduction of infiltration rates, a sealing up of the sand, and the accumulation of sulfides. This problem can be solved by replacing the top 10.2 cm of sand with clean sand (152).

Various maintenance techniques may be employed when the bed becomes clogged. Some of these include: (1) resting the bed for a period of time, (2) raking the surface layer and thus breaking the inhibiting crust, or (3) removing the top surface media and replacing the top 10.2 cm of sand with clean sand (152). However, the effectiveness of each technique has not been clearly established in the literature.

6.2.2 Disposal of Septic Tank Effluent in a Mound

The sand filter system proposed as an alternative to the conventional soil absorption system (127, 128) appears to fail frequently on clay soils with high water tables, mainly due to clogging (323). Another alternative called a "mound" has been proposed on slowly permeable soils and soils with high water tables (89, 258, 322, 82, 2). Mounds were developed in North Dakota and are often called Nodok Systems in recognition of their origin. They were described as early as the 1950's by SALVATO (Figure 35) (296).

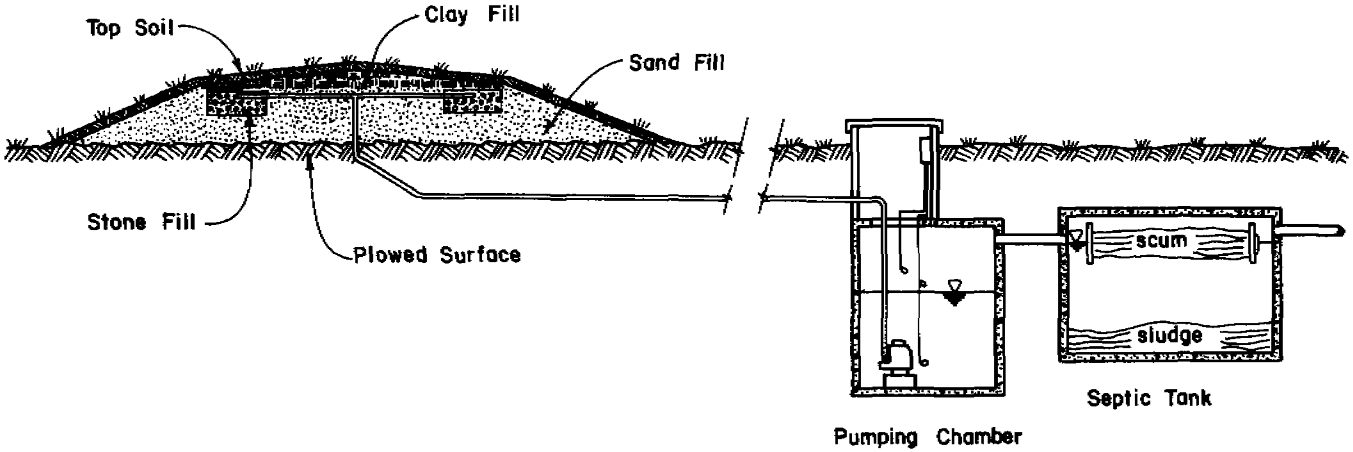


Figure 35 Cross Section of a Typical System Consisting of a Septic Tank, Pumping Chamber and the Mound (151)

A mound system is a soil absorption system that is elevated above the natural soil surface in a suitable fill material. The purpose of the design is to overcome site restrictions that prohibit the use of conventional soil absorption systems (377,59). Such restrictions are: (1) slowly permeable soils, (2) shallow permeable soils over creviced or porous bedrock, and (3) permeable soils with high water tables. In slowly permeable soils, the mound serves to improve adsorption of the effluent by utilizing the more permeable top soil and eliminating construction in the wetter and more slowly permeable subsoil, where smearing and compaction are often unavoidable. In permeable soils with insufficient depth to groundwater or creviced or porous bedrock, the fill material in the mound provides the necessary treatment of the wastewater.

A properly designed and installed septic tank mound system can provide satisfactory treatment under conditions unsuitable for conventional subsurface soil absorption fields. Heavy rainfall or fluctuations in organic and inorganic contaminants in the septic tank effluent seems to have little or no effect on the quality of the treated wastewater (151). The design, construction and field performance of mound systems used in place of conventional septic tank systems in problem soils were reviewed by CONVERSE et al. (59). The major approaches and procedures of mound design have been reported in detail (231, 258). A brief discussion of mound design is given below.

6.2.2.1 Design of a Mound

There are two key features of mound design (296): (1) there should be about 0.6 m (2 ft) of suitable soil, preferably a sandy loam or a loam, between the bottom of the soil absorption bed or trenches and the native topsoil; and (2) the effluent should be applied as uniformly as possible over a sufficiently large soil absorption system in the mound. The design of mounds for a particular site involves five steps: (a) sizing of the required basal area, (b) sizing of the absorption trenches; (c) design of the distribution system; (d) final dimensioning of the mound; and (e) sizing of the dosing chamber. Mound systems rely on pressure from submersible sewage pumps to distribute the effluent through perforated PVC pipes in the elevated absorption trench or bed.

(a) Fill Materials and Thickness of Fill

The performance of mound systems depends to a greater extent on the fill material. Medium sand is commonly used as a fill material within the mound. Loamy sands or sandy loams have better fill aeration properties than sands, but their potential for clogging is higher. Column studies on mound systems have indicated that sand can be very effective as a filter, and consequently the use of medium size sands is recommended (3). A topsoil and sand mixture producing 92 percent sand size particles can be used in an artificially created sewage disposal system at a 3.3 cm/day effluent loading rate. A higher loading rate would cause rapid clogging in a given soil material (325). Laboratory studies of columns, filled with medium sand representing mound sand fill, showed that the mound sand fill was clogged due to the high loading rate, the low temperature and the oxygen conditions. The results of this study indicated that 30 cm may be sufficient to avoid accelerated clogging caused by wetness, and the maximum safe loading rate of sand fill should be about 2 cm septic tank effluent/day (324). SIMONS and MAGDOFF (323) have suggested the use of 45 cm of sand fill to provide an extra margin of safety for permeable soil/high water table sites. To keep costs of construction to a minimum, the fill should be selected from locally available materials. Very permeable materials should be avoided, because their treatment capacity is less, and there is a greater risk of surface seepage from the base of the mound when used over more slowly permeable soils.

The pollutant removal efficiency of mound systems is largely determined by the thickness of the fill. The purification will increase as the fill thickness increases, but a minimum of 60 cm (2 ft) of sand fill (231) is sufficient to reduce waste constituents to very low levels. The BOD, suspended solid (SS), fecal streptococci and fecal coliform are effectively removed by a mound of 60 cm (2ft) of medium sand fill (231, 89, 243, 258), although inadequate removal of nitrate nitrogen has been observed due to nitrification in the well-aerated mound (90). Adding 2 cm of septic tank effluent every six hours to columns consisting of a light textured fill over a silt loam, creates the potential for nitrification to occur in the fill and for denitrification in the silt loam (2). In the mound system, denitrification reduces the nitrogen content, and microbial respiration removes the carbon from septic tank effluent.

(b) Geometry of the Absorption Bed

The absorption area within the mound system can either be a bed or a series of trenches. Beds are typically used for single homes or other small systems because they are easier to construct. The shape of the bed depends on the permeability of the natural soil and the slope of the site. In most instances, a rectangular bed with its long axis parallel to the slope contour is preferred to minimize the risk of seepage from the base of the mound. In soils with percolation rates greater than 24 min/cm (60 min/in), the bed can be square if the water table is greater than 0.9 m (3 ft) below the natural ground surface (377,379).

The dimensions of the mound are dependent on the size and shape of the absorption bed, the permeability of the natural soil, the slope of the site, and the depth of fill below the bed. A detailed procedure for dimensioning the mound has been well documented (59).

(c) Effluent Distribution

Although both gravity and pressure distribution networks have been used in mound systems, pressure distribution networks are superior (4, 24, 25). With pressure distribution, the effluent is spread more uniformly over the entire absorption area to minimize saturated flow through the fill and short circuiting, thus assuring good treatment and absorption. An application of approximately four doses per day has been recommended (379).

6.2.3 Evapo-transpiration (ET) Beds

Evapo-transpiration (ET) beds can be used to dispose of septic tank effluent into the atmosphere so that no discharge to surface or groundwater is required. ET beds for the disposal of septic tank effluent have been used in Colorado as an alternative disposal system where soil conditions do not permit the use of soil absorption fields (169, 174). The systems were designed as shown in Figure 36.

On-site ET disposal normally consists of a sand bed with an impermeable liner and effluent distribution piping. The surface of the sand bed may be planted with vegetation. An ET bed functions by raising the effluent to the upper portion of the bed by capillary action in the sand, and then allowing it to evaporate into the atmosphere. In addition, vegetation transports water from the root zone to the leaves, where it is transpired.

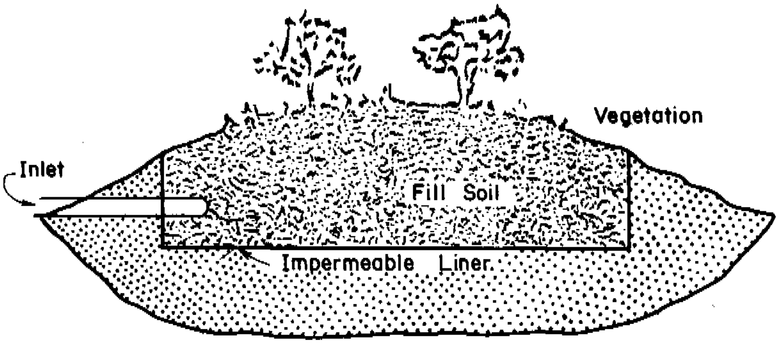


Figure 36 Evapotranspiration Bed (174)

6.2.3.1 Application of ET Systems

On-site systems utilizing ET disposal are used where geological limitations prevent the use of subsurface disposal, and where discharge to surface waters is not accepted. The geological conditions that determine the use of ET systems include a very shallow soil mantle, high groundwater, relatively impermeable soils, or fractured bedrock. However, ET systems may be used where the feasibility of subsurface disposal systems is limited, but their application also has certain limitations. As with other disposal methods that require area-intensive construction, the use of ET systems can be restricted by limited land availability and site topography. The maximum area required for an ET system based on the number of persons is not available in the literature, and the maximum slope at which an ET system is applicable has not been established.

The most significant constraint on the use of ET systems is climatic conditions. The evaporation rate is controlled primarily by climatic factors such as precipitation, wind speed, humidity, solar radiation, and temperature, and thus the performance of ET beds will depend on these factors. Recent studies indicate that essentially all of the precipitation that falls on an ET bed infiltrates into the bed and becomes part of the hydraulic load that requires evaporation (381,297). ET systems seem to be more applicable in subtropical and tropical countries because of the high temperature, humidity, solar radiation and other preferable climatic factors which prevail.

6.2.3.2 Factors Affecting the Performance of an ET System

The following factors affect the performance of an ET system:

- Climate,
- Hydraulic loading,
- Sand capillary rise characteristics,
- Cover soil and vegetation,
- Construction techniques,
- Salt accumulation, and
- Depth of free water surface in the bed,

(1) Climate

Solar radiation, temperature, humidity, wind speed, and precipitation all influence performance. Since these parameters fluctuate from day to day, season to season, and year to year, evaporation rates also vary substantially. In order to insure adequate overall performance, these fluctuations need to be considered in the design.

(2) Hydraulic Loading

The hydraulic loading rate of an ET bed affects its performance. Too high a loading rate may result in discharge from the bed; too low a loading rate may cause lower gravity (standing) water levels in the bed and inefficient utilization. The decrease of evaporation rates with decreased water levels have been recorded (381, 382).

(3) Sand Capillary Rise Characteristics

The capillary rise characteristic of the sand used to fill the ET bed is important because this mechanism is responsible for transporting the water to the surface of the bed. Hence, the sand needs to have a capillary rise potential at least as great as the depth of the bed, and yet should not be so fine that it becomes clogged by solids in the applied wastewater (381).

(4) Cover Soil and Vegetation

The use of vegetation that is tolerant to moisture extremes becomes necessary when significant seasonal fluctuations in the free water surface are normal. A variety of vegetation, including grasses, alfalfa, broad leaf trees, and evergreens, will increase the average annual evaporation rate from an ET bed to above that for bare soil (382). Nevertheless, grasses and alfalfa also result in nearly identical or reduced evaporation rates as compared to bare soil in the winter and the spring when the evaporation rates are normally at a minimum (381,382). Certain evergreen shrubs, on the other hand, have been shown to produce slightly greater evaporation rates than bare soil throughout the year (381). Thus, it can be seen that there are conflicting data on the benefits of cover soil and vegetation.

(5) Construction Techniques

The performance of an ET system will be affected less by construction techniques than most subsurface disposal methods. However, some aspects of ET construction can affect performance such as an impermeable liner and the selection of the sand. Insuring the integrity of the impermeable liner and selecting the sand to provide for maximum capillary rise properties are typically the most important considerations.

(6) Salt Accumulation

Salt accumulation in an ET bed occurs as wastewater is evaporated. The salt accumulation rate will depend upon the concentration of the salt in the wastewater. Salt accumulation is particularly pronounced at the surface of the bed during dry periods, although it is redistributed throughout the bed by rainfall. According to the existing literature, salt accumulation does not interfere with the operation of nonvegetated ET systems (383). For ET systems with surface vegetation, salt accumulation may adversely affect performance after a long period of use, although observations of ET systems that have been in operation for 5 years indicate no significant problems (33). In order to minimize potential future problems of salt accumulation, the ET piping system may be designed to permit flushing of the bed.

6.2.3.2 Design of an ET System

ET systems should be designed so that they are acceptable in performance and operation. Requirements for acceptability vary. On the one hand, acceptable performance can be defined for an ET system as zero discharge for a specified duration, based on the weather data for a similar period. Alternatively, occasional seepage or surface overflow during periods of heavy rainfall may be allowed.

Design criteria for an ET system vary with location. For example, occasional discharge may be acceptable in low-density rural areas, whereas completely nondischarging systems are more appropriate in higher density suburban areas.

The size and consequently the cost of an ET system are dependent on the design hydraulic loading rate. Where a total evaporation system is required, the loading rate should be low enough to prevent the bed from filling completely. The reports of system designs based on higher loading rates have been presented in the literature (383,384).

For the efficient operation of the system, medium fine sand is recommended as the bed media. The sand utilized must be small enough to provide adequate hydraulic conductivity of water up to the surface. However, the sand available for ET bed construction should be tested for capillary rise height and rate before one is selected. Sand with a size range of 0.12-0.18 mm and a uniformity coefficient of 4 or less is reported to be satisfactory. In general, clean and uniform sand with a size of D50 = 0.1 mm (50% by weight smaller than or equal to 0.1 mm) is desirable (381). BENNETT and LINSTEDT (381) have conducted lysimeteric studies to investigate the design parameters for ET beds. The design parameters included loading rate, water depth, and surface cover. The results indicate that the loading criteria should be based on the evaporation rate minus precipitation during the critical portion of the year, and the unit should not be designed on the basis of the annual evaporation rate.

6.2.4 Artificial Marsh Waste Water Treatment Systems

FETTER et al. (142) carried out a pilot scale experiment to treat septic tank effluent using emergent marsh vegetable (BAKRYSG and SCIRPUS VALIDUS) and reported that the plant, which grows in a gravel substrata in a plastic line trench, is capable of removing more than 70 percent organic and 99 percent coliform bacteria. The author advocated this system for rural or summer houses where growth of bulrushes is possible.

6.2.5 Treatment of Septic Tank Effluent by Anaerobic Upflow Filter

The disposal of effluent in soil from septic tanks serving individual houses or small suburban communities becomes difficult in areas of compact soil conditions, a high water table, and limited availability of open land. Under these conditions, the secondary treatment of septic tank effluent is accomplished by sand filters and mounds. These systems require frequent maintenance and need additional pumps. One alternative is to use an anaerobic upflow filter, as described by WITHEROW, COULTER and ETTINGER (331), RAMAN and CHAKLADAR (332, 333), and RAMAN and KHAN (334, 335). The anaerobic upflow filter can be successfully used as a simple secondary treatment device for treating septic tank effluent and settled domestic sewage, or used as a composite sewage treatment unit (335) (Figure 37).

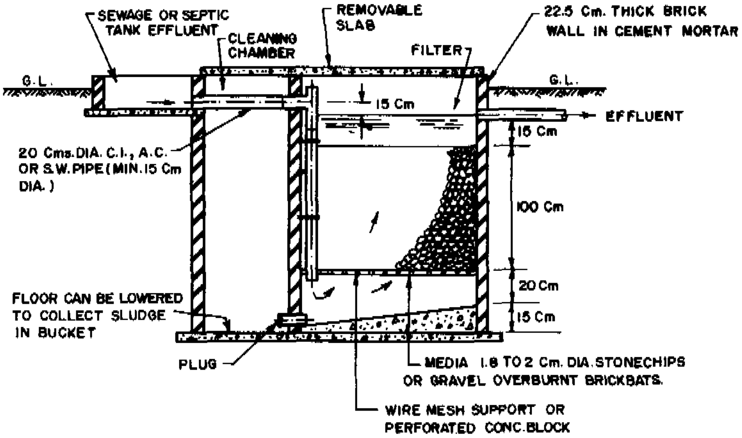


Figure 37 Upflow (Anaerobic) Filter (336)

In an anaerobic upflow filter, the septic tank effluent enters at the bottom of the filter through a system of underdrains, flows upward through a bed of coarse material so that the filter is completely submerged, hence producing an anaerobic condition. Anaerobic micro-organisms accumulate in the void spaces between the materials so that the waste comes in contact with a large active biological mass as it passes through the filter.

The use of anaerobic upflow filter for industrial and synthetic waste treatment is well documented (339-351, 353-356, 358-361, 363-366). MULLER and MANCIMI (351) listed information on anaerobic filters treating various industrial wastes and synthetic wastes such as potato processing waste, wheat starch waste, petrochemical wastes and pharmaceutical wastes, etc. Continuous attempts have also been made to evaluate the effectiveness of the anaerobic upflow filter as a domestic sewage treatment method and as a possible viable alternative to the septic tank, in order to produce better effluent quality (387). A summary of anaerobic filter investigations, carried out on diluted wastewaters, is presented in Table 16.

6.2.5.1 Design Parameters of the Anaerobic Upflow Filter

The performance of the anaerobic filter is generally governed by certain design parameters such as the size of the media, the depth, and hydraulic loading. The design parameters for efficient operation recommended by investigators are shown below (335,336):

Parameters	Criteria
size of the media	1.8 cm to 2.5 cm
Depth of the media	120 cm to 180 cm at least 90 to 120 cm
Detention time	6-12 hrs

Table 16. Anaerobic Treatment of Dilute Wastewaters

Nature of wastewater	Characteristics of wastewater	Process	Type of study (Scale)	Loading rate	HRT h	% Removal	Temperature °C	Reference
Diluted city (Durban, SA) wastewater	20 % municipal + 80 % industrial COD–1100–1300 mg/L BOD–300 -400 mg/L	Contact digester	Pilot plant	0.04 lb BOD/ft^3-d (0.64 kg BOD/m^3-d)		80 (BOD)		384
Diluted raw wastewater (Pretoria, SA)	COD – 500 mg/L	Contact digester	Laboratory and pilot plant	0.03 lb COD/ft^3-d (0.48 kg COD/m^3-d)	24(1)	90 (COD)		338
Dilute (synthetic) wastewater	COD – 480 mg/L	Two stage anaerobic filter	Laboratory	0.5 kg COD/m^3-d	15	83	21–26	385
				1.0 kg COD/m^3-d	8	79	21–26	
				2.0 kg COD/m^3-d	4	71	21–26	
Dilute (synthetic) wastewater	COD – 900 mg/L	Anaerobic filter	Laboratory	0.8 kg COD/m^3-d	12.8	96	24–33	344
				1.2 kg COD/m^3-d	9.1	95	24–33	
				1.6 kg COD/m^3-d	6.4	91	24–33	
				2.2 kg COD/m^3-d	4.8	90	24–33	
Settled sewage	BOD – 120 mg/L	Anaerobic filter	Laboratory	0.26 kg BOD/m^3-d	5	80	25–33	335
	198 mg/L			0.42 kg BOD/m^3-d	5	84	25–33	
Raw sewage	BOD – 175 mg/L	Anaerobic filter	Laboratory	0.26 kg BOD/m^3-d	5	73	28	335
	210 mg/L			0.23 kg BOD/m^3-d	5	80	31	
Septic tank effluent	1) BOD – 240 mg/L	1) Upflow anaerobic filter	Field scale	0.02 kg BOD/m^3-d (2)	6 d (2)	71		335
	2) BOD – 210 mg/L	2) Down & upflow anaerobic filter	Field scale	low loading (2)	High (2)	75		
Septic tank effluent	BOD – 290 mg/L	Upflow anaerobic filter	Laboratory	0.34 kg BOD/m^3-d		76	23–33	335
Dilute synthetic	COD – 50 – 600 mg/L	Anaerobic	Laboratory	upto 8 kg COD/m^3-d	6–0.33	>80	10–30	386

Note : 1) *HRT (Hydraulic Retention Time) is the recommended* parameter

2) Low flows from household (only toilet wastes)

Hydraulic loading	1-1.5 cu.m./sq.m.-day
Capacity of the unit for secondary treatment of septic tank effluent	0.042-0.056 cu m per capita or 1/3 to 1/2 of liquid capacity of septic tank it serves

The most commonly used medium for anaerobic upflow filter is either crushed stones or gravel with sizes ranging from 1.8 cm to 2.5 cm and void ratio about 0.45. RAMAN and CHAKLADAR (332) reported that the media of stone ranging from 1.25 cm to 1.9 cm is desirable for treating septic tank effluents with a per capita filter capacity ranging from 42.5 1 to 58.0 1. CHIAN and DEWALLE (343) carried out experiment with plastic media and suggested that the void ratio may have some effects on the solid removal efficiency. They also stated that the plastic media is cost effective in industrialized countries but may not be feasible for developing countries.

6.2.5.2 Start Up Procedure of the Anaerobic Upflow Filter

The start up of the anaerobic filter depends on the population of microorganisms. YOUNG and McCARTY (339), who studied the treatment of synthetic organic liquid waste by the anaerobic contact filter, have pointed out that the micro-organisms remained dispersed and a significant fraction washed out with filter effluent, whereas in the highly seeded filter, rapid flocculation was observed, and consequently biological mass remained in the filter. Based on these results, they recommended heavy seeding for rapid start up of anaerobic filters. FOREE and LOVAN 360) reported more than 90% COD removal after 25 days of operation when the filter seeded with anaerobic digester supernatent at the initial loading rate of 0.8 kg COD/cu.m-d.

RAHMAN and CHAKLADAR (332) and RAHMAN and KHAN (335) carried out investigations on septic tank effluent treatment by anaerobic filter, and reported that it takes about three months of continuous operation for the filter to become mature without any seeding where the temperature varies from 25 to 32 Celsius degrees. COULTER et al (393) reported to have obtained 84% TSS removal and 65% BOD removal of pilot scale filter without seeding.

6.2.5.3 Performance of the Anaerobic Upflow Filter

The efficiencies of treatment are reported to decrease with an increase in organic loading for steady-state removal of the soluble BOD, whereas at the same organic loading the percentage COD removal increased when the concentration of the influent COD increased (339). EL-SHAFIE et al. (340) constructed a unit consisting of a group of six filters operating in series. Their study indicated that the percentage removal of organic material is constant regardless of the concentration of organic load applied to anaerobic filters in a continuous flow system; the intensity of biological activity in anaerobic filters appears to decrease exponentially with the retention period. These studies were based on a synthetic wastewater.

KHAN and SIDDIQUI (344) found that the anaerobic upflow filter treatment efficiency decreased with an increase in organic loading or decrease in hydraulic detention time. RAMAN and CHAKLADAR (332, 335) noted that the high efficiency of filter can be maintained even at low influent concentrations of 125 to 150 mg/1 of BOD and with continuous or intermittent flow.

PRETORIUS (338) investigated the feasibility of anaerobic processes for pretreatment of raw sewage. About 90 percent COD reduction of raw sewage was obtained at a residence time of 24 hrs and a temperature of 20 Celsius degrees by using a simple settling system combined with a stone packed upflow filter, and stated that the hydraulic loading rate could be a better parameter for design purposes than the waste concentration. CAUDIL (389) treated settled domestic sewage with a COD of 226 mg/l, using an anaerobic filter having a 1.1 day detention time and a loading of 0.1 kg COD/cu.m-d, (the rate of the organics applied per empty bed volume of the filters is called as organic loading rate), and noted a 60 percent COD removal for the filter or a 76 percent COD removal for the settling and anaerobic filter treatment combined. Using a similar waste, THAULOW (390) noted a 75 percent COD removal and a 90 percent SS removal at a maximum loading rate of 0.18 kg COD/cu.m-d and 0.8 day detention time. ROATS (391) observed a 60 percent removal and a 28 percent SS removal in an anaerobic downflow sand filter treating septic tank effluent. In a full scale 2.5 cu.m anaerobic filter installed following a septic tank and receiving 0.19 kg COD/cu.m-d, HAMILTON (391) observed a 28 percent COD removal.

A study on the treatment efficiencies of two septic tank systems, anaerobic filter and aerobic filter, indicated that the system with an anaerobic filter provided better organic and solid removal than the aerobic filter (143). CHOI (39) conducted a laboratory scale experiment using a two-compartment tank and a submerged filtering unit with a two-day hydraulic retention time at about 20 Celsius degrees for a period of 170 days. The results indicated that the filtering unit showed little BOD removal efficiency and overall efficiency was 60 percent COD, 52 percent BOD and 68 percent SS removal, whereas the solids reduction rate was 0.54 g SS per g BOD removed. RAMAN and KHAN (335) carried out laboratory and field studies on anaerobic upflow filter and found an average removal of 70 to 80 percent BOD and 70 percent suspended solids. WITHEROW et al. (331) attempted to improve the efficiency of the anaerobic filter by increasing the depth of the media. However, experimental results suggested that doubling the depth of the media from 1.22 to 2.43 m (4 to 8 ft) may not result in a corresponding improvement in removal efficiencies.

RAMAN and CHAKLADAR (332) operated an anaerobic filter in India where the temperature variation in a day was 12.5 celsius degree to 26 celsius degree during winter and 25 celsius degree to 36 celsius degree during summer, but found that the treatment efficiencies did not vary appreciably from season to season.

DEWALLE, et al (387) conducted a statistical evaluation of performance data of laboratary scale anaerobic filters treating domestic sewage using septic tanks as control treatment units. This study was aimed at determining statistically the effect of major design and operating variables (such as influent concentration, hydraulic detention time, temperature, sludge seeding, waste type and reactor type etc.) on filter performance. A simplified regression model (using influent BOD, influent SS and hydraulic detention time as predictor variables, as these are the only variables for which sufficient observations were availables) was formulated to predict BOD removal of anaerobic filters and septic tanks treating domestic sewage, as shown below:

$$\%\ \text{BOD Removal} = b + b\ (\ln \text{BOD}\ ) + b\ (\ln \text{SS}\ ) + b\ (\text{time}\ )$$

where BOD and SS are in mg/l, time is in days, and ln represents the natural logarithm. b , b , b and b are the dimensionless coefficients. It was observed that the model predicted higher BOD removals for 4 out of 5 anaerobic filters studies and for 6 of the 10 septic tanks. The model explained more than 90% of the removal variability. The coefficient b , ranging from 4 to 19 was significant at the 5% level for 4 of the 5 filters, while b was not significant and b significant for 2 of the 5 filters indicating that the influent BOD is the primary factor determining the removal efficiency and that the actual effluent concentration is independent of the influent concentration.

6.2.5.4 Application of a Anaerobic Upflow Filter for Denitrification

SEIDEL et al. (337) investigated the feasibility of using an anaerobic filter for the denitrification of a secondary sewage effluent. A 90 percent removal of the inorganic nitrogen was obtained with a 1.5 hr detention time. They also cited several advantages of the anaerobic upflow filter over other methods of denitrification, notably low initial and operating cost, simplicity of operation, and the absence of any sludge recycle or disposal effluent.

6.2.5.5 Cleaning and Maintenance

The anaerobic upflow filter can function continuously for at least 18 months without any need for cleaning. Cleaning of sludge from the filter can be accomplished by emptying the filter through the bottom and pouring water from the top. Scheduling sludge cleaning once or twice a year for septic tanks can keep the filter in operation for long periods (335) and COD removal efficiency would be increased to 20 percent by a yearly cleaning (331).

6.2.5.6 Advantages of an Anaerobic Upflow Filter

The main advantages of an anaerobic upflow filter can be enumerated as follows (336):

(1) Simplicity in construction, operation and maintenance of the filter.

(2) A high degree of waste stabilization: 70 to 80 percent reduction in BOD and SS.

(3) Low production of waste biological sludge.

(4) Low nutrient requirements.

(5) Low capital and operating costs.

(6) Low loss of head in the filter - 10 to 15 cm in normal operation.

(7) Clear, odour- and nuisance-free effluent.

(8) Efficiency is not affected by the intermittent nature of flows.

(9) It can be used as a compact unit along with a septic tank, or as a complete unit by itself.

6.2.5.7 Limitations

(1) Longer periods are required for starting the process than the aerobic treatment.

(2) The filter may get clogged after one to two years of continuous operation, but periodic flushing by water from the top can prolong its life.

6.2.6 Other Alternatives

WEIGAND (318) surveyed six alternative systems, namely the Nodak mound, West Virginia, and Wisconsin mounds, the shallow trench field, dual fields, the evaporation bed and the filter trench, which have been installed in Wood County, West Virginia. The main aim of this survey was to determine the performance and the cause of failure. The data obtained from the survey suggested a more stringent supervision of installation and maintenance practices of septic tank operation and showed a need for greater emphasis on proper site selection. RANDE and RAO (132) conducted pilot plant studies on a percolating filter to treat the effluent from a septic tank. Their results revealed an 80 percent removal of BOD and indicated that the treatment of septic tank effluent from small communities can be achieved economically and efficiently by using percolating filters.

6.2.7 Removal of Nitrogen and Phosphorus from Septic Tank Effluent

For areas where soils cannot effectively remove nitrogen and phosphorus from septic tank effluent, modification of the septic tank system can be made to remove these chemical pollutants (15). The efficiency of such a home unit was recently demonstrated by BRANDES (31) whose system removed up to 99.6 percent of phosphorus from wastewater introduced into the septic tank used for the study. SIKORA et al. (326) demonstrated the effectiveness of an individual home phosphorus removal system, using a vertical plainfield sand column followed by a series of columns filled with calcite or dolomite. The system showed a 99 percent phosphorus removal during the first few months, but it decreased to 12 percent after sixth months of operation.

Trisodium nitrilotriacetate (NTA) is being considered as a partial replacement for phosphate builders in synthetic detergents. KLEIN (107) carried out experiments to establish the survival potential of NTA in ground water, including the removal efficiency of NTA in septic tanks, oxidation ponds, anaerobic digestion, anaerobic (saturated) soil columns, and aerobic and anaerobic percolation fields. The septic tanks showed 21.8 to 23.3 percent removal of NTA during the nine months of operation. The presence of NTA did not have a noticeable effect on the performance of septic tank--subsurface soil absorption fields or sewage treatment systems.

LAAK (179) conducted two laboratory experiments to design a biological denitrification process for a household wastewater system. The results obtained revealed that gray water can serve as an acceptable carbon source for denitrification of black water septic tank effluent, and a nitrifying reactor of concrete sand media can provide a reliable method for the nitrification of black water septic tank effluent. Stones loaded with 0.02 cu m/m/d (1.4 g/ft/d) provided an acceptable anaerobic medium which did not clog (176). Methanol was found to be a suitable energy source for denitrification of nitrified septic tank effluent (117, 103) and nearly complete nitrate removal was obtained after 17 hr at 5 Celsius degrees, 13 hr at 13 Celsius degrees, and less than 2 hr at 20 Celsius degrees (103).

7. DISPOSAL AND MANAGEMENT OF SEPTAGE

A septic tank is designed in such a way that the solids present in the incoming sewage settles in the tank, while the liquid passes into a soil absorption system or an alternative effluent disposal system. The accumulated solids in a septic tank must be removed periodically at a recommended removal frequency, and disposed of or utilized in some manner.

The chemical and bacteriological properties of the sludge and septage depend mainly on the strength of the raw sewage and on the detention time of the sewage in the tank. Longer detention times contribute to better decomposition of organic materials (36), and consequently to lower accumulation of sludge and to smaller average amounts of septage to be pumped out per year.

A mixture of sludge and supernatant pumped from septic tanks is known as septage. Analysis of raw septage samples confirms that this material represents an extremely complex waste (22). The characteristics of septage as reported in the literature are presented in Table 17. In general, septage contains 1.86 to 2 percent solids (124, 125).

COLABRO et al. (108) have investigated the microbiology of septage, and have given details on the methodology for inspection of the biochemical activities and the enumeration of the predominant types present. Levels of nutrients available for microbial flora and the survival of pathogens in septage are reported by COLABRO et al. (108) and KOLEGA (24).

ANDERSON-NICHOLS (120) have proposed five alternatives as a long term solution for septage disposal: (1) Disposal at a wastewater treatment facility, (2) Chemical oxidation ("Purifax"), (3) Composting, (4) Anaerobic/Aerobic treatment, and (5) Land application. GAIN et al. (182) reviewed chemical treatment, aerobic treatment, anaerobic treatment and lime stabilization-sand bed dewatering. The most commonly used methods of septage treatment are shown in Table 18. PHANAPAVADHIKUL (173) evaluated the possible treatment methods of septic tank sludge in Bangkok. Methods included were thickening, lagooning, sand bed drying and wedge wire bed drying, anaerobic digestion and chemical conditioning. The results indicated that sludge thickening followed by sand bed drying treatment were most applicable for dry weather conditions in Bangkok, whereas lagooning and wedge wire bed drying treatments proved to be inefficient. Chemical conditioning was found effective if used before other dewatering processes. ESCRITT (184, 302) and VANKLEECK (274) recommended septic tank sludge disposal to lagoons and then to land for use as fertilizer, or directly to ploughed land or trenches. TEAL (304) suggested septage discharge to city sewers or burial at least 91.44 m (300 ft.) from any residence, office or drinking water well. The Joint Committee on Rural Sanitation recognized that sludge may contain pathogenic intestinal organisms and recommended disposal by burial (303). FLOOD (185) stated that digested sewage solids removed from septic tanks should only be disposed of where there is no resultant danger to public health. Sludge disposal through manholes into the nearest municipal sewerage system can be undertaken if approved by local authorities.

JEWELL et al. (22) presented guidelines to achieve a high degree of control of odor, foam, BOD, VSS and solids concentrations (Table

Table 17: **Septage Characteristics as Reported in the Literature (187, (45, 212, 9)**
(All Units in mg/l except pH)

Septage Characteristics*	Minimum	Maximum
Total Solids	6,380	130,000
Total Fixed Solids	1,880	59,100
Total Volatile Solids	4,500	71,400
Total Suspended Solids	5,200	93,400
Fixed Suspended Solids	1,600	9,000
Volatile Suspended Solids	3,600	30,000
Biochemical Oxygen Demand	3,780	12,400
Chemical Oxygen Demand	24,700	62,500
Total Kjeldahl Nitrogen	320	1,900
Ammonia Nitrogen	40	150
Nitrite Nitrogen	0.2	1.3
Nitrate Nitrogen	0.87	9.0
Organic Nitrogen	26	26
Total Phosphorus	20	310
Orthophosphate	10	170
Chromium	1	1
Alkalinity	1,020	1,020
Iron	163	200
Manganese	5.0	5.4
Zinc	50	62
Cadmium	0.2	0.2
Nickel	1.0	1.0
Mercury	0.022	0.1
Hexane Extractables	9,561	9,561
Copper	8.5	8.5
pH	4.2	9.0
Aluminum	50	—
TOC	15,000	—
Grease	9,600	—
LAS	150	—
Lead	2	—

* Minimum and maximum values are presented to show that septage characteristics vary substantially.

Table 18: Septage Treatment Methods (187)

Treatment System	Design Criteria and Advantages	Disadvantages	References
1. Chemical Treatment	- Lime is surplus and very economical. - Mostly pathogenic organisms are killed because of high pH due to lime addition. - Heavy metals removed and water volume reduced by utilization of sand beds.	Solids quantity increased by volume of lime used by process. This increases handling and disposal problems. Some pathogenic organisms may be alive even at high pH. Requires approximately 170 lb. of lime per ton of dry solids. pH has to be adjusted prior to discharge. Needs further treatment.	(201, 209, 203, 211, 212)
2. Anaerobic/Aerobic Treatment	Low operation and maintenance costs. Capable of absorbing shock loadings. Good settleability as obtained after 30 to 70 days of aeration. Anaerobic digestion. Requires 15 days detention time.	Toxic metals can inhibit anaerobic digestion. Poor nitrate removal. Lack of proven design criteria. Required further sludge disposal.	(203, 204)
3. Chemical Oxidation (Purifax)	Sludge dewaters to 30 % in approximately 1 to 3 days on sand drying beds. Approximately 96 % removal of COD, BOD, P, Fe, and 83 % removal of nitrogen can be obtained.	High chemical and lower costs. Large capital investment. Required pH adjustment prior to discharge. Uses chlorine gas which is hazardous to use and handle.	(202, 205, 206)
4. Sand Drying Beds	Requires low construction costs.	Requires a remote site possibility of ground water contamination. Cloggs easily and difficult to-maintain. Requires further disposal.	(203)
5. Composting	Low capital, operation and maintenance cost. No chemical addition necessary for treatment. Pathogenic organisms are killed.	Requires power for aeration prior to composting. Requires a carbon such as sawdust or wood chips. Pathogen kill may not be complete through out entire bed. May require some initial dewatering.	(207, 214, 213)
6. Land Application	Limiting criteria is 300 lb. of nitrogen per acre per year. Low energy use. No chemical addition and no sludge handling are required.	Nitrogen loading is limiting criteria for site requirements. Soil must be well drained and permeable. Edible crops cannot be grown. Public concerns of transmission of diseases, odor and groundwater contamination.	

Table 19: Recommended Guidelines for Septage Treatment (22).

Parameter	Degree of Control	Recommended Treatment
Odor	Complete elimination	1 to 2 days of aeration
Foam	Complete elimination	Foam fractionation
Soluble BOD_5	Less than 20 mg/l	20 days of aeration
VSS	40 percent reduction	More than 30 days of aeration
Solids Concentration	20 percent cake solids	Addition of 2 - 4 percent (by dry solid weight) $FeCl_3$ or alum, and 3 days of sand bed

19). CHUANG (139) reported 99 percent reduction of BOD, COD and suspended solids when septage was retained for 15 days in an anaerobic digester heated to 32 Celsius degrees. The supernatant liquor was aerated for 40 days at ambient temperature and then passed through a sand bed.

Land application is practiced legally in the USA and guidelines have been developed (121). A pilot study (27) demonstrated that soil injection of septage can be a feasible disposal method although further investigations are required both in terms of an increase in the rate of septage application and long-term effects on ground water quality from continued application of septage to a given plot of land. Additional information should also be obtained on the effects on crop responses of land on which septage has been applied. The Rehoboth pilot project (46) successfully demonstrated that septage composting can be a viable and economically attractive process for septage disposal.

CASELL et al. (61) presented an overview of septage management in Vermont, including an inventory of disposal patterns and an evaluation of the extent of management problems. This report included a literature review of septage characteristics and reviewed the legal constraints to septage management. In a second series of septage management reports from Vermont, BARLOW and CASSELL (62) reviewed and discussed alternative septage treatment and disposal technology. A detailed cost analysis for several case histories was also included. The legal and institutional alternatives for septage management were reviewed by LAPPING and MEYERS (63) in the third volume of this series. The authors presented alternatives for institutional arrangements for septage handling in Vermont. CASSELL et al. (64) presented in the urban and rural areas of Vermont.

8. POLLUTANT REMOVAL EFFICIENCIES OF SOIL MATERIALS

The main objective of liquid waste disposal for individual homes in unsewered areas is to purify the liquid before it reaches potable or recreational waters. Organic matter, chemicals, pathogenic bacteria and viruses that are not removed prior to application to the soil must be removed by the soil material. Many field and laboratory studies have examined the efficiency of the soil for pathogen removal and the various factors that affect its efficiency. Factors which are important in removal of pathogens by soil include soil type, temperature, pH, bacteria absorption to the soil and soil clogging materials, soil moisture, nutrient content and bacterial antagonism (242). ZIEBELL et al. (99) and McCOY et al. (242) reported removal of fecal coliforms and fecal streptococci from septic tank effluent by two columns packed with 0.6 m (2 ft) of plain field loamy sand. Faecal streptococci and Pseudomonas aeroginosa were not detected in effluent from the more lightly loaded column (242). Septic tank effluent innoculated with more than five plaque forming units (PFU) per liter of polivirus type I was applied to a 0.6 m (2 ft) column of medium sand. All viruses were effectively removed at a loading rate of 5 cm/day over a period of more than one year (92). Similar results of virus removal have been reported (244, 245). At a loading rate of 50 cm/day, virus breakthrough occured, whereas 61 percent of the influent virus was removed when sand columns 2-4 cm deep were ponded. However, 96 percent virus removal was achieved when the same volume of waste was applied dropwise (92).

Bacterial removal varies according to the nature of the soil, the amount of organic matter present and the depth below the surface. Bacterial activity decreases with depth until 1.2 m (4 ft), and complete sterlization occurs at 3 to 3.6 m (159). ZIEBEL et al. (243), in their studies on the fecal and total coliform removal ability of an absorption field in sandy soil, have shown that the concentration of bacteria decrease from 10,000 per 100 g of soil at the base of a leaching bed trench to less than 200 per 100 g of soil at a distance of 30 cm below the base. TAYLER et al. (111) reviewed the literature regarding the fate of bacteria, viruses, nutrients, and heavy metals in soils below septic tank soil absorption systems. They concluded that unsaturated soil can achieve nearly complete removal of most pollutants. BROWN et al. (54) reported that except for nitrates, all the pollutants were removed within 1.2 m below the trench. Lateral movement was slight. BROWN et al. (37), based on lysimetric studies, reported that 120 cm of any soil tested appeared to be sufficient to minimize the possibility of ground water pollution by fecal coliforms and coliphages from septic tank effluent disposal. DREWRY and ROLE (313) reported that viruses are trapped near the surface of silty and clayey soils.

High reductions of COD, BOD, soluble carbon and ammonia have been reported in septic tile systems (47, 288, 289, 290, 101). BRINK (123) observed 99 percent reduction in phosphate, whereas VIRARAGHAVAN and WARNOCK (47) obtained 25 to 50 percent reduction in phosphate. The absorption of pollutants by soil depends on temperature. Physical absorption increases with a decrease in temperature (291, 123) and this fact is true especially in the case of phosphates (292). However, it has been reported that normal temperature variations generally have minor effects on the absorption process in water and wastewater treatment (291). Seasonal variations influence the efficiency of the septic tile system. High soil temperature and air may enhance the efficiency of the system (47, 35).

The regoliths of soil have an important influence on the migration of septic tank effluent. Minor variations in regolith, the absorptive capacity and the texture, the local hydrology, and possibly the soil microbiology cause complex patterns of waste migration (165). The soil life expectancy as a contaminant treatment medium can be determined by analysing data of soil absorption constituents and textural variability (165).

9. ENVIRONMENTAL EFFECTS OF SEPTIC TANK SYSTEMS

The U.S. Geological Survey (17) investigated the effects of septic tank effluent on the quality of the water. Results indicated that except at one site, no fecal coliforms were found below a depth of 3 m (10 ft). Total coliforms exceeded a count of one colony per ml at a depth of 18.3 m (60 ft) at two sites. Fecal streptococci counts of 7 and 53 colonies per ml were found at a depth of 12.2 and 18.3 m, respectively. Bacteria concentrations were higher where the septic tanks were more concentrated.

PEAVY (56) and PEAVY and GROVES (58) investigated the effects of septic tank absorption systems on the ground water below two existing drain fields located in sandy soils 1.2 m above the water table. Well samples were analyzed for alkalinity, chloride, chemical oxygen demand, phosphates, nitrates, and fecal coliforms. Only nitrates were found to reach significant quantities. MILLER et al. (266) have discussed many severe cases in the Great Lakes region of the Midwest. Effluents that are not sufficiently purified during soil percolation may give rise to bacterial and chemical pollution of ground water, which can create health hazards or eutrophication problems (217, 218, 219, 220, 225). This problem is mostly encountered when septic tanks are constructed in sandy soils where the biochemical and physical purification process of filtration, sorption and oxidation are insufficient (221, 89, 222).

9.1 Chemical Pollution of Ground Water

High absorptive capacity does not necessarily correlate with the capacity of soils to remove pollutants from infiltrating wastewater. Many soils of high permeability can be rapidly overloaded with organic and inorganic chemicals and microorganisms, permitting pollution to spread rapidly through the ground water, which would result in a potential contamination of the water supply. This problem is common in many areas using septic systems (374). The potential for chemical pollution of ground water contamination has been discussed by WALKER (312). He cites selected case histories involving movement of chemical pollutants into ground waters. In each case, the pollutant readily entered the ground water through substrata, creviced limestone or dolomite aquifiers. The particular danger of transport in areas of fractured limestone strata has been pointed out by several researchers (278, 100, 218).

Certain chemical species released from septic tanks exhibit greater mobility through the soil, due to the nature of chemical, biochemical and physico-chemical reactions in the soil. MILLER et al. (266) have reported distances of travel of several chemical substances transported in ground water. CALDWELL (227) found that chemical pollutants from latrines travel 12 m (35 ft) through the soil within 9 days. Pollutants normally travel in the direction of ground water flow (271). The extent of chemical pollution of ground water varies with the time of year, because of changes in the course and movement of the ground water (272).

9.2 Nitrogen Contamination of Ground and Surface Waters

Nitrogen principally occurs in organic and ammoniacal forms in sewage and in septic tank effluent. These forms are converted to nitrate through biological action under aerobic conditions. Nitrogen, in the form of nitrate or nitrite, cause methemoglobinemia in infants. A safety limit for nitrate of 10mg/l as nitrogen is recommended by the

U.S. Public Health Service (274). There are many reports of nitrate concentrations above 10mg/l N limit that often occur in wells near septic tank systems (247, 248, 104, 224). The contribution of 5.4 kg (12 lb) nitrogen per person per year to lake water from septic tank fields adjacent to lakes has been reported (273). Concern has been expressed for potential nitrate pollution from home waste disposal systems, especially in areas having a high residence density, as a result of ground water contamination (213, 83). The correlation between nitrogen and phosphorus build up in ground or surface water and septic tank location has been studied (104, 105). STARR and SAWHNEY (164) reported ground water contamination due to nitrate as a result of nitrification of ammoniacal nitrogen in a septic system drainfield. Similarly soil disposal systems of septic tank effluent in sand were found to add significant quantities of nitrate formed by nitrification of ammoniacal nitrogen. The data obtained suggest that in sand the only active mechanism for lowering the nitrate content is by dilution with uncontaminated ground water (224). Ammoniacal nitrogen concentration above the plinthic horizon decreased with the increased distance from the drainfield in the direction of ground water flow, although the same pattern was not observed with nitrite and nitrate concentrations (108).

9.3 Phosphorus Contamination of Ground and Surface Waters

Phosphate is a common component of domestic waste, and currently considered to be a major cause of eutrophication. Phosphorus enrichments of ground waters seldom occur below septic tank systems because phosphorus is readily fixed in soil by sorption reactions, or as phosphate precipitates of calcium, aluminum or iron. The phosphorus leakage to the ground water may be expected where high water tables exist, very coarse sand and gravel occur, or where the seepage bed has been loaded heavily for a long period of time. In such instances, higher concentrations of phosphate have been reported (104, 110). JONES and LEE (167) presented a literature review of phosphorus migration in soils and ground water as a result of the release of septic tank effluents, based on the results of monitoring the ground water adjacent to a septic tank waste water disposal system in Wisconsin. The authors conclude that the likelihood of phosphorus transport to surface waters from septic tank effluent is, in general, slight.

Phosphorus has been observed to move downward 50-100 cm per year through clean silica sand and 5-10 cm per year in loams, silt loams and clays (249). The movement of phosphorus from the absorption trench can occur in both downward and horizontal directions (34). However, a logarithmical decrease of phosphorous with distance has also been observed (320).

9.4 Biological Contamination

Numerous investigators have demonstrated the movement of coliform bacteria and their contamination effects in well or ground water (226, 227, 228, 229, 230). Movements over long distances by fecal coliforms in saturated soils at rates up to 15 m per hr. have been observed (252, 253). Flow through the micropores of the soil is believed to be the reason for the movement. Table 20 indicates extremely long distances of transport through the subsurface soil (115). RENEAU (57) observed the movement of coliform bacteria from 11.6 to 19.2 m at depths of 0.95 to 1.23 m. Studies on the movement of coliform bacteria through soils demonstrated that variations in the distance travelled by coliform bacteria were related to soil properties and hydrological

Table 20: Distance of Travel of Fecal Micro-organisms (115)

Type of Organism	Distance Transported, m.		References
	Vertical	Horizontal	
E. coli	3.04 - 9.14	70.71	(271)
" "			(305)
" "		24.38	(227)
" "		121.92	(306)
"Lactose Fermenters"	0.76	0.61	(309)
Coliform bacteria	0.61 - 0.91	3.048 - 121.92	(266)
" "			(310)
" "		54.86	(311)
" "	45.72		(75)
Clostridium welchii	2.13 - 2.43		(75)
"Bacteria"		609.6	(312)

variables (228, 110, 294, 226, 57, 113). RENEAU and PETTRY (110) have shown that indicator bacteria do not move into the impermeable subsoil but move laterally over a slowly permeable subsoil as far as 13.5 cm from the point of introduction.

Field studies conducted by MACK et al. (315) and WELLING et al. (314) indicated both vertical and lateral movement of type II poliovirus and, in the latter case, coxsackie B4 virus travelled as far as 30 cm from the point of surface wastewater application. CALDWELL and PARR (227) reported that bacterial pollutants travelled less than 1.2m per day in soils of low permeability and more than 3.0 m per day in highly permeable soils. STILES and CROHUST (228) observed that during periods of 2 years and a half, viable bacteria from flooded trenches travelled 71m in permeable soils in the direction of ground water. Bacteria introduced to absorption fields traveled 30 m in 2 days and 6.1 m and 9.1 m in 3 and 10 days, respectively (226). More extensive information on bacterial movement through natural soil systems is available in the literature (294). Data from many experiments conducted in the U.S.A indicate the presence of virus in the effluents from soil and sand columns receiving septic tank effluents. However, with a long absorption distance, such as filtration through 61 m (200 ft) of 2.4-3.6 m (8-12 ft) layer of sand gravel, no virus was detected in the effluents (155). The survival of bacteria in the septic tank and subsurface soil absorption system depends on the detention time and the soil characteristics. Table 21 summarizes the available data on time of survival of fecal bacteria in the septic tank and soil absorption field.

The removal of microorganisms in their travel through unsaturated soil and through the ground water depends on many factors, notably the slope, direction, and level of the ground water and the soil permeability. VIRARAGHAVAN (49) observed a declining trend of indicator organisms in relation to the distance away from the septic tile in the direction of ground water flow. RENEAU et al. (48) reported large reductions in total and fecal coliform bacteria in the perched ground water above the restricting layers as the distance from the drainfield increased. They also indicated that these restricting soil layers are effective barriers to the vertical movement of indicator organisms. Similarly, a decrease in the total and fecal coliform counts in subsurface samples has been reported as a function of the distance from the source of pollution (181).

Table 21: Time of Survival of Fecal Bacteria (115)

Types of Organisms	Survival			References
	Septic Tank	Soil	Other	
Salmonella typhosa			165	(271)
" "	27 days	25 - 41 days		(307)
" "	24 days			(308)
E. coli			2yr. 8months	(271)
"		2yr.		(305)
Coliform bacteria		3 months		(310)

10. RESEARCH NEEDS

MACKENZIE (368) pointed out the need for basic studies on the factors involved in the proper design and satisfactory operation of septic tanks, and stated that this had received comparatively little attention. LUDWIG and LUDWIG (297) stated that the percolation and absorptive capacity of the soil is the single most important aspect of proper septic tank operation, yet there is no really reliable way to determine this capacity. Most soils will rapidly lose up to 20 percent of their absorptive capacity as measured by routine percolation tests. The standard percolation test, which measures the rate at which effluents may be applied, is far from reliable (367). McGAUHEY and WINNEBERGER (67), in their comprehensive study on the failure of septic systems, agree that there is a lack of a good predictive test for soil absorption capacity. The most publicised recommendations for research on septic systems are as follows:

(1) Research on the design and operation of septic tanks (115).

(2) Research to design septic tanks that encourage quiescent settling (321).

(3) Research on sludge disposal from septic systems and cleaning frequency (174).

(4) Research on the quantity and environmental consequences of chemicals and micro-organisms released from septic systems (115, 174).

(5) The development of new, more effective sewage disposal systems to replace septic tanks in rural and fringe urban areas (115, 174). LEE (265) has pointed out that, particularly in unsewered rural and fringe urban areas, the septic tank is often a needless and extravagent method of sewage disposal, which may be both a nuisance and a hazard to public health.

(6) Research on the basic causes of failure of soil absorption systems (269).

(7) Research on the improvement of present-day individual household septic system practices (77).

Independent research findings have shown contrary and controversial design and operation parameters leaving significant doubts about the best septic system. The following is a list of conflicting findings by independent researchers (170).

1. (a) One compartment tank is better than a multicompartment tank system.
   (b) Multicompartment tanks appear better than a single compartment tank.

2. (a) Ferrous sulfide (under anaerobic conditions only) is a major clogging component.
   (b) Ferrous sulfide is present under anaerobic conditions, but is an insignificant clogging component.

3. (a) Soil clogging is an irreversible phenomenon; ie., the soil interface clogs, and the life of the septic system can be predicted using failure rate curves. Other studies have been made to show failure rates and half life.
   (b) Failure rate studies have not proven that absorption fields have a finite life caused by creeping failure. Initially progressive clogging occurs until a long term acceptance rate or equilibrium rate is reached. In this state, clogging and unclogging occur with acceptance rates fluctuating by several magnitudes.

4. (a) Infiltrative rates of soil interfaces can be restored by resting.
   (b) Resting and dosing and/or equal distribution enhance total infiltration capacity. In the long run, the total infiltrated volume of liquid is greater under continuous loading conditions as opposed to dosing patterns with up to 3-day rest periods.

5. (a) Treatment through soil is improved as the clogging mat or biocrust matures.
   (b) Aerobic conditions are essential for proper field operation. Resting and dosing is contrary to achieving the best treatment, and anaerobic conditions do not constitute an inefficient field operation. Equal distribution is not essential, and serial distribution provides a continuous mature clogging mat.

6. (a) The percolation test is at present the legal test applicable to size absorption systems. The percolation test is unreliable. The Gypsum Crust tests performed in situ for developing K-curves (permeability of unsaturated flow) and measuring the range of soil moisture tensions under mature and operating absorption field clogged zones are considered to be the relevant design method for absorption fields.
   (b) The maximum absorptive rate at which soil can carry water depends on the saturated permeability. The design of absorption fields involves the evaluation of the site for maximum capacity to drain additional water, coupled with the orientation and length of the irrigation or absorption field. The second evaluation involves the clogging mat or biocrust which controls the required infiltration soil surface area. The third evaluation involves the required soil treatment.

7. (a) The infiltrative soil surface is the bottom area for shallow systems, and the sidewalls for pits.
   (b) Sidewalls are the significant infiltrative surfaces. Infiltrative surfaces can be at any angle, the infiltration rate being dependent on the clogging mat and the hydraulic gradient.

8. (a) Aerobic effluent, as compared with anaerobic effluent of equal concentrations of 5-day BOD and TSS, does not effect infiltration capacity. The degree of pretreatment, aerobic versus septic tank effluent, does not affect the infiltrative capacity.
   (b) Pretreatment affects infiltration, and very low substrate of effluent loads maintain high infiltration rates.

If the public health and the environment is to be protected in unsewered areas, there is clearly a need to understand how a septic tank system works, why it fails and what alternative systems might be employed.

ACKNOWLEDGEMENTS

The authors wish to thank Dr J. Valls and Mr D.M. Tam for their assistance during the preparation of the manuscript. Thanks are also due to Ms Sunee Siriwiphanan who meticulously prepared the typescript.

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