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SEPTIC SYSTEM FAILURE CAUSES

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Causes and Remedy of Failure of
Septic Tank Seepage Systems¹

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1. Introduction

Large numbers of people throughout the United States live continually in rural or suburban areas which are not served by communal sewage collection and treatment systems and must therefore rely upon on-site private systems for purification and disposal of their household wastewaters. In addition, many citizens own second homes in remote scenic or recreational areas and also depend upon private means of sewage disposal during the intermittent periods of use of their recreational homes. Many public or community facilities in recreational areas, such as campgrounds, motels, restaurants, and bars also receive heavy seasonal use and must dispose of large volumes of wastes by on-site treatment.

The commonest method of wastewater disposal currently makes use of septic systems, involving collection and septic treatment (anaerobic bacterial digestion) of all wastes in a large baffled tank and purifying disposal of the clarified water flowing from the tank by percolation through soil. Usually, before a permit for installation of such a system is issued by public health authorities, determinations are made on the basis of water percolation tests whether the soil in each particular location is suitable for accepting and purifying septic tank effluent at an adequate rate. Depending on the outcome of the percolation tests and the projected loading of the system, requirements are set for the capacity of the tank and the size (area) of the soil seepage bed through which the tank effluent will percolate before the purified water returns to the groundwater aquifer. Theoretically, on the basis of these requirements each system should function properly for indefinite periods.

Unfortunately this ideal situation is rarely encountered in practice. Regardless of the initial porosity of the soil, many septic systems fail

after a few years of use. Failure may be evidenced by surfacing of unpurified effluents, causing nuisance stenches and public health hazards. Alternatively, subsurface ponding of water in the seepage bed may cause the tank to overflow, resulting in sluggishness or stoppage of the drains in the buildings being serviced by the septic facility. Water then backs up in toilets and sinks in the buildings.

The reason for system failure is the gradual formation underground of an impermeable clogged or crusted layer in the soil below and surrounding the seepage bed. Flow of water through this clogged or crusted zone is severely restricted or even eliminated, although the permeability of the surrounding soil remains essentially unchanged. Consequently, huge volumes of stagnant septic tank effluent accumulate in the seepage bed.

2. Mechanisms of Formation of Soil Crusts

Several physical, chemical and biological phenomena occur in progression or jointly to produce zones of gradually decreasing permeability in soils inundated by septic tank effluent. These processes are largely independent of the composition or constitution or texture of the soil at the system site, the design or layout of the seepage bed, or the nature of the materials and techniques used in its construction. As a result, even the most carefully constructed systems installed in soils of optimum permeability are subject to failure through clogging or crusting. Some of the mechanisms involved in soil clogging by septic tank effluent are described in the following paragraphs.

Every soil is composed of myriads of particles of varying shapes and sizes. Since these particles cannot fit together perfectly to form a solid mass, each soil is replete with labyrinthic series of inter-

joining pores or capillaries, which are normally filled to varying proportions with air or water, depending upon the moisture content of the soil. Because these capillaries or pores are interconnected, moisture, e.g., from rainfall, can soak through them under gravity and slowly pass from higher to lower layers (horizons) in the soil and eventually into the groundwater. Soils composed mainly of large particles (sands) have larger capillaries and conduct water faster, i.e., water soaks or percolates through sandy soils at higher rates. As soil particle sizes decrease, the sizes of the capillaries also decrease, and although the number of capillaries increases, water soaks or percolates much slower through finer grained soils (rates decrease in the series coarse sand > fine sand > sandy loam > silt > silty clay > clay).

When large amounts of pure water are allowed to pass through soils composed of particles of different sizes, the rate of percolation is found to gradually decrease. The reason for this is that the flow of water causes smaller particles to become dislodged and to be swept into some of the larger capillaries, where they become stuck in constrictions, effectively blocking the capillaries.

This phenomenon causes deterioration of the physical structure of the soil; when referred to surface soil it is given the name "puddling." Compression of puddled soils can cause "smearing," i.e., more effective blockage of the soil capillaries under compression forces. Smearing can occur during construction of septic systems, if heavy machinery is run over wet soils. This compression effect can compound the reduction in flow caused by puddling as soon as septic tank effluent is admitted to the bed.

Puddling is not the only phenomenon initiating blockage of the soil capillaries. Although most of the solids present in household wastewaters (usually about 400 ppm) settle out as a sludge at the bottom of the septic tank, and the bulk of fats and grease separates as a floating scum at the top of the tank, the water leaking out at an intermediate height from the tank into the distribution system leading to the bed is not completely free from suspended insoluble solids. Residues of vegetable matter and fibers from toilet tissue and the like form highly swollen gel-like particles not much different in density from water. Such particles do not therefore settle out rapidly and some flow over with the effluent into the seepage bed. Normal septic tank effluent usually contains about 140-150 ppm of suspended solids. The capillaries in the soil of the seepage bed filter out these suspended particles very effectively, but the pores of the filter become stopped up by them, reducing the rate of percolation further.

Effluent from the tank also contains large numbers of bacteria, as many as 12,000 per milliliter. The bacterial cells also behave like small particles. They are filtered out of the percolating effluent by the soil capillaries, causing further blockage of the soil pores.

These bacteria and the natural soil bacteria present in the bed are provided with a constant supply of dissolved inorganic and organic nutrients contained in the effluent flowing into the bed. In consequence, all these bacteria multiply very rapidly in the soil, and the resulting microbial biomass creates further barriers to seepage of water through the soil capillaries.

Although these phenomena cause a detrimental reduction in the rate of flow of water through the soil, on the other hand they produce a beneficial increase in the wastewater purification capability of the

soil: the tighter filter is more efficient at removing suspended solids, and the large bacterial biomass is more efficient at degrading organic wastes in the septic tank effluent.

Septic tank effluent does not enter the bed in an equable continuous stream but rather in a haphazard way, reflecting the pattern of water use in the building being serviced. As long as the percolation rate in the soil remains high enough, so that water that has spilled over into the bed has completely soaked away before more water flows over, air also enters the bed intermittently.

As long as air continues to be drawn into the bed as water soaks away, a mixed population of aerobic microorganisms remains in the bed to effect biodegradation of the soluble and insoluble organics transported into the bed with the septic tank effluent.

However, as more and more soil capillaries become plugged, the rate at which the water seeps away becomes slower and slower, so that less and less air gets drawn into the bed. Under these conditions, aerobic fermentation in the bed is gradually replaced by anaerobic fermentation.

During microbial fermentations, microorganisms digest organic materials, using part of them for maintenance energy and part for forming their cellular mass. In order to break down and utilize organic compounds, microorganisms must have other compounds available to be used as electron acceptors. The oxygen present in air is the normal terminal electron acceptor used by all aerobic organisms in this process. The oxygen is reduced to water and used to produce CO_2 from some organic compounds. If no air is available, microorganisms that can live in the absence of air (anaerobic bacteria) will use other inorganic (e.g.,

nitrate or sulfate) or organic compounds as electron acceptors. Reduction products associated with organic matter conversion under anaerobic conditions include nitrogen (from nitrate), sulfide (from sulfate), and methane (from organics), each again being accompanied by CO_2 produced from organic matter decomposition.

In seepage beds, when air is no longer drawn into the soil, the range of electron acceptors available to microorganisms in the bed becomes very restricted. There is no dissolved oxygen in the septic tank effluent since any air in the water has been used up in fermentations in the tank. There is no nitrate either since there are normally no nitrates in household wastewaters. Most of the simple readily biodegradable organic compounds have also been converted in the tank, so that these too are no longer available as electron acceptors. Only minor amounts of methane are produced in ponded effluents. The only significant electron acceptor available in ponded beds is sulfate (4-10 ppm). This is rapidly reduced to sulfide. Even though septic tank effluent is highly alkaline (pH = 7.5 - 8.0), owing to free ammonia in the water, free hydrogen sulfide becomes detectable in beds that have been constantly ponded for a few months.

Sulfides are toxic to most microorganisms. Only sulfur bacteria, which can reduce sulfides further to elemental sulfur, can survive in the presence of high sulfide concentrations. The presence of free sulfide in stagnant beds may therefore kill off many of the bacteria which would otherwise be degrading organics in the bed. Some of the free sulfide may be converted to insoluble sulfur, causing further blockage of soil pores. However, very little of the sulfide produced in the bed remains in the free state. The bulk of it combines with ions of heavy or transition metals (e.g., iron, manganese, nickel, copper, magnesium, zinc, etc.) present in the soil or in the wastewater (~5 ppm total metal cations in

septic tank effluent). This causes deposition of black insoluble inorganic sulfides in the beds. The beds of failed septic systems invariably have intensely black impervious layers underneath and around the gravel. The gravel itself is generally coated with black slime. This is not surprising since incoming tank effluent already contains 2-5 ppm of sulfide.

The insoluble sulfides contribute to further blockage of the soil capillaries, but this may not be their most deleterious effect. Many elements tied up in insoluble form as sulfides are required by microorganisms for their redox enzymes, the organic catalysts needed for respiratory functions, including degradation of organic matter. Binding of trace elements by sulfides may therefore inhibit organisms otherwise capable of destroying organic materials in the seepage bed.

One last contributor of clogging substances is the anaerobic bacteria themselves. Many microorganisms, especially anaerobic bacteria, produces polysaccharide slimes or gums, which they secrete into their surroundings. These seem to function as a protective sheath around the bacterial cell wall. When formed in situ in the seepage bed, such polysaccharides help to form an impermeable layer in the bacterial zone. Organic matter obtained from clogged layers of ponded beds contains about 5% polysaccharides, some of which may be from bacterial slimes or gums of this type.

3. Appearance of the Clogged Zone.

A combination of physical deterioration in soil structure, soil pore blockage by solids and bacteria from the effluent, proliferation of heterotrophic soil bacteria, and deposition of insoluble sulfides and bacterial slimes, gums, and other metabolites (e.g. sulfur) produces a zone of clogging in the soil which will not allow water to seep away at a tolerable rate. Measurement of the distribution of organic matter through typical clogged layers reveals that the bulk of this material

occurs in the soil immediately next to the gravel. The amount decreases abruptly with distance outward or downward from the gravel. A similar distribution is found in the amounts of sulfides in the soil.

Where this type of zone occurs in a coarse textured soil, when the flow of water diminishes, air begins to penetrate into the soil beneath the clogged areas, restoring aerobic conditions. The minor amounts of organic matter present under the zone of maximum clogging are then apparently oxidized and degraded rapidly, so that the soil in this region reassumes an almost natural appearance. A relatively sharp boundary then results between this aerobic layer and the heavily blocked, black anaerobic layer. The dense anaerobic layer becomes very hard and brittle, assuming the character of a crust in the soil. Occasionally a narrow grey intermediate zone is observed underneath the black crust. This crust is very strong, since it is capable of retaining thousands of gallons of stagnant water ponded above it in the bed under several feet of hydrostatic head. The soil above the crust is thus permanently saturated with moisture, but that below the crust is unsaturated, generally having about the same moisture content as similar soils at the same depth in areas quite far removed from the bed.

4. Reagents for Oxidation of Sulfides

Since the sulfides formed under anaerobic conditions in seepage beds play such a cardinal role in the formation and maintenance of the crust, it is imperative that they be removed to restore percolation to the bed. Sulfides are very readily oxidized by a variety of soluble oxidizing agents, but many of these are not very attractive for reasons of cost or the disturbing effect they would have on the bed microbiome.

For example, although sulfides can be oxidized inexpensively by chlorine or oxychlorides (e.g. hypochlorites), these reagents would cause sterilization of the bed, destroying the microorganisms needed to subsequently decompose the organics in the clogged/crusted zones. Moreover, chlorinating reagents would also produce toxic chloramines from the ammonia and amino compounds present in the bed and stagnant water. It would be inadmissible to risk inputs of these carcinogenic compounds into the groundwater. Other conventional oxidants, such as permanganate or dichromate, are too expensive and act only under acidic conditions. The reagent of choice is therefore hydrogen peroxide: this inexpensive oxidant rapidly converts sulfide to sulfate at neutral or slightly alkaline pH over a wide range of concentration without creating any noxious byproducts. Excess reagent is destroyed by natural processes in the soil, actually with beneficial effects in reducing soil clogging (see below).

5. Laboratory Studies with Soil Columns

In order to test the efficacy of hydrogen peroxide in restoring permeability to soils clogged or crusted by the above mechanisms, preliminary experiments were performed in the laboratory using soil columns. Four-inch diameter plastic columns (e.g. polyvinyl chloride drain pipe or plexiglass tubing) were fitted at the bottom end with caps, nipples, and stopcocks and with removable nipped covers at the top. Glass wool was filled into the lower nipple to prevent soil from washing through and the columns were filled with 25-30 inches of sand, which was then covered with a glass wool mat or a layer of 3/4 inch diameter gravel. These columns thus simulated a cross-section through

a highly porous sandy soil such as would be ideal for installation of a conventional septic system seepage bed or for the fill of a mound type septic system. Septic tank effluent from a conventional system was intercepted before passing into the seepage bed and brought to the laboratory in 5 gallon plastic canisters, which were stored in a cold room at 5°C. Doses of about 1.7 gallons of effluent were added daily to each column to simulate the normal influx of septic tank effluent into a seepage bed. Each column was kept ponded by closing the stopcock before the last liquid could drain away, to expedite clogging of the column by immediate creation of an anaerobic condition. Within short periods, the gravel and soil in every column became very black and heavily crusted/clogged layers developed in the sand immediately underneath the gravel. Various parameters were studied in several columns, including subcrust soil moisture tensions, redox potentials, (Eh), the volume and nature of gases released, the sulfate and sulfide concentrations, the concentrations of dissolved trace metals, and the BOD and COD of the influent and effluent waters. In time, the rate of flow of water through each column slackened and finally fell off to almost zero, or ceased altogether, even with the stopcocks open and a high hydrostatic head on the top of the column. The clogged/crusted zones were thus effectively sealing the soil on such columns. When holes were drilled in the side walls of sealed columns to admit air below the upper crust, the sand in the lower sections gradually lightened in color, but water still did not flow through the column. The heavy band of black slimy material forming a crust just underneath the gravel was not oxidized and still retained stagnant water above it.

The brightening of the sand in the lower parts of the column on admission of air is not due to chemical oxidation of sulfides, as has been surmised (1). Instead, it is again a biological phenomenon.

It is well known that obligate anaerobes (bacteria that can live only in the absence of oxygen) are killed in the presence of air. The reason for this behavior is that these microorganisms lack a recently discovered enzyme called superoxide dismutase, which is required for one step in the reduction of oxygen in respiratory processes (2).

When a microorganism uses molecular oxygen from air as an electron acceptor, it first causes the oxygen diradical to react with a proton and one electron, producing the superoxide anion radical O_2^-



In the next step of respiration, the superoxide anion radical is reduced further by another proton and one more electron, creating the hydroperoxide ion



This is the reaction catalyzed by superoxide dismutase (2). Since obligate anaerobes cannot perform this second step, they are poisoned by the accumulation of their own respiratory metabolite, viz. the superoxide anion radical.

This material is a very strong oxidizing agent, and therefore inadvertently oxidizes inorganic sulfides in the vicinity, causing brightening of the soil where anaerobes have been. However only limited amounts of this reagent are produced because of the restricted number of obligate anaerobes present in the bed. Facultative

anaerobes, which can live with or without oxygen, do produce superoxide dismutase and therefore do not accumulate superoxide anion radicals. Thus, only small amounts of sulfide can be oxidized by this mechanism. Consequently, it is only in lower layers of the columns, where little sulfide is present, that brightening occurs. The upper layers, where high sulfide concentrations are found, remain unoxidized, thus leaving the crust unattacked. For this reason, the proposal (1) to use resting as a means to reinstate permeability in failed systems is unlikely to succeed within short periods of time.

As columns are irrigated with effluent, the redox potentials in the sand fall to levels low enough to reduce sulfate to sulfide; on subcrust reaeration, the Eh rises again with restoration of oxidizing conditions. Before the columns begin to clog, all the sand is saturated with water, so that there is zero moisture tension anywhere in the soil. As clogging and crusted zones develop, the tension increases in lower reaches of the column until it attains equilibrium values for the texture of sand being used. The development of high tensions under crusts in subcrust aerated columns is a good additional indicator that no water can penetrate through the crust. Since sand covered with glass wool and sand covered with gravel both clog equally well, filtration of suspended solids from effluent is obviously not the sole or even the major mechanism initiating soil clogging. Only very small amounts of gases are produced in the columns. The gases found include carbon dioxide, methane and hydrogen sulfide; the methane sometimes makes up half of the sample collected. The restriction in flow of the columns is not due to "airlocks" by gases produced in the columns.

6. Treatment of Failed Columns with Peroxide

Columns which allowed little or no effluent to pass through were treated in various manners with hydrogen peroxide to destroy the crusted zone. Normally about 50-100 ml of 30% H_2O_2 suffice to break through an impermeable crust. If the peroxide is poured gently onto the top surface, it gradually erodes through the crust, bleaching the sand as it operates. Some of the peroxide decomposes with effervescence, causing minor agitation of the soil surface and flotation of the lighter organic components of the crust as a creamy scum. It takes one to several hours for the peroxide to eat through the crust, but after breakthrough the water flows rapidly down through the subcrust regions of the column. The soil moisture tensions there rapidly decrease to zero. The first effluents emerging from the column are colored blue-green because they contain high concentrations of the soluble sulfates of the metal ions that had been trapped as insoluble sulfides on the column.

If the peroxide is injected with a long hypodermic syringe needle into subcrust layers of the sand, the sand is bleached almost instantaneously at the point of injection, indicating the much lower level of sulfide there. Some peroxide immediately begins to decompose, forming large bubbles of oxygen that erupt to the surface, mechanically agitating the crust and creating channels in the sand. The vigorous mixing causes better distribution of the reagent and thus more rapid oxidation of the black crusted layers, so that breakthrough is more rapid. Again the organic coatings on the sand and gravel are dislodged and the column effluents are colored.

The breakdown of some peroxide to water and oxygen in the bed is caused by three mechanisms: Catalytic decomposition on the surface of some soil particles, catalytic decomposition by heavy metal ions brought into solution by oxidation of their insoluble sulfides to soluble sulfates, and enzymatic decomposition by catalases produced by some of the soil microorganisms. Peroxide destroyed in this way is not necessarily lost without effect. The oxygen produced may be metabolized to radical anions by obligate anaerobes or used later by aerobes or facultative anaerobes to oxidize organics. The agitation caused by the vigorous gas release helps loosen up the crust. In this way, the bed is returned to an aerobic state.

The first effluent emerging from the columns is sterile, but later, when fresh effluent is added, some bacteria wash through, just as with fresh sand columns. This is a good indicator that the peroxide returns the column almost to its initial porosity. Much of the organic matter in the crust is removed or decomposed by the peroxide. Organic carbon contents in sand samples from peroxide-treated columns are about one-half of those found in clogged columns before treatment. Some of the organic materials are solubilized and eluted with the first effluents. The remaining organics are no doubt rapidly decomposed by bacteria once the peroxide has recreated aerobic conditions in the bed.

The peroxide thus mechanically disturbs the crust and destroys or removes many of the blocking substances: it oxidizes the insoluble sulfides, making trace elements again available for redox enzyme synthesis, it eliminates some organic matter, and makes the remainder amenable to subsequent aerobic decomposition.

7. Treatment of Failed Septic Systems with Peroxide

Following the encouraging results obtained with soil columns in the laboratory several badly failed septic systems were treated. These were on a variety of soil types: three in sandy soils, two in glacial till, and one in heavy clay. Effluent was surfacing in two instances, the tank was being used merely as a holding facility in three others, being pumped out twice a week, and water use had been reduced to intolerable levels with the last system. In each case, the septic tank was emptied by a commercial pumper to allow some time for work on the bed before fresh effluent would come flowing over from the tank. Several feet of stagnant water were found in each bed, suspended within strong biological crusts surrounding each gravel bed. A deep pit was dug alongside each bed, and tensiometers were buried in the soil underneath the bed. The bed was then drained, either by puncturing the crust at one point and allowing the water to flow into the pit, from which it was then pumped away, or by driving sand points into the gravel bed and pumping out the water through the points. The water was either pumped onto nearby fields, woods, or pasture, or pumped back into the empty septic tank, which was used as a temporary holding facility. Peroxide was then added in portions at various points along the bed, for example, down the vent pipe, into the distribution box, and through 3-inch PVC pipes inserted into the ground by augering holes down to the gravel. Alternatively, the peroxide was added to the distribution line by tapping the four-inch iron pipe and screwing on a 1-inch galvanized pipe. Between 15 and 40 gallons of commercial 50% hydrogen peroxide (Du Pont's Tysul WW 50) was used, depending upon the size of the bed.

The peroxide was diluted during addition by simultaneously running in fresh water through a garden hose; about 300-600 gallons of water was added in this way.

In each case, breakthrough of the crusts was achieved. After several hours, the tensiometer readings began to fall, indicating that water was entering the soil below the bed where each tensiometer was buried. The readings continued to drop for about 48 hours, as fresh effluent began to spill over into the bed again after the tank refilled. Final low equilibrium values characteristic of the prevailing soils were then maintained as the beds began to function properly again. Only minor variations up or down ($\pm 2-5$ mm of mercury) were observed, reflecting variations in the head of water in the bed. A slight gradual increase in tension appears to take place in time, suggesting that a clogged or crusted area begins to reform in some systems. However, in no system has complete crust formation recurred, as would be indicated by tensiometer readings as high as those measured before peroxide treatment. One system has now been operating satisfactorily for 15 months since peroxide treatment in August 1974.

8. Preventive Maintenance with Peroxide

Although recovery of failed systems with peroxide treatments can be easily achieved, this is obviously not the best use for the reagent. Failure prevention is better than cure.

If a system has failed, it is necessary to pump out the massive volume of stagnant water from the bed, to prevent excessive dilution of the peroxide and to ensure that enough oxidant reaches the crust.

Moreover, relatively large amounts of reagent are required. Though the cost of the amount of chemical needed for cure is certainly tolerable, compared to costs of other methods of relieving failed systems (generally installation of a larger or alternate system is prescribed), much less peroxide is needed for maintenance. For economy, peroxide must be shipped in the highest concentration compatible with safety. The standard 50% commercial solution is still quite hazardous. As a strong oxidizing agent, it will rapidly attack almost any organic matter. The manufacturer's safety recommendations should be followed in its handling, storage and dispensing.

It is therefore cheaper and safer to use smaller amounts of peroxide in an intelligent preventive maintenance program rather than wait for systems to fail. In good septic tank practice, the sludge should be pumped out of the tank periodically, about once every two years at least, to prevent massive amounts of solids from spilling over into the bed. Tank pumping for sludge removal can be conveniently coupled with peroxide bed treatment. With systems that are still operating, water seeps away from the bed during the period when an emptied tank is refilling. After most of the water has drained away from the bed, shortly before the tank is full, the time is opportune to add lesser amounts of peroxide (approximately 5 gallons) to destroy any incipient crusts forming in the bed. Because there is still some residual permeability in the bed, the oxidant has a better opportunity of reaching the clogging zones than it has in a completely sealed system. If the tank pumping and peroxide treatment can be performed at a time when the system is not in use, for example, during a vacation, the situation is

ideal, for the reagent has then plenty of time to work without being diluted with fresh effluent, and aerobic conditions can become well reestablished in the bed.

It is unfortunately difficult to assess the success of such a preventive maintenance procedure. Nonetheless experiments are currently underway to evaluate such treatments on a badly undersized system installed in a problem soil.

In view of the success achieved so far with peroxide, it would appear warranted that provisions be incorporated into future systems to provide for easy maintenance or remedial treatments with peroxide. For example, during construction of new systems, plastic tubing could be installed leading from the manhole cover of the septic tank into the distribution lines, to allow peroxide to be funneled into the system any time after the tank is pumped out. A dip should be made at the start of the line to prevent peroxide from flowing back into the tank. A perforated sump could be installed at the end of each line underneath the vent pipe to allow excess stagnant water to be pumped out of the system conveniently at that point if desired. If peroxide treatment of septic beds becomes an accepted practice, such simple design modifications can be incorporated into state plumbing codes.

End

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