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Optimizing the Performance of Sand Filters and Packed Bed Filters Through Media Selection and Dosing Methods

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More than 100 years ago sand filters were first used to treat wastewater in North America. Since the 1960s, they have enjoyed a resurgence of interest and today sand filters are among the most successful methods for onsite wastewater treatment wherever high groundwater, poor soils, or other site constraints rule out conventional septic systems. Their capability for nutrient and pathogen removal, their low maintenance and power requirements, and their tolerance for periodic surges in loading rates make them practical and economical.

Nevertheless, obtaining sand of the proper size, uniformity, and cleanliness has in some locations been a stumbling block in the spread of this technology. When sand filters are introduced into an area, sand meeting the required specifications may require long-distance transport if a local supplier is not willing to gear up to produce the small amount required for the first few installations. To combat these costs, contractors may jointly guarantee the purchase of an amount of material sufficient to make its production cost-effective. One important caveat: relying on the ASTM C-33 concrete sand specification as a filter medium specification may be dangerous to a sand filter's health.

When it's available, affordable, clean, and properly sized, sand is an excellent filter medium. It is not, however, the only alternative. In fact, sand filters are just one example of what is known, generically, as packed bed filters. Packed bed filters may use any of a variety of filter media, including sand, glass, slag, ceramic, plastic and even textile. Their success in treating wastewater depends largely on selection of the proper form and correct placement of the medium as well as on the dosing methods used in applying wastewater to the filter medium.

To understand how filter media and dosing methods affect performance, it's instructive to review some of the conditions essential for a properly operating sand filter.

The Hidden Life of a Sand Filter

As wastewater percolates slowly through the filter medium, physical, biological, and chemical processes remove contaminants. On the surfaces of the grains of sand or other medium grows a naturally occurring, microscopically thin zoogleal film composed of large populations of bacteria and other microorganisms. As septic tank effluent flows over the surface of the zoogleal film, organic material contained in the wastewater is absorbed onto the film where it becomes food for the bacteria. For maximum treatment, then, it is essential that all the wastewater have sustained contact with the film attached to the medium. And because the aerobic organisms in the zoogleal film need oxygen to live, it is also essential to maintain unsaturated flow conditions through the filter medium.

Unsaturated flow and sustained contact are achieved by distributing the wastewater evenly over the surface of the filter medium and by keeping doses small and frequent over the course of the day. Even

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distribution also ensures that all of the filter medium is used, thus preventing clogging that can result when parts of a filter go unused and others are hydraulically and organically overloaded.

Even distribution is best accomplished by applying septic tank effluent to the surface of the sand by means of uniformly spaced orifices (Fig.1) that are drilled using a drill press or guide. Accurately sized orifices for uniform flows are nearly impossible to achieve when drilling "freehand" [Ball (1)]. Note that 3 inches (7 cm) of pea gravel is placed over the leveled sand to support the distribution manifold and to prevent depressions in the sand from forming under the orifices. An additional 2 inches (5 cm) of gravel over the distribution manifold stabilizes it in position (Fig. 2). Even distribution is also dependent on the infiltrative capacity of the sand (or other medium), the rate of flow through the orifices, and the total volume of the dose.

How Media Size and Gradation Affect Filter Performance

An ideal filter medium has both large surface area permitting wastewater maximum contact with the zoogleal film and sufficient pore space to allow aeration and unsaturated flow.

To illustrate how particle size of a filter medium relates to the void or pore space between the particles, surface area and void volume were calculated for packed spheres of various sizes (Table 1). Note that the percentage of void volume remains the same

Table 1: Surface area and void volume of packed spheres

			Uncompacted *Volume voids = 48%*		*Compacted* *Volume voids = 35%*	
Diameter mm	**Sphere Volume, cmm**	**Surface Area, sq. mm**	**Number Spheres/ cu. ft.**	**Surface Area, sq. ft./cu. ft.**	**Number Spheres/ cu. ft.**	**Surface Area, sq. ft./cu. ft.**
0.3	0.01	0.3	1.05E+09	**3192**	1.3E+09	**3962**
0.55	0.09	1.0	1.70E+08	**1741**	2.1E+08	**2161**
1	0.52	3.1	2.83E+07	**958**	3.5E+07	**1189**
2	4.19	12.6	3.54E+06	**479**	4.4E+06	**594**
3	14.14	28.3	1.05E+06	**319**	1.3E+06	**396**
4	33.51	50.3	4.42E+05	**239**	5.5E+05	**297**
5	65.45	78.5	2.27E+05	**192**	2.8E+05	**238**

even as the diameter of the spheres changes. While the surface area of a 0.3 mm diameter medium, for example, is much greater than that of 5 mm diameter medium, the size of the pores between the 0.3 mm diameter particles is much smaller and maintenance of unsaturated flow, therefore, would be more difficult to achieve.

Sand from most sources contains a variety of grain sizes with smaller grains of sand filling in the pores between the larger grains. Sand filters benefit from this condition as surface area per unit of volume increases, but can suffer when pore size becomes too small for unsaturated flow to occur.

In fact, sand filters have suffered where ASTM's C-33 standard has been adopted unconditionally as the specification for sand filter medium. At first glance, the C-33 specification appears similar in size and uniformity to what is needed for a sand filter. However, C-33 sand has too large a percentage of fine particles to make it permissible for this use. Developed for the manufacture of concrete, the C-33 specification is designed to minimize voids. That runs counter to the objective for sand filters: sufficiently large pore space to allow ample oxygenation and unsaturated flow around the sand particles.

Using sand or other granular media that falls within the C-33 size and gradation specifications may be appropriate, *but only if the percentage of fines is carefully controlled.* The C-33 standard allows 0 to 12 percent passing the number 100 sieve. Experience has shown that sand with 12 percent fines lacks sufficient pore size for unsaturated flow, so that in a sand filter, dosing at a normal loading rate usually results in formation of a biomat that quickly plugs the surface of the sand. Any sample of sand filter medium tested by sieve analysis (ASTM-136) must also first be washed and sieved (ASTM-117) to accurately measure the percentage weight of the smallest particles which may not be separated in the ASTM-136 procedure.

How Dosing Affects Performance

The hydraulic loading rate (HLR) has long been the prime criterion for determining the size of an intermittent sand filter. The HLR is the volume of wastewater applied daily to the sand filter divided by the surface of the sand filter. If a hypothetical HLR were 1 gpd/ft^2 (4 cm/day) then a wastewater flow of 100 gal/day (379 L) would require a sand filter 100 square feet (2.8 m^2) in area.

How wastewater is applied to a sand filter is critical. Even distribution is best accomplished by many orifices, closely spaced. The liquid must not be applied too rapidly or saturated flow will occur and treatment will be compromised. For any given size and gradation of a medium, there is a maximum hydraulic application rate (HAR = volume/dose) beyond which quality of treatment will diminish.

Visualize an unusual packed bed filter: a 4-inch (10 cm) diameter column of golf balls being dosed with wastewater by means of an eyedropper. Each drop of liquid spreads itself into a very thin layer over one or several golf balls allowing for maximum contact with the zoogleal film attached to the balls. The result is the wastewater receives maximum treatment by the time it exits the filter. If the same column of golf balls were to be dosed instead with a garden hose-sized flow of wastewater, most of the liquid would flow through the column without the zoogleal film contact required for treatment.

Research at the University of California, Davis, during the past seven years, has confirmed that frequent doses (24 doses/day) and small volume doses significantly improve the performance of intermittent sand filters [Emrick et al. (2), Darby et al. (3)].

Media For Packed Bed Filters

Sand is not the only medium useful for packed bed filters treating wastewater. Crushed glass, slag, crushed limestone, polyethylene pellets, polystyrene pellets, and closed cell foam cubes have all been shown to be capable of providing good treatment when used as media in packed be filters [Swanson and Dix (4), Jowett (5), Weaver et al (6)].

The newest medium to show promise is a textile. At the third annual Oregon Onsite Wastewater Conference in March, 1997, Christiane Roy of Option Environnement, Québec, Canada, presented data resulting from several years of testing a textile medium in packed bed filters. The data indicated not only that treatment of residential wastewater by the textile medium is comparable to that of sand filters, but it is achieved with comparatively high hydraulic loading rates: 15 gpd/ft^2 (60 cm/day) for intermittent (single pass) filters and 30 gpd/ft^2 (120 cm/day) for recirculating filters.

Evaluation of the textile material reveals two significant features: (1) a very high surface area per unit of volume–5300 ft^2/ft^3 (17,900 m^2/m^3) for the textile vs. 1200 ft^2/ft^3 (4000 m^2/m^3) for sand, and (2) a very large void volume–greater than 80 percent for the compacted textile vs. 35 percent for compacted sand.

It's the complex fiber structure of the textile material that creates the extremely large surface area for biomass attachment. The compacted textile's measured field capacity–i.e., the water holding capacity, calculated as the volume of water retained after 30 minutes of draining divided by the total sample volume– is about 40 percent. The corresponding hydraulic conductivity exceeds 4 in/sec (10 cm/sec), a rate that ensures that solids are distributed throughout the depth of the medium, reducing the potential for solids accumulation and clogging of the top surface of the filter bed.

In terms of treatment, the water holding capacity of the textile material appears to be the key factor. It has been shown that COD removal in the textile filter is related to the depth of the medium and to the retention time of the wastewater within the textile medium. Water retention is due primarily to capillary effects in the micropores of the textile's structure and to the height over which the capillary forces are exercised. Subdividing the filter bed into hydraulically independent layers optimizes the textile material's hydraulic and capillary properties. Ultimately, the water holding capacity is determined by the type of textile material used and on the degree of compaction [Roy (7)].

Because the textile medium can handle a very high HLR, the filter can be relatively small. A 5-foot (1.5 m) diameter by 2-foot (0.6 m) deep layered textile packed bed filter can easily provide treatment for a single-family home. On a top surface area this small, a high pressure spray nozzle is ideal for distributing small doses uniformly.

For nine months this textile material was used as filter medium in a monitored recirculating trickling filter fitted on a septic tank. The trickling filter has operated with various media since 1993 [Ball (8)]. The screened, untreated effluent from the septic tank prior to installation of the trickling filter averaged BOD_5 of 125 mg/L and total nitrogen of 68 mg/L. BOD_5 reduction accomplished by the trickling filter ranged from 84% for corrugated plastic to 90% for textile medium. Total nitrogen reduction ranged from 78% for the plastic and foam to 91% for the textile (Table 2).

Table 2: Average quality of trickling filter treated septic tank effluent

Filter Medium	BOD_5	TN	Pump Run Time
corrugated plastic	20 mg/L	15 mg/L	6.0 kwhr/day
open-cell foam	18 mg/L	15 mg/L	4.2 kwhr/day
textile	12 mg/L	6 mg/L	2.4 kwhr/day

Conclusion

1. The medium in packed bed filters, whether sand or another material, must meet these two requirements: a large surface area (ft^2/ft^3 or m^2/m^3) to maximize contact between the wastewater and the microorganisms that do most of the treatment, and pore space large enough to permit unsaturated flow to keep the microorganisms aerated.

2. Sand that meets the ASTM C-33 standard is not an appropriate sand filter medium unless the percentage of fines passing the number 100 sieve (ASTM C-136) added to the percentage of fines determined by ASTM C-117 is no more than 4 percent.

3. Treatment in a packed bed filter is optimized when doses are (1) evenly distributed over the top surface of the medium, (2) small in volume, and (3) fairly frequent.

4. A recently introduced textile medium for packed bed filters shows great promise. Thanks to the material's large surface area, large void volume, and water holding capacity, treatment is maximized even at very high loading rates. In a recirculating trickling filter the textile medium can reduce BOD_5 and total nitrogen in septic tank effluent by 90%.

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