RULE DEVELOPMENT COMMITTEE ISSUE RESEARCH REPORT

DRAFT

SAND / MEDIA SPECIFICATIONS

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Specific WAC Section Reference, if WAC related:

Topic & Issues:

Sand Media Specifications

- **Should we continue using the two different sand specifications?**
- **Is there a need to make adjustments to our existing specifications?**
- **Do we allow the use of other media?**

Summary:

This report summarizes the literature on the topic of specifications for media of sand-based on-site wastewater treatment systems. The granular media must be coarse enough to permit a sufficient flow rate yet fine enough to provide adequate treatment. Media that is too coarse lowers the wastewater retention time to a point where treatment becomes inadequate. Media with small grain size slow the water movement and increase the chance of clogging. The effective size (D_{10}) and uniformity coefficient (Uc) are the principal characteristics of granular media treatment systems. The ideal sand media for intermittent sand filters is a coarse sand with an effective size between 0.3 mm and 0.5 mm. The media sand grains should be relatively uniform in size having a low Uc value (less than 4.0) to promote movement of water and prevent clogging.

KEYWORDS: sand/ media specifications, filter media, media grain size

Introduction:

A goal of a granular media specification is to balance the desired wastewater treatment performance with the preferred hydraulic performance. Granular media should be neither too coarse nor too fine. Coarse media may allow wastewater to pass too quickly through the filter without receiving adequate treatment, while very fine media can slow the water movement too much, reduce aeration within the media, and increase the chance of clogging.

There have been many different types of media used in single-pass granular media filters, such as sand filter and mound systems. Washed graded coarse sand is the most common. Because of its availability and relatively low cost, the ATSM C-33 specification for fine aggregate has been a standard specification in the state of Washington for sand media filters for many years. To address problems concerning premature sand clogging and failures with ASTM C-33 sand as the filter media, revisions were made to the Recommended Standards and Guidance (RS&G) for Intermittent Sand filters in 2000. The revised RS&G began to allow the use of a coarser sand media specification that is more clog-resistant than the ASTM C-33 sand specification. Although, the ASTM C-33 sand specification still remains an option, the revised RS&G suggests lower loading rates (<1.2 gpd/ft^2) and methods of improving oxygen exchange within the filter to reduce the sand clogging potential when ASTM C-33 sand is used.

The purpose of this review is to synthesize the literature available on the topic of standard specifications for sand media so that the Technical Review Committee can make appropriate recommendations about how the standards should be set and applied in Washington State. Foam chips (polystyrene), peat, and synthetic geotextile materials are generally restricted to proprietary products and are not covered in this review. More than 20 publications, which include peer reviewed journal articles, conference proceedings, textbooks, master thesis, and government reports were collected and reviewed.

Body:

Media Characteristics

The media characteristics of sand-based treatment systems are among the most important design criteria. The primary sand media characteristics affecting filtration performance are the effective grain size and uniformity coefficient (Crites and Tchobanoglous, 1998). These characteristics tend to affect the retention time of liquid passing through the media and the potential for clogging.

Effective Particle Size

The effective size (ES) is defined by the size of screen opening where 90 percent of a sample of granular media is retained on the screen and 10 percent passes through the screen, and is referred to as D_{10}. The larger the grain size, the faster the wastewater moves through the sand and the more wastewater that can be filtered. However, if the grain size is too large, treatment efficiency will be reduced. Boller et al. (1994) observed larger breakthroughs of unoxidized matter due to short retention times and instantaneous lack of oxygen when applying relatively large hydraulic loads to filter media with coarse grain size, especially above 1 mm.

The ideal sand for intermittent sand filters receiving domestic wastewater is coarse sand with an effective size between 0.3 mm and 0.5 mm (Crites and Tchobanoglous, 1998; Ohio State University, 1999). Clogging becomes a major concern when using sand with an effective size less than 0.3 mm, therefore it is important that filters using this size sand be lightly loaded (<1.2 gpd/ft^2) (Converse and Tyler, 2000). Clogging is less of a concern when using coarser sand. In a field evaluation of sand filter systems, Converse (1999) found that sands with too many fines have a greater chance of hydraulically failing (clogging) than sand with an effective particle size 0.3-0.5 mm, assuming similar loading rates.

"Dirty sand" (too much material passing #100 sieve) has been implicated as the cause of poor operation and clogging of sand-based systems on numerous occasions (Aqua Test and Stuth 1995; Newman, 1997; Crites and Tchobanoglous, 1998; Seattle-King County Department of Pubic Health, 1999). The ASTM C-33 specification for fine aggregate allows up to 10% of the material finer than a #100 mesh sieve. Weaver et al. (1998) recommends that sand used for constructing sand filters has no more than 4% fines passing the 100 sieve size. Ball (1997) indicates that sand with excessive fine particles lacks sufficient pore sizes 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.

The most important feature of granular media is not the grain particles, but rather the pore space in the media. The treatment of wastewater occurs in the pores where suspended solids are trapped, microorganisms grow, and air and water flow (Emerick, 1997). Ball (1997) illustrated how the particle size of a filter media is related to the size of the void or pore space between the particles by calculating the surface area and void volume for packed spheres of various sizes (Table 1). The percentage of void volume generally remains the same even as the diameter of the spheres changes. However, the surface area of packed spheres increases and the size of the pores per unit volume area significantly decreases with smaller diameter spheres. A granular media filter can benefit from increases in the surface area per unit of volume, but can suffer when pore size becomes too small for unsaturated flow to occur (Ball. 1997).

Table 1. Surface Area and Void Volume of Packed Spheres (taken from Ball, 1997)

			Uncompacted Volume Voids = 48%		Compacted Volume Voids = 35%	
Sphere Diameter mm	**Sphere Volume, mm^3**	**Surface Area, sq. mm**	**Number Sphere/ cu.ft.**	**Surface Area, Sq.ft./cu.ft.**	**Number Sphere/ cu.ft.**	**Surface Area, sq.ft./cu.ft.**
0.3	0.01	0.3	10.5E+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**

Uniformity Coefficient

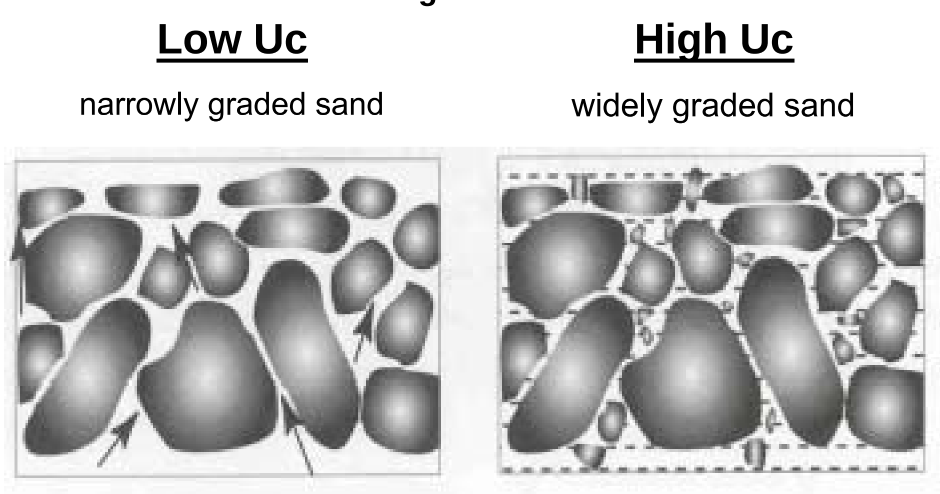
The uniformity coefficient (Uc) is a numeric estimate of how sand is graded, and is a dimensionless number or in other words it has no units. The term "graded" relates to where the concentrations of sand particles are located by size. Sand with all the particles in two size ranges would be defined as narrowly graded sand and would have a low Uc. Sand with near equal proportions in all the fractions would be defined as widely graded sand and would have a high Uc value. The Uc is calculated by dividing D_{60} (the size of screen opening where 60% of a sample passes and 40% is retained) by D_{10}

(the effective particle size- that size of screen opening where 10% of a sample passes and 90% is retained). The larger the Uc the less uniform the sand.

It's important that the sand grains all be about the same size; i.e. relatively uniform. A uniformity coefficient of 4 or less is recommended for all filter media (National Small Flows Clearinghouse, 1997; Crites and Tchobanoglous, 1998; EPA, 2002). This recommendation is intended to avoid clogging at higher loading rates (Darby et al., 1996). Sands from most natural sources are widely graded containing a variety of grain sizes, which results in a high Uc. If the grain sizes vary greatly, the smaller ones will fill the spaces between the larger particles, making it easier for the filter to clog (National Small Flows Clearinghouse, 1997).

An ideal sand media has both large surface area to permit wastewater to have maximum contact with the zoogleal film on the particles where most of the treatment is accomplished, and sufficient pore space to allow aeration and unsaturated flow (Ball, 1997). Because sand media treatment is aerobic in nature, the exclusion of fines from the filter media is extremely important to maintain open passages for air (Figure 1).

Figure 1.



Large pore space allows rapid oxygen diffusion and unsaturated flow around the sand particles.

Inclusion of small particles filling interspaces between large particles encourages clogging.

Concrete sands are designed to minimize voids, and usually have a high Uc (between 4-6) to pack and offer strength and stability (Dixon, 1994). Developed for the manufacturing of concrete, sands meeting the ASTM C-33 specification have a fairly broad and even size distribution (Ball, 1997). This size distribution allows the smaller sand particles to fill interstices between large particles, resulting in smaller and more convoluted pores spaces. When used for filter media, this condition encourages clogging of remaining void spaces with suspended solids and biological growth (Boller and Kavanaugh, 1995; Darby et al. 1996).

Table 2 shows how the physical performance of the granular media changes in response to different values in the Uc. Sands with higher Uc values have a more tortuous path (smaller and more convoluted pores spaces) for wastewater to move through and will have lower infiltration rates or permeabilities. Usually the water retention is also greater with sands that have a higher Uc due to smaller pore volumes and higher bulk densities. These conditions run counter to the objective for a good filter media, which should have sufficiently large pore spaces to allow ample oxygenation and unsaturated flow around the sand particles (Ball, 1997).

Table 2. Physical Performance Data for the Various Uc Values (taken from Dixon, 1994)

Physical Properties	Sand Uc = 1.5	Sand Uc = 2.3	Sand Uc = 4.6
Infiltration Rate (in/hr)	41.1	34.9	12.7
Bulk Density (g/cc)	1.5	1.6	1.8
Total Pore Space (%)	42.4	39.5	32.3
Capillary Pore Space (%)	5.0	4.6	14.4
Saturation (%)	11.8	11.6	14.4

Media uniformity does not appear to have as much effect on treatment performance as the media's effective size does at a hydraulic loading rate of 4 gpd/ft^2 and high dosing frequencies (24 times/day) (Nor, 1991, Darby et al., 1996). The lower per-dose application rate supports thin-flow flow conditions and allows good treatment regardless of media uniformity. At a high dosing frequency of 24 times/day, Nor (1991) observed that a sand with high uniformity (D_{10}=0.42 mm, Uc = 1.42) produced worse, but still good (3.9 log) total coliform removal compared to washed concrete sand (D_{10}=0.29 mm, Uc= 4.52), which produced a 4.7 log coliform removal. However, as the per-dose application rate increases (less frequent dosing), media uniformity becomes more significant because it affects pore geometry and conditions under which thin-film flow occur (Darby, 1996).

State Sand Media Specifications

To provide examples of various sand specifications for single-pass sand media filters, a review of the requirements from other states was conducted. Table 3 and 4 summarizes the findings of this review. Of the states reviewed, a number were found to either require sand media similar to the ASTM C-33 specification for fine aggregate, or the coarse sand specification that Washington State currently uses, or allow both specifications.

Table 3. Summary of Sand Specifications from other States (Similar to ASTM C-33)

Sieve No.	Opening (mm)	ASTM C-33	Indiana	Montana	Texas	Missouri	Minn.	Alaska
3/8	9.50	100	100	100	100	100		
4	4.75	95-100	95-100	95-100	95-100	90-100	95-100	
8	2.36	80-100	80-100	80-100	80-100		80-100	
10						62-100	0-100	85-100
16	1.18	50-85	50-85	45-85	50-85	45-82		
20								60-90
30	0.60	25-85	25-60	20-60	25-60	25-55		
40							0-100	25-50
50	0.30	5-30	5-30	10-30	10-30			
60						0-10	0-40	≤15
100	0.15	0-10	0-10	0-3	2-10	0-4		
200	0.075	≤3	0-3		0-3		0-5	<5
ES (D_{10})		0.15-0.35 mm	-	0.15-0.30 mm				
Uc		4-5	-	4-6				

Table 4. Summary of Various States with Coarse Sand Specification

Sieve No.	Opening (mm)	Washington	Vermont	Ohio	Oregon	Wisconsin	Rhode Island	Montana
3/8	9.50	100	100	100	100	100	100	100
4	4.75	95-100	95-100	95-100	95-100	95-100	95-100	95-100
8	2.36	80-100	80-100	80-100	80-100	80-100	80-100	80-100
16	1.18	45-85	45-85	45-85	45-85	45-85	45-85	45-85
30	0.60	15-60	15-60	15-60	15-60	15-60	15-60	15-60
50	0.30	3-15	3-15	3-15	3-15	3-15	3-15	3-10
100	0.15	0-4	0-4	0-4	0-4	0-4	0-4	0-2
ES		0.25-0.5 mm	Same as WA	Same as WA	Same as WA	Same as WA	Same as WA	0.3-0.5mm
Uc		< 4	“	“	“	“	<3	

Cost Information

The sand media can be the most significant factor affecting costs of constructing sand-based treatment systems. In areas where media is expensive or needs to be hauled a long distance, costs can be much higher. Sand media meeting a new specification may not be readily available in many parts of the state, and therefore, can subsequently increase costs. However, the benefits of having a media specification that can reduce the number of sand-based treatment system failures can outweigh the increased cost for the media.

Conclusions:

A comprehensive review of the literature to address identified key issues on the subject of media specifications for on-site treatment systems was conducted. The following conclusions can be drawn from the information available in the literature:

1) Important criteria for media to meet are: a large surface area to maximize contact between the wastewater and the microorganisms that do most of the treatment, and pore spaces large enough to promote unsaturated flow to keep the microorganisms aerated.

2) Sand that meets the ASTM C-33 specification is not an ideal media. Developed for the manufacturing of concrete, ASTM C-33 is designed to minimize voids and has a high Uc, between 4-5. Excessive fines are allowable to pack and offer strength and stability. These allowances create concerns for using this same material as a treatment media in a sand media filter.

3) The recommended coarse sand media specification for an intermittent sand filter has an ES (D_{10}) of 0.3 to 0.5 mm with a uniformity coefficient (Uc) of <4 with no more than 4% passing a 100 sieve.

- **Should we continue allowing the use of two media specification for sand filters?** Yes.
- **What is the preferred sand/media specification?** The preferred sand media should be a coarse grade (ES = 0.3-0.5 mm), uniform (Uc should always be less than 4), and washed (limiting amount of fine particles passing the U.S. No. 100 sieve. ASTM C-33 sand does not typically meet this specification.

- **Is there a need to make adjustments to our existing standards?** Yes.
- **If yes, what adjustments should be made?**
    - The Coarse Sand Media Specification's effective particle size (D_{10}) should range from 0.3-0.5 mm along with a uniformity coefficient less than 4.
    - If sand meeting the ASTM C-33 specification is used, the design hydraulic loading rate should be adjusted down to 1.0 gpd/ft^2 and the volume of wastewater applied per dose decreased to help compensate for media's grain size distribution.

References:

American Society for Testing and Materials. 2002. C33-02a Standard Specification for Concrete Aggregates. West Conshohocken, PA. p.11.

Amini F. and H.V. Troung. 1998. Effect of Filter Media Particle Size Distribution on Filtration Efficiency. Water Quality Research Journal of Canada. 33(3): 589-594.

> The results of an experimental study of a sand filter water quality model are presented. The model is built to represent an underground confined water quality sand filter structure. Three types of sands, namely fine, medium and coarse, were used to study the effect of filter media particle size distribution on sediment removal efficiency. The results indicated that the sediment removal efficiency for all sand types decreased with time. The use of medium sand provided the scale model filter with the highest sediment removal efficiency. The finding of this study indicates that the media grain size has a measurable effect on the efficiency of the sand filter water quality structure.

Aqua Test, Inc., and Stuth Co., Inc. 1995. Crushed Recycled Glass as a Filter Medium for the Onsite Treatment of Wastewater. Clean Washington Center, Seattle Wash. Report No. GL-95-5.

Ball, Harold L., 1997. Optimizing the Performance of Sand Filters and Packed Bed Filtered Through Media Selection and Dosing Methods. In Proceedings Ninth Northwest On-Site Wastewater Treatment Short Course, College of Engineering, University of Washington, Seattle, WA. pp. 205-213.

> 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.

Boller, M., A. Schwager, J. Eugster, and V. Mottier. 1994. Dynamic Behavior of Intermittent Sand Filters. Water Science and Technology 28(10): 99-107.

> Buried filters were investigated in pilot and full scale and were operated by intermittent flushing which causes the water and the pollutant transport through the unsaturated media to be of highly dynamic nature. Various schemes of hydraulic flushing frequencies were found to be inversely proportional to loading. These findings were confirmed in a full scale plant through monitoring of the dynamic washout of inoxidized matter under different hydraulic loads. The moisture retention capacity of the filter media correlated to the grain size distribution was found to be an important parameter. COD removal and nitrification rates depend strongly on the oxygen supply to the media. In general, oxygen diffusion into the media and the air exchange, induced by intermittent flushing, is sufficient. However, when applying relatively large hydraulic loads to coarse filter grains, especially in the range above 1 mm, buried filters tend to larger breakthroughs of inoxidized matter due to short retention times and instantaneous lack of oxygen. Experiments on average treatment performance and showed that under optimized conditions even wastewaters containing relatively high ammonia contents can fully be nitrified when limestone type filter material is used. Full scale operation revealed further that careful pretreatment (e.g. septic tank) for the removal of most of the suspended solids is necessary to guarantee safe operation.

Boller, M.A., and M.C. Kavanaugh. 1995. Particle Characteristics and Headloss Increase in Granular Media Filtration. Water Research. 1995. 29(4): 1139-1149.

Size density relationships for aggregated particulates in suspension are transferred into a model describing the accumulation of particulate deposits in the pore space of granular media filters. Using data from several shallow filter layer experiments, the deposit density and the actual pore volume occupied by the captured particulates were estimated for solids of different characteristics. Based on extension of existing headloss models, the effects of particulate size, particulate density, filtration rate, and media grain size on headloss development during particle deposition were evaluated.

Converse, M. M. 1998. An Evaluation of Single Pass Sand Filters in a Northern Climate. M.S. Thesis, Biological Systems Engineering, University of Wisconsin-Madison. pp. 1-121

Converse, M. M., J.C. Converse, and E. Jerry Tyler. 1999. Sand Filter Evaluation in a Northern Climate. In: NOWRA 1999 Conference Proceedings of NOWRA: New Ideas For A New Millennium, Jekyll Island, GA. pp. 201-210.

Converse James C. and E. Jerry Tyler. 2000. Wisconsin Mound Soil Absorption Systems: Siting, Design and Construction Manual. Small Scale Waste Management Project. 345 King Hall, University-Madison, 1525 Linden Drive, Madison, WI 53706.

Crites, R. and G. Tchobanoglous. 1998. Small and Decentralized Wastewater Management Systems. WCB McGraw-Hill, Inc. Boston, Massachusetts. pp. 703-760.

Darby, Jeannie, George Tchobanoglous, M. Asri Nor and David Maciolek. 1996. Shallow Intermittent Sand Filtration: Performance Evaluation. Small Flows Journal 2(1): 3-15.

Twelve shallow sand filters (0.38 m deep, nominal diameter of 1.2 m) were loaded intermittently with primary effluent to evaluate the effects of hydraulic loading rate (HLR), dosing frequency (DF), and filter media characteristics on removal of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), suspended solids (SS), turbidity, and organic and ammonia nitrogen. Hydraulic loading rates between 0.041 and 0.652 m/d were applied during an 85-day period at DFs of between 4 and 24 times/d. Media effective sizes (d10) ranged from 0.29 to 0.93 mm with uniformity coefficients between 1.4 and 4.52. At an HLR of 0.163 m/d and a DF of 24 times/d, effluent quality was excellent and comparable to effluent from advanced wastewater treatment facilities. Specifically, average removal rates of between 90 and 99 percent for BOD, SS, organic and ammonia nitrogen, and turbidity, and at least 81 percent for COD, occurred regardless of media characteristics.

Dixon, Charles R. 1994. The Application of Sand Technology for Turf Systems. Sports Turf Magazine. June. 5 pages.

Emerick, R.W., R.M. Test, G. Tchobanoglous, and J. Darby. 1997. Shallow Intermittent Sand Filtration: Microorganism Removal. Small Flows Journal. 3(1): 12-22.

Twelve shallow circular sand filters (0.38 m deep, nominal diameter of 1.2 m) were loaded intermittently with primary effluent to evaluate the effects of hydraulic loading rate (HLR) -coupled with a high dosing frequency (DF) -and filter medium characteristics on the removal of indigenous coliphages, total coliforms, turbidity, chemical oxygen demand (COD), and total suspended solids (TSS). HLRs between 0.041 and 0.162 m/d were applied during an 84-day period at a DF of 24 doses/d. Two types of filter media were investigated: medium-size and coarse sand and crushed glass. Effective sizes ranged from 0.44 to 3.3 mm, and uniformity coefficients ranged from 1.3 to 5.0. Average removal rates greater than 94, 96, and 92 percent occurred for turbidity. TSS, and COD, respectively, regardless of medium characteristics. Removal of microorganisms was found to be affected by the combination of HLR and DF, with an increase in HLR at a constant DF resulting in a decrease in the log removal of both total coliforms and indigenous coliphages. Indigenous coliphage appeared to be more sensitive to changes in HLR than seeded polioviruses.

EPA . 2002. Onsite Wastewater Treatment Systems Technology Fact Sheet 10, Intermittent Sand/Media Filters. In Onsite Wastewater Treatment System Manual. EPA/625/R-00/008. pp. TFS 53-59,

National Small Flows Clearinghouse. 1997. In Summer 1997 Pipeline: Sand Filters Provide Quality, Low-Maintenance Treatment. 8(3): 1-8.

Newman, Thomas, A. 1997. Assessment of Intermittent Sand Filter Systems in Clark County, Washington. Southwest Washington Health District, Vancouver, Washington. p.19.

Nor, M. Asri. 1991. Performance of Intermittent Sand Filters: Effects of Hydraulic Loading Rate, Dosing Frequency, Media Effective Size, and Uniformity Coefficient. Master of Science, Department of Civil Engineering, University of California at Davis. pp. 1-80.

Ohio State University. 1999. Sand Bioreactors for Wastewater Treatment for Ohio Communities. Bulletin 876-99. pp. 1-5.

Peeples, J., K. Mancl, amd D. Widrig. 1991. An Examination of the Role of Sand Depth on the Treatment Efficiency of Pilot Scale Intermittent Sand Filter. In On-Site Wastewater Treatment: Proceedings of the Sixth National Symposium On Individual and Small Community Sewage Systems. ASAE. St. Joseph, MI. pp. 114-124.

> Sand filter systems were used widely at the turn of the century, particularly by communities in Massachusetts. It is likely that the decline in use of sand filters was a result of the land requirement for sand filtration and the demand for space in urban areas. Intermittent sand filters currently represent a promising technology for low-cost, low-maintenance wastewater treatment where conventional septic tank-soil absorption systems are not suitable. Sand filters have been found to be the most cost effective wastewater treatment systems for small communities and clusters of homes. The depth of sand used in an intermittent sand filter will generally affect the construction cost of the system. Many variables, other than depth, affect the treatment efficiency of sand filters. These variables include: wastewater pretreatment, media size, uniformity and composition, hydraulic and organic loading rate, temperature, and dosing technique and frequency. Generally, the effects of these variables are interrelated such that it is difficult to view only one of them in isolation. The purpose of this study was to evaluate the effect of sand depth on the treatment efficiency of pilot scale sand filters while maintaining the other primary variables constant.

Seattle-King County Department of Pubic Health. 1999. Monitoring King County Alternative On-Site Sewage Treatment and Disposal Systems, August 12, 1999.

Venhuizen, David. 1995. Intermittent Sand Filter New Frontiers for an Ancient Art. In the 3rd Annual On-Site Wastewater Treatment Research Council Conference. Austin, Texas. pp.103-116

> Attachment of biological films on solid surfaces is of considerable importance to engineers. Biological film development may constitute a nuisance in conveyance lines, heat exchangers and cooling towers. In cooling systems, biofilms increase frictional resistances, accelerate corrosion and impair heat transfer. Alternately, sanitary engineers have used biofilms in wastewater treatment plants for BOD and nitrogen removal. Although there is some knowledge about the dynamics of film development, and a considerable body of information about the kinetics of substrate removal by biofilms, the mechanisms and factors governing film attachment are still unclear. Work done by marine biologists and engineers has shown that colonization of a solid surface by bacteria is a rather selective process, which is affected by environmental conditions. Ionic strength, pH, substrate and nutrient concentration, water temperature, the surface properties of the solid, are all thought to influence biofilm attachment and development. Despite the obvious importance of biological films, there is paucity of information on the dynamics of biofilm development in the sanitary engineering literature. This paper summarizes a good deal of the available information on the subject, and presents the results of preliminary research on the effect of surface preconditioning on the formation and growth of biological films.

Weaver, Charles P., B.S. Gaddy, and H. L. Ball. 1998. Effects of Media Variations on Intermittent Sand Filter Performance. In On-Site Wastewater Treatment: Proceedings of the Eighth National Symposium On Individual and Small Community Sewage Systems. ASAE. St. Joseph, MI. pp. 363-370.