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TREATMENT OF SMALL FLOWS WASTEWATER–ON–SITE WITH INTERMITTENT SAND FILTRATION

In the evaluation of alternate onsite treatment and disposal processes for residential or commercial wastewaters, there are a number of criteria which may be used in the selection process including costs, health, environment, esthetics, safety, social adaptation, and technology. Site constraints often dictate final process selection and the disposal method will dictate wastewater quality required prior to disposal. If suitable soils exist on site to employ one of the subsurface soil absorption methods of disposal, the quality of wastewater required is minimized due to the assimilative capacity of the soil. Where suitable soil conditions do not exist onsite, other methods of disposal that require a higher quality wastewater may be necessary. In these situations, a relatively low cost process that has been successfully employed for many years may be considered; the intermittent granular filter. This paper reviews the current application of intermittent granular filters for onsite wastewater treatment.

Intermittent granular filtration may be defined as the intermittent application of wastewater to an artificial bed of granular material (usually sand) which is underdrained to collect and discharge the final effluent. One of the oldest methods of wastewater treatment known, intermittent filtration, if properly designed, operated and constructed, will produce effluents of very high quality. Currently, many intermittent filters are used throughout the United States to treat wastewater from small commercial and institutional developments and individual homes. The use of intermittent granular filters for upgrading stabilization ponds has also become popular.

DESCRIPTION

Intermittent granular filters are beds of granular materials, usually sand, 0.6 to 1 meter 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 (open filters) or may be buried in the ground (buried filters). A relatively new concept in filtration employs recirculation of filter effluent (recirculating filters). Figure 1 depicts these three general systems.

The mechanisms of purification attained by intermittent filters are complex and not well understood, even today. Filters provide physical straining and sedimentation of solid materials within the media grains. Chemical sorption also plays a role in the removal of some materials. However, successful treatment of wastewaters is primarily dependent upon the biochemical transformations occurring within the filter. Without the assimilation of filtered and sorbed materials by biological growth within the filter, the process would fail to operate properly.

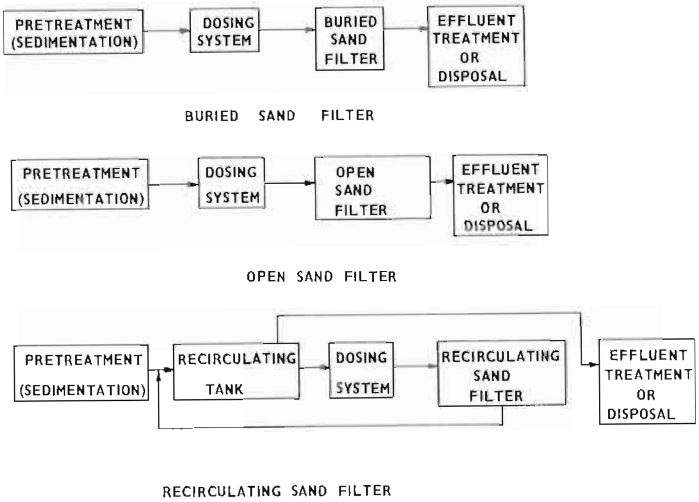

Fig 1. SAND FILTER SYSTEMS

Since filters entrap, sorb, and assimilate materials in the wastewater, it is not surprising to find that the interstices between the grains fill and the filter eventually clogs. Clogging may be caused by physical, chemical, and biological factors. Physical clogging is normally caused by the accumulation of stable suspended materials within or on the surface of the sand. It is dependent upon grain size, porosity and wastewater suspended solids characteristics. The precipitation, coagulation, and adsorption of a variety of materials in wastewater may also contribute to the clogging problem in some filter operations (ref.1). Biological clogging is due primarily to an improper balance of the intricate biological population within the filter. Toxic components in the wastewater, high organic loading, absence of dissolved oxygen, and decrease in filter temperatures are the most likely causes of microbial inbalances. Resultant accumulation of biological slimes and a decrease in the rate of decomposition of entrapped wastewater contaminants within the filter accelerates filter clogging. All forms of pore clogging occur simultaneously throughout the filter bed. The dominant clogging mechanism is dependent upon wastewater characteristics, method and rate of waste application, characteristics of the filtering media and filter environmental conditions.

FACTORS AFFECTING PERFORMANCE

The degree of stabilization attained by an intermittent filter is dependent upon: (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 filter.

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

Media Size and Distribution

The successful use of a granular material as a filtering media is dependent upon the proper choice of size and uniformity of the grains. The size of the granular media affects 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 is too coarse lowers the retention time of the applied wastewater through the filter to a point where adequate biological decomposition is not attained. Too fine a media limits the quantity of wastewater that may be successfully filtered and will lead to early filter clogging. This is due to the low hydraulic capacity and the existence of capillary saturation characteristic of fine materials. Metcalf and Eddy (ref.2) and Boyce (ref.3) recommended that not more than 1 percent of the media should be finer than 0.13 mm. Recommended filter media effective sizes range from a minimum of 0.25 mm up to approximately 1.5 mm. Uniformity coefficients for intermittent filter media normally should be less than 4.0 (ref.4,5,6,7,8).

There are a variety of granular media that may be used for intermittent filters including sand, anthracite, garnet, ilmenite, activated carbon, and mineral tailings. The media selected should be durable and insoluble in water. Total organic matter should be less than 1 percent and total acid soluble matter should not exceed 3 percent. Any clay, loam, limestone, or organic matter may increase the initial adsorption capacity of the sand, but may lead to a serious clogging condition as the filter ages.

The arrangement or placement of different sizes of grains throughout the filter bed is also an important design consideration. A homogeneous bed of one size media does not occur often in practice. Numerous fine and coarse stratified layers of granular media occur throughout the bed due to construction practice; thus, making it nonhomogeneous. 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 (ref.9). 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.

Hydraulic Loading Rate

The hydraulic loading rate may be defined as a volume of liquid applied to the surface area of the sand filter over a designated length of time. Hydraulic loading is normally expressed as cm/day or gallons/d ft^2. 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. They normally range from 3 to 60 cm/d (.75 to 15 gal/d ft^2).

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 designated length of time. Organic loading rates are not often reported in the literature; however, early investigators found that the performance of intermittent granular filters was dependent upon the accumulation of stable organic material in the filter bed(ref.1, 9). To account for this, hydraulic loading rates today are often prescribed for a particular type of wastewater. Low loading rates are suggested for raw wastewater with increasing rates suggested for primary settled, septic tank treated, and secondary treated effluents. A strict relationship establishing an organic loading rate, however, has not yet been clerly defined.

Depth of Media

Depths for intermittent granular filters were initially designed to be 1.2 to 3.0 meters; however, it was soon realized that most of the purification of wastewater occurred within the top 0.2 to 0.5 meters of the bed (ref.9). Additional bed depth did not improve the wastewater purification, but not to any significant degree. Most media depths used today range from 0.6 to 1.0 meters. The use of shallow filter beds helps keep the cost of installation low. Deeper beds tend to produce a more constant effluent quality, are not affected as severely by rainfall or snow melt (ref.10), and permit the removal of more media when cleaning operations are necessary.

Dosing Techniques and Frequency

Dosing of intermittent filters is critical to the performance of the process. The system must be designed to insure uniform distribution of wastewater throughout the filter cross-section. Sufficient resting must be also provided between dosages to obtain aerobic conditions. In small filters, wastewater is applied in doses large enough to entirely flood the filter surface with at least 8 cm of water; thereby, insuring adequate distribution. Dosing frequency is dependent upon media size but should be greater with smaller doses for coarses media.

Dosing methods that have been used include ridge and furrow application, drain tile distribution, surface flooding and spray distribution methods. Intermittent filters in use today are often built below the ground surface and employ tile distribution.

The frequency of dosing intermittent filters is open to considerable design judgment. Most of the earlier studies used a dosing frequency of 1/day. Studies investigating multiple dosages have concluded that the BOD removal efficiency of filters with media effective size greater than 0.45 mm is appreciably increased when the frequency of loading is increased beyond twice per day (ref.11). This multiple dosing concept is being used successfully in recirculating sand filter systems (ref.12). These installations use a media with effective size ranging from 0.3 to 1.5 mm and a dosing frequency of approximately once per 30 minutes.

FILTER PERFORMANCE

A summary of the performance of selected intermittent filters based on experience with wastewaters generated from rural households in the U.S.A. appear in tables 1, 2, and 3. These tables illustrate that intermittent filters will produce high quality effluents with respect to BOD_5 and suspended solids.

TABLE 1
PERFORMANCE OF SUBSURFACE INTERMITTENT FILTERS - SEPTIC TANK EFFLUENT

Filter Characteristics: Eff. Size (mm)	Uniformity Coefficient	Hydraulic Loading (cm/d)	Depth (m)	Effluent Characteristics (mg/l): BOD	SS	NH_3^-N	NO_3^-N	Filter Run (Months)	Reference
0.24	1.0	4	0.8	2.0	4.4	0.3	25	34	[14]
0.30	4.1	4	0.8	4.7	3.9	3.8	23	>40	[14]
1.0	2.1	4	0.8	4.3	4.9	3.7	24	>48	[14]
2.5	1.2	4	0.8	8.9	12.9	6.7	18	>48	[14]
0.17	11.8	0.8	1.0	1.8	11.0	1.0	32	>23	[10]
0.23-0.36	2.6-6.1	4.6	0.6	4	12	0.7	17	-	[7]

TABLE 2
PERFORMANCE OF FREE ACCESS INTERMITTENT FILTERS

Source	Filter Characteristics: Eff. Size (: m)	Unif. Coef.	Hyd.Loading cm/d	Depth (m)	Dose Freq. (per day)	Effluent Quality (mg/l): BOD	SS	NH_3^-N	NO_3^-N	Filter Run (Months)	Reference
Septic Tank	0.23-0.25	-	18	1.5	-	23*	-	8	32	6 - 9**	[9]
Septic Tank	0.41	-	9.2	1.5	-	11*	-	3	46	6 - 9**	[9]
Trickling Filter	0.27	-	45.6	1.5	-	17*	-	2	29	6**	[9]
Trickling Filter	0.41	-	18.4	1.5	-	18*	-	2	33	Raked 6"dp./12mo**	[9]
Primary	0.25	-	11	.75	1	6	6	5	19	4.5	[11]
Primary	0.25	-	18.8	.75	2	3	8	2	22	36	[11]
Primary	1.04	-	-	.75	2	28	36	10	13	>54	[11]
Primary	1.04	-	56	.75	24	4	9	3	17	>54	[11]
Septic Tank	0.45	3.0	20	.75	3-6	8	4	3	25	~ 3	[15]
Extended Aer.	0.19	3.3	15.2	.75	3-6	3	9	0.3	34	~12	[15]
Lagoon (Summer)	0.19	9.7	36.4	.9	1	2	3	0.5	4.0	~ 1	[16]
Lagoon (Winter)	0.19	9.7	36.4	.9	1	9.4	9.6	4.6	1.0	~ 4	[16]

*Estimated from "oxygen consumed"
**Weekly raking 3 inches deep

TABLE 3
PERFORMANCE OF RECIRCULATING INTERMITTENT FILTERS***

Filter Characteristics: Eff. Size (mm)	Unif. Coeff.	Hyd. Loading (cm/d)	Depth (m)	Recycle (return/forward)	Dose	Effluent Quality (mg/l): BOD	SS	NH_3^-N	NO_3^-N	Mtnce	Reference
0.6-1.0	2.5		0.9	4/1	5-10 min/ 30 min	4	5	-	-	Weed/rake as req'd	[12]
0.3-1.5	3.5	12-20*	0.6	3/1-5/1	20 min/ 2-3 hr	15.8**	10.0**	8.4**	-	Rake 1/week	[17]
1.2	2.0	12*	0.9	4/1	5 min/ 30 min	4	3	-	-	Weed removal	[18]

*Based on forward flow
**Overall averages 12 inerallations (household flow to 25,000 L/day plant)
***Septic tank effluent

Normally, nitrogen will be transformed almost completely to the nitrate form provided the filter remains aerobic. The exchange capacity of most sand used is low and phosphorus removal after bed maturation is low. Use of calcareous sand or other high aluminum or iron materials intermixed within the sand may produce significant phosphorus removal. Chowdhry (ref.13) and Brandes et al (ref.14) reported phosphorus removals up to 90 percent when addition of 4 percent "red mud"(high in Al_2O_3 and Fe_2O_3) were made to medium sand. Intermittent filters are capable of reducing total and fecal coliform by 2 to 4 logs (ref. 7,13,15).

DESIGN CRITERIA

Table 4 summarizes suggested design criteria for intermittent granular filters used for onsite wastewater treatment. Loadings are based upon typical wastewaters generated in rural households in the U.S.A. (170L/capita/day).

TABLE 4
SUGGESTED DESIGN CRITERIA FOR INTERMITTENT FILTERS

ITEM	BURIED FILTERS	FREE ACCESS FILTERS: SEPTIC TANK EFFLUENT	AEROBIC EFFLUENT	LAGOON EFFLUENT	RECIRCULATING FILTERS
Media					
Depth (m)	0.6	0.5 Min	0.6 Min	0.75-0.9	0.6 Min
Effective size (mm)	.35-1.0	.35-1.0	.35-1.0	.15- .75	0.3-1.5
Uniformity Coefficient	<3.5	<4	<4	-	<4
Physical Configuration	Duplicate filters Each to handle 1/2 flow Dosing system	Duplicate filters Each to handle entire flow Dosing system	Single filter Dosing system	Duplicate filters Each to handle entire flow Dosing system	Single filter Recirculation tank Recirculation pump
Hydraulic Loading (cm/d)	3-5	20	20	32-60	12(Forward Flow)
(gal/dft²)	.75-1.25	5	5	8-15	3
Recirculation ratio	--	--	--	--	3:1-5:1
Dosing Schedule (No./day)	3-5	3-5	3-5	Continuous 24 hours	8-12

OPERATION AND MAINTENANCE

Intermittent filters require relatively little operational control or maintenance. Once wastewater is applied to the filter, it takes from a few days to two weeks before the sand has matured (ref.13,15). BOD and suspended solids concentrations in the effluent will normally drop rapidly after maturation. Depend-upon media size, rate of application, and ambient temperature, nitrification may take from 2 weeks up to 6 months to develop. Cold weather start-up should be avoided since maturation of the media may not fully develop (ref.1).

Clogging of the filter which is dependent upon organic loading to the filter, media size and uniformity will eventually occur as the pore space between the media grains begins to fill with inert and biological materials. Once hydraulic conductivity falls below the average hydraulic loading, permanent ponding will develop. Although effluent quality may not suffer initially, anaerobic conditions within the filter will result in further rapid clogging and a cessation of nitrification. Application of wastewater to the filter should be discontinued when continuous ponding occurs at levels in excess of 0.3 meters above the sand surface.

Since buried filters can not be easily serviced, the media size is normally large and hydraulic application rates are low (usually less than 5 cm/d). Proper pretreatment maintenance is of paramount importance. Free access filters, on the other hand, may be designed with finer media and at higher application rates. Experience has indicated that intermittent filters receiving septic tank influent will clog in approximately 30 and 150 days for effective sizes of 0.2 mm and 0.6 mm respectively (ref.15). Aerobically treated effluent can be applied at the same rates for up to 12 months if suspended solids are under 50 mg/l (ref.11,15). Results with recirculating filters using coarse media (1.0-1.5 mm) indicate filter runs in excess of one year (ref.18).

Maintenance of Media

Maintenance of the media includes both routine maintenance procedures and media regeneration upon clogging. These procedures apply to free access filters only. The effectiveness of routine raking of the media surface has not been clearly established, although employed in several studies (ref.1,9,12,15). Filters open to the air may require occasional weed removal as well. Cold weather maintenance of media may require different methods of wastewater application. Use of insulated covers have permitted trouble free winter operation in areas with ambient temperatures as low as -40°C(ref.15)

Eventually, filter clogging requires media regeneration. Raking of the surface will not in itself eliminate the need for more extensive rehabilitation (ref.1,15). The removal of the top layer of sand and replacement with clean sand when sand depths are depleted to less than 0.6 to 0.7 meters appears to be very effective for filters clogged primarily by a surface mat. In-depth clogging, however, often prevails in many intermittent filters requiring oxidation of the clogging materials. Resting of the media for a period of time has proven to be very effective in restoring filter hydraulic conductivity (ref.15).

Other Maintenance Requirements

The successful operation of filters is dependent upon proper maintenance of the pretreatment processes. The accumulation of scum, grease, and solid materials on the filter surface due to inoperative pretreatment will result in premature filter failure. This is especially critical for buried filters.

Routine maintenance requirements have not been well documented for intermittent filtration but visits on site should be made four times per year to check filters and their appurtenances. Based on a meager data base, unskilled manpower requirements for buried filter systems would be less than 2 man days per year for examination of dosing chamber and appurtenances and septic tank. Free access filters may require from 2 to 4 man days per year for media maintenance and placement and examination of dosing chamber, septic tank, and appurtenances. Power requirements would be variable, depending upon the dosing method employed, but should be less than 0.1 kwhr/d. The disposal of waste media from free access filters may amount to $0.08 m^3/m^2$ surface area each time media must be removed.

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