TECHNOLOGY ASSESSMENT

OF

INTERMITTENT SAND FILTERS

By

Damann L. Anderson
Robert L. Siegrist
Richard J. Otis

of

RSE, INCORPORATED
Engineers / Soil Scientists
5708 Odana Road
Madison, Wisconsin 53719

PROJECT OFFICER

James F. Kreissl
Wastewater Research Division
Municipal Environmental Research Laboratory

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

EXECUTIVE SUMMARY

Intermittent sand filtration of wastewater is not a new technology. Sand filters were often used by sewered communities around the turn of the century. However, as wastewater flows and land costs increased, they were replaced by mechanical treatment processes. Recently, as the need for low cost facilities in rural areas has grown, intermittent filters have received increased use again.

Intermittent sand filters are beds of medium to coarse sands, usually 24 to 36 inches deep and underlain with gravel containing underdrains. Primary or secondary effluent is intermittently applied to the surface and purification of the effluent occurs as it infiltrates and percolates through the sand bed. Underdrains collect the filtrate and convey it to additional treatment processes and/or discharge. Intermittent sand filter design concepts include buried filters, open single-pass filters and open recirculating sand filters.

Laboratory and field investigations have demonstrated that intermittent sand filters can produce very high quality effluents. Concentrations of effluent BOD_5 and TSS are typically less than 10 mg/L with ammonia nitrogen less than 5 mg-N/L. Only limited removal of phosphorus and fecal coliform bacteria are achieved, however. Design considerations important to achieving this level of treatment include pretreatment, media characteristics, hydraulic and organic loading rates, temperature and filter dosing techniques.

Operation and maintenance are important to achieving high levels of treatment and to maintain long filter runs. Raking of the sand surface, resting and periodic removal of the surface sand are commonly employed. Energy requirements of intermittent filters are less than approximately 0.28 HP-hr per 1000 gal. (0.055 kWh per m^3) of processed flow.

Intermittent sand filters compare favorably in economics and performance with extended aeration package plants and lagoon systems. Compared to extended aeration units, intermittent filters possess a lower present worth cost, consume substantially less energy, produce a more consistent and high quality effluent, but require more land area. Compared to facultative lagoons, intermittent filters possess a lower present worth cost, consume slightly more energy, produce a substantially higher quality effluent and require less land area. Operational requirements for these filters are significantly less than for extended aeration units, but more than for lagoons.

Intermittent sand filtration represents attractive wastewater treatment process that can satisfy the significant treatment needs of small communities. Treatment needs for communities with flows less than 0.106 MGD for which sand filtration is ideally suited, represent 63 percent of the total national needs to the year 2000. In addition to small community needs, many rural housing developments and business establishments can utilize sand filtration where site and soil conditions preclude the use of subsurface disposal systems.

Despite the long historical use of intermittent sand filters and the recent increase in their use, their performance capabilities have not been fully optimized. Further investigation is needed to optimize relationships between design criteria and performance

capabilities. The development of a data base regarding the design and performance of full-scale plants as well as their operation and maintenance requirements and costs would facilitate this effort and provide other needed data as well.

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TECHNOLOGY DESCRIPTION

INTRODUCTION

More than 23 percent of all housing units in the United States are beyond the reach of public sewers and approximately 350,000 new homes are being built each year in unsewered areas. Traditionally, wastewaters from these homes are treated and disposed of by septic tank-soil absorption systems. Many of these systems have failed because of unsuitable soil and site conditions, poor design and installation and lack of maintenance. Where failures are widespread, communities are forced to consider construction of public collection and treatment facilities.

Due to low population densities, conventional sewage collection and treatment is often too costly. It is not uncommon for residents of small communities to pay two or three times as much for sewer services as residents of larger municipalities. The impact of these user charges on family budgets can be quite severe because the average annual incomes in rural communities are significantly lower than in more urbanized areas. As a result, plans for construction of needed facilities are often rejected and public health hazards, nuisances and environmental degradation from improperly functioning septic tank systems continue while economic development is impeded. Less costly but equally effective alternatives to conventional sewerage are needed.

Significant savings to the community can be made by reducing the operation and maintenance costs of the treatment plant. The costs of construction are usually eligible for grant assistance from various funding agencies, but the day-to-day costs of operating and maintaining the facility must be borne solely by the community. Conventional treatment plants are often highly mechanized and require substantial attention by a skilled operator. Most small communities do not have the skilled personnel or financial resources to provide the needed operator. Simple, low maintenance treatment processes which can achieve required effluent standards or avoid effluent discharges into surface waters are needed if user charges are to be kept within realistic limits.

Intermittent sand filters are one such alternative which are ideally suited to rural communities, small clusters of homes, individual residences and business establishments. They can achieve advanced secondary or even tertiary levels of treatment consistently with a minimum of attention. They are also relatively inexpensive to construct and have low energy requirements. Because of these advantages, their use in rural management districts and small communities is expected to grow.

PROCESS DESCRIPTION

Intermittent sand filters are beds of medium to coarse sands, usually 24 to 36 in. deep underlain with gravel containing collection drains. Primary or secondary effluent is intermittently applied to the surface and percolates through the sand to the bottom of the filter. The underdrains collect the filtrate and convey it to additional treatment processes and/or discharge.

The treatment processes are complex, involving physical, chemical and biological mechanisms. Straining and sedimentation of suspended solids occurs between the sand grains and chemical sorption on the grain surfaces plays a role in the removal of some materials. However, it is the biological transformations that occur within the filter which are the most significant (Calaway, 1957). Since these are most efficient under aerobic conditions, intermittent application of the wastewater and venting of the underdrains helps to insure aeration of the sand. Biomass and associated waste byproducts develop during treatment and are retained within the filter. Biological degradation including endogenous respiration helps to minimize solids accumulations. However, with time, accumulations of biomass and other particulate matter may build up near the filter surface to such a degree that the sand bed must be rejuvenated to restore the hydraulic capacity of the filter to an acceptable level.

PROCESS DESIGNS

Buried Sand Filters

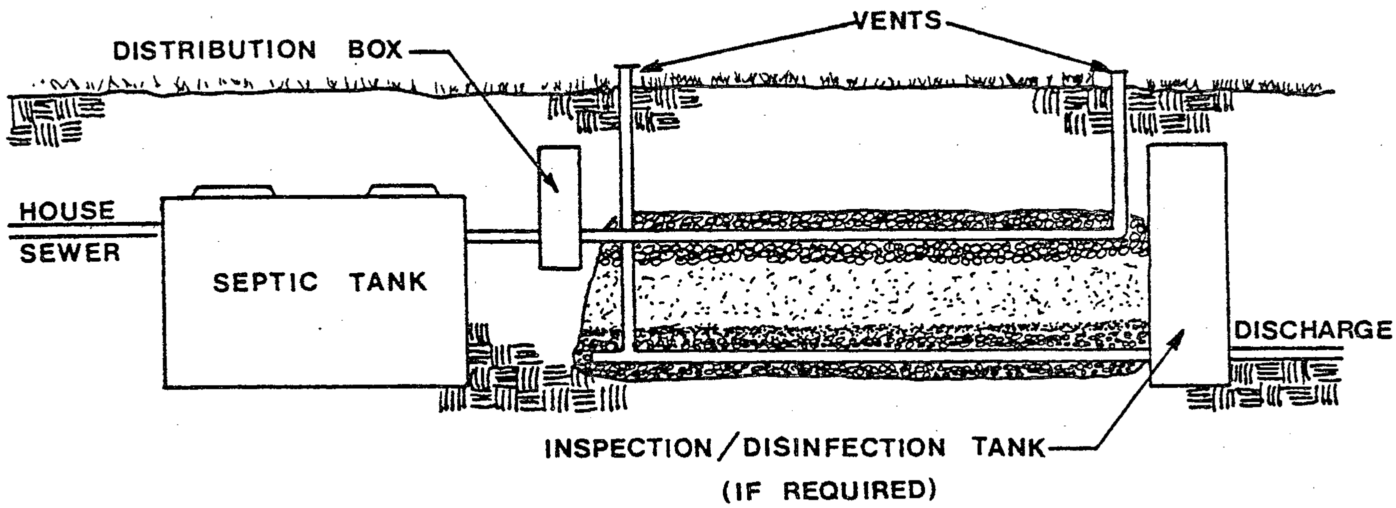
Buried sand filters are constructed below grade and covered with backfill material (Figure 1). A 4 to 5 foot deep excavation is generally made. The underdrains are surrounded by graded gravel or crushed rock and the upstream ends are brought to the surface and vented. A thin layer of fine gravel is commonly placed over the larger gravel to prevent piping of the filter sand into the underdrains. After placement of the filter sand, another layer of washed graded gravel or crushed rock is laid over the filter surface along with the distribution piping for wastewater application. These pipes are vented to the ground surface at their downstream end. The entire filter is then backfilled. Buried filter designs are most commonly used for very small flows such as those from single homes and small commercial establishments. These filters are designed to perform for very long periods of time (up to 20 years) without the need for operation and/or maintenance.

Open (Single Pass) Sand Filters

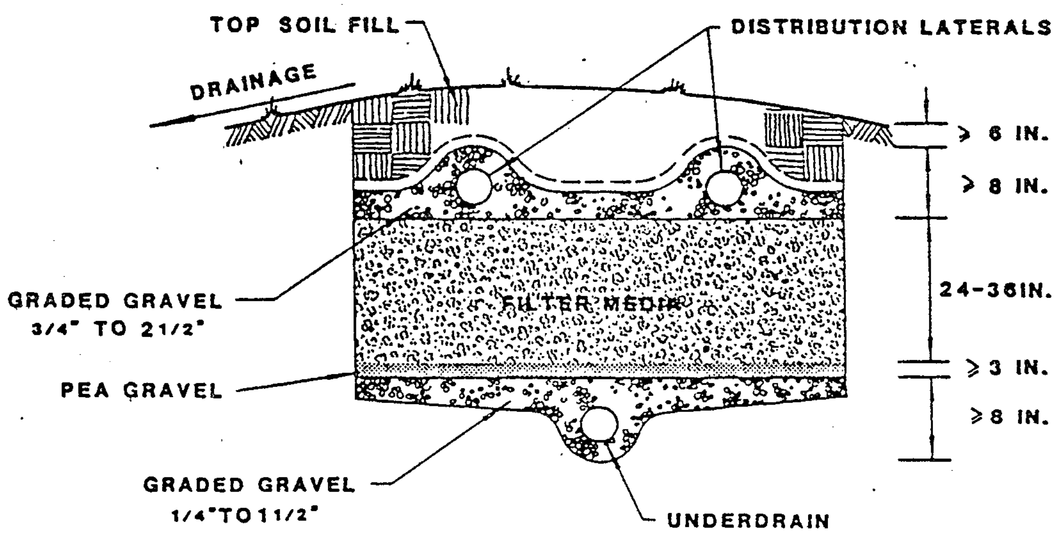
Open (single-pass) sand filters (Figure 2) are similar to buried sand filters except that the surface of the filter is left exposed and higher hydraulic and organic loadings are generally applied. In cold climates, removable covers may be used. In addition to perforated distribution piping, the wastewater may be applied by flooding the surface periodically or through spray distribution. These filters are used for individual homes as well as larger flows from small communities or industries (up to 0.2 MGD).

Recirculating Sand Filters

Recirculating sand filters are open filters which utilize somewhat coarser media and employ filtrate recirculation. Wastewater is dosed from a recirculation tank which receives both settled waste (e.g., septic tank effluent) and the filtrate (Figure 3). A recirculation rate of 3:1 to 5:1 is typical. A portion of the filtrate is diverted for further treatment or disposal during each dose or when the recirculation tank is full. (These filters have been applied to both individual homes and small communities (up to 0.2 MGD).



PROFILE



SECTION

Figure 1. Typical Buried Sand Filter

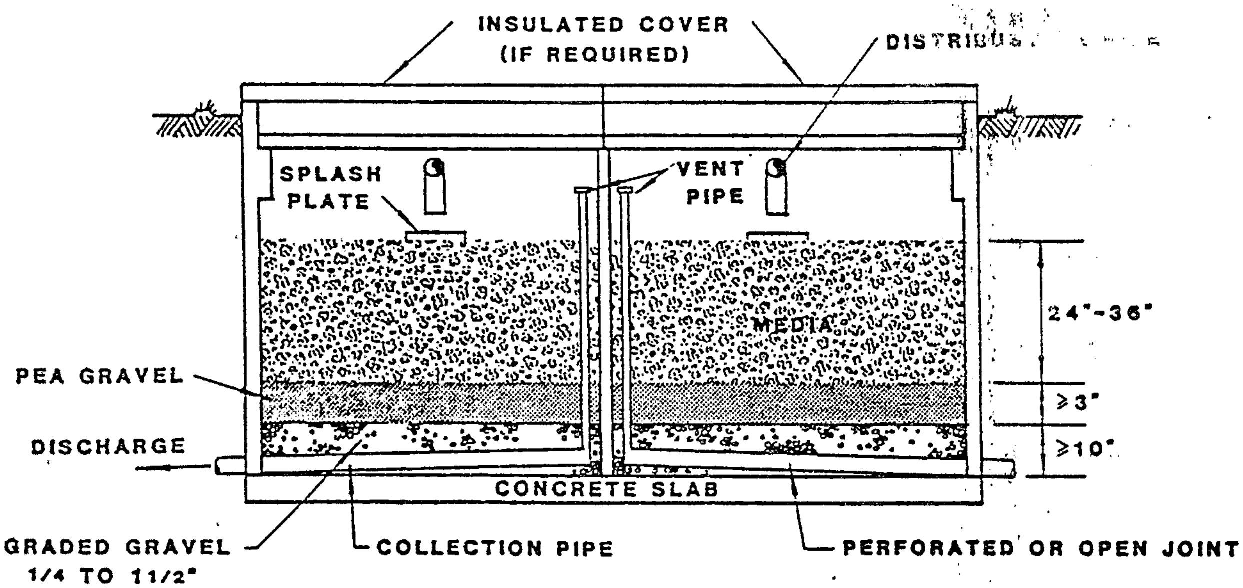


Figure 2. Open (Single-Pass) Sand Filter

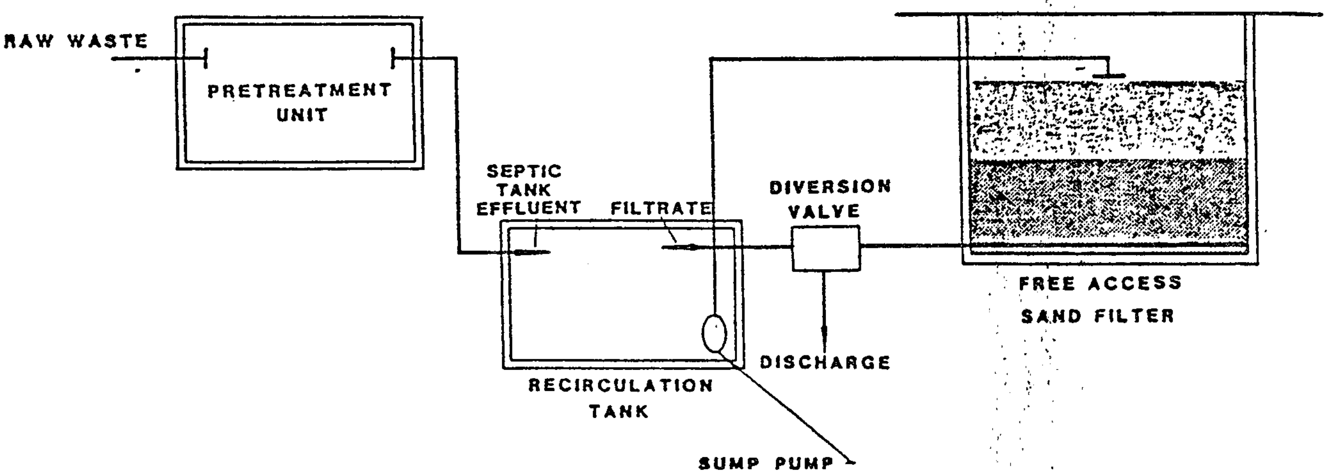


Figure 3. Typical Recirculating Sand Filter

SECTION 2

DEVELOPMENT STATUS

The full-scale use of intermittent sand filters as a secondary wastewater treatment process is in general not a new technology. They were frequently used by sewered communities around the turn of the century. However, as wastewater volumes increased and land costs rose, they were replaced by mechanical treatment processes. Only recently, as the need for low cost facilities in small communities is growing, have intermittent filters been re-employed. (Salvato, 1955; Teske, 1978; Evans, et. al., 1978; Ronayne, et. al., 1982; Curran, et. al., 1983).

The design and performance characteristics for a number of community-scale intermittent sand filters have been compiled in Tables 1 and 2. Most facilities are open surface filters of single-pass or recirculating design serving small communities with design flows up to approximately 120,000 gpd. Pretreatment consists of sedimentation/digestion in imhoff tanks or septic tanks. Individual filter units typically have surface areas of less than 11,600 ft^2 and media depths of 2 to 3 ft. Filter media are exclusively sand of medium to very coarse grain size (0.25 mm - 2.00 mm). Multiple filter units are provided with one or more standby units for use during filter maintenance or periods of increased flows. Filter effluent is disinfected using chlorine or ultraviolet irradiation with final disposal to infiltration basins, ditches or water courses. In some cases effluent is discharged into subsurface absorption trenches without disinfection. Table 1 lists several facilities for which data are available. Most of these facilities were put into operation since 1976, although one of these intermittent filters has been in operation since 1953.

The performance of full-scale intermittent sand filters, both single pass and recirculating, appear to be consistent with laboratory and field studies. A high quality effluent is produced. Concentrations of BOD_5 and TSS equal to 10 mg/L or less and nitrification of 80 percent or more of the applied ammonia are typically achieved (Table 2). Removals of phosphorus are limited and reductions in fecal coliform bacteria are less than two logs, slightly less than might be expected.

Further developments in intermittent sand filter technology as generally utilized today are likely. Several process modifications have been investigated as means of enhancing the effluent quality produced by intermittent filters. Increased removal of soluble organics and phosphorus has been demonstrated with mixed media of sand and chemically active substances such as silt and clay soils, limestone fragments or activated carbon (Schwartz, et. al., 1967; Brandes, et. al., 1975). Increased removal of coliform bacteria may be achieved with filters comprised of multiple layers of sand of decreasing particle size (Scherer and Mitchell, 1982). The application of modifications such as these in full-scale facilities awaits further demonstration.

A promising development in the application of intermittent sand filters involves their use prior to wastewater absorption in subsurface soil absorption systems. In this capacity, recent data suggests that sand filters may enable increased hydraulic loading rates, as much as 300 percent higher than typically possible with conventional septic tank effluent (Ronayne, et. al., 1982).

The equipment and hardware typically utilized in intermittent sand filters should be available locally in most municipalities. The critical component is the media, which often is also available locally.

Table 1. Example Community-Scale Sand Filter Systems

Location	Population Served[1]	Filter Type[2]	Design Flow (gpd)	Filter Media E.S. (mm)	Filter Media U.C. -	Filter Media Range (mm)	Filter Media Depth (ft.)	Design Loading (gpd/ft^2)	Filter Area Per Unit (ft^2)	Filter Area Units[3] (No.)	Pre-Filtration Treatment	Effluent Disposal	Start-Up Date
Community of Bluford, Jefferson, Co., IL	600 (A)	RSF	65,000	-	-	0.3-0.6	2.5	3	11550	2 (1)	Septic Tank	CL_2, Surface Ditch	1976
Community of Thompsonville, Franklin Co., IL	500 (A)	RSF	65,000	-	-	0.3-0.6	2.5	3	11550	2 (1)	Septic Tank	CL_2 Surface Ditch	1972
Miranda Comm. Serv. Dist. Miranda, CA	463 (D)	RSF	46,300	-	<2.5	1.0-1.5	3.0	3	4000	4 (3)	Septic Tank	CL_2, Infiltration Beds	12/82
Town of Dexter Dexter, OR	-	RSF	60,000	-	-	-	-	3	-	-		Absorption Trenches	4/83
Community of Cisne Wayne Co., IL	700 (A)	ISF	70,000	-	-	0.35-0.5	2.5	3	11600	2 (0)	Imhoff Tank	Stream	1953
Town of Sabbattus Sabbattus, ME	1500 (D)	ISF	120,000	0.44	<3.5	0.3-1.0	2.0	3	10000	6 (2)	Imhoff Tank	UV, River	12/82
Gardiner Sewer Dist. No. 1 Ulster County, NY	500 (A)	ISF	-	-	<3.5	0.30-0.60	2.5	-	5800	4 (?)	Septic Tank	CL_2 River	12/82
Town of Glover Glover, VT	49 (D)	BSF	7,000	0.2	3.5	-	2.5	1.4	5000	2 (1)	Septic Tank-Rock Filter	Surface Water	1983
Beecher City, IL	750 (D)	RSF	52,500	-	<3.5	0.25-1.0	2.0	3.0	4375	5 (1)	Septic Tank	Disinfection Surface Water	1983
Vassalboro, ME	750 (D)	ISF	27,000	0.25	4.0	-	2.5	2.0	7040	2 (0)	Septic Tank	Stream	10/82
Farmersville, IL	1250 (D)	ISF	125,000	0.35	3.5	-	-	15.0	5160	2 (0)	Lagoon	Surface Water	Spr./83
Hoyleton, IL	518 (D)	ISF	59,000	0.3	3.5	-	2.0	15.0	2520	2 (0)	Lagoon	Surface Water	Spr./82
Hanover, IL	1500 (D)	ISF	100,000	-	<3.5	0.6-0.8	1.5	10.0	5200	2 (1)	Stab. Pond	Surface Water	2/83
Newport Ctr., VT	364 (D)	BSF	41,500	-	3-6	0.25-0.6	2.5	1.1	18125	4 (2)	Septic Tank	Soil Absorption	10/82

1 (D) = Design population, (A) - Actual population (See Table 2).
2 Filter type: RSF = Recirculating sand filter; ISF = Intermittent (Single-pass) sand filter; BSF = Buried sand filter.
3 Filter units: Total number installed over (Number of installed units kept on standby).

Table 2. Performance Data for Community-Scale Sand Filter Systems

Location[1]	Type	Actual Flow	Filter Loading[2]	Influent/Effluent Quality												Data Period
				BOD_5 (mg/L)		TSS (mg/L)		NH_4-N (mg-N/L)		NO_3-N (mg-N/L)		P (mg-P/L)		FC (Log#/L)		
		(gpd)	(gpd/ft^2)	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	
Thompsonville, Franklin Co., IL	RSF	30,000	2.7	218	7	79	7	27.9	4.8	1.0	27.0	13.4	8.9	7.1	5.7	3/77-10/77
Miranda Comm. Serv. Dist. Miranda, CA	RSF	20,000	5.0	48	2	36	11	-	-	-	-	-	-	-	-	1/83-9/83
Community of Cisne, Wayne Co., IL	ISF	70,000	3.0	148	4	62	5	22.4	0.7	0.7	24.4	8.0	7.2	7.2	5.5	3/77-10/77
Town of Sabbattus, Sabbattus, ME	ISF	45,000	1.1	-	10	-	10	-	-	-	-	-	-	-	-	12/82-11/83
Town of Glover, Glover, VT	BSF	5,100	1.0	200	<1	150	<5	-	-	-	-	-	-	-	-	1983
Beecher City, IL	RSF	-	-	-	10	-	12	-	1.5-4.0	-	-	-	-	-	3.6	-
Vassalboro, ME	ISF	22,000	1.7	-	10-30	-	10-30	-	-	-	-	-	-	-	5.2	-
Hanover, IL	ISF	70,000	13.5	30	11	10	2	-	-	-	-	-	-	-	-	2/83-4/83

1 See Table 1 for system characteristics.

2 Measured during data period.

SECTION 3

TECHNOLOGY EVALUATION

PROCESS THEORY

It is known that physical, chemical, and biological treatment processes all occur to some degree within the filter. Straining, sedimentation, inertial impaction, interception, adhesion, flocculation, diffusion, adsorption and biological activity have all been suggested as mechanisms of contaminant removal in wastewater filtration (Tchobanoglous, 1968, 1970). Straining involves a mechanical sieve action as well as lodging of particles in crevices. Sedimentation occurs as gravity settling takes place in the interstices of the media. Inertial impaction, interception, and adhesion occur as particles moving through the filter strike media granules and are removed. Particles moving through the pores will also collide with each other and flocculate causing subsequent removal by other mechanisms. Diffusion is important in the removal of very small particles such as viruses, and occurs because of the small interstices in porous media and the fact that laminar flow exists. Physical adsorption of pollutants takes place on media surfaces due to electrostatic, electrokinetic and van der Waals forces while chemical adsorption occurs due to bonding and chemical interaction between wastewater constituents and the filter media. Biological activity on the filter media results in removal of polluting materials by biological assimilation and biosynthesis.

While physical and chemical processes play an important role in the removal of many materials by filtration, successful treatment of wastewaters by intermittent filtration is dependent upon the biochemical transformations occurring within the filter. Bacteria are the primary workers in intermittent sand filters, although there is a broad range of trophic levels operating within the filter, from bacteria to multi-cellular animals including the metazoa (Calaway, 1957).

Since filters entrap, sorb, and assimilate materials in the wastewater, the interstices between the grains may fill, and the filter may eventually clog. Clogging may be caused by physical, chemical, and biological factors. Physical clogging is normally caused by the accumulation of stable solid materials within or on the surface of the sand. It is dependent on grain size and porosity of the filter media and on wastewater suspended solids. The precipitation, coagulation, and adsorption of a variety of materials in wastewater may also contribute to the clogging problem in some filter operations (Schwartz, et. al., 1967). 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 imbalances. 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 likely occur simultaneously. Although the dominant clogging mechanism is dependent upon wastewater characteristics, method and rate of wastewater application, characteristics of the filtering media, and filter environmental conditions.

PROCESS CAPABILITIES AND LIMITATIONS

Intermittent sand filtration is well adapted to small flows wastewater treatment. The process is applicable to single homes, clusters of dwellings and small communities. The wastewater applied to the intermittent filters should be pretreated at least by sedimentation.

Normal site contraints other than land availability should not limit the application of intermittent sand filters, although odors from open filters receiving septic tank effluent may require a suitable buffer zone between the system and nearby dwellings Filters are often partially (or completely) buried in the ground, but may be constructed above ground when dictated by shallow bedrock or high water tables. Covered filters are required in areas with extended periods of subfreezing weather. Excessive long-term rainfall and runoff on submerged filter systems is detrimental to performance, requiring appropriate measures to divert these sources away from the system.

The degree of stabilization attained by an intermittent sand filter is dependent upon the characteristics of the wastewater applied to the filter and the environmental conditions within the filter.

Since intermittent sand filtration is largely a biological process, the characteristics of the applied wastewater affect the purification achieved. Domestic wastewaters are very amenable to sand filtration, whereas wastewaters resistant to biodegradation may result in poor performance.

Temperature and reaeration are two of the most important environmental conditions that affect the degree of wastewater purification through an intermittent sand filter. Temperature directly affects the rate of microbial growth, chemical reactions, adsorption mechanisms, and other factors that contribute to the stabilization of wastewater within the sand media. Availability of oxygen within the pores allows for aerobic decomposition of the wastewater and almost complete stabilization of substances that are readily biodegradable. Under aerobic conditions, the major end products of biochemical stabilization of carbonaceous and nitrogenous substances are water, carbon dioxide, bicarbonates, sulfates, phosphates, and nitrates. In the absence of oxygen, carbonaceous material may be converted to carbon dioxide and methane, but nitrogenous substances degrade only to ammonia, and cannot be oxidized to nitrate.

The selection of process design variables affects the degree of purification of wastewater achieved by intermittent filters. Variables should be chosen to optimize the previously discussed factors while providing a practical, manageable treatment system. A discussion of design considerations is presented in the next section.

DESIGN CONSIDERATIONS

There are many variables which affect the operation and performance of intermittent sand filters (ISF's). Some can be specified in design and some cannot. Although an enormous amount of information is available in the literature regarding intermittent filters, the confounding effects of the many variables make it difficult to come up with simple relationships between design and performance factors.

Design considerations for sand filter systems include:

- Pretreatment
- Media size, uniformity and composition
- Media depth
- Hydraulic loading rate
- Organic loading rate
- Temperature
- Dosing techniques and frequency

Pretreatment

The operation and performance of ISF's are directly related to the degree of pretreatment of the applied wastewater. Schwartz, et. al. (1967) showed a direct relationship between degree of pretreatment and both hydraulic longevity and effluent quality in lysimeter studies with 0.20 mm Ottawa sand loaded at 5 gpd/ft^2. Comparisons of intermittent sand filtration of household aerobic unit effluent and septic tank effluent have also shown higher acceptance rates of wastewater infiltration, longer filter runs, ("filter run" is defined as the service time during which the filter successfully accepts and treats the design flow) and equal or better effluent quality with the additional pretreatment (Sauer, 1975; Stothoff, 1976).

Media

The successful use of a granular material as a filter media is dependent upon the proper choice of size and uniformity of the grains. The effective 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 wastewater retention time to a point where adequate biological decomposition is not attained. Too fine a media limits the quantity of wastewater that may be successfully filtered due to early filter clogging. Effective size alone can be misleading when describing media size. Sands of similar effective size but different uniformity coefficient can produce significantly different performance characteristics. Metcalf and Eddy (15) and Boyce (16) recommended that not more than 1% of the media should be finer than 0.13 mm. Recommended filter media effect sizes range from a minimum of 0.40 mm up to approximately 1.5 mm. Uniformity coefficients (UC) for intermittent filter media normally should be less than 4.0. (PHS, 1967; Glumrb, 1960; ASCE, 1937; Salvato, 1955; WPCF, 1977; EPA, 1980).

Granular media other than sand that have been used include anthracite, garnet, ilmenite, activated carbon, and mineral tailings. Alternate media such as these must be durable and insoluble in water. Any clay, loam, limestone, or organic material may increase the initial adsorption capacity of the sand, (usually for phosphorus removal) but may lead to a serious clogging condition as the filter ages. Any non-sand media should conform to the same reuqirements discussed herein for sand and have a total organic content of less than 1%, total acid soluble matter less than 3%, hardness of less than 3 on the Moh's scale, and be genreally rounded in shape.

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 often does not occur due to construction practices and variations in local materials. Abrupt textural changes will create zones of saturation which can act as water seals and can limit oxidation, promote clogging, and reduce the action of the filter to a mere straining mechanism. The use of media with a UC of less than 4.0 minimizes this problem. The media arrangement of coarse over fine appears theoretically to be the most favorable, but it may be difficult to maintain such a filter due to internal clogging throughout the filter.

Media Depth

Media depths used in intermittent sand filters were initially 4 to 10 feet. However, studies revealed that most of the purification of wastewater occurred within the top 9 to 12 inches (23 to 30 cm.) of the bed (Clark and Gage, 1909; Emerson, 1945; Furman, et.

al., 1955), with the additional bed depth improving purification only slightly. Later studies confirmed this but pointed out the need for the additional depth from a moisture standpoint (Schwartz, et. al., 1967). The capillarity of sand causes high moisture contents in the deeper sand limiting aeration and thus the bacterial oxidation process. Schwartz, et. al. (1967) reported satisfactory ammonia removals (greater than 80%) only for unsaturated depths of 4 feet (1.2 meters) or greater and showed a direct relationship between filter depth and filter run length in 0.20 mm effective size Ottawa sand loaded with 5 gpd/ft^2 of septic tank effluent. These results were attributed to the fine sand used and the high degree of capillarity of such sand. It is critical to maintain sufficient depth of sand so that the zone of capillarity does not infringe on the zone required for treatment. For these reasons most media depths used today range from 24 to 42 inches (62-107 cm.). The use of shallower filter beds helps to 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 (Brandes, 1970), and permit the removal of more media before media replacement becomes necessary.

Hydraulic Loading Rate

The hydraulic loading is normally expressed as gallons per day per square foot (gpd/ft^2), or as centimeters per day (cm/day). Values of recommended loading rates for intermittent sand filtration vary throughout the literature and range from 0.75 to 5 gpd/ft^2 (3.1 to 20.4 cm/day). Higher hydraulic loading rates are normally applied to filters with larger media size or those receiving higher quality wastewater. Higher hydraulic loadings of a given wastewater produce correspondingly shorter filter runs. The relationship between hydraulic loading and effluent quality is unclear and depends on other design factors. In general, increased hydraulic load causes a decrease in effluent quality for a given media.

Organic Loading Rate

Organic loading rates are not often reported in the literature, however, previous studies have indicated that the performance of ISF's is affected by the accumulation of organic material in the filter bed (Schwartz, et. al., 1967; Clark and Gage, 1909). To account for differences in organic strength of various wastewaters, hydraulic loading rates are often adjusted for the type of wastewater. Hydraulic loading rates may be increased in direct proportion to the degree of pretreatment. A specific relationship between organic loading rate and effluent quality is not clear but Schwartz, et. al. (1967), showed that effluent COD levels as well as COD removals were directly proportional to influent COD strength for 0.20 mm Ottawa sand loaded at 5 gpd/ft^2 with different waste types. Like hydraulic loading, higher organic loading rates produce correspondingly shorter filter runs. One of the conclusions of the early ISF work performed at the Lawrence Experiment Station from 1887 to 1908 was that the volume of sewage that can be purified by intermittent sand filtration is dependent upon the amount of organic matter present in the wastewater rather than the volume of wastewater in which this organic material is held (Clark and Gage, 1909).

Temperature

Temperature directly affects the rate of microbial growth, chemical reactions, adsorption mechanisms, and other factors that contribute to the stabilization of wastewater within an intermittent sand filter. Somewhat better operation and performance therefore may be expected from filters in warmer locales. For filters operated in cold climates, it has been suggested that the temperature at which the filter is started and matured is an important consideration. Schwartz, et. al. (1967) reported tha started in warm weather significantly outperformed those started in cold w regards to hydraulic longevity (filter run length) as well as effluent quality.

Dosing Techniques and Frequency

The method of application of wastewater to an intermittent sand filter is important to the performance of the process. A dosing system should provide uniform distribution of wastewater throughout the filter cross-section. Sufficient time must also be provided between doses to allow reaeration of the pore space. Dosing methods used include ridge and furrow application, drain tile distribution, surface flooding, and spray distribution methods.

The frequency of dosing intermittent sand filters is important to their performance. Most of the earlier studies used a dosing frequency of 1/day, but studies in Florida concluded that better performance and treatment was obtained with dosings of 2/day on sands with effective sizes ranging from 0.25 to 0.46 mm (Grantham, et. al., 1949; Furman, et. al., 1955). Other studies have shown that dosing frequencies beyond 2/day provide no additional benefit for fine to medium sand sizes (Clark and Gage, 1909; Furman, et. al., 1955; Schwartz, et. al., 1967). For filters with media greater than about 0.45 mm, it has been concluded that better purification is obtained when the frequency of dosing is increased beyond twice per day. This is because the lower retention capacity of the coarser media limits the amount of wastewater that should be applied at one time (Clark and Gage, 1909; Furman, et. al., 1955). This multiple dosing concept is successfully used in recirculating sand filter systems which employ a dosing frequency of once every 30 minutes (Hines and Favreau, 1975).

Summary of Design Considerations

While no specific relationships have been developed between design and performance factors discussed in this section, general trends can be predicted for these relationships based on the results of laboratory and field investigations. Table 3 summarizes some of these trends between design considerations and the performance factors effluent quality, length of filter run, and cost. Example design values for three types of intermittent filters are summarized in Table 4.

Table 3. SUMMARY OF GENERAL TRENDS BETWEEN DESIGN AND PERFORMANCE FACTORS.

Design Factors	Performance Factors: Effluent Quality	Performance Factors: Filter Run Length	Performance Factors: Capital Cost of ISF
Increasing Pretreatment	↑	↑	↓
Increasing Media Effective Size $\bar{w}$ u.c. ≤ 4.0	↓	↑	Dependent on Local Availability
Increasing Filter Depth	Very little effect past 24"-36" depending on sand size	Very little effect past 24"-36" depending on sand size	↑
Increasing Hydraulic Loading Rate	↓	↓	↓
Increasing Organic Loading Rate	↓	↓	↓
Increasing Operating Temperature	↑	↑	↓
Increasing Dosing Frequency	↑ Medium to Coarse Sand; Very little effect Fine to Medium Sand	↑ Medium to Coarse Sand; Very little effect past Fine to Medium Sand	Very little effect

NOTE: This figure shows only general trends suggested from a review of studies on intermittent sand filtration; however, it should be noted that many of the factors shown are interrelated and therefore must be considered together on design. Upward pointing arrows indicate an increase in the factor described, while a downward pointing arrow indicates a decrease.

Table 4. EXAMPLE DESIGN VALUES

Design Factor	Buried	Open	Recirculating
Pretreatment	- - - - - - - - - Minimum of Sedimentation - - - - - - - - -		
Media			
Material	- - - - - - - Washed, Durable Granular Material - - - - - - -		
Effective Size	0.40-1.00 mm	0.40-1.00 mm	0.40-1.5 mm
Unif. Coeff.	<4	<4	<4
Depth	24-36 inches (61-91 cm)	24-36 inches (61-91 cm)	24-36 inches (61-91 cm)
Hydraulic Loading	<1.5 gpd/ft^2 (<6.1 cm/day)	2-5 gpd/ft^2 (8.2-20.4 cm/day)	3-5 gpd/ft^2* (12.2-20.4 cm/day)
Organic Loading	- - - - - <5 x 130^{-3} lbs. BOD$_5$/day/ft^2 - - - - - (<2.4 x 10^{-2} kg. BOD$_5$/day/m^2) - - - - -		
Media Temperature	- - - - - - - - - - - - - >5° C - - - - - - - - - - - - -		
Dosing Frequency	>2 per day	>2 per day	5 - 10 min/30 min.
Recirculation Ratio	NA	NA	3:1 to 5:1

+ Values given are based upon past experience and current practice. They are not necessarily optimum values for a given performance objective. See text for discussion.

* Based upon forward flow only.

FILTER PERFORMANCE

A summary of the performance of selected intermittent sand filters treating domestic wastewaters appears in Tables 5 - 6. These tables illustrate that intermittent filters produce high-quality effluents with respect to BOD_5 and suspended solids. Normally, nitrogen is transformed almost completely to the nitrate form. Rates of nitrification may decrease in winter months as temperatures fall. Some denitrification can occur in single-pass filters and produce total nitrogen removals of 0-50%.

Total and ortho-phosphate concentrations can be reduced up to approximately 50% in clean sand; but the exchange capacity and phosphorus removal of sand after maturation is low. Use of calcareous sand or other high-aluminum or iron materials intermixed within the sand may produce significant phosphorus removal. (Chowdhry, 1974, Brandes, et. al. 1975). Intermittent filters are capable of reducing total and fecal coliforms by 2 to 4 logs, producing effluent values ranging from 1,000 to 100,000 and 100 to 3,000 per 100 ml, respectively (Schwartz, et. al., 1967; Chowdhry, 1974; SSWMP, 1978; Salvato, 1955).

Table 5. Performance of Open Intermittent Filters

Wastewater Source	Media Characteristics				Loading Rates		Effluent Quality				Filter Run Months	Ref.
	E.S. (mm)	U.C.	Depth (in.)	Dose Freq. # /day	Hyd. Loading gpd/ft^2	Org. Loading lb. BOD/d/ft^2	BOD_5 mg/L	SS mg/L	NH_3-N mg/L	Total -N % Removal		
Septic Tank Tank	0.23 0.26	–	60	–	4.5	3.5×10^{-3}	23[a]	–	8.0	–	6–9[b]	9.
Septic Tank	0.41	–	48	–	2.3	1.4×10^{-3}	11[a]	–	3.0	–	6–9[b]	9.
Primary	0.25	2.2	30	1	2.8	3.5×10^{-3}	7	6	1.8	15	5	15.
Primary	0.46	2.8	30	1	2.9	3.8×10^{-3}	21	8	4.8	21	6	15.
Primary	0.25	2.2	30	2	4.7	4.9×10^{-3}	3	8	2.0	21	33	15.
Primary	0.46	2.8	30	2	4.9	5.3×10^{-3}	19	15	4.2	10	36	15.
Primary	1.04	1.7	30	2	7.0	7.5×10^{-3}	35	45	10.4	9	40	13.
Primary	1.04	1.7	30	24	14.0	12.0×10^{-3}	4	9	3.0	0	40	13.
Septic Tank	0.45	3.0	24"	4–13	5	5.2×10^{-3}	9	7	0.9	0	3.9	30.
Extended Aer. Unit	0.19	3.3	24"	2.5	3.5	0.8×10^{-3}	4	11	0.3	4	9	30.
Septic Tank	0.44	2.5	30"	3.3	3.8	3.7×10^{-3}	4	11	0.4	20	18	40,41.
Extended Aer. Unit	0.44	2.5	30"	4.5	5.0	1.7×10^{-3}	3	33	0.2	0	18	40,41.
Septic Tank[c]	0.14–0.30	1.5–4.0	24"	2–5	0.3–0.7	$0.6\text{–}1.1 \times 10^{-3}$	3	10	0.2	47	5–49	24.
Stab. Pond (Summer)	0.17	9.7	36"	1	9.1	1.5×10^{-3}	2	3	0.5	–	1	22.
Stab. Pond (Winter)	0.17	9.7	36"	1	9.1	1.4×10^{-3}	5	5	2.4	–	4	[illegible]

[a] Estimated from oxygen consumed; [b] Weekly raking 3 inches deep; [c] Average of 7 sites.
BOD_5 = 3 x oxygen consumed

Table 6. Performance of Recirculating Intermittent Filters Treating Septic Tank Effluent

Filter Characteristics						Effluent Quality				
Effective Size	Unif. Coeff.	Hydraulic Loading[a]	Depth	Recirculation Ratio	Dose	BOD	SS	NH_3-N	Mtnce.	Ref.
mm		gpd/ft^2	in.	r/Q		mg/L	mg/L	mg/L		
0.6 - 1.0	2.5	3.0	36	4:1	5-10 min every 30 min.	4	5	-	Weed/Rake as Req'd.	18.
0.3 - 1.5	3.5	3.0 - 5.0	24	3:1 - 5:1	20 min every 2-3 hr	15.8[b]	10.0[b]	8.4[b]	Rake Weekly	39.
1.2	2.0	3.0 (1.45 actual)	36	4:1	5 min every 30 min	3	4	0.45	Weed as Req'd.	24.

[a] Design loading based on forward flow.

[b] Average for 12 installations (single home to 65,000 gpd plant).

OPERATION AND MAINTENANCE

Intermittent sand filters require relatively little operational control or maintenance. Once wastewater is applied to the filter, it takes from a few days to several weeks before the sand has matured (Schwartz, et. al., 1967; SSWMP, 1978). BOD and SS concentrations in the effluent will normally drop rapidly after maturation. Depending upon media size, rate of application, and ambient temperature, nitrification may take from 2 weeks up to 6 months to develop. Winter start-up should be avoided since the biological growth on the filter media may not develop properly (Schwartz, et. al., 1967).

Clogging of the filter eventually occurs as the pore space between the media grains begins to fill with inert and biological materials. The operational period before clogging occurs is a function of the design factors discussed previously. Once hydraulic conductivity falls below the average hydraulic loading, permanent ponding occurs. Although effluent quality may not initially suffer, anaerobic conditions within the filter result in further rapid clogging and a cessation of nitrification. Application of wastewater to the filter should be discontinued when continuous ponding occurs.

Maintenance of the media includes both routine maintenance procedures and media regeneration upon clogging. These procedures apply to open filters only. Buried filters are designed to perform without maintenance for up to 20 years. The effectiveness of routine raking of the media surface has not been clearly established, although employed in several studies (SSWMP, 1978; Schwartz, et. al., 1967; Clark and Gage, 1909; Hines and Favreau, 1975). Filters open to sunlight require weed removal. Cold weather maintenance of media may require different methods of wastewater application, including ridge and furrow and continuous flooding. These methods are designed to eliminate ice sheet development. Use of insulated covers may permit trouble-free winter operation in areas with ambient temperatures as low as -40° F (SSWMP, 1978).

Eventually, filter clogging requires media regeneration. Raking of the surface may not in itself eliminate the need for more extensive rehabilitation (SSWMP, 1978; Schwartz, et. al., 1967). The removal of the top layer of sand, as well as replacement with clean sand when sand depths are depleted to less than 24 to 30 in. (61 to 76 cm.), appears to be very effective for filters clogged primarily near the surface. This includes filters receiving secondary effluent (SSWMP, 1978). In-depth clogging can occur which requires oxidation of the clogging materials. Resting of the media for a period of months has proven effective in restoring filter hydraulic conductivity (SSWMP, 1978).

A distinct advantage of intermittent sand filtration systems is the low energy requirements in comparison to systems which offer comparable effluent quality. Open intermittent sand filters using pumped dosing should only require approximately 0.07 HP-hr per thousand gallons (0.013 kWh per m^3) assuming a 10 foot (3.05 m) pumping head and pump efficiency of 60%. With the same assumptions and a 3:1 recirculation ratio (Recycle: Forward Flow) a recirculating intermittent sand filter would require approximately 0.28 HP-hr per thousand gallons (0.055 kWh per m^3).

SECTION 4

COMPARISON WITH EQUIVALENT TECHNOLOGY

Intermittent sand filtration of partially treated wastewater is primarily a biological wastewater treatment process. It may be further characterized as an advanced secondary treatment process as it achieves significant reductions in BOD_5 and TSS as well as nearly complete nitrification. Representative conventional treatment alternatives which might be acceptable to authorities but not equivalent in terms of effluent quality include extended aeration package plants and potentially facultative lagoon systems. A comparison was made between intermittent sand filters and these two processes in terms of costs, energy consumption, performance and land area requirements.

COSTS

The costs to install and operate comparable wastewater facilities were estimated to enable a cost comparison of single-pass and recirculating sand filters to facultative lagoons and extended aeration package plants. Two different size facilities, 5,000 and 30,000 gpd, were considered. Despite the inherent inaccuracies in cost estimation comparisons, intermittent sand filters appear to possess present worth costs in the range of those associated with facultative lagoons and extended aeration package plants (Tables 7 and 8).

ENERGY REQUIREMENTS

Reduced energy consumption represents a potentially significant advantage of intermittent sand filtration over extended aeration. The estimated energy consumption of single-pass and recirculating sand filters is generally less than 10% of that of extended aeration (Table 9). Energy requirements of facultative lagoons are often very low, comparatively less than those of single-pass filters.

PERFORMANCE

Under normal operating conditions, intermittent sand filters will produce high quality effluents, significantly better than that produced by extended aeration package plants and definitely superior to that achieved with conventional facultative lagoons (Table 10). Concentrations of BOD_5 and TSS of 10 mg/L or less are typically achieved through intermittent sand filtration as compared to 30 and 30 mg/L for extended aeration units (Hinrichs, 1978). Effluent qualities from facultative lagoons are characteristically somewhat poorer than either sand filters or extended aeration plants. Effluent BOD_5 concentrations range from 20 to 60 mg/L, but TSS concentrations fluctuate even more widely (USEPA, 1983). TSS values of up to 150 mg/L are not uncommon in warmer periods due to the presence of algal solids.

Table 7. COST COMPARISON[1] — 5,000 GPD FACILITY

Cost	Lagoon	Extended Aeration	Single-Pass Filter	Recirculating Filter
Capital Costs				
Construction Costs				
Septic Tank Pretreatment	-	-	1,900	1,900
Pumping System	-	-	2,140	4,170
Sand Filters	-	-	9,780	8,650
Aeration Package Plant	-	21,770	-	-
Lagoon	18,660	-	-	-
Subtotal	18,660	21,770	13,810	14,710
Non-Component Costs[2]	2,610	3,050	3,870	4,122
Engineering[3]	3,190	3,720	2,650	2,826
Contingencies[3]	3,190	3,720	2,650	2,826
Land[4]	3,900	500	750	650
Total	31,550	32,760	23,730	25,144
Annual O & M Costs				
Labor @ $10/hr.	2,400	4,800	2,400	2,400
Power @ 7¢/kwH	Neg.	610	10	30
Chemicals	Neg.	Neg.	Neg.	Neg.
Sludge Disposal @ 3.5¢/gal.	Var.	170	170	170
Subtotal	2,400	5,580	2,580	2,600
Present Worth Costs[5]	56,300	90,200	50,300	51,901

1 Costs included for only those unit processes shown (first quarter, 1982 dollars)

2 Non-component costs (e.g., piping and electrical) estimated to equal 28 percent of construction costs for all processes except the lagoon system, for which 14 percent was used.

3 Costs were each estimated to equal 15 percent of construction costs.

4 Land costs were estimated at $5,000 per acre with total land requirements equal to 300 percent of unit process land area.

5 20 year life at 7-3/8 percent interest rate (PWF = 10.2913).

Table 8. COST COMPARISON[1] 30,000 GPD FACILITY

Cost	Lagoon	Extended Aeration	Single-Pass Filter	Recirculating Filter
Capital Costs				
Construction Costs				
Septic Tank	-	-	7,320	7,320
Pumping System	-	-	4,560	13,700
Sand Filters	-	-	68,060	44,480
Aeration Package Plant	-	71,970	-	-
Lagoon	110,950	-	-	-
Subtotal	110,950	71,970	9,[illegible]40	65,500
Non-Component Costs[2]	15,530	10,080	22,380	18,340
Engineering[3]	18,970	12,310	15,350	12,580
Contingencies[3]	18,970	12,310	15,350	12,580
Land[4]	23,500	500	4,400	3,440
Total	187,920	107,170	137,420	112,440
Annual O & M Costs				
Labor @ $10/hr.	4,800	9,600	4,800	4,800
Power @ 7¢/kwH	Neg.	3,680	40	160
Chemicals	Neg.	Neg.	Neg.	Neg.
Sludge Disposal @ 3.5¢/gal.	Var.	1,020	1,020	1,020
Subtotal	4,800	14,300	5,860	5,980
Present Worth Costs[5]	237,300	254,300	197,700	173,970

1 Costs included for only those unit processes shown.

2 Non-componenet costs (e.g., piping and electrical, estimated to equal 28 percent of construction costs for all processes except the lagoon system, for which 14 percent was used.

3 Costs were each estimated to equal 15 percent of construction costs.

4 Land costs were estimated at $5,000 per acre with total land requirements equal to 300 percent of unit process land area.

5 20 year life at 7-3/8 percent interest rate (PWF = 10.2913).

Table 9. ESTIMATED ENERGY CONSUMPTION OF INTERMITTENT SAND FILTERS (kWh/yr)

Unit Process Size (gpd)	Intermittent Sand Filters*		Extended Aeration+
	Single-Pass	Recirculating	
10,000	180	770	15,800
25,000	455	1,915	39,400
50,000	910	3,830	49,100

*Estimated energy consumption due to pumping of effluent onto filter.
+Estimated energy consumption due to pumps and blowers (SCS Engr., 1977).

Table 10. ESTIMATED TREATMENT PERFORMANCE BY PROCESS TYPE

Process	Removal Efficiency (%)		Effluent Quality (mg/L)	
	BOD_5	SS	BOD_5	SS
Single-pass Sand Filter	85-95	70-90	5-10	5-10
Recirculating sand filter	85-95	70-90	5-10	5-10
Extended Aeration	85-90	75-90	20-30	20-50
Facultative Lagoon	70-90	25-85	20-60	30-150

Intermittent sand filters are inherently very stable wastewater treatment processes compared to biological package plants such as extended aeration. With limited supervision and control of operating conditions, sand filters can produce consistently high quality effluents (BOD_5 and TSS _ 10 mg/L). In contrast, good supervision and operating conditions are essential for extended aeration plants to consistently maintain BOD_5 and TSS effluent concentrations below 30 mg/L (SCS, 1977). As a fixed film process, sand filters should be less subject to upsets and poor effluent quality than suspended growth processes such as extended aeration package plants. Facultative lagoon systems have a reputation for fluctuating effluent qualities, particularly with respect to TSS, in response to climatic influences and other factors. Careful operation of these facilities (controling pond water levels, distribution between cells, and controlled discharge) can minimize the fluctuations and need for post-treatment prior to surface discharge.

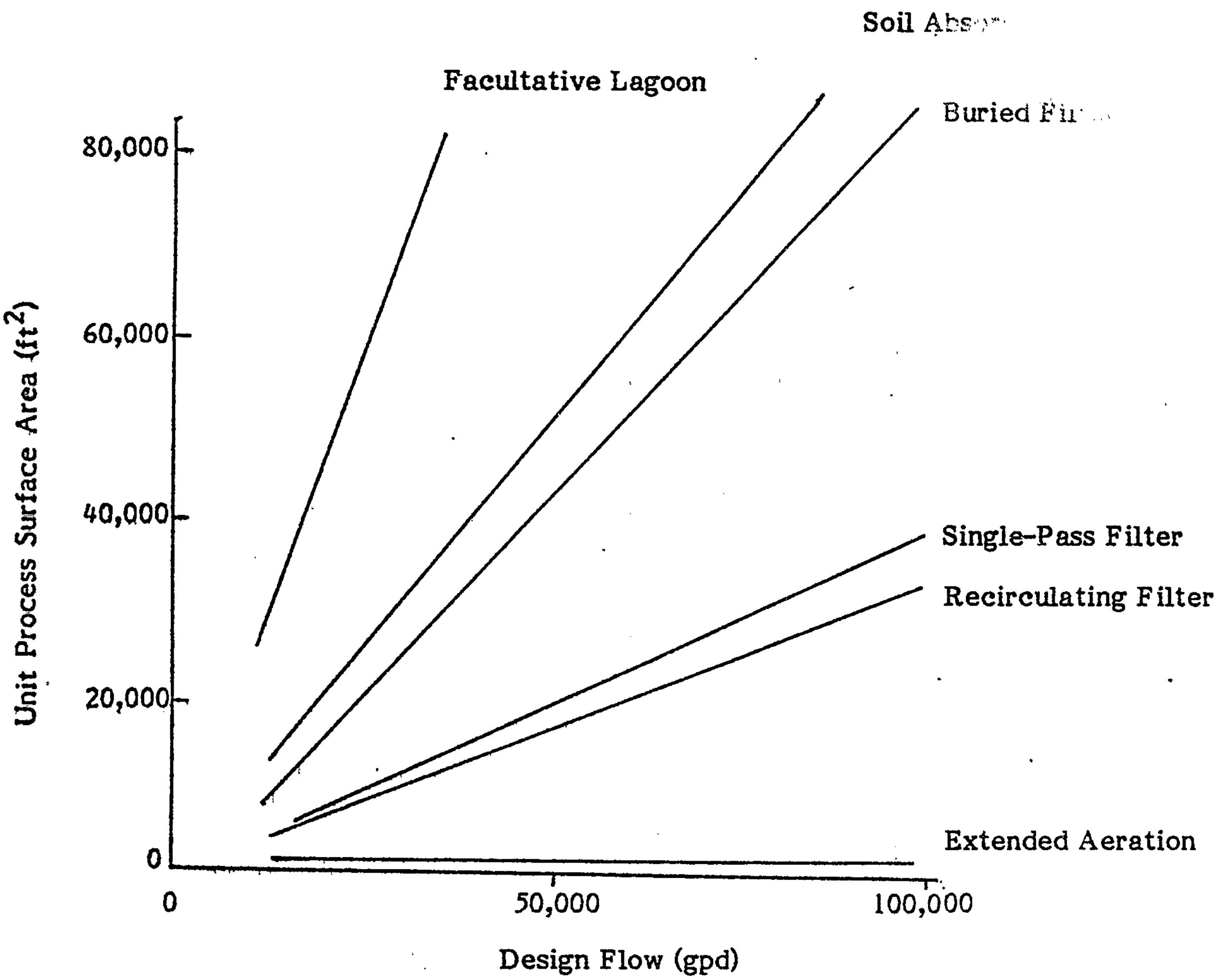
LAND AREA REQUIREMENTS

Intermittent sand filter units require substantial land areas as their hydraulic loading rates, are typically 5 gpd/ft^2 (20 cm/d) or less. Figure 4 summarizes the estimated surface areas required for intermittent sand filters, facultative Lagoons, extended aeration units and subsurface soil absorption beds. These area requirements are for the unit process above and do not include area for standby units, pre-treatment or post-treatment units, control rooms, access roads, fencing, etc.

Using the package plant area requirements as a baseline, the following ratios were estimated for the areas required by the other processes:

- Extended Aeration - 1.0 x
- Recirculating Filter - 17.5 x
- Single-pass Filter - 21.0 x
- Buried Filter - 45.6 x
- Soil Absorption Bed - 52.4 x
- Facultative Lagoon - 118.8 x

Single-pass and recirculating sand filters require land areas greater than that required by extended aeration units, but substantially less than that of a facultative lagoon. Buried sand filters require substantially greater land areas than open filters but less than soil absorption beds or facultative lagoons.



NOTE: Unit process surface area based upon following:

Soil Absorption Bed: $A = (Q \div 1.0 \text{ gpd/ft}^2)$
Buried Filter: $A = (Q \div 1.15 \text{ gpd/ft}^2)$
Recirculating Filter: $A = (Q \div 3.0 \text{ gpd/ft}^2)$
Single-pass Filter: $A = (Q \div 5.0 \text{ gpd/ft}^2) \times 2$ parallel units
Extended Aeration: $A = (Q \times 1\text{d} \div 10 \text{ ft})$
Lagoon: $A = (Q \times 90\text{d} \div 5.3 \text{ ft})$

The areas shown are for the unit processes alone and do not include areas required for other treatment units, control buildings, access roads, etc.

Figure 4. Estimated Land Areas For Intermittent Sand Filters And Comparable Processes.

SECTION 5

ASSESSMENT OF NATIONAL IMPACT

MARKET POTENTIAL

Intermittent sand filtration is a potentially low-cost method of wastewater treatment which produces an effluent quality meeting many advanced waste treatment levels. Maintenance requirements are less than those necessary for most mechanical plants and can be performed by unskilled personnel. Energy costs are only those associated with pumping of the wastewater onto the filter surface. However, areal requirements are large in comparison to mechanical treatment methods and their application might be constrained somewhat in severe winter climates. Therefore, intermittent sand filters are best suited for small flows, generally less than 0.2 MGD.

Within these limitations, the potential market for intermittent sand filters is large. The EPA 1982 Needs Survey revealed that of the new secondary treatment plants required by the year 2000, those treating less than 0.50 MGD (1.9 x 10^3 m^3/d) represents 91 percent of the total number and 33 percent of the estimated $5.1 billion total capital costs (USEPA, 1983a). The treatment project needs for flows less than 0.10 MGD (0.38 m^3d) for which sand filtration is ideally suited represent 63 percent of the total number of new secondary treatment plants needed (Table II). The advanced secondary plants of less than 0.50 MGD (1.9 x 10^3 m^3/d) required by the year 2000 represent 89 percent of the total number and 40 percent of the estimated $2.4 billion total capital costs.

In addition to the small community needs identified in the survey, many rural housing developments and business establishments can utilize sand filtration where site and soil conditions preclude the use of septic tank-subsurface soil absorption systems. Many state and local authorities restrict their use to publicly-owned treatment works, however. Local regulations must be reviewed to determine what restrictions exist.

COST AND ENERGY IMPACTS

Capital and operating costs compare very favorably to conventional methods of treatment. Land acquisition and sand media are the controlling costs of construction and these costs are very site specific. Energy costs are primarily those associated with the pumping of wastewater onto the filter. Therefore, energy costs associated with sand filters are lower than most other small community processes except lagoons.

RISK ASSESSMENT

Sand filtration is a well proven process. It is a fixed growth biological reactor and granular filtration method of wastewater treatment. It is a highly stable process able to accept wide variations in organic and hydraulic loading with little deleterious effect on effluent quality. Further, the effluent is extremely low in turbidity which facilitates all methods of disinfection, if required.

Table 11. EXISTING NUMBER AND PROJECTED NUMBER OF SECONDARY AND ADVANCED SECONDARY TREATMENT PLANTS BY DESIGN CAPACITY (USEPA, 1983a)

Flow (MGD)	Year 1982 Secondary	Year 1982 Advanced Secondary	Year 2000 Secondary	Year 2000 Advanced Secondary
0.0-0.10	2467	624	5146	1768
0.11-0.50	2700	1310	3881	1775
0.51-1.05	843	588	1015	671
1.06-5.01	1024	1005	1178	1091
5.02-10.56	232	231	262	248
10.51-50.19	201	228	220	239
50.2	49	55	54	57
Totals	7516	4041	11756	5849

SECTION 6

RECOMMENDATIONS

RESEARCH AND DEVELOPMENT EFFORTS

Due to the long historical use of intermittent sand filters for wastewater treatment, much is known of their basic capabilities. Acceptable design criteria and operation parameters are available, but not widely used. Further research and full-scale demonstrations would help to optimize the process. The following are suggested.

1. Development of a more defined relationship between media characteristics, hydraulic loading rate and treatment efficiency and how this relationship is affected by operation and environmental factors.

2. Development of operation guidelines to maximize treatment efficiency and/or filter run length.

3. Development of a data base for performance, operation and maintenance requirements and capital and operating costs from full-scale plants.

It would appear prudent for all communities under 10,000 population to consider and evaluate intermittent sand filters as alternative treatment systems, based on their high process efficiency and reliability, low present worth cost and low operation and maintenance requirements.

PROCESS/TECHNOLOGY MODIFICATIONS

Intermittent sand filters are customarily used to achieve secondary treatment. However, limited data suggest that advanced secondary treatment is common and nutrient removal is possible. Modifications in media characteristics to remove phosphorus and changes in operation to promote denitrification are promising.

Use of intermittent sand filters may be limited in some areas where suitable sand is unavailable. Other media may be suitable after investigation.

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