INTERMITTENT SAND FILTRATION AND DISINFECTION OF SMALL WASTEWATER FLOWS

D. K. Sauer   W. C. Boyle

A study involving the intermittent sand filtration of septic tank effluent and aerobically treated effluent was conducted by the Small Scale Waste Management Project at the University of Wisconsin from 1973 through 1976. Disinfection of the sand filter effluent by chlorination and ultraviolet light irradiation was also performed. The objective of the study was to evaluate the effectiveness of these waste treatment methods to achieve a water quality acceptable for surface discharge. Surface discharge of treated wastewater is an alternative disposal method for homes where conventional septic tank - soil absorption systems can not be used.

DESCRIPTION OF EXPERIMENTAL STUDIES

Three sand filter-disinfection systems were constructed at three rural homes located on University of Wisconsin experimental farms. The system at the Ashland Experimental Farm employed the sand filtration of septic tank effluent while sand filtration of aerobic unit effluent was performed at the Electric Research Farm. Disinfection of the sand filter effluent at both of these sites was provided by gravity flow through dry-feed chlorinators. At the Arlington Experimental Farm, sand filtration of both septic tank effluent and of aerobic unit effluent was investigated. Disinfection of the sand filter effluents was performed by an ultraviolet light irradiation unit.

The field sand filters ranged from 1.3 to 1.5 m² (14 to 16 ft²) in area and contained 0.61 to 0.76 m (24 to 30 in) of washed pit run sand. The effective size and uniformity coefficient of the sand used at each site is listed in Table 1 (Sauer 1976). It is important to emphasize that the sand was selected because it was locally available and was relatively inexpensive throughout the State of Wisconsin. The sand was underlain by 15.2 cm (6 in) of pea gravel and 15.2 cm (6 in) of coarse gravel as shown in Fig. 1 (Sauer 1976).

Table 1. Sands Used for Field Experiments

	Effective Size (mm)	Uniformity Coefficient
Arlington Experimental Farm	0.28	2.8
Electric Research Farm	0.19 - 0.22	3.3 - 4.0
Ashland Experimental Farm	0.43 - 0.45	3.0 - 3.3

The sand filters were enclosed in concrete block basins and were placed below ground level to prevent freezing problems. The top 10.1 cm (4 in) of the basins were above ground level to allow easy access to the filter sand while an insulated and removable cover was fastened to the top of the filter. The

The authors are: D. K. SAUER, Environmental Engineer, Wisconsin Department of Natural Resources, Madison, Wisconsin, and W. C. BOYLE, Professor, Civil and Environmental Engineering, University of Wisconsin, Madison, Wisconsin.
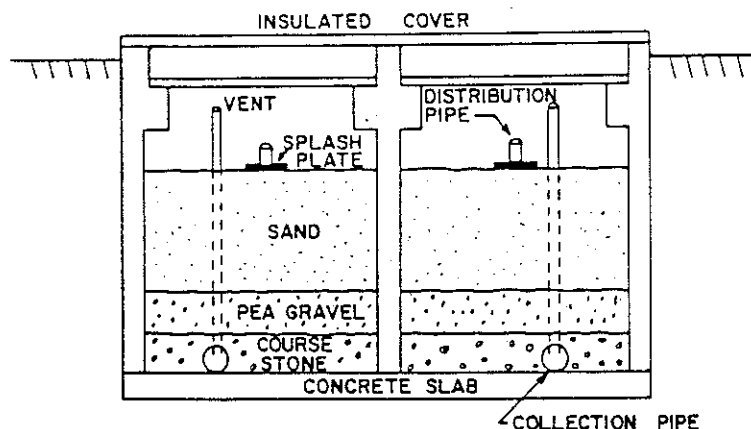
INSULATED COVER

Fig. 1. Profile of Intermittent Sand Filter

covers prevented the accumulation of debris on the sand surface, reduced odor and also eliminated freezing problems which would have occurred in Wisconsin's climate. An open space of 40 cm (16 in) was left between the sand surface and the insulation to allow for intermittent ponding of wastewater above the sand.

The collection system for the sand filters consisted of a 10.1 cm (4 in) per-forated pipe located in the center of each sand filter surface area. The distribution system consisted of a 5 cm (2 in) plastic pipe with an up-turned elbow located in the center of each filter bed. A splash plate was placed underneath the outlet elbow to reduce erosion of the sand surface. Loading rates employed for the sand filter studies ranged from .08 to 1.6 m/d (2-40 gal/d/ft^2) with the rates normally falling between .08 to 0.4 m/d (2-10 gal/d/ft^2). These high loadings were employed to reduce the surface area and thereby the initial installation cost of the sand filters requiring hydraulic loading rates to be higher than previous studies. The sand filters were dosed by 0.25 kw (1/3 h.p.) submersible pump operated at approximately 3.65 m (12 ft) of head and discharging at a rate of 87 L/min (23 gal/min). The total volume of effluent applied per dose was approximately 150 L (40 gal). Waste-water was applied to the sand filters 7 days/week and flow rates from the home were highly variable resulting in dosings of up to 13 times per day.

Effluent from the sand filters at two home sites flowed by gravity through a dry-feed chlorinator and finally into a chlorine contact chamber. Hypochlo-rite in the form of tablets that contained a minimum of 70% free chlorine was used as the chlorine source. The filtered effluent dissolved the tablets in the chlorinator as it trickled past the tablets, while the contact chamber provided detention times ranging from 3 to 21 hours (Sauer 1976).

A commercially available ultraviolet light water purifier was also evaluated as a disinfection method of sand filter effluent. Experiments involved the U.V. irradiation of aerobic unit-sand filter effluent and of septic tank-sand filter effluent (Final Summary Report). Sand filter effluent was collected in a wet well and was then pumped through the U.V. water purifier at a rate of approximately 15.1 L/min (4 gal/min).

RESULTS AND DESIGN RECOMMENDATIONS

Septic Tank - Intermittent Sand Filter

Operation and Maintenance: Throughout the experimental studies a record was maintained of the infiltration rate of the sand filters loaded with septic tank effluent. The pattern of infiltration rate reduction through the sand filters was similar in all of the studies. Figure 2 shows the infiltration

rate decline and the effect of maintenance of a sand filter loaded with septic tank effluent. The sand had an effective size of 0.43 mm and an initial saturated hydraulic conductivity of 22.6 m/d (565 gal/d/ft^2). The average hydraulic loading rate was 0.2 m/d (5 gal/d/ft^2).
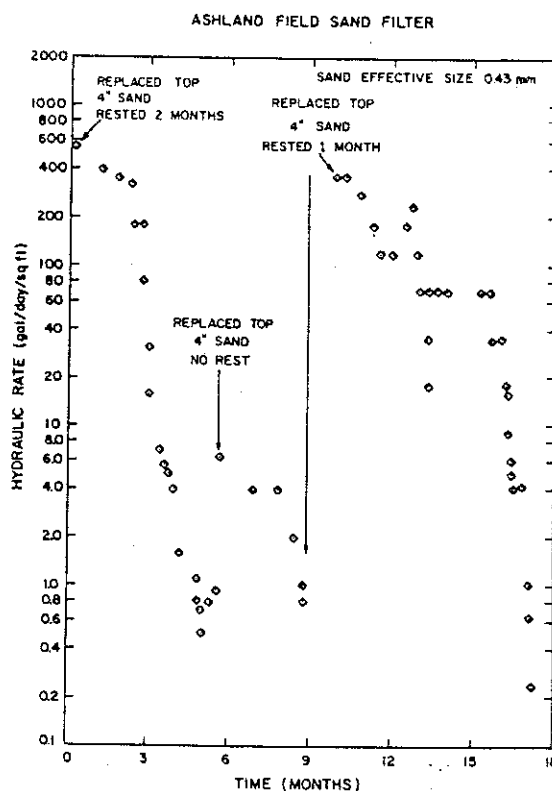
ASHLAND FIELD SAND FILTER

Fig. 2. Infiltration Rate Decline of Sand Loaded with Septic Tank Effluent

With clean sand or newly regenerated sand, initial ponding times following pumping were approximately 4 minutes. As the sand filter matured, products of microbial growth accumulated throughout the sand bed increasing ponding times to 8-15 minutes. Major portions of the filter runs were conducted when ponding times ranged from 15 to 30 minutes and infiltration rates ranged from 1.4 to 4.6 m/d (36-114 gal/d/ft^2). It is thought that microbial growth products eventually reduced the volume of the sand pores resulting in the decline of the infiltration rates as shown in Fig. 2 (Final Summary Report). Once ponding times increased to one hour or greater, continuous ponding occurred rapidly. This was due to the dosing arrangement to the filters. The variable flow rates from the home resulted in a high percentage of dosings which occurred consecutively over a short period of time, usually less than two hours. When ponding times exceeded one hour in length, there was a high probability that the filter would be continually ponded by subsequent dosings.

By definition in this work, failure point of the sand filters was reached when wastewater had ponded 30.4 cm (12 in) above the sand surface. This mode of operation allowed peak loading rates to intermittently pond the sand surface without requiring immediate performance of maintenance. Infiltration rates at "failure" ranged from .02 to .04 m/d (0.5 to 1.0 gal/d/ft^2) for nearly all the experimental studies. Infiltration rates as low as .005 m/d (0.12 gal/d/ft^2) were recorded, however, after the sand surface had remained ponded for up to 60 days. This information demonstrates that although high infiltration rates may be attained initially, eventual sand clogging causes extremely low rates of infiltration for septic tank effluents.

Length of filter runs using sand with an effective size of 0.43 mm and a hydraulic loading rate of 0.2 m/d (5 gal/d/ft^2) ranged from 83 to 143 days (Final Summary Report). Other field experiments utilizing smaller effective size sands showed similar mechanisms of sand filter failure; however, corresponding run lengths were shorter. To regenerate the clogged sand beds, various maintenance techniques were tested. Results showed that a physical breakup of the crust which forms throughout the top 5.0 to 10.1 cm (2 to 4 in) of sand, along with a resting period of at least 30 to 60 days was required to adequately restore the infiltration capacity of the sand. The breakup of the crust was performed by raking the top 5.0 to 10.1 cm (2 to 4 in) of sand or by replacement of the crust with clean sand. The resting period of at least 30 to 60 days was essential in order to allow the lower portion of the sand bed to aerate and regenerate.

Based on the field study of septic tank-sand filter systems employing a medium sand, a hydraulic loading rate of 0.2 m/d (5 gal/d/ft^2) is recommended for designing sand filters. Due to the clogging properties of septic tank effluent, however, it is also recommended that an additional sand filter of equal size be installed. Recommended application of effluent onto the sand filters would alternate between the two sand beds dependent upon the effective size of the sand as shown in Table 2 (Sauer 1976). Decreasing the hydraulic loading rate to the sand filters would yield longer filter runs; however, this would require the construction of a larger filter bed to handle equal amounts of waste.

Table 2. Filter Run Lengths as a Function of Sand Size

Effective Size (mm)	Uniformity Coefficient	Filter Run Length (Days)
0.2	3-4	30
0.4	3	90
0.6	1.4	150

Effluent Quality and Variability: An analysis of the effluent quality from the sand filters loaded with septic tank effluent at an average rate of 0.2 m/d (5 gal/d/ft^2) is shown in Table 3 (Final Summary Report). In all the sand filter studies the mean BOD$_5$ concentration was $\leq$ 10 mg/L. Only during the initial start-up and maturation period of the sand filters were the BOD$_5$ concentrations significantly greater than the mean value. Throughout the filter runs as biological and physical clogging occurred, the quality of the sand filter effluent improved. The BOD$_5$ of the septic tank effluent occurred largely in the soluble fraction and was assimilated biologically throughout the entire depth of the sand filter.

Mean values for the total suspended solids concentrations of the sand filter effluents were usually $\leq$ 14 mg/L. Further evaluation showed that 50 to 70% of the total suspended solids were non-volatile suspended solids. This non-volatile fraction was attributed to the fine sand grains which were washed from the filter bed.

Concentrations of total nitrogen through the sand filters were relatively unchanged; however, almost complete nitrification of the septic tank effluent occurred. Only after the sand surface remained continuously ponded for over 3 weeks did ammonia nitrogen appear in the sand filter effluent. Orthophosphorus concentrations were initially reduced 20 to 30% by the sand filters with clean sand. As the sand filters aged however, little or no orthophosphorus reductions were found. This was thought to be due to the limited absorption capacity of the sand and/or the formation of organic films over individual sand grains.

Table 3. Septic Tank - Sand Filter Effluent Quality

	Site and Dates					
	Ashland experimental farm				Arlington experimental farm	
	Aug. 1974 - Mar. 1975		Mar. 1975 - Dec. 1976		June 1976 - Dec. 1976	
Parameter and statistics	Septic tank effluent	Sand filter effluent	Septic tank effluent	Sand filter effluent	Septic tank effluent	Sand filter effluent
BOD_5 (unfiltered), mg/L						
Mean (# of Samples)	123(13)	9(25)[a]	109(13)	7.1(21)[a]	57(12)	1.6(24)[a]
95% conf. interval	81-165	6-14	73-145	4.8-10	47-66	1.3-1.9
Suspended Solids, mg/L						
Mean (# of Samples)	48(11)[a]	7(23)[a]	39(13)[a]	2.9(21)[a]	34(12)[a]	14(24)[a]
95% conf. interval	26-89	3.9-12	26-57	1.3-6.3	29-40	11-18
Ammonia Nitrogen, mg-N/L						
Mean (# of Samples)	21(11)	0.9(19)[a]	19(9)	5.5(15)	26(12)	0
95% conf. interval	15-26	-	7-30	2.4-8.6	22-29	-
Nitrate Nitrogen, mg-N/L						
Mean (# of Samples)	0.3(11)	20(19)[a]	0.1(9)	32(16)	0.2(12)	34(24)
95% conf. interval	-	10-40	0-0.2	14-50	0-0.3	31-37
Orthophosphorus, mg-P/L						
Mean (# of Samples)	10(11)	7(19)[a]	8(10)	10(16)	15(12)	13(24)
95% conf. interval	7-13	5.4-9.0	5-12	7.8-12	13-16	12-14

[a] Log-normal distribution

Fecal coliforms and fecal streptococci concentrations in the septic tank effluent were reduced by 2 logs by the sand filters. The effluent levels of coliforms, however, remained higher than current surface discharge recommendations (fecal coliforms $\leq$ 200/100 mL) thus requiring some type of disinfection.

Aerobic Unit - Intermittent Sand Filter

Operation and Maintenance: Studies involving the intermittent sand filtration of aerobic unit effluent were performed at loading rates ranging from .04 to 0.3 m/d (1 to 7.3 gal/d/ft^2). Throughout the filter runs, suspended solids accumulated on top of the sand surfaces. At the lower loading rates only a slight deposition of suspended solids occurred on the sand surface; however, at the higher loading rates a much more rapid accumulation resulted.

To characterize the type of filter clogging that was occurring, the infiltration rates through the sand filters were monitored. Figure 3 shows the infiltration rate decline of a sand filter loaded with aerobic unit effluent (Sauer 1976). The sand had an effective size of 0.22 mm and an initial saturated hydraulic conductivity of 16.5 m/d (418 gal/d/ft^2). The average hydraulic loading rate was 0.2 m/d (5 gal/d/ft^2).

Due to the formation of the solids mat on the sand surface, an immediate decline in the infiltration rate occurred as shown in Fig. 3. Flow rates dropped to as low as 0.12 m/d (3 gal/d/ft^2), once continuous ponding occurred. When the crust was allowed to dry and crack open, however, infiltration rates increased to as high as 4 m/d (100 gal/d/ft^2). Eventually continuous ponding predominated causing infiltration rates to lower below the hydrualic loading rate. When wastewater ponding above the sand reached 30.4 cm (12 in) the filter run was terminated. Infiltration rates at failure remained $\geq$ 0.12 m/d (3 gal/d/ft^2).

The length of filter runs appeared to be dependent upon the mass of suspended solids applied to the sand surface. The mass is determined by the hydraulic loading rate and the concentration of suspended solids in the aerobic unit effluent. At loading rates ranging from .16 to .24 m/d (4 to 6 gal/d/ft^2) and suspended solids concentration $\simeq$ 50 mg/L, filter run lengths of one year were experienced. At the same loading rate and suspended solids concentration $\simeq$ 100 mg/L, filter run lengths were reduced to approximately 6 months. Larger sand sizes offered little increase in total run lengths for the same loading rates.
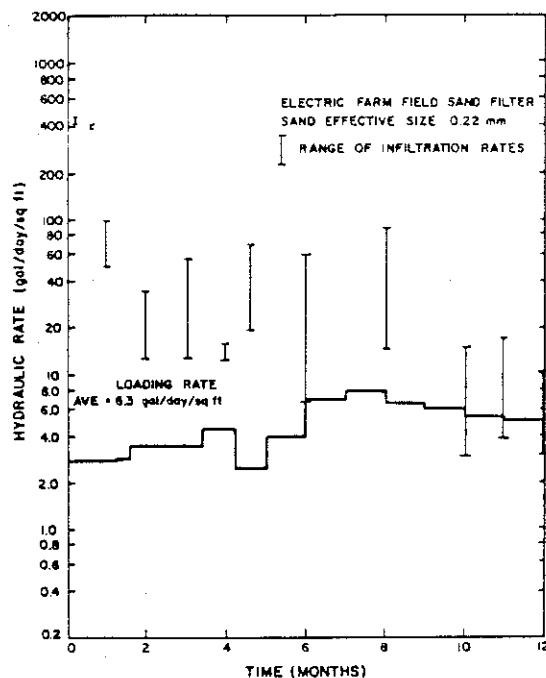
Fig. 3. Infiltration Rate Decline of Sand Filter
Loaded With Aerobic Unit Effluent

To regenerate the clogged sand filters various maintenance techniques were
studied. Results showed that removal of the solids mat which was 1.9 to 3.8
cm (.75 to 1.5 in) in depth restored the infiltration capacity to between
2-4 m/d (50 to 100 gal/d/ft^2). There appeared to be no need for resting the
sand bed, thus eliminating the need for alternate filters. Apparently little
biological decomposition occurs below the sand surface due to the low soluble
organic material in the aerobic unit effluent. This statement is true only
when the sand surface remains aerobic and the bed remains at a high oxidation
reduction potential. Periodic biological and hydraulic upsets can be assimi-
lated by the sand filters; however, extended time periods of these upsets
have led to shorter filter runs.

Effluent Quality and Variability: An analysis of the effluent quality from
the field sand filters loaded with aerobic unit effluent at rates ranging
from 0.15 to 0.3 m/d (3.8 to 7.3 gal/d/ft^2) is shown in Table 4 (Final
Summary Report). One of the major conclusions from the study was that the
aerobic unit - sand filter effluent quality was quite similar to the septic
tank - sand filter effluent quality. The aerobic unit effluent had a lower
organic strength than the septic tank effluent; however, it was also much
more variable than the septic tank effluent. Sand filtration of aerobic unit
effluent produced a mean BOD$_5$ concentration $\leq$ 5 mg/L and a mean total suspen-
ded solids concentration $\leq$ 11 mg/L. Sand filter effluent quality improved
with time as the mat of suspended solids accumulated on the sand surface.
This was explained by noting that most of the BOD$_5$ of the aerobic unit efflu-
ent was contained in the suspended solids which were filtered out of solution
at the surface of the sand.

For most of the experimental studies, the aerobic unit effluent contained
very low concentrations of ammonia-nitrogen and was highly nitrified. No
nitrogen conversions were noted through the sand filters. Orthophosphorus
concentrations were initially reduced 20 to 30 percent by the sand filters
with clean sand. However, as the sand filters aged and the absorption capa-
city of the sand was reached, little or no orthophosphorus reductions were
found. This was similar to what was found with the septic tank - sand filters.

Table 4. Aerobic Unit - Sand Filter Effluent Quality

Parameter and statistics	Site and Dates					
	Ashland experimental farm				Arlington experimental farm	
	Aug. 1973 - Feb. 1975		Mar. 1975 - May 1976		June 1976 - Dec. 1976	
	Aerobic unit effluent	Sand filter effluent	Aerobic unit effluent	Sand filter effluent	Aerobic unit effluent	Sand filter effluent
BOD$_5$ (unfiltered), mg/L						
Mean (# of Samples)	26(48)	3.5(56)[a]	48(15)	3.5(24)[a]	6(11)	1.2(22)[a]
95% conf. interval	21-31	2.7-4.5	30-65	2.2-5.7	2-10	1.0-1.4
Suspended Solids, mg/L						
Mean (# of Samples)	48(51)[a]	11(58)[a]	23(15)[a]	6.4(23)[a]	12(11)	3.9(20)[a]
95% conf. interval	39-58	8.5-14	16-32	3.2-13	6-17	2.8-5.4
Ammonia Nitrogen, mg-N/L						
Mean (# of Samples)	0.4(47)	0.3(51)	7(8)	0.5(10)	0(12)	0
95% conf. interval	0-1.6	-	0.2-14	0-1.1	-	-
Nitrate Nitrogen, mg-N/L						
Mean (# of Samples)	34(50)	35(51)	22(8)	28(10)	30(12)	30(24)
95% conf. interval	30-38	31-39	9-34	19-37	30-31	29-32
Orthophosphorus, mg-P/L						
Mean (# of Samples)	28(41)	21(49)	10(8)	9(10)	8(12)	7(24)
95% conf. interval	23-33	17-25	8-13	5-13	7-9	6.2-7.0

[a] Log-normal distribution

Fecal coliforms and fecal strep concentrations in the aerobic unit effluent were reduced by 1 log in the sand filters. The effluent concentrations, however, were similar to the septic tank - sand filter effluent concentrations thus requiring some type of disinfection to meet current surface discharge recommendations.

Dry Feed Chlorination

Field studies of chlorinated sand filter effluents were performed at two home sites over an 18-month period. Sand filtered effluent flowed by gravity through a sampling basin, a Diamond Shamrock Sanuril Chlorinator and, finally, into a chlorine contact chamber. Within the chlorinator, wastewater was directed past one stack of 7 cm (3 in) diameter calcium hypochlorite tablets containing a minimum of 70% free chlorine. Dosage was found to be a function of flow rate as depicted in Fig. 4 (Sauer 1976), ranging from 7 mg/L to 40 mg/L Cl for the septic tank-filtered effluent and averaging 18 mg/L Cl for aerobic unit-filtered effluent.
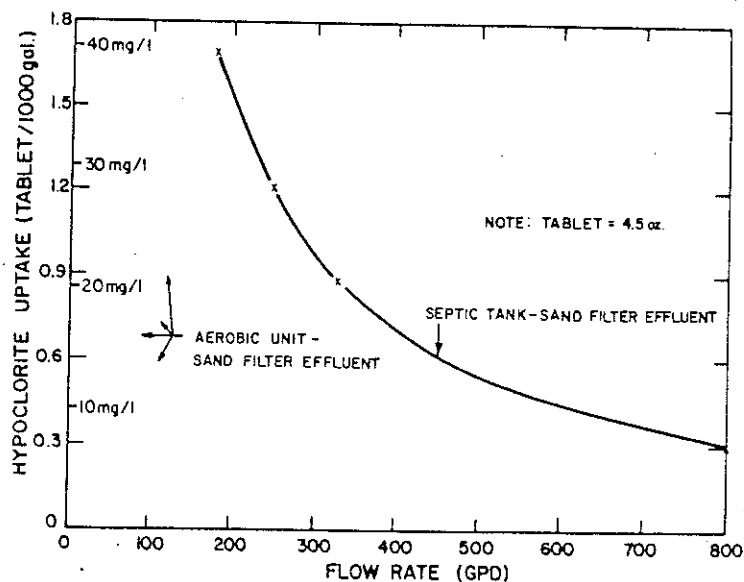

Fig. 4. Hypochlorite Uptake During Dry Feed Chlorination

The chlorine contact chamber, consisting of a length of concrete pipe placed vertically and outfitted with a concrete base and three wooden baffels, provided for sufficient chlorine contact time. For the septic tank - sand filter site the 0.57 m^3 (150 gal) chamber provided detention times ranging from 3 to 21 hours, whereas a 0.43 m^3 (115 gal) chamber provided 14 to 17 hours contact for the aerobic unit - sand filter system.

The effect of sand filtration and chlorination on the reduction of indicator bacteria in the treatment unit effluents is shown in Table 5 (Final Summary Report). As would be expected, the higher chlorine dosage at the septic tank - sand filter site resulted in slightly higher kills, yet, with the exception of total bacteria, these kills were not significantly higher at the 95% confidence level. Of the indicator organisms, fecal and total coliforms appear to be more sensitive to destruction by chlorination (the highest percentage reduction) while total bacterial counts were least affected. A substantial portion of the reduction of bacteria can be attributed to removal in the sand filters. No tests were performed to determine the impact of these chlorinators on the level of viruses in effluents.

Table 5. Bacterial Levels Following Sand Filtration and Chlorination

	Site and Dates								
	Ashland experimental farm						Electric research farm		
	Oct. 1973 - May 1974			Aug. 1974 - Mar. 1975			Sept. 1973 - Feb. 1975		
Parameter and statistics	Septic Tank	Sand Filters	Chlorine Contact	Septic Tank	Sand Filters	Chlorine Contact	Aerobic Unit	Sand Filters	Chlorine Contact
Flow	1.5 to			0.76 to			0.38 to		
Range	3.0 m^3/d			1.5 m^3/d			.57 m^3/d		
Total Bacteria, log #/L									
Mean (# of Samples)	9.8(14)	8.7(10)	8.5(12)	9.3(9)	7.8(9)	6.0(11)	8.5(45)	7.8(40)	6.6(42)
95% conf. interval	9.6-9.9	8.2-9.1	8.0-8.8	8.9-9.5	6.9-8.8	5.0-6.9	8.4-8.6	7.5-8.1	6.1-7.0
Total Coliforms, log #/L									
Mean (# of Samples)	7.3(15)	5.2(11)	3.3(13)	7.0(12)	4.1(12)	1.5(11)	6.2(50)	5.2(44)	2.5(51)
95% conf. interval	7.1-7.5	4.3-6.1	2.0-4.6	6.7-7.2	3.3-5.0	0.7-2.2	6.0-6.4	4.9-5.3	2.0-3.1
Fecal Coliforms, log #/L									
Mean (# of Samples)	6.7(14)	4.7(11)	2.8(15)	6.8(14)	3.8(13)	1.3(11)	5.3(51)	4.3(49)	1.9(51)
95% conf. interval	6.4-7.0	3.7-5.7	1.7-3.9	6.6-7.0	3.0-4.7	0.7-2.1	5.1-5.4	4.0-4.6	1.5-2.3
Fecal Strep, log #/L									
Mean (# of Samples)	4.5(15)	3.3(11)	2.1(14)	4.5(14)	2.8(14)	1.3(12)	4.4(52)	3.7(50)	1.9(52)
95% conf. interval	4.2-4.8	2.3-4.0	1.3-3.0	4.1-4.8	2.0-3.2	0.8-1.8	4.2-4.6	3.2-4.1	1.5-2.2
Ps. Aeruginosa, log #/L									
Mean (# of Samples)				4.5(13)	2.4(12)	<1.3(9)	4.3(17)	3.4(18)	1.7(16)
95% conf. interval				4.1-4.8	1.7-3.1	-	3.9-4.7	3.0-4.0	1.3-2.1

The major maintenance problem experienced during the use of these chlorinators was the failure of the tablets to move downward as the bottom tablets dissolved. This was caused by a disintegration of the upper tablets due to high humidity in the chlorinator. At other times, this disintegration caused parts of the tablet to slake off and thus produce excessive dosages of chlorine. Residual chlorine concentrations were normally found to range from 0.1 to 1.0 mg/L after contact times up to 21 hours. The highest residual measured was 20 mg/L. Since residual chlorine concentrations greater than .005 mg/L may be toxic to aquatic life (Zillich 1972), it is concluded that acceptable discharge of this effluent would be dependent upon the dilution provided in the receiving stream.

The chlorine tablets utilized in the chlorinator cost about $4.20 per kilogram ($1.98/lb). If one considers an average dose of about 20 mg/L, then it would cost about $23 per year to treat an average flow of 0.76 m^3/d (200 gpd), based on the rate of tablet uptake in these field studies.

Ultraviolet Light Irradiation

Disinfection of sand filter effluents using a commercially available ultra-violet water purifier (Ultradynamics Corp., Model 500) was performed at one field site where both aerobic unit-filtered effluent and septic tank-filtered effluent was available. The unit which was designed for water supply disin-fection consisted of a .75 m (30 in), low pressure mercury vapor lamp enclosed in a quartz jacket, 2.4 cm (15/16 in) outside diameter, and centered in a stainless steel tube, 7.3 cm (2-7.8 in) inside diameter. The path length of light was 2.2 cm (7/8 in) perpendicular to any point on the side of the stain-less steel jacket. Both wave length and light intensity were metered. The system was equipped with an automatic wiper which periodically cleaned the quartz jacket. Rate of flow through this unit was set at 15 L/min (4 gpm) providing a detention time of 11 seconds. The ultraviolet energy being emitted by the lamp was 15 W according to the manufacturers specifications.

The U.V. lamp was operated continuously during the field studies in order to realize full life expectancy from the lamp. Sand filtered effluent was pumped through the unit, however, on an intermittent basis depending upon the flow rates from the sand filter. A submersible pump, controlled by high and low float switches pumped approximately 75.6 L (20 gal) of filtered effluent at a rate of 15 L/m (4 gpm) through the U.V. unit at each dosing. This unit was under test for a 7-month period during which the average volume of effluent treated was 378 L/d (100 gal/d). The results of this 7-month field test are summarized in Table 6 (Final Summary Report). The reductions of indicator bacteria by the septic tank - sand filter irradiation system were very high (about 99.999%) for all the monitored organisms. They do not appear as high for the aerobic unit - sand filter - irradiation system but it must be noted that the levels received from the aerobic unit were substantially lower than out of the septic tank and that the numbers coming out of the ultraviolet unit were usually below the bacterial detection limit (about 1 per 100 ml).

Table 6. Bacterial Reductions by Ultraviolet Irradiation

| | Arlington experimental farm | | | | | | | |
| | Sept. 1976 - Nov. 1976 | | | July 1976 - Aug. 1976 | | | Log Reduction Thru Septic Tank - Sand Filter - U.V. Unit | Log Reduction Thru Aerobic Unit - Sand Filter - U.V. Unit |
	Septic Tank	Sand Filters	U.V. Unit	Aerobic Unit	Sand Filters	U.V. Unit		
Total Coliforms, log #/L								
Mean (# of Samples)	6.73(5)	4.07(8)	1.01(6)	4.53(10)	2.53(20)	<1.0(10)	5.72	>3.53
Coeff. of Variation	0.11	0.13	64.8	0.10	0.37	-		
Fecal Coliforms, log #/L								
Mean (# of Samples)	6.38(5)	3.94(8)	0.89(6)	4.13(10)	1.88(20)	<1.0(10)	5.49	>3.13
Coeff. of Variation	0.06	0.13	6.65	0.17	0.57	-		
Fecal Strep, log #/L								
Mean (# of Samples)	5.73(5)	3.56(8)	0.79(6)	3.01(10)	2.31(20)	0.83(10)	4.94	2.18
Coeff. of Variation	0.05	0.24	4.38	0.33	0.73	6.62		

To test the effectiveness of the ultraviolet unit against virus, a 15 liter batch of septic tank - sand filter effluent was inoculated with poliovirus-1 and passed through the unit. The inoculated sample had 4×10^4 PFU/mL, but no virus (> 1 PFU/mL), was detected in the irradiated fluid.

The U.V. unit had an automatic cleaning device to prevent build-up of residues on the quartz jacket; however, the cleaner was deliberately disconnected in order to determine the consequences of inadequate maintenance. Seven months later, another pass of inoculated septic tank - sand filter effluent (> 10^6 PFU of poliovirus-1 per milliliter) was put through the unit. No reduction of virus titer was observed. A substantial build-up or opaque material was noted on the quartz jacket. Given proper maintenance, ultraviolet irradia-tion appears to be capable of achieving good disinfection both for virus and bacteria.

Operation and maintenance of this unit involved periodic cleaning of the quartz enclosure and the provision of power to the U.V. lamp. Removal of the opaque scale was achieved by immersion of the quartz jacket in a concentrated solution of dicromate and sulfuric acid. The lamp, which was operated for 7 months, did not need replacement. Although the unit was equipped with an intensity meter, it was not sensitive enough to determine if the lamp was decreasing its output of energy. The ultraviolet lamp utilized power at a rate of 1.5 kwhr/day when operated continuously.

Cost Analysis of Alternative Systems

To further evaluate the experimental treatment systems a cost analysis was performed and is shown in Table 7 (Sauer 1976). Initial capital costs and annual operation and maintenance costs are presented. Assumptions in the analysis include a three bedroom home, a family size of five, wastewater production of 50 gal/cap/day, and the availability of a local inexpensive sand with effective size $\approx$ 0.4 mm and a uniformity coefficient of $\approx$ 3.5. Sampling costs are not included in the cost analysis; however, state regulatory agencies will undoubtedly require some type of monitoring program.

The cost ranges presented in Table 7 suggest that the alternative treatment systems have similar albeit high costs when compared with septic tank - soil absorption fields. These costs could likely be reduced if water conservation and waste segregation was practiced. It must be recognized, however, that isolated treatment systems can only be evaluated on a case by case basis and conclusions on cost effectiveness cannot be drawn by examining natural averages.

Table 7. Initial Capital Costs and Annual Operation and Maintenance Costs

Unit	Cost, in 1977 Dollars
Septic Tank (1000 gal)	
Equipment and Installation Cost	350-450
Maintenance Cost	10/yr
Aerobic Treatment Unit	
Equipment and Installation Cost	1300-2000
Maintenance Cost	35/yr
Operation Cost, 4 kwhr/day at 4¢/kwhr	60/yr
Wet Well Pumping Chamber	
Equipment and Installation Cost	250-350
Operation Cost,[a] 1/4 kwhr/day at 4¢/kwhr	4/yr
Sand Filter	
Equipment and Installation Cost	10-15 dollars/sq ft
Maintenance Cost	1 dollar/sq ft/yr
Chlorination and Settling Chamber	
Equipment and Installation Cost	700-1000
Operation and Maintenance Cost[a]	40/yr
Ultraviolet Irradiation Unit	
Equipment and Installation Cost	1100-1500
Operation Cost,[a] 1-1/2 kwhr/day at 4¢/kwhr	20/yr
Maintenance Cost, Cleaning and Lamp Replacement	45/yr

[a] Does not include pump replacement.

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