

**PRIMARY EFFLUENT FILTRATION:
RESULTS FROM A FIELD COMPARISON OF THREE FILTERS**

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ABSTRACT

In primary effluent filtration (PEF), primary effluent is treated to reduce TSS, BOD, or other contaminants without resorting to secondary treatment in trickling filters or activated sludge basins. If PEF can meet the effluent quality requirements applicable to a wastewater stream, substantial cost reductions can be realized by using PEF instead of secondary treatment. In other instances, PEF can reduce the secondary treatment load if it is used between the primary and secondary treatment processes. Previously, no directly comparable data have been available for the various technologies that could be used for PEF. The Orange County Sanitation District conducted a project to test three filters simultaneously, representing three different approaches to PEF, to produce direct comparison data.

The test involved two types of sand filters (intermittent and continuous backwash types) and a filter using a synthetic filter medium that operates at higher hydraulic loads than sand filters. The tests explored the ranges of hydraulic load and operating settings appropriate for each filter. The filters' effects on TSS and BOD levels were of particular interest, since these are of most concern for NPDES discharge purposes, but various other characteristics also were measured to better differentiate the performance of the filters. Measurements of particle size distributions in filter influents and effluents showed that the effect of filtration on the particle distribution depended on the filter being studied, the particle size being evaluated, and the operating conditions of the filter. Operating cost comparisons based on the test results were done for the three filters, as were cost comparisons of PEF to other treatment technologies.

KEYWORDS

primary effluent filtration, TSS removal, BOD removal, particle size distribution, operating costs

INTRODUCTION

In primary effluent filtration (PEF), physical filtration is used to treat primary effluent to reduce TSS, BOD, or other contaminants without using secondary treatment in trickling filters or activated sludge processes. Filtration is a relatively low cost form of treatment; if PEF can meet the effluent quality requirements applicable to a wastewater stream, substantial cost reductions could be achieved by using PEF instead of secondary treatment. Shifting part of the processing load from secondary treatment to PEF also might increase the capacity of the existing secondary treatment facilities.

In 1982, the Orange County Sanitation District (OCSD) tested PEF using a shallow-bed sand filter. Both single-stage and dual-stage filtration were investigated. Starting from initial levels of 82 mg/L TSS and 270 mg/L BOD, single-stage filtration reduced TSS by 62% and BOD by 37%. With the addition of alum and polymer, dual-stage filtration reduced TSS by 86% and BOD by 82%. These tests indicated that PEF could meet OCSD's TSS and BOD ocean discharge requirements, but further work was not carried out for several reasons: (1) secondary treatment facilities were under construction; (2) the status of the NPDES 301(h) permit waiver was unclear; and (3) full-scale PEF had not been used elsewhere in the country.

In June 1998, a new NPDES permit with a 301(h) waiver became effective that provides flexibility to use cost-effective treatment options (such as PEF) to meet the effluent discharge requirements. Although additional PEF technologies have become available since the 1982 tests, no directly comparable data have been available to evaluate the options. Accordingly, OCSD conducted a PEF test program in 1997 to generate the data needed to make informed decisions about the role of PEF in its future operations, which are expected to include a large water reclamation project.

TEST OBJECTIVES

The principal objectives of PEF are to reduce TSS and BOD in the treated water. The amount of reduction that can be achieved typically will depend on the influent contaminant concentrations and characteristics, the type of filter being used, and the operating conditions chosen for the filter. Depending on the ultimate destination or use of the filtered effluent, the preferred amount of contaminant removal may or may not be the maximum removal that a filter can attain; in general, achieving the maximum possible removal probably will increase a filter's operating costs.

Typical values for OCSD's influent, primary effluent, and discharge limits are shown in Table 1. **(See Table 1 "Relevant TSS and BOD Levels for PEF Test")** To meet the NPDES limits, relatively small reductions in TSS and BOD would be needed. However, greater reductions might be needed for water reclamation purposes. The objective of the PEF test was not simply to produce filtrate that would meet the discharge permit limitations but to operate the test filters over a range of conditions and to characterize the filtrate that was produced.

METHODOLOGY

Three filters were included in the test: the U.S. Filter/Zimpro Hydro-Clear[®], the Parkson DynaSand[®], and the Schreiber Fuzzy Filter[®]. These filters represent distinctly different approaches to filtration.

The Hydro-Clear is a downflow, shallow bed sand filter with separate filtration and backwash cycles. It uses periodic air pulses upward through the sand bed to break up the solids layer that forms, thereby extending the filter cycle time between backwashes. When the filter does backwash, it uses filtrate taken from a clear well below the bed.

The DynaSand is an upflow, deep bed filter that continuously washes a portion of its sand, so there is no separate backwash cycle. It continuously produces filtrate and reject (equivalent to backwash) water streams.

The Fuzzy Filter is a relatively new product that had not been tested as a primary effluent filter previously. It is an upflow, intermittent backwash filter with a synthetic filter medium in the form of 1½-inch porous pink balls. For filtering, these balls are compressed by a movable plate on top of the filter bed. For backwashing, the plate is raised, and unfiltered influent and air are used to agitate the balls vigorously. In tests of tertiary treatment operation, the Fuzzy Filter had been able to operate at substantially higher hydraulic loads than sand filters, but whether it would be able to do so when filtering primary effluent was unknown.

The field test program ran for ten weeks. To ensure that all three filters received comparable feed, a common feed tank was used. Each test condition, defined by the target hydraulic load [gsf (gallons per minute of feed per square foot of filter bed)] of a filter, was maintained for one week, during which multiple influent (primary effluent) and effluent (filtrate) grab samples were taken and analyzed for a variety of constituents. Each filter was started at a low hydraulic load, which was increased incrementally until an effective upper limit for acceptable performance was reached. The upper limit determination was based on such factors as increasing backwash frequencies at high loads, decreasing effluent quality, and the manufacturers' recommendations about normal and acceptable operating conditions for their filters. In the second half of the test program, the Fuzzy Filter was tested with a different bed compression setting.

The design characteristics and tested hydraulic loads of the three filters are shown in Table 2 (**See Table 2 "Test Filter Characteristics"**), and the principal tests and measurements that were completed on the samples are listed in Table 3. (**See Table 3 "Principal Analyses of Samples"**) Grab samples were used for all tests except BOD and COD, which used multiple grab samples combined into "daily average" composite samples.

RESULTS

Effluent TSS and BOD

The TSS removal results as a function of hydraulic load are presented graphically for each filter. (**See Figure 1 "TSS Removal by DynaSand and Hydro-Clear Filters"**) (**See Figure 2 "TSS Removal by Fuzzy Filter"**) Each point shows a daily average value; typically, these are based on three influent and effluent grab samples taken weekdays at mid-morning, noon, and mid-afternoon, although on some days fewer samples were taken. To remove effects of differences in influent contaminant concentrations, the figures show percent removals based on the concentration differences between the influent and effluent samples. For each set of grab samples taken in a single day, the TSS percent removal was calculated, then the daily average value was calculated as an unweighted mean of the day's individual values.

The BOD removal trends (not shown) were similar to the TSS removal trends. This is not surprising since the filters all are physical, not biological, filters. The BOD reductions should be the result of particle removal, not of biological removal of soluble BOD.

For all three filters, the TSS removal generally was between 40% and 70%, and the BOD removal was between 10% and 30%. The daily average effluent TSS concentrations ranged from 9 mg/L to 49 mg/L, and the daily average effluent BOD concentrations ranged from 67 mg/L to 107 mg/L. The BOD discharge limit of 100 mg/L was exceeded by 2.7% (3 of 112) of the daily average values.

All three filters showed a decreasing trend in TSS removal efficiency with increasing hydraulic load. The Hydro-Clear and DynaSand TSS removal efficiencies were similar at equal hydraulic loads up to 5.5 gsf, although the Hydro-Clear results show more variation. The DynaSand filter, though, was able to operate at higher loads, up to 8.9 gsf, although the removal efficiency tended to be lower at high loads. The Fuzzy Filter showed TSS removal efficiencies comparable to those of the other filters.

While there are visible trends in Figures 1 and 2, there also is a large amount of scatter. One might suspect that this would be caused by filter efficiency changes as the filtration cycle progresses; for example, the removal efficiency just after a backwash might be different from the efficiency hours later when a backwash is imminent. The data do not support this explanation, however. No correlation between contaminant removal efficiency and elapsed cycle time was found. Also, the amount of filter bed compression does not explain the variability in the Fuzzy Filter data.

Microbiological Results

Throughout the test, influent and effluent samples were tested for microbiological contamination to determine PEF's removal effectiveness for bacteria and viruses. Tests for fecal coliform, total coliform, and coliphage (as an indicator of viruses) were done twice weekly, and differences in contaminant concentrations between the influent and effluent sample pairs were calculated.

Since the effective pore sizes of these filters are much larger than bacteria and viruses, the filters were not effective in removing microbiological contaminants. The largest log removal was 0.58 (74% removal) [Fuzzy Filter, total coliform, 34 gsf hydraulic load], but most of the values were less than 0.30 (50% removal), and one-third of the values were negative (indicating a greater concentration in the effluent than in the influent). Only the coliphage data consistently showed positive (although small) removal results for all three filters. Disinfection regulations typically require contaminant reductions of "3 logs" (99.9% removal), "4 logs" (99.99% removal), or more. Clearly, PEF is not a disinfection technology.

Particle Size Distribution

The particle size distribution of an effluent stream can affect its settling characteristics, its plume distribution from an ocean outfall, and its disinfection requirements for reclamation. Particle size distributions of influent and effluent samples were analyzed to determine the effects of filtration on the particle distribution. The intent was to investigate the removal efficiencies over a wide range of particle sizes by each of the filters, analyze the changes in the removal efficiencies during each filter's filtration cycle, and identify the effect of varying the hydraulic loads.

A logarithmic transformation was applied to the raw data to generate volumetric distributions of the particles. A statistical examination of the data indicated that the counts for particles larger than $10 \text{ }\mu\text{m}$ contributed statistical noise to the analysis process without being representative of the particle distribution in any useful way, so the data files were cleaned by eliminating data outside the range of 0 to $1 \log d$ (0 to $10 \text{ }\mu\text{m}$). Also, a statistical analysis of multiple influent samples from each filter indicated that a common averaged influent distribution could be used for the particle analyses.

The data showed similar trends in the removal efficiency of all three filters: each filter's efficiency increased with an increase in particle size. There also was a similar pattern of negative removals (carryover) of particles less than $0.2 \log d$ ($1.58 \text{ }\mu\text{m}$). The carryover indicates the presence of more particles of a certain size in the effluent than in the influent. This may be due to the breakup of larger aggregates during transport through the filter media. Another possibility is that during filtration, as particles deposit on and around the filter media, fluid shear increases and may detach parts of attached flocs, which appear in the effluent as particle carryover. Various other causes could contribute to the carryover including flocculation, growth of biofilm on the media, or incomplete backwashing of the filter bed.

A comparison of the typical particle volumetric removal efficiencies shows that the filters' performance was not identical and varied for different particle sizes. The removal efficiency generally was higher for larger particles. Data from each filter showed carryover of particles less than $0.2 \log d$ ($1.58 \text{ }\mu\text{m}$); however, the magnitudes of these negative removals differed among filters and cycle stages.

In the influent, the largest particle counts occurred at approximately $0.2 \log d$ ($1.58 \text{ }\mu\text{m}$). Interestingly, the particle removal analysis showed that $0.2 \log d$ was also a general crossover point where the filters greatly increased their efficiency and the percent removal values changed from negative to positive. Why both phenomena occur at the same particle size is not obvious; however, the data show this trend to be typical for all three filters.

Individual Filter Performance: DynaSand Filter

The DynaSand filter data show that the particle removal efficiency is affected by the hydraulic load. **(See Figure 3 "DynaSand Particle Removal at Different Hydraulic Loads")**

At the lowest load condition of 2.8 gsf , the DynaSand filter performed most efficiently. The efficiency was generally above 80% removal for particles greater than $0.5 \log d$ ($3.16 \text{ }\mu\text{m}$), and there are no particle sizes showing carryover. At higher hydraulic loads, the particle removal percentages were lower than at the lowest hydraulic load. At the highest load, the DynaSand filter performed least efficiently for small particles; the removal efficiency ranged from -10% to less than -100% for particles smaller than $0.15 \log d$ ($1.41 \text{ }\mu\text{m}$). The analysis suggests that the high negative removal values are a result of shearing due to increased hydraulic load rates.

Individual Filter Performance: Fuzzy Filter

The Fuzzy Filter, having a highly porous and compressible medium, can operate at 4 to 7 times the hydraulic load of traditional filters. The hydraulic load during the four weeks of the particle analysis sampling ranged from 24.6 gsf to 36.2 gsf . Figure 4 shows the particle removal data at various hydraulic

loads during the late stage of the filtration cycle. **(See Figure 4 "Fuzzy Filter Performance at Different Hydraulic Loads")**

The Fuzzy Filter performed most efficiently in removing fine particles at all stages of the filtration cycle when it operated at the lowest hydraulic load. At 24.6 gsf, the filter removed small particles with considerable efficiency and no particle carryover, and the removal efficiency for larger particles generally exceeded 70% for particles larger than $0.4 \log d$ ($2.51 \mu\text{m}$).

For the early and middle filtration cycles (not shown), the removal efficiency distributions were similar for hydraulic loads as high as 33.8 gsf, but the removal efficiency decreased when the hydraulic load increased to 36.2 gsf. The removal at 36.2 gsf was less than 20%, but it increased in the middle and late cycle stages. This is an indication of filter ripening occurring in which solids build up in the filter during filtration, contributing to increased particle removal by entrapment as the pore sizes decrease. The data suggest the Fuzzy Filter's removal efficiency at high filtration rates may be poor early in a filter run.

Individual Filter Performance: Hydro-Clear Filter

Comparisons of the Hydro-Clear filter's performance at different stages of its filtration cycle show the filter performed most efficiently during the late cycle stage (shortly before a backwash). **(See Figure 5 "Hydro-Clear Particle Removal at Different Filter Cycle Stages")** For particles greater than $0.5 \log d$ ($3.16 \mu\text{m}$), late cycle particle removal was above 70%, while for the early and middle stages, removals generally were less than 70% and reached as low as 10%.

Focusing just on the performance of the Hydro-Clear filter during the early cycle stage at different hydraulic loads **(See Figure 6 "Hydro-Clear Particle Removal at Different Hydraulic Loads: Early Cycle")**, for particles larger than $0.2 \log d$ ($1.58 \mu\text{m}$), the expected pattern of higher hydraulic loads leading to lower removal efficiency is not demonstrated consistently. This may be a reflection of the dynamic nature of a sand filter during its early ripening period before it achieves quasi-steady state filtration conditions.

In removing small particles, the Hydro-Clear filter tended to perform more efficiently at low hydraulic loads. At 3.0 gsf, there was no particle carryover and the removal efficiency consistently was above 40%. This pattern also was observed in the middle and late cycles (not shown). The removal efficiency of small particles was substantially lower at the highest hydraulic load (5.0 gsf) than at lower loads.

The data show removal efficiencies as low as -100%. This pattern of negative values for the Hydro-Clear filter was observed only for the early stage of the filtration cycle and is very similar to the DynaSand filter at its highest hydraulic load. The carryover from the Hydro-Clear filter may be a result of filter ripening.

Operating Costs

Although the three filters achieved similar TSS and BOD removal results, their general operating conditions differed substantially. For example, the influent pump head for a small DynaSand unit (such as was tested in this project) typically is much higher than for either of the other filters, resulting in higher energy costs for identical flow rates. (A large DynaSand filter, being a basin design rather than a tower design, does not have the high head requirement). The Hydro-Clear backwashes more frequently than the Fuzzy Filter (and at intervals that vary with the hydraulic load) but for a shorter time. All three filters use compressed (or blown) air, but at rates that can differ by several orders of magnitude. These operating differences complicate the analysis of which filter would produce filtrate at the lowest cost.

For the purposes of comparing costs, a baseline filtering scenario was established and used for each filter. The comparison included three parameters that are common to all three filters: the energy cost for water pumping, the energy cost for air compression, and the net filtrate volume from a specified influent volume (which reflects differences in backwash rates and procedures that cause the net filtrate volume to be less than the influent volume.) In addition, costs for periodic chemical cleaning of the Hydro-Clear filter were included.

Table 4 summarizes the operating (energy and chemicals) costs for the three filters. **(See Table 4 "Comparison of Filter Operating Costs")** It is important to remember that these costs use a common basis to permit comparison of the filters, but the costs in any actual installation will be site-specific. The pumping costs in particular will be subject to the specific characteristics of the installation location. Nevertheless, these costs are useful for comparing the general operating cost features of the individual filters. Normalized costs (relative to the Hydro-Clear costs) are shown as an aid in comparing the results.

It is interesting to compare the PEF operating (energy and chemicals) costs to the operating costs for primary treatment, advanced primary treatment (APT), and activated sludge treatment (AS). The effluents produced by these processes obviously are not identical; the processes are used to accomplish somewhat different things. But a cost comparison can indicate the potential benefits available if PEF is included as part of the overall treatment train.

Table 5 presents the operating costs of primary treatment, APT, AS, and PEF on a common basis (cost per MG of process feed). **(See Table 5 "Comparison of Process Operating Costs")**. The PEF costs span the Fuzzy Filter, Hydro-Clear, and large DynaSand filter costs; the small DynaSand filter is excluded because it is unlikely to be used by OCSD. PEF (following APT, as tested in this project) is substantially less expensive than either APT or AS. The PEF costs could change if less efficient primary treatment (rather than APT) were done, but the amount of such a change is not known. Also, the PEF costs do not include the costs of treating a filter's backwash flow. However, it appears that post-primary treatment operating costs can be reduced substantially if the physical treatment load is switched from AS to PEF.

CONCLUSIONS

- All three filters successfully removed TSS and BOD from primary effluent, generally to levels that were less than the applicable NPDES ocean discharge limits. On a daily average basis, OCSD's TSS permit discharge limits were met 100% of the time, and the BOD discharge limits were met more than 97% of the time.
- Hydraulic load affected the filters' performance. At high loads, the filtering effectiveness generally decreased, and the filtering cycle time between backwashes shortened as the load increased.
- The Fuzzy Filter operated acceptably at considerably higher loads than either of the other filters.
- The projected operating costs for the filters differed substantially. The lowest operating costs (for the Hydro-Clear filter) were about one-half of the highest costs (for the Fuzzy Filter). The pump power requirements, which would be an important factor in the operating costs for an actual installation, would be site-specific. Changes in the pump power requirements would affect the operating costs of each filter to a different degree.
- Particle distribution analyses showed differences in the effluents from different filters, and the particle removal efficiency of a filter was shown to be affected by the filter's operating conditions. The differences among the filters did not seem to be correlated to differences in TSS or BOD removal performance.
- The operating costs for PEF appear to be substantially lower than the operating costs (energy and chemicals) for either advanced primary treatment or activated sludge treatment. Shifting the processing load from AS to PEF to the extent possible should reduce the overall operating costs for energy, chemicals, and solids production and disposal. Using PEF should allow the chemical usage for APT to be optimized and probably reduced since some of the solids capture load could be transferred to the PEF step. If PEF were preceded by conventional primary treatment rather than by APT, the PEF costs would change, but the amount of this change is not known.

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Table 1. Relevant TSS and BOD Levels for PEF Test

	TSS (mg/L)	BOD (mg/L)
Primary Influent (typical)	220-230	230-240
Traditional Primary Treatment Effluent (without chemical addition) (typical)	75-85	160-170
OCSD Advanced Primary Treatment Effluent (1996-97)	55-68	110-130
NPDES Limit	60*	100

* 60 mg/L or 75% removal, whichever yields the higher value

Table 2. Test Filter Characteristics

Filter	Flow Direction	Bed Material	Bed Depth	Bed Surface Area	Backwash (or Reject) Flow Rate	Tested Hydraulic Load Range, gsf
Hydro-Clear	Down	0.45 mm (fine) sand	10"	4.0 ft ²	12 gpm/ft ²	2.1 - 5.5
DynaSand	Up	Coarse sand	80"	10.7 ft ²	~5% of influent	1.3 - 8.9
Fuzzy Filter	Up	Synthetic	30"	2.5 ft ²	10 gpm/ft ²	19.3 - 36.2

Table 3. Principal Analyses of Samples

Constituent	Test Method	Constituent	Test Method
TSS	EPA 160.2	Settleable Solids	EPA 160.5
BOD	EPA 405.1	Iron	EPA 200.8
COD	EPA 410.4	Coliform (Total & Fecal)	Multiple Tube Fermentation
Turbidity	EPA 180.1	Coliphage	Overlay Agar
Oil & Grease	EPA 413.1	Particle Size Distribution	Coulter Counter

Figure 1. TSS Removal by DynaSand and Hydro-Clear Filters

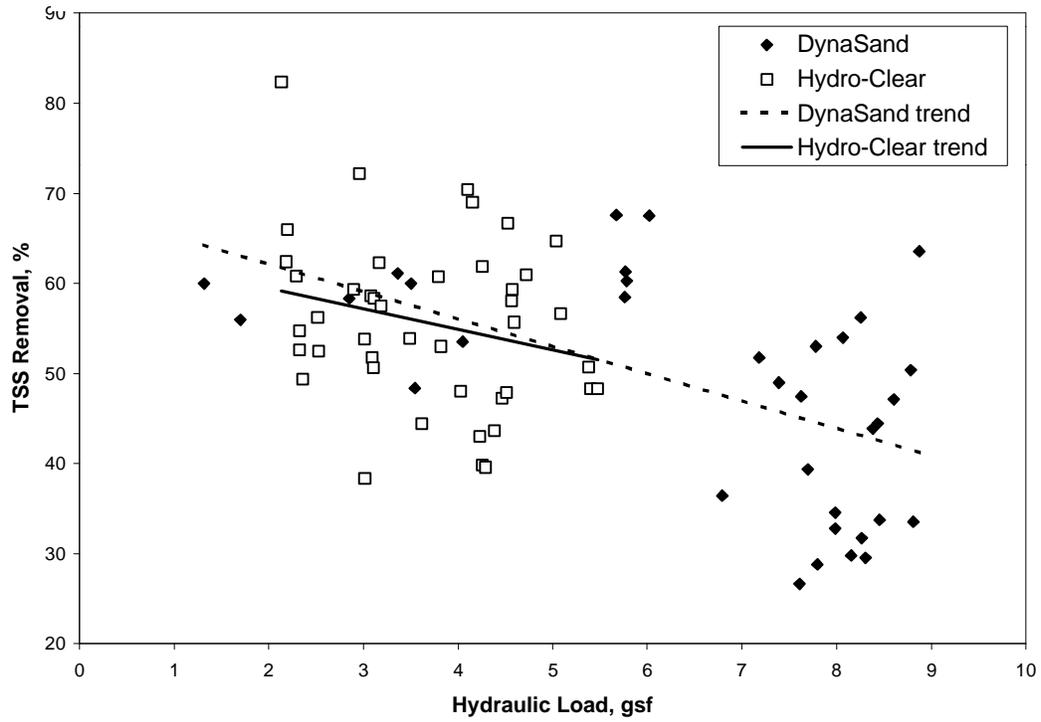


Figure 2. TSS Removal by Fuzzy Filter

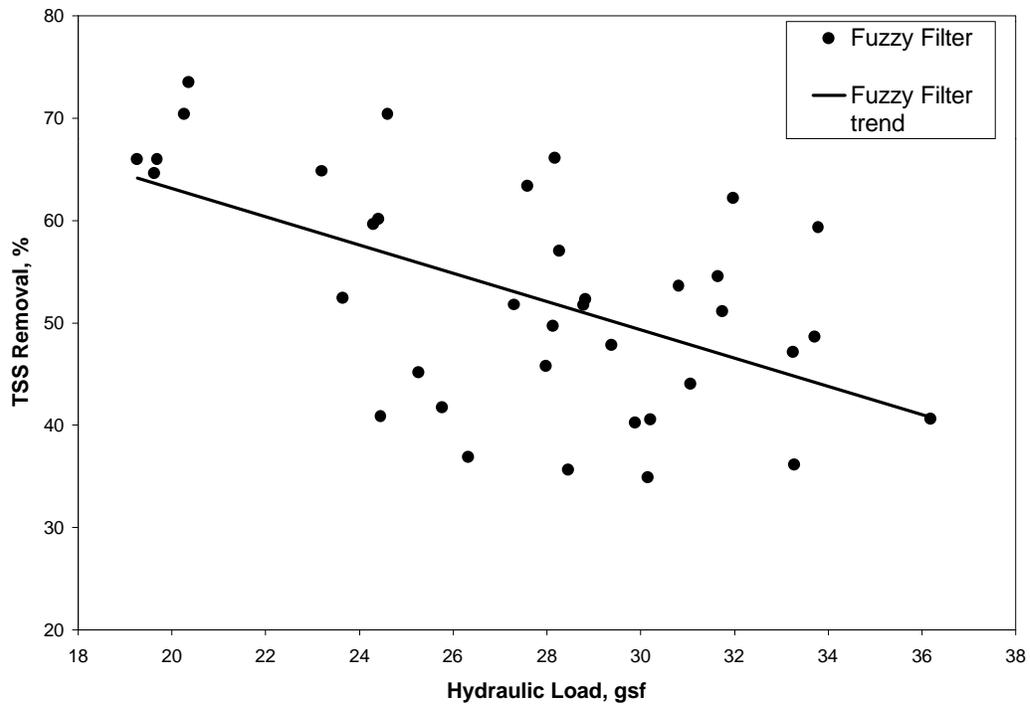


Figure 3. DynaSand Particle Removal at Different Hydraulic Loads

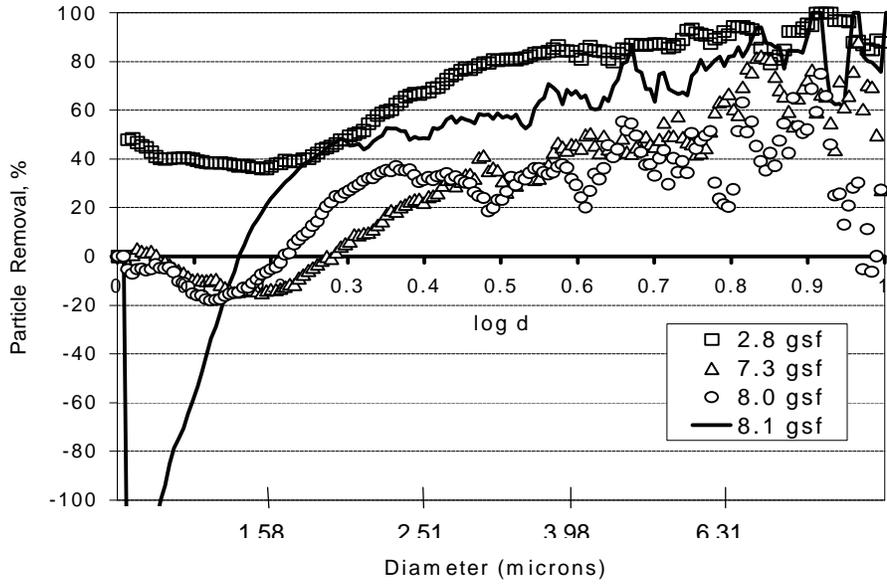
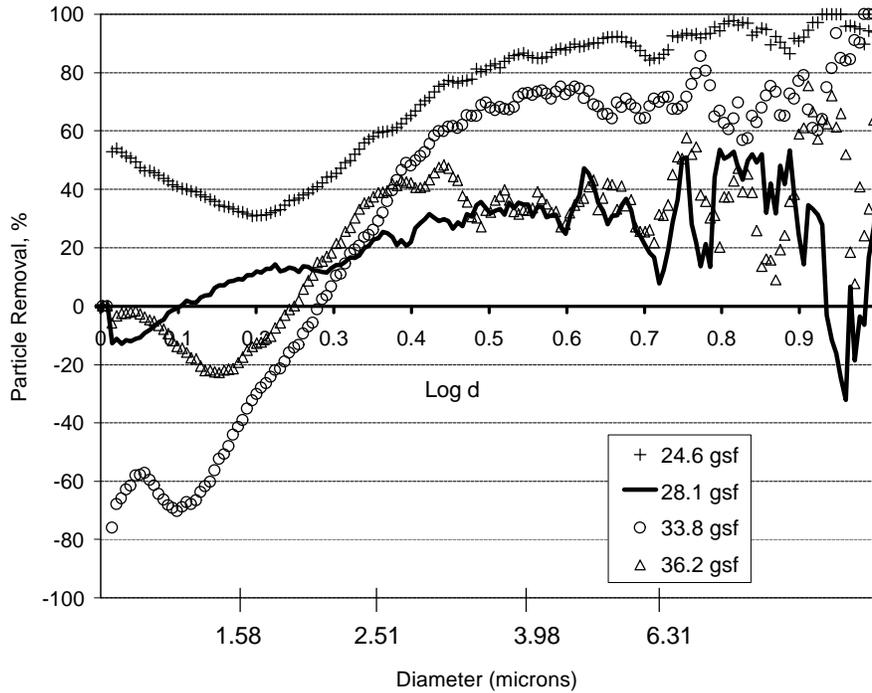
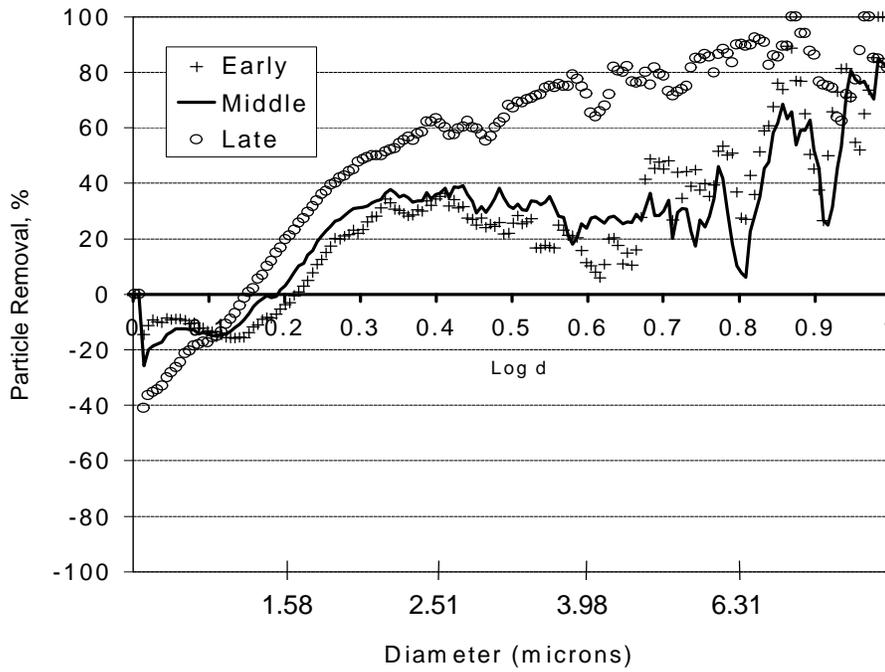


Figure 4. Fuzzy Filter Particle Removal at Different Hydraulic Loads (Late Cycle)



**Figure 5. Hydro-Clear Particle Removal at Different Filter Cycle Stages
(Hydraulic Load at 4.3 gsf)**



**Figure 6. Hydro-Clear Particle Removal at Different Hydraulic Loads
(Early Cycle)**

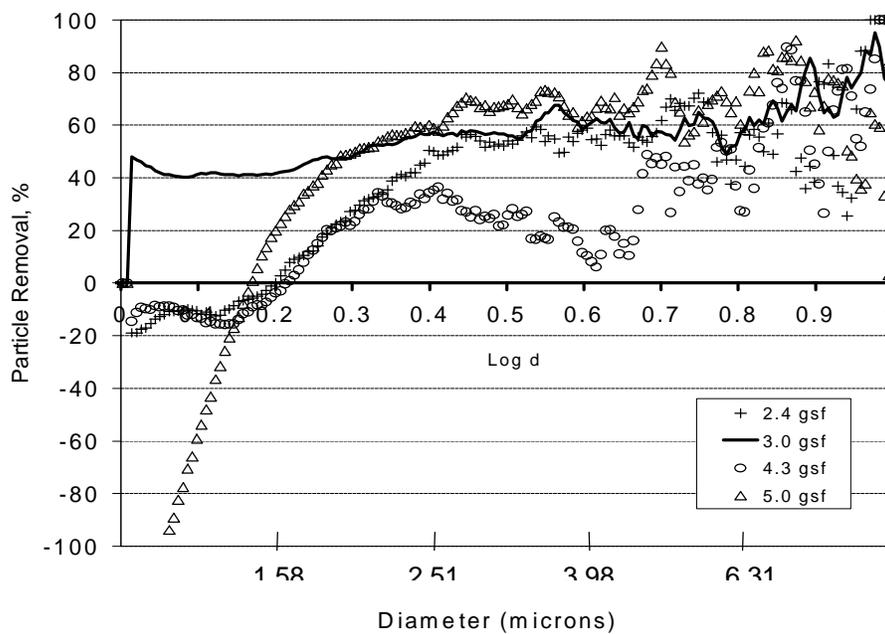


Table 4. Comparison of Filter Operating Costs

Filter	Hydraulic Load Range (L), gsf	Operating Cost Range, \$/MG of Filtrate	Normalized Cost
Hydro-Clear	~2.5 # L # 5.5	3.19 - 3.39	1.0
DynaSand (small)	2 # L # ~9	10.30	3.1
DynaSand (large)	2 # L # ~9	3.95	1.2
Fuzzy Filter	~20 # L # ~35	6.15 - 6.94	2.0

Table 5. Comparison of Process Operating Costs

Process	Operating Cost, \$/MG of Process Feed
Simple Primary Treatment (no chemicals)	1.33
Advanced Primary Treatment (APT)	12.51
Activated Sludge (AS)	13.72
Primary Effluent Filtration (PEF) after APT	2.91 - 6.77

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