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TRICKLING FILTER/SOLIDS CONTACT PERFORMANCE WITH ROCK FILTERS AT HIGH ORGANIC LOADINGS

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The trickling filter process was formerly the most popular method for treating municipal wastewater. In 1975, about 4,300 trickling filter plants were operating in the United States, which was almost two times the number of activated sludge plants.[1] The popularity of the trickling filter process declined in the 1970s and early 1980s because the existing plants were often exceeding the newly established secondary treatment standard of 30 milligrams per liter (mg/l) for total suspended solids (TSS) and 5-day biochemical oxygen demand (BOD_5).

Recent work on the trickling filter/solids contact (TF/SC) process[2,3,4,5] has demonstrated that trickling filters can reliably achieve secondary treatment and advanced treatment standards with relatively simple plant modifications. The popularity of the TF/SC process has increased dramatically since its development in 1979 because it produces significantly better effluent than the trickling filter process alone. The process is applicable to new plants as well as existing trickling filter plants.

The U.S. Environmental Protection Agency (USEPA) estimated that approximately 55 percent of the existing 2,700 trickling filter plants will be upgraded or abandoned by the year 2000.[1] Many of these changes are necessary to treat increasing plant loads or improve effluent quality. Substantial savings would be realized if relatively simple modifications could enable existing trickling filter plants to operate at higher loads with greater reliability. The TF/SC process is an important topic of study because it shows promise for producing just these results--significant improvements in effluent and plant reliability, even at higher organic loadings.

Study Objectives

Most of the operating trickling filter plants use rock media. To test TF/SC performance with rock filters at high organic loadings, USEPA sponsored full-scale studies at the Morro Bay-Cayucos TF/SC plant. The studies also included an assessment of trickling filter performance with flocculator-clarifiers and reaction rate coefficients for soluble carbonaceous BOD_5 ($SCBOD_5$) removal in rock trickling filters.

The studies included 9 weeks of field investigations at the Morro Bay-Cayucos facility in Morro Bay, California. The field investigations data were supplemented with operating records from the Morro Bay-Cayucos plant and from plants in Coeur d'Alene, Idaho; Corvallis, Oregon; and Oconto Falls, Wisconsin.

PLANT FACILITIES AND EXPERIMENTAL PROCEDURES

The investigators conducted full-scale studies at the Morro Bay-Cayucos plant between March and June 1986. The plant and the experimental procedures are described below.

Plant Description

The Morro Bay-Cayucos plant is located on the Pacific coast in central California. The original plant was constructed in 1954. It was expanded in 1964 and again in 1983. The recent expansion was designed to comply with the 1978 Water Quality Control Plan for Ocean Waters of California. In 1985, the City of Morro Bay and Cayucos Sanitary District obtained a waiver of full secondary treatment in accordance with Section 301(h) of the 1977 Clean Water Act.

The plant uses split treatment to meet its discharge requirements. Figure 1 shows the plant's flow schematic. Raw influent undergoes preliminary treatment (screening and aerated grit removal) and then primary sedimentation. A portion of the primary effluent receives secondary treatment with the TF/SC process. The remaining fraction of primary effluent is blended with secondary effluent and chlorinated before discharge to the ocean outfall.

Table 1 lists the plant's design data. The Mode III TF/SC process, which includes return sludge aeration and aerated solids contact provides secondary treatment. The two rock filters are relatively shallow with a mean loading of 750 grams per cubic meter day (g/m^3-d) [47 pounds per day per 1,000 cubic feet (ppd/1,000 cu ft)] at the secondary treatment design flow of 0.042 cubic meters per second (m^3/s) [0.97 million gallons per day (mgd)]. The return sludge aeration and aerated solids contact times at design flow are 13 and 3.3 minutes, respectively.

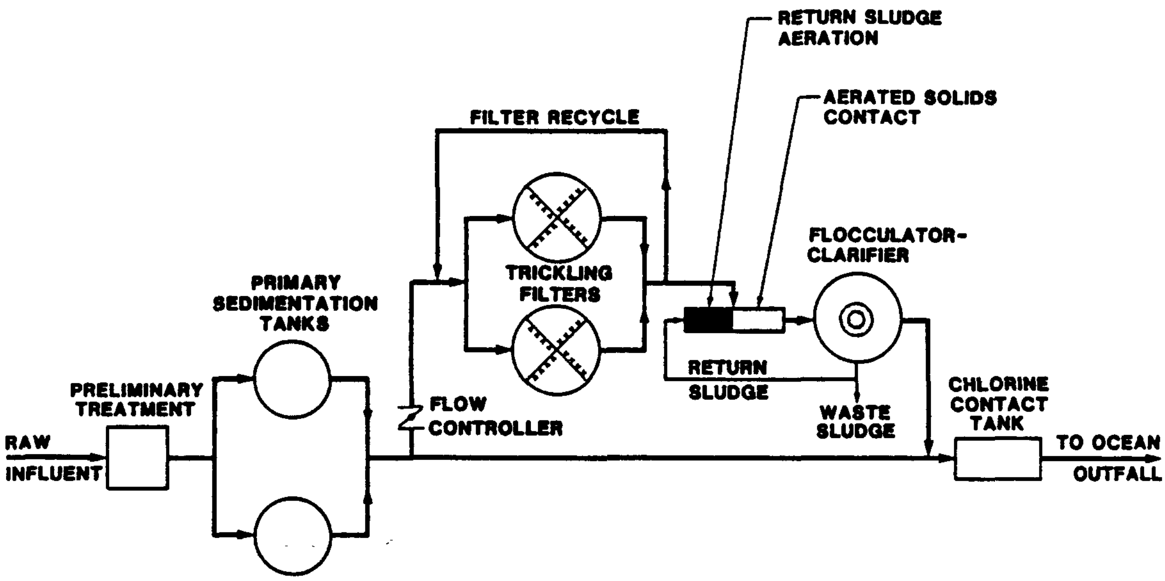

Figure 1. Plant Schematic

The secondary effluent TSS for the TF/SC process for the year before the full-scale studies is shown on Figure 2. The TF/SC process generally produced effluent with TSS between 5 and 10 mg/l at the design flow of about 0.043 m^3/s (1.0 mgd). In August 1985, the plant staff changed operation from split treatment to full secondary treatment. The average secondary effluent TSS increased to 19 mg/l when the secondary flow increased 50 percent to accommodate full secondary treatment.

Experimental Program

The plant has unusual flexibility because of its split treatment feature. This flexibility allowed the study team to conduct relatively closely controlled experiments on the full-scale secondary treatment process.

The experimental program consisted of three phases. In Phase 1, the secondary process operated in the TF/SC mode with both rock filters in operation. In Phase 2, the study team stopped secondary solids recirculation, and the secondary process operated in the trickling filter mode. In Phase 3, the secondary process operated in the TF/SC mode with only one filter to determine TF/SC performance at high organic loadings.

Table 1. Design Data

Parameter	Value	
PLANT CAPACITY		
Flow, m^3/s (mgd)		
Average dry-weather flow (ADWF)	0.090	(2.06)
Peak seasonal dry-weather flow (PSDWF)	0.103	(2.36)
Peak dry-weather flow (PDWF)	0.291	(6.64)
Peak wet-weather flow (PWWF)	0.289	(6.60)
Waste strength, mg/l		
Biochemical oxygen demand (BOD_5)	280	
Total suspended solids (TSS)	280	
PRIMARY TREATMENT		
Sedimentation tanks		
Number	2	
Diameter, m (ft)		
Tank 1	15	(50)
Tank 2	12	(40)
Average side water depth, m (ft)	2.7	(9)
Overflow rate at PSDWF, m^3/m^2-d (gpd/sq ft)	29.7	(730)
TRICKLING FILTERS (in partial secondary treatment mode of operation)		
Flow distribution at PSDWF, m^3/s (mgd)		
Filter 1	0.017	(0.39)
Filter 2	0.025	(0.58)
Diameter, m (ft)		
Filter 1	18	(60)
Filter 2	21	(70)
Average media height, m (ft)		
Filter 1	1.4	(4.5)
Filter 2	1.5	(5.0)
Hydraulic loading rate, l/m^2-s (gpm/sq ft)		
Filter 1	0.23	(0.34)
Filter 2	0.26	(0.38)
BOD_5 loading rate, g/m^3-d (ppd/1,000 cu ft)	750	(47)
SOLIDS CONTACT CHANNEL		
Channel length, m (ft)		
Reaeration portion	7.6	(25)
Contact portion	7.6	(25)
Channel depth, m (ft)	1.2	(4)
Channel width, m (ft)	1.2	(4)
Reaeration time (based on 33 percent return), minutes	13	
Aerated solids contact time (based on total flow including 33 percent return), minutes	3.3	
SECONDARY CLARIFIER		
Diameter, m (ft)	17	(55)
Average sidewater depth, m (ft)	4.6	(15)
Overflow rate at PSDWF, m^3/m^2-d (gpd/sq ft)	16.6	(408)

The filter organic loading for the TF/SC process was increased from 480 g/m^3-d (30 ppd/1,000 cu ft) in Phase 1 to 960 g/m^3-d (60 ppd/1,000 cu ft) in Phase 3. A study of 63 trickling filter plants in the northern United States showed that 86 percent of the plants had organic loadings less the 960 g/m^3-d (60 ppd/1,000 cu ft) and 62 percent had loadings less than 480 g/m^3-d (30 ppd/1,000 cu ft).[6] Thus, the filter organic loadings tested at the Morro Bay-Cayucos plant are above average to high values.

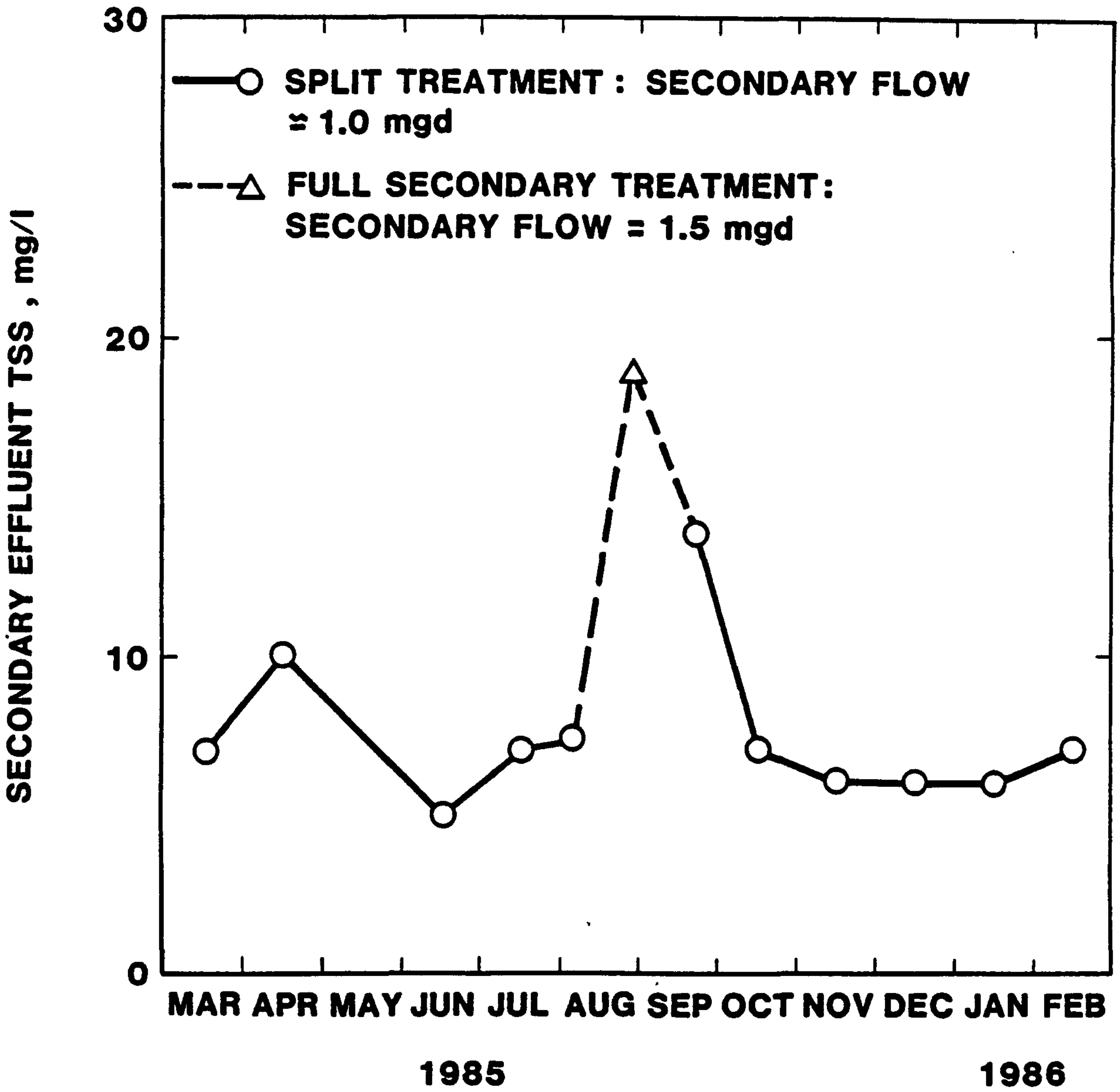

Figure 2. Secondary Effluent Suspended Solids at the Morro Bay-Cayucos TF/SC Plant

The filter organic loading rate during Phase 2 (trickling filter mode) was 445 g/m^3-d (28 ppd/ 1,000 cu ft). Phases 1, 2, and 3 lasted 4, 2-1/2, and 3-1/2 weeks, respectively. The study team allowed 1 to 2 weeks between phases before resuming sampling to allow the secondary process to equilibrate.

Figure 3 shows a typical diurnal flow curve for plant inflow. Plant inflow varies significantly within each hour because of the intermittent operation of large constant speed pumping stations nearby in the collection system.

The flow controller (Figure 3) maintains a flow to the filters of approximately 0.043 m^3/s (1 mgd) at all times. To maintain the desired filter wetting rate, the plant also incorporates recycle of a fraction of unsettled trickling filter effluent back through the filters. This operating approach kept the secondary clarifier overflow rates, aerated solids contact times (Phases 1 and 3), and filter wetting rates at consistent levels during the three phases of the study.

The primary effluent samples were taken downstream of the flow controller thus accounting for dilution with returned secondary effluent during the low flow periods. BOD_5 and TSS analyses of selected samples (Figure 3) during a 24-hour period showed that concentrations were slightly lower during periods of low inflow. For the purposes of this paper, the term primary effluent refers to the trickling filter influent, which may include the recycled fraction of secondary effluent during periods of low inflow.

Sampling and Analytical Procedures

The study team used refrigerated automatic ISCO samplers to collect 24-hour composited samples of primary effluent, unsettled trickling filter effluent, and secondary effluent three days per week. The composite sample collection began at 8:30 a.m. and was completed the following morning. The treatment plant staff collected grab samples of mixed liquor and return secondary sludge during the days of composite sample collection. The plant staff also collected a grab sample of secondary effluent near the peak daily flow (10 a.m.) for TSS analysis. The study team and plant staff used a Secchi disk to measure clarity of the secondary effluent.

The field investigators packed all composite samples and grab samples of mixed liquor and return secondary sludge in an ice chest and shipped them by bus to the Brown and Caldwell Pasadena laboratory for analysis. The laboratory staff analyzed primary effluent and secondary effluent for TSS, BOD_5, and $SCBOD_5$. They analyzed effluent from each trickling filter for TSS and $SCBOD_5$ and the mixed liquor and return secondary sludge samples for TSS and volatile suspended solids (VSS).

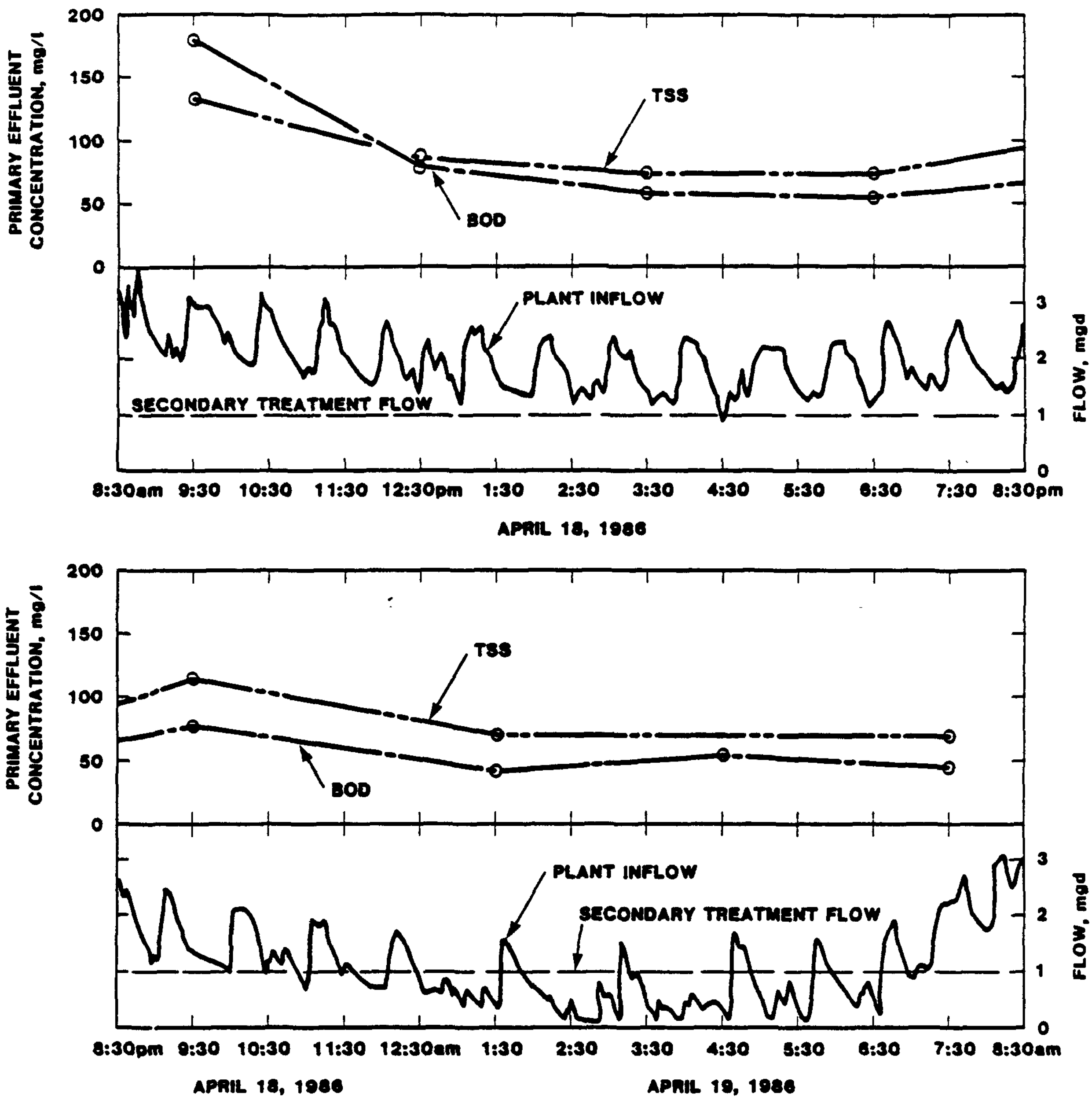

Figure 3. Diurnal Flow and Variation in Primary Effluent Quality

Analytical determinations were performed in accordance with the 16th edition of Standard Methods.[7] The laboratory staff used a Whatman 934AH glass fiber filter to distinguish between particulate and "soluble" substances. They also used a Hach nitrification inhibitor to measure the carbonaceous fraction of the soluble BOD_5 samples.

The study team determined the significance of differences with the t-test at the 95-percent confidence level. They used the modified Velz equation to compute K_{20} values[8] and a specific surface value of 44.3 m^2/m^3 (13.5 ft^2/ft^3) for the rock media.

Professor David Jenkins and associates at the University of California at Berkeley performed microscopic examinations of unsettled trickling filter effluent and solids contact tank samples. They characterized floc size and shape and identified and quantified filamentous organisms.

STUDY RESULTS

Table 2 lists the results of the Morro Bay-Cayucos studies. Raw waste concentrations of TSS and BOD_5 were significantly higher during Phase 3 than in Phases 1 and 2. The significant increase in primary effluent BOD_5 during Phase 3 seems to have been caused by a higher soluble fraction. Primary effluent TSS did not vary significantly between phases, yet the Phase 3 $SCBOD_5$ was significantly higher than in the other two phases.

Secondary Performance

The secondary effluent TSS significantly increased 15 mg/l based on the composite samples and 10 mg/l based on the grab samples when the plant switched from the TF/SC mode to the trickling filter mode. When the filter organic loading increased to 960 g/m^3-d (60 ppd/1,000 cu ft) in the TF/SC mode, the mean composite secondary effluent TSS value was 2 mg/l higher than observed in Phase 1 TF/SC operation, although this difference was not significant. The grab samples of secondary effluent TSS indicated a slight (4 mg/l), but statistically significant, increase in secondary effluent TSS.

The Secchi depths shown in Table 2 indicate the differences in secondary effluent clarity between phases. TF/SC at above average filter loadings (Phase 1) produced the highest clarity followed by TF/SC at high loadings (Phase 3). The trickling filter mode (Phase 2) had the lowest clarity as indicated by the lowest Secchi depth. Differences between phases were statistically significant.

Figure 4 shows the relationship between Secchi depth and secondary effluent TSS. The data are based on grab samples of secondary effluent taken by the plant staff at the same time the Secchi depth was measured. The trend line was based on Beer's law, which states that light absorbance (100 percent for the Secchi depth test) is proportional to depth multiplied by concentration.

Table 2. Study Results

Parameter	Phase 1	Phase 2	Phase 3
Secondary treatment mode	TF/SC	TF	TF/SC
Flow, m^3/s (mgd)			
Plant influent	0.061 (1.40)	0.054 (1.24)	-
Secondary treatment	0.047 (1.07)	0.046 (1.06)	0.045 (1.03)
Return secondary sludge	0.021 (0.47)	-	0.024 (0.54)
Waste temperature, degrees C	17.9	18.6	20.2
Concentration, mg/l			
Raw waste			
TSS	275	254	334
BOD_5	236	212	282
Primary effluent[a]			
TSS	66	81	79
BOD_5	114	99	133
$SCBOD_5$	39	45	77
Trickling filter effluent			
TSS - Filter 1	52	53	-
TSS - Filter 2	47	61	43
$SCBOD_5$ - Filter 1	11	9	-
$SCBOD_5$ - Filter 2	14	10	16
Secondary effluent[b]			
TSS	13	28	15
BOD_5	19	19	19
$SCBOD_5$	11	12	12
Secchi depth, m (ft)	1.0 (3.4)	0.55 (1.8)	0.73 (2.4)
Plant secondary effluent[c]			
TSS	6	16	10
Secchi depth, m (ft)	0.94 (3.1)	0.46 (1.5)	0.61 (2.0)
Operating parameters			
Filter hydraulic loading rate,[d] l/m^2-s (gpm/sq ft)			
Filter 1	0.23 (0.34)	0.23 (0.34)	-
Filter 2	0.28 (0.41)	0.27 (0.40)	0.28 (0.41)
Filter BOD_5 loading rate, g/m^3-d (ppd/1,000 cu ft)			
Filter 1	460 (29)	430 (27)	-
Filter 2	500 (31)	460 (29)	960 (60)
Filter reaction rate coefficient (K_{20})			
Filter 1, $(l/m^2\text{-s})^{0.5}$	5.3×10^{-3}	6.7×10^{-3}	-
$(gpm/sq\ ft)^{0.5}$	(6.4×10^{-3})	(8.1×10^{-3})	-
Filter 2, $(l/m^2\text{-s})^{0.5}$	3.2×10^{-3}	5.7×10^{-3}	7.7×10^{-3}
$(gpm/sq\ ft)^{0.5}$	(3.9×10^{-3})	(6.9×10^{-3})	(9.4×10^{-3})
Return sludge parameters			
Return secondary solids, mg/l	4,210	-	5,340
Reaeration time, minutes	9.3	-	8.3
Aerated solids contact parameters			
Mixed liquor TSS, mg/l	1,140	-	2,390
Sludge volume index, ml/g	129	-	101
Solids contact time, minutes	2.8	-	2.8
Flocculator center well time,[e] minutes	19	-	18
Secondary clarifier overflow rate, m^3/m^2-d (gpd/sq ft)	18.4 (451)	18.2 (447)	17.6 (433)

[a]Collected downstream of flow controller for secondary treatment.
[b]24-hour composite samples except for Secchi depth.
[c]Grab samples taken during peak plant flow.
[d]Includes filter recycle.
[e]Based on total flow in the center well including recycle.

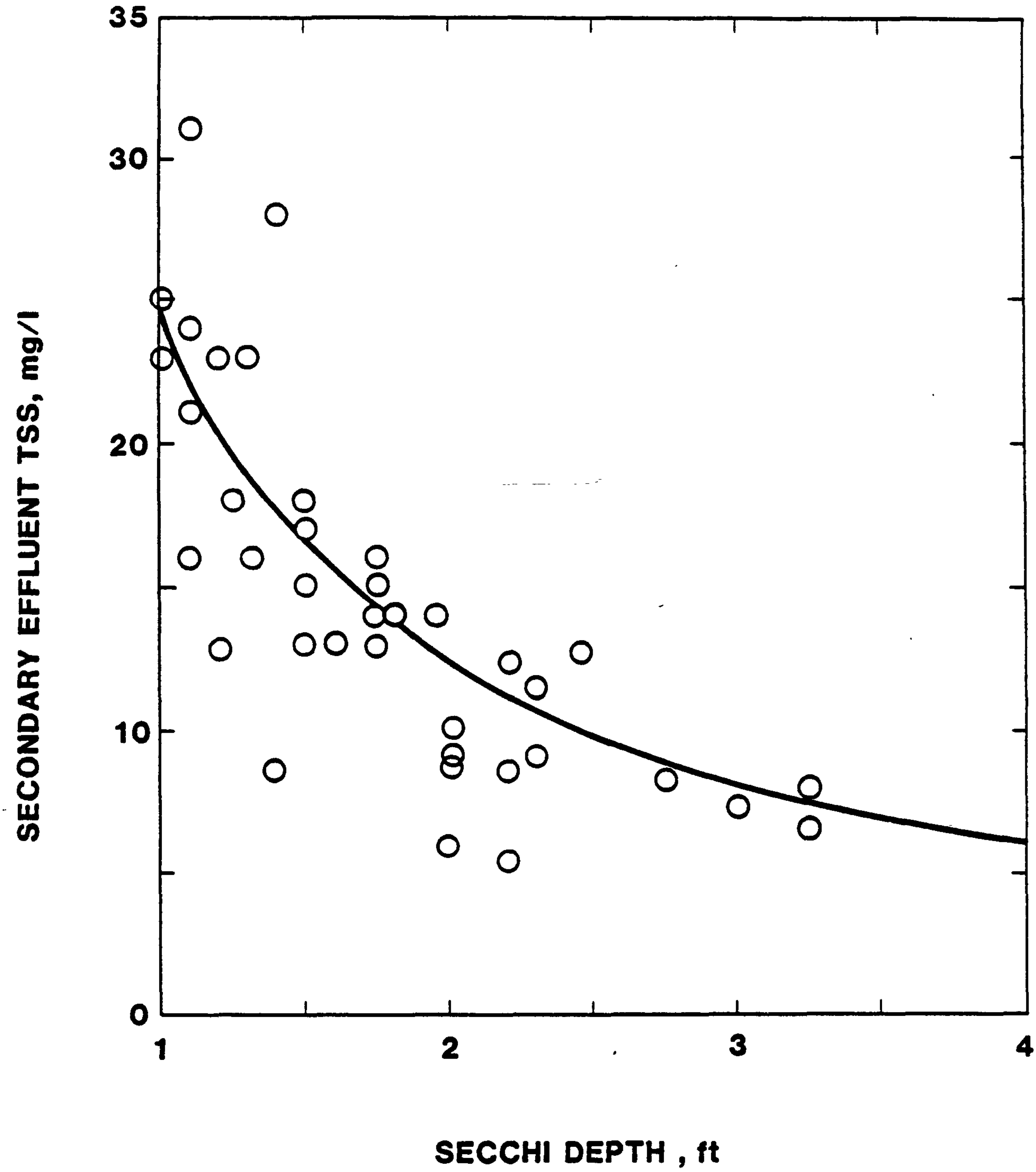

Figure 4. Relationship Between Clarity and Secondary Effluent TSS

Secondary effluent BOD_5 values did not increase in Phase 2 as expected, although the TSS increased and the clarity decreased significantly. The secondary effluent particulate BOD_5 (BOD_5 minus $SCBOD_5$) to TSS ratios for Phases 1, 2, and 3 were 0.62, 0.25, and 0.47, respectively. In our experience, the particulate BOD_5 to TSS ratio is almost always above 0.5. The Phase 2 value of 0.25 is unlikely and probably indicates the secondary effluent BOD_5 was actually higher.

Microscopic Examinations

Microscopic examinations and identification of filamentous organisms have been useful in developing an understanding of activated sludge operating conditions.[9] These examinations can also provide useful information on the operation of TF/SC plants. Table 3 summarizes results of the microscopic examinations performed during Phases 1 and 3 on unsettled trickling filter effluent and mixed liquor samples.

Table 3 Filamentous Organisms in Trickling Filter Effluent and Mixed Liquor

Date	Sample	Filamentous organism type	Filament abundance	Suspected operating condition[a]
April 21, 1986 (Phase 1)	TF Effluent	H. hydrossis	Few	Low food-to-microorganism ratio
		Thiothrix	Few	-[b]
		Type 1701	Rare	Low dissolved oxygen
		S. natans	Rare	Low dissolved oxygen
	Mixed Liquor	S. natans	Some	Low dissolved oxygen
		Thiothrix	Few	-[b]
		Type 1701	Few	Low dissolved oxygen
		H. hydrossis	Few	Low food-to-microorganism ratio
June 16, 1986 (Phase 3)	TF Effluent	S. natans	Few	Low dissolved oxygen
		Beggiatoa	Few	Sulfides
		H. hydrossis	Few	Low food-to-microorganism ratio
		Thiothrix	Few	-[b]
	Mixed Liquor	Beggiatoa	Abundant	Sulfides
		S. natans	Some	Low dissolved oxygen
		Thiothrix	Some-to-few	-[b]

[a]Based on Reference 9.

[b]Thiothrix species possibly indicative of presence of sulfides, nutrient deficiency, or low-dissolved oxygen.

Note: Ranking--abundant, common, some, few, rare, none.

The examinations revealed that the trickling filter solids and contact tank floc were generally firm, round, and compact. They also identified five different types of filamentous organisms. These organisms indicated that low food-to-microorganism (F/M) conditions and low dissolved oxygen concentrations existed concurrently in the trickling filters. The filamentous organisms identified in the trickling filter samples were often present in the mixed liquor samples. The abundance of filamentous organisms was highest during Phase 3 when the filter loading was highest. In Phase 3, the presence of Beggiatoa indicated significant amounts of sulfides existed in the trickling filter. Beggiatoa became abundant in the solids contact tank. Many of these organisms were dispersed and reduced the clarity of the secondary effluent.

Other Results

The first-order reaction rate coefficients (K_{20}) for $SCBOD_5$ removal in the trickling filters are shown in Table 2. The Morro Bay-Cayucos K_{20} values for the rock filters ranged from 3.2×10^{-3} to 7.7×10^{-3} $(l/m^2\text{-}s)^{0.5}$ [3.9×10^{-3} to 9.4×10^{-3} (gpm/sq ft)$^{0.5}$]. Filter 1 yielded slightly higher removal rate coefficients than filter 2. For each filter, the removal rate coefficient increased as primary effluent $SCBOD_5$ increased. The return sludge aeration and aerated solids contact times were short. Studies at the Morro Bay-Cayucos plant indicated that the aerated solids contact tank removed about 1 to 2 mg/l of $SCBOD_5$. Additional $SCBOD_5$ removal in the contact tank would require longer detention times.[25]

PERFORMANCE COMPARISONS

The following discussion draws on results of previous studies as well as the Morro Bay-Cayucos study. It covers the effect of trickling filter loading on TF/SC performance, trickling filter performance with flocculator-clarifiers, and reaction rate coefficients for rock media trickling filters.

Trickling Filter Loading

Trickling filter loading had some effect on TF/SC performance. Loading did not have the same effect at each plant. Variations may be due to differences in operating conditions. This section compares the effect of loading on the performance of the Morro Bay-Cayucos plant with the other plants.

Morro Bay-Cayucos. The lack of substantial effect of filter loading on effluent TSS at the Morro Bay-Cayucos plant indicates that the TF/SC process will produce good effluent as long as the trickling filters can operate at the higher loads. The presence of significant quantities of Beggiatoa, however, suggested the rock trickling filter was approaching its limit at the loading of 960 g/m^3-d (60 ppd/1,000 cu ft).

Beggiatoa are aerobic autotrophic organisms that use sulfides as their primary source of energy.[10] Sulfides are a by-product of anaerobic activity and are often associated with highly or overloaded rotating biological contactors[11] and trickling filters. Despite the high loadings, the trickling filter did not produce any noticeable odors.

Figure 5 shows the effect of filter loading at the Morro Bay-Cayucos plant and other TF/SC plants with rock filters. The Morro Bay-Cayucos composite samples are the Phase 1 and 3 averages from the full-scale studies. The grab samples are monthly average values (based typically on 20 samples per month) collected by the plant staff the year before the study and phase averages collected during the study. The Morro Bay-Cayucos plant results are the only data available for rock filter loadings above 480 g/m^3-d (30 ppd/1,000 cu ft). The composite samples showed a 2 mg/l increase in effluent TSS when the loading was doubled from 480 to 960 g/m^3-d (30 to 60 ppd/1,000 cu ft). The grab samples showed a 4 mg/l increase in effluent TSS.

The highest secondary effluent TSS shown on Figure 2 (19 mg/l) occurred when all of the plant flow [0.066 m^3/s (1.5 mgd)] received secondary treatment, rather than a fraction [typically 0.043 m^3/S (1.0 mgd)] when split treatment was used. The filter loading increase occurred because of the higher primary effluent flow to the filters. The 50 percent primary effluent flow increase reduced contact times and increased the secondary clarifier overflow rate by 50 percent. Consequently, large changes in contact times and overflow rate in addition to filter loading, probably contributed to the increase in secondary effluent TSS.

The Morro Bay-Cayucos plant performed well at the high loadings. One factor that may contribute to the unusually good performance at the Morro Bay-Cayucos plant is the consistent secondary treated flow. As noted earlier, the secondary treated flow was maintained at about 0.043 m^3/s (1.0 mgd) with no diurnal variation. This consistency should improve clarification. The secondary effluent TSS increase during full secondary treatment may have been affected by the diurnal flow variation in addition to the contact time reduction and overflow rate increase noted earlier.

Corvallis. At Corvallis,[2] the secondary effluent TSS increased from 8 to 11 mg/l when filter loading increased from 160 to 400 g/m^3-d (10 to 25 ppd/1,000 cu ft). One of the two filters was shut down briefly in September 1980 to assess the effect of higher loading. Filter loading was increased to about 640 g/m^3-d (40 ppd/1,000 cu ft), but the test was discontinued because of odors.[5]

The Corvallis filters developed odors at loadings significantly lower than loadings successfully applied to the Morro Bay-Cayucos filters. The Corvallis rock filters are 2.4-m (8-feet) whereas the Morro Bay-Cayucos filter depths are 1.4- and 1.5-m (4.5- and 5-ft). As a result, the Corvallis filters may have less

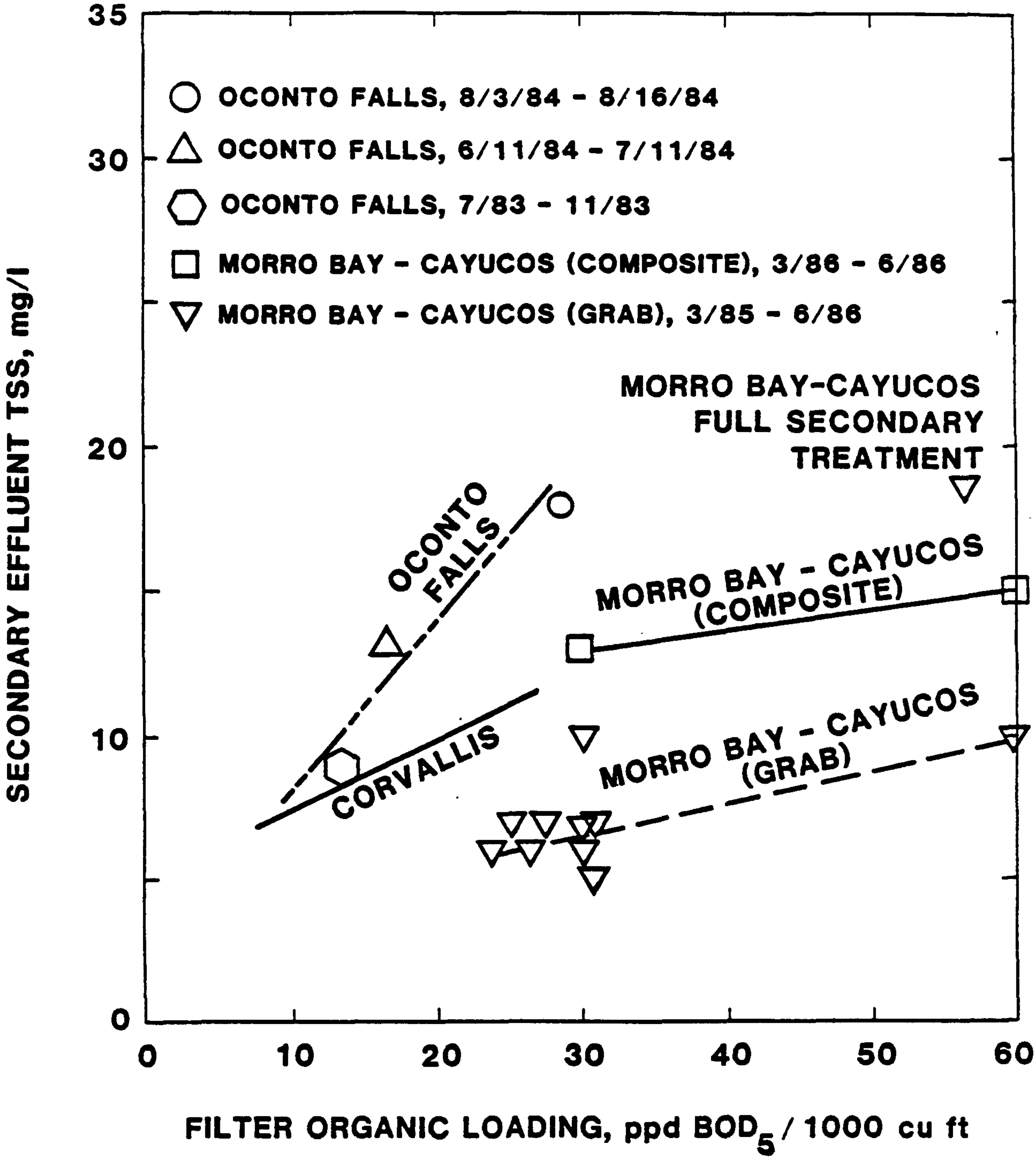

Figure 5. Effect of Loading on TF/SC Performance with Rock Filters

ventilation. Also, for an equivalent volumetric BOD_5 loading, deeper filters receive higher loadings in the top portion of the filter where most BOD_5 removal occurs. The higher loadings near the filter top may create an overload condition and cause odors.

Oconto Falls. Data collected at the Oconto Falls TF/SC plant for months with a similar waste temperature indicated a greater effect of loading on TF/SC performance than at the Morro Bay-Cayucos and Corvallis TF/SC plants. Average secondary effluent TSS increased 8 mg/l when loading was increased from 160 to 400 g/m^3-d (10 to 25 ppd/1,000 cu ft), instead of 3 mg/l as at Corvallis. Loading may have had a greater effect at Oconto Falls than at Corvallis or Morro Bay-Cayucos because Oconto Falls only averages 8 minutes of aerated solids contact time with no return sludge aeration, which decreases the opportunity for physical and biological flocculation.

Trickling Filter Performance With Flocculator-Clarifiers

Flocculator-clarifiers generally include high sidewater depths (5.0 to 6.3 m), flocculator center wells, hydraulic sludge removal, and inboard effluent launders. The benefits of flocculator-clarifiers have been discussed[12,13]; however, no data has been presented to show how they can improve trickling filter plant performance when an aerated solids contact tank is not used. Recent data from the Morro Bay-Cayucos facility and long-term data from the Coeur d'Alene, Idaho, plant demonstrate that flocculator-clarifiers can significantly improve performance of trickling filters plants with conventional shallow clarifiers.

Morro Bay-Cayucos. The trickling filter mode (Phase 2) produced secondary effluent with an average TSS of 28 mg/l when the trickling filter loading was 445 g/m^3-d (28 ppd/1,000 cu ft). The secondary effluent quality was not as good as the TF/SC process but did meet secondary effluent standards. The clarity of the secondary effluent was significantly less than the TF/SC process because of the lack of aerated solids contact for flocculation.

Coeur d'Alene. The Coeur d'Alene operating records provide long-term data to assess the effect of flocculator-clarifiers on trickling filter performance. The Coeur d'Alene plant has an average dry weather flow of 0.10 m^3/s (2.3 mgd) and a 2.1-m (7-foot) deep rock trickling filter with an average filter loading of about 290 g/m^3-d (18 ppd/1,000 cu ft). The original plant included a shallow 2.1-m (7-foot) deep secondary clarifier with peripheral effluent weirs and a scraper mechanism for sludge removal. In 1983, the shallow secondary clarifier was replaced with a flocculator-clarifier, the only major modification made to the plant.

Figure 6 shows the effect of the flocculator-clarifier on plant performance. The flocculator-clarifier significantly reduced the average effluent TSS from 25 mg/l to 16 mg/l. Additionally, the plant operated more stably as noted by the reduction in the standard deviation of the monthly average values. No secondary treatment permit violations have occurred since the flocculator-clarifier was installed.

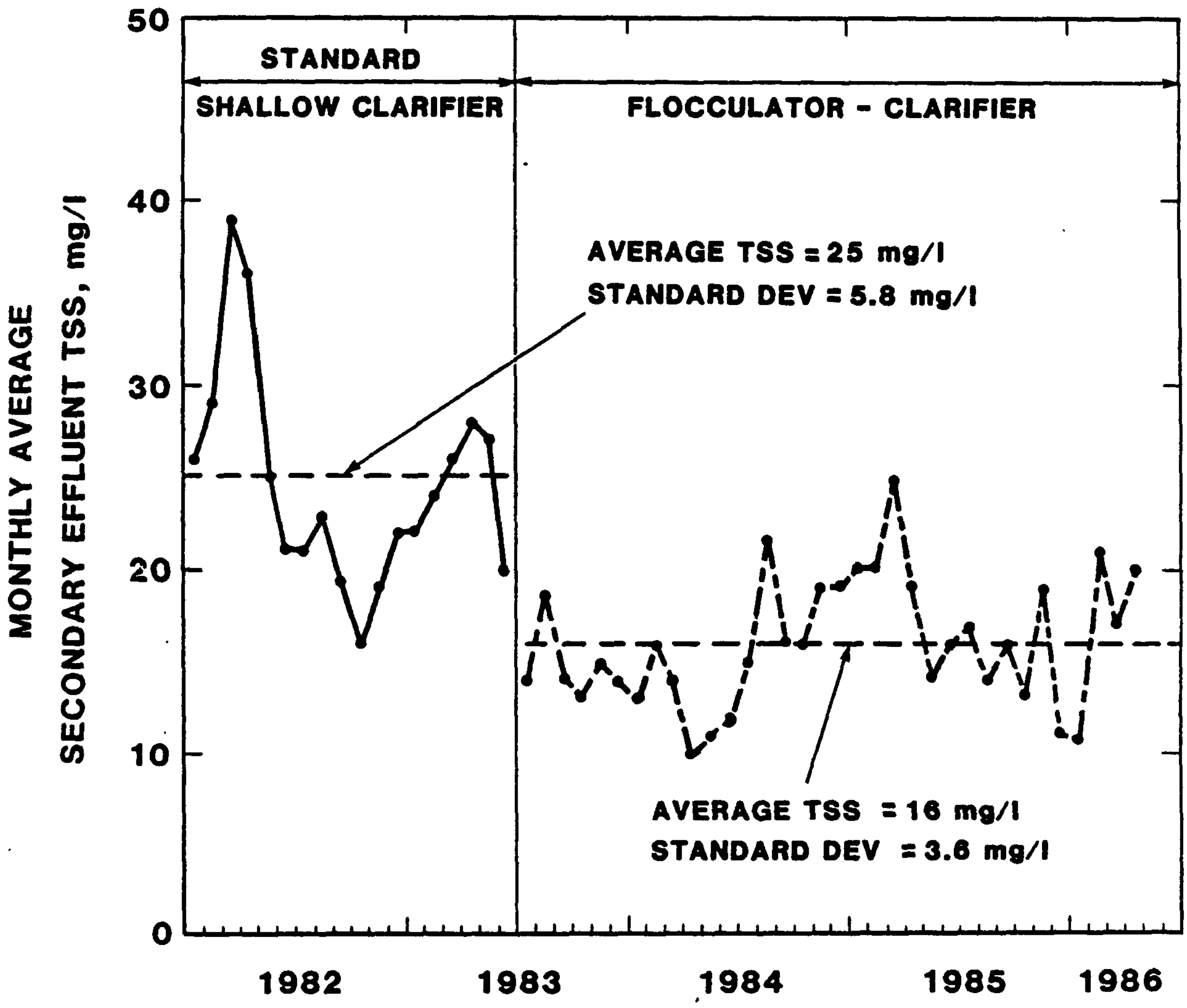

Figure 6. Effect of Flocculator-Clarifier on Trickling Filter Performance at Coeur d'Alene, Idaho

It should be noted that the new flocculator-clarifier is 23-m (75-foot) in diameter, while the old clarifier was 18-m (60-foot) in diameter. The reduction in average effluent TSS with the flocculator-clarifier, however, is not attributable to the increase in clarifier surface area. The performance of the two clarifiers was compared at the same overflow rate [24 m^3/m^2-d (590 gpd/sq ft)] using low flow data with the old clarifier and high flow data with the flocculator-clarifier. The flocculator-clarifier yielded the same average effluent TSS value (16 mg/l), while the old clarifier yielded a higher average effluent TSS value (31 mg/l). Consequently, the flocculator-clarifier improved effluent quality because of its inherent features and not because of the increase in clarifier surface area.

Reaction Rate Coefficients

The K_{20} values computed from the Morro Bay-Cayucos data were substantially higher than the K_{20} values reported for plastic media. Studies at Oconto Falls yielded the same range in K_{20} values for rock filters.[3] Richards, et al.[14] summarized K_{20} values for cross-flow media from various studies and showed they ranged from 1.7 x 10^{-3} to 2.1 x 10^{-3} $(l/m^2\text{-}s)^{0.5}$ [2.0 x 10^{-3} to 2.6 x 10^{-3} (gpm/sq ft)$^{0.5}$]. Drury, et al.[15] reported a K_{20} value of 3.2 x 10^{-3} $(l/m^2\text{-}s)^{0.5}$ [3.9 x 10^{-3} (gpm/sq ft)$^{0.5}$] for a 1.02-m (3.33-ft) deep filter with cross-flow media.

K_{20} values developed with the modified-Velz equation show that a unit of rock media surface area is more efficient at removing $SCBOD_5$ than a unit of plastic media surface area. Differences in K_{20} values may be caused by a decrease in the resistance to mass transfer in the liquid film[16] when comparing rock and plastic media. Differences in K_{20} values may also be caused in part by the inadequacy of the modified-Velz equation to account for depth. Drury, et al.,[15] noted relatively high K_{20} values for a shallow plastic media filter, although the K_{20} values were in the low end of the range measured with the rock filters at Morro Bay-Cayucos and Oconto Falls. Plastic media, however, typically has a specific surface area (media surface area/unit of media volume) that is 2 to 3 times as great as rock media, which may compensate for differences in efficiency.

The K_{20} values from the Morro Bay-Cayucos studies increased with influent $SCBOD_5$. This relationship indicates that the modified-Velz equation does not accurately describe $SCBOD_5$ removal in rock trickling filters.

CONCLUSIONS

The Morro Bay-Cayucos studies showed that TF/SC can produce high quality effluent with rock filters even up to loadings as high as 960 g/m^3-d (60 ppd/1,000 cu ft). Results indicate that if the trickling filter can operate satisfactorily at this high load, the TF/SC process will produce its typically high quality effluent.

The study team noted the presence of Beggiatoa in trickling filter effluent at 960 g/m^3-d (60 ppd/1,000 cu ft) loadings. These bacteria became abundant in the solids contact tank. Their presence indicates an increase in anaerobic activity in the filters and suggests that the 960 g/m^3-d loading may mark an upper limit for good trickling filter performance at the Morro Bay-Cayucos plant.

Nevertheless, these loadings are significantly higher than the previously tested 400 g/m^3-d (25 ppd/1,000 cu ft) loadings at the Corvallis TF/SC plant. They provide a wide margin of potential increased capacity at existing rock filter plants and indicate that these plants can be expanded merely by adding solids contact features without constructing new trickling filters. Each plant should be evaluated individually, since all rock filters may not operate effectively at such high loadings. The possibility of such economical expansion is particularly important in view of the large number of rock filter plants that will need upgrading by the year 2000. The USEPA has estimated that number to be about 1,500.[1]

Work at the Morro Bay-Cayucos plant and long-term data at the Coeur d'Alene plant showed that effluent quality from rock trickling filter plants can be improved significantly simply by replacing conventional secondary clarifiers with flocculator-clarifiers. The flocculator-clarifier at Coeur d'Alene reduced average effluent TSS from 25 mg/l to 16 mg/l. The plant effluent was also more stable and has not exceeded secondary treatment discharge limits since addition of the flocculator-clarifier.

Another result has implications for the design of expansions to rock filter plants. K_{20} values reported for filter $SCBOD_5$ removal are often higher for rock media filters than for deeper plastic media filters. The higher K_{20} values indicate rock media adequately removes $SCBOD_5$ and compensates for its lower specific surface area with higher reaction rates. The differences indicate a unit of rock media surface area is more efficient than a unit of plastic media surface area. The K_{20} values increased with $SCBOD_5$ concentration indicating the modified-Velz equation does not accurately describe $SCBOD_5$ removal in rock media filters. Designers must be aware of the limitation of the modified-Velz equation.

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Credits

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