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Evaluation of plastic media in trickling filters

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A pilot-scale study was conducted at the Utoy Creek Water Pollution Control Plant, Atlanta, Georgia to obtain design information for upgrading the existing activated sludge plant to comply with NPDES requirements for additional biochemical oxygen demand (BOD) removal and seasonal nitrification. The pilot plant could evaluate either two-stage trickling filters or combined trickling filter-suspended growth systems. The first phase of the study evaluated the impact of media configuration on BOD removal. Results of this phase are presented here.

DESCRIPTION

The pilot plant consisted of two parallel plants, each with a 6.1-m (20-ft) tower for carbonaceous BOD removal, aeration basins, clarifiers, and a 6.1-m tower for nitrification (Figure 1). There were also two independent 3-m (10-ft) towers. The cross-sectional area of all towers was 1.2 m × 1.2 m (4 ft × 4 ft). The pilot plant configuration allowed direct comparison of various types of plastic media by parallel operation of otherwise identical systems. The influence of depth on treatment efficiency was studied through parallel operation of the 3-m and 6.1-m (10 ft and 20 ft) towers.

Influent to the pilot plant was primary effluent from the Utoy Creek plant. Flow to the Utoy Creek plant is approximately 5% industrial and 95% domestic/commercial. Wastewater characteristics are shown in Table 1. Feed to the pilot plant was pumped to a flow control box on top of the tower complex for distribution to each tower in service. Wastewater was distributed across the media of each individual tower by nine circular splash plates in a random splash pattern. To simplify the study, effluent recirculation was not used. At loadings less than 2.4 m/h (1.0 gpm/ft^2), influent was dosed to evenly distribute wastewater across the media surface. Doses to the 6.1-m (20-ft) towers were applied with mechanically driven fill-and-dump systems. Dosing siphons were used to feed the 3-m (10-ft) towers. Both types of devices discharged approximately once every 12 seconds.

During parallel operation, the towers were allowed to acclimate for a minimum of 6 weeks at each flow rate before effluents were compared. Grab samples were collected every 2 hours, composited over 24 hours, and analyzed using methods outlined in "Standard Methods for the Analysis of Water and Wastewater:"[1] total Kjeldahl nitrogen (TKN), method 420A; ammonium nitrogen, method 417E; nitrate nitrogen, method 418C; nitrite nitrogen, method 419; total and soluble (1.5-μm membrane filtered) chemical oxygen demand (COD), method 508A; suspended solids, methods 209C and 209D; total and soluble (1.5-μm membrane filtered) BOD, method 507. All BOD samples were nitrification-inhibited. A paired *t*-test was performed to determine if significant differences existed in soluble BOD removal of parallel towers at the 95% confidence level.

The five types of plastic media compared are described in Table 2. They consisted of one vertical-flow, three crossflow, and one random media. The crossflow media had corrugations of a 60° or 45° angle with the horizontal plane. Results of media comparisons were divided into three sections: crossflow (CF) versus vertical flow (VF), CF versus CF, and CF versus random media. The 60° CF media used in the study were from two different manufacturers; they are designated 60° CF (A) and 60° CF (B).

PERFORMANCE

Crossflow versus vertical-flow media. The performance of 60° CF (A) and VF media in the 6.1-m (20-ft) towers at three hydraulic loadings is summarized in Table 3. The CF media consistently achieved higher BOD removal than the VF media. For the three loadings tested, the average soluble BOD removal with CF media was 79% versus 67% with VF media.

Crossflow media. Results of the parallel comparisons of 60° CF (A) and 45° CF in the 3-m (10-ft) towers and two types of 60° CF media in the 6.1-m (20-ft) towers are shown in Tables 4 and 5, respectively. According to the paired *t*-test based on soluble BOD removal, the 45° CF media was slightly superior to the 60° CF media at a hydraulic loading of 1.37 m/h (0.56 gpm/ft^2) but not at 0.86 m/h (0.35 gpm/ft^2). The paired *t*-test indicated no significant difference between the two types of 60° CF media based on soluble BOD removal.

Differences in media performance were attributed to differences in contact time, which is determined by the flow distribution characteristics and media plugging.

The nitrification results, however, conflicted with soluble BOD data. Although soluble BOD removal was significantly greater with the 45° CF media in the 3-m tower, nitrification was consistently less. Alternately, when the hydraulic loading was lowered and both media performed similarly with regard to soluble BOD removal, the 45° CF media achieved greater ammonia reduction. The reasons for this discrepancy are not known at this time. The 60° CF (A) media in the 6.1-m tower also removed more ammonia than the 60° CF (B) media even though the soluble BOD removal was not statistically different. The 60° CF (A) media had been operating for 2 months during the summer at a low hydraulic loading before the parallel testing so that nitrifiers were already well established.

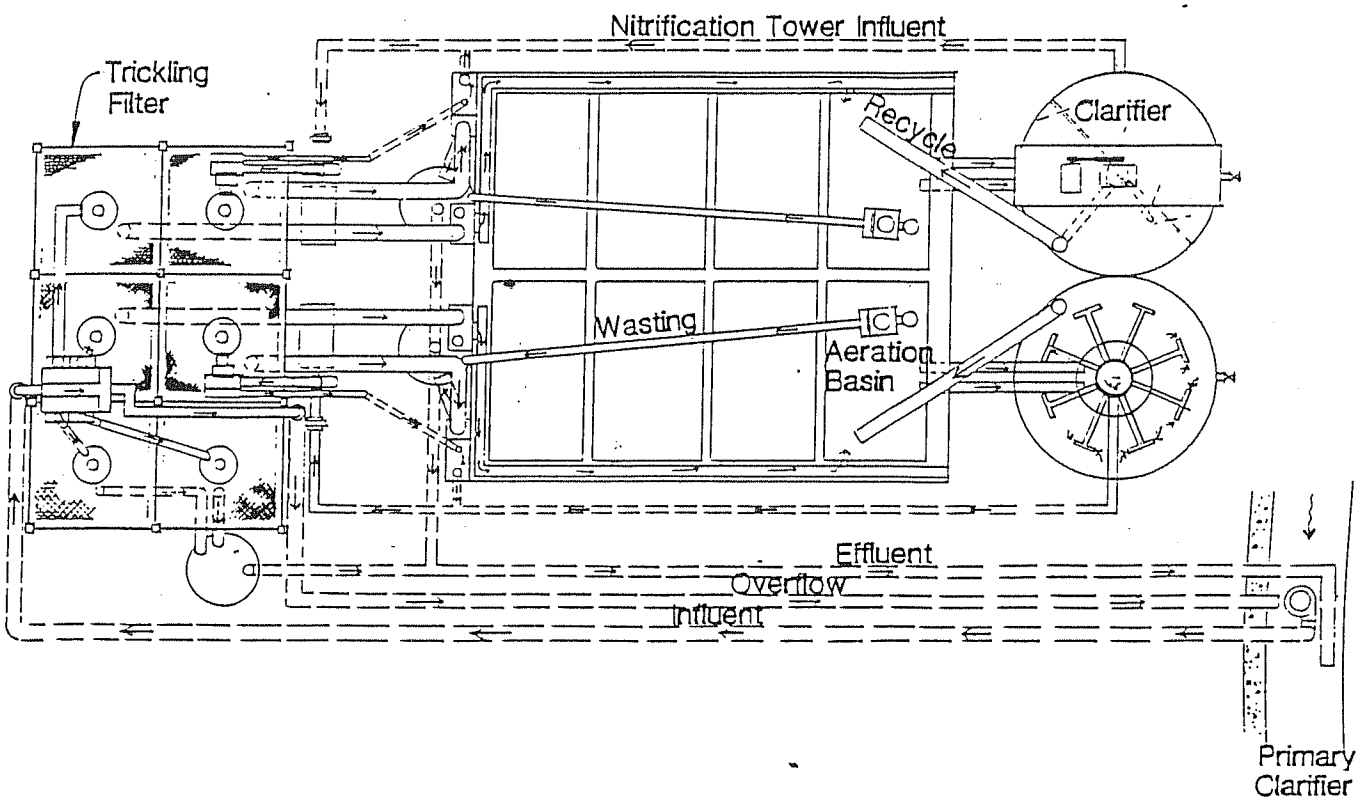


Figure 1—Pilot plant plan.

Crossflow versus random media. Results of the parallel comparison between 45° CF and random media in the 3-m (10-ft) tower are shown in Table 6. These data indicate that the CF media achieved higher BOD removal than the random media at all loadings tested. Furthermore, significant nitrification occurred with the CF media at the lowest loading rate while very little occurred with the random media.

DESIGN

BOD removal. A variety of methods are used to design packed towers. Calculated depth and media volume required for a specific effluent BOD concentration may vary significantly with the design method. The two methods most frequently used are probably performance curves and empirically derived equations. A performance curve is a plot of organic loading versus percent BOD removal. An example of an empirically derived equation is the modified Velz equation:

$$\text{Ln } S_o/S_e = kA_s D\theta^{T-20}/Q^n \quad (1)$$

Where

S_o = influent BOD, mg/L
S_e = effluent BOD, mg/L
k = kinetic coefficient, $(L/m^2 \cdot s)^n$
A_s = media surface area, m^2/m^3
D = depth, m
θ = temperature correction factor, assumed to be 1.0
T = temperature, °C.
Q = hydraulic loading $L/m^2 \cdot s$
n = hydraulic coefficient

Table 1—Average pilot plant influent characteristics.

Total BOD, mg/L	83
Soluble BOD, mg/L	48
Soluble COD, mg/L	124
NH_3-N, mg/L	11
TKN, mg/L	16
pH	7.2
TSS, mg/L	50

Table 2—Types of media compared.

Media type	Specific surface area (m^2/m^3)	Tower depth (m)
CF 60° (A)	98	6.1, 3
VF	101	6.1
CF 45°	98	3
CF 60° (B)	98	6.1
Random	104	3

Table 3—Performance summary of 6.1-m trickling filters for test periods 1, 2, and 3.

	Influent			Effluent 60° CF (A) media			Effluent VF media		
Test period	1	2	3	1	2	3	1	2	3
Flow (m^3/h)				5.5	3.4	2.5	5.4	3.3	2.5
Hydraulic load (m/h)				3.7	2.3	1.7	3.6	2.2	1.7
Organic load (total BOD, $kg/m^3 \cdot d$)				1.3	0.8	0.6	1.3	0.8	0.6
Organic load (soluble BOD, $kg/m^3 \cdot d$)				0.8	0.5	0.4	0.7	0.5	0.4
Intermittent dosing				No	No	Yes	No	No	Yes
Total BOD (mg/L)	92	92	93	25[a]	—	—	38[a]	—	—
Soluble BOD (mg/L)	53.0	54.0	54.0	16.0	10.3	8.1	23.0	17.7	13.1
Soluble COD (mg/L)	148	162	129	70	52	43	80	81	46
pH	7.2	7.2	7.2	7.4	—	—	7.4	—	—
Alkalinity (mg/L)	102	96	92	94	—	—	87	—	—
TSS (mg/L)	59	53	49	20[a]	44	42	27[a]	47	45
VSS (mg/L)	44	43	36	14[a]	34	29	19[a]	38	34
NH_3-N (mg/L)	10.5	11.6	11.8	9.3	11.0	6.8	9.4	10.5	8.4
NO_3-N (mg/L)	0.03	0.04	0.09	1.03	1.24	5.30	0.82	0.73	3.20
TKN (mg/L)	18.1	16.9	15.1	13.4	15.8	11.2	13.8	16.1	12.7
Average wastewater temperature (°C)	18	25	21						
Paired t-test for effluent soluble BOD									
Number of points							26	18	25
Calculated t							5.0	7.6	10.2
Significant difference exists at 95% confidence level							Yes	Yes	No

[a] Clarified samples.

Studies with packed towers have demonstrated that temperature correction is usually not required when wastewater temperatures are above 10°C.[2]

According to the modified Velz equation, as tower depth increases, media volume required to achieve a specific BOD removal decreases. The performance curve method, however, does not include depth as a basis for design, which implies that BOD removal efficiency does not change with tower depth. Therefore, pumping cost could be saved by building shorter, wider towers.

To determine whether tower depth affects treatment efficiency, data from the 3-m (10-ft) and 6.1-m (20-ft) towers at identical organic loadings were compared. Both towers contained 60° CF

Table 4—Performance summary of 3-m trickling filters for test periods 1 and 2.

	Influent		Effluent 60° CF (A) media		Effluent 45° CF media	
Test period	1	2	1	2	1	2
Flow (m^3/h)			2.0	1.3	2.0	1.3
ydraulic load (m/h)			1.4	0.9	1.4	0.9
Organic load (total BOD, $kg/m^3 \cdot d$)			1.0	—	1.0	—
Organic load (soluble BOD, $kg/m^3 \cdot d$)			0.6	0.4	0.6	0.4
Intermittent dosing			Yes	Yes	Yes	Yes
Total BOD (mg/L)	92	93	—	—	—	—
Soluble BOD (mg/L)	55	54	17.3	11.6	14.6	11.7
Soluble COD (mg/L)	156	129	48	38	50	44
pH	7.2	7.2	7.4	—	7.4	—
Alkalinity (mg/L)	101	92	—	—	—	—
TSS (mg/L)	52	49	67	39	57	41
VSS (mg/L)	41	36	49	29	43	29
NH_3N (mg/L)	11.4	11.8	8.7	7.5	10.1	5.8
NO_3N (mg/L)	0.04	0.09	0.99	3.2	0.65	5.74
TKN (mg/L)	17.1	15.1	13.1	10.4	14.9	9.4
Average wastewater temperature (°C)	25	21				
Paired t-test for effluent soluble BOD						
Number of points					16	19
Calculated t					3.3	0.1
Significant difference exists at 95% confidence level					Yes	No

Table 5—Performance summary of 6.1-m trickling filters for test periods 4, 5, and 6.

	Influent			Effluent 60° CF (B) media			Effluent
Test period	4	5	6	4	5	6	60° CF (A) media
Flow (m^3/h)				8.3	5.2	3.7	3.6
Hydraulic load (m/h)				5.6	3.5	2.5	2.4
Organic load (total BCD, $kg/m^3 \cdot d$)				1.6	1.0	0.8	0.8
Organic load (soluble BCD, $kg/m^3 \cdot d$)				0.9	0.6	0.5	0.4
Intermittent dosing				No	No	No	No
Total BCD (mg/L)	72	72	81	39	29	25	25
Soluble BCD (mg/L)	39	42	46	14	10	11	9
Soluble COD (mg/L)	100	95	124	35	32	36	32
pH	6.9	7.0	7.0	7.0	7.1	7.3	7.2
Alkalinity (mg/L)	83	94	99	79	72	85	69
TSS (mg/L)	49	49	45	42	45	40	40
VSS (mg/L)	—	—	—	—	—	—	—
NH_3-N (mg/L)	9.4	8.1	12.0	10.0	6.9	10.7	8.9
NO_3-N (mg/L)	0.19	0.5	0.23	0.37	1.8	0.77	2.1
TKN	13.2	13.1	19.0	14.3	9.9	17.8	16.3
Average wastewater temperature (°C)	19	23.5	20				
Paired t-test for effluent soluble BCD							
Number of points							16
Calculated t							1.6
Significant difference exists at 95% conficence level							No

(A) media. As shown in Figure 2, a significantly greater percentage of BOD was removed by the taller tower, which indicates that depth does influence treatment efficiency. The data plotted came from Tables 3 and 4.

The exponent, n, was estimated to determine if the modified Velz equation would successfully predict effluent BOD for the Utoy Creek pilot plant. Because n is a function of the hydraulic characteristics of a media, it may change with different media

Table 6—Performance summary of 3-m trickling filters for test periods 3, 4, and 5.

	Influent			Effluent 45° CF media			Effluent random media		
Test period	3	4	5	3	4	5	3	4	5
Flow (m^3/h)				1.8	1.3	3.6	1.8	1.3	3.6
Hydraulic load (m/h)				1.2	0.9	2.4	1.2	0.9	2.4
Organic load (total BCD $kg/m^3 \cdot d$)				0.6	0.5	1.5	0.6	0.5	1.5
Organic load (soluble BCD $kg/m^3 \cdot d$)				0.4	0.3	0.9	0.4	0.3	0.9
Intermittent dosing				Yes	Yes	Yes	Yes	Yes	Yes
Total BCD (mg/L)	66	81	80	46	32	37	43	35	46
Soluble BOD (mg/L)	42	43	45	13	9	19	18	13	24
Soluble COD (mg/L)	102	90	124	47	29	37	55	36	44
pH	7.0	7.0	7.0	7.1	7.0	7.3	7.1	7.1	7.3
Alkalinity (mg/L)	87	96	100	80	41	94	80	92	98
TSS (mg/L)	45	50	46	52	45	48	40	50	45
VSS (mg/L)	30	—	—	34	—	36	33	—	33
NH_3-N (mg/L)	9.2	8.6	12.7	9.5	2.4	12.6	10.0	7.4	12.8
NO_3-N (mg/L)	0.39	0.05	0.23	0.59	4.2	0.30	0.67	1.43	0.13
TKN (mg/L)	14.1	12.9	19.0	13.7	5.2	17.8	13.9	11.0	19.2
Average wastewater temperature (°C)	18	23	20						
Paired t-test for effluent BCD									
Number of points							12	11	13
Calculated t							3.5	3.2	5.5
Significant difference exists at 95% confidence level							Yes	Yes	Yes

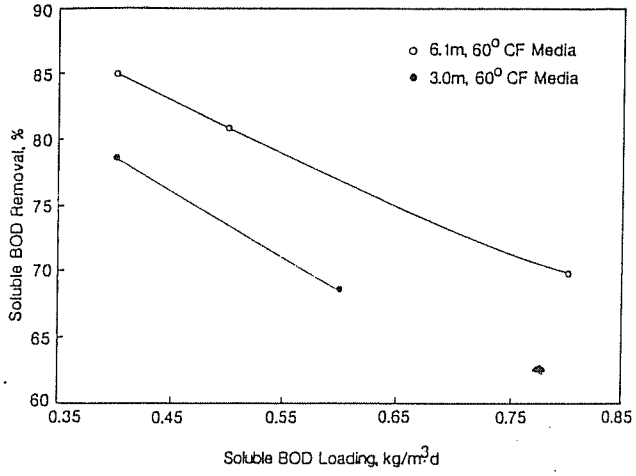


Figure 2—Soluble BOD loading versus soluble BOD removal in 6.1-m and 3-m towers with 60° CF media.

types. By trial and error, the value for n that gave the best straight line fit in a log-log plot of $A_s D/Q^n$ versus BOD removal was determined for each media type. The value of n obtained for each type of media was 0.65, which is consistent with results from other research.[3]

Once n was known, the kinetic coefficient, k, which indicates substrate removal rate, could be determined from the slope of the line. The values of k for the media types in this study are shown in Table 7. The different types of CF media had similar kinetic coefficients; values for VF and random media were significantly lower. Therefore, a larger volume of VF or random media would be required to achieve the same effluent BOD as CF media. These results indicate that k is not only a function of wastewater characteristics but also media characteristics. Therefore, a comparison of k values from different media under identical conditions and influent characteristics would provide insight into media efficiency. However, media with a higher kinetic coefficient in this pilot study will not always perform more efficiently. Other factors that affect treatment efficiency, such as plugging and oxygen limitations, may have a more or less significant effect on BOD removal under different circumstances.

Table 8 shows a comparison of kinetic coefficients for CF and VF media from various studies with domestic wastewater. To provide a basis of comparison, an n value of 0.5 was used to develop k values. In all studies, except Hillsboro,[4] the k values of the CF media were higher than those of the VF media. The Hillsboro study differed from the other studies in three major ways: use of fully corrugated instead of partially corrugated VF media, a significantly greater influent BOD concentration, and use of grab sampling instead of composite sampling. It is not known which, if any, of these factors contributed to the difference in the CF and VF media performance in the Hillsboro study.

A k value from a study with a similar influent type is sometimes used in designing trickling filters. There is a 21% difference in the k values for CF media in the studies shown in Table 8.[3-5] A variation of this magnitude in k, in the modified Velz equation, can make a 38% difference in the media volume required to achieve a specific effluent BOD concentration if an n of 0.5 is used. Thus, it is important to perform pilot plant testing before full-scale trickling filters are designed.

Sludge production. The quantity of sludge produced by the trickling filter is important in design of sludge handling facilities. One approach is to relate solids produced to substrate removed with Equation 2.[6]

$$P_x A_m = Y'(S_r)/A_m - k'_d \qquad (2)$$

Where

P_x = VSS production, kg/d
A_m = total media surface area in tower, m^2
Y = gross yield coefficient, kg/kg
k'_d = decay coefficient, d^{-1}
S_r = substrate removed, kg BOD/d (total BOD in minus soluble BOD out).

Equation 2 is similar to that used to predict activated sludge production; it assumes, however, that the total mass of organisms is proportional to media surface area.

Once Y' and k'_d are known, sludge production can be estimated. To determine Y' for the Utoy Creek pilot plant trickling filters, effluent volatile suspended solids (VSS) were plotted against substrate removed, as shown in Figure 3. The resulting Y' of 0.60, obtained from the slope of the line, was similar to yield coefficients obtained for typical activated sludge processes and in full-scale plant studies using plastic media.[6,7]

Solids production from the various media types were compared by calculating average yield coefficients. The average yield coefficients for the random, 45° CF, and 60° CF media with influent dosing were 0.62, 0.52, and 0.46, respectively. Differences in yield coefficients noted in Hillsboro, Oreg. were attributed to differences in media geometry.[4] The geometry of random media apparently induces greater turbulence and leads to a lower overall solids retention time (SRT). When random and 45° CF media were run in parallel, microscopic observations of the effluent revealed very different microbial communities. The 45° CF media effluent contained primarily stalked ciliates and rotifers, often associated with longer SRTs in activated sludge systems, while the predominant protozoa in the random media effluent were free-swimming ciliates. A large number of *Beggiotoa*, a sulfur bacteria, were also in the random media effluent. *Beggiotoa* requires a reduced sulfur source; therefore, pockets of solids may have accumulated and become anaerobic. Hence, solids accumulation areas and high shear areas may exist simultaneously in the random media.

Research has also shown a direct relationship between total suspended solids (TSS) applied and TSS produced.[6] Data from this study supports this relationship. With 1 to 10 kg TSS applied

Table 7—Kinetic coefficients for various media types.

Media type	Number of points	n	k $(L/m^2 \cdot s)^{0.65}$[a]	Correlation coefficient
60° CF (A)	5	0.65	2.14×10^{-3}	0.9997
60° CF (B)	3	0.65	2.31×10^{-3}	0.993
45° CF	5	0.65	2.22×10^{-3}	0.998
VF	3	0.65	1.46×10^{-3}	0.9995
Random	3	0.65	1.48×10^{-3}	0.998

[a] Based on soluble BOD.

Table 8—Comparison of k values from various trickling filter studies using n = 0.5.

	k, $(L/m^2 \cdot s)^{0.5}$					
	CF		VF			
	A_s = 98 m^2/m^3	A_s = 140 m^2/m^3	A_s = 101 m^2/m^3	A_s = 135 m^2/m^3	Tower influent soluble BOD, mg/L	Effluent recycle used
Hillsboro[4]	1.67×10^{-3}	—	2.03×10^{-3}	—	119	No
	1.67×10^{-3}	—	2.14×10^{-3}	—	140	Yes
Duck Creek[5]	1.88×10^{-3}	—	1.40×10^{-3}	—	68	Yes
Malmo[3,5]	—	1.73×10^{-3}	—	1.05×10^{-3}	44	Yes
Utoy Creek	2.13×10^{-3}	—	1.45×10^{-3}	—	54	No

Note—Duck Creek k values corrected for temperature.

per day, TSS production averaged 91% of TSS applied (Figure 4).

Oxygen limitation. Differences in media performance may be caused by different oxygen transfer capabilities of the media.[5,8] To determine whether this explanation was applicable to this study the soluble BOD concentrations were measured in grab samples collected under identical conditions at intermediate depths through ports cut 0.5 m into the media in the 6.1-m (20-ft) VF and CF media towers. Results are shown in Figure 5. Removal rates were then calculated for each 0.6-m (2-ft) section of depth and plotted against soluble BOD concentration (Figure 6). Removal rates increased with soluble BOD at low concentrations; however, at about 40 mg/L soluble BOD the removal rate becomes fairly constant, regardless of increasing concentrations. This change in the relationship between soluble BOD concentration and soluble BOD removal rate through a trickling filter has also been noted by Parker and Merrill,[5] who attribute it to oxygen transfer limitations. They cite research by Williamson and McCarty[9] that showed that BOD removal may become oxygen-limited when the biofilm is exposed to soluble BOD concentrations greater than 40 mg/L. Whether oxygen transfer efficiency is the primary factor responsible for differences in performance in this study, however, is questionable. In all of the intermediate sampling, removal rates at every depth of the VF tower were less than the CF tower, even when soluble BOD concentrations were small and oxygen limitation should not be a factor. For this reason, oxygen limitation is not believed to be the primary reason for these differences in media performance.

Retention time. Many models for trickling filter design, including the modified Velz equation, are based on first-order kinetics of biological oxidation, as shown in Equation 3.

$$\text{Ln } S_o/S = kt_c \quad (3)$$

Where

t_c = contact time

In the modified Velz equation, contact time is assumed to be equal to retention time. An empirical equation which estimates liquid retention time is shown in Equation 4.[5]

$$t = cA_sD/Q^n \quad (4)$$

Where

t = retention time
c = constant

If Equation 4 is substituted into Equation 3, Equation 5 results, from which the modified Velz equation is easily derived by combining c and k.

$$\ln S_o/S = kcA_sD/Q^n \quad (5)$$

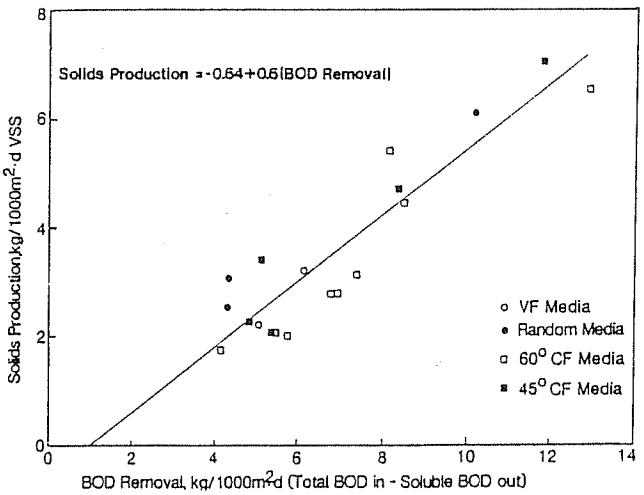


Figure 3—BOD removal (total BOD in/soluble BOD out) versus solids production in 3-m and 6.1-m trickling filters with various media.

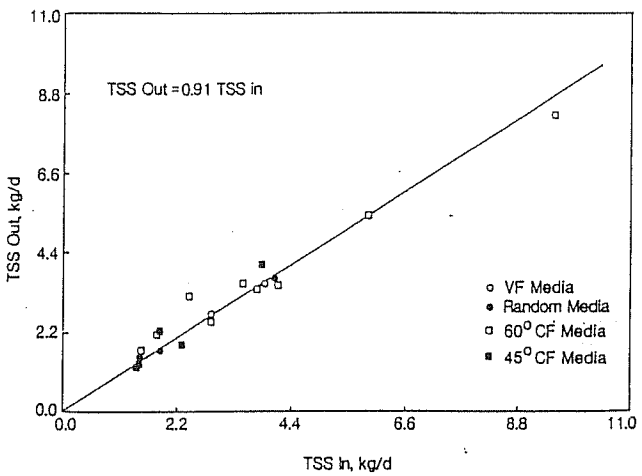


Figure 4—Total suspended solids in versus total suspended solids out of 3-m and 6.1-m trickling filters with various media.

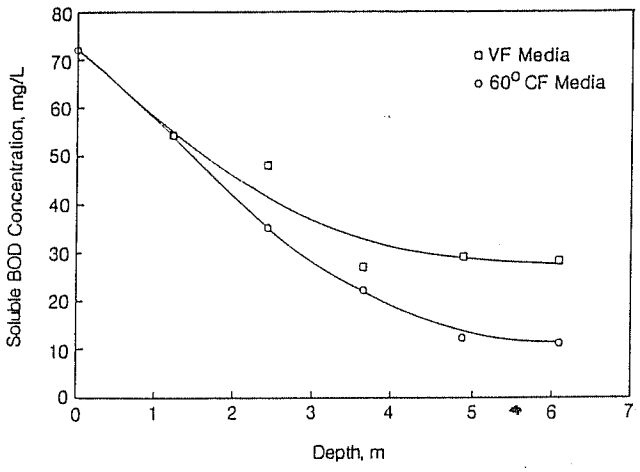


Figure 5—Soluble BOD profile through VF and 60° CF media at 2.3 m/h hydraulic loading.

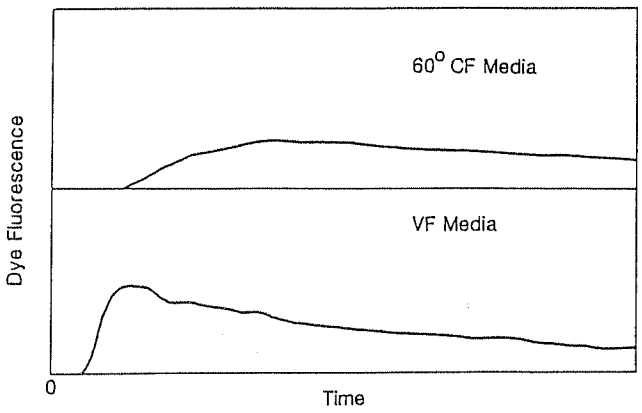


Figure 7—Dye tracings of 6.1-m trickling filter, 60° CF, and VF media at 2.4 m/h hydraulic loading after 10 months operation.

Because liquid retention time is important in the derivation of the modified Velz equation, and the modified Velz equation was successfully applied in this study, differences in liquid retention time may be the primary factor responsible for differences in treatment efficiency.

Dye studies were performed to determine to what extent liquid retention time affects treatment efficiency. Retention time was defined as the time in which half the mass of yellow-green fluorescent dye had passed through the tower. A fluorometer with strip chart recorder was used to measure dye concentration. The dye concentration in the effluent was measured until it was less than 10% of peak value because of time limitations. The tail of the curve was then extrapolated and the area under the curve was determined. Figure 7 shows examples of dye tracings from 6.1-m VF and 60° CF media with established biofilm at identical hydraulic loadings. The tracings indicate that more shortcircuiting occurred in the VF than CF media because dye appeared in the effluent in a shorter period. In fact, the CF media had a greater retention time for all flow rates tested, as shown in Figure 8. The 60° and 45° CF media had very similar retention times in the 3-m towers (Figure 9), but the random media had a lower retention time at the flow rates tested. The greater retention time of the CF versus VF and random media was believed to be caused by the CF configuration, which allows for better distribution of wastewater within the media and thereby reduces shortcircuiting.

If first-order kinetics, as shown in Equation 3, apply, and contact time and retention time are equivalent, then plotting retention time versus log of treatment efficiency should yield a straight line. Figure 10 shows that a linear relationship does exist; however, it differs depending on whether the tower is dosed or continuously fed. These results indicate that dosing improves treatment efficiency at identical liquid retention times. This is a misleading conclusion, however, because both dosed and continuously fed towers fit the modified Velz model predictions. Therefore, both dosed and continuously fed towers, which have identical media at the same hydraulic loading, provided equal treatment even though retention times differed. Thus, although dosing decreases retention time, it seems to compensate by improving treatment efficiency. The improvement in efficiency with

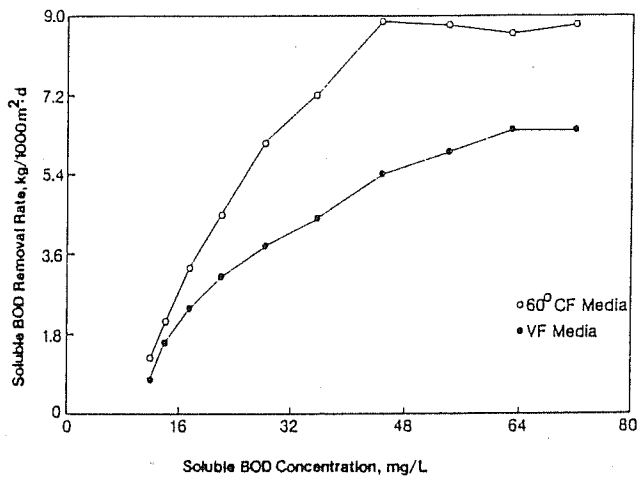


Figure 6—Soluble BOD concentration versus soluble BOD removal rate in 60° CF media and VF media at 2.3 m/h hydraulic loading.

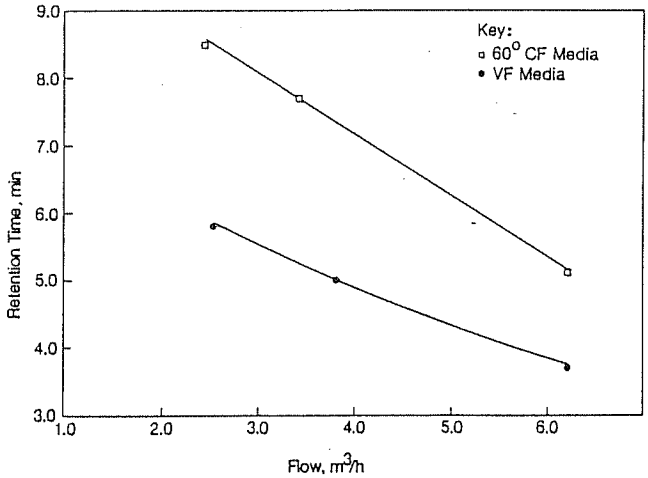


Figure 8—Flow versus retention time for 6.1-m trickling filters without influent dosing.

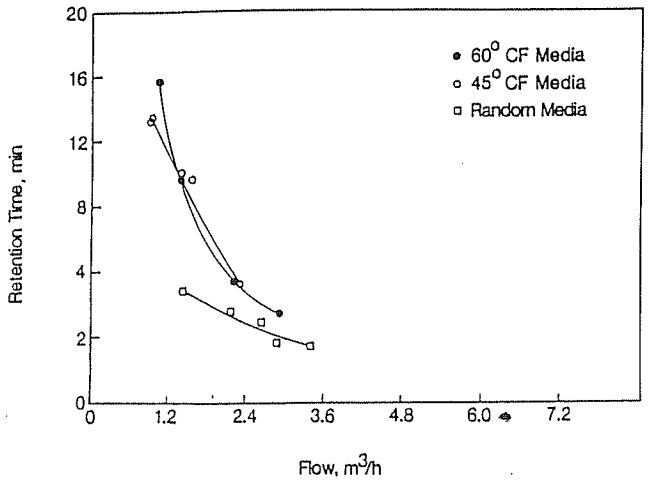


Figure 9—Retention time versus flow for 3-m towers with dosing.

dosing could result from a variety of factors including increased oxygen transfer efficiency, increased turbulence which decreases resistance of substrate diffusion into the biofilm layer, and increased shear which results in thinner, more efficient biofilms. An alternate explanation for the fact that dosing decreased retention time but did not decrease treatment efficiency, is that liquid retention time, t, in Equation 4 and contact time, t_c, in Equation 3 are related but not identical. Hence dosing may have decreased retention time without significantly decreasing biofilm-substrate contact time.

To investigate whether retention time and contact time are identical, an estimate of the hydraulic exponent, n, was made using Equation 4. If they are the same, then n values obtained from this equation using a log-log plot of hydraulic loading versus retention time should theoretically be the same as the n value obtained by empirical fit of performance data in Equation 1. As Table 9 shows, however, the n values were significantly different than 0.65 that gave the best fit of the performance data. Other researchers[10] have also shown that values for n obtained on the basis of retention time differ from values based on performance data. Therefore, although both retention time and BOD removal

Table 9—Hydraulic coefficient (n) obtained by log-log plot of flow versus retention time.

Media type	Depth (m)	n	
		Continuous feed	Dosed
60° CF (A)	6.1	0.56	1.39
60° CF (A)	3.0	—	1.25
45° CF	3.0	—	0.89
VF	6.1	0.51	0.98

efficiency vary inversely with hydraulic loading, the degree of influence is not the same. This would suggest that contact time and retention time, although related, are not identical. Nevertheless, as Figure 10 shows, under identical feed conditions, comparative liquid retention times can give a good indication of the relative treatment efficiencies of various media types.

Plugging. Plugging characteristics of various media types by sloughed biofilm solids is of interest because it can reduce treatment efficiency and cause fly and odor problems. To compare potential plugging characteristics of the 60° CF media and VF media the top two packs of media from each 6.1-m (20-ft) tower were removed and inspected. The towers has been in operation for about 6 weeks during winter months at a loading of 1.33 kg/$m^3 \cdot d$ total BOD (83 lb/1000 $ft^3 \cdot d$ total BOD). Although none of the media flow channels were completely plugged, partial blockages were evident. The CF media were partially blocked by large (2.5 to 5 cm diameter) black gelatinous deposits within the media as well as at the interfaces between packs, as shown in Figure 11. Most of the solids in the media accumulated at contact points in the pack media where two parallel sheets touched. A large number of these same gelatinous deposits were associated with the VF media; however, they occurred primarily at the interfaces between packs and not in the packs (Figure 12).

Even so, plugging in the CF media may not affect treatment efficiency as much as the same degree of plugging in the VF media. If a mass of solids block a channel in the VF media, flow cannot enter at other points and the surface area within the

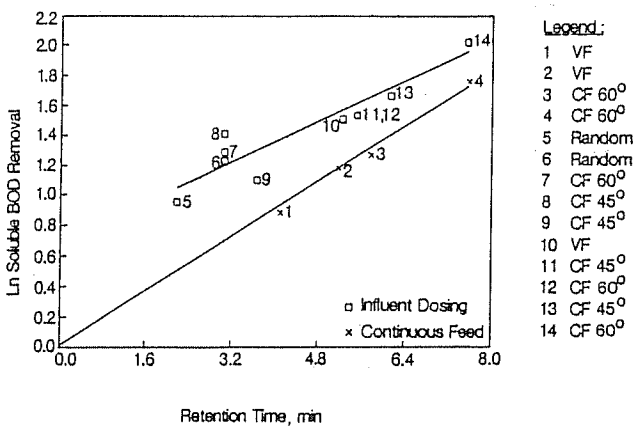


Figure 10—Retention time versus ln soluble BOD removal for all media types.

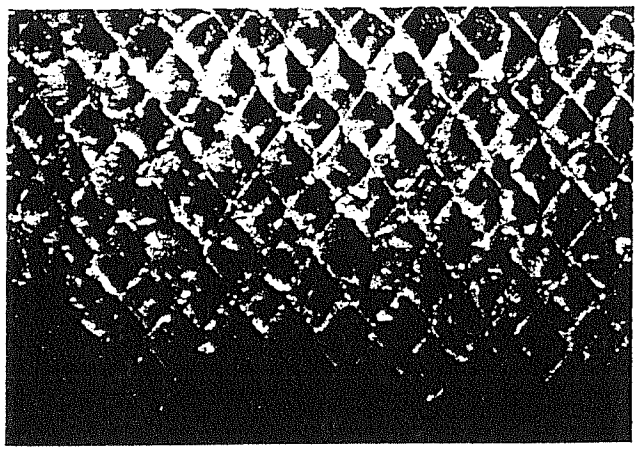


Figure 11—Solids accumulation on 60° CF media, 1.2 m from top of trickling filter operated 6 weeks at 1.3 kg/$m^3 \cdot d$ total BOD.

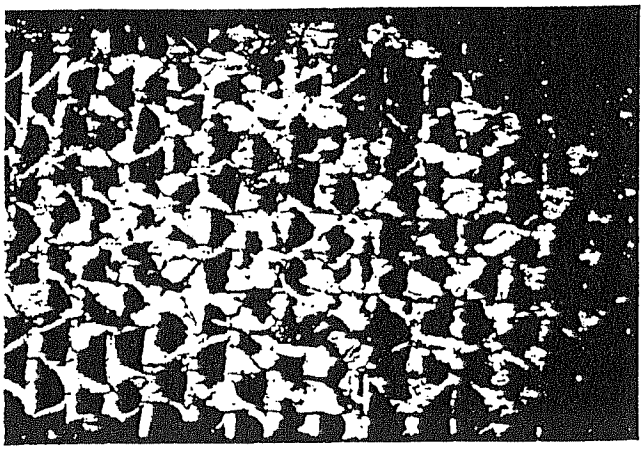


Figure 12—Solids accumulation on VF media, 1.2 m from top of trickling filter operated 6 weeks at 1.3 kg/m^3·d total BOD.

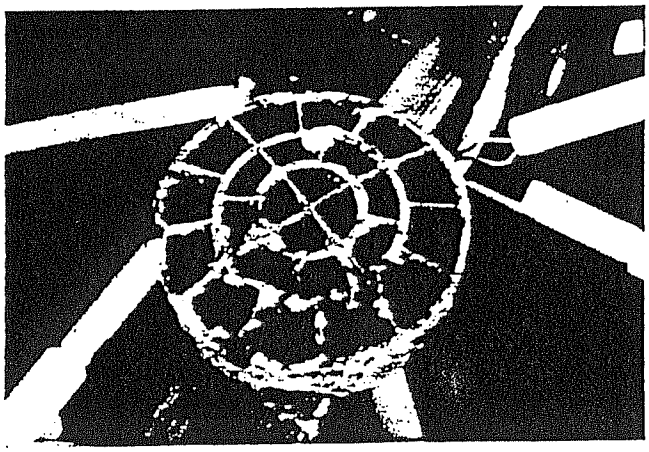


Figure 14—Solids accumulation on random media, 0.6 m from top of trickling filter after 6 weeks operation at 1.5 kg/m^3·d total BOD.

channel is lost. This is not the case with CF media because flow can redistribute from other parts of the media.

Inspection of the media over time revealed that solids accumulation was heaviest during winter months and a period of heavy sloughing occurred in late March as temperatures increased. This is probably because film thicknesses are typically greater at lower temperatures.[11,12]

Solids also accumulated in the random media as stated earlier and may be responsible for a loss of nitrification noted during one run. The 45° CF and random media in 3-m (10-ft) towers were operated at hydraulic loadings of 1.22, 0.86 and 2.4 m/h (0.5, 0.35, 1.0 gpm/ft^2). When the loading was decreased from 1.22 to 0.86 m/h (0.5 to 0.35 gpm/ft^2), nitrification began to occur in both towers. Figure 13 shows ammonia removal over time. Nitrification first increased then decreased in the random media and never attained the degree of nitrification in the 45° CF media. When the first metre of random media was removed, there were black gelatinous solids containing large numbers of *Beggiotoa* at the media interfaces (Figures 14 and 15). *Beggiotoa* also occurred in the solids accumulations in the pack media; however, very few occurred in the pack media effluent. *Beggiotoa*, on the other hand, was present in large numbers in the random media effluent, which possibly indicated more extensive solids accumulation.

When the hydraulic load to both 3-m (10-ft) towers was increased to 2.4 m/h (1.0 gpm/ft^2) a large amount of black solids appeared in the random media effluent. It was expected that solids accumulation might decrease and treatment efficiency improve because of increased hydraulic shear, particularly since influent dosing was used. No improvement occurred, however, and when the first metre of media was again inspected, solids accumulation had slightly increased. It must be noted that recirculation was not used, but it might have helped to prevent solids accumulation by increasing hydraulic shear without increasing the organic loading.

Solids accumulation may have inhibited nitrification and reduced BOD removal efficiency by causing shortcircuiting of flow through the tower. Visual observations of dye passing through the random and 45° CF tower at identical loadings showed the dye appeared 6 seconds sooner from the random media. Shortcircuiting would decrease BOD removal in the upper portions of the tower by decreasing both retention time and available surface area. The increased BOD concentration to the lower

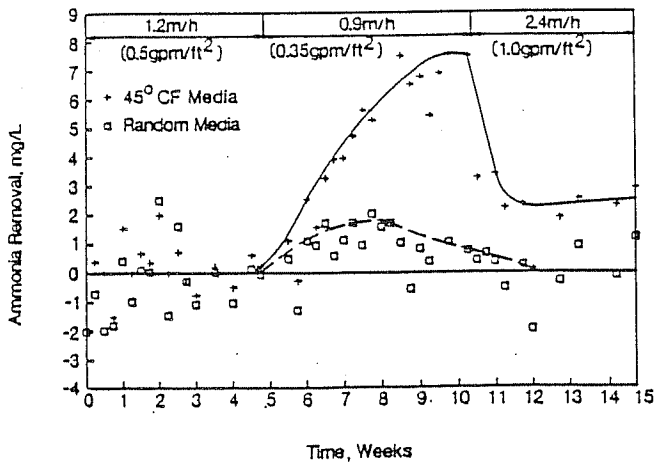


Figure 13—Ammonia removal of 45° and random media over time at three hydraulic loadings.

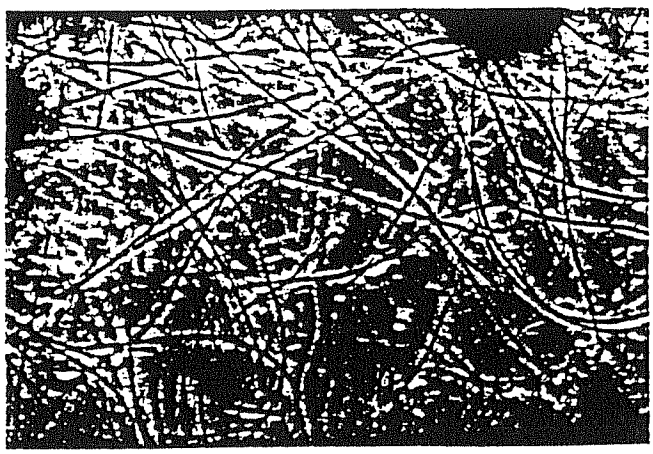


Figure 15—*Beggiotoa* in solids accumulation on random media.

portions of the tower would then decrease surface area available to nitrifiers. The accumulations of solids may also have inhibited nitrification by producing reduced materials which may have made conditions unsuitable for nitrifiers.

CONCLUSIONS

- Crossflow media achieved higher BOD removal than vertical-flow and random media.
- Three types of crossflow media tested provided nearly comparable treatment.
- Depth affected treatment efficiency. As depth increased, efficiency increased. The data did not conform to performance curves but did fit the predictions of the modified Velz equation using coefficients developed during the study.
- Differences in oxygen transfer efficiencies did not seem to be the primary reason for differences in media performance. Oxygen transfer of the media may play a more significant role in performance efficiency for higher strength wastewater.
- Differences in media performance were attributed primarily to differences in biofilm-substrate contact time, which is related to liquid retention time. Contact time is affected by liquid redistribution characteristics of media and the tendency of media to plug.
- An average yield coefficient of 0.6 was determined for the Utoy Creek pilot plant trickling filters. Additionally, a relationship was found between suspended solids produced and suspended solids applied.

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