

TIME VS. SPACE: TWO SUCCESSFUL BIOLOGICAL NUTRIENT REMOVAL STRATEGIES

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ABSTRACT

Two distinct strategies have been practiced successfully for nutrient removals at a facility. One utilizes a continuous flow strategy with designated anaerobic, anoxic and aerobic zones. This strategy was targeted for biological nitrogen and phosphorus removal with minimal chemical addition. The other utilizes anaerobic, anoxic and aerobic cycle times in sequence at existing basins under a timer control. Chemical addition is a primary means of phosphorus removal in this strategy.

Results show good performance in meeting current discharge limits. Process parameters for design and operation are presented with corresponding discussion on advantages and disadvantages of two strategies.

KEYWORDS

Anaerobic selector, phosphate accumulating organisms, activated sludge, nitrification, denitrification, costs of nutrient removal.

INTRODUCTION

The Philip Morris USA Park 500 facility near Richmond, VA is a tobacco reprocessing facility. The wastewater has a high concentration of natural organic material. The wastewater is also high in both inorganic and organic nitrogen compounds as well as phosphorus.

The facility operates a 3.0 MGD Wastewater Treatment Plant that has consistently met Virginia permit requirements. The facility has been removing phosphorus over 10 years, utilizing both biological and chemical methods. One of the activated sludge units was upgraded to include anaerobic selector followed by one anoxic zone before aeration resumes in the subsequent three aeration zones. The remaining units have been fed ferric chloride for phosphorus removal.

Consistent with the Chesapeake Bay program goals, the facility started voluntarily to remove nitrogen in the existing basins by modifying the operating procedures for denitrification. This paper describes two distinct approaches to successfully meet the goal of removing phosphorus and nitrogen at this facility. The VPDES permit requirements for the facility are presented in Table 1.

Figure 1 presents a process flow diagram for the plant. The treatment process includes primary settling, activated sludge and clarification, tertiary filtration, and disinfection of the effluent. For nutrient removal, the plant has two parallel systems. System 1 consists of a new anaerobic selector tank built ahead of an existing aeration basin for biological phosphorus removal. The first quadrant of the aeration basin was converted into an anoxic zone, while the remaining three quarters were maintained as aerobic zones. An internal recirculation line brings MLSS from the fourth quadrant back to the first quadrant for de-nitrification... This system was optimized for high performance for both P and N removal, based on extensive testing of wastewater characteristics and process parameters.

System 2 employs a new strategy of controlling cycle times in the existing complete-mixed basins with surface aerators. This system maintains aerobic cycle followed by anoxic and anaerobic cycles, by the use of timers. Phosphorus removal is done principally by use of chemical, while nitrogen is removed by nitrification/de-nitrification via sequential aeration/non-aeration. This strategy for System 2, was conceived and implemented by the facility staff in order to maximize the nutrient removal by operational changes, without capital expenditures (1). Since nitrogen removal was voluntary at this point, operating parameters were developed and then optimized for seasonal and other operational parameters.

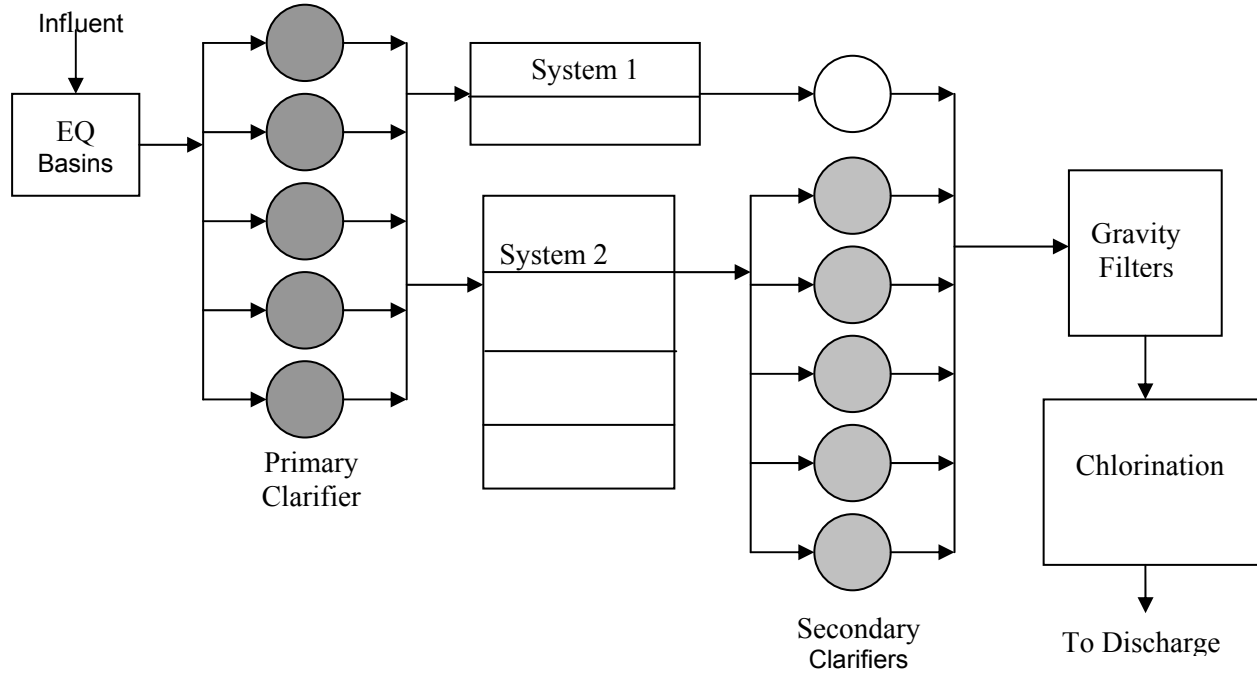
VPDES PERMIT LIMITS

Table 1: VPDES Permit Requirements

Parameter/units	Value
Flow	(Report) Rated Capacity : 3 MGD.
pH, s.u.	6.0 – 9.0
TSS, lb/day	450 average, 900 maximum
D.O., mg/L	4.6 minimum
Total P, mg/L	2.0 average
Total P, kg/year	4527 maximum
Ammonia-N, lb/day	92 average, 184 maximum
TKN, kg/year	75740 maximum
CBOD5, lb/day	600 average, 1200 maximum

DESCRIPTION OF TWO STRATEGIES

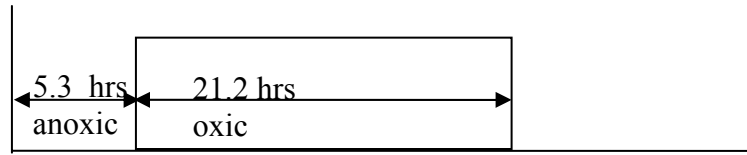
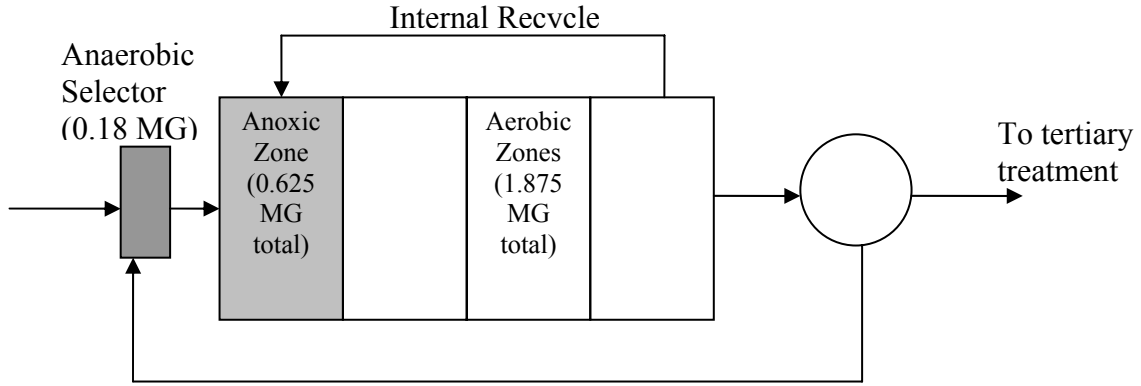
Figure 1: Process Flow Diagram for WWTP



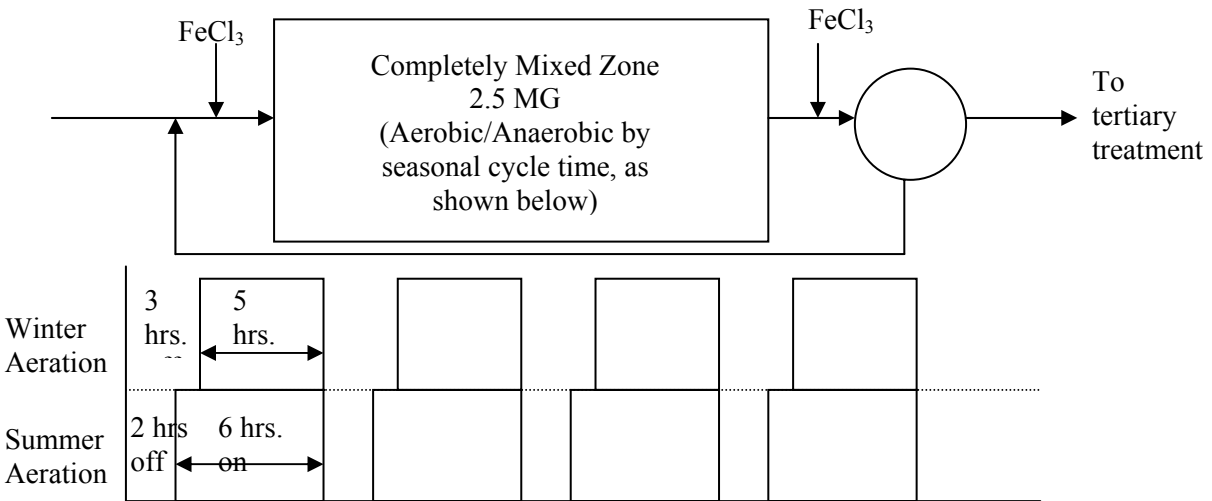
The two strategies are depicted in Figure 2. System 1 consists of a 0.18 MG anaerobic selector tank constructed in front of a 2.5 MG basin. The basin was divided into four quadrants, with the first quadrant being converted into an anoxic zone. New mixers were installed in place of surface aerators. Partition walls were constructed in the existing basin. As the system removes both phosphorus and nitrogen biologically, no chemical addition is needed, except during startup periods following annual shut downs during year end holidays or the fourth of July holidays, and during occasional phosphorus spikes. System 2 consists of four completely-mixed 2.5 MG basins, with ferric chloride addition to the basin ahead of the clarifier for phosphorus removal. Ferric addition following the basin is available if needed for effluent polishing. These basins are sequentially aerated and not aerated via the surface aerators being turned on and off. The times for turning the aerators on and off were determined through observation of the amount of time needed to bring dissolved oxygen up to 2-3 mg/L, and the amount of time needed to take the dissolved oxygen to essentially zero during non-aerated periods. Seasonal adjustment to give more aeration time and less off time during summer months was also found to be appropriate.

Figure 2: Depiction of Treatment Strategies

System 1: Plug Flow Biological Nutrient Removal



System 2: Complete Mix Under Alternating Aeration (4 available)



WASTEWATER CHARACTERISTICS AND PROCESS DATA

Table 2 presents primary effluent data for the year 2004. During that year, the plant received average 2.2 MGD. It can be seen that the primary effluent retained relatively high BOD, TSS, nitrogen, and Total P. Early pilot testing data indicated favorable characteristics for biological phosphorus removal.(1,2) The BOD to TP ratio exceeded 20 at all times, averaging 28. Approximately 60% of the BOD was soluble. The soluble phosphorus was also around 60% of

the total P. Both ammonia and nitrate nitrogen were available for oxidation and reduction by the activated sludge.

Table 2: Primary Effluent Data

	NH ₄ -N (mg/L)	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Total P (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)
Jan-04	2.76	838	1186	597	25.5	4.59	65.5
Feb-04	5.62	1006	1334	680	33.8	1.11	91.4
Mar-04	6.66	948	1410	800	35.6	0.18	108.1
Apr-04	3.86	868	1298	610	28.8	0.20	---
May-04	4.78	858	1150	870	27.9	0.44	---
Jun-04	4.68	763	1094	750	28.9	0.19	---
Jul-04	7.16	676	1012	800	21.0	2.76	---
Aug-04	4.81	771	1146	670	25.6	2.13	---
Sep-04	3.93	707	1065	700	26.2	0.20	---
Oct-04	3.11	863	1042	920	24.7	0.97	---
Nov-04	3.18	721	994	850	27.3	1.63	---
Dec-04	9.53	653	1008	940	33.0	0.85	---
Average	5.01	806	1145	766	28.2	1.27	88.3

Table 3 presents secondary effluent BOD, ammonia, nitrate nitrogen, and Total P. It can be seen from these data that both secondary systems provide outstanding removals.

Table 3: Secondary Effluent Data

	BOD (mg/L)	Total P (mg/L)	NH ₃ -N Sys. 1 (mg/L)	NH ₃ -N Sys 2 (mg/L)	NO ₃ -N Sys. 1 (mg/L)	NO ₃ -N Sys. 2 (mg/L)
Jan-04	12	1.03	0.19	0.22	2.42	1.41
Feb-04	10	0.88	0.28	0.75	0.69	1.67
Mar-04	9	1.47	0.22	0.39	1.61	0.90
Apr-04	10	1.56	0.22	0.35	1.35	1.65
May-04	9	1.41	0.18	0.36	1.94	1.28
Jun-04	8	1.77	0.16	0.51	2.04	1.61
Jul-04	6	0.99	0.14	0.28	1.76	2.64
Aug-04	10	1.46	0.20	0.40	2.56	1.56
Sep-04	10	1.64	0.14	0.28	2.05	1.51
Oct-04	12	1.37	0.23	0.29	2.36	1.32
Nov-04	19	1.72	0.20	0.25	1.46	0.43
Dec-04	21	2.63	0.57	0.36	2.38	1.56
Average	11.09	1.49	0.23	0.37	1.88	1.46
Limits	24	2.0	3.7	3.7	---	---

Figure 3 shows a time series for nitrate removal by denitrification during a May 2002 startup of System 2. . It is shown that as soon as the process was introduced to alternating aeration mode, denitrification started immediately and reached a new level in 4 days: the NO₃ concentration dropped from 23 mg/l on Day 1, to 0.7 mg/l on Day 4. This conversion was made with initial monitoring of D.O. ammonia nitrogen and nitrate nitrogen each day, and adjustment of aeration time to ensure that the D.O. was maintained between 0 and 2 mg/L. D.O concentration in Figure 3 is the average of the day, representing the on and off hour measurements during the period. Subsequent modifications were made to aeration times based on changing temperature and organic loadings at the facility.

Figure 3: Time Series for NO₃-N, May 2002

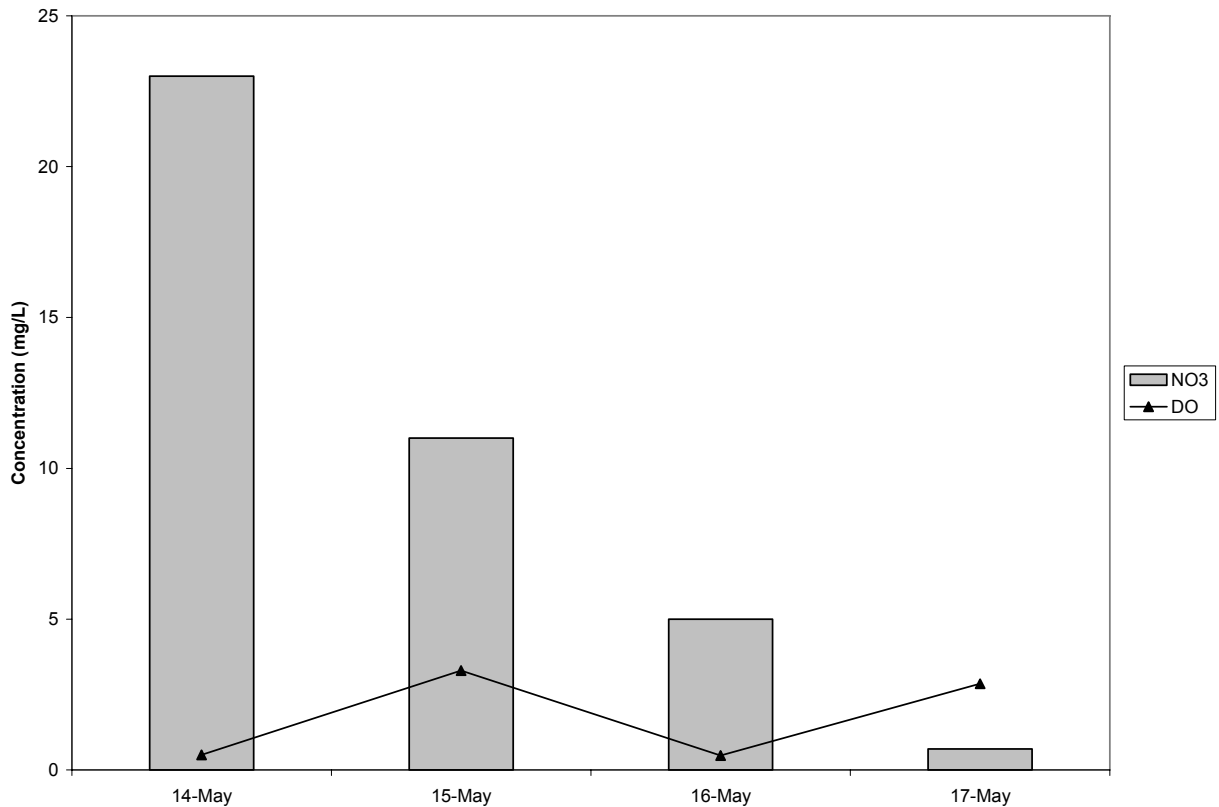


Table 4 presents 9-month (April to December 2004) averages of HRT, MCRT, biological sludge yield, and organic loading rates for the two systems.

Table 4: 9-month average Process Parameters for Systems

Parameter	System 1	System 2
HRT, days	4	5
MCRT ,days	16	16
Yield, lb VSS/lb BOD@ PE	0.88	1.32
Organic Load Rate, lb/kcf-d	10	9
VSS production, lb/MG	5631	8185
NVSS production, lb/MG	2036	3261
Ferric Dosage, lb/MG	167	1281
MLSS, mg/L	3529	4247
MLVSS, mg/L	2582	2995

Table 4 presents the monthly costs for electrical usage, ferric, and sludge disposal for the two systems.

Table 4: 10 Month Costs per Million Gallons treated for Systems 1 and 2

Month	System 1			System 2			Total 1	Total 2
	Electrical	Ferric	Sludge	Electrical	Ferric	Sludge		
Mar-04	\$194	\$82	\$653	\$150	\$325	\$586	\$929	\$1,061
Apr-04	\$219	\$249	\$474	\$185	\$310	\$623	\$942	\$1,118
May-04	\$234	\$151	\$415	\$211	\$236	\$573	\$801	\$1,020
Jun-04	\$245	\$0	\$364	\$219	\$469	\$561	\$609	\$1,250
Jul-04	\$269	\$0	\$248	\$246	\$416	\$466	\$517	\$1,128
Aug-04	\$239	\$0	\$274	\$201	\$378	\$573	\$513	\$1,152
Sep-04	\$242	\$0	\$350	\$211	\$376	\$586	\$592	\$1,173
Oct-04	\$211	\$0	\$400	\$165	\$288	\$569	\$612	\$1,022
Nov-04	\$196	\$0	\$451	\$138	\$246	\$577	\$647	\$960
Dec-04	\$203	\$0	\$421	\$153	\$356	\$544	\$624	\$1,053
Average	\$225	\$48	\$405	\$188	\$340	\$566	\$679	\$1,094

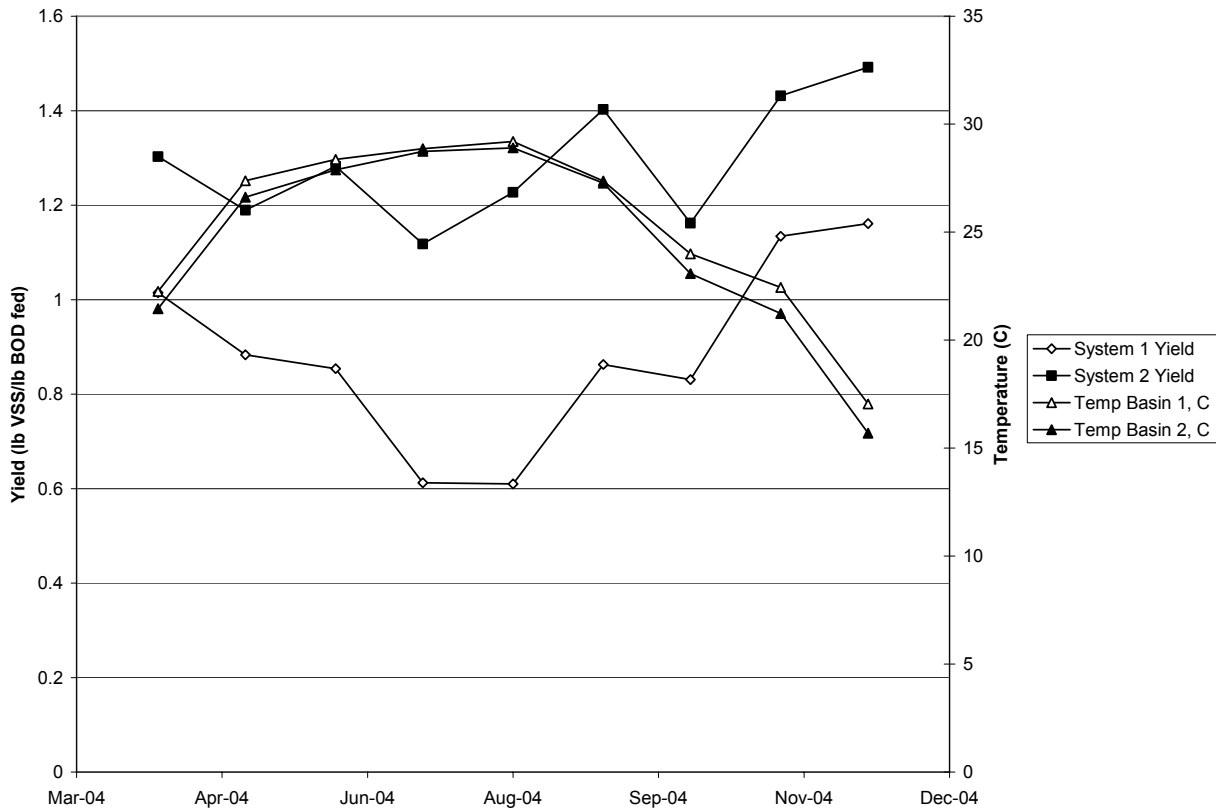
DISCUSSION

Nutrient Removal. As the data show, the plant has complied with the current VPDES limits in all parameters including the limits in ammonia nitrogen and phosphorus. On nitrogen removal, the performance has proven very effective in achieving the voluntary goal. Both strategies removed nitrate nitrogen down to a very low level, typically below 3 mg/l. The strategies were also effective at removing bioavailable reduced nitrogen compounds, while non-bioavailable nitrogen compounds showed no reduction in either system.

Power Usage. Power Usage was higher in System 1, \$225/MG, than in System 2, \$188/MG. The power is based on \$0.045 per KWH currently paid to the local power agency. System 1 operates mixers and aerators around the clock, while System 2 operates aerators only a part of the time. The results are obvious: the periodic aeration for System 2 saves power costs.

Sludge Production. The total solids production via WAS consists of volatile solids and non-volatile solids. The volatile solids production averaged to be similar at 5631 lbs per MG in System 1 and 8185 lbs per MG in System 2. Both systems operated at a similar Sludge Retention Time (SRT) of 16 days during the year. Figure 4 shows monthly data on yield, 0.88 in System 1 and 1.32 in System 2. This is an interesting trend in that the VSS production is significantly higher in periodic aeration, even at a similar sludge age. Figure 4 shows seasonal changes in the yield values with changes in the basin temperature.

Figure 4: 9 Month Yields for Systems



The increase in non-volatile solids is primarily from ferric chloride addition. The ferric chloride dosage averaged to be 167 lbs per MG in System 1 and 1281 lbs per MG in System 2 for the 9 months period. The non-volatile solids for the year averaged 2036 lbs per MG in System 1 and 3261 lbs per MG in System 2, or 60 % more in System 2. During the year, except for January and February, the System 1 operated biologically well and thus received little ferric chloride. During normal operating periods, March through December, the non-volatile solids produced from System 2 averaged approximately 1 lbs non-volatile suspended solids per lb of ferric chloride added. The average cost of chemicals is \$48 per million gallons treated for System 1, \$340 for System 2.

Costs for sludge disposal were also considered for this analysis. The cost of sludge disposal at \$0.05 per lb is \$405 /MG for System 1 and \$566 / MG for System 2.

Total Costs of phosphorus removal and nitrogen removal averaged \$679/MG for System 1 and \$1094/MG for System 2 for this period of 9 months. This includes power, ferric chloride, and sludge disposal costs. These figures, however, do not include costs for thickening, and dewatering. It should be noted that System 1 was built for BNR at a substantial amount of capital expenditure over 10 years ago and thus the savings in operating cost is realized ever since.

CONCLUSIONS AND RECOMMENDATIONS

Based on the long term operating experience at the facility, the following can be concluded/recommended:

1. Both strategies, one continuous aeration in a dedicated BNR system and the periodic aeration, have been effective in nitrogen removal.
2. Strategy 1, works well in both nitrogen and phosphorus removal. This uses more electric power, less chemical and produces less sludge than Strategy 2. This, however required significant capital expenditure to build anaerobic selector tank, creation of anoxic zone and continuous aeration of $\frac{3}{4}$ of the aeration basin.
3. Strategy 2, works well in both nitrogen and phosphorus removal. This uses less electrical power, a lot more chemical and thus produces more sludge than Strategy 1. This, however, was done without capital expenditures.
4. If the VPDES permit requires more stringent limits or when the waste loadings change, some modification is recommended in the System 2 to ensure higher level of performance for nitrogen removal and ease of operation..

ACKNOWLEDGEMENTS

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