Nitrification in Single-Stage Trickling Filters

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An assessment of nitrification of municipal wastewater in trickling filters was performed using operating data from wastewater treatment facilities currently in operation. A survey of trickling filter use in the United States found twenty-seven plants accomplishing some degree of nitrification. Of the twenty-seven plants ten were identified as having operating data sufficient for further analysis. Although most of the plants evaluated were not designed as single-stage systems they all provided sufficient data to evaluate trickling filter performance as a single-stage system. The evaluated plants were generally meeting their permit requirements, including ammonia-nitrogen limits when applied. Analysis of the data compared favorably with the BOD_5 loading rates suggested by the EPA Process Design Manual for Nitrogen Control.

INTRODUCTION

Many municipalities may have ammonia limits added to their effluent discharge permits in the near future because of stringent water quality based ammonia limits. For the large number of facilities that include trickling filters in their treatment train, modifications to the filters would frequently be the most cost-effective solution for this additional treatment need. This manuscript evaluates the use of trickling filters for nitrification of municipal wastewater.

A survey was conducted to identify the extent to which trickling filters are used at municipal facilities in the United States to accomplish nitrification. This was not meant to be an exhaustive search, but of sufficient coverage to assess the state-of-the-art, and to determine the availability of performance data.

Information was obtained from several sources. This included a computer search, using the USEPA Permit Compliance System (PCS). Other sources included USEPA regional and/or State offices; consultants/engineering firms having expertise in this area; and treatment plants cited in the literature. The data was collected from full-scale treatment facilities and used to evaluate process performance and aid in understanding the effect of various operating parameters. Twenty-seven trickling filter plants that are accomplishing some degree of nitrification were identified. But only 10 of these plants were included in the present study because they had sufficient relevant data for analyses. The design and performance data for the plants were obtained directly from the facility operators.

This study originally focused on single-stage trickling filters, a biological process application wherein carbon oxidation and nitrification are accomplished within the same unit without the separation of the biomass used to accomplish these operations. Multiple-stage systems were added to the study due to the limited number of single-stage facilities. The multiple-stage systems evaluated in this report had performance data that were available for each stage which could be compared to the single-stage systems.

Of the ten plants studies, only one was straight single-stage trickling filter, two were single-stage trickling filters followed by solids contact process and the rest (seven) were two-stage trickling filter plants.

Design flows ranged from 1.3 mgd to 42.0 mgd with most plants operating at rates between 50 and 100% of their design capacity. The majority of plants use plastic media. Six are exclusively plastic, while there is one slag media plant and one rock media plant. The rest (two) have combinations of rock and plastic media. Depths of the rock and slag filters range between 6 and 9.5 feet. The plastic media filters are generally deep, typically between 7 and 32 feet. Shallower filters with plastic media are typically retrofits of old rock filters.

Trickling filters are generally designed with effluent recycle capabilities to maintain stable hydraulic loadings during normal diurnal variations. The plants 2 and 4 do not practice recirculation, while a recirculation ratio of 1:1 is maintained at plants 1 and 5. Recirculation rates at plant 7 range between 2.4 and 6.0. At several plants, although recirculation is practiced, recycle rate measurements were not available and estimates of the recirculation ratio could not be made.

None of the plants were experiencing problems with meeting permit requirements for BOD_5, suspended solids (SS), and ammonia-nitrogen removal (if required), particularly during warmer temperature seasons. The BOD_5 referred in this manuscript is total five-day BOD_5 unless soluble or carbonaceous is specifically mentioned. Problems have been noted at plants 3 and 5 with ammonia-nitrogen removal during cold temperature (less than 16°C) periods.

BACKGROUND

At present, ammonia-nitrogen removal is a major concern for many wastewater treatment facilities because of the U.S. Environmental Protection Agency's approach to implementing more stringent water quality based ammonia-nitrogen limits. This has resulted in an increased interest to find cost effective technologies for ammonia-nitrogen removal.

Ammonia is biologically converted to nitrite and nitrate in a two-step nitrification process. It is first oxidized to nitrite (NO_2) by Nitrosomonas bacteria and then to nitrate (NO_3) by Nitrobacter bacteria, both of which are autotrophic.

Nitrification can be accomplished by both suspended and fixed growth processes as long as a sufficient amount of oxygen is available to nitrifiers and enough alkalinity is present in the wastewater. Oxidation of high soluble BOD_5 concentrations in the liquid phase by heterotrophic bacteria deplete oxygen availability, and the nitrifiers are unable to compete with the relatively faster growing heterotrophs. Nitrification begins only when soluble BOD_5 concentrations in the liquid phase are low enough for the nitrifiers to compete with the heterotrophs.

A number of wastewater treatment plants in the United States are practicing nitrification with trickling filters because of stability, ease of operation, and cost effectiveness of the treatment process. The trickling filter is an aerobic fixed film reactor which uses a solid surface medium to support biological film growth. Media traditionally consists of rocks, slag, or synthetic materials. Rock and slag trickling filters generally have four to ten feet of media depth. Plastic media trickling filters are normally constructed much deeper (15 to 25 feet) because of the lighter weight and better ventilation capabilities of the packing. Generally, longer depth allows longer contact time. Recent advances in the development of plastic media with different structural configurations have made this technology more efficient and cost effective. Various types of trickling filter configurations in use for achieving nitrification are discussed in this section.

SINGLE-STAGE NITRIFICATION

Little information is available for the process in which carbon oxidation and nitrification are accomplished in a single trickling filter unit. Steinquist et al. studied the process in a plastic media trickling filter, the results of which suggested that organic loading is the limiting factor [*1*]. Organic loadings less than 25 lbs $BOD_5/1{,}000\ ft^3$-d (0.40 kg/day/m^3) were found to favor a high degree of nitrification in plastic media filters.

The EPA Process Design Manual for Nitrogen Control recommends an organic loading of 10 to 12 lbs $BOD_5/1{,}000\ ft^3$-d (0.16 to 0.19 kg/day/m^3) to attain 75 percent nitrification in single-stage rock media filters [*2*]. Higher allowable organic loadings for plastic filters, as reported by Steinquist, are attributed to the greater specific surface area of plastic media and better oxygen supply [*1*].

The minimum hydraulic loading rate for plastic media trickling filters is in the range of 0.5 to 1.0 gpm/ft^2 (0.20 to 0.41 m^3/m^2-minute) to ensure uniform wetting of the medium. A recirculation ratio of 1:1 was consistently found to improve removals in a rock media trickling filter at Stalford England [*2*]. Data from this study show lower effluent ammonia-nitrogen levels with recirculation over a range of loadings between 3.2 and 22.5 lbs $BOD_5/1{,}000\ ft^3$-d; the greater effect on removals was apparent at higher loadings. The EPA Design Manual recommends provision for recirculation for better ammonia-nitrogen removals [*2*].

Parker and Richards investigated single-stage nitrification in trickling filters by comparing the data from two pilot studies [*3*]. Results show that nitrification begins only when soluble BOD_5 concentration is less than 2 mg/L. Hence, nitrifiers become established in the biofilm only in the lower portion of the tower, where soluble BOD_5 concentrations are low enough for nitrifiers to compete against heterotrophs. They also reported that cross-flow plastic media was the most efficient for achieving nitrification in a single-stage system. Process interactions, like the return of untreated digester supernatant to the headworks, increase the soluble BOD_5 concentration and affect the single-stage nitrification process. According to Parker and Richards, favorable operating conditions required to achieve carbonaceous BOD_5 removal and nitrification in a single-stage trickling filter are low organic loadings, high residence times, sufficient oxygen availability and consistency in hydraulic, organic and ammonia-nitrogen loadings [*3*].

SEPARATE-STAGE NITRIFICATION

Most of the wastewater treatment facilities using trickling filters for nitrification are configured as two-stage systems, with intermediate clarification. In the first stage, the removal of carbonaceous BOD_5 is accomplished, followed by the second stage where nitrification is achieved.

An early study of nitrification in trickling filters was conducted by Duddles et al., which demonstrated the feasibility of using a plastic media trickling filter for nitrification [*4*]. In separate stage nitrification, the rate of nitrification was found to be directly related to the surface area of the media, rather than the media volume. Plastic media have high specific surface areas (27 to 68 ft^2/ft^3) as compared to rock media (13 to 20 ft^2/ft^3) resulting in smaller volume requirements, and reducing the cost for space, structure, and distributor arms.

The USEPA Process Design Manual for Nitrogen Control gives design curves for nitrification in plastic media trickling filters, showing that the efficiency of nitrification is directly related to the surface loading [*2*]. The curves also demonstrate the temperature dependency of the nitrification process, indicating lower surface area requirements at higher temperatures. These curves are based on data collected in pilot scale studies in Midland, Michigan and Lima, Ohio, where primary and secondary treatment for carbonaceous BOD_5 removal were followed by plastic media (corrugated vertical type) trickling filters.

Gullicks and Cleasby suggested that there were deficiencies in the EPA trickling filter nitrification design procedure, and that the design curves are applicable only to municipal wastewater and conditions under which the data were generated [5]. The accuracy of the EPA design curves was questioned and they suggested the effects of the hydraulic loading rate and influent NH_3-N concentration to the tower are not adequately addressed.

Gullicks and Cleasby proposed new design curves which incorporate the effects of four critical design parameters: the hydraulic loading rate, the influent NH_4^+-N concentration, the recycle rate, and the wastewater temperature [5]. Their empirical approach was based on a flux-limited fixed film process theory, which suggests that: (1) when wastewater temperature increases, the mass transfer rate should increase due to the increase in the film diffusivity and biomass activity, and (2) when the hydraulic loading rate or the influent ammonia-nitrogen concentration increases, the mass transfer rate should increase because the concentration gradient from the liquid phase to the biofilm is increased. The proposed design curves apply only to nitrification of municipal secondary effluent that has been settled before application to the trickling filter towers. The curves are based on 6.55 m of vertical-type plastic media with a specific surface area of 88.6 m^2/m^3. Gullicks and Cleasby recommended that these curves should be used with caution at wastewater temperatures less than 10°C and hydraulic loading rates greater than 1.36 L/s-m^2 (7 gpm/ft^2) of tower cross-section.

The principal difference between the design curves proposed by Gullicks and Cleasby and the EPA design curves is that the required media surface area is dictated by the loading criteria (concentration and hydraulic load), whereas in the EPA curves it is dictated by the effluent quality.

Gujer and Boller proposed a theoretical nitrification model for tertiary trickling filters [6]. This model emphasizes residual ammonia concentration, recirculation rates, arrangement of filters in series, alkalinity, residual nitrite concentration and temperature. Basic design information was collected during a 20 month long pilot study. Sampling was conducted with depth, allowing an estimate of actual nitrification rates at various levels within the trickling filters as a function of the respective ammonia-nitrogen concentration. The peak nitrification rate declined significantly with depth, apparently due to patchy development of biofilm at lower depths. This was caused by the absence of a continuous supply of ammonia to these lower regions of the filter. The study also showed significant temperature dependency.

Boller and Gujer reported that plastic media trickling filters following conventional mechanical-biological secondary wastewater treatment were suited for nitrification when ammonia-nitrogen load fluctuations were not too high [7]. Low solids production enabled direct discharge without the need for additional clarification. Specific media surface areas in the range of 150 to 200 m^2/m^3, hydraulic loads higher than 2 $m^3/m^2/h$, and ammonia-nitrogen loads approximately 0.4 $g/m^2/d$ were favorable conditions for full nitrification (<2 mg/L NH_3-N) under winter conditions (water temperature, 10°C).

Parker et al. investigated the use of biofilm control mechanisms to enhance reaction rates in separate stage nitrifying trickling filters [8]. These included use of cross flow plastic media with higher oxygen transfer characteristics and provisions for flooding and backwashing to control predator organisms. The backwashing was also used to control the biofilm inventory, eliminating excessive sloughing and the need for subsequent clarification. The study showed a significant improvement in the reaction rates in tertiary nitrifying trickling filters; regular flooding and backwashing were successful in preventing the suppression of nitrification typically caused by filter fly larvae and other predators. Parker also concluded that properly designed and operated nitrifying trickling filters are reliable, and yield significant cost savings when compared to competitive nitrification technologies [8].

Okey and Albertson analyzed data from five pilot tertiary treatment facilities to study the kinetics of ammonia-nitrogen oxidation under varying operating conditions [9]. The study concluded that more than one kinetic regime existed in the nitrifying tower, corresponding to ammonia-nitrogen concentration. A zero order region existed when the ammonia-nitrogen concentration was high and the system was oxygen limited. A first order regime for ammonia-nitrogen oxidation occurred at low ammonia nitrogen-concentration. At loading rates greater than 1.2 g NH_3-N/m^2-d the units periodically exhibited an oxygen deficient condition. The study recommended the use of forced ventilation for plants that are required to produce an effluent with less than 3 mg/L ammonia-nitrogen.

Okey and Albertson also studied temperature effects on ammonia nitrogen oxidation in nitrifying trickling filters [9]. They indicated that changes in the nitrification reaction rates with temperature are controlled by diffusivity and external concentration and not by the basic changes in the rate at which the cell processes the substrates; this suggests that using Arrhenious-type temperature corrections for reaction rates may not be appropriate.

TRICKLING FILTERS/SOLIDS CONTACT (TF/SC) PROCESS

The TF/SC process was first developed in the late 1970's to enhance the BOD_5 and suspended solids removal efficiency of an existing trickling filter facility at the City of Corvallis [10]. It has since been widely applied, particularly for upgrading existing trickling filters.

The TF/SC process is biological/physical in nature and typically includes a trickling filter, an aerobic solids contact tank, flocculation and secondary clarification. Biological solids are continuously extracted from the secondary clarifier and returned to the aerated solids contact tank for contact with trickling filter effluent.

In a typical TF/SC process, most of the soluble BOD_5 removal takes place in the trickling filter. The trickling filter effluent is mixed with the return sludge from the secondary clarifier in order to improve particulate BOD_5 removal and SS reduction via enhanced flocculation. The solids contact tank is normally designed for less than one hour contact time; typical design values for solids retention time in the solids contact tank are less than two days.

Field investigations were conducted by USEPA in 1984 at Oconto Falls, Wisconsin; Tolleson, Arizona; Medford, Oregon; and Chilton, Wisconsin [11]. Within the narrow range of organic loadings studied at the different TF/SC plants, organic loading was not found to affect final effluent quality significantly. Matasci et al. emphasized the need for reliable primary treatment for this type of treatment process; an increase in the primary effluent suspended solids was found to correlate well with an increase in final effluent suspended solids [12].

Keeping the secondary solids and return sludge in an aerobic condition appears to be an important factor in the successful operation of the TF/SC process. A minimum solids contact time of 12 minutes is required for reliable performance. Although the solids contact tank is primarily designed to increase solids flocculation and capture, it is also found to remove additional soluble BOD_5 from the trickling filter effluent if longer aeration contact time is provided. At the Medford facility, a 75 percent reduction in the trickling filter effluent soluble BOD_5 was accomplished at a solids contact time of 39 minutes.

The TF/SC process can operate over a broad range of mixed liquor suspended solids (MLSS) concentration without affecting effluent quality. Other major advantages noted for the TF/SC process are relatively low capital costs, an ability to withstand high organic loadings, production of very dense sludge, and high quality effluent. Solids retention time in the solids contact tank is less than two days. Although the minimum required solids retention time for nitrifying bacteria is a function of temperature, dissolved oxygen and pH, typical minimum SRTs reported in the literature for nitrifying bacteria are over two days. Hence, it is likely that minimal nitrification enhancement is being accomplished in the solids con-

Table 1 Summary of Performance Data for Selected Trickling Filter Plants

Facility Description	Plant 1	Plant 4		Plant 8	Plant 3	
	T > 17°C	T > 17°C	T < 16°C	T < 16°C	T > 17°C	T < 16°C
Influent						
BOD_5 (mg/L)	101	62.0	67.1	55.6	104	85.7
NH_3-N (mg/L)	20	14.7	13.0	11.3	15.5	13.0
Temperature (°C)	23–28	17–20	8–15	11–16	17–22	13–16
Flow (mgd)	7.73	1.86	2.12	5.82	2.7	3.3
Permit[a]						
NH_3-N (mg/L)	None	3	6	None	2	11
BOD_5 (mg/L)	30	10	10	25	10	10
Effluent						
NH_3-N (mg/L)	2.61	1.75	3.0	5.4	3.5	3.6
BOD_5 (mg/L)	7.43	7.5	7.6	10.8	6.0	5.8
BOD_5 Loading						
(lbs BOD_5/1,000 ft^3-d)	11.11	7.3	9.0	15.69	7.6	8.6
(lbs BOD_5/1,000 ft^2-d)[b]	0.55	0.24	0.3	0.78	0.25	0.29
NH_3-N Loading						
(lbs NH_3/1,000 ft^3-d)	2.15	1.8	1.8	3.2	1.14	1.17
(lbs NH_3/1,000 ft^2-d)[b]	0.11	0.06	0.06	0.16	0.04	0.04
Hydraulic Loading						
(gpd/ft^2)[c]	125	517	589	407	267	327

[a] 30-day average
[b] media surface area
[c] filter cross-sectional area

	Plant 7 (Three Parallel Two-Stage Systems)					
	Plant A		Plant B		Plant C	
Facility Description	First Stage	Second Stage	First Stage	Second Stage	First Stage	Second Stage
	T > 17°C	T > 17°C	T > 17°C	T > 17°C	T > 17°C	T > 17°C
Influent						
BOD_5 (mg/L)	78.9	25.6	67.1	18.6	85.8	16.9
NH_3-N (mg/L)	20.5	10.5	17.6	5.7	21.0	5.6
Temperature (°C)	20–27	20–27	20—27	20–27	20–27	20–27
Flow (mgd)	0.64		0.35		1.23	
Permit[a]						
NH_3-N (mg/L)		4–6		4–6		4–6
BOD_5 (mg/L)		10		10		10
Effluent						
NH_3-N (mg/L)	10.5	2.8	5.7	0.52	5.6	0.5
BOD_5 (mg/L)	25.6	6.6	18.6	5.8	16.9	3.6
BOD_5 Loading						
(lbs BOD_5/1,000 ft^3-d)	22.4	8.2	11.8	3.3	10.5	2.7
(lbs BOD_5/1,000 ft^2-d)[b]	0.18	0.14	0.37	0.154	0.28	0.07
NH_3-N Loading						
(lbs NH_3-N/1,000 ft^3-d)	5.8	3.4	3.1	1.0	2.5	0.6
(lbs NH_3-N/1,000 ft^2-d)[b]	0.18	0.053	0.097	0.015	0.068	0.016
Hydraulic Loading						
(gpd/ft^2)[c]	271	271	147	147	233	233

[a] 30-day average
[b] media surface area
[c] filter cross-sectional area

Table 1 (Continued) Summary of Performance Data for Selected Trickling Filter Plants

	Plant 2		Plant 5				Plant 6			
Facility Description	Single Stage		First Stage		Second Stage		First Stage		Second Stage	
	T > 17°C	T < 16°C	T > 17°C	T < 16°C	T > 17°C	T < 16°C	T > 17°C	T < 16°C	T > 17°C	T < 16°C
Influent										
BOD_5 (mg/L)	127	107	40.4	43.6	10.6	15.2	122	118	50	73
NH_3-N (mg/L)	17.4	13.6	8.8	10.7	1.1	2.7	13.1	14.2	10	11.4
Temperature (°C)	17–21	11–16	17–18	10–14	17–18	10–14	17–19	11–16	17–19	11–16
Flow (mgd)	0.61	0.76	1.1	1.1			34.5	32.1		
Permit[a]										
NH_3-N (mg/L)	14.4	4			6	9			3	9
BOD_5 (mg/L)	10	10			10	10			30	30
Effluent										
NH_3-N (mg/L)	0.67	1.26	1.12	2.72	0.8	2.1	10	11.4	4.7	5.9
BOD_5 (mg/L)	10	13	10.6	15.2	3.1	5.2	50	73.1	12	12.4
BOD_5 Loading										
(lbs BOD_5/1,000 ft^3-d)	11.73	12.28	5.7	6.33	5.7	8.2	74.3	71.8	6.9	10
(lbs BOD_5/1,000 ft^2-d)[b]	0.391	0.409	0.16	0.18	0.28	0.41	2.4	2.4	0.34	0.5
NH_3-N Loading										
(lbs NH_3-N/1,000 ft^3-d)	1.6	1.56	1.24	1.53	0.65	1.5	8.0	8.6	1.4	1.5
(lbs NH_3-N/1,000 ft^2-d)[b]	0.048	0.046	0.036	0.044	0.033	0.074	0.266	0.29	0.07	0.08
Hydraulic Loading										
(gpd/ft^2)[c]	312	386	548	555	384	389	2193	2043	132	123

[a] 30-day average
[b] media surface area
[c] filter cross-sectional area

tact tank. Matasci et al. have also mentioned in their study that solids contact tanks are not designed for nitrification [*12*]. Thus the trickling filters themselves, even if operating in a TF/SC system will still accomplish some soluble BOD_5 reduction and nitrification.

RESULTS AND DISCUSSION

Of the twenty-seven facilities that were identified as trickling filter plants accomplishing nitrification, ten were selected for further evaluation. These had sufficient data for analysis, which were made available by the individual plant operators. The plant performance data of twelve to eighteen months for these plants are summarized in Table 1. The following discussions present a description and assessment of the plants performance.

Plant 1 utilizes a single stage trickling filter system with four filters in parallel. This plant was operating at approximately 70 percent of its design flow of 10.9 mgd. Influent temperatures were moderate year-round, ranging between 23 to 28°C. The hydraulic loading rate to the trickling filters was relatively low at 125 gpd/ft^2 of filter cross-sectional area. The plant maintains a recirculation ratio of 1:1. Overall, the plant 1 secondary filter generates a consistent effluent quality, accomplishing high levels of ammonia-nitrogen removal. Although not required to nitrify, the loadings imposed on the system are consistent with those generally imposed for ammonia-nitrogen removal.

Plant 2 utilizes a single-stage trickling filter system with two filters in parallel. The trickling filters are each 50 feet in diameter and 28 feet deep, with plastic media. The media specific surface area is 30 ft^2/ft^3. The average flow to the plant was approximately 0.7 mgd, or about 50 percent of its design capacity. Cold month influent temperatures ranged between 11 and 16°C, with a range of 17 to 21°C during the warmer months. BOD_5 and ammonia-nitrogen loadings are consistent with those generally imposed for ammonia-nitrogen removal. Overall the plant is generating a high quality effluent and meeting its effluent requirements for both BOD_5 and ammonia-nitrogen.

Plant 3 is a single-stage trickling filter plant with two biotowers in parallel and a solids contact tank. The biotowers are 80 feet in diameter and 30 feet deep, with plastic cross-flow media. The media specific surface area is 30 ft^2/ft^3. Average design flow for the plant is 5.0 mgd. Mean monthly flow ranged from 54 to 66 percent of the 5.0 mgd design flow, with higher flows occurring in the colder months. Influent temperatures ranged from 17 to 22°C in the warm months and 13 to 16°C in the cold months. The mean flow, trickling filter BOD_5 and ammonia-nitrogen influent levels varied considerably, with high levels in the warm months and low levels in the cold months. Because higher BOD_5 and ammonia-nitrogen influent levels were offset by lower flow levels, loadings were very consistent for the one year period. Recirculation is practiced, but the rates are not measured. The plant has consistently met its effluent limits. The effluent ammonia-nitrogen levels are somewhat anomalous with high levels in the October through December period (average 8.6 mg/L), and 4.6 mg/L in January. Levels were consistently lower in the April through September period preceding this and February and March afterward.

Plant 4 utilizes two trickling filters placed in series without intermediate clarification. The trickling filters are each 40 feet wide, 90 feet long and 17 feet deep, with plastic cross-flow media. Currently, the plant is operating at an average flow equivalent to its design flow of 2.0 mgd. Influent wastewater temperatures for October through May ranged between 8 and 15°C, while the summer month temperatures ranged between 17 and 20°C. BOD_5 and ammonia-nitrogen loadings to the trickling filters were relatively low. Recirculation is not practiced. This plant has consistently met ammonia-nitrogen removal requirements at loadings generally associated with nitrification design practices. Lower temperatures did cause lower removal rates in the winter.

Plant 5 is a two-stage trickling filter process. The first-stage biotowers are each 35.3 feet in diameter, and 32 feet deep, with plastic media specific surface area (34 ft^2/ft^3). The second-stage rock filter is 60 feet in diameter and 6 feet deep. Current flow is 85 percent of the 1.3 mgd design flow. Temperatures ranged from 10 to 14°C for the months November through May, and from 17 to 19°C for the remaining months. BOD_5 loadings to the first-stage biofilters are relatively low, because of low effluent concentrations from the primary clarifiers. Loadings to the second-stage rock filter were not greatly different than the first stage loading due to differences in volume and media surface area. The plant was consistently in compliance with its discharge permit requirements for BOD_5 and ammonia-nitrogen.

Plant 6 utilizes a two-stage trickling filter design. The first stage trickling filters are each 100 feet in diameter and 32 feet deep, with plastic media. The second stage is a large rock trickling filter, 8 feet deep and covering an area of approximately 8 acres. Normally 2 of the first-stage filters and 75 percent of the second stage filter are in service. The average flow was 82 percent of the 40.0 mgd design flow. The influent temperature ranged from 17 to 19°C for the warmer months and 11 to 16°C for the colder months. First-stage hydraulic, BOD_5 and ammonia-nitrogen loadings were very high, more typical of roughing filters. The second stage loadings at this plant were more in line with those shown for the preceding plants and are consistent with design loadings for nitrifying plants. Recirculation is practiced only on the second stage, with a target ratio of 0.2:1. The plant consistently met its BOD_5 effluent permit requirements, but had trouble meeting the ammonia-nitrogen requirements during the summer months.

Plant 7 operates three separate parallel treatment plants. All utilize a two-stage trickling filter system. All of the trickling filters utilize plastic media. The first-stage filters for Plants 7A and 7B are 8 feet and 7 feet deep, respectively, and 55 feet in diameter. The media specific surface area for both is 32 ft^2/ft^3. The second-stage filters for Plants 7A and 7B are each 7 feet deep, 55 feet in diameter, and use media with a specific surface area of 64 ft^2/ft^3. The first-stage of Plant 7C is 82 feet in diameter and 16 feet deep, while the second-stage has a diameter of 82 feet and a depth of 12 feet. The packing in both units is comprised of alternative layers of vertical (27 ft^2/ft^3) and cross-flow (48 ft^2/ft^3) plastic media.

The design flow for the treatment facility as a whole is 6.2 mgd, which is split to the three plants (7A—29%, 7B—16%, 7C—55%). The current average flow for the facility is 35 percent of the design flow. Influent temperatures are moderate year-round, ranging between 20 and 27°C. Loadings to each plant differ to a degree. Loadings for BOD_5 and NH_3-N, for both stages, range from low in Plant 7C to highest in Plant 7A. Recirculation is practiced in both stages of all three plants. The recirculation ratio ranges from 2.4:1 to 6.0:1. The plants are all producing high quality effluent. The facility is consistently in the low flow range and meeting permit requirement for both BOD_5 and NH_3N.

The plant 8 is in its first year of operation. The plant utilizes two trickling filters in series without intermediate clarification. The trickling filters are each 135 feet in diameter and 6 feet deep, with rock media. Influent temperatures ranged from 11 to 16°C. The average flow to the plant was 5.8 mgd. BOD_5 and ammonia-nitrogen loadings to the trickling filters were somewhat higher than the preceding plants. A recirculation ratio of approximately 3:1 is utilized. The plant is meeting its BOD_5 effluent permit limit. No effluent ammonia-nitrogen limit has been established.

The plants are all producing high quality effluent. Effluent BOD_5 and NH_3-N levels from each plant were consistent with the loadings to each plant. Effluent permit requirements are based on total effluent flow from the facility. The facility is consistently in the low flow range and meeting permit requirement for both BOD_5 and NH_3-N.

The data that were received from various plants were reviewed as a whole, assessing the general operational characteristics for accomplishing nitrification. These analyses must necessarily be of a general nature, given the limits of the data and the narrow range of operating conditions experienced by the individual plants.

Figure 1 presents the ratio of the ammonia-nitrogen removal to the BOD_5 removal as a function of the BOD_5 removal rate. As would be expected, the ratio decreases with increasing BOD_5 removal rates, shifting to a process dominated by carbonaceous BOD_5 removal with ammonia-nitrogen removal limited to that required for cell growth. If a nitrogen requirement for active ammonia-nitrogen removal systems is assumed to be 0.8 to 0.12 (lbs NH_3-N/lbs BOD_5), then the plant 6 first-stage, plant 5 first-stage and plant 3 are considered carbonaceous removal processes with marginal ammonia-nitrogen removal activity outside that needed for cell growth. The remaining units show higher ratios (in particular the second-stage units for plant 5, plant 7 and plant 4), indicating nitrification activity. The transitional BOD_5 removal rate appears to be in the range of 0.2 to 0.4 lbs BOD_5/d-1,000 ft^2.

The effluent ammonia-nitrogen concentrations are compared to the equivalent period effluent BOD_5 levels accomplished by the system on Figure 2. This suggests that ammonia-nitrogen levels less than 2 to 4 mg/L NH_3-N will be reached when the effluent BOD_5 concentration is at levels less than 15 mg/L and preferably less than 10 mg/L.

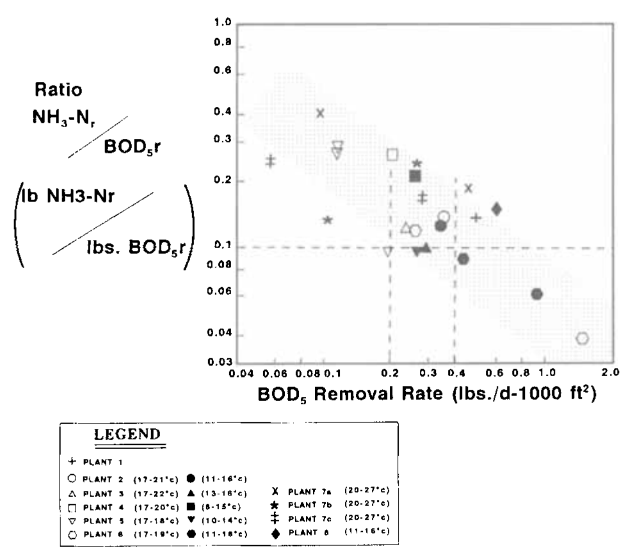

FIGURE 1. Ratio of NH_3-N removed to BOD_5 removed as a function of the BOD removal rate.

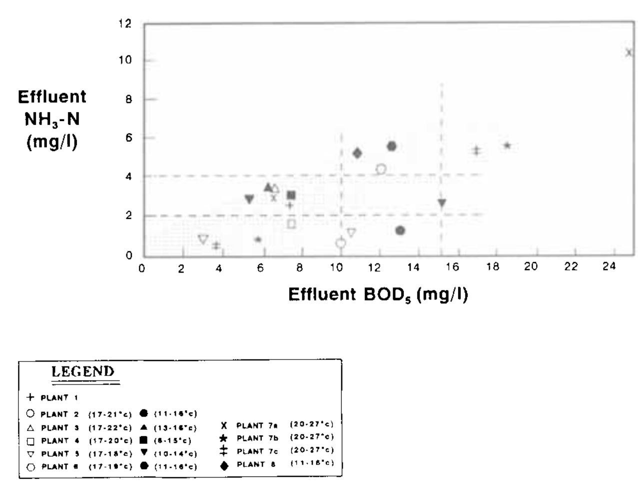

FIGURE 2. Effluent NH_3-N levels compared to equivalent BOD_5 effluent levels.

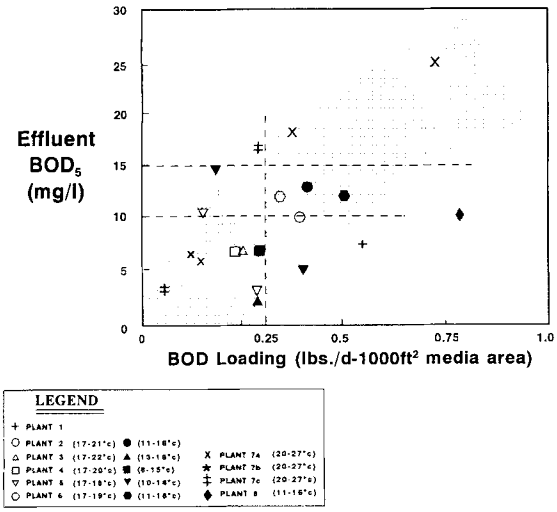

FIGURE 3. Effluent BOD$_5$ concentration as a function of the media area BOD loading.

Figures 3 and 4 present the average effluent BOD$_5$ concentrations as a function of the BOD$_5$ loadings to the trickling filters. These loadings are expressed on the basis of the media surface area (Figure 3) and the reactor volume (Figure 4). In both cases there is considerable scatter. The data on Figure 3 suggest that surface area loadings should be less than approximately 0.3 lbs BOD$_5$/1,000 ft^2-d to accomplish effluent BOD$_5$ levels less than 10 to 15 mg/L.

A similar analysis is shown on Figures 5 and 6. Figure 5 presents effluent ammonia-nitrogen concentration as a function of the media surface area BOD$_5$ loadings. The variability is somewhat high, but the data indicate a surface area loading less than 0.25 to 0.30 lbs BOD$_5$/1,000 ft^2-d is needed in order to yield effluent ammonia-nitrogen levels less than 2 to 4 mg/L. When BOD$_5$ loading is expressed on a volumetric basis (Figure 6), the variability is reduced. This also shows that the BOD$_5$ loadings need to be less than 10 lbs/1,000 ft^3-d for effective ammonia-nitrogen removal.

These loadings conform to those suggested by the USEPA Process Manual for Nitrogen Control (1975) [2], which recommends an organic loading of 10 to 12 lbs BOD$_5$/1,000 ft^3-d for nitrification in a single-stage trickling filter. On an areal basis, the USEPA suggested design loadings are 0.1 to 0.3 lbs BOD$_5$/1,000 ft^2-d, depending on temperature and effluent targets. These compare favorably to the loadings suggested on Figure 5.

Most plants practice recycle; and it is recommended by the EPA (1975) [2] at a rate of approximately 100 percent Q for adequate media wetting. The plant 2 is the lowest hydraulically loaded plant and does not practice recycle. Plant 4 does not recycle, but has a relatively high hydraulic loading of 500 to 600 gpd/ft^2. Effluent ammonia-nitrogen levels in this case range between 1.5 and 3.5 mg/L, with applied ammonia levels similar to plant 2. The plants 7A, 7B, and 7C all practice recirculation at relatively high rates, with the lowest ammonia-nitrogen levels accomplished through the second stage. Hydraulic loadings in these plants range from 1,000 to 1,600 gpd/ft^2.

Overall, recirculation is beneficial to trickling filter performance lowering the applied concentrations, assuring uniform surface wetting (particularly in the lower depths) and helping to control filter flies and predators. There is no clear indication of optimum rates from the available data, although ratios in the order of 1 to 3 would appear to be adequate.

The temperature effects on nitrification were evaluated for temperatures less than 16°C and those above 17°C. Nitrification data from plants 2, 3, 4, 5, and 6 were available at low and high temperatures for evaluation (Table 1). For some plants (2, 4, and 5) the lower temperatures reduced the ammonia-nitrogen removal to some extent even though the ammonia-nitrogen and BOD$_5$ loadings to the filters were the same for summer and winter conditions. These plants still met the winter ammonia-nitrogen effluent permit requirements. For other plants (3 and 6) the effluent ammonia-

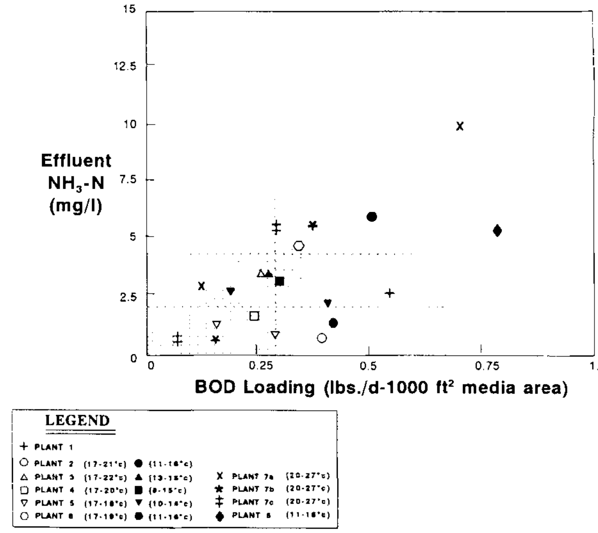

FIGURE 5. Effluent ammonia-nitrogen concentration as a function of BOD media surface loading.

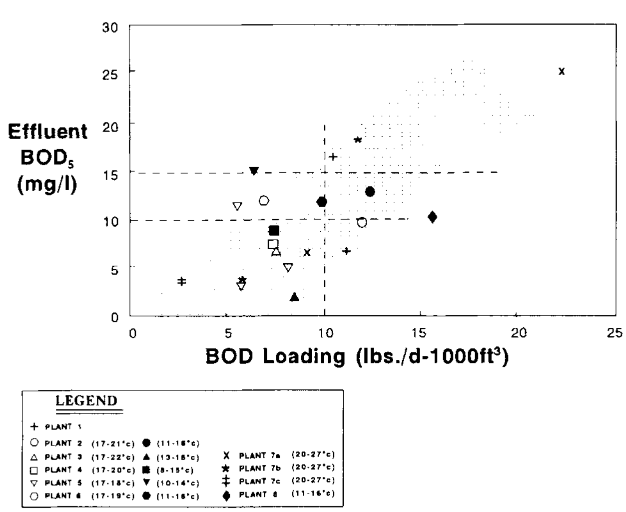

FIGURE 4. Effluent BOD$_5$ concentration as a function of the volumetric BOD loading.

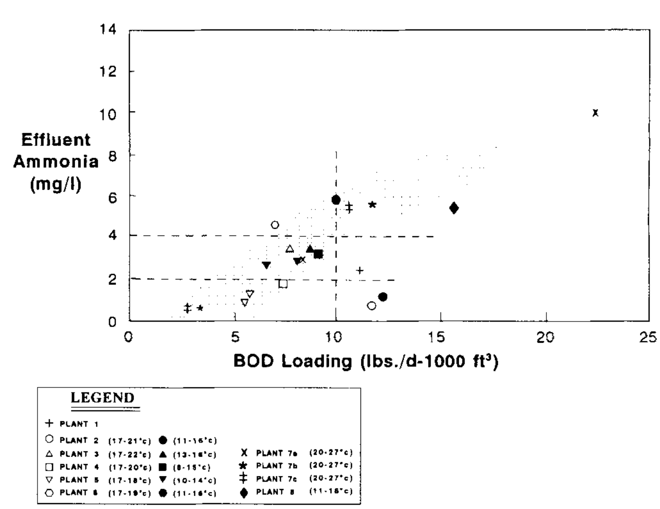

FIGURE 6. Effluent ammonia-nitrogen concentration as a function of BOD volumetric loading.

nitrogen concentration was about the same under warm and cold temperature conditions. Apparently, temperature played a minor role in ammonia nitrification at these plants.

The presence of solids contact systems at plants 2 and 3 gave mixed results as far as nitrification performance was concerned. At both low and high temperatures the plant 2 with solids contact system produced a better effluent (lower ammonia-nitrogen concentration) compared to other systems (plants 4 and 5) at similar BOD_5 and ammonia-nitrogen loading rates. However, plant 3 nitrification performance was quite similar to that of other single-stage trickling filter plants such as plant 4. More comparative data is needed to evaluate the nitrification performance of TF/SC Process.

SUMMARY AND CONCLUSIONS

The evaluated plants were generally meeting their permit requirements, including ammonia-nitrogen limits when applied.

Several plants exhibit some increase in effluent ammonia-nitrogen and BOD_5 levels during cold weather months, although the differences are relatively small and there was no direct temperature correlation apparent. Both plastic media and rock filters were represented in the plants studied. There were no apparent differences in performance related to the media; the reactor sizings were different because of the various specific area characteristics of the media.

Nitrification requires relatively low organic loadings. These can be expressed on a volumetric or media area loadings basis, and were generally set to yield BOD_5 levels less than 10 to 15 mg/L. Operating at these levels assured an environment in which the autotrophic nitrifying bacteria could compete with the faster growing heterotrophic bacteria responsible for carbonaceous BOD_5 removal. Loadings that were less than 10 lbs BOD_5/1,000 ft^3-d or 0.3 lbs BOD_5/1,000 ft^2-d allowed for nitrification and gave effluent ammonia-nitrogen levels less than 4 mg/L. These loadings, based on a review of combined data from 10 selected plants, compared favorably with the organic loading guidelines suggested by the USEPAA [2] for proper design and operation of single-stage trickling filters.

Recirculation was beneficial to the process performance of trickling filters. There was no clear indication of optimum recirculation rates from the selected plant data. Ratios of recycle to raw wastewater flow in the order of one to three would appear to be adequate operational criteria to achieve this performance.

Several process configurations were available to accomplish nitrification with trickling filters. The predominant application utilized a two-stage arrangement with intermediate clarification. The single-stage operation, however, could offer a more cost-effective approach, requiring less tankage and unit operations. This presumed that loadings would be similar to those required for two-stage operation.

The results of nitrification performance of TF/SC process as compared to conventional single stage trickling filters were mixed. In one case it was found that presence of the solids contact system increased the efficiency of ammonia-nitrogen removal but in another case the results were inconclusive. More comparative data is needed to assess the nitrification performance of TF/SC process.

ACKNOWLEGMENTS

The views/opinions expressed in this paper are those of the authors and should not be construed as opinions of the United States Environmental Protection Agency.

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