Wastewater treatment and nitrogen removal using submerged filter systems

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Abstract The performance of two submerged filter systems: a two filters-in-series system and a single combined filter system, in treating a strong nitrogenous wastewater with nitrogen concentration of 480 mg/L was evaluated. Both systems were equally effective in removing up to 90% of nitrogen and 98% of COD from the wastewater for loading rates up to 5 kg COD/m^3.d and 0.5 kg N/m^3.d. The second system in which anaerobic, anoxic, and aerobic zones were incorporated in a single filter offers a greater flexibility in treatment in that by repositioning the locations of the aeration point and effluent recycling inlet, the zonal volumes can be altered easily to treat wastewaters with different COD and nitrogen concentrations.

Keywords Submerged filters-in-series; single combined filter; anaerobic, anoxic and aerobic zones; nitrogen removal

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Introduction

Stringent requirements on discharge quality as well as a need for protection of receiving waters required that nutrients be removed from wastewaters. While existing treatment plants are being upgraded, new ones have to incorporate additional processes to meet these new requirements. At present, treatment facilities mostly in developed countries, notably Europe and North America, are complying with these discharge standards, typically 20 to 30 mg/L for both BOD and SS, and below 10 mg/L for total nitrogen residuals.

Many existing treatment facilities have adopted biological filter processes for final effluent polishing because of its flexibility in combining with other treatment processes as well as for its compactness. Their ability to sustain shock loadings because of high bacterial concentrations also makes them ideal for pretreatment of industrial wastewaters. Pilot-scale studies (Paffoni *et al.*, 1990; Dillion and Thomas, 1990; Vedry *et al.*, 1994; Tschui *et al.*, 1994) have confirmed the suitability of aerated submerged filters for carbonaceous oxidation of settled sewage and tertiary nitrification of secondary effluent. Full-scale applications of biological aerated filters in conventional wastewater treatment facilities have also been reported (Rogalla and Sibony, 1992; Pujol *et al.*, 1994).

For complete nitrogen removal, two separate submerged filters connected in series for nitrification and denitrification have been proposed (Jimenez *et al.*, 1987; Cecen and Gonenc, 1992; Ryhiner *et al.*, 1994). In these systems, nitrified effluent from the first aerated filter is combined with the influent wastewater and fed to a second non-aerated filter for organics and nitrogen removal. Simplifications have been made to such systems by incorporating aerobic and anoxic/anaerobic processes in a single filter (Rogalla and Bourbigot, 1990; Tallec *et al.*, 1997; Ros and Vrtovsek, 1998). These systems were, however, mostly used in treating domestic effluent with low nitrogen concentrations. The objective of this paper is to investigate the performance of these filter systems in treating high strength nitrogenous wastewaters. The first system comprised two submerged filters connected in series, while the second system makes use of a single filter with anaerobic, anoxic, and aerobic zones incorporated in it.

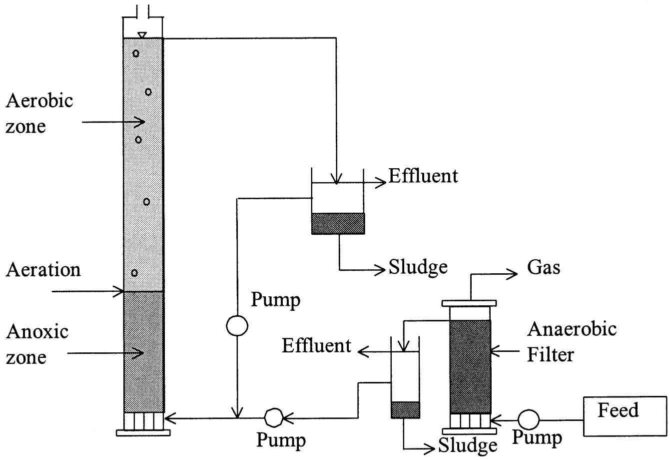

Figure 1 Schematic diagram of the submerged filters-in-series system

Materials and methods

The configuration of the submerged filters-in-series system is shown in Figure 1. The filters were fabricated out of 140 mm (internal diameter) acrylic columns. The shorter anaerobic filter, which was 0.5 m in height, was connected in series with a 2 m high anoxic-aerobic (A/O) filter. Sampling ports were provided at 400 mm intervals along the height of the A/O filter while only effluent samples were collected from the anaerobic filter. The columns were randomly packed with a porous glass rings support medium and the porosity of the packing was 0.87. The clean bed liquid volume of the short and long filters was 7 L and 26 L, respectively. Aeration was provided at a location 0.6 m from the base of the A/O filter by an air compressor. Both the submerged filters were operated in the upflow flow direction.

Subsequently, in an attempt to simplify the operation of the submerged filters-in-series system, a single filter system incorporating all the three zones as shown in Figure 2, was proposed. The locations of the air diffuser and inlet for the recycle flow were re-positioned such that three different zones with anaerobic, anoxic, and aerobic conditions were created within the filter. The ratio of the respective zones in terms of the initial clean bed liquid volume was 1:1:2.

The anaerobic filter was started up by seeding with three litres of digester sludge from a domestic wastewater treatment plant. The A/O filter was similarly seeded with 2 L of settled activated sludge obtained from the same plant. The filters were operated in a constant temperature room at 35 °C for various tests for about two years prior to the present study. In this study, the filters were fed with a synthetic wastewater consisting of tap water and the following chemical constituents: glucose (3,400 mg/L); peptone (1,000 mg/L); meat extract (700 mg/L); $NaHCO_3$ (2,000 mg/L); $CaCl_2.H_2O$ (24 mg/L); $MgSO_4.7H_2O$ (27 mg/L); $FeSO_4.7H_2O$ (20 mg/L); NH_4Cl (800 mg/L); and KH_2PO_4 (200 mg/L). The chemical characteristics of the make-up wastewater were: COD = 5,000 mg/L; TKN = 480 mg/L; NH_3–N = 220 mg/L; total phosphorus = 56 mg/L; and alkalinity = 1,200 mg/L as $CaCO_3$. The make-up feed provided a constant strength wastewater with chemical characteristics similar to such industrial wastewaters as dairy wastes, animal rendering wastewater, coke plant wastewater, heat treated sludge liquor and other thermal conditioned liquors.

Samples collected from sampling ports along the height of the A/O filter as well as effluent from the anaerobic filter were analyzed for pH, oxidation-reduction potential (ORP), dissolved oxygen concentration, alkalinity, COD, volatile suspended solids, and different species of nitrogen. Soluble samples were filtered through 0.45μm cellulose membrane fil-

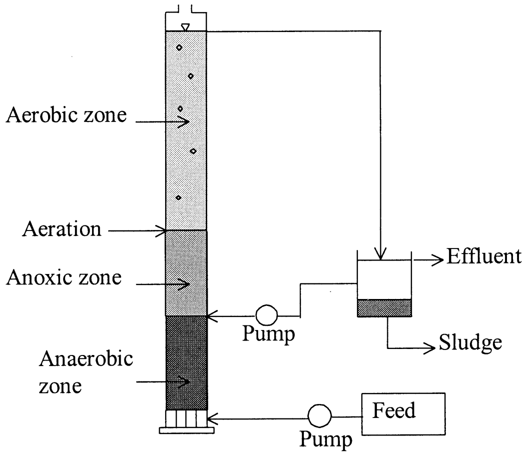

Figure 2 Schematic diagram of the single combined filter system

ters before testing. Ammonia and nitrite nitrogen was determined by the direct nesslerisation and naphthylamine hydrochloride-sulfanilic acid methods, respectively. Nitrate nitrogen was determined either by the brucine colorimetric or the nitrate electrode method. Soluble samples for TKN analysis were first digested and distilled using the modified semi-micro Kjeldahl method, followed by ammonia determination using the direct nesselrisation method. All the tests were carried out in accordance with the *Standard Methods (*1995).

Results and discussion

Submerged filters-in-series system

The minimum COD/N ratio requirement for effective denitrification in A/O filters is between 5 and 6 (Rogalla and Bourbigot, 1990; Chiu *et al.*, 1996). Based on a potential 10% loss in the influent nitrogen to assimilation by biomass in the anaerobic filter, the minimum COD concentrations required for the A/O filter would be about 2,200 mg/L. From previous operational results of the anaerobic filter, a hydraulic retention time (HRT) of 6 hr was required for the given feed concentration of 5,000 mg COD/L to produce the desired effluent COD (Chui, 1999). Other operating conditions adopted for the A/O filter were: HRT = 24 hr; effluent recycling ratio = 3; and average bulk DO in the aerobic zone was maintained above 4 mg/L.

Initially, the system was fed with half-strength wastewater for about a month, after which full-strength wastewater was applied. The daily variation of the effluent soluble COD and TKN concentration after first-stage anaerobic treatment is shown in Figure 3. Both concentrations attained steady levels fairly quickly. The residual COD values were between 2,500 and 2,900 mg/L while TKN concentrations were consistently around 430 mg/L. The resulting COD/N ratio of the effluent after the first-stage treatment was thus about 6.0. Loss in total nitrogen due to biomass assimilation in the anaerobic filter was approximately 10%. About 65% of the influent organic nitrogen was also converted to ammonia nitrogen. Effluent pH was between 6.3 and 6.7, while alkalinity was about 1,350 mg/L as $CaCO_3$. The increase in the alkalinity was due to alkalinity production during organic nitrogen conversion and endogenous decay of biomass.

Effluent discharged from the anaerobic filter was collected and pumped together with the recycled nitrified substrate as feed into the bottom anoxic zone of the A/O filter. Typical steady-stage profiles of nitrogen concentrations in the A/O filter in Figure 4. The influent organic nitrogen was further converted to ammonia in the anoxic zone, as observed from an increase in the ammonia concentration. However, some ammonia was likely to be

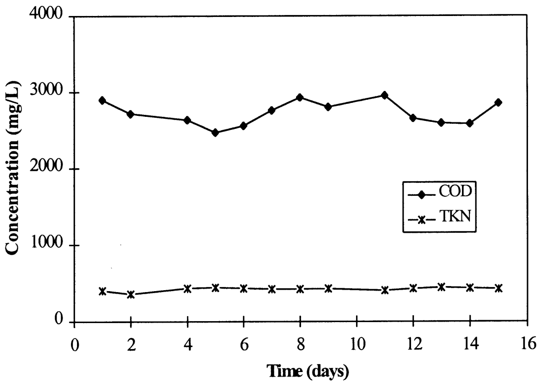

Figure 3 Concentrations of effluent after first-stage anaerobic treatment

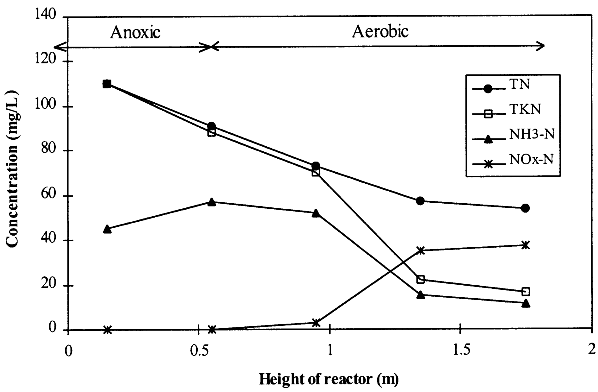

Figure 4 Profiles of nitrogen species in the A/O filter

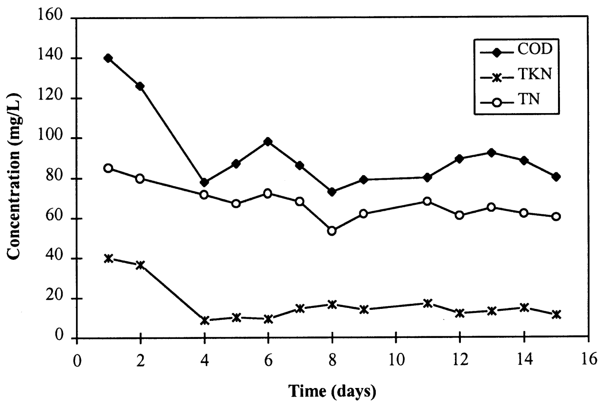

Figure 5 Concentrations of effluent after second-stage A/O filter treatment

assimilated by the heterotrophic bacteria in the anoxic zone. However, some ammonia was likely to be assimilated by the heterotrophic bacteria in the anoxic zone. Oxidation of ammonia was almost complete in the aerobic zone with ammonia nitrogen concentration significantly reduced to about 10 mg/L. On the other hand, oxidized nitrogen concentration increased from zero in the anoxic zone to a maximum value of 40 mg/L at the top of the filter as a result of nitrification. Complete denitrification was achieved in the anoxic zone as indicated by the low oxidized nitrogen levels.

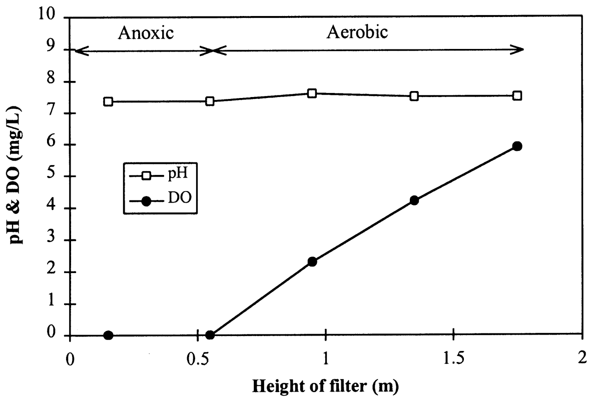

Figure 6 DO and pH profiles in the A/O filter

The concentrations of the final effluent after A/O filter treatment are shown in Figure 5. COD and TN concentrations were reduced to 80 mg/L and 60 mg/L, respectively, from the initial concentrations of 5,000 mg COD/L and 480 mg N/L. TKN in the effluent was about 20 mg/L, half of which was unconverted organic nitrogen. Total system removal efficiency was 98% for COD and 88% for nitrogen under a loading rate of 4 kg COD/m^3.d and 4 kg N/m^3.d.

Residual alkalinity in the final effluent of between 365 and 570 mg/L as $CaCO_3$ indicated that the amount of sodium bicarbonate provided in the influent feed was adequate. The pH and DO distribution along the height of the A/O filter are shown in Figure 6. As shown, pH was ranged between 7.4 and 7.6 while DO concentration in the aerobic zone increased form zero to a maximum value of 5.9 mg/L. The average bulk DO in the aerobic zone was 4.1 mg/L.

Single combined filter system

The combined system incorporating anaerobic, anoxic, and aerobic zones in a single filter was operated at a HRT of 24 hr. The recycling rate of the nitrified effluent into the anoxic zone was similarly maintained at three times the influent flow rate. Airflow rate into the diffuser was carefully controlled so as to achieve a high DO in the bulk solution while avoiding excessive biomass scouring in the anaerobic zone. The filter was initially fed with diluted wastewater for acclimatization. Subsequently, the filter was fed with full-strength wastewater at organic and nitrogenous loading rates of 5 kg COD/m^3.d and 0.5 kg N/m^3.d, respectively. Steady-state conditions for the effluent quality were reached after 4 weeks of operation.

The change in nitrogen concentrations with filter depth is shown in Figure 7. Average TN concentration of 300 mg/L in the anaerobic zone was less than that in the aerobic filter of the previous system. This was probably the result of back mixing of substance in the anaerobic zone due to turbulence caused by the recycle flow. TN concentration was further declined to about 110 mg/L in the anoxic zone as a result of dilution and removal through denitrification. A low concentration of oxidized nitrogen of 6 mg/L was also observed at the end of the anoxic zone, which increased to 25 mg/L at the top of the aerobic zone. Total nitrogen concentration in the effluent was 43 mg/L, which corresponded to a nitrogen removal efficiency of 91%.

The pH and DO profiles with filter depth are shown in Figure 8. As shown, pH increased from 6.4 in the anaerobic zone to 7.8 in the aerobic zone as acidity produced during anaerobic digestion was eliminated as the substrate flowed through the filter. DO was not present

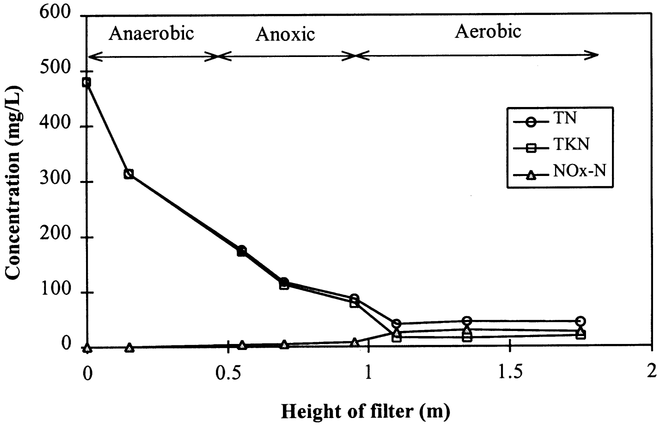

Figure 7 Profiles of nitrogen species in the single combined filter

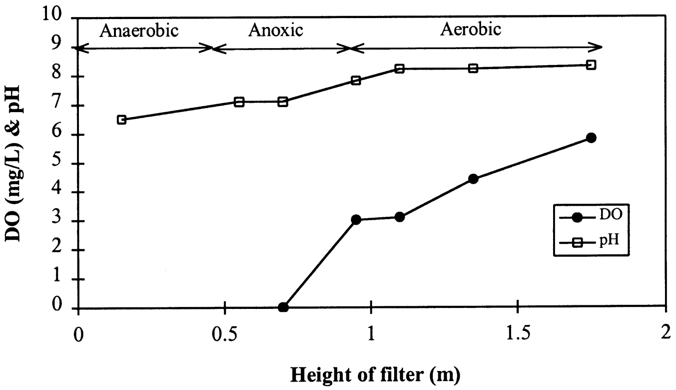

Figure 8 DO and pH profiles in the single combined filter

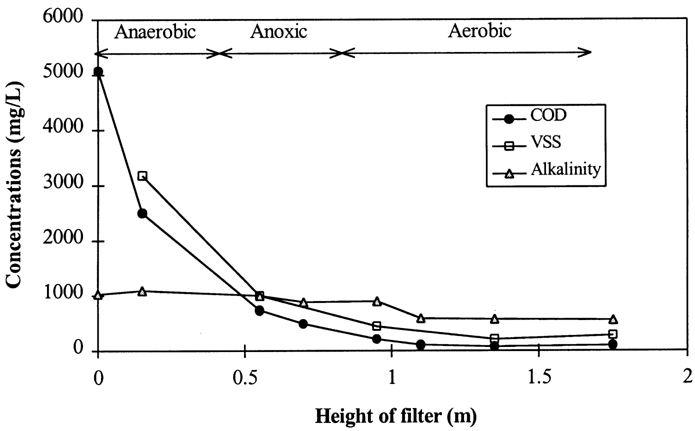

Figure 9 COD, VSS and alkalinity profiles in the single combined filter

in the anoxic zone, but increased from the aeration point to a maximum of 5.8 mg/L at the top of the filter.

Figure 9 shows the COD, VSS, and alkalinity profiles in the filter. The removal of organic carbon was accomplished mainly in the anaerobic zone, with about 50% or 2,500 mg/L of the influent COD removed. COD in the final effluent was reduced to 90 mg/L, comprising mainly non-biodegradable matter. VSS in the anaerobic zone was 3,200 mg/L. It decreased to 600 mg/L in the anoxic zone, and then to 250 mg/L in the aerobic zone due to biomass washout. Alkalinity increased slightly from 1,000 mg/L as $CaCO_3$ in the influent to 1,090 mg/L in the anaerobic zone. In the aerobic zone, it was reduced to about 570 mg/L as a result of alkalinity consumption during nitrification.

Conclusions

The operational results of the submerged filters-in-series system and the single combined filter system show that both systems are effective in treating a synthetic wastewater with COD and nitrogen concentrations of 5,000 and 480 mg/L, respectively. High removal efficiencies of around 90% for nitrogen and 98% for COD were achieved by both systems. The single combined filter system was slightly more efficient as it was operated at a shorter system HRT of 24 hr. Nitrogen and COD removal rates were 0.45 $kg/m^3.d$ and 4.8 $kg/m^3.d$, respectively. Effluent concentrations were reduced to 43 mg N/L and 90 mg COD/L, enabling it to be discharged to public sewers for further polishing.

The study had demonstrated that with proper arrangement of the different zones, simultaneous removal of organics and nitrogen could be achieved in a single reactor. Furthermore, by shifting the aeration and effluent recycling locations, the volume of the various zones can be adjusted to treat wastewaters with different COD and nitrogen concentrations.

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