Studies in nitrification of synthetic fertilizer wastewater in an upflow biofilter

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The upflow aerated biofilter was used to investigate the nitrification performance of fertilizer-industry wastewater. A synthetic composition of ammonium nitrogen concentration in the range of 500-2500 mg/L was considered as a representative composition of actual fertilizer wastewater and was studied at a HRT of 24 h (corresponding applied ammonium load range was 0.5-2.5 kg NH₄⁺-N/m³/d). For the influent concentration increase from 500 to 2500 mg/L NH₄⁺-N, the ammonium removal efficiency varied was observed to be in the range of 81-58 %. The maximum ammonium removal efficiency of 81 % was observed for the applied ammonium load of 0.5 kg NH₄⁺-N/m³/d. The relative lower efficiencies were attributed to the probable substrate (ammonium) and/or product (nitrite) inhibition. The experiments were conducted in non-backwash conditions of the biofilter. The results were found to be satisfactory.

In the interest of environmental protection, wastewater treatment facilities today must meet increasingly stringent quality standards, with nearly constant efficiency. At the same time, treatment facilities are being installed closer to the urban areas and sometimes even form part of the cityscape. This new trend, often justified on economic grounds, affects the choice of the technology to be used. To comply with new effluent discharge standards of 10-20 mg TN/L, as stated by European Directive, nitrogen removal has become increasingly important. The nitrification requirements usually lead to a reactor volume four times larger than that for carbon removal only. Because of high specific area and intensely aerated environment, granular filters provide favourable conditions for autotrophic bacteria attachment and so nitrification becomes independent of sludge age requirements. The slow growth rate of nitrifiers is counterbalanced by their attachment on media. The nitrifying filters were supposed to nitrify and polish the residual organic pollution contained in the secondary purified water. Nitrification inhibition was usually not a problem in the treatment of domestic wastewater. In wastewaters with a high unoxidized nitrogen content, such as fertilizer wastewaters, complete nitrification might not occur because of free ammonia or free nitrous acid inhibition. Nitrite oxidizer micro-organisms are more sensitive than the ammonia oxidizers to free ammonia inhibition, this being the main responsible factor causing the nitrite accumulation. In the present study, the suitability of the upflow biofilter system for the nitrification treatment of fertilizer industrial wastewater was carried-out.

Experimental Procedure

Materials

The schematic diagram of the upflow aerated biofilter fabricated for the present study is shown in Fig. 1. The square shaped biofilter was made up of 4 mm perspex sheet, of dimensions, length, width and height of 50, 50 and 40 cm respectively. The bottom 11 cm height of the biofilter was occupied with the water inlet and the air distribution parts. The biofilter was packed randomly with 4000 numbers of polyurethane foam cubes, of 2 cm size (foam porosity: 0.4), to a height of 14 cm, between two perspex perforated plates of 3 mm thickness. At the top portion of the biofilter immediately after the packing at 25 cm height, a sampling port (10) was provided for the treated wastewater. A provision was made at the bottom portion (4) of the biofilter for the entry of process wastewater to be treated. An aquarium aerator of capacity 176 L/h supplied the required air. The uniform air distribution was ensured with 6 numbers of stone air distribution-aids. Wastewater was pumped into the reactor by means of a peristaltic pump. The effective volume of the biofilter was 45.4 L with the bed porosity of 0.57. The carbon requirement for cell synthesis and alkalinity requirement for nitrification were met with sodium bicarbonate.
I. Perspex Reactor
2. PUF Packing
3. Drain
4. Wastewater Inlet
5. Air Inlet
6. Air Distribution
7. Aquam Aerater
8. Peristaltic Pump
9. Feed Tank
10. Wastewater Outlet
11. Perforated Plates

Fig. 1—Schematic diagram of upflow biofilter

Start-up operation of the biofilter

The biofilter was inoculated by feeding the sewage water of aeration tank of Nesapakkam Sewage Treatment Plant, Chennai, India, for two weeks, at the rate of 5 L/h, in the batch mode. Later on, the population of nitrifiers was increased by pumping enrichment culture medium of a specified composition as given in Table 1, for about three weeks at the rate of 1.89 L/h in batch mode. When the enough biomass concentration was observed visibly, and was in conformation with the literature of 30 days of acclimation, the acclimation was stopped after five weeks and continuous experiments were started with the fertilizer wastewater to be studied. The pH of the influent wastewater was adjusted to 8.0 with sodium bicarbonate.

Wastewater characteristics

A synthetic composition of NH$_4^+$-N as (NH$_4$)$_2$SO$_4$ in the range of 500-2500 mg/L (based on the composition of fertilizer wastewater), was studied as the synthetic fertilizer wastewater with no presence of urea, and dissolved solids. The COD was maintained below detectable limits.

Method

The required composition (500-2500 mg/L NH$_4^+$-N) of wastewater was prepared in the feed tank and then it was pumped into the biofilter at the required flow rate (1.89 L/h corresponding to the hydraulic retention time of 24 h). The wastewater entered the biofilter at its bottom portion, in order to be an up flow type. The samples of treated effluents were collected from the sampling port of the biofilter for the estimation of ammonium, nitrite and nitrate nitrates, dissolved oxygen and pH as the case may be. All the experiments were conducted in non-backwash conditions of the biofilter.

Analytical methods

All analyses and preservation techniques were in accordance with those outlined in Standard Methods. The NH$_4^+$-N analyses were done with Nesslerization method. The NO$_3^-$-N was determined by ultra-violet spectrophotometric method. The NO$_2^-$-N was estimated by Diazotization method. The DO concentration was measured by Winkler’s method.

Results and Discussion

Table 1—Enrichment culture medium composition

<table>
<thead>
<tr>
<th>Constituents</th>
<th>g/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>(NH$_4$)$_2$SO$_4$</td>
<td>2.0</td>
</tr>
<tr>
<td>K$_2$HPO$_4$</td>
<td>1.0</td>
</tr>
<tr>
<td>MgSO$_4$</td>
<td>0.5</td>
</tr>
<tr>
<td>FeSO$_4$</td>
<td>0.4</td>
</tr>
<tr>
<td>NaCl</td>
<td>0.4</td>
</tr>
<tr>
<td>CaCO$_3$</td>
<td>1.0</td>
</tr>
<tr>
<td>MgCO$_3$</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Fig. 2 shows the effluent NH$_4^+$-N concentration profile with time for the five different inlet ammonium nitrogen concentrations viz., 500, 1000, 1500, 2000 and 2500 mg/L. In each case, three different phases of increasing profile followed by decreasing profile and a subsequent steady state profile of effluent ammonium nitrogen concentration can be identified. When the run was started, the available ammonium concentration was almost nil in the reactor. As time progresses, more and more fresh feed entered the biofilter and more residuals find their way into the effluent. The increasing trend is in accordance with the investigations of high strength synthetic ammonium chloride wastewaters studied by Cecen and Orak and Cecen and Gonenc. The decreasing trend can be explained as follows. The supporting media used in the present study was a spongy foam material. The residual concentration of ammonium present in the reactor was slowly getting adsorbed on the surface of the foam particles, therefore the residual concentration appearing in the effluent decreased. In some investigations, the supporting media used were pull rings and
polyethylene cylinders which were having polished surfaces, lack adsorption property compared to foam and so a similar decreasing trend was not observed in their investigations. Liu and Capdeville\textsuperscript{12} reported a similar decreasing trend of effluent ammonium nitrogen concentration in water nitrification process (using positively charged polystyrene films as the supporting medium). As the inlet concentration of ammonium nitrogen increases (500-2500 mg/L), the effluent ammonium nitrogen concentration increased (95-1043 mg/L) and the time to attain the steady-state also increased (70-320 h). Similar studies\textsuperscript{6} on ammonium chloride wastewater system had revealed that the steady-state effluent ammonium nitrogen concentration of 230 mg/L was attained after 120 h for the inlet ammonium nitrogen concentration of 487 mg/L compared to the result of 95 mg/L steady-state effluent ammonium nitrogen concentration, which was attained in 70 h for the feed ammonium concentration of 500 mg/L in the present study. The higher performance of the present system can be attributed to the high porosity of the supporting material.

Fig. 3 shows the effluent nitrogen concentration profile with time for five different influent ammonium nitrogen concentrations. The increasing profile was due to the reason that more and more feed enters the reactor. The decreasing profile of nitrite nitrogen concentration can be attributed to the subsequent nitrate formation and presumed adsorption on foam cubes. The steady-state concentrations of nitrite nitrogen were in the range of 80-395 mg/L. The high concentration of effluent nitrite nitrogen can be attributed to the inhibition of nitrite oxidizers caused by the high applied ammonium nitrogen

Fig. 2—Variation of effluent ammonium nitrogen concentration with time for varying influent ammonium nitrogen concentrations (System: Synthetic Fertilizer Wastewater)

Fig. 4—Variation of effluent nitrate nitrogen concentration with time for varying influent ammonium nitrogen concentrations (System: Synthetic Fertilizer Wastewater)
concentrations. In the study of ammonium sulphate system, Fdz, Polanco et al.\textsuperscript{13} observed that, for an increase of feed ammonium concentration from 50 to 150 mg NH\textsubscript{4}\textsuperscript{+}-N/L, the ammonium oxidizers activity increased (\(K_{\text{max}}\) from 100 to 110 mg NH\textsubscript{4}\textsuperscript{+}-N/g VAS.h) and the nitrite oxidizers activity decreased (\(K_{\text{max}}\) from 20 to 10 mg NO\textsubscript{2}\textsuperscript{-}-N/g VAS.h) with the consequent accumulation of nitrite (as shown by the increase of the ratio of \(K_{\text{max}}\) of the ammonium oxidizers from 6 to 10). However in the present study the oxidizers activity was not determined.

Fig. 4 shows the effluent nitrate nitrogen concentration profile with time. The three regions of decreasing, increasing and steady-state profiles can be seen from the figure. Due to the initial increase of ammonium and nitrite nitrogen concentrations, the decrease in the concentration of effluent nitrate nitrogen was as expected. In the case of 500 mg/L inlet concentration of ammonium nitrogen, the effluent nitrate nitrogen concentration decreased initially as in other cases and attained the steady-state value faster. The increase of the inlet concentration of ammonium nitrogen (500-2500 mg/L), caused to increase the steady-state concentration of effluent nitrate nitrogen from 65 to 226 mg/L. In the studies\textsuperscript{6} for applied ammonium nitrogen concentration of 487 mg/L, the steady-state concentration of nitrate nitrogen was 30-50 mg/L at 3.2 mg/L DO, which is very much less than the present value of 65 mg/L which was attained at a DO of 6.4 mg/L and an inlet of 500 mg/L ammonium nitrogen concentration.

The linear variation of ammonium removal load (0.4-1.5 kg NH\textsubscript{4}\textsuperscript{+}-N/m\textsuperscript{3}.d) with the applied ammonium load (0.5-2.5 kg NH\textsubscript{4}\textsuperscript{+}-N/m\textsuperscript{3}.d) is shown in Fig. 5.
The maximum ammonium removal load of 1.5 kg NH$_4^+$-N/m$^3$.d was obtained for the applied load of 2.5 kg NH$_4^+$-N/m$^3$.d. This is in accordance with the studies made by Rogalla et al.$^2$ and Rogall and Bourbigot$^3$ on the full scale sewage treatment plants for the applied ammonium load ranges of 0.1-2.1 and 0.2-2 kg NH$_4^+$-N/m$^3$.d respectively and Peladan et al.$^4$ on the synthetic ammonium chloride wastewater system for the applied ammonium load range of 0.5-4 kg NH$_4^+$-N/m$^3$.d.

The percentage ammonium removal is defined as,

\[
\% \text{ Ammonium removal} = \frac{(\text{Influent ammonium nitrogen concentration} - \text{Effluent ammonium nitrogen concentration})}{\text{Influent ammonium nitrogen concentration}} \times 100
\]

... (1)

The percentage ammonium removal as defined in Eq. (1) was plotted against influent NH$_4^+$-N concentration, and this can be seen from Fig. 6. As the inlet ammonium concentration increases (for the increase of applied ammonium load from 0.5-2.5 kg NH$_4^+$-N/m$^3$.d), the percentage ammonium removal decreased from 81 to 58 %, which is comparable with the studies made by Chui et al.$^5$ on the synthetic ammonium chloride wastewater system, where, for the variation of applied ammonium load from 0.25 to 1.0 kg NH$_4^+$-N/m$^3$.d, a decrease in ammonium removal efficiency from 86 to 41% was observed. A similar trend was also observed in the investigation of Kraft and Seyfried$^{15}$ on municipal wastewater treatment, where, for the applied ammonium loads of 0.9, 1.0 and 1.32 kg NH$_4^+$-N/m$^3$.d, a decrease in ammonium removal efficiencies as 88, 69 and 64 % respectively were reported.

The Scanning Electron Microscope (SEM) study of the sludge sample (Fig. 7) has shown the presence of Bacillus and Cocci type bacteria in the biofilter (structural similarity with the nitrifying bacteria).

Conclusions

(i) An increase of ammonium nitrogen concentration in the inlet of the biofilter (500-2500mg/L, in terms of ammonium load 0.5-2.5 kg NH$_4^+$-N/m$^3$.d) decreased the ammonium removal efficiency (81-58 %).

(ii) The maximum ammonium removal efficiency of 81 % was obtained for the applied ammonium load of 0.5 kg NH$_4^+$-N/m$^3$.d.

(iii) By maintaining a higher level of DO, at nearly same HRT, the possibility of obtaining higher ammonium removal efficiency was observed.

(iv) The relatively lower efficiencies of the present system, can be attributed to the substrate (ammonium) and/or product (nitrite) inhibition and there is a need to dilute higher nitrogen concentration in fertilizer wastewaters to obtain reasonably higher removal efficiencies in the biofilter.

References