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Performance of simultaneous nitrification and denitrification in lateral flow biological aerated filter *

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Abstract: A new wastewater treatment facility—lateral flow biological aerated filter (LBAF) was developed aiming at solving energy consumption and operational problems in wastewater treatment facilities in small towns. It has the function of nitrification and removing organic substrate. In this study, we focused on the denitrification performance of LBAF and its possible mechanism under thorough aeration. We identified the existence of simultaneous nitrification and denitrification (SND) by analyzing nitrogenous compounds along the flow path of LBAF and supportive microbial microscopy, and studied the effects of air/water ratio and hydraulic loading on the performance of nitrogen removal and on SND in LBAF to find out the optimal operation condition. It is found that for saving operation cost, aeration can be reduced to some degree that allows desirable removal efficiency of pollutants, and the optimal air/water ratio is 10:1. Hydraulic loading less than $0.43\ \mathrm{m\,h^{-1}}$ hardly affects the nitrification and denitrification performance; whereas higher hydraulic loading is unfavorable to both nitrification and denitrification, far more unfavorable to denitrification than to nitrification.

Keywords: lateral flow biological aerated filter; simultaneous nitrification and denitrification; air/water ratio; hydraulic loading

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1 Introduction

Water eutrophication becomes increasingly serious owing to untreated or illegally discharged domestic as well as industrial wastewater. Hopefully, more strict requirements for nitrogen and phosphorus removal have been set in new wastewater treatment facilities. When we search after new approaches towards nitrogen and phosphorus removal, capital cost and energy consumption are the factors that should be taken into account. The Biological aerated filter stands out in terms of its reduced footprint resulting from the removal of secondary clarifiers and hence the associated operational difficulties, and also a low hydraulic retention time attributed to high biomass retention in the system [1]. The lateral flow biological aerated filter (LBAF) reactor used for secondary biological treatment was developed for solving the problem of large energy consumption and operational difficulties in wastewater treatment facilities especially in small towns. Owing to the flexible aeration mode and the way fillers are arranged, both nitrification mode and denitrification mode can be realized through proper adjustment in the LBAF reactor. In this paper, we studied the service data of nitrogenous compounds along the flow path of the reactor and reached the conclusion that the loss of total nitrogen (TN) should be attributed to simultaneous nitrification and denitrification action. We verified this conclusion by further study with microbial microscopy. We also investigated the effects of aeration and hydraulic loading on simultaneous nitrification and denitrification in the LBAF.

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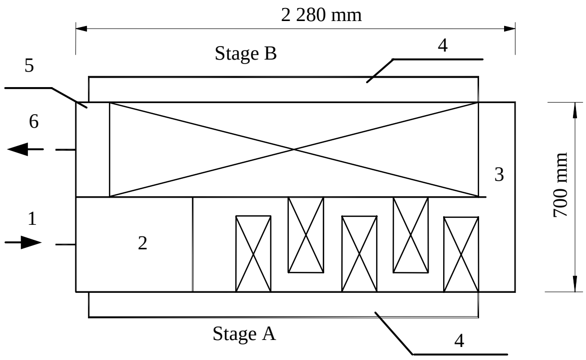
2 Experimental

2.1 System setup

An LBAF (Fig. 1) comprises stages A and B. The flow path starts with the influent into stage A, then transitional zone, stage B and finally out as effluent. Zeolite is packed in both stages. Stage A is staggered by five cages of (10 to 15) mm zeolite. Alundum mipor aeration devices are installed at the bottom of the cage. A 25 mm low-drag sluice is set along the cage, and the specialty is the S-type flow channel formed through staggered arrangement to relieve the head loss and prolong the backwash cycle. Fillers for (3 to 6) mm small particles are evenly equipped in stage B, mainly used to achieve nitrification. The aeration device is separated evenly for the convenience of aeration accommodation.



1. Influent; 2. Rectifier zone; 3. Transitional zone; 4. Backwash outlet slot; 5. Outlet zone; 6. Effluent

Fig. 1 Schematic diagram of LBAF

2.2 Experiment wastewater

The system was fed with domestic wastewater from a student dormitory of Chongqing University collected by a blow-off line and pumped into an impounding reservoir outside the laboratory for primary sedimentation. A compression water pump delivered the sewage to an elevated tank in the lab, where the sewage flowed down into the reactor by gravity. The test was done from May to October of 2005, and the sewage specifications during that period were as follows: temperature between (20 to 29.2) ℃, pH in the range from 6.8 to 7.4, chemical oxygen demand (COD) concentration within (128 to 494) mg L^{-1}, and TN (46.04 to 94.14) mg L^{-1}.

2.3 Analytical methods

Tested parameters include COD, TN, ammonia nitrogen (NH_3-N), nitrate-N (NO_3-N) and nitrite-N (NO_2-N). All forms of nitrogen were measured everyday and dissolved oxygen (DO) concentration was measured periodically by relevant standard methods in Ref. [2]. Bacteria were studied by microscopy.

3 Results and discussion

3.1 Simultaneous nitrification and denitrification

3.1.1 Changes of nitrogenous compounds along the flow path

From Figs. 2 and 3 it is clear that NH_3-N concentration decreased gradually at the beginning, and started to drop sharply at the length of 2.91 m where NO_3-N and NO_2-N concentrations in contrast showed a jump. This implies a certain correlation between NH_3-N depletion and NO_3-N and NO_2-N increase; whereas the increase in NO_2-N concentration was far less than that in NO_3-N, indicating that nitrification was stronger than NO_2-N accumulation. Low DO concentration and high organic substrate bearing in feed wastewater that inhibited the activity of nitifiers accounted for this. By the length of the reactor, DO became higher as organic substrate was degraded, and sufficient DO and space renewed the activity of nitrifiers. As a result, nitrification performance was greatly enhanced especially in stage B. There was a similar change in NH_3-N removal. According to the traditional concept of nitrogen removal, 1 mol NH_3-N converts into 1 mol NO_2-N, and the same with NO_2-N into NO_3-N. When hydraulic loadings were (0.43 and 0.61) m h^{-1}, the converted NH_3-N concentrations were 40.49 mg L^{-1} and 23.41 mg L^{-1}, respectively, while total NO_2-N and NO_3-N were 17.36 mg L^{-1} and 12.94 mg L^{-1}, respectively. It is obvious that the NH_3-N conversion was more than the production of NO_2-N and NO_3-N. Another possible explanation for that is biofilm with a certain thickness, to penetrate to a deep level DO requires a large mass transfer impetus; therefore, even with high DO concentration, anoxic microzone still exists inside the biofilm, and denitrification occurs in the inner layers because of a DO gradient within the biofilm [3]. Additionally, inside the LBAF, aeration was distributed unevenly because of uneven drag distribution, and partial anoxic microzone occupied a rather large proportion.

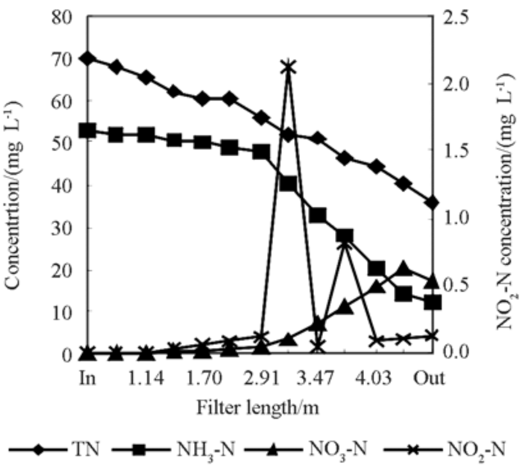


Fig. 2 Changes of nitrogenous compounds along flow path of LBAF under hydraulic loading 0.43 m h^{-1}

Generally speaking, short-cut nitrification and denitrification occurs when nitrosating ratio (NO_2-N/NO_x-N)>50% [4], suggesting NO_2-N accumulation in the reactor. However in the present experiment, collected data showed no accumulation of nitrite-N. All conditions were suitable for simultaneous nitrification and denitrification (SND).

3.1.2 Microscopic biofacies

Zeolite media was sampled to observe biofilm configuration in every operational cycle. It was found that along the flow path, biofilm got less in thickness and lighter in color. With a large organic substrate loading, the biofilm was gray and black especially in stage A and the forepart of stage B; microscopy showed conglobated black particulate matter accumulated randomly, and filamentous colonies interpenetrated, which was supposed to have relation with suspended substance blocked by the filler.

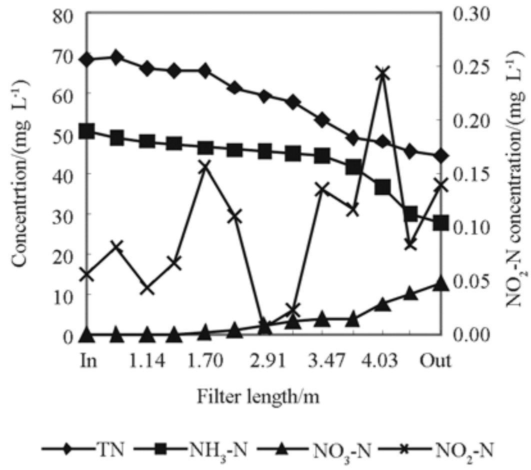


Fig. 3 Changes of nitrogenous compounds along the flow path of LBAF under hydraulic loading 0.61 m h^{-1}

Tian et al. [5] observed biofacies when they treated domestic wastewater with zeolite. They found sessile ciliates were primarily microorganism in nitrogen removal/nitrification zone; while in nitrogen zone there were only nitrifiers. They assumed the place where sessile ciliates population decreased remarkably as the boundary of the above two zones. During the whole experiment, we observed wandering ciliates by microscope inside stage B under thorough aeration in the early operation period; they were mainly Aspidisca costata, Lionotus, Colpidium and Colpoda. After stable operation, as shown in Fig. 4, the biofilm in stage B was mostly protozoans, in which the predominant species included *Vorticella microstoma*, *Opercularis*, *Rotifer* and *Nemato*, and there were more biofacies in this stage. There were sessile ciliates all through stage B, instead of showing obvious boundary of different microbiology. The result was in accordance with nitrogen removal/ nitrification zone stated by Tian.

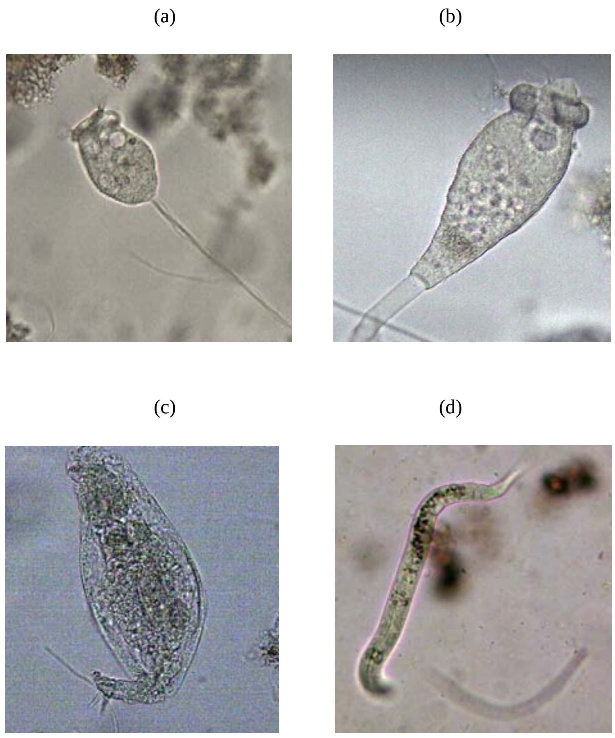


Fig. 4 Morphological character of microorganisms through electronic microscope: (a) *Vorticella microstoma*; (b) *Opercularis*; (c) *Rotifer*; and (d) *Nemato*

3.2 Effect of aeration on the performance of LBAF

Four groups of air/water ratio were carried out at hydraulic loading 0.43 m h^{-1}. The results are shown in Fig. 5. When the air/water ratio was beyond 10, there was little change in the removal efficiency of COD, TN and NH_3-N as the air/water ratio varied, with respective removal efficiency being 78.97%, 80.05% and 82.21%. No significant influence on SND reaction was observed. The possible reason was that the increased air/water ratio improved nitrification and denitrification, and this was favorable for increased substrate concentration to which denitrifiers could be applied. Meanwhile, increased air/water ratio means less anaerobic or anoxic microzone and less living environment for denitrifiers; thus extensive denitrification is rejected. We suggested reducing aeration properly to cut down operation cost on the premise that pollutants removal efficiency maintains preferable. Further research to determine the effect of optimal aeration on SND and TN removal will be carried out according to DO, partial pressure and oxidation-reduction potential (ORP).

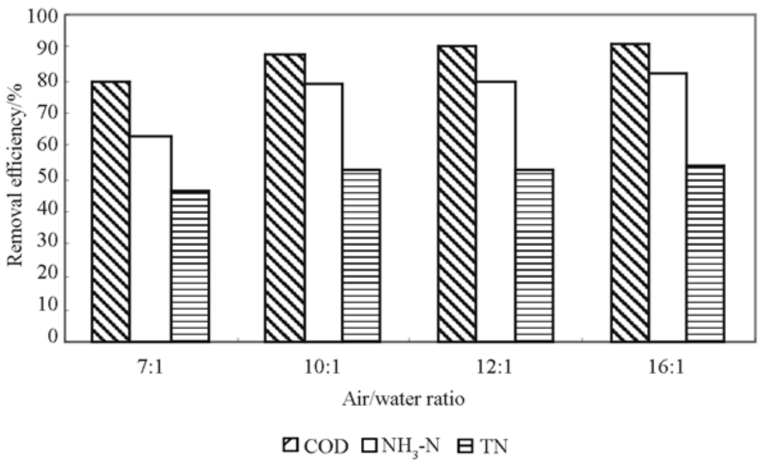


Fig. 5 Effect of air/water ratio on pollutants removal efficiency

3.3 Effect of hydraulic loading on the performance of LBAF

Influent NH_3-N concentration changed considerably under different hydraulic loadings. When the hydraulic loading increased from (0.18 to 0.61) m h^{-1}, NH_3-N removal efficiency reduced from 83.68% to 57.44%. From Fig. 6 it is clear that when hydraulic loading was between (0.18 and 0.43) m h^{-1}, NH_3-N removal efficiency was above 75%, which implied that there was basically no influence on nitrification performance. While when hydraulic loading increased from (0.43 to 0.51) m h^{-1}, the NH_3-N removal efficiency dropped sharply from 78.97% to 60.78%, though the influent NH_3-N concentration was low. The NH_3-N removal efficiency showed slow drop with continuously increased hydraulic loading. It was obvious that the higher hydraulic loading probably deteriorated nitrification seeing that the biofilm could not grow well before flushed.

The TN removal efficiency decreased with increasing hydraulic loading, as shown in Fig. 7. The TN removal efficiency was hardly affected when the hydraulic loading was up to 0.43 m h^{-1}, but it decreased a lot from 62.58% to 29.35% when the hydraulic loading reached 0.51 m h^{-1}. When the hydraulic loading continued to increase to 0.61 m h^{-1}, the decrease in TN removal efficiency slowed, which was an explanation for the reactor recovering after an adapting time to the increased hydraulic loading. Ma Jun [6] reported that increased hydraulic loading had a significant effect on nitrogen removal in their research on the effect of hydraulic loading on the performance of BAF; whereas the results in our research showed little influence when the hydraulic loading was between (0.18 and 0.43) m h^{-1}. Because of the plug-flow pattern in the LBAF, when suffered from hydraulic flushing, an amount of organic substrate was trapped in stage A, and the rest went into stage B which was filled with small-particle-size zeolite. Functionally, stage A buffered the heavy load imposed on stage B. Practical operation indicated that stage A mainly removed organic substrate and thus was denominated carbonization phase, and stage B was nitrification phase. Within a certain range, the change of hydraulic loading had little effect on stage B; once the hydraulic loading exceeded the limit and higher substrate loadings resulted, the region of the N phase where maximum nitrification activity occurred was “pushed” further up in the phase, and frequent backwash should be adopted to offset the limited reaction length and large resistance caused by small zeolite. Therefore nitrifiers could not grow well and nitrification was deteriorated. The nitrogen removal efficiency decreased also.

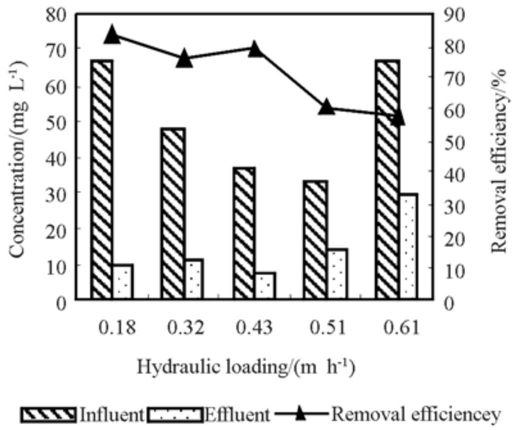


Fig. 6 Effect of hydraulic loading on NH_3-N removal efficiency

From the results above, when the hydraulic loading increased from (0.43 to 0.51) m h^{-1}, the TN removal efficiency dropped by nearly a half, far beyond the drop in that of NH_3-N, which implied that increase in hydraulic loading had a larger effect on denitrification performance.

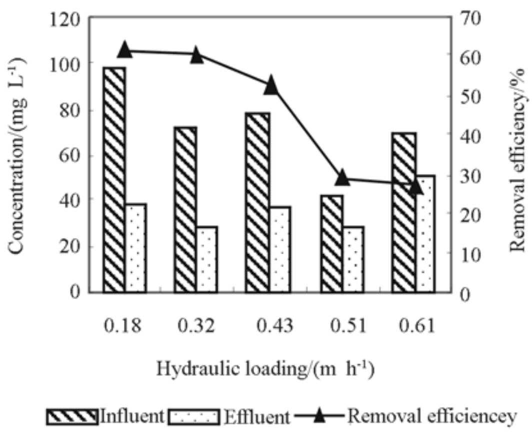


Fig. 7 Effect of hydraulic loading on TN removal efficiency

4 Conclusions

1) SND in LBAF was identified by investigation on the spatial distribution of nitrogenous compounds and microbial population.

2) Four groups of air/water ratio were carried out to investigate the effect of aeration on SND. The results indicated that the removal efficiency of COD and TN

changed little with an air/water ratio beyond 10.

3) Hydraulic loading between (0.18 and 0.43) m h^{-1}, had little influence on both nitrification and denitrification performance; when hydraulic loading increased from (0.43 to 0.51) m h^{-1}, NH_3-N and TN removal efficiency dropped obviously, showing adverse effect on both nitrification and denitrification performance. Nevertheless, when the hydraulic loading increased to 0.61 m h^{-1}, the drop in NH_3-N and TN removal efficiency slackened,which indicated that the reactor recovered well after an adjustment time to the increased hydraulic loading.

On the whole, with proper ranges of air/water ratio and hydraulic loading, there was partial denitrification in LBAF on the basis of well nitrification, suggesting the LBAF had the potential to remove nitrogen.

References

1 Gilmore K R, Husovitz K J, Holst T, et al. Influence of organic and ammonia loading on nitrifier activity and nitrification performance for a two-stage biological aerated filter system [J]. Wat Sci Tech, 1999, 39 (7): 227-234.

2 State Environmental Protection Administration of China. Monitoring and analytical methods for water and waste-water [M]. 4nd ed. Beijing: China Environmental Science Press, 2002: 254-284. (in Chinese).

3 Zhao H W, Mavinic D S, Oldham W K, et al. Controlling factors for simultaneous nitrification and denitrification in a two-stage intermittent aeration process treating domestic sewage [J]. Wat Res, 1999, 33 (4): 967-970.

4 Li Y Z, He Y L, Liu Y H, et al. Nitrogen removal approaches of membrane bioreactor in wastewater treatment [J]. Environmental Pollution and Control, 2005, 27 (2): 127-130. (in Chinese).

5 Tian W H, Wen X H, Yang A H, et al. Performance and its influencing factor of a zeolite biofilter for dilute domestic wastewater treatment [J]. Chinese Journal of Environmental Science, 2003, 24 (5): 97-101. (in Chinese).

6 Ma J, Qiu L P, Zhang L X. Influence of hydraulic retention time on treatment efficiency and operational characteristics of biological aerated filter [J]. Environ-mental Pollution and Control, 2004, 26 (6): 433-436. (in Chinese).

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