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# Research on a pre-denitrification double-layer media biological aerated filter in municipal wastewater treatment

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ABSTRACT

In this study, a pre-denitrification double-layer media biological aerated filter was employed for municipal wastewater treatment. A double-layer biological aerated filter made up of a top layer of granular activated carbon (GAC) material and a bottom layer of coal-ash ceramic material was investigated. In the double-layer media biological aerated filter (DLBAF), the ceramic layer is located at the bottom, bearing a larger impact of hydraulic load and the GAC layer is located at the top, maintaining a higher amount of active biomass and a variety of microbic populations. The DLBAF was highly efficient in the removal of COD, suspended solids (SS), $NH_4^+$-N and total nitrogen (TN), and was more capable of sustaining microorganisms than a single layer filter. The system was stable and a steady state was maintained for over 120 days, and the average COD, SS, $NH_4^+$-N and TN in the effluent were 28.7 mg/L, 5.4 mg/L, 2.7 mg/L and 12.3 mg/L, respectively, which were all up to the Integrated Wastewater Discharge Standard (GB18918-2002) Level-one A.

*Keywords*: Pre-denitrification; Double-layer media; Biological aerated filter; Granular activated carbon; Coal-ash ceramics

## 1. Introduction

The biological aerated filter process was developed in Europe and then widely applied all over the world as a novel wastewater treatment system due to its advantages relative to other systems [1].True BAF, as defined by Stephenson, contain granular medium that provides a large surface area per unit volume for biofilm development. They can combine BOD, solids and ammonia nitrogen removal and be utilized at both secondary and tertiary stages of wastewater treatment [2]. It can be utilized at both secondary and tertiary stages of wastewater treatment, wastewater reclamation engineering and pretreatment process of newly developed membrane techniques, particularly when low land usage is required in urban areas [3].

Media selection is critical in the design and operation of BAF to achieve effluent quality requirements. As BAF technology is applied to wastewater treatment, the selection of granular media plays an important role in maintaining a high amount of active biomass and a variety of microbe populations [2]. The most frequently applied media includes natural zeolite, expanded clay, puzzolane particle, clayey schist, polypropylene, etc. [4,5]. Granular activated carbon (GAC) is a highly porous material capable of supporting a large bacterial population, however it has poor mechanical strength and easily abrades in backwash. In addition, GAC is costly as media which is largely used in BAF process. Coal-ash ceramic particle is a potential filter media for BAF. It has low-cost compared

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to GAC, which uses clay as the main raw material [6]. It is non-metallic mineral with characteristics of high porosity and large specific surface area, which is similar to GAC characteristics. Although the specific surface area is smaller than GAC, the hardness is much stronger [7]. So a double-layer biological aerated filter made up of a top layer of GAC material and a bottom layer of coal-ash ceramic material is investigated. In the double-layer media biological aerated filter (DLBAF), the ceramic layer is located at the bottom, bearing a larger impact of hydraulic load, and the GAC layer is located at the top, maintaining a higher amount of active biomass and a variety of microbe populations. In addition, the density of GAC is lower than that of ceramics, so that the media will not be out of order when backwashed [8]. In this study, we decided to verify if a system with a single bed composed of two separate layers within a single reactor would be able to improve the results. The municipal wastewater was fed to lab-scale pre-denitrification double-layer media BAF and the performance of the system with GAC and ceramic media was observed.

## 2. Materials and methods

### 2.1. Pilot-scale system

A pilot-scale BAF system was set up for this study, as shown in Fig. 1. The main system was composed of two upflow biofilter columns connected in series. Each column was 1.5 m in height and 0.05 m in diameter and made of synthetic glass. The columns were packed with combined media of 1.0 m in height, which were ceramics of 0.5 m in height and granular activated carbon of 0.5 m in height. The characteristics of ceramics and GAC are listed in Table 1. (The active biomass was measured when the two types of medium were cultivated in the same column containers as described above respectively for a month and the medium was adopted at the bottom of the filter.) To the fist column functioning as denitrification, air was not provided, and in contrast, to the second column functioning as nitration, air was provided to maintain the concentration of dissolved oxygen (DO) through diffusers located at the bottom of the column. The system was operated in cycles based on the direction of column 2 to column 1 (see Fig. 1). The recycle ratio was about 120%.

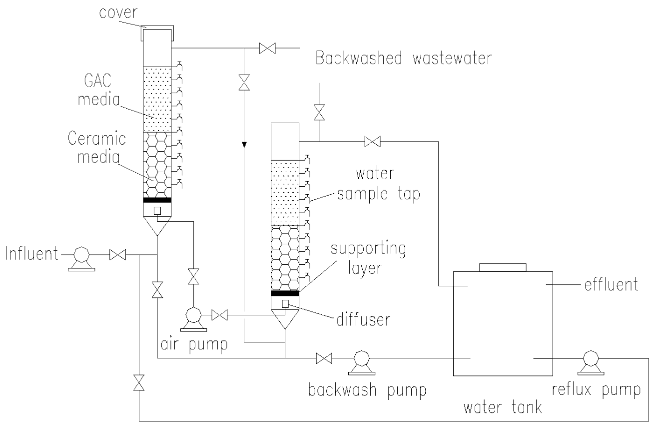

Fig. 1. Flow scheme of the treatment process.

### 2.2. Characteristics of raw influent

The system was fed with municipal wastewater which after primary treatment in Malanhe Wastewater Treatment Plant (second stage) Dalian, China. The characteristics of the raw influent are shown in Table 2. All samples in the experiments were measured according to Standard Methods [9].

### 2.3. Operational conditions

The feed wastewater was introduced to the DLBAF with a metering pump and treated by microbial degradation and mechanical filtration. The system has been operated at room temperature ranging from 15°C to 25°C. Hydraulic loading was controlled in the range of 0.57–1.00 $m^3/(m^2\ h)$.

In order to remove excess biomass and solid particles accumulated in the media, each column was backwashed in a counter-current manner at regular intervals. A backwashing procedure was as follows: gas for 2 min, gas

Table 1
Characteristics of ceramic medium

| Characteristic | Ceramics parameter | GAC parameter |
|---|---|---|
| Grain diameter, mm | 3–5 | 3 |
| Density, $g/cm^3$ | 2.3 | 2.0–2.1 |
| Bulk density, $g/cm^3$ | 0.85 | 0.35–0.55 |
| Specific surface, $m^2/g$ | 9.2 | 590–1500 |
| Active biomass, nmol $P/cm^3$ | 14.3 | 21.6 |

Table 2
Average influent characteristics

| Parameter | Average value |
|---|---|
| Suspended solid, SS, mg/L | 45–60 |
| Total chemical oxygen demand, TCOD, mg/L | 130–160 |
| Total nitrogen (TN), mg/L | 30–40 |
| $NH_4^+$-N, mg/L | 25–35 |
| $PO_4$-P, mg/L | 2–3 |
| Water temperature, °C | 15–25 |
| pH | 7.0–7.5 |

and water 8 min at the same time, and water 5 min in the end with a backwashing rate of 10 L/(m$^2$.s) of both gas and water.

## 3. Results and discussion

### 3.1. Overall performance

The DLBAF fed with the municipal wastewater was performed for about 120 days. Figs. 2, 3, 4, and 5 illustrate the concentration–time profiles of COD, SS, $NH_4^+$-N and TN, respectively. As was expected, the effluent quality from the DLBAF satisfied the standard Integrated Wastewater Discharge Standard (GB18918-2002) Level-one A in China.

As for COD, the data in Fig. 2 have shown a good removal effect. COD in the influent and effluent were kept around 149–162 and 26–32 mg/L, respectively. COD removal was attributed to the microbial degradation and mechanical filtration, especially, the GAC is a highly porous material capable of supporting a large bacterial population.

It was found that the SS in influent and effluent were in the range of 45–60 mg/L and 4–8 mg/L; the average SS removal efficiency was about 90% (Fig. 3). These high SS removal performances would be due to biofiltration through a double-layer medium that serves two purposes: biological conversion of organic matter by the biomass attached to the large support medium surface and physical retention of suspended particles by filtration through the deep filter bed.

The effluent $NH_4^+$-N concentration of the BAF system is presented in Fig. 4. The average influent and effluent concentrations of ammonia nitrogen were 25–35 mg/L and 2–4 mg/L, respectively. Correspondingly, the removal efficiencies of ammonia nitrogen were 92%, revealing relatively high nitrogen removal in this system. The unique configuration of the system allowed for independent nitrification in column 2 and it would be responsible for an increase in the nitrification capacity of the BAF system.

Fig. 5 shows that TN varied from 30 mg/L to 40 mg/L in the influent and from 11 mg/L to 15 mg/L in the effluent. The average decreasing TN in the influent to effluent was about 20 mg/L, and there was an overall reduction in TN of exceeding 63%. In this system a pre-denitrification was adopted, denitrification process occurred in column 1, the nitrification liquor was refluxed from the effluent of column 2 to influent of column 1 and the recycle ratio was operated at 120%.The detailed function of this BAF system is provided in the following sections.

### 3.2. COD removal

Fig. 6 shows COD variation vs. height of combined media bed in column 1 and column 2. The average COD removal efficiencies were 65% and 35%, respectively, in

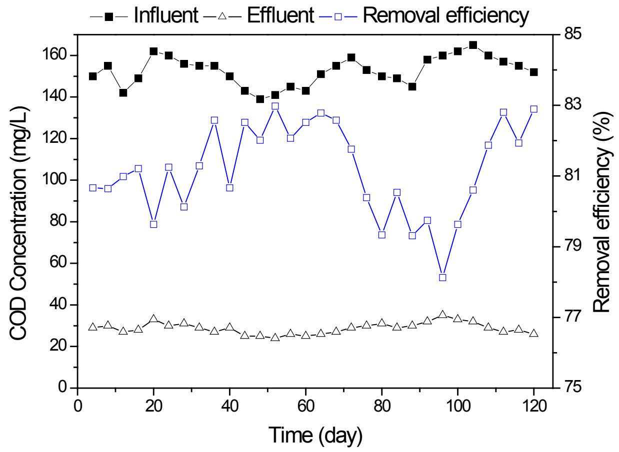

Fig. 2. COD removal characteristics of the BAF system.

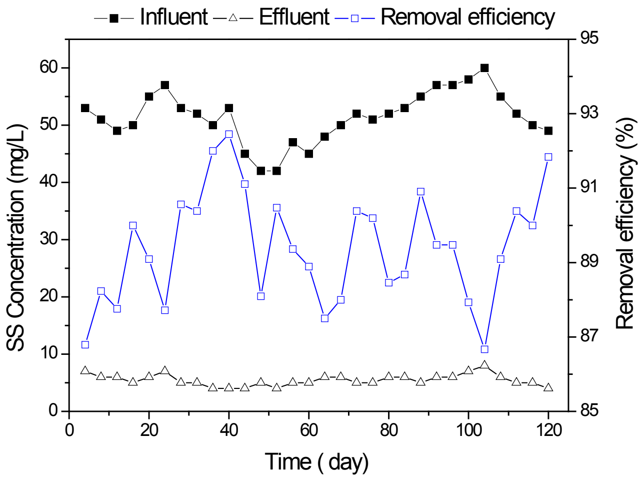

Fig. 3. SS removal characteristics of the BAF system.

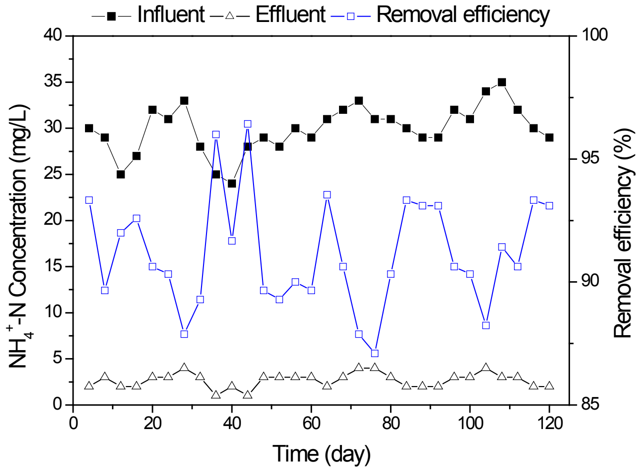

Fig. 4. $NH_4^+$-N removal characteristics of the BAF system.

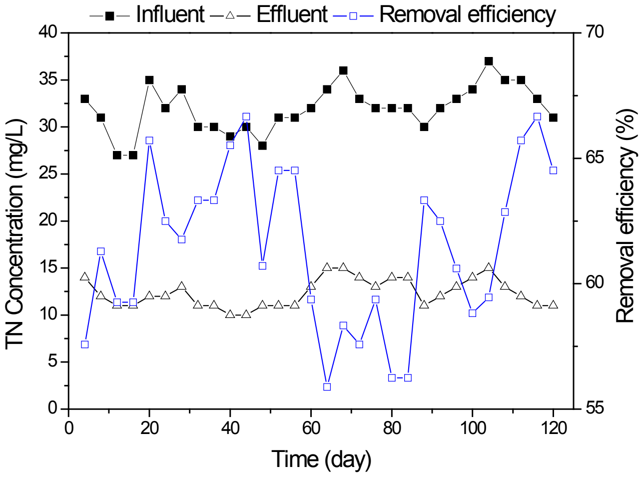

Fig. 5. TN removal characteristics of the BAF system.

column 1 and column 2. The most COD was removed in column 1, which was used for denitrification and the organic pollutant was used as carbon source. In a general way, organic loading is higher at the filter inlet, which induces bacteria growth and the bioactivity attained is higher at under-layer media. And at the top-layer media, due to decrease of carbon source concentration, the COD removal rate was the slowest. Within the 100 cm media height in column 1, GAC acted as the top-layer media for 50 cm and ceramic acted as the under-layer media for 50 cm, too. As shown in Fig. 6, the COD removal efficiency maintained a higher level in the top-layer media, although the COD concentration had got low. In the ceramic layer, COD removal efficiency was 65.7% and in the GAC layer, COD removal efficiency was 34.3% in column 1. There are two reasons: (1) GAC is a highly porous material capable of supporting a large bacterial population. (2) GAC can adsorb part of organic matter.

In column 2 functioning as nitration and further removal organic pollutant, COD variation vs. height of combined media is also shown in Fig. 6. In the 100 cm media height in DLBAF, COD removal efficiencies of 35% were achieved. Mean influent concentration of around 49 mg/L was reduced to an average value of about 29 mg/L. And in the ceramic layer COD removal efficiency was 70%; in the GAC layer, COD removal efficiency was 30%. In a general way, the effluent of municipal wastewater could not be achieved at such a low value in biological treatment due to some non-degradable organic matter in it. Within the 100 cm media height in the DLBAF, GAC acted as the top-layer media and played a role in adsorbing non-degradable organic matters. As a result, most degradable organic matter was captured and degraded by the ceramic layer, and part of non-degradable organic matter was adsorbing by the GAC layer. As shown in Fig. 6, the COD concentration almost did not change in the 40 cm of media bed height to 50 cm and continued to decline from 50 cm to 100 cm of media bed height in column 2.

### 3.3. Nitrogen removal

In column 1 functioning as denitrification, COD and $NO_x$-N bio-sorbed on the media would be utilized as the substrate for the denitrification reaction. The concentrations of different species of nitrogen in the effluent at different heights are shown in Fig. 7. The influent TN concentration was 21.6 mg/l; the effluent ammonia was 15.4 mg/l; and the TN removal efficiency was about 28.7%, among the effluent, concentration of $NO_x$-N was only 1.4 mg/L. The results observed in Fig. 7 were remarkable as compared with other pre-denitrification BAF studies in municipal wastewater treatment [10]. The explanation could be down to high biomass which was closely related to the properties of media and the low DO concentration

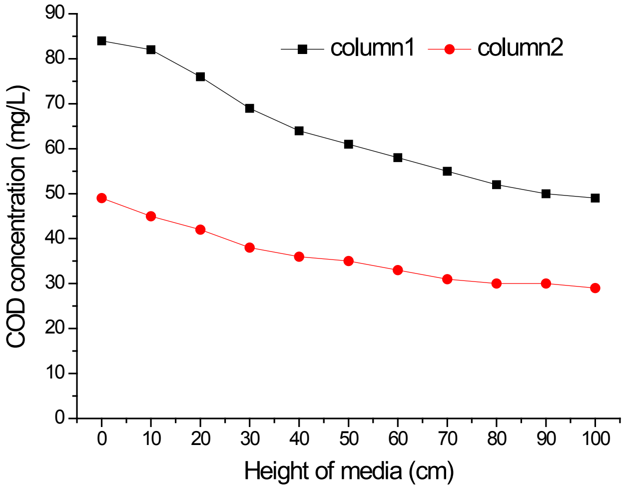

Fig. 6. COD variation vs. height of media bed.

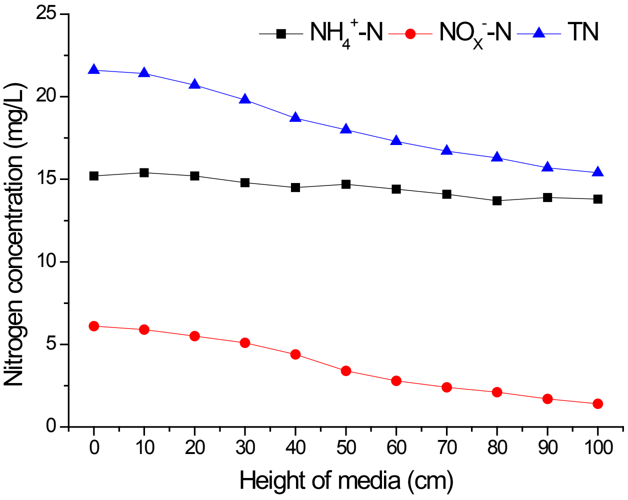

Fig. 7. Species of nitrogen variation vs. height of media bed.

in column 2 which would be recycle to column 1. The high biomass provided more denitrifying bacteria and low DO concentration was favorable to denitrification. It is worth mentioning that $NH_4^+$-N can be removed to some extent, too, especially in the top-layer media. This may be due to adsorption of GAC media.

Fig. 8 shows $NH_4^+$-N and TN variation vs. height of combined media bed in column 2. The average $NH_4^+$-N and TN removal efficiencies were 79.7% and 7.6%, respectively. DO concentration in column 2 was kept at 3–4 mg/L. Autotrophic bacteria compete with heterotrophic bacteria for oxygen, substrates and inhabitation area within the biofilm. DO is one of the major factors responsible for nitrification, therefore it is the limiting factor of nitrification when DO in the system is lower than that needed by bio-reaction [11]. However, in this system a pre-denitrification process was adopted and most of the organic pollutants were removed in the denitrification stage, the influent COD concentrations were around 49 mg/L. So, a relatively low DO concentration could satisfy the requirement for nitrification. In a general way, direct competition between aerobic heterotrophic bacteria and autotrophic bacteria is the main cause of the decrease in nitrifying activity [12]. In column 2, $NH_4^+$-N in influent was almost completely converted into nitrate with 79.7% efficiency on average. Such a high efficiency of nitration is attributed to low concentration of organic load and high biomass which was closely related to the properties of media.

Fig. 8 also shows the TN removal efficiency which was about 7.6%. The loss of TN could be due to simultaneous nitrification–denitrification (SND) in the biofilm. The existent grades of DO and substrate concentrations result in different microenvironments formation in biofilms, which makes simultaneous nitrification–denitrification taking place in the DLBAF. SND is relevant to the amounts and activities of anaerobic microorganisms, thus SND is indirectly controlled by the thickness of anaerobic layers in biofilms. The 7.6% TN removal efficiencies were lower than other papers mentioned. This may be because pre-denitrification process need reflux, in this system a recycle ratio for about 120% was adopted, and of course, reflux means decreasing of HRT of the process unit. The decrease of HRT led to stronger scour for media surfaces, which weakened the thickness of anaerobic layers. On the other hand, the concentration of influent COD which was used as the denitrifying substrate was very low, too.

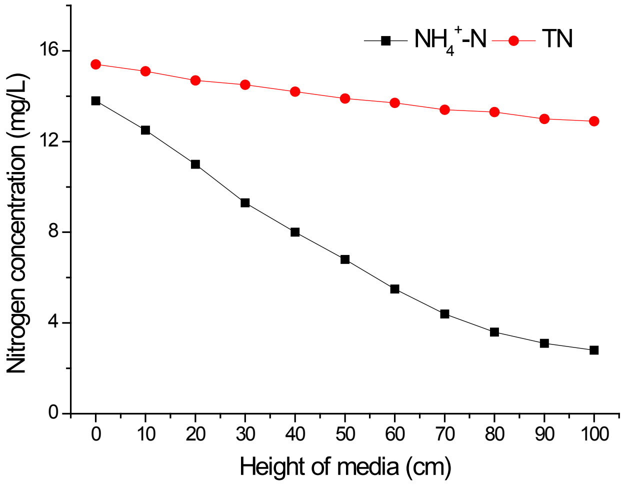

Fig. 8. $NH_4$-N and TN variation vs. height of media bed.

## 4. Conclusions

A pre-denitrification double-layer media biological aerated filter was employed for municipal wastewater treatment in this study, and the results obtained are as follows:

1. Good performance of the reactor was achieved and the average COD, SS, $NH_4^+$-N and TN in the effluent were 28.7 mg/L, 5.4 mg/L, 2.7 mg/L and 12.3 mg/L, which satisfied the standard for the Integrated Wastewater Discharge Standard (GB18918-2002) Level-one A.
2. The average COD removal efficiencies were 65% and 35%, respectively, in column 1 and column 2. In the ceramic layer, COD removal efficiency was 65.7% and in the GAC layer, COD removal efficiency was 34.3% in column 1, 70% and 30% in column 2. The GAC media layer was a highly porous material capable of supporting a large bacterial population and besides that GAC can also adsorb part of organic matter.
3. In column 1 functioning as denitrification, the influent TN concentration was 21.6 mg/l; the effluent ammonia was 15.4 mg/l; and the TN removal efficiency was about 28.7%, among the effluent, concentration of $NO_x$-N was only 1.4 mg/L. In column 2 functioning as nitration and simultaneous nitrification–denitrification(SND), the average $NH_4^+$-N and TN removal efficiencies were 79.7% and 7.6%.

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