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Effect of media heights on the performance of biological aerated filter

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Abstract: The optimum media height of carbon oxidation and nitrification in a down-flow biological aerated filter was determined, and the distribution of the heterotrophic and nitrifying populations through studying the changes of organic carbon contents and ammonia concentration at different media height was got. The results showed that as a down flow BAF with granular media, the active layer of nitrifiers was deeper than heterotrophs in BAF. And the optimum media height for the removal of SS, COD_{Cr} and NH_4^+-N was 40 cm, 60 cm and 80 cm respectively. The removal efficiency of SS, COD_{Cr} and NH_4^+-N was 79.1%, 63.9% and 96.4% respectively under the influent COD_{Cr} and NH_4^+-N of 122.1 mgCOD_{Cr}/L and 14.84 mgNH_4^+-N/L, the influent flux of 15.8 L/h, air to liquid ratio of 3:1.

Keywords: biological aerated filter; bed material height; sewage treatment

Introduction

Biological aerated filter (BAF), a fixed-film reactors that used media with a high specific surface was used for secondary and tertiary treatment of wastewater (Stensel, 1988). Carbonaceous removal, solids filtration and nitrification can be carried out in a single unit (Sllan, 1999). The sewage treatment mechanism of BAF mainly include adsorption, filtration and biological metabolism (Pujol, 1992). In bio-film processes, where mixed population bio-films contain aerobic and anaerobic microenvironments, competition for space, oxygen and organic carbon between the different microbial groups can result in a spatial distribution of micro-organisms with the bio-film (Fdz-Polanco, 2000). Spatial distribution of microbes affects mass transfer, reactions and thus the stability and performance of bio-film reactors.

As we know, the media height of BAF was one of important factors that influence the treatment efficiency and investment of capital construction especially when carbon oxidation and nitrification were in the same reactor. So the object of this paper was to determine the optimum media height of carbon oxidation and nitrification in a down-flow biological aerated filter, and to get the distribution of the heterotrophic and nitrifying populations through studying the changes of organic carbon contents and ammonia concentration at different media height.

1 Materials and methods

The down-flow biological aerated filter was used (Fig. 1). The bio-filter was a cylinder of 2.8 m height and 0.15 m outside diameter, i.e. 42 L volume. The filter was up to 2 m height filled with ceramsites 2—5 mm diameter, density 1.16×10^3 kg/m^3. The plexiglas reactor was provided with ten sampling ports located at each 20 cm high. The sewage was pumped to the top of the reactor through the collecting tank by pump controlling flow rate as 0.24 m/h and the aeration was untaken at a constant ratio of air to liquid of 3:1. Filter backwashing was carried out with clean water and air for 15—20 min at the bottom of the filter. And set the top of media height as the zero point increasing with the water flow direction.

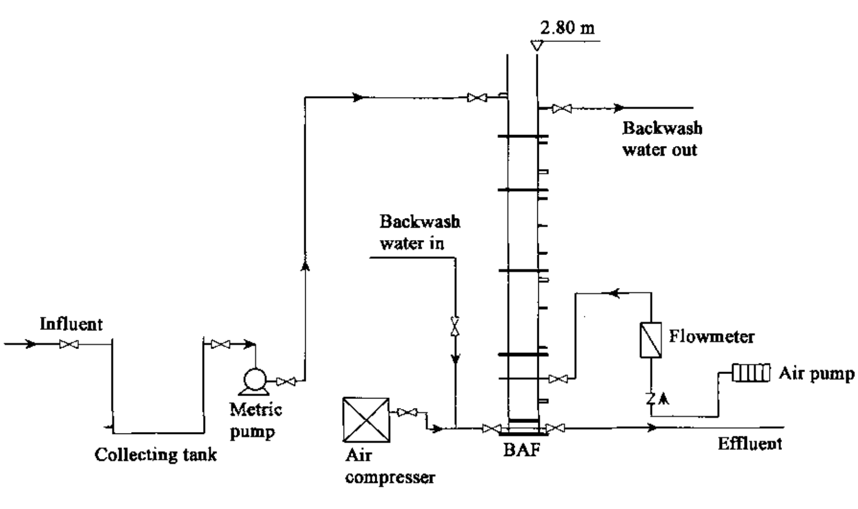

Fig. 1 Scheme of the pilot-scale biological aerated filter

Throughout all the experimentation period the BAF was fed with raw domestic wastewater taken from campus (Table 1). For all liquid samples ammonia, suspended solids (SS), chemical oxygen demand (COD_{Cr}) were analyzed by standard methods; dissolved oxygen (DO) was measured using a JPB-607 portable DO meter and temperature and pH were measured with a Ecoscan pH meter.

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Table 1 Characteristics of the domestic sewage used in the experiment

Temperature, ℃	pH	COD_{Cr}, mg/L	BOD_5, mg/L	NH_4^+-N, mg/L	SS, mg/L
28—30	6.8—7.5	65.4—161.5	34.5—60.4	5—41.3	45—84

2 Results and discussion

2.1 Start-up and steady state operation

In order to promote the biomass growth, the granular media of ceramisites had been marinated with some activated sludge for seven days before fill into reactor. After continuous aeration with the sewage flow rate of 13.5 L/h for a few days, a higher accumulation of attached biomass on the filter media was found. A plenty of filiform flocculate (biological velum) being attached at the top of the filter inside. The color of bio-film covering on the media darkened, from grey to pale yellow. It could be seen by microscope that there were plenty of microorganism as well as amoebae, vorticella and so on in the sloughing off velum. At the same time the quality of effluent was steady(Fig. 2, Fig. 3), it means that the reactor get into steady state operation period.

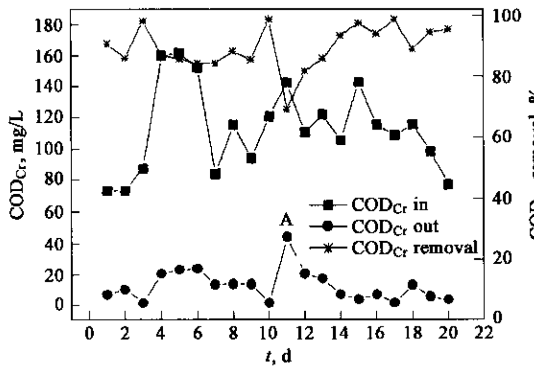

Fig. 2 Results of COD_{Cr}

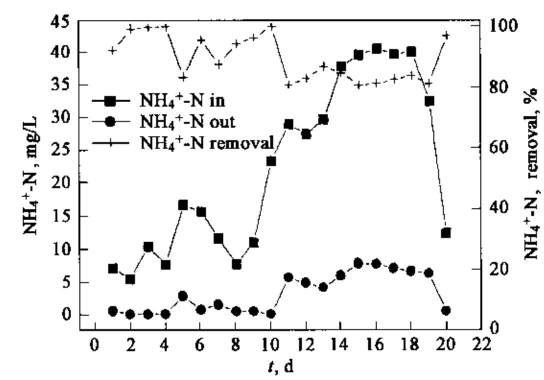

Fig. 3 Results of NH_4^+-N

During the steady state operation period, the removal efficiency of COD_{Cr} varied from 69% to 98% and the effluent COD_{Cr} concentration were all below 23 mg/L when organic loading of influent varied from 0.45 to 1.6 $kgCOD_{Cr}/(m^3 \cdot d)$ under the condition that the hydraulic retention time(HRT) was 2.6 h and the ratio of air to liquid was 3:1. The result of A point in Fig. 2 was measured after backwashing 4 h. Since backwashing can cause some biomass loss in the reactor and lead to the microorganism reduction of BAF, so the removal efficiency of organic compounds would decrease after backwashing and would restore to average level after steadily operating for a while which could reach over 85%.

Numerous bio-film mathematical models describe bio-films as layered structures containing an inner layer formed by a majority of inert biomass near the substratum, and with nitrifying population mostly positioned in a middle layer and heterotrophic bacteria dominating the outer layer (Wanner, 1995; van Loosdrecht, 1995). Experimental observation revealed that the BAF has great nitrification ability, although the change of influent NH_4^+-N concentration was significantly, the effluent was stable as shown in Fig. 3. The removal efficiency of NH_4^+-N was keeping above 80% even to 99% while the applied NH_4^+-N loading changing from 0.03 to 0.55 $kgNH_4^+$-$N/(m^3 \cdot d)$, and lower applied NH_4^+-N loading could get higher NH_4^+-N removal efficiency. The results showed that under the experiment conditions, the removal efficiency of NH_4^+-N would be slightly lower when the applied NH_4^+-N loading was exceeded 0.27 $kgNH_4^+$-$N/(m^3 \cdot d)$, corresponding that the influent NH_4^+-N concentration was above 25 mg/L. It was caused by that no additional alkalinity was supplied throughout experimental period, the final effluent pH value was about 5.6 which restrained the growth and activity of nitrifying populations.

2.2 The effect of media height on suspended solid(SS) removal

Under different media height, the majority of SS removal profiles indicated that only part of the filter was being utilized for SS removal. Since the reactor was down-flow, the most of SS content were removed by those media with contact the raw sewage first, and the middle and bottom media had a little effect on the SS removal. Fig. 4 shows that SS removal efficiency was increased significantly within the top 40 cm media height. The residual SS concentration and removal efficiency was 13.5 mg/L and 79.1% respectively. And then, the SS removal efficiency was improved slowly with the adding of media height. After media height higher than 100 cm, the removal efficiency keep steady. The highest SS removal efficiency reached 98% and the final effluent SS was lower than 1 mg/L. Therefore, the height of bed could be lowered appropriately if the value of influent SS was low.

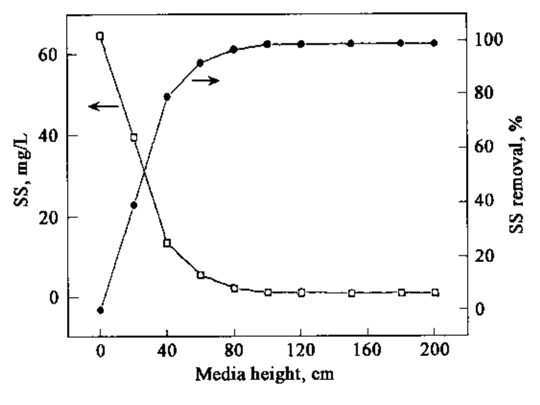

Fig. 4 Variation of SS concentration with media height

2.3 The effect of media height on COD_{Cr} removal

The COD_{Cr} removal performance under different media height is shown in Fig. 5. Under two kinds of different applied organic loading, the changes of effluent COD_{Cr} concentration and efficient removal were shown the similar regular. The greatest increment of removal efficiency was all happened on the top of 60—80 cm media height. Since the concentration of organic compounds on the top of the filter was the highest for a down-flow BAF, which had provided enough nutrition for heterotrophic bacteria growth. The activity and quantity of biomass on the top were higher than in the bottom of the filter, so the degradation speed of organic compounds was fast. Within the first 60 cm media height, the lower and higher applied organic loading obtained 75.9%

and 63.9% removal efficiency respectively, corresponding the residual COD_{Cr} concentration was 15.37 mg/L and 44.09 mg/L respectively. For higher applied organic loading influent, the removal rate increased about 8.3% when the media height from 60 cm to 80 cm. It means that heterotrophic populations could keep activities in the middle of the bed as long as the influent organic nutrition was enough. And at the media height from 80 to 150 cm, the removal efficiency of COD_{Cr} was increased slightly for short of heterotrophic organic matter oxidizers. Since no aeration at the bottom of filter, the anaerobic micro-environment could release some soluble organic contents which caused the slightly increase of final outlet COD_{Cr} concentration comparing with 180 cm section. The final effluent COD_{Cr} removal efficiency was obtained up to 85%. As most of large organic molecules were removed through the first 80 cm media height, and some fine dissolvable organic molecule lightly go through the filter and be drop off with final effluent, and the final organic contents removal efficiency could be reached while increasing the height of media appropriately.

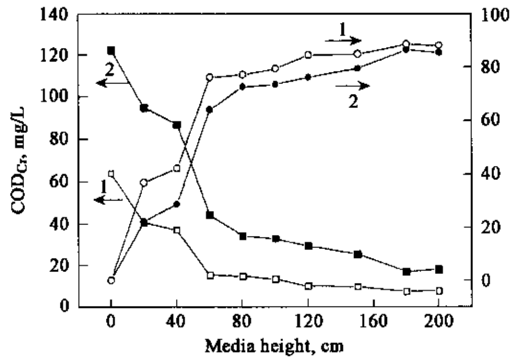

Fig. 5 Variation of effluent COD performance

1. Applied organic loading of 0.69 $kgCOD_{Cr}/(m^3 \cdot d)$; 2. applied organic loading of 1.32 $kgCOD_{Cr}/(m^3 \cdot d)$

2.4 Variation of DO concentration with media height

Dissolved oxygen(DO) was one of the main factors which affect the performance of BAF. It was related to the air flow rate directly. Generally, the more aeration the smaller mass transfer resistance and the higher DO concentration in the bio-film could be obtained. For aerobic metabolism, the activity could be improved under enough dissolved oxygen conditions which enhanced the degradation abilities of heterotrophic and autotrophic for organic compounds and ammonia. But the excessive airflow would increase the consumption of power and the cost of operation, especially for the sewage which has lower organic concentration and higher ammonia concentration. The control of airflow rate and the keep of lower air: liquid can improve the anaerobic denitrification effectively in the bio-film and improve the nitrogen loss performance in the reactor. Variation of DO concentration with the media height is shown in Fig. 6 under the influent flux of 15.8 L/h, air flow rate of 40 L/h and influent organic loading of 0.69 $kgCOD_{Cr}/(m^3 \cdot d)$ and 1.32 $kgCOD_{Cr}/(m^3 \cdot d)$ respectively.

In Fig. 6, the highest DO concentrations of influent 1 and 2 were both in the media height of 80 cm under the two organic loading and the DO concentrations were 3.6 mg/L and 2.84 mg/L respectively. The concentration in the main part was lower at higher influent organic loading than at lower loading because the higher organic concentration will cause the more consumption of DO. At the middle and top height of 0—80 cm, the DO concentration was decided by the organic concentration in the sewage. According to the sewage's flow direction-flowing into the reactor from the top, the organic concentration decreased gradually along the flow direction, with the increasing of the media

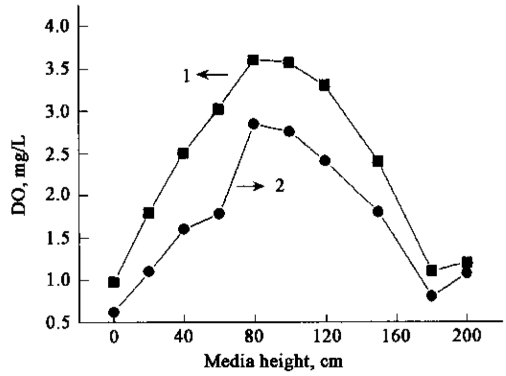

Fig. 6 Variation of DO with media height

1. Applied organic loading of 0.69 $kgCOD_{Cr}/(m^3 \cdot d)$; 2. applied organic loading of 1.32 $kgCOD_{Cr}/(m^3 \cdot d)$

height, so the oxygen consumption decreased, the DO concentration increased to the highest gradually. While in the bottom of 100—150 cm, the DO concentration was decided by the bubble residence time in the media pore. The bottom perforated tube was used to aerate in bio-filter, the oxygen transfer mainly go through the approach of interface transfer way under the continuous bubble aerating. The longer the bubble residence time was, the higher the DO concentration was. Near the bottom where there was aeration, the bubble resistance was small, the residence time was shorter so the DO concentration tends to decrease gradually. At the 180 cm under the perforated tube, there was a section of no aeration where the DO concentration decreased to the lowest point.

2.5 Variation of NH_4^+-N concentration and its removal efficiency with media height

Under the same hydraulic and organic loading, the different influent ammonia concentrations, the variation of the removal efficiency of NH_4^+-N with height is shown in Fig. 7 in which the influent flux was 15.8 L/h, aeration flux was 40 L/h and the influent organic load was 1.32 $kgCOD_{Cr}/(m^3 \cdot d)$.

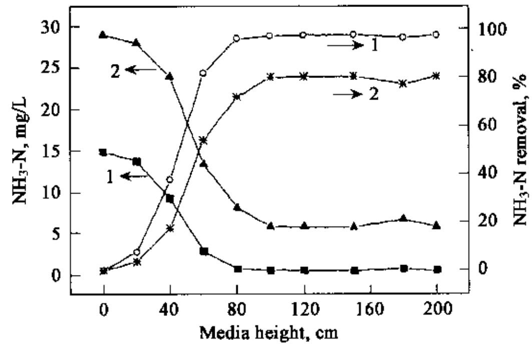

Fig. 7 Variation of NH_4^+-N performance in nitrification
The same organic load as in Fig. 6

In Fig. 7, the optimum media height for the nitrification of NH_4^+-N was 40—80 cm. At the height of 80 cm, the removal efficiency of ammonia in influent 1 and 2 was 96.4% and 72.3% respectively. When the height increased to 100 cm, the removal efficiency in influent 2 reached 80.3%. At the height of 100 cm, the efficiency was almost invariable. At last the effluent ammonia concentrations of influent 1 and 2 were 0.34 mg/L and 5.68 mg/L respectively and the corresponding removal efficiencies were 97.7% and 80.4%. Comparing with the DO concentration variation under the same organic load(Fig. 6), it was shown that the removal of NH_4^+-N was influenced greatly by DO. At the top of the bio-filter, the removal efficiency of NH_4^+-N was limited by DO concentration. With the DO concentration increasing, the removal increased, too. But in the middle and bottom, when the ammonia concentration lowered below 2—5 mg/L, the NH_4^+-N concentration became the limited factor of the removal of NH_4^+-N.

The NH_4^+-N removal efficiency of influent 1 was higher than that of influent 2 because under the two different influent concentration, the different alkalinity consuming in nitrification caused the variation of pH under different media heights as shown in Fig. 8.

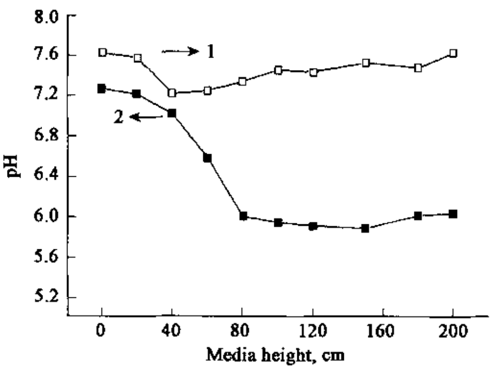

Fig. 8 Variation of pH with height

1. Influent NH_4^+-N concentration of 14.84 mg/L; 2. influent NH_3-N concentration of 29.05 mg/L

In Fig. 8, when the influent concentration of ammonia was 14.84 mg/L, the pH value changes little during the nitrification and the value was among 7.2—7.6 which made the nitrifiers maintain good activity. So both the efficiencies of nitrification and the removal of ammonia were high. When the influent concentration was 29.05 mg/L, the pH value changes greater with the media height and when the height exceeds 80 cm, the value of pH decreases under 6 which restrained the growth of nitrifiers and decreased the nitrification efficiency. In the section where it was not aerated, the denitrification happened which made the effluent pH increased a little.

2.6 Variation of organic and ammonia volume loading with media height

When the carbon oxidation and the nitrification of ammonia were in the same bioreactor, the competition for space and oxygen between the heterotrophic and nitrifying populations in different media heights made different ability to oxidize organic content and nitrify ammonia. Variation of the volume loading and NH_4^+-N with the media height is shown in Fig. 9. Under filtering velocity of 1.04 m/h and ratio of air to liquid of 3:1 and space was stronger than that of the nitrifiers. Simultaneously, due to the main trapping section of SS, the COD_{Cr} loadings were improved in these sections. The NH_4^+-N loadings increased only 0.05 kg NH_4^+-N/($m^3 \cdot d$) in the height of 0—40 cm. But in the height of 40—100 cm, it increased from 0.05 kgNH_4^+-N/($m^3 \cdot d$) to 0.25 kgNH_4^+-N/($m^3 \cdot d$). It showed that the active layer of nitrifies was deeper than that of heterotrophs. Since nitrifying bacteria are easily out-competed by heterotrophic microbes. Therefore in a fixed-film, plug-flow reactors, nitrification only occurs once COD_{Cr} level are low at the base of filter when using a down-flow configuration(Rebecca, 2001). So under experiment conditions, the concentration of carbonaceous organic compounds decreased due to the biological degradation, which made the amount of heterotrophs decrease as the result of the absence of nutrition. Compared with heterotrophs, the autotrophic nitrifiers became superiority bacteria which improved the NH_4^+-N volume loading rate. However, at the height of 40—60 cm, the volume loading rate of COD_{Cr} and NH_4^+-N all increased obviously which indicated that it was the optimum media height for the accumulations of heterotrophs and nitrifiers at the same time.

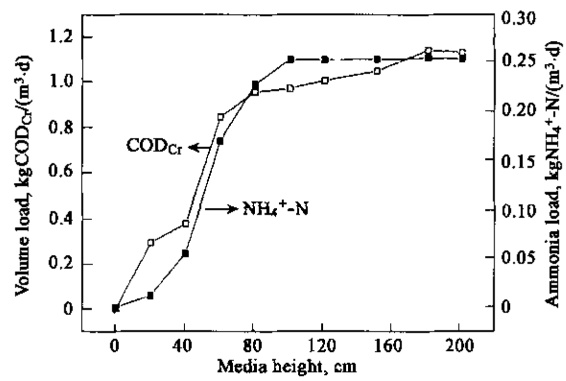

Fig. 9 Variation of volume loading and ammonia loading with height

3 Conclusions

As a down-flow BAF reactor, the optimum media height for the removal of COD_{Cr} was 60 cm and NH_4^+-N was 40—80 cm. The average removal efficiency of COD_{Cr} and NH_4^+-N was 71.5% and 84.4% respectively. At the height of 40—60 cm, there was a dramatic increase of the loadings of volume and NH_4^+-N was 56% and 71% respectively. That means, just here the accumulation of the heterotrophs for organic content degradation and the autotrophs for NH_4^+-N nitrating was the fastest and bacteria have higher activity.

When the influent organic loadings were higher, the distributing of heterotrophs in bed layer was more equality and the organic contents can degrade more in the middle bed layer of 80 cm, which made the concentration of dissolved oxygen(DO) in reactor body lower than that of the lower influent organic loadings. The peak of the DO concentration was at the media height of 80 cm.

Biological aerated filter has a good removal efficiency of SS. And most of SS was trapped when they first attach to the media at the height of 40 cm. When NH_4^+-N concentration was higher, the alkalinity was consumed during the process of nitration, which made pH value lower and restrained the growing of the nitrifiers and made the removal efficiency of NH_4^+-N lower.

Variation of volume loading and NH_4^+-N loading with the media height further verified that the active layer of nitrifiers was deeper than heterotrophs in BAF and at the top of the bed layer the organic content degradation by heterotrophs was prior, however, at the middle and bottom the nitration of NH_4^+-N by nitrifiers was prior.

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