Feasibility Study of Shell Powder as Biological Aerated Filter

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Abstract: Shells are widely used as biofilm carriers for biological contact oxidation treatment because of their rough surface and the abundance of CaCO3 on their surface. shells have the advantage of high helium and phosphorus removal efficiency compared to conventional carrier materials. The CaCO3 in the shell provides a source of alkalinity for nitrification. Shell fillers are used in biological aerated filter reactors. Experimental results show that extended hydraulic retention time (HRT) can effectively improve the pollutant removal efficiency of biofilm reactors. When the HRT was 12 h, the biofilm reactor was more effective in removing organic matter, with the removal rate of COD increasing from 70.6% to 92.5%. the average removal rate of ammonia nitrogen increased from 37.3% to 95.8% when the HRT was 4 h to 12 h. The highest treatment effect for phosphorus was 74.5% when the HRT was 8 hours. At 12 hours HRT, the effluent concentration of ammonia reached 1.5 mg/L. The pH of the treated effluent from the shell-filled biofilter was stable between 7 and 8.5.

1 INTRODUCTION

Global water pollution poses an increasingly serious threat to human survival and socio-economic development. Wastewater treatment is an indispensable component of economic development and water resources. Wastewater is divided into secondary and advanced treatment. After conventional secondary treatment, although most of the suspended and organic matter has been removed, there are still traces of suspended and dissolved harmful substances such as nitrogen and phosphorus compounds. As plant nutrients, nitrogen and phosphorus can help algae and aquatic life to grow and provide nutrients for algae and aquatic life, but excess nitrogen and phosphorus can cause eutrophication of water and affect drinking water sources. The most important feature of the biological aerated filter (BAF) is the combination of biological oxidation and interception of suspended matter, saving the subsequent steps of settling tanks to treat the effluent (e.g. secondary sedimentation tanks). The BAF treatment process is characterized by high volumetric load, high hydraulic load, small footprint, low capital investment, high oxygen transfer rate and good effluent quality. The reaction principle of aeration bioreactor is that aerobic and parthenogenic microorganisms grow on the surface of the biofilm, and the microorganisms in the inner layer of the biofilm are in an anaerobic state. When aerobic microorganisms continuously react to consume oxygen, resulting in less oxygen in the reactor and more anaerobic reaction, when the thickness of the anaerobic layer exceeds that of the aerobic layer, the biofilm located on the reactor will fall off and a new biofilm will be regenerated on the surface of the carrier. Thus ensuring regular renewal of the biofilm and maintaining the normal operation of the biofilm reactor (Ding, Chu, Wang.2018).

In this experiment, shells, a waste material from the sea, were chosen as fillers in an aeration bioreactor. The shells not only have a rough surface suitable for biological growth, but the surface is also rich in $CaCO_3$ for removing nitrogen and phosphorus from the wastewater. It is now widely used in biofilm reactors for wastewater treatment in Japan (Lei, Qing, Wen, 2020). Compared to conventional carrier materials, biofilm reactors filled

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with shells have the advantage of high helium and phosphorus removal efficiency. The alkalinity source for the nitrification reaction is provided by the $CaCO_3$ in the shells as an alkalinity source. The rough surface of the shells and the large amount of $CaCO_3$ can be used as a carrier for the biofilm and as a source of alkalinity for the nitrification reaction.

2 MATERIALS AND METHODS

2.1 Materials

In this experiment, The main water quality index of artificially prepared domestic sewage is TP 3~6 mg TP 3~6 mg/L, NH_4-N 33~50 mg/L, COD 480~500 mg/L. The amount of trace elements added was $CuSO_4 \cdot 5H_2O$ 0.8 mg/L, $MnCl_2 \cdot 4H_2O$ 5 mg/L, $CoSO_4 \cdot 7H_2O$ 0.3 mg/L, $MgSO_4 \cdot 7H_2O$ 50 mg/L.

Using marine waste shells as aeration bioreactor filler, many small equal holes were made on the surface of the shells and two shells were tied together to form an anoxic environment in the middle of the two shells and an aerobic environment on the surface of the shells. The nitrification denitrification pattern and phosphorus removal characteristics of the shell-filled bioaeration filter were investigated by varying the hydraulic retention time (HRT).

2.2 Experimental Equipment

The test set-up is shown in Figure 1. The aeration biofilm reactor is made of polyethylene with a column height of 0.8 m. The aeration biofilm reactor is filled with a shell layer of 0.6 m height (porosity of 90.7%). An aeration head is set at the bottom for aeration to keep the whole reactor in an aerobic state (DO>4mg/L). The raw water enters at the bottom of the column and the treated water exits at the top. The hydraulic retention time of the aerated biofilm reactor is set by adjusting the influent, effluent and overflow volumes. The treatment effect at different hydraulic retention times is investigated by varying the hydraulic retention time.

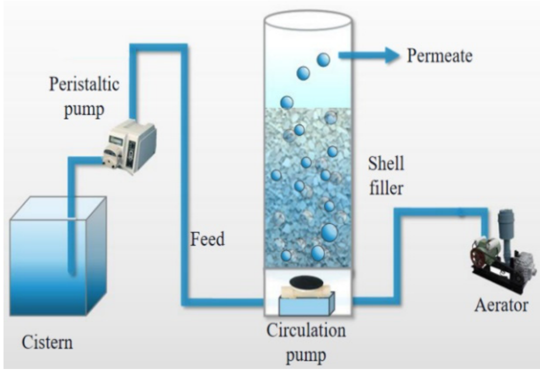

Figure 1: Aeration biofilm reactor installation diagram.

3 RESULTS AND DISCUSSION

3.1 Film Hanging Process and Phenomenon

In order to promote biofilm formation, the sludge used in the experiment was the return sludge from the secondary sedimentation tank of the First Wastewater Treatment Plant in Dalian Economic and Technological Development Zone. The return sludge was filled into the aeration biofilter reactor with a water content of 98.90% in the feed sludge and suspended solids (SS) of 9757 mg/L. Aeration started the day after the return sludge was placed and lasted for 24 hours with a water temperature between 11℃ and 15℃ more suitable for microbial growth. During the hanging period it could be observed that a sticky substance was slowly produced on the surface of the filter media. After the 7th day some greyish-white spots were observed, which then continued to spread. By day 10, a thin brownish-yellow biofilm was attached to the shells in the aeration biofilm reactor. It was the lack of oxygen to the biofilm due to uneven aeration that caused some of the biofilm to turn dark brown. (Chen, Zeng, Ma, 2019).

3.2 Removal of Organic Matter by Biological Aerated Filter

As can be seen from Figure 2, the average removal rate of COD by the aeration bioreactor gradually increased with the increase of HRT. The COD removal rate is not high and the effluent COD concentration is high when the HRT is 8 hours for one week, which proves that the inoculation of sludge has just started at the beginning of the experiment, resulting in the $CaCO_3$ on the surface of the shells just contacting with the microorganisms in the sludge, the operation of the aeration bioreactor is not stable, and the biofilm generated by the reaction is not completely attached to the shell packing, resulting in the COD removal rate was not high. But the removal effect increased after a period of stable operation compared to before. From 4hr to 12hr, the removal rate of CODcr increased from 70.6% to 92.5% and the removal rate of organic matter increased. From the overall trend, it seems that the longer the HRT time the better the removal effect of COD and the lower the concentration of COD at a more stable feed water concentration.

Figure 2 illustrates the treatment effect of the shell-filled aeration filter. However, it was found that the blackening of the bottom of the aeration bioreactor occurred in the latter part of each filtration cycle due to the large volume of dirt intercepted in the bottom area of the aeration bioreactor, rapid biofilm growth, thicker biofilm and insufficient oxygen supply inside the membrane. Shortening the HRT increases the hydraulic load and correspondingly increases the organic load, which inevitably affects the treatment efficiency (Lei, Qing, Wen. 2020).

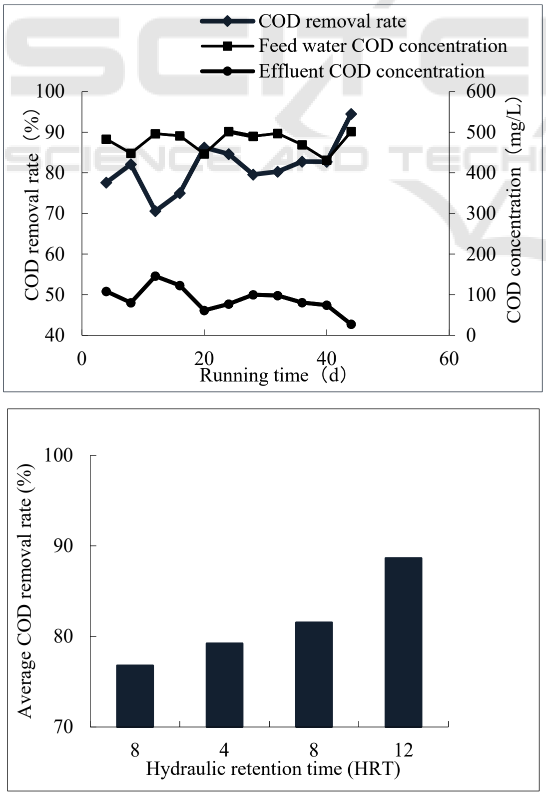

Figure 2: Effectiveness of aeration biofilm reactor on COD removal after adding shell-filled (up) Relationship between average COD removal and HRT (down).

3.3 Aeration Biofilter Nitrogen Removal Efficiency

As can be seen from Figure 3, the ammonia nitrogen removal rate and average removal rate for the HRT initiated at a residence time of 8 hours in the test were not high. Furthermore, the effluent concentrations of ammonia nitrogen ranged from 21.3 to 13.7 mg/L. This indicates that the biofilm did not fully adhere to the biological treatment during the test start-up and was ineffective. However, Figure 3 shows that the average removal of ammonia nitrogen ranged from 37.3% to 95.8% from HRT 4 hours to HRT 12 hours, while the lowest effluent concentration of 1.5 mg/L of ammonia nitrogen was reached at HRT 12 hours, indicating that extending the HRT significantly improved the nitrification and denitrification of the reactor and that the shell-filled aeration biofilm had a significant effect on the nitrification process.

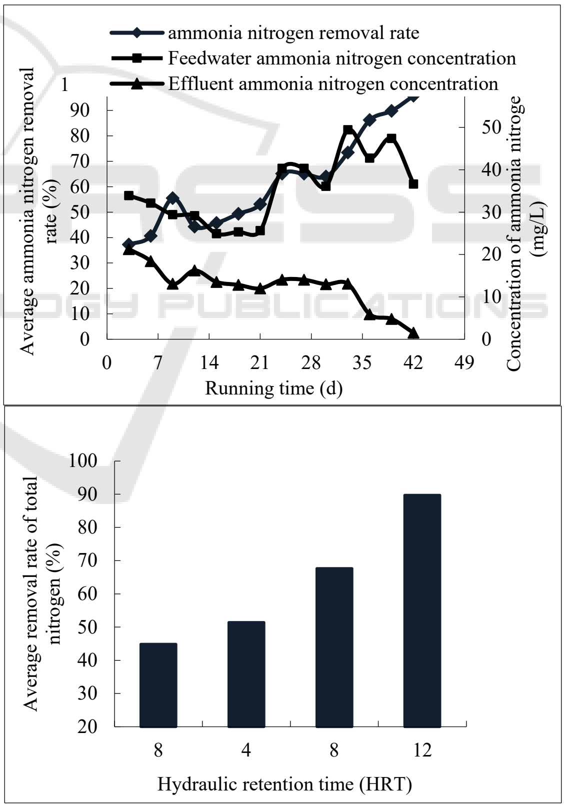

Figure 3: Removal of ammonia nitrogen by aeration biofilm reactors with shell filling (up) Mean ammonia nitrogen removal versus HRT (down).

At a hydraulic retention time of 4 hours, for an aeration biofilter that removes both organic matter and ammonia nitrogen, shortening the HRT will have an impact on the biofilm micro-ecology in the reactor, making ammonia oxidizing bacteria and nitrifying bacteria easily eluted in the backwash process, thus reducing the nitrification capacity of the whole reactor ammonia nitrogen removal rate is low (Ding, Chu, Wang, 2018). And with the increase of hydraulic retention time, the removal rate of ammonia nitrogen significantly increased, and the effluent concentration of ammonia nitrogen significantly decreased. This indicates that the aeration biofilter with shells as filler has a significant effect on the removal of ammonia nitrogen.

3.4 Phosphorus Removal Effect of Shell-filled Biofilters

Figure 4 show that the highest phosphorus treatment effect of 74.5% was achieved at the beginning of the experiment, i.e. when the HRT was 8 hours. The reasons for this are, firstly, that phosphorus removal is good under acidic conditions with low pH, secondly, chemical phosphorus removal dominates

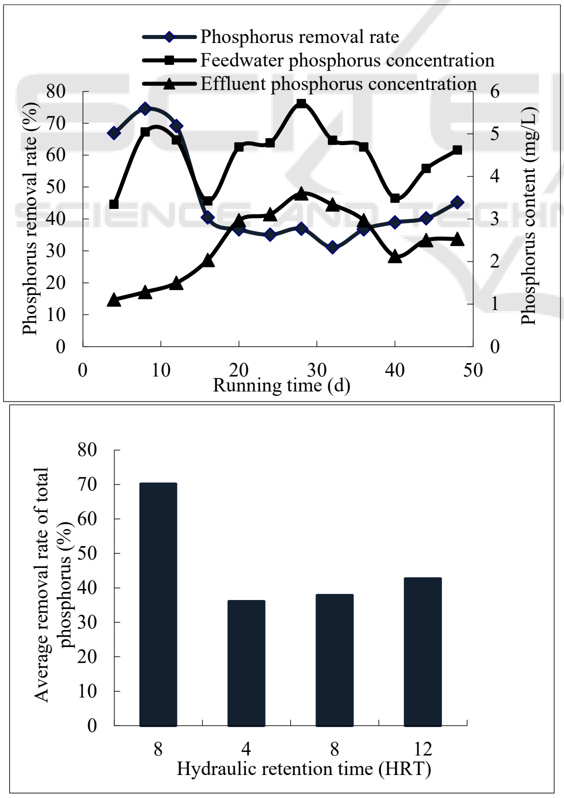

Figure 4: Effectiveness of aeration biofilm reactor on total phosphorus removal after adding shell-filled (up) Relationship between average total phosphorus removal and HRT (down).

and the generated biofilm does not completely encase the shells, and the Ca^{2+} that precipitates in the shells helps to remove phosphorus, so the phosphorus removal effect is significant at the beginning of the test. As the residence time varied, the change in hydraulic load also had an effect on the phosphorus removal.

Combined with Figure 4 it can be seen that at an HRT of 4 hours, biological phosphorus removal dominates due to the increase in pH. The shell filler was wrapped by the biofilm and could not precipitate Ca^{2+}, resulting in a poor phosphorus treatment effect and a decreasing trend. When the HRT was shortened to 4h, the phosphorus removal rate did not decrease significantly. It can be seen that when the HRT was controlled above 4h, the biodegradation and the acidity level of the system were sufficient to ensure that the chemical precipitation for phosphorus removal by bioinduced action could be carried out properly.

3.5 Effect of pH on Shell-filled Aeration Biofilters

The Figure 5 demonstrates that the effluent pH of the aeration biofilm reactor was stable between 7 and 8.5. The slight drop in pH at the beginning of the hook-up is caused by the instability of the system, and effluent indicators for this period indicate that the system is unstable at the beginning of the hook-up, with rebound fluctuations at a later stage and then gradual stability.

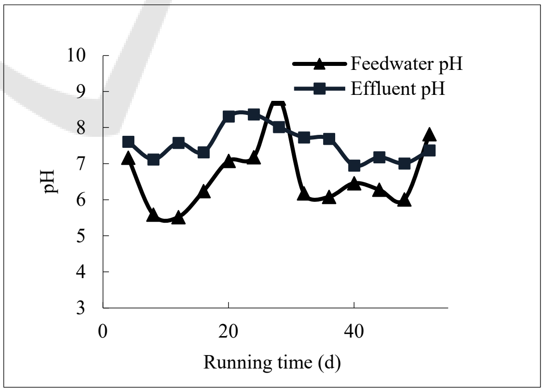

Figure 5: Changes in pH of aeration biofilm reactors after addition of shell fillers.

The treatment effect of the aeration biofilm is closely related to the pH value and has a very strong influence on ammonia nitrogen and phosphorus in particular. Under acidic conditions, phosphorus was treated significantly, whereas in the middle of the run, the pH of the influent was adjusted to around

8.2 due to changes in the test conditions, resulting in a significant decrease in phosphorus removal. After this trial, when the alkali addition was stopped, the phosphorus removal effect increased significantly. It can be seen that the effect of pH on the treatment effect of biofilm cannot be ignored.

4 RESULTS AND DISCUSSION

The aeration biofilm method used in this experiment to treat domestic wastewater investigates the pollutant removal effectiveness of shell-filled aeration biofilters at different hydraulic retention times. The following conclusions were drawn from the tests and analysis:

The rough surface of shells contains a large amount of calcium carbonate, which can be used as a carrier for biofilms and a source of alkalinity for nitrification reactions (Yang, Liu, Zhang, 2019). In the aeration biofilm reactor, $CaCO_3$ dissolved in the shells provides alkalinity for the nitrification reaction, so that the activity of nitrifying bacteria is protected from the inhibition of acidic substances and the nitrification reaction rate can be maintained at a high level.

HRT has a significant effect on the treatment efficiency of the aeration biofilter, and extending HRT can effectively improve the efficiency of the reactor in removing pollutants. When the HRT is 4 hours, the treatment effect of the reactor on organic matter decreases significantly, which is due to frequent backwashing and short time for microorganisms to stay on the shell surface. When the HRT is 8 hours or the HRT is 12 hours, the reactor has a better effect on the removal of organic matter, which is significantly higher than the effect when the HRT is 4 hours.

The aeration biofilter with shells as filler had a significant effect on the removal of ammonia nitrogen, and the simultaneous nitrification and denitrification processes occurring in the reactor tended to increase the removal rate of nitrogen as the residence time increased.

During the start-up phase of the experiment, the phosphorus removal effect was obvious, which fully indicates that chemical phosphorus removal dominated, while Ca^{2+} precipitated in the shells helped biodegradation of phosphorus.

The aeration biofilter had a significant effect on the degradation of organic matter, up to 90%, with the lowest effluent concentration reaching 27.4 mg/L. The average removal rate was above 75% during stable operation.

The effect of pH on the treatment effect is obvious. pH between 6.5~8.5 is more suitable for aerobic organisms. In the middle of the experiment, the pH was changed and it was confirmed that a slightly acidic pH was more effective for the treatment of phosphorus.

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