A contrast experiment research on rural wastewater treatment efficiency of BAF with zeolite and zeolite-haydite combined packing

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Abstract. In order to investigate the effect of biological aerated filter (BAF) with zeolite filler and combined packing, a contrastive experimental study was carried out on zeolite BAF and zeolite-haydite combined packing BAF with the operation parameters such as hydraulic retention time (HRT), temperature and DO keeping constantly throughout the experimental process and the removal efficiency of CODcr, NH₄⁺-N and SS were analysed during the start-up stage and the steady stage. The results showed that on condition that the average temperature was 27°C and DO 6mg/L and HRT 8h, BAF with zeolite filler formed film completely in 30 days, with the removal rate of CODcr, NH₄⁺-N and SS 59.6%, 94.6% and 87%, while zeolite-haydite BAF formed film completely in 25 days, with the removal rate of CODcr, NH₄⁺-N and SS 63.7%, 95.9%, 88.5% respectively, which was better than the former. In summary, BAF with combined zeolite and haydite is superior to BAF with single zeolite for rural wastewater treatment.

1. Introduction
Biological aerated filter (BAF) is a novel biofilm process which has developed in occident countries since 1980s. It has been widely studied and applied in recent two decades because it has advantages of high efficiency, energy-saving, small occupation area and convenience management [1]. The filler is the core part in BAF and previous studies [2, 3, 4] showed that the most popular two kinds of fillers for BAF were zeolite and haydite, which had better application effect than other kinds of fillers. But it was seldom reported that the comparison between BAF filled with single filler and BAF filled with composite filtering material under the same conditions.

In this paper the treatment effects of BAF with single natural zeolite and BAF with combined zeolite and haydite in 1:1 proportion were analyzed, and their removal effects of chemical oxygen demand (CODcr), ammonia nitrogen (NH₄⁺-N) and suspended solid (SS) were investigated in both the start-up stage and the steady operation stage. The running laws and treatment effects of two kinds of BAFs will provide a reference standard for its optimal design and operation management.
2. Experimental device and methods

2.1. Experimental device

The BAF design was based on the data correlation of removal performances with BAF dimensions obtained from the previous studies [5]. Two laboratory-scale BAF systems made of transparent polyvinyl chloride (PVC) were designed with the dimensions of 55 cm height (H) ×13 cm diameter (D) with an effective working volume of 6 L. The diameter of zeolite particles ranged from 3 mm to 5 mm. Only zeolite particles, in size order smallest on top, were filled into 1# reaction column (zeolite BAF), while zeolite and haydite were respectively layered into 2# reaction column (zeolite-haydite combined packing BAF) in 1:1 proportion from top to bottom. The total filling height of 2# reaction column is about 50 cm, with a supporting layer of 8 mm-diameter gravels at the bottom. The air inlet is 1 cm from the bottom which is for aeration and air-water backwashing. The air flow rate was controlled by an air flow meter. Sampling ports (SPs) were placed along the height of the column at 11 cm intervals to allow biomass and water samplings. A backwash system was periodically operated using a water pump to remove the excess biomass to prevent the reactor from clogging, thereby maintaining biofilm activity [6]. The BAF system was operated in an up flow direction. Rural wastewater was pumped from the influent tank into the BAF column using a peristaltic pump, flowing upward through the medium at a flow rate of 0.3 L/h to occupy the BAF column in about 18 h. The experimental device is shown in Figure 1.

![Figure 1. Experimental device.](image)

The experimental device continuously operates in July and August, with the temperature of the laboratory ranging from 23 to 34 °C. The influent contains high biodegradable components, so a wide range of microorganisms in raw water would be absorbed onto the surfaces of the filler, and then formed biofilms on it. Flow velocity was as small as 0.3 per hour, therefore a large number of microorganisms could be absorbed onto the surfaces of particle easily. The hydraulic loading was gradually increased until biofilm was matured. Previous studies [7] have shown that ammonia nitrogen removal ratio can be regarded as an indicator for biofilm maturation. It takes more time for this kind of biofilm growth manner to finish, but it runs more steadily during the steady operation stage. Water-air combined backwashing was adopted in this experiment, owing to its superior to single water or gas backwashing [8]. The back-washing sequence started with air scour, followed by air scour and water backwash and terminating by air scour, and the air and water flows kept up-flow. Backwashing was carried out when a preset head pressure loss reached. Intense and short backwashing were carried out on the basis of our experience, with 5 L/s of water and 15 L/s of air.
2.2. Filler
Zeolite is a kind of natural porous silicate mineral which has intense adsorb ability and enrichment effect on polar molecule and bacteria. Early experiments suggested that nitrifying bacteria adsorbed on the surface of zeolite could transform ammonia nitrogen into nitrate nitrogen [9]. Ammonia removal by bio Zeolite filter was high because of the dynamic bio-regeneration process. In addition, this system has powerful resistance to impact load. As for the haydite filter, it takes less biofilm maturation time and reaches higher treatment efficiency on treating micro-polluted raw water [10, 11]. Furthermore, it has high resistance to low temperature and erosion [10, 11]. Single filler of BAF has less microbial biomass, resulting in instability treatment effect. This present thesis aims to explore the treatment effects of BAF with single natural zeolite and BAF with combined zeolite and haydite. Physical properties and chemical properties of zeolite and haydite are shown in Table 1.

| Name | Physical Properties | Chemical Elements /% |
|------|---------------------|----------------------|
|      | specific surface / m²·g⁻¹ | total pore volume /cm³·g⁻¹ | loose bulk density /g·L⁻¹ | Na | Mg | Al | Si | Fe | Others |
| Zeolite | 0.46 | 0.0269 | 830 | 4.25 | 11.48 | 18.27 | 40.28 | 10.14 | 15.58 |
| Haydite | 3.99 | 0.103 | 976 | - | 1.5 | 21.5 | 63.5 | 6.5 | 7 |

2.3. Influent quality
Dynamic experiment was operated under a condition of continuous water input by peristaltic pump from water tank. The wastewater used in this study was collected from wastewater plant of Pangge Town, Beijing. The raw water is characterized by high contents of CODₐ and NH₃-N, thus, the water quality is unstable. Water quality and determination of test sample are summarized in Table 2.

| Parameters | T/℃ | PH | CODₐ/mg·L⁻¹ | NH₃-N/mg·L⁻¹ | SS/mg·L⁻¹ |
|------------|-----|-----|-------------|--------------|-----------|
| Maximum    | 36  | 7.93| 386         | 28.8         | 240       |
| Minimum    | 18  | 6.87| 217         | 18           | 78        |
| Average    | 27  | 7.36| 301.5       | 23.4         | 159       |
| Determination | Thermometer | pH meter | potassium dichromate method | Nessler's reagent spectrometry | Gravimetric Method |

3. Results and discussion
3.1. Removal effect of CODcr
During the start-up stage, influent CODcr concentration was about 217mg/L, while effluent CODcr concentration from both BAFs were not stable, with CODcr removal rate lower than 40%. Effluent quality from 1st reaction column fluctuates greatly, whose CODcr concentration is occasionally higher than influent’s. Previous studies [12] showed that biofilm on the zeolite was not mature and stale at this stage, and the biofilm can easily be divorced from the surface of zeolite due to the washing action of influent, so CODcr concentration of effluent increased. On the other hand, 2nd reaction column, with a CODcr removal rate above 60%, forms film completely in about 25 days which is shorter than 1st reaction column. It can be seen that 2nd reaction column with haydite has higher aerobic biofilm growth rate and more steady bioactivity at the same time.

Varieties and quantities of the organisms increased and basically tended to be stable after 30 days. Removal rate of CODcr of two kinds of BAFs reached about 59%, which showed that heterotrophic bacteria has grown to maturity. However, Filler was gradually clogged by pollutants with increasing operation time, and biofilm was not to be regenerated in time, so the removal rate of
CODcr declined after 30 days. As can be seen from Figure 2, removal rates of 1st reaction column and 2nd reaction column have declined to 26.3% and 37.1% respectively after 43 days. The removal rate regained its previous level gradually after air-water backwashing.

![Figure 2. CODcr removal rate.](image)

![Figure 3. CODcr removal effect.](image)

3.2. Removal effect of NH$_4^+$-N
NH$_4^+$-N removal effects of the start-up stage are shown in Figure 4 and Figure 5. In the 9th day of start-up stage, NH$_4^+$-N removal rates of 1st reaction column has increased to 96.8%. In 9th ~30th days, the average removal rate of NH$_4^+$-N was 92.3%. Respectively, in the 13th day of start-up stage, NH$_4^+$-N removal rates of 2nd reaction have come to 96.7%. In 9th ~30th days NH$_4^+$-N average removal rate was 95.1%. After the formation of biofilm, NH$_4^+$-N removal rates of both BAFs reached 90%.

Why could the removal rates of NH$_4^+$-N keep high at the start-up stage? There was no biofilm formed on the surface of zeolite at the initial stage of starting-up, so high removal rate of ammonia nitrogen on zeolite was mainly due to ion-exchange action [13]. It is estimated that the ability of ion exchange ammonia nitrogen was saturable in the 16th day, which caused the removal rate of influent ammonia nitrogen decreased, however, in 19th day, the removal rate of NH$_4^+$-N abruptly decreased, because nitrifying bacteria played an important role in removing nitrifying bacteria, which prolonged the regeneration period of biofilm on zeolite. Haydite in 2nd reaction column have no selective adsorption for NH$_4^+$-N, and zeolite in the upper layer played a main role in removing NH$_4^+$-N because of the ion-exchange action, whose removal rate was lower than 1st reaction column. However, haydite filler has advantages of larger interspace and rough surface, and as times goes on, the microorganism grows not only on the surface of the haydite but also in the interspace[14], therefore haydite in the lower layer is more easily to culture biofilm and activated nitrification earlier. So NH$_4^+$-N removal rate of BAF with combined zeolite and haydite is more stable, whose removal rate of NH$_4^+$-N generally remains high.

As showed in Figure 4 and Figure 5, NH$_4^+$-N average removal rate of 1st reaction column is 94.62±3.42%, NH$_4^+$-N concentration of effluent ranging from 0.37 mg/ L to 2.25 mg/ L. While NH$_4^+$-N average removal rate of 2nd reaction column is 95.93±2.15%, NH$_4^+$-N concentration of effluent ranging from 0.44 to 1.52mg/L. In conclusion, NH$_4^+$-N removal effect of BAF with combined zeolite and haydite is more stable, whose removal rate of NH$_4^+$-N is generally higher than the former.

At the initial stage of starting-up, adsorption and ion exchange play a part in removing ammonia nitrogen. In contrast, nitrification of microbes played a main role in removing ammonia nitrogen at steady operation stage. Nitrification is a biological oxidation of ammonia-nitrogen which goes through two stages, where NH$_4^+$-N in the presence of oxygen, is firstly converted to nitrite-nitrogen (NO$_2^-$-N) by the strictly Chemolithotrophic Nitrosomonas, Nitrosococcus and Nitrosospira bacteria, and secondly to nitrate-nitrogen[15]. The reasons for higher NH$_4^+$-N removal rate of 2nd reaction column is that hydite has larger porosity, which provides larger space for Microorganism's growth and reproduction [16], and ensured better removal effect and stability of effluent quality. Besides, hydite, as a kind of floating media filter, can increase the flow resistance and make distribution of flow even, which is benefit for
the growth of nitrifying bacteria. As a result, BAF with combined zeolite and haydite is superior to the
BAF with single filler.

3.3. Removal effect of SS
The removal effects of SS are shown in Figure 5 and Figure 6. From the 30th day to biofilm culturing
ending, effluent SS concentration of 2\textsuperscript{nd} reaction column ranged from 3.5 to 18.5mg/L, while effluent
SS concentration of 1\textsuperscript{st} reaction column ranged from 8.7 to 49.3mg/L. It can be seen that SS removal
rate of 1\textsuperscript{st} reaction column is gradually rising during the start-up stage, however, SS removal rate of 2\textsuperscript{nd}
reaction column is higher and steadier.

During the steady operation stage, SS removal rates of both BAFs are stable with influent SS
concentration ranging from 78 to 210mg/L. The effluent SS concentration of 2\textsuperscript{nd} reaction column is 15.9
mg/L with average removal rate 87\%, while the effluent SS concentration of 1\textsuperscript{st} reaction column is 19.5mg/L with average removal rate is 88.5\%. It can be obviously seen in Figure 4 that SS removal
rate of 2\textsuperscript{nd} reaction column is higher and more stable, mainly due to the fact that hydite has larger
interception capacity and higher efficiency of intercepting sewerage.

4. Conclusion
The results show that the removal rates of COD\textsubscript{cr}, NH\textsubscript{4}\textsuperscript{+}-N and SS were 63.7\%, 95.9\% and 88.5\%
respectively for the BAF with combined packing, which formed film completely in 25 days. while for
the BAF with zeolite filler, the removal rates of COD\textsubscript{cr}, NH\textsubscript{4}\textsuperscript{+}-N and SS were 59.6\%, 94.6\% and 87\%
respectively, which formed film completely in 30 days. When BAF with combined zeolite and haydite
was used to treat rural sewage, zeolite and haydite are complementary to get rid of COD\textsubscript{cr} and NH\textsubscript{4}\textsuperscript{+}-N.
It has powerful resistance to impact load of NH\textsubscript{4}\textsuperscript{+}-N. Meanwhile, haydite presenting low density,
which helps to reduce energy consumption during backwashing operation; on the other hand, the
weight of filler can be reduced, so it will cut down the operational cost. In summary, BAF with
combined zeolite and haydite can be widely used to treat rural wastewater, in view of their superior removal rates of CODcr, NH4+-N and SS, great reserves and lower cost in China.

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References
[1] X.B.Sun, H.Y.Pan, Y.F. Sun, F.Y. Cui and Z.W. Zhao, Comparative experimental research on start-up of biological aerated filter with zeolite filler and combined packing, Journal of Harbin University of Commerce (Natural Sciences Edition). 28 (2012) 171-172.
[2] L.J. Gao, Comparison of biological aerated filtration performance between zeolite media and ceramisite media, Technology of Water Treatment. 35 (2009) 53-54.[In Chinese]
[3] E.D. Du, X. Liu, H. Wang and D. Deng, Ammonia removal behaviour and biological characteristics of zeolite media in a biological aerated filter[J]. Techniques and Equipment for Environmental Pollution Control. 7 (2006) 89-93. [In Chinese]
[4] P. Wang and G.C. Li, Preparation of Biological Aerated Ceramsite Filter Medium and Its Performance, Non-Metallic Mines. 29 (2006) 53-55. [In Chinese]
[5] X.C. Ma and S.T. Liu, Experimental study on Biological Aerated Filter(BAF)Process in Treating Domestic Sewage, Environmental Protection Science. 35 (2009) 34 -36. [In Chinese]
[6] H.J. Wang, W.Y. Dong, T Li. and T.Z. Liu, A modified BAF system configuring synergistic denitrification and chemical phosphorus precipitation: Examination on pollutants removal and clogging development, Bioresource Technology.189 (2015) 44–52.
[7] X.Q. Li, Y.H. Wang and J.D., Zhou The research of the film formation and start-up zeolite biological aerated filter, Environment Science and Management. 33 (2008) 91-93.[In Chinese]
[8] Y. Feng, X. Li, T. Song, L.S. Fan, Y.Z. Yu, J.Y. Qi and X.W. Wang, Effect of backwashing on the microbial community structure and composition of a three dimensional particle electrode coupled with biological aerated filter reactor (TDE-BAF), Ecological Engineering.101 (2017) 21-27.
[9] J.X. Liu, J.S. Lou and C.N. Chen, Test of treatment of slightly polluted source water by zeolite-ceramics biological aerated filter, Industrial Water & Wastewater. 36(2005) 10-12.[In Chinese]
[10] B. B. Baykal, Clinoptilolite and multipurpose filters for up-grading effluent ammonia quality under peak loads, Water Science and Technology. 37 (1998) 235-242.
[11] W.S. Xiao, W.G. Xu and J.C. Yang, Activity of Biomembranes and Biofloccules in Biological Aerated Filters, Transactions of Beijing Institute of Technology. 23 (2003) 656-658. [In Chinese]
[12] Y. Guo, L.J. Chen and D.H. Wen, Study on Nitrite Nitrogen Accumulation in Zeolite Biological Aerated Filter, China Water&Waste Water. 22 (2006) 73-77. [In Chinese]
[13] W.H. Tian, X.H. Wen and Y. Qian, Characteristics of zeolite media biological aerated filter during start-up, Techniques and Equipment for Environmental Pollution Control. 3 (2002) 38-41. [In Chinese]
[14] S.B. Zhang, L.P. Qiu, M.A. Du and J. Ma, Treatment efficiency and nitrification properties in three biological aerated filters (BAF) with different media, Journal of Harbin University of Technology. 41 (2009) 57-60. [In Chinese]
[15] S.I. Abou-Elela, M.E. Fawzya and A.S. El-Gendy, Potential of using biological aerated filter as
a post treatment for rural wastewater, Ecological Engineering. 84 (2015) 53-57

[16] D. Pak, W. Chang and S. Hong, Use of natural zeolite to enhance nitrification in biofilter, Environmental Technology. 23 (2002) 791-798.