Effect on the operation properties of DMBR with the addition of GAC

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Abstract. The membrane bioreactor and dynamic membrane bioreactor were used to examine the effect of granular activated carbon (GAC) on the treatment of synthetic wastewater. After the addition of different volume fractions GAC in the DMBR, the operation parameters, effluent COD, NH₄⁺-N, NO₃⁻-N, TN concentrations and sludge viscosity of the bioreactor was investigated. The results showed that the addition of GAC could relieve the membrane fouling and improve the removal efficiencies of pollutants in the DMBR. The effluent concentrations of pollutants were linear correlation with the addition of volume fractions of GAC in the bioreactor. The value of R² of each modulation was almost more than 0.9. The sludge viscosity was almost not affected by the volume fractions of GAC in the bioreactor. The best volume fractions of GAC were 20% in the DMBR.

1. Introduction

Energy conservation and environmental industry is one of the fastest growing industries in the world and the major industry of Xiamen. Based on the cogent investment and development in Fujian province, a series of new techniques was developed, such as the dynamic membrane bioreactor process. The widespread application of membrane technology to wastewater treatment has assisted pollutants removal performance [1]. Although membrane bioreactor (MBR) process is reliable in terms of perfect capture of solids in the system, membrane fouling has restricted its practical application and increased operational costs [2]. Various approaches have been adopted to prevent fouling such as increasing fluid velocity [3], increasing fluid pumping or gas sparging rate, relaxation, backwashing [4], modifying the membrane surface [5], subcritical flux operation [6] and so on.

A widely used method of fouling control in MBRs involves the use of additives such as powdered activated carbon (PAC) [7]. The membrane fouling was relieved by the low dose powdered activated carbon addition at high sludge retention times [8]. The application of PAC was effective in decreasing the content of extracellular polymeric substances (EPS) [9].

A new kind of membrane, made up of common silk and fouling cake, has been developed to actively utilize the separation ability of fouling cake. Based on the fact that the silk with large pores of 50-500 μm has no separation ability, while sludge in reactor is actually rejected by the fouling cake which looks like a new separation membrane added onto the silk, this kind of membrane is thus called dynamic membrane[10]. The dynamic membrane process would also be an effective method to settle the problem of membrane fouling. Dynamic membrane could be formed and re-formed in-situ.
the membrane was severely fouled, the dynamic layer can be replaced by a new deposited layer. Dynamic membrane not only has almost all characteristics belonging to common membrane, but also has some distinct features, such as low expenditure, low energy consumption and high flux and so on. The dynamic membrane bioreactor (DMBR) is a kind of submerge membrane bioreactor in which the separation membrane is substituted by dynamic membrane [11].

The studies of selection of membrane materials and the pollutants removal effects was mainly focused in the DMBR [12, 13]. The research on the addition of granular activated carbon (GAC) was not much, which was used to improve the effluent water qualities in the DMBR.

The purpose of this study is, therefore, to investigate the operation characteristics in the addition of GAC in the DMBR. The operation parameters, effluent concentrations of pollutants and sludge viscosity were investigated in the DMBR, when the addition of volume of GAC was changed.

2. Materials and methods

2.1. Materials

The commercial GAC with 10~20 mesh size was used in this study. The volume fractions of GAC were 0, 10%, 20%, and 30% in the DMBR.

The components of synthetic wastewater were 278 mg•L⁻¹ glucose, 278 mg•L⁻¹ starch, 13.16 mg•L⁻¹ potassium dihydrogen phosphate, 132.8 mg•L⁻¹ ammonium sulfate, 66.0 mg•L⁻¹ magnesium sulfate, 111.0 mg•L⁻¹ sodium bicarbonate, 6.0 mg•L⁻¹ manganese sulfate, 6.0 mg•L⁻¹ calcium chloride, 2.0 mg•L⁻¹ ferrous sulfate [14]. The concentrations of influent COD, total nitrogen, ammonia and total phosphorus were 237.6 ~ 311.4 mg•L⁻¹, 28.0 ~ 28.5 mg•L⁻¹, 27.5 ~ 28.0 mg•L⁻¹, 2.37 ~ 3.28 mg•L⁻¹, respectively. The pH of influent was 6.5 ~ 7.5.

The activity sludge of the bioreactor was from an oxidation ditch in a municipal wastewater treatment plant. The activity sludge was cultivated by a fill-and-draw process for one month with synthetic wastewater.

2.2. Experiment

The effective volume of DMBR was 10.0 L. The schematic of the reactor setup was shown in Figure 1. The DMBR had a submerged 37 μmterylene filter module with a surface area of 0.10 m². The total aeration rates of DMBR and MBR were 0.16 m³•h⁻¹. The concentrations of dissolved oxygen (DO) were between 3~4 mg•L⁻¹. Hydraulic retention times (HRTs) were 4 h.

The influent flow of DMBR were 2.5 L•h⁻¹. When the transmembrane pressure of DMBR increased to 4000 Pa, 45000 Pa, respectively, the membrane module was taken out and cleaned by rinsing with tap water. During this period, GAC was added three times in DMBR. Each time the volume of GAC was 1000 mL.

2.3. Analytical methods

![Diagram of an integrated dynamic membrane bioreactor](image)
The influent and effluent were simultaneously sampled every day. The routine monitoring items included pH, the influent and effluent concentrations of COD, NH$_4^+$-N, NO$_3^-$-N and TN. These items were measured by using Chinese NEPA Standard Methods[Chinese NEPA, 2002]. DO was measured using DO meter. Sludge viscosity was measured by the rotational viscometer (NDJ-5S).

3. Results and discussion

3.1. Operation parameters

Figure 2 show the transmembrane pressure of DMBR with different GAC volume fractions. The value of transmembrane pressure of DMBR was about 3.5×10$^3$Pa. The addition of GAC had no effect on the transmembrane pressure. When the value of volume fractions of GAC was more than 10%, the transmembrane pressure has not changed.

3.2. Removal of pollutants

3.2.1. COD. Variations of effluent COD concentrations with the volume fractions of GAC are shown in Figure 3. Variations of the COD removal efficiency with the volume fractions of GAC are shown in Table 1. The removal efficiencies of COD were more than 90% in the bioreactor. Effluent COD concentration decreased from 26.1 mg·L$^{-1}$ to 12.0 mg·L$^{-1}$ in the DMBR, when the volume fractions of GAC was raised from 0 to 30%. Because the addition of GAC can immobilize microorganisms and absorb refractory organic compounds in the bioreactor, increasing in the volume fractions of GAC could improve the removal efficiency of COD. When the value of volume fractions of GAC was more than 20%, COD removal efficiencies were over 95% in the bioreactor.

Figure 2. The transmembrane pressure of DMBR with different GAC volume fractions

Figure 3. Effluent COD concentrations for different GAC volume fractions in the bioreactor
According to Figure 3, the effluent COD concentration of DMBR was correlated with a linear equation in the following form ($r_{DMBR}^2=0.938$):

$$E_{COD-DMBR} = 26.36 - 0.522(V)$$  \((1)\)

Where $E$ is the effluent COD concentration in the DMBR and $(V)$ is the volume fraction of GAC.

| Volume fraction of GAC | Removal efficiency of COD |
|-----------------------|--------------------------|
| 0%                    | 91.30%                   |
| 10%                   | 92.34%                   |
| 20%                   | 95.67%                   |
| 30%                   | 96.00%                   |

### 3.2.2. $NH_4^+\text{-}N$

Variations of effluent $NH_4^+\text{-}N$ concentrations with the volume fractions of GAC are shown in Figure 4. Variations of the $NH_4^+\text{-}N$ removal efficiency with the volume fractions of GAC are shown in Table 2. The removal efficiency was improved with the addition of the volume fraction of GAC in the bioreactor. The effluent $NH_4^+\text{-}N$ concentrations decreased with the addition of GAC. Because microorganisms were immobilized on the surface of GAC, the addition of GAC could improve the removal efficiency of $NH_4^+\text{-}N$ in the bioreactor. When the value of the volume fraction of GAC was more than 20%, $NH_4^+\text{-}N$ removal efficiency was over 70% in the DMBR.

According to Figure 4, the effluent $NH_4^+\text{-}N$ concentration of DMBR was correlated with a linear equation in the following form ($r_{DMBR}^2=0.998$):

$$E_{NH_4^+\text{-}N-DMBR} = 13.64 - 0.299(V)$$  \((2)\)

Where $E$ is the effluent $NH_4^+\text{-}N$ concentration in the DMBR and $(V)$ is the volume fraction of GAC. The concentration of $NH_4^+\text{-}N$ was linear correlation with the volume fraction of GAC.

### 3.2.3. $NO_3^-\text{-}N$

Variations of effluent $NO_3^-\text{-}N$ concentrations with the volume fractions of GAC are shown in Figure 5. The effluent $NO_3^-\text{-}N$ concentrations were quickly increased with the addition of GAC in the DMBR. Then, the denitrification ability was not changed in the DMBR and the concentration of effluent nitrate in the DMBR increased.

According to Figure 4, the effluent $NO_3^-\text{-}N$ concentration of DMBR was correlated with a linear equation in the following form ($r_{DMBR}^2=0.743$):

$$E_{NO_3^-\text{-}N-DMBR} = 1.489 + 0.202(V)$$  \((3)\)

Where $E$ is the effluent $NO_3^-\text{-}N$ concentration in the DMBR and $(V)$ is the volume fraction of GAC. The concentration of $NO_3^-\text{-}N$ was linear correlation with the volume fraction of GAC.

| Volume fraction of GAC | Removal efficiency of COD |
|-----------------------|--------------------------|
| 0%                    | 51.62%                   |
| 10%                   | 63.14%                   |
| 20%                   | 73.61%                   |
| 30%                   | 83.14%                   |
3.2.4. TN. Variations of effluent TN concentrations with the volume fractions of GAC are shown in Figure 6. Variations of the TN removal efficiency with the volume fractions of GAC are shown in Table 3. The removal efficiency of TN was almost not changed in the DMBR. The effluent TN concentration decreased with the addition of GAC. Because microorganisms were immobilized in the surface of GAC, the addition of GAC could improve the removal efficiency of TN in the bioreactor. When the value of the volume fraction of GAC was more than 20%, TN removal efficiency was over 49% in the DMBR.

According to Figure 6, the effluent TN concentration of DMBR was correlated with a linear equation in the following form ($\rho_{DMBR}^2=0.935$): 

$$ E_{TN-DMBR} = 13.84 - 0.054(V) $$  \hspace{1cm} (4) 

Where E is the effluent TN concentration in the DMBR and V is the volume fraction of GAC. The concentration of TN had an linear correlation with the volume fraction of GAC.

| Volume fraction of GAC | Removal efficiency of COD |
|------------------------|---------------------------|
|                        | DMBR                      |
| 0%                     | 44.38%                    |
| 10%                    | 45.91%                    |
| 20%                    | 49.15%                    |
| 30%                    | 49.65%                    |
3.2.5. The sludge properties. Sludge viscosity reflected on the relative amount of micelle in the bioreactors. The micelle was related to the extracellular polymeric substances (EPS), such as polysaccharide, protein and so on. The increase of EPS resulted in the increase of the sludge viscosity in the sludge mixture [15].

Variations of sludge viscosity concentrations with the volume fractions of GAC are shown in Figure 7. The value of sludge viscosity has almost not changed in the bioreactor, whatever GAC was added or not. The value of DMBR was about 16 mPa*s. Therefore, the concentration of EPS did not change in the bioreactor.

The SEM of activated sludge of two bioreactors is shown in Figure 8. From Figure 8-b, many kinds of microorganisms are found in the bioreactor, such as nematodes, bacteria and filamentous.
Figure 8-a, as microorganisms were arranged densely in the DMBR, the oxygen could not be easily transferred to the interior of the microorganisms. An anoxic environment was easily formed.

4. Conclusion
This study compares the operation characteristics, the removal efficiencies of pollutants and sludge properties with different volume fractions of GAC in the DMBR treating synthetic wastewater. The addition of GAC can improve the removal pollutants efficiencies of DMBR. The best volume fractions of GACwere 20% in the DMBR. The concentrations of effluent pollutants had alinear correlation with the volume fractions of GAC in the bioreactor. The sludge viscosity was almost not affected by the volume fractions of GAC in the bioreactor.

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