Experimental Study on Removal of Organics from Landfill Leachate by Stage Aeration AFMBR Process

Chen Qiuling¹*, Wang Kai¹ and Zhu Zhaocun¹

¹ School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan, Hubei Province, 430070, China

*Corresponding author’s e-mail: 297484568@qq.com

Abstract. This paper used a stage aeration anaerobic fluidized bed membrane bioreactor (AFMBR), combined the advantages of membrane bioreactor (MBR) and anaerobic fluidized bed bioreactor (AFBR), put forward to add granular activated carbon (GAC) to make up for the deficiency of AFMBR process, and explored its impact on the process effect. At the same time, it was proposed to utilize the stage aeration to enhance the membrane flux, and to increase the residence time of organic pollutants in the facultative environment through the fluidized bed membrane bioreactor to improve the removal characteristics of organic pollutants in landfill leachate. The influence of aeration rate on the process effect was also investigated. Finally, the relationship between temperature and AFMBR treatment effect was briefly analyzed.

1. Introduction

Landfill leachate is a kind of wastewater with serious pollution and high concentration of refractory organic matter, mainly from precipitation, surface runoff, surface irrigation, groundwater and internal water content of garbage itself [1]. When the waste contains 47% water, about 0.0722 tons of landfill leachate can be produced per ton of waste [2]. If the leachate is improperly treated, it will affect the surface water and groundwater at the same time, causing serious environmental pollution.

For its treatment, even the treatment efficiency of the membrane bioreactor (MBR) with the best treatment efficiency in the common biochemical treatment method is difficult to meet the emission requirements. Many leachate treatment processes cannot degrade refractory organic pollutants, but only separate them into the concentrated drainage of membrane units, which cannot solve the environmental pollution problem of landfill leachate.

2. Stage aeration AFMBR process and characteristics

The principle of MBR is the biofilm method, that is, the microbe attaches to the surface of a solid or suspended carrier to form a film. When the wastewater is treated, the sewage flows through the surface of the carrier and contacts with the biofilm, and the microorganism adsorbs, stabilizes, and transforms the organic matter, with the characteristics of stable yielding water quality and good treatment effect. But the membrane is susceptible to pollution during the operation process, resulting in low water production and high energy consumption.

AFBR is to add a small particle carrier to the columnar structure system, allowing anaerobic microorganisms to adhere to the surface growth of the carrier [3], combining biofilm method with fluidization technology. The surface of the biofilm is constantly updated, and the microorganisms are always in a vigorous growth stage, thereby accelerating the degradation of the wastewater substrate. The low energy consumption, less land occupation, and stable operation can avoid the blockage of the
biofilm reactor, but as the biofilm grows on the surface of the carrier, the density of the carrier will decrease, causing the carrier to be taken out of the reactor by the yielding water.

The anaerobic fluidized bed membrane bioreactor AMFBR is a combination of the above two processes. The membrane module is placed inside the anaerobic fluidized bed reactor and separated from the main reaction zone by a cylindrical barrier. The sewage is purified by the combined action of the inner and outer cylinders and the membrane module, so that the treatment speed can be further improved, with the advantages of the anaerobic technology. The problem that the biological fluidized bed carrier is easily carried out by the water is solved by the membrane technology. However, it still has the problem that the residence time of dissolving organic pollutants is too short to limit the biological treatment effect.

Granular activated carbon (GAC) has a good adsorption capacity due to its large specific surface area. GAC is introduced into AMFBR. On the one hand, its pore structure provides a carrier for the growth of microorganisms, avoiding it being detached by the shearing force of flowing water. On the other hand, the adsorption of organic pollutants increases the retention time of pollutants, simultaneously alleviates membrane fouling, reduces the physiological toxicity of pollutants, and strengthens biodegradation, thereby solving the problem of limiting the treatment effect of AFMBR.

3. Method for removing landfill leachate by stage aeration AFMBR process

3.1 Research objectives
The feasibility of removing the organic pollutants from landfill leachate by phase aeration AFMBR reactor was determined through experimental research. The removal mechanism was analyzed, and the best aeration process parameters were determined by different aeration schemes, providing a basis for the study of AFMBR treatment of organic pollution in landfill leachate.

3.2 Technical route

![Fig.1 Technical route](image)

3.3 Research content and implementation plan
3.3.1 Initially determine the feasibility of removing organic pollutants from landfill leachate by GAC-based AFMBR reactor. Using artificial water distribution method, aerobic sludge was used as inoculum, and microorganisms were cultured in the AFMBR reactor. After the yielding water quality of the AFMBR reactor is stable, taking GAC as the carrier, the AFMBR landfill leachate treatment system using the circulating pump to maintain the fluidized state is constructed as shown in Fig. 2 below:

![AFMBR reactor with GAC as carrier](image)

**Fig.2** AFMBR reactor with GAC as carrier

3.3.2 Removal mechanism of organic pollutants by AFMBR reactor with GAC as carrier. Two groups of AFMBR reactors were constructed. One group was added with activated carbon, and the other one was not. By comparing the highest organic load ORL that the two groups of AFMBR reactors can bear, the efficiency of GAC in removing organic pollutants from AFBR reactor was comparatively analyzed. Then two groups of parallel AFMBR reactors were constructed, and the contents of the two groups of microorganisms were changed. The contents of TOC in the incoming and yielding water and the supernatant were compared and analyzed, and the removal effects of microorganisms on organic pollutants in landfill leachate were compared. Through the above comparative analysis, the removal mechanism of organic pollutants in landfill leachate by GAC, microorganism and membrane treatment in AFMBR reactor was studied.

3.3.3 Study on the effect of stage aeration on the AFMBR reactor. Firstly, the basic experiments with aeration conditions of 150, 200, and 300 L/h were carried out. The COD and NH4+-N concentrations in the incoming water were compared and analyzed. The relationship between the aeration rate and the treatment effect was preliminarily obtained, which provided the basic direction for the later experiments. It was proposed to design orthogonal experiments with three kinds of stage aeration conditions (no aeration, 2 times / d, 4 times / d) and the aeration rate of 2L / min, 4L / min each time, to determine the best aeration working conditions.

3.3.4 Study on the effect of temperature on the AMFBR reactor. By comparatively analyzing the treatment effect of the reactor under different experimental temperatures, the relationship between temperature and treatment effect is obtained, which provides an idea for adjusting the operating temperature of the reactor to obtain the maximum experimental running speed.

3.4 Analyses and calculations of experimental results
3.4.1 Effect of granular activated carbon (GAC) on anaerobic fluidized bed (AFBR) treatment. For the 2 groups, there were a total of 6 reactor control experiments \cite{4}, one group added GAC (experimental group), one group not added GAC. After inoculation with anaerobic activated sludge, the maximum organic load (OLR) was gradually increased from 1.3 kg COD/ (m$^3$·d), maintaining the hydraulic retention time (HRT) for 10d, and when the reactor broke down it was stopped. The maximum OLR that can be borne by the two experimental reactors in stable operation was investigated. The reactor operation was as follows:

From the results of the above experiments, shown as Fig. 3 \cite{4}, by gradually increasing the OLR, the methane yield is regarded as the evaluation criteria, and the methane yields of the experimental group and the control group are all improved, while the methane yield of the experimental group is more obvious. When the OLR is gradually increased to 7.8 kg COD/ (m$^3$·d), the experimental reactor can still operate stably. At the end of the operation cycle, the remaining COD concentration in the system is at a low level, and the methane conversion rate maintains above 80%, with a stable pH in neutral; Under this load, the remaining COD in the reactor is still at a very high level at the end of the control cycle, and the methane yield decreases linearly, from >2000 mL/d to less than 100 mL/d in 5 days. A large amount of acetic acid, propionic acid, and butyric acid accumulate, while the pH decrease significantly, and the acidification in the reactor collapses.

The above results indicate that GAC can significantly improve the efficiency of anaerobic treatment, and the highest OLR for stable operation is 7.8 kg COD/ (m$^3$·d), which is over 33% higher than that of the control group \cite{4}.

3.4.2 Effect of microorganisms on the removal of organic pollutants. The removal of total organic pollutants (TOC) by two groups of membrane bioreactors (MBR) with different microbial contents was compared to determine the effect of microorganisms on the removal efficiency of organic pollutants.
One group was added sludge-based activated carbon SBAC as a carrier for microbial growth to increase the content of microorganisms, while the other group was not added SBAC. Control experiments for treating landfill leachate were carried out to investigate the changes and removal rates of TOC in incoming and yielding water and supernatant in the two groups of reactors during steady operation. The results are shown in Fig. 4-1\textsuperscript{[5]}, 4-2\textsuperscript{[5]}:

Comparing and analyzing the data of MBR and SBAC-MBR in Fig. 4-1, the results show that the average TOC in the yielding water by SBAC-MBR process is larger than that by MBR, and the average removal rate by TOC is higher than that by MBR process. For the phenomenon that the yielding water TOC and TOC removal rate of by SBAC-MBR process were higher than those by the MBR after 10 days of stable operation, through analysis it is considered that the addition of SBAC provides a carrier for the growth of microorganisms in the reactor, thereby enhancing the degradation of pollutants by microorganisms, which is one of the reasons for the above phenomenon. In addition, that SBAC has a certain adsorption effect on the organics in the incoming water is another reason.

The calculated values of Fig. 4-2 are shown as Tab. 1:

| Process       | TOC content of supernatant (mg/L) | Removal rate of TOC (%) of supernatant |
|---------------|-----------------------------------|---------------------------------------|
| MBR process   | 79.72 ± 34.25                     | 77.79 ± 9.66%                        |
| SBAC-MBR process | 78.01 ± 37.18                    | 78.29 ± 10.75%                      |
Through the comparison of the results in Tab. 1, it is found that TOC content and removal rate of supernatant of the SBAC-MBR process are slightly higher than those of MBR. After comparing the Fig. 4-1 and 4-2, it can be considered that the removal of TOC by the MBR process mainly relies on the degradation of microorganisms, while the membrane module in the process has almost no removal ability.

3.4.3 Effect of stage aeration on AFMBR treatment. Based on the structure and principle of AFMBR, the effect of aeration on AFMBR is actually the effect on the MBR part.

For the experiments that 3 parallel running MBRs (M1, M2 and M3) were set and the aeration quantities were 150, 200, 300L/h \(^6\), the effect of aeration rate on MBR treatment was analyzed by examining the removal rate. The COD and NH\(_4^+\)-N concentrations in the incoming water are 385 and 42 mg/L, respectively and the results are shown in Tab. 2 below \(^6\):

| Sample | COD | NH\(_4^+\)-N |
|--------|-----|-------------|
|        | Supematant/(mg L\(^{-1}\)) | Yielding water/(mg L\(^{-1}\)) | Total removal /% | Supematant/(mg L\(^{-1}\)) | Yielding water/(mg L\(^{-1}\)) | Total removal /% |
| M1     | 89 ± 10.1 | 40 ± 8.0 | 89.5 ± 2.8 | 4.5 ± 1.6 | 3.4 ± 0.9 | 91.9 ± 2.4 |
| M2     | 101 ± 7.3 | 38 ± 8.4 | 90.2 ± 2.3 | 4.6 ± 1.3 | 3.3 ± 1.1 | 92.1 ± 2.3 |
| M3     | 106 ± 8.5 | 35 ± 8.0 | 90.9 ± 2.0 | 3.7 ± 1.1 | 3.1 ± 1.0 | 92.4 ± 3.2 |

Observing the data in the table, it can be found that the total removal rate of COD and NH\(_4^+\)-N improves with the increase of aeration rate.

Further observations showed that as the aeration rate increases, the concentration of COD in the supernatant augments, while the concentration of COD in the yielding water decreases. The reason for this phenomenon is that the membrane bioreactor has two functions to remove pollutants, one is membrane interception and the other is biological removal. This phenomenon is caused by the removal of contaminants by membrane bioreactors \(^6\). One is membrane shut-off and the other is biological removal. In the process of increasing aeration, the enhancement of membrane interception enlarges the concentrations difference between the supernatant and the yielding water, while the reduction of biological removal decreases the concentration difference between the incoming water and supernatant. Meanwhile, the metabolic rate of the sludge is increased, so that the total removal rate is improved.

3.4.4 Brief summary. From the comprehensive analysis of the effect of GAC on the effect of AFBR, the effect of microorganisms on the removal of organic pollutants, and the influence of stage aeration on AFMBR, it can be considered that microorganisms can promote the removal of organic pollutants, and GAC can significantly improve the efficiency of anaerobic biological treatment. Simultaneously, the increase of aeration rate in the MBR process can promote the sludge metabolism. The AMFBR process combined with several processes can improve the ability to degrade pollutants, and through the above analysis, its operating mechanism is preliminarily determined.

3.4.5 Supplementary analysis to explore the effect of temperature on AFMBR treatment. Through the experiment of the project, the experimental data were collated and analyzed. The basic data of the AFBR and AFMBR reactors at different experimental temperatures were averaged and summarized into the following table, making the following Tab. 3 and drawing Fig. 5 accordingly:
Combined with the results of other experiments \(^7\) for the same experimental purpose (Fig. 6\(^7\)), it is known that the reaction efficiencies of the AFBR and the AFMBR reactors decline with the decreases of temperature. According to the analysis, for the anaerobic microorganisms in the reactors, it is suitable for their growth and reproduction in an environment at a high temperature of 31.5±2.5 °C, with the highest activity. The reduction of temperature decreases the microbial activity, thereby affecting the reaction rate of the device.
In addition, in the device, the temperature may also influence the membrane fouling and the biological communities in the device, which provides an idea in the actual sewage treatment, that is, reasonable adjustment of the reactor temperature makes the reactor to achieve an efficient reaction rate, so as to improve the treatment effect.

4. Conclusions
This paper proposed a scheme to remove organics from landfill leachate by the stage aeration AFMBR process added with GAC, compared the related data of references [4,5,6,7], conducted related experiments, analyzed its treatment effect, and explored its operation mechanism, verifying the feasibility of the scheme. The scheme combines the advantages of different processes to improve the removal efficiency of organic pollutants without increasing occupied area, which can effectively alleviate its impact on surface water and groundwater and achieve the purpose of protecting the environment. In addition, an exploratory technical direction and technical means for the treatment process of landfill leachate was put forward.

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