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Dynamics Study of Membrane Aeration Biofilm Reactor for Food Wastewater Treatment

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In this study, the model focusing on the microbial dynamics of membrane aeration biofilm reactor (MABR) is established based on membrane aeration biofilm reactor material balance calculations according to the characteristic of membrane aeration biofilm reactor and the process of sewage treatment by self-designed membrane aeration biofilm reactor. By fitting experimental data, the operating biodegradation dynamics has been analyzed, the sludge yield and the dynamics of activated sludge of membrane aeration biofilm reactor have been compared and the simultaneous nitrification and denitrification dynamics has been researched. The conclusion of this study can provide reference for crafts designing of the wastewater treatment of membrane aeration biofilm reactor.

Keywords: Membrane aeration biofilm reactor, Dynamical model, Sewage treatment.

INTRODUCTION

Membrane aeration biofilm reactor (MABR) is a membrane bioreactor and it is a new sewage treatment process combining membrane technology for gas separation, bio-membrane method and water treatment technology. Membrane aeration biofilm reactor (MABR) is able to absorb, oxidize and decompose organic substances in wastewater through utilizing bubble less aeration of the microporous membrane, a biofilm carrier. In this way, the operating condition for bioreactor is optimized and the ability of microbial degradation of organic pollutants in wastewater is improved[1]. There are many advantages in wastewater treatment of MABR such as strong sewage treatment capacity under conditions of unit volume, integration for nitrification and de-nitrification, smaller volume of equipment, high efficiency in making use of oxygen, convenience in assembling and maintaining membrane, automatic control realization and so on.

Currently, a few advanced methods have been used to study MABR. Yamagiwa *et al.*[2] compared the biological phase characteristics in each layer under two conditions of hydrophobic polyvinylidene fluoride membrane aeration and traditional oxygen supply. Hibiya *et al.*[3] analyzed the microbial distribution on biomembrane by means of liquid phase ion selective microelectrodes and fluorescence *in situ* hybridization technology. Cole *et al.*[4] observed microbial community structure of biofilm using biological membrane slice technique. Debus *et al.*[5] constructed the first MABR model and used this model to predict the effect of xylem's biologically removal. Pankhania *et al.*[6] carried out dead end MABR experiments by using hydrophobic micro-porous polypropylene hollow fiber membrane as membrane component. Castillo *et al.*[7] used MABR to carry out biologically phosphorus removal experiment. Brindie *et al.*[8] experimentally studied dead end MABR. Livingston *et al.*[9] used silicon rubber membrane MABR to treat wastewater containing phenol. Zheng and Zhu *et al.*[10] used MABR to treat synthetic wastewater.

In summary, previous researches on MABR are mainly focused on the MABR bio-membrane, its bio-model, removing COD, BOD, nitrogen, phosphorus, or dealing with all kinds of process wastewater. However, there still existed few reports about the dynamics of dealing with food wastewater by MABR. This study will construct a dynamical model for dealing with food wastewater by MABR. The time history of ammonia, nitrogen and nitrate nitrogen will be obtained by experiments.

EXPERIMENTAL

Membrane module and its parameters: Commercially available polyvinylidene fluoride (PVDF) hollow-fiber membranes were used in the experiment. The fibers had an outer and inner diameters of 275 and 237 μm, respectively and a pore size of 0.02-0.04 μm. Prior to startup, membrane module was prepared from 800 fibers resulting in the surface area of 0.75 m^2.

Reactor configuration: The MABR system is schematically depicted in Fig. 1. A bank of hollow-fiber membranes was inserted into an open rectangular bioreactor, with the

effective volume of 30 L. Oxygen from air compressor was supplied to one end of the hollow fibers *via* an inlet pipeline at the base of the MABR module, then was exhausted *via* an exhaust pipeline, which was connected with gas fine-tuning valve. It was easy to be controlled the partial oxygen pressure and gas velocity by regulating the gas fine-tuning valve and made the air steadily flow in the lumen of hollow fibers. The submersible pump was connected with one side of the lateral circulation line, thus, circulation velocity could be controlled *via* throttle. Furthermore, the connection between circulation line outside the bioreactor and bypass line inside the bioreactor, led the backflow sludge from the center to the two sides of bioreactor. Thus, by the recoiling of the wall of bioreactor, the hydraulic shear force was reduced, which provided a good condition for bio-film attached. Finally, the effluence overflowed *via* overflow weir.

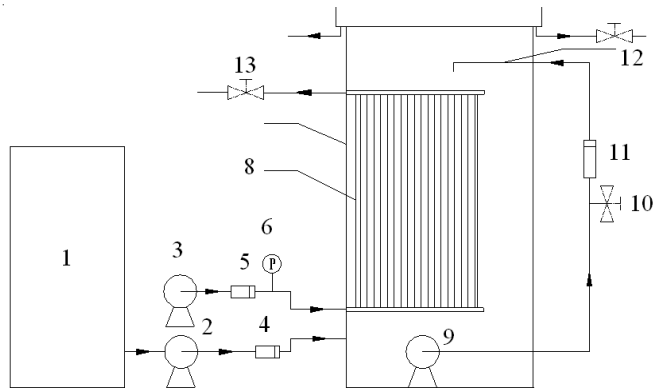

Fig. 1. Membrane aeration biofilm reactor experimental setup, (1) Feed chamber; (2) Booster pump; (3) Air compressor; (4) Fluid flowmeter; (5) Gas flowmeter; (6) Pressure gage; (7) Bio-reactor; (8) Membrane module; (9) Submersible pump; (10) Throttle; (11) Fluid flowmeter; (12) Bypass line; (13) Gas fine-tuning valve

Sewage and activated sludge used in experiment: Sewage used in the experiment is artificially prepared and its chemical composition is listed in Table-1. The pollutant removal efficiency was determined by measuring COD, NH_4^+-N and NO_3^--N in the original and drained sewage, respectively, with all the measuring methods corresponding to national standards. The sludge was taken from No. 2 Sewage treatment plant in Dalian economic and technological development zone.

The experimental data of concentration changing for the NH_4^+-N and NO_3^--N over time in 6 h have been obtained through laboratory tests. The results are shown in Tables 2 and 3.

Dynamics analysis of MABR: Based on the growth law of sludge and the organic matter degradation dynamics characteristics, dynamics analyses of MABR for this purpose by using material balance method, provides the r theoretical basis for optimizing the design and operation control of MABR. This article focuses on the dynamical study of simultaneous nitrification and denitrification.

TABLE-1
SEWAGE CHEMICAL COMPOSITION

Species	Content (mg/L)
$C_6H_{12}O_6$	300-400
NH_4Cl	100-160
KH_2PO_4	40
$NaHCO_3$	110-280
$CaCl_2 \cdot H_2O$	20-30
$MgSO_4 \cdot 7H_2O$	30
EDTA	20
$FeCl_3 \cdot 7H_2O$	1.5

When performing of dynamical setup for the MABR synchronous nitrification and denitrification, it should be assumed firstly that: (1) It ignores the impact of nitrogen compounds change. In the process of dealing with food waste water, sludge grows little. Therefore it can be assumed that the nature and quantity of nitrifying bacteria and denitrifying bacteria in the activated sludge don't change over time. (2) Since the Monod equation is fully applicable to the actual wastewater biological treatment, so it can be concluded that nitrification and denitrification reaction is in line with Monod equation and the two reactions can happen simultaneously without disturbing each other.

Based on the assumption above, it can be considered that NH_3-N in the reactor change is caused by nitrification, which is expressed in eqn. 1.

$$\frac{dS_{NH}}{dt} = -\frac{1}{Y_A}\mu_A\left(\frac{S_{NH}}{S_{NH}+K_{NH}}\right)\left(\frac{S_O}{K_{OA}+S_O}\right)X_{BA} \quad (1)$$

In the formula, S_{NH}-ammonia nitrogen density, Y_A-sludge production rate of autotrophic bacterium, μ_A-maximum specific growth rate of autotrophic bacterium, K_{NH}-ammonia nitrogen saturation constant, S_o-dissolved oxygen concentration, K_{OA}-dissolved oxygen saturation constant of autotrophic bacterium, X_{BA}-natural bacteria concentration. Y_A, μ_A S_o, K_{OA} and X_{BA} are constant, according to the IAWQ NO. 1 model. In the early and middle stage of this experiment, because ammonia is more than Ammonia nitrogen saturation constant, the formula (1) can be transformed to eqn. 2, K is constant.

$$\frac{dS_{NH}}{dt} = -K \quad (2)$$

According to the result of the formula above, the change of ammonia nitrogen in the process of nitrification should be

TABLE-2
NH_4^+-N CONCENTRATION OVER TIME

Time (h)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Concentration of NH_4^+-N (mg/L)	121	115	106	94	87	78	62	45	44	32	27	15

TABLE-3
NH_3^--N CONCENTRATION OVER TIME

Time (h)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Concentration of NH_3^--N (mg/L)	4	8	13	16	18	20	22	28	30	32	34	38

a linear change and the concentration decreases with time passing by, which correspond with the experimental result above. The linear fit of the experimental data is shown in Fig. 2 and the value of K is 20.2.

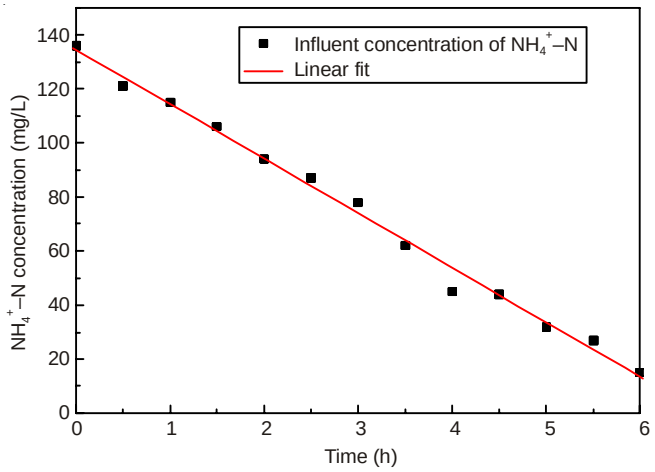

Fig. 2. Curve of NH_4^+-N removal efficiency over time and fitted curve

In MABR, the calculations of NO_3^--N can be carried out like this:

$$\frac{dS_{NO_3}}{dt} = \left(\frac{dS_{NO_3}}{dt}\right)_{nitration} + \left(\frac{dS_{NO_3}}{dt}\right)_{denitrification} \quad (3)$$

In the whole period of experiment, the content of NO_2^--N is low. It can be approximately thought in the nitrification process ammonia has been completely transformed into NO_3^--N. In MABR, the calculations of NO_3^--N, eqn. 4 forms:

$$\frac{dS_{NO_3}}{dt} = -\frac{dS_{NH}}{dt} + \left(\frac{dS_{NO_3}}{dt}\right)_{denitrification} \quad (4)$$

The eqn. 5 reflects the denitrification process.

$$\left(\frac{dS_{NO_3}}{dt}\right) = -\frac{1\text{-}Y_H}{2.86Y_H}\mu_H X_{BH}\left(\frac{S_S}{K_{NO_3}+S_{NO_3}}\right)\eta_g \left(\frac{K_{OH}}{K_{OH}+S_O}\right)\left(\frac{S_{NO_3}}{K_{NO_3}+S_{NO_3}}\right) \quad (5)$$

In the formula, S_{NO_3}-nitrate nitrogen concentration, Y_H-heterotrophic bacteria yield coefficient, μ_H-maximum specific growth rate of heterotrophic bacteria, η_g-correction factor hypoxia on growth of sludge, X_{BH}-heterotrophic bacteria concentration, K_{NO_3}-saturation constant of nitrate nitrogen, K_{OH}-dissolved oxygen saturation constant of Heterotrophic bacteria, S_s-saturation constant of organic matter. Y_H, μ_H, S_o, K_s, K_{OH}, η_g, X_{BH} is constant. Simultaneous nitrification and denitrification certain demand for carbon source. It is required that the concentration of organics in the membrane bioreactor should be maintained in a small range. The Average value of K_s is about 20 mg/L, which is far below S_s during the trial. Therefore, $S_s/(K_s+S_s)$ can be considered as constant. According to the analysis above, the eqn. 5 can be transformed to eqn. 6, A is constant.

$$\frac{dS_{NO_3}}{dt} = k - A\left(\frac{S_{NO_3}}{K_{NO3}+S_{NO_3}}\right) \quad (6)$$

Upon integration of eqn. 6, we get eqn. 7 as follows:

$$t = \frac{S_{NO_3}}{K-A} + \frac{K_{NO_3}}{K-A}\ln\left[\frac{AK_{NO_3}}{AK_{NO_3}+(K-A)S_{NO_3}}\right] \quad (7)$$

With K equaling to 20.2, after fitting eqn. 7 with the experimental results in Table-1, it can be concluded that A equals to 14.7316 and K_{NO_3} equals to 3.4436.

RESULTS AND DISCUSSION

The saturation of nitrate is 0.1-0.2 mg/L during single stage denitrification process. However, the constant is = 3.4436 mg/L which is far bigger than that during the MABR denitrification process through the above expression. Because the simultaneous nitrification and denitrification is achieved through aerobic-anaerobic micro-environment in which diffuse resistance exists in the processing. In the process of denitrification, the nitrate saturation of hypoxic zones is lower than that of bulk solution. Under the equal amounts of nitrate, the denitrification actual process is slower than single stage denitrification process in bulk solution. So the model shows that the saturation of nitrate rises sharply which is far bigger than that of single stage denitrification process.

Comparing the result of data fitting and actual measurement, the conclusion is showed in the Fig. 3. Through the experiment it is found that the concentration of NO_3^--N increases linearly over time. Meanwhile, the data fitting result coincides with that of experiment with little deviation.

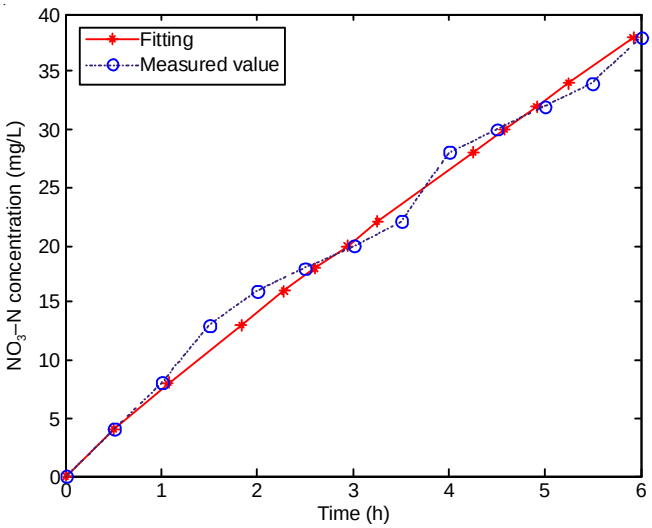

Fig. 3. Curve of NO_3-N removal efficiency over time and fitted curve

Conclusion

Based on this microbial dynamical model of MABR, this study has studied the mechanism of operation process of MABR, compared the dynamics of sludge production with that of activated sludge and fitted the experimental data. The results show the advantage that the sludge production by MABR is lower than that by activated sludge method through

balancing sludge and substrate. Second, we derived KNO_3 = 3.4436 through nitrification and de-nitrification of MABR. The time history of NO_3^--N effluent concentration by experiment is well fitted with the prediction by model.

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