Modeling for Membrane Bioreactor Process Included the Concept of Soluble Microbial Product

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1. Introduction

There are considerable evidences that soluble microbial product (SMP) formation plays an important role in determining the nature of the effluent from a biological reactor, especially from the membrane bioreactor because of the high activated sludge concentration remained by membrane and longer SRT. It is not appropriate to ignore the formation of microbial products as the major contributor of organic matter to the effluent, and a model including SMP formation and degradation may offer a rational approach for the performance of biological wastewater treatment process. Therefore, the objective of this study is to propose a mathematical model including the concept of SMP in order to develop a new conceptual framework for the membrane bioreactor.

2. Model Development

SMP consists of two types. The first type, utilization-associated product (UAP), is controlled by the specific substrate utilization rate and is comprised of the direct by-products of substrate utilization and cell growth. The second type, biomass-associated product (BAP), is controlled by the cell concentration and can be considered a by-product of endogenous respiration of cell mass. The total SMP is the sum of UAP and BAP. A preliminary metabolism model for simultaneous nitrification-denitrification and organic removal under aerobic and anoxic condition in a membrane bioreactor is shown in Fig.1. Symbol S represents soluble, while X particulate. Subscript S represents biodegradable matter, while I non-biodegradable matter. Soluble biodegradable matter can be directly taken by bacteria for the growth of new biomass. Particulate biodegradable matter must be converted into soluble biodegradable matter through hydrolysis before being degraded. Biomass decay acts to convert biomass to a combination of particulate and soluble products, each is divided into biodegradable and non-biodegradable groups. Biodegradable particulate products can be degraded by biomass after hydrolysis, and biodegradable soluble products from biomass decay are classified as BAP. Non-biodegradable soluble products are lost through sludge wastage and part in the effluent, while non-biodegradable particulate products are lost only through sludge wastage. SMP can be degraded again by heterotrophic biomass directly according to the multiplicative Monod expression. Since SMPs are comprised of macromolecules, a fraction of SMPs (30%) are considered to be retained in the reactor by membrane separation. SMP, which includes UAP and BAP, is calculated as one parameter in model simulation.

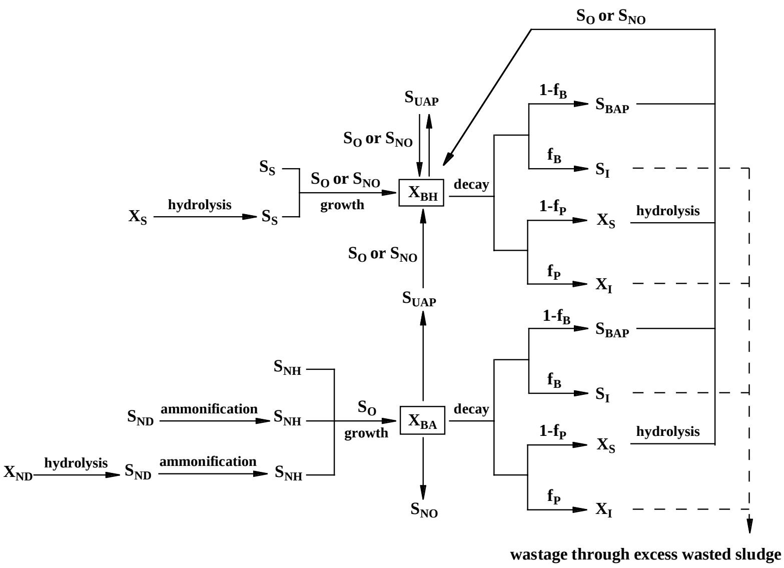

Fig.1 Schematic description of SMP formation-degradation model.

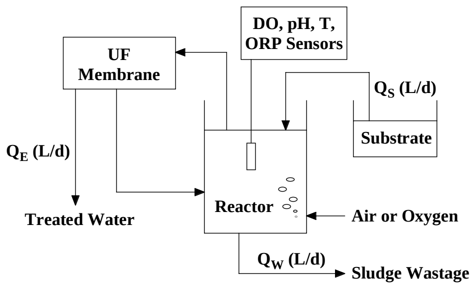

Fig.2 Process flow of experimental apparatus.

Table 1 Characteristics of substrate.

Symbol	Unit	Value
S_S	mgCOD/L	1500
X_S	mgCOD/L	1300
S_I	mgCOD/L	10
X_I	mgCOD/L	10
S_{NO}	mgN/L	0
S_{NH}	mgN/L	580
S_{ND}	mgN/L	140
X_{ND}	mgN/L	80

3. Materials and Methods

The experiment was carried out in a single completely mixed membrane bioreactor with a working volume of 40 liters (see Fig. 2). Artificial wastewater, which comprised of peptone, meet EX, urea, NH_4Cl, $(NH_4)_2CO_3$ mainly and other trace materials, was used as substrate and its characteristics are shown in Table 1.

Keywords : membrane bioreactor, model simulation, soluble microbial product, intermittent aeration process
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The quantity of treated water was 15 L/day. pH was adjusted to neutral automatically. HRT was 2.67 days. The average SRT was 50 days by wasting 800 mL of sludge from the reactor once per day. Intermittent aeration operating conditions with 60-minute cycle (30 min aeration on - 30 min aeration off, temperature T=25℃, MLSS=14.0 g/L, MLVSS=8.55 g/L, DO=5.0 mg/L under aerobic period) was carried out for simultaneous carbon and nitrogen removals. Samples in one cycle were taken from the reactor , then centrifuged and filtered through 0.45 μm filter. Treated samples were analyzed for COD_{cr}, NH_4-N, $NO_{2,3}$-N and T-N.

4. Results and Discussion

After a global steady-state condition obtained, samples in one cycle were taken from the reactor. The measured data and simulation results are shown in Figs. 3 and 4, and it can be seen that the simulation results are in good agreement with the experimental data. The major difference of current model from accepted activated sludge models is that this model provides a rational explanation for the observation that the bulk of the soluble biodegradable organic matter is of microbial origin and not merely substrate which remains in an undegraded state. SMP dominated most to the soluble COD in the reactor. During aerobic period, soluble COD increased due to the product increase of microbial origin which corresponded to the biomass activity. In contrast, soluble COD decreased due to the lower activity of biomass during anoxic period. Soluble inert organic matter, S_I, contributed about 20.7% to total soluble COD and SMPs about 79.1%. The high soluble inert organic matter retained in the reactor was due to the utilization of membrane and long SRT.

Model simulation for nitrogen also shows a good agreement with the experimental data. Ammonia nitrogen was consumed under aerobic condition and rose steadily under anoxic condition. While, nitrate nitrogen was produced during aerobic period but declined during anoxic period. Total soluble nitrogen increased gradually under aerobic period due to the increase of nitrate nitrogen through nitrification and the input of substrate, and it decreased under anoxic condition due to denitrification.

Fig.5 presents the model predictions of biomass compositions, effluent COD and T-N with the change of SRT. Due to membrane separation, no biomass was washed out in the effluent. However, particulate inert organic matter was also remained in the reactor. The minimum effluent COD was achieved at SRT controlled at 20 days. At shorter SRT the effluent COD increased owing to an increased concentration of SMP, and at longer SRT a slight increase of effluent COD was due to the increase of S_I. After SRT was over 30 days, effluent T-N seemed to have no significant improvement. At longer SRT, not only active biomass, but also particulate inert organic matter were remained in the reactor. The active biomass increased slowly after SRT was controlled over 50 days, however, particulate inert organic matter increased considerably which must have influence on the membrane performances, such as membrane flux, operational pressure, membrane washing and energy efficiency. Based on the model simulation, it is concluded that SRT should be controlled at 30-50 days for the good achievement of treatment performance in this study.

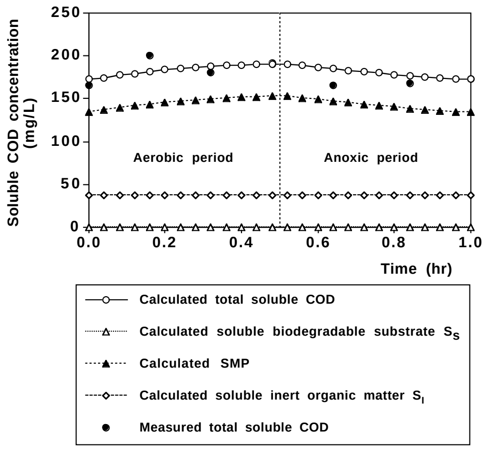

Fig.3 COD comparison of experimental and model predicted results.

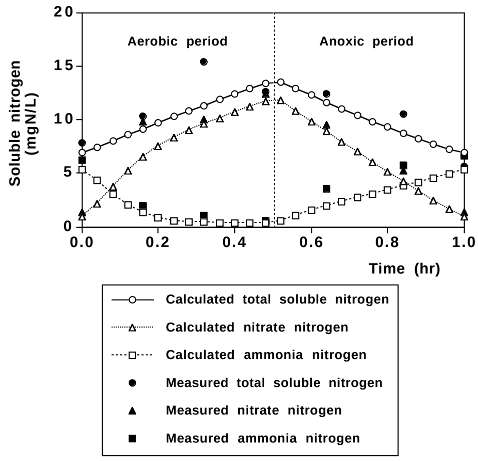

Fig.4 Nitrogen comparison of experimental and model predicted results.

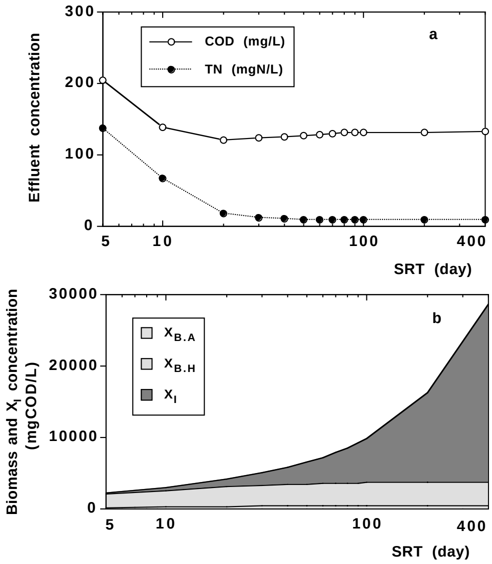

Fig.5 Influent of SRT on (a). effluent COD and T-N; (b). biomass concentration.

5. Conclusion

The model of SMP formation-degradation was successfully applied in the membrane bioreactor process. Based on the model simulation, it is demonstrated that SRT is better at 30-50 days in our study. However, for obtaining an optimal operational condition in practice, it should take account of effluent quality, membrane maintenance, cost for excess sludge disposal, etc..