Modification of ASM No.1 for a submerged membrane bioreactor system: including the effects of soluble microbial products on membrane fouling

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Abstract In this study, a mathematical model for the submerged membrane bioreactor (SMBR) was developed by combining the activated sludge model (ASM) with a membrane resistance-in-series model. Some modifications were introduced to make ASM to be suitable for describing the characteristics of SMBR. A set of the 1st-order differential equations was established for 13 dependent variables relevant to particles and soluble matters. Performing model simulations for various conditions, the time when a membrane would be fouled could be predicted as well as the effluent quality. From simulation results, F/M ratio and SRT can be considered as major factors of the soluble microbial products (SMP) concentration in a reactor and it is clear that SMP can play an important role in membrane fouling and water quality simultaneously. The model would be very helpful in optimizing operation conditions as well as in designing an optimal SMBR system.

Keywords Fouling; membrane bioreactor (MBR); soluble microbial products (SMP); specific resistance; submerged membrane

Introduction

Many researchers have been developing various models for membrane fouling phenomena during SMBR process. But no attempt has been made to integrate biological processes and membrane fouling at the same time. A good SMBR model should be able to properly describe the behavior of particulate and soluble matter relevant to a biological process and its effects on membrane fouling. In this study, the distinct characteristics of SMBR considering SMP importantly as a membrane foulant (Nagaoka *et al*., 1996; Chang and Lee, 1998; Shin *et al*., 1999) were described as follows. First, the absolute retention of all biomass by membrane was possible and TSS in effluent could be assumed to be zero. Second, to reflect the influence of SMP, consisting of utilization-associated product (UAP) and biomass-associated products (BAP) on effluent quality and membrane fouling, new variables for SMP were introduced into the ASM1 using a Monod-type equation (Namkung and Rittman, 1986; Noguera *et al*., 1994) and its effects on membrane fouling were incorporated into the resistance-in-series model (Nagaoka *et al*., 1998). Third, the resistance-in-series model was adapted to describe the cake formation by SMP and total suspended solids on membrane surface. The total resistance was expressed by means of specific resistance for considering SMP characteristics on membrane fouling.

Materials and methods

Model development

ASM No.1 was used to quantify the relationships among the heterotrophic bacteria, autotorphic bacteria such as nitrosomonas, nitrobactor, target inorganic substances (NH_4^+, NOx etc.), and organic compounds in municipal wastewater. In the case of the SMBR process (with high biomass and long sludge retention time) there is a high possibility for both the UAP and BAP to be degraded into a substrate for cell growth unlikely to a conventional activated sludge process. In this paper, instead of calibrating the model parameters, all the necessary parameters were estimated by referring to preceding research (Silva *et al*., 1998; Lu *et al*., 2001; Henze *et al*., 1987; Gujer *et al*., 1999) and data fitting by trial and error. The fundamentals for describing the SMP fate were almost same as the research of Lu *et al* and Silva. But referring to numerous research, it was reasonable that BAP could be also biodegradable (Gaudy *et al*., 1985; Barker *et al*., 1999). Therefore a portion of BAP was considered to be biodegradable in this model although its kinetics of degradation was assumed to be slower than UAP. Theoretically, the conventional resistance-in-series model is valid for expressing the condition of dead end filtration. In a cross flow filtration, not all the particles (X_{TSS}) would be deposited onto the membrane surface. Therefore, in practice in this model, however, by introducing the coefficient, reflecting the cross flow filtration effect, the above equations might be adapted to the SMBR system. The specific resistance, α, was defined as cake resistance divided by accumulated mass on membrane surface and could be determined experimentally by stirred cell batch test. The specific resistance would be varied for SMP amount in the foulant (X_{TSS}). The established differential equations were calculated numerically by Runge-Kutta 4th order equations method using MATLAB 5.3 (MATHWORK, Inc.).

A bench scale experiment

A bench-scale SMBR system was constructed to evaluate the developed model and to determine the constants necessary for model simulations. The system consists of three commercial hollow-fiber MF membrane modules (Mitsubishi Rayon, Japan) with an effective filtration area of 0.2m^2/module. The membrane is made of polyethylene with hydrophilic coating, and its nominal pore size is 0.4 μm. Each membrane was fully immersed and symmetrically placed in the system. An air diffuser was installed underneath each membrane module to provide dissolved oxygen in the reactor as well as to control membrane fouling by hydraulic shear force and agitation. The experimental conditions and operating strategies are listed in Table 1. Figure 1 shows a schematic of the constructed SMBR system, which was installed in a municipal wastewater treatment plant in Kwangjoo, Korea. A data acquisition/control system, called LabView (National Instrument, USA), was employed for remote monitoring as well as remote control. Figure 2 demonstrates typical variations of transmembrane pressure during each operation cycle.

Results and discussion

The condition for simulation was established to investigate the relationship between SRT, food to microorganisms ratio, water quality and membrane flux. Influent total COD was determined to be pertinent to food and the heterotrophic organism to microorganisms in F/M ratio. SRT was selected as a control factor. Changing SRT to 2, 5, 10, 20, 50 and 100 days for the same influent condition, other variables were calculated until initial unsteady state was transferred into steady state. From time to time, the F/M ratio would be varied for

Table 1 Bench-scale experiment operating condition

Operating factor	Descriptions
Flux	10, 20 and 30 LMH
HRT	4 hour
SRT	20, 50, 150 days
Aeration	10 L/min/module, continuous aeration
Operation cycle	10 minutes (8 min suction with 2 min rest)
Backwashing	For initial 30sec during the rest period
F/M ratio	Low: 0.1 kgCOD/kgMLVSS High: 1.0 kgCOD/kgMLVSS

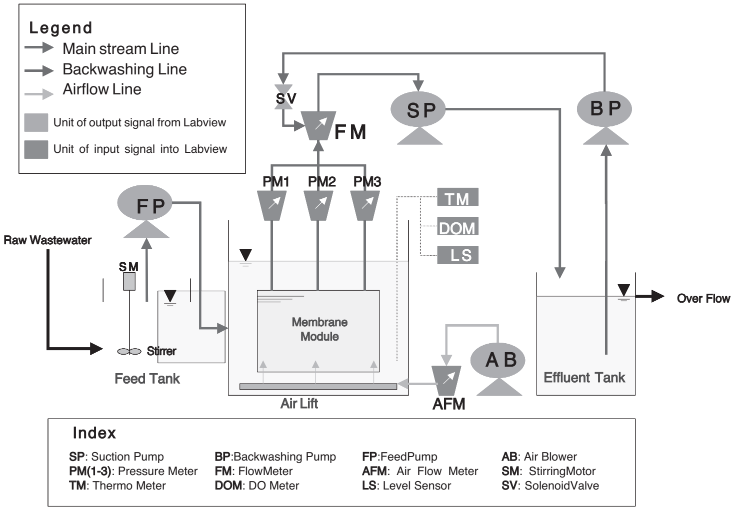

Figure 1 Schematic diagram of the bench-scale SMBR system

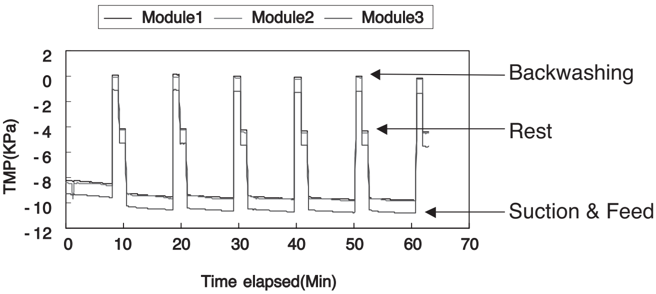

Figure 2 Variation of trans-membrane pressure during operation

a change of the heterotrophic organism growth in the reactor with constant influent COD. But at the steady states all the variables could have a constant value. Accordingly at a given SRT, a variable could be plotted with operating time or F/M ratio with 0.1, 0.2, 0.5, 1, 1.5, and 2.0.

Data fitting for finding the value of specific resistance and k_m was performed as shown in Figure 3. In Figure 4, the simulation results for soluble COD and nitrogen (NH_4^+-N plus NO_x) was compared with the experimental data from bench scale MBR at steady state. The accumulation amount of TSS in the reactor had a steady state value someday except for SRT = ∞, because in this model, all the relationships between substrates and biomass were expressed by rate limiting Monod equations. The flux decline expressed by the specific flux with operation time was presented as shown in Figure 5. With increasing SRT, the decrease of flux became faster but after SRT = 20 days, the practical difference in flux decline was not shown. For different SRT, the characteristics of biomass, SMP and specific resistance of the cake would be changed as mentioned by Chang and Lee (1998). But for simplicity, specific resistance was considered constant in this model. The reasonable method for expressing specific resistance as a function of SRT, SMP and biomass is being studied. The variation of SMP concentration with F/M ratio for different SRT was illustrated in Figure 6. Each result was expressed as a relative value with respect to the SMP concentration of SRT = 10 days for discerning each other's value clearly. When the F/M ratio was below about 1.2, SMP concentration was increasing for decreasing SRT, and vice versa after F/M ratio was above 1.2. But after SRT = 20, the difference in SMP concentration was not great for

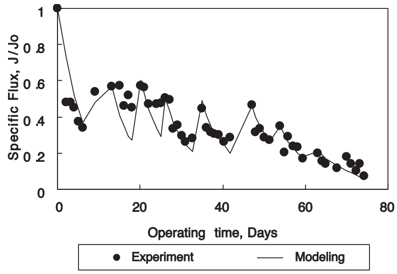

Figure 3 Data fitting for finding the value of specific resistance and k_m

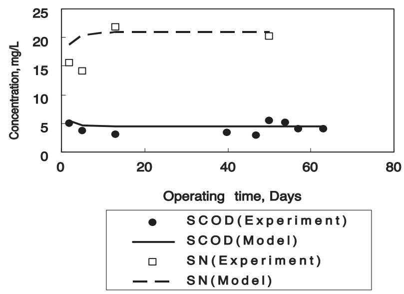

Figure 4 Comparing simulation results with the soluble COD and nitrogen data from bench scale MBR

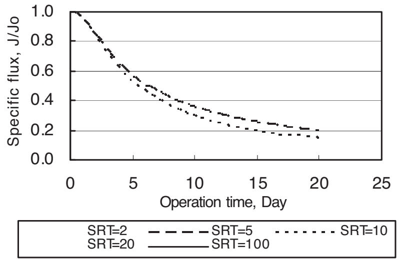

Figure 5 Specific flux variation with operation time for different SRT

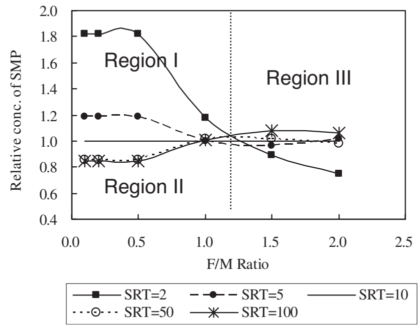

Figure 6 SMP variation in the bioreactor with F/M ratio for different SRT

increasing SRT. For the constant influent condition, F/M ratio would be reduced by biomass growth and increase of the biomass resulted in the increase of the SMP production rate from cell lysis. Accordingly the higher amount of SMP was depicted in region I of Figure 6. But in the case of region II, although high biomass concentration was built up for long SRT, the SMP concentration decreased for increasing SRT. In that region, the generated SMP from cell lysis seemed to be taken up actively as substrates to maintain the large population of biomass after all the available substrates from influent were exhausted. From these results it could be inferred that when F/M ratio was less than 1.2, there was a certain inflection in biomass concentration to generate the lesser amount of SMP. In region III, a little amount of biomass, compared to regions I and II, resulted in a small amount of SMP produced from cell destruction and from this reason, the relative concentration of SMP decreased by the decreasing SRT. From the above results, it was concluded that when the F/M ratio was less than 1.2, SMP would be considered as the main factor affecting membrane fouling in low SRT but TSS would appear to be the most important parameter to control membrane fouling in high SRT.

Conclusions

The availability of combining the activated sludge model including SMP with resistance-in series model was investigated. From model simulation, it can be shown that the SMP production was closely related to biological kinetic parameters and in MBR system membrane fouling should not be controlled apart from the biological factors such as SMP, TSS, SRT and F/M ratio. The calibration for parameters used in this model is being performed through OUR and AUR tests with the sludge from a pilot plant scale MBR and real wastewater. The evaluation of the developed model should be taken by comparing simulation results with experimental data including SMP concentration from pilot scale MBR. The specific resistance was assumed to be a function of SMP and X_{TSS} amounts in the reactor, but the exact relationship between SMP and specific resistance was not presented in this paper. So, considering this defect, developing the resistance in series model is being studied.

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