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MODELING OF BIOOLOGICAL PHOSPHORUS REMOVAL USING MEMBRANE BIOREACTOR: PART II

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ABSTRACT

Mathematical models for biological phosphorus removal with pre and post denitrification in activated sludge process along with membrane bioreactor (MBR) process, under aerobic-anoxic-anaerobic condition have been developed. An experimental data required to validate the model was taken from laboratory scale studies at Mahavir Chemical Pvt. Ltd., Nagpur, India. Activated Sludge Models such as activated sludge model no.2 (ASM2), activated sludge model no.2d (ASM2d) and activated sludge model no.3P (ASM3P) were used with resistance in series model to consider various processes occurring in the MBR. The unsteady state differential equations are solved using Runga-Kutta method (MATLAB7). From results it is found that ASM2 is the most suitable base model with pre denitrification condition in terms of chemical oxygen demand (COD), ammonia nitrogen and phosphorus removal than rest of the five models.

Key words: reverse osmosis; biological phosphorus removal, Modeling

I. INTRODUCTION

In recent time, membrane bioreactor is gaining attention for wastewater treatment for better effluent quality compared to conventional activated sludge process. Mathematical models are tools by which the biological wastewater treatment designers can predict the performances of a number of potential systems under a variety of conditions [1]. Many researchers have reported studies on membrane bioreactor systems with different kinds of wastewater [1-3]. However, a few developments of mathematical models for membrane bioreactor are yet to be included.

Modeling of Membrane bioreactors for COD and Nitrogen removal has become a standard practice and valuable instrument for process design and operation. Earlier studies have used Activated Sludge Model no.1 (ASM1) [1,2] and Activated Sludge Model no.3 (ASM3) [3] as a base model to develop the MBR model by incorporating resistance in series model (Membrane fouling phenomena). In respect of biological phosphorus removal, very limited studies have reported found in literature. The objective of the paper is to propose a mathematical model to remove phosphorus biologically along with COD and ammonia nitrogen by membrane bioreactor from municipal wastewater treatment by using Activated sludge model 2 (ASM2), activated sludge model no.2d (ASM2d) and activated sludge model no.3P (ASM3P) with pre and post denitrification in activated sludge process along with membrane separation process (MBR) process, under aerobic-anoxic-anaerobic condition.

II. CASE STUDY

A Lab-scale study of wastewater treatment has been operated in Nagpur, India. Municipal wastewater collected from the staff colonies at Mahavir Chemical Pvt. Ltd., Nagpur, India. The case study here investigated is side-stream reverse osmosis (RO) membrane module with pre and post denitrification biological phosphorus removal system. Spiral wound polymide RO membrane module, 0.001µm pore size and 0.075m^2 of filtration area used in this study. The operating parameters for MBR system are given in table 1 and specification of RO membrane module is given in table 2. The figure 1 shows the schematic diagram of pre –denitrification and post-denitrification biological phosphorus removal MBR plant

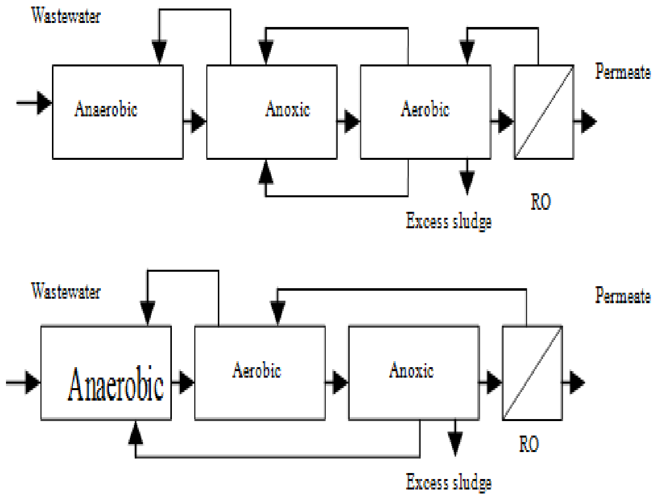

Figure 1: Schematic of pre –denitrification and post-denitrification biological phosphorus removal MBR plant

III. MODEL DEVELOPMENT

The stoichiometric and composition matrixes and process rate equations were same as considered in Activated sludge model 2 (ASM2), activated sludge model no.2d (ASM2d) and activated sludge model no.3P (ASM3P). The process rates include aerobic, anoxic and anaerobic hydrolysis, growth and lysis of all the three microorganism. The model parameters include a fermentable readily organic substrate, fermentable product (acetate), ammonia concentration and phosphorus concentration.

3.1 Assumptions

Following assumption are made for formulating the model equations to study the COD, ammonia nitrogen and phosphorus removal from municipal wastewater and to develop the model :

3.1.1. System is under unsteady state process and flow is continuous with completely mixed membrane bioreactor.

3.1.2. In Case of pre dentrification process, first anaerobic process occurs and then aerobic followed anoxic process.

3.1.3. In Case of post dentrification process, first anaerobic process occurs and then anoxic followed aerobic process.

3.1.4. System is under constant pH and alkalinity term has been removed
3.1.5. The system operates at constant temperature
3.1.6. Influent substrate concentration remains constant
3.1.7. The volume of reactor is constant
3.1.8. Complete rejection of particulate matter
3.1.9. Soluble substrate is not rejected completely

3.2 Membrane Bioreactor Model Equation

A set of ordinary differential equations is formulated to make MBR model are presented as follows

The concentration of readily biodegradable organic matter (ASM3P)

$$V\frac{dS_S}{dt} = Q_O S_S^o - \left(Q_P S_S^P + Q_W S_S^W\right) \pm V\sum \rho_{SS} \qquad 1)$$

The concentration of fermentable, readily organic substrate (ASM2 and ASM2d)

$$V\frac{dS_F}{dt} = Q_O S_F^o - \left(Q_P S_F^P + Q_W S_F^W\right) \pm V\sum \rho_{SF} \qquad 2)$$

The concentration of fermentable product (acetate) (ASM2 and ASM2d)

$$V\frac{dS_A}{dt} = Q_O S_A^0 - \left(Q_P S_F^P + Q_W S_A^W\right) \pm V\sum \rho_{SA} \qquad 3)$$

The ammonia concentration

$$\frac{dS_{NH4}}{dt} = Q_O S_{NH4}^0 - \left(Q_P S_{NH4}^P - Q_W S_{NH4}^W\right) \pm V\sum \rho_{NH4} \qquad 4)$$

The phosphorus concentration

$$\frac{dS_{PO4}}{dt} = Q_O S_{PO4}^0 - \left(Q_P S_{PO4}^P + Q_W S_{PO4}^W\right) \pm V\sum \rho_{PO4} \qquad 5)$$

The set of differential and algebraic equations constitute an Initial value Problem (IVP).Initial condition for the model. The model equations are highly stiff in nature. Therefore, the numerical differentiation formulas with backward difference formula have been used to solve the IVP. In the present model, ode15s has been used to solve the stiff differential equations in MATLAB 7. Kinetic parameters, conversion factor for nitrogen and stoichiometric parameters need to valid the model are taken from activated sludge model 2 (ASM2), activated sludge model no.2d (ASM2d) and activated sludge model no.3P (ASM3P).

3.3 Resistance in Series Model

To study the performance of MBR, it is essential to focus on the permeate flux that eventually affect the permeate flow rate (Q_P).

Permeate flow rate is known by the product of the permeate flux and membrane surface area

$$Q_P = J.A_M \qquad 6)$$

Where,

Permeate flux defined by Darcy's Law in terms of Pressure resistance relationships

$$J = \frac{\Delta P}{\mu R_T} \qquad 7)$$

The various resistances contribute with different extent to the total resistance R_t. In the ideal case, only the membrane resistance R_m (in present model, R_m= 5.2 x 10^{11} 1/m) is involved.

IV. RESULTS AND DISCUSSION

In present study, it is found that concentration of S_I, S_A and S_F in municipal wastewater were 5 % for S_I, 2 % for S_A and 40% for S_F of total COD concentration for ASM2 and ASM2d based MBR model and that concentration of $S_{I\ and}$ S_S were 5 % for S_I, 42 % for S_F of total COD concentration for ASM3P. Rest of the concentration of other components of the COD is simulated to get close results to validate the MBR model with experimental results. Table 5 shows the results of MBR model in the present study.

4.1 COD removal

In the present study, the COD percentage removal efficiency using MBR model was found to be approximately 96 % removal for pre denitrification process and 97 % for post denitrification process .The model results shows that COD removal were 95 % for ASM2 based model(MBR2) , 99 % for ASM2d based model(MBR2d) and 88 % ASM3Pbased model (MBR3P) for pre denitrification MBR process and 94 % for MBR2, 97 % for MBR2d and 87 % MBR3P for post denitrification MBR process. The results shows that the COD removal in case of MBR2 and MBR2d is more close then other that of MBR3P.Similarly COD removal for MBR2 is more close to experimental results then MBR2 and MBR3P models for pre denitrification MBR process and that for MBR2d it is more close then MBR2 and MBR3P.

In general, results of MBR2 are closer to experimental results then MBR2d and MBR3P.

The permeate COD includes the S_I, S_F and S_A. In MBR2 and MBR2d model, the variation of S_F and S_A with time shows the decrease in trends, but there is no variation of S_I with time. Similarly in case of MBR3P the variation of S_S with time shows the decrease in trends, but there is no variation of S_I with time. This indicates that efficiency of COD removal based on the fermentable products and fermentable readily biodegradable organic substrates for MBR2 and MBR2d based model and in case of MBR3P, COD removal based on readily biodegradable organic substrate. Also, It is clear from MBR2 and MBR2d that ,the concentration of fermentable products is reduce by the growth of heterotrophic bacteria (in both aerobic and anoxic conditions) and fermentation process and is increased by the hydrolysis of slowly biodegradable substrate in the presence of all the three process and similarly concentration of a fermentable biodegradable substrate reduce by the growth of heterotrophic bacteria (in both aerobic and anoxic conditions) and fermentation process and is increased by the hydrolysis of slowly biodegradable substrate in the presence of all the three process in addition storage of a cell international storage products of phosphorus accumulating organisms is responsible for the S_A. In case of MBR3P, reduce by the growth of heterotrophic bacteria (in both aerobic and anoxic conditions) and is increased by the hydrolysis of slowly biodegradable substrate.

4.2 Biological ammonia nitrogen and phosphorus removal

In the present study, the ammonia nitrogen percentage removal efficiency using MBR model was found to be 92 (for MBR2), 90 (MBR2d), 85(for MBR3P)in pre denitrification condition and it was found to be 90 (for MBR2), 89 (MBR2d), 84(for MBR3P)in post denitrification condition. Decrease in ammonia nitrogen concentration is basically a nitrification process occurs due to anoxic process in the absence of oxygen. Nitrate is the main electron acceptor in this case. Concentration of COD in terms autotrophic microorganisms is the main factor that affect the removal efficiency.

In the present study, the ammonia nitrogen percentage removal efficiency using MBR model was found to be 90 (for MBR2), 85 (MBR2d), 75(for MBR3P) in pre denitrification condition and it was found to be 88 (for MBR2), 82 (MBR2d), 70(for MBR3P) in post denitrification condition. Decrease in phosphorus concentration is found to be responsible due presence of PAO. More the presence of PAO in wastewater more will be the phosphorus removal efficiency .In most of the case concentration of PAO found to be 0 – 1 % of total COD in municipal wastewater. In the present study it is assumed to be 1.00 %.

V. CONCLUSION

In the present paper mathematical model is applied to describe MBR performance. The MBR model is able to predict with an excellent accuracy for the biological phosphorus removal through pre and post denitrification MBR process condition with RO system as membrane separation process. The model matched the observed trends for effluent COD, ammonia nitrogen and phosphorus, which gives significance that the model can be used to identify the cause for performance trends. The results were in good agreement with the experimental data which indicate that the model can successfully describe the treatment performance terms of Chemical Oxygen Demand, Nitrogen and phosphorus removal. Finally, it is concluded that the results MBR2 is the most suitable base model with pre denitrification condition in terms of chemical oxygen demand (COD), ammonia nitrogen and phosphorus removal than MBR2 (post denitrification),MBR2d (pre and post denitrification)and MBR3P (pre and post denitrification) based model.

SYMBOLS

A_m Membrane surface area, m^2
J Membrane flux, m^3/m^2.day
ΔP Transmembrane pressure, KPa
Q_0 Influent flow rate, m^3/day
Q_P Permeate flow rate, m^3/day
Q_W Waste flow rate, m^3/day
S_I Inert soluble organic material, g COD/m^3
S_{NH4} Ammonia plus ammonia nitrogen, g N/m^3
S_{NO3} Nitrate plus nitrite nitrogen, g N/m^3
S_A Fermentable product (acetate), g COD/m^3
S_F a fermentable readily biodegradable organic substrates, g COD/m^3
S_S Readily biodegradable organic matter, g COD/m^3
R_m Membrane resistance, 1/m
R_t Total resistance, 1/m
V Volume of membrane bioreactors, m^3

Greek Symbols

ρ Process rate Equations, g COD / m^3 day or g N / m^3 day or g P / m^3 day
η Viscosity, Kg/m-s

Superscript

O input
P Permeate
W Waste

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Table 1. Operating Condition of system

Parameters	Values
Volume of bioreactor	9 L
Influent flow rate	30.09-43.2 L/day
Waste flow rate	0.3-0.9 L/day
HRT	5-7 hours
SRT	10-30 days
DO	> 4 g/m^3

Table 2. Characteristics of membrane

Parameters	Details
Membrane materials	Polyamide
Surface Area	0.075 m^2
Transmembrane Pressure	10 KPa
Membrane resistance	5.2 x 10^{11} 1/m

Table 3. Experimental results of MBR Process

Parameters	Raw Wastewater	Pre dentrification	Post Denitrification
COD	290	14.50	8.70
PO_4	1.3	0.091	0.078
NH_4	21	1.47	1.26
NO_3	0	19.00	17.00

All value in g/m^3

Table 4. The various fractions of COD in municipal wastewater

Parameters	Value (g/m^3)
S_I	14.5
S_S	122.25 (ASM3P)
S_F	116.00 (ASM2 and ASM2d)
S_A	6.25 (ASM2 and ASM2d)
X_I	27.87
X_S	83.62
X_H	33.45
X_A	1.45
X_{PAO}	1.45
X_{PP}	1.45
X_{PHA}	1.45

All value in g/m^3

Table 5: Results MBR model

Base Models	**Pre-Denitrification** Removal percentage			**Post-Denitrification** Removal percentage		
	COD	NH_4	PO_4	COD	NH_4	PO_4
MBR2	95	92	90	94	90	88
MBR2d	99	90	85	97	89	82
MBR3P	88	85	75	87	84	70