Journal of Environmental Sciences Vol. 15, No. 6, pp. 757—761, 2003 ISSN 1001—0742 CN11—2629/X

Article ID: 1001-0742(2003)06-0757-05 **CLC number**: X703 **Document code**: A

Biodegradation kinetic of organic compounds of acrylic fiber wastewater in biofilm

ZHANG Ya-lei*, ZHAO Jian-fu, GU Guo-wei

(State Key Laboratory of Pollution Control and Resource Reuse, Tongji University, Shanghai 200092, China. E-mail: yhzktzk@online.sh.cn)

Abstract: A group function relation curve between flux(J) and bulk phase concentration of substrate(S) was set up. The biodegradation kinetic of organic compounds of acrylic fiber wastewater in biofilm is studied(the treatment technology is coagulation/sedimentation-anoxic/aerobic biofilm process), and the results showed that the concentration of non-degradation pollutants in effluent is 77 mg/L. In aerobic zone, the half-rate constant is 72.84 mg/L, the maximum removal rate of organic compounds at unit area filler is very low, 0.089 g/($m^2 \cdot d$), which corresponds to the fact that there are some biorefractory compounds in the wastewater.

Keywords: acrylic fiber wastewater; biodegradation kinetic; organic compounds; biofilm

Introduction

Biofilm kinetic model plays an important role in the rational optimization of biofilm reactor design, operation and research. Whereas, its application in the design of full-scale operations is far from reaching the acceptance level because which is complicated mathematical entities. The approach of illustration loading curve can be used to design the biofilm reactor and avoid the complex solution for equation group of the model.

Fixed biofilm systems have various advantages over more conventional activated sludge process, including the ability to support a variety of microbial populations at various locations within the biofilm which may degrade different organic substrates, and the sequestering ability of the glycocalyx surrounding the microorganisms which protects them from harm from toxicants(Josephson, 1982; Collins, 1988; Zhang, 1994).

Biofilm kinetic models are commonly used as optimization tools in engineering applications, biofilm reactor designing, and as research tools to identify and fill gaps in our knowledge of biofilm processes. In the mid-1980s, Kissel *et al*. (Kissel, 1984), Wanner and Gujer(Wanner, 1986) presented the first mechanistic models to describe the spatial distribution and growth of microbial species in a mixed culture biofilm(MCB model) as a function of transport and transformation processes. In subsequent years, these models were progressively improved(Arvin, 1990; Gujer, 1990; Wanner, 1994), and several other one-dimensional models(Rittmann, 1992; Furumai, 1994) were presented.

Characteristics of biofilm kinetics: The models above served well for describing the development and metabolic functioning of biofilms. Whereas, their application in the design of full-scale operations is far from reaching the acceptance level that other models already have(the IWA activated sludge models) (Noguera, 1999).

This limited use in design can be explained by a combination of factors: (1) Biofilm models are perceived as complicated mathematical entities; (2) simplifications and assumptions used in 1 D (dimension) models are often not supported by experimental observations; (3) there are many phenomena not considered in the models, such as the fate of particulate substrates, the activity of higher organisms, and the role of exopolymeric substance(EPS) production; (4) there is a general lack of trust in the capability of the models to make accurate and reliable predictions; (5) the usefulness of biofilm models for

Foundation item: The National Natural Science Foundation of China(No. 50008011); * Corresponding author

the design of full-scale systems is not fully appreciated. Many engineers prefer to use simple empirical correlations for design, while models are mostly used as troubleshooting tools when operational problems arise; (6) biofilm models have not been adequately distributed or commercialized; (7) parameters used in biofilm models are something difficult to estimate.

Characteristics of acrylic fiber wastewater: The biodegradability of the acrylic fiber wastewater was very low: the ratio of BOD_5/COD_{cr} was 0.1—0.2, and there were some biorefractory organic pollutants in the wastewater (Zhang, 1999a). In field research, the treatment technology was selected as coagulation/sedimentation (pretreatment)——anoxic/aerobic biofilm process. Through this combined process, the wastewater could be removed to the level of effluent standard, i.e., COD_{Cr} < 100 mg/L, BOD_5 < 30 mg/L, NH_3-N < 15 mg/L (Zhang, 1999b). In this paper, the biodegradation kinetic of organic compounds of acrylic fiber wastewater in biofilm (aerobic zone) is studied.

1 Materials and methods

1.1 Kinetic models of organic substrate biodegradation in biofilm

The theoretical scheme of organic substrate biodegradation in biofilm is represented in Fig. 1. Which shows that the concentration of substrate in biofilm is variable, and is much lower than bulk phase concentration of substrate.

The substrate movement and utilization outer of biofilm can be described as:

$$J = -D\frac{dS}{dZ} = -\frac{D}{L}(S_s - S_b), \qquad (1)$$

where: J is the flux of substrate across the biofilm-bulk phase interface, $M_S L^{-2} T^{-1}$; D is the diffusion coefficient of substrate, $L^2 T^{-1}$; Z is the diffusion space upright with biofilm, L; L is diffusion layer thickness.

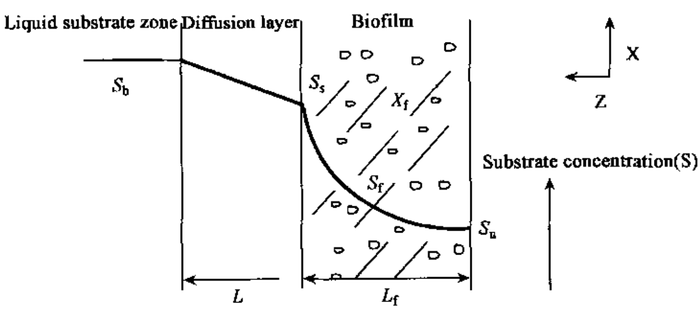

Fig. 1 Theoretical scheme of organic substrate biodegradation in biofilm

S_b——bulk phase concentration of substrate; S_s——substrate concentration at the outer edge of biofilm; X_f——biofilm density; L——diffusion layer thickness; S_f——substrate concentration in biofilm; S_n——substrate concentration at the inner edge of biofilm; L_f - biofilm thickness

The substrate movement and utilization in biofilm as per:

$$\frac{\partial S_f}{\partial t} = 0 = D_f\frac{\partial^2 S_f}{\partial Z^2} - \frac{qX_f S_f}{K + S_f}, \qquad (2)$$

where: D_f is the substrate diffusivity in the biofilm, $L^2 T^{-1}$; q is the maximum specific utilization rate of substrate, $M_S M_X^{-1} T^{-1}$; K is the saturation constant, $M_S L^{-3}$.

The limitation of Equation (2) as per:

$$Z = 0, \frac{\partial S_f}{\partial Z} = 0; \qquad (3)$$

$$Z = L_f, S_f = S_s. \qquad (4)$$

Under the steady state condition:

$$L_f = \frac{JY}{b'X_f}, \qquad (5)$$

where: Y is the apparent yield coefficient of cell material, $M_S M_X^{-1}$; b' is the decay coefficient of cell material, $M_S M_X^{-1} T^{-1}$.

To maintain the steady state of the biofilm, the minimum substrate concentration should be:

$$S_{min} = \frac{Kb'}{Y_q - b'}. \tag{6}$$

Equation (2) to (6) are a set of models to describe the organic substrate biodegradation in biofilm. But which are complicated mathematical entities, and could not used to design fixed biofilm reactor directly.

The approach of illustration loading curve can be used to design the biofilm reactor and avoid the complex solution for equation group as above. This approach sets up a group function relation curve between flux (J) and bulk phase concentration of substrate (S), where the J and S are switched to standardization parameters. Utilization of this approach is described by the simple equation as per:

$$J_a = \frac{Q(S_0 - S_1)}{aV} = \frac{J_{max} S_1}{K_S + S_1}, \tag{7}$$

where: J_a is the flux of substrate across the unit area filler, $M_S L^{-2} T^{-1}$; J_{max} is the maximum flux of substrate across the unit area filler when the concentration is saturation, $M_S L^{-2} T^{-1}$; Q is the wastewater flow, $L^3 T^{-1}$; V is the volume of filler, L^3; a is the specific surface area, L^{-1}; K_S is the saturation constant, the value is the substrate concentration when $J_a = J_{max}/2$, $M_S L^{-3}$; S_0 is the substrate concentration of influent, $M_S L^{-3}$; S_1 is the substrate concentration of effluent, $M_S L^{-3}$. In Equation (7), J_{max} and K_S are the kinetic constants of substrate degradation.

When substrate concentration is very high ($S_1 \gg K_S$), the K_S can be omitted compared with S_1, i.e.,

$$J_a = J_{max}. \tag{8}$$

From above, substrate is removed at maximum rate when the substrate concentration is very high, the bio-chemical reaction is zero-order. When substrate concentration is very low ($S_1 \ll K_S$), the S_1 can be omitted compared with K_S, i.e.,

$$J_a = \frac{J_{max} S_1}{K_S} = KS_1, \tag{9}$$

where: $K = J_{max}/K_S$.

From above, substrate removal rate is linearity versus the rudimental concentration of substrate. This case will occur in a continuous inflow completely mixed reactor under steady state situation. Which means that the microorganism is in the period of retardment growth, the bio-chemical reaction is first-order.

If there is non-degradation compounds in the substrate, the Equation (7) can be represented by:

$$J_a = \frac{J_{max}(S_1 - S_n)}{K_S + (S_1 - S_n)}, \tag{10}$$

where: S_n is the concentration of non-degradation substrate, $M_S L^{-3}$.

Then the Equation (9) as per:

$$J_a = K(S_1 - S_n). \tag{11}$$

The kinetic constants of substrate degradation, J_{max} and K_S, could be determined by experiment. The values of the kinetic constants are related to characteristic of substrate, microorganism species, types of filler and environmental condition. To the certain substrate and filler, the correlative kinetic constants under certain environmental condition can be gained.

Generally, there is non-biodegradation compounds in wastewater, so it is necessary to ascertain the concentration of non-biodegradation substrate (S_n) firstly before ascertain the kinetic constants. Using Equation (9), the S_n can be gained by illustration or linear regression approach. Then, the reciprocal of Equation (10) is:

$$\frac{1}{J_a} = \frac{1}{J_{max}} + \frac{K_s}{J_{max}} \times \frac{1}{(S_1 - S_n)}. \tag{12}$$

The J_{max} and K_S can be estimated from the linear-regression line of $1/J_a$ (ordinate) versus $1/(S_1-S_n)$ (abscissa).

1.2 Experimental material

The treatment technology in the experiment is coagulation/sedimentation(pretreatment)-anoxic/aerobic biofilm process. In this case, the kinetic of organic compounds biodegradation in biofilm of aerobic zone of the A/O reactor is studied. The specific surface area of the soft fiber filler used in the experiment is 2000 m^2/m^3, the total volume of filler in aerobic zone is 0.0274 m^3, the total surface area of filler is 54.8 m^2. Fig.2 presents the sketch of filler and its installation.

2 Results and discussions

Experimental results are presented in Table 1. The data include the influent flow, substrate concentration (COD) of coagulation/sedimentation pretreatment effluent, COD of influent of aerobic zone of the A/O reactor, and COD of effluent. Table 2 presents a summary of the experimental data, in order to illustrate the kinetic parameters.

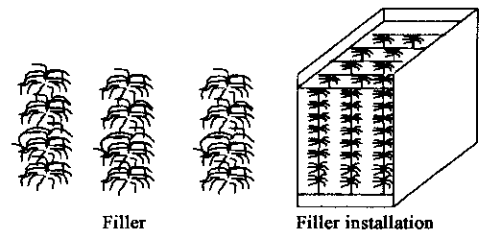

Fig. 2 Sketch of filler and installation

Table 1 COD concentration of influent and effluent

No.	Influent flow Q, m^3/d	COD of pretreatment effluent, mg/L	COD of influent of aerobic zone S_0, mg/L	COD of effluent S_1, mg/L
1	0.033	421	113	91
2	0.033	417	108	88
3	0.048	371	117	96
4	0.048	447	156	117
5	0.0504	399	141	110
6	0.0504	380	132	107

Table 2 List of experimental data for illustration analysis

$Q(S_0-S_1)$, G/d	Area of filler, m^2	J_a, $g/(m^2 \cdot d)$	$1/J_a$, $(m^2 \cdot d)/g$	$1/(S_1-S_n)$, 1/mg
0.72	54.8	0.013	76.92	0.073
0.66	54.8	0.012	83.33	0.093
1.01	54.8	0.018	55.56	0.055
1.86	54.8	0.034	29.41	0.026
1.59	54.8	0.029	34.48	0.031
1.26	54.8	0.023	43.48	0.034

According to the data in Table 1 and 2, through illustrate approach and linearity regression analysis, the S_n can be gained(Fig.3). The linearity regression equation is:

$$J_a = 0.0008S_1 - 0.0618 .$$

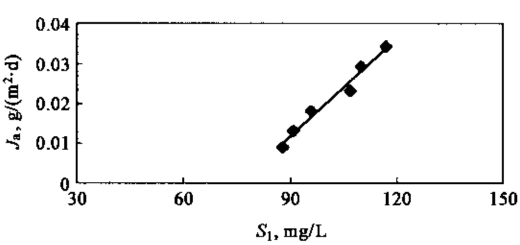

Fig. 3 Graphical estimation of S_n

From Fig. 3 or regression equation, S_n = 77.25 mg/L, correlation coefficient R^2 = 0.9759. The correlation coefficient of the line is R^2 = 0.9759, which screens that the regression correlation is good. The slope of the line is first-order reaction constant, the value is rather small, which shows that the organic pollutants removal rate is very slow in aerobic zone. The intercept on X axile is S_n, i.e., the concentration of non-degradation pollutants in effluent is 77 mg/L.

According to the data in Table 1 and 2, through illustrate approach and linearity regression analysis, the J_{max} and K_s can be obtained(Fig.4). The linearity regression equation:

$$1/J_a = 819.47/(S_1 - S_n) + 11.251 .$$

From Fig. 5 and regression equation, J_{max} = 0.089 $g/(m^2 \cdot d)$, K_s = 72.84 mg/L, correlation *coefficient* $R^2 = 0.9656$.

In aerobic zone, the half-rate constant is 72.84 mg/L, the maximum removal rate of organic compounds at unit area filler is 0.089 g/($m^2 \cdot d$), it can be seen that the removal rate of organic compounds at unit area filler is very low, which corresponds to the fact that there are some biorefractory compounds in the wastewater.

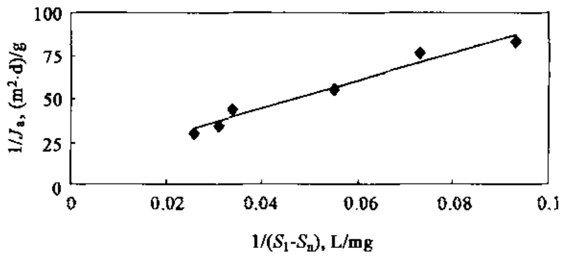

Fig. 4 Graphical estimation of J_{max} and K_s

3 Conclusions

The biodegradability of the acrylic fiber wastewater was very low. It can be obtained from the experiment of coagulation/sedimentation-anoxic/aerobic biofilm process that fixed biofilm systems have several advantages. But, the biofilm kinetic model is difficult to used in designing directly because of its complicated mathematical solution.

The approach of illustration or linear regression analysis can be used to confirm design parameters. In this work, the biodegradation kinetic of organic compounds of acrylic fiber wastewater in biofilm (aerobic zone) is studied, and the result shows that the concentration of non-degradation pollutants in effluent is 77 mg/L. In aerobic zone, the half-rate constant is 72.84 mg/L, the maximum removal rate of organic compounds at unit area filler is very low, 0.089 g/($m^2 \cdot d$), which corresponds to the fact that there are some biorefractory compounds in the wastewater.

References:

Arvin E, Harremoës P, 1990. Concepts and models for biofilm reactor performance[J]. Wat Sci Tech, 22(1/2): 171—192.

Bishop P, 1997. Biofilm structure and kinetics[J]. Wat Sci Tech, 36(1): 287—294.

Bishop P, Rittmann, 1995. Modeling heterogeneity in biofilms[J]. Wat Sci Tech, 32(8): 263—265.

Collins A G, 1988. Fixed-film biological nitrification of a strong industrial waste[J]. J WPCF, 60(4): 499—504.

Furumai H, Rittmann B, 1994. Interpretation of bacterial activities in nitrification filters by a biofilm model considering the kinetics of soluble microbial products[J]. Wat Sci Tech, 30(11): 147—156.

Gujer W, Wanner O, 1990. Modeling mixed population biofilms[M]. In: Biofilms. New York: John Wiley & Sons, Inc. 397—443.

Josephson J, 1982. Fixed-film biological process[J]. Environ Sci Tech, 16(7) : 380A—384A.

Kissel J, McCarty P, 1984. Numerical simulation of a mixed-culture biofilm[J]. J Environ Eng Div ASCE, 110: 393—411.

Lewandowski Z, Stoodley P, Altobelli S *et al.*, 1994. Hydrodynamics and kinetics in biofilm systems-recent advances and new problems[J]. Wat Sci Tech, 29(10/11): 223—229.

Noguera D, Okabe S, 1999. Picioreanu biofilm modeling: present status and future directions[J]. Wat Sci Tech, 39(7): 273—278.

Rittmann B, Manem J, 1992. Development and experimental evaluation of a steady-state, multi-species biofilm model[J]. Biotechnol Bioeng, 39: 914—922.

Wanner O, 1986. A multispecies biofilm model[J]. Biotechnol Bioeng, 28: 314—328.

Wanner O, Reichert P, 1996. Mathematical modeling of mixed-culture biofilms[J]. Biotechnol Bioeng, 49: 172—184.

Zhang T, Bishop P, 1994. Structure, activity and composition of biofilms[J]. Wat Sci Tech, 29(7): 335—344.

Zhang Y L, 1999. Study on the treatment technology for biorefractory organic wastewater (acrylic fiber wastewater) and biodegradation of organic pollutants[D]. Ph.D thesis. Dept Environ Sci Eng of Tongji University, Shanghai, China.

Zhang Y L, Yang H Z, Gu G W, 1999. Research on treatment technology of acrylic fibers wastewater & biodegradation pathway of organic pollutants[C]. Proceedings of 7th IAWQ Asian WATERQUAL. Taipei University, Taipei. 1169—1174.

(Received for review July 23, 2002. Accepted September 12, 2002)