DIFFUSION OF SINGLE OXIDATION POND

by

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The hydraulic characteristic of an oxidation pond was studied by the tracer experiment, and an empirical formula of Peclet number was obtained, which can be well applied to the model of plug flow reactor with longitudinal diffusion.

Key words: *oxidation pond, trace experiment, mathematical model, Peclet number*

Introduction

Oxidation pond is one kind of wastewater treatment establishments, and is widely applied to treat municipal sewage and various industrial wastewaters in many countries [1, 2]. The hydrodynamic of oxidation pond is an important aspect as it significantly affects the performance of the pond. Recently, the advancement of computational resources has facilitated the use of CFD models as a predictive tool for mixing behavior in oxidation pond systems [3, 4]. However, in view of combining hydraulic behavior with a kinetic process model, the computational load is too high for practical use [5]. Tracer study is a widespread and effective method for evaluating the hydraulics of pond systems. The hydraulic characteristic of the oxidation pond is unideal. For anomalous diffusion behavior, it can be well described by the discrete fractional model [6], the plug flow reactor with longitudinal diffusion (PFD) and continuous stirred tank reactor model [7]. Peclet number is a critical parameter for studying fluid diffusion behavior, and is widely used in thermal engineering [8, 9]. Because Peclet number is very difficult to be exactly predicted, a simple and effective method was proposed to ascertain Peclet number value by testing the hydraulic residence time distribution of oxidation ponds. The empirical formula of Peclet number was established by fitting data obtained from tracer experiments. This empirical formula could be applied in PFD model commendably, and the accuracy of this mathematical model was also checked by operating data from Xianhe oxidation pond of Sinopec Shengli Oilfield company.

Experimental

In order to study the hydraulic properties, an oxidation pond model device was installed and shown in fig. 1. The size of pond device was 2.4 × 1.2 × 0.11 m. The acid red was chosen as the tracer, and total 30 tracer experiments were carried out. Six different kinds of ar-

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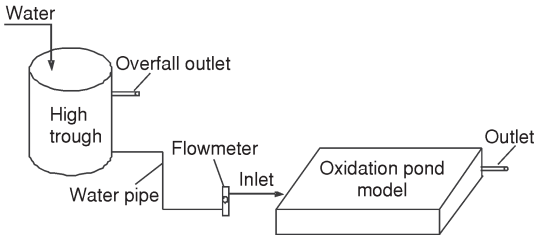

Figure 1. The experimental device of oxidation pond model

rangement from inlet to outlet were considered, and five tracer experiments were done in each arrangement. The longitudinal diffusion coefficient, D, can be calculated by the following formulas. The distribution density and distribution function are expressed by eqs. (1) and (2), respectively:

$$J(t) = \frac{Q}{M}C(t) \tag{1}$$

$$J(t) = \frac{Q}{M}\int_0^t C(t)\mathrm{d}t \tag{2}$$

Average residence time, variance and contrast variance are described by eqs. (3)-(5):

$$t_M = \int_0^\infty tJ(t)\Delta t \Big/ \int_0^\infty J(t)\Delta t \tag{3}$$

$$\sigma^2 = \int_0^\infty t^2 J(t)\mathrm{d}t - t_M^2 \Big/ \int_0^\infty t^2 J(t)\Delta t \Big/ \int_0^\infty tJ(t)\Delta t \tag{4}$$

$$\sigma_\theta^2 = \frac{\sigma^2}{t_M^2} \tag{5}$$

According to the empirical formula of closed reactor [10], eq. (5) can be converted to:

$$\sigma_\theta^2 = \frac{2}{\mathrm{Pe}} - \frac{2}{\mathrm{Pe}^2}(1 - \mathrm{e}^{-Pe}) \tag{6}$$

The relation between D and Peclet number can be expressed by eq. (7):

$$d = \frac{D}{uL} = \frac{1}{\mathrm{Pe}} \tag{7}$$

where u is the superficial velocity, L – the beeline from inlet to outlet, and d – the diffusion factor.

The relative parameters were calculated and shown in tab. 1. All of Peclet number values were less than 10, which indicated that back mixing was severe in this reactor model.

Modeling and verification

Combining the consequences of tracer experiments and the previous findings about empirical formula of diffusion coefficient [11], it was confirmed that the water depth, H, distance from inlet to outlet, L, and flow velocity, u, were very important factors in hydraulic properties. Thus, they were chosen to ascertain the D value. After fitting relative data by using a MATHCAD software, the empirical formula about D was obtained and shown as eq. (8). Applying F test to check the significance level of this formula, the consequence indicated that it was highly significant:

$$D = 10^{4.623} H^{1.085} u^{1.938} L^{0.0052} \tag{8}$$

In view of eqs. (7) and (8) can be converted to:

$$\mathrm{Pe} = \frac{L^{0.9948}}{10^{4.623} H^{1.085} u^{0.938}} \tag{9}$$

Table 1. Calculating results of experimental parameters

No.	t_M [min]	σ_θ^2	Pe	$u\ 10^{-4}$ [ms^{-1}]	d	$D\ 10^{-4}$ [m^{2}s^{-1}]
1-1	4.240	0.480	2.747	2.255	0.364	2.167
1-2	1.700	0.461	2.941	3.446	0.34	3.311
1-3	2.596	0.259	6.536	3.992	0.153	3.836
1-4	4.099	0.523	2.358	2.160	0.424	2.076
1-5	2.710	0.288	5.747	2.377	0.174	2.285
2-1	2.918	0.245	6.993	2.035	0.143	1.815
2-2	4.086	0.284	5.848	1.774	0.171	1.582
2-3	3.394	0.272	6.173	1.862	0.162	1.661
2-4	3.839	0.205	8.621	2.191	0.116	1.954
2-5	3.183	0.522	2.364	1.983	0.423	1.769
3-1	3.813	0.508	2.488	1.482	0.402	0.885
3-2	4.054	0.400	3.676	1.292	0.272	0.771
3-3	4.123	0.504	2.519	1.216	0.397	0.726
3-4	4.896	0.185	9.709	1.071	0.103	0.639
3-5	3.427	0.385	3.891	1.627	0.257	0.971
4-1	3.773	0.413	3.497	1.931	0.286	1.722
4-2	3.369	0.444	3.125	1.858	0.32	1.657
4-3	3.949	0.399	3.690	1.727	0.271	1.540
4-4	3.718	0.292	5.650	1.869	0.177	1.667
4-5	3.380	0.193	9.259	2.160	0.108	1.926
5-1	3.229	0.261	6.494	1.182	0.154	0.563
5-2	4.863	0.286	5.780	0.995	0.173	0.475
5-3	3.640	0.249	6.849	0.948	0.146	0.452
5-4	4.000	0.372	4.082	0.986	0.245	0.470
5-5	2.505	0.598	1.786	1.022	0.56	0.487
6-1	3.138	0.252	6.757	2.079	0.148	1.786
6-2	3.818	0.410	3.546	1.768	0.282	1.519
6-3	3.427	0.445	3.115	1.695	0.321	1.456
6-4	4.124	0.368	4.149	1.792	0.241	1.539
6-5	2.796	0.498	2.571	1.884	0.389	1.619

Applying the PFD model, the mathematical model of oxidation pond in zero order reaction was established. In first order reaction, the fluid mass transfer equation is expressed:

$$\frac{\partial C}{\partial t} \quad \frac{\partial C}{\partial x} u \quad D \frac{\partial^2 C}{\partial x^2} \quad kC \tag{10}$$

where u is the longitudinal mean flow rate, k – the pollutant removal rate constant, C – the reactant concentration, x – the longitudinal distance, and t – the reaction time. Under steady-state and zero order reaction condition, eq. (10) can be converted to:

$$\frac{\mathrm{d}^2 C}{\mathrm{d}x^2} \quad \frac{u}{D} \frac{\mathrm{d}C}{\mathrm{d}x} \quad \frac{k}{D} \tag{11}$$

Equation (11) can be solved to:

$$C \quad \alpha_1 \quad \alpha_2 \mathrm{e}^{ux/D} \quad \frac{kx}{u} \tag{12}$$

where α_1 and α_2 are the constants, and they can be confirmed by the boundary condition of the closed type reactor [12]:

$$f(0–) = f(0+) = 1 \tag{13}$$

$$\frac{\mathrm{d}f}{\mathrm{d}z}(1) \quad 0 \tag{14}$$

where z is the dimensionless length, $z = x/L$, L – the length of oxidation pond, and f – the residual ratio of pollutant. When $z = 1$, simultaneous eqs. (12)-(14) can be transformed to:

$$\frac{C_\mathrm{e}}{C_0} \quad 1 \quad \frac{1}{C_0}\frac{kT}{\mathrm{Pe}}\mathrm{e}^{\ \mathrm{Pe}} \quad \frac{1}{C_0}\frac{kT}{\mathrm{Pe}} \quad \frac{1}{C_0}kT \tag{15}$$

where T is the apparent residence time, $T = L/u$, C_e – the pollutant concentration at outlet, and C_0 – the pollutant concentration at inlet.

The relative error between measured chemical oxygen demand (COD) values and predicted values was listed in tab. 2. The consequence indicated that the calculated values could reflect ture values well, and the relative error was less than 7.5%.

Table 2. Compare between predicted value and measured value of COD [mgL^{-1}]

No.	COD_0	Measured COD_e	Predicted COD_e	Relative deviation
1	188.4	107.0	102.7	4.02%
2	180.0	105.0	112.6	7.24%
3	175.0	86.4	82.5	4.51%
4	189.2	145.0	144.8	0.14%

Conclusion

According to the hydraulic residence time distribution experiments and comprehensive analysis for the oxidation pond model, an empirical formula about Peclet number was obtained by fitting data. The length from inlet to outlet, depth of water, and velocity of flow were major influence factors. Basis of PFD model, the mathematical model of oxidation pond in zero order reaction was established. The operating data of Xianhe oxidation pond was used to verify this model, and the consequence of low COD relative deviation indicated that this mathematical model can be applied to design the real oxidation ponds.

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