KINETIC MODEL ON THE PERFORMANCE OF AN ANAEROBIC BAFFLED REACTOR FOR THE TREATMENT OF TEXTILE WASTEWATER

A. Bhuvaneswari

Assistant Professors, Department of Civil Engineering, Annamalai University, India.

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Abstract - *A laboratory-scale anaerobic baffled reactor (ABR) was operated at mesophilic temperature (36°c) for treating the real time textile dye waste stream at five hydraulic times (HRT)s of 1.748, 1.165, 0.874, 0.699 and 0.582 days. The reactor was allowed to operate at an OLR of 2.745 Kg COD/m^3.day with a HRT of 1.748 days attained COD removal efficiency was 91.67%. The objective of the study was to formulate an improved mathematical model to describe textile wastewater treatment. In this study, the mathematical model such as, first order kinetic (FOK), cubic polynomial (CP), Quadratic polynomial (QP) models were applied to determine the substrate removal kinetic of anaerobic baffled reactor. Kinetic parameters were determined through linear regression using the experimental data. The predicted COD concentrations were calculated using the kinetic constants. It was found that these simulated data were in good agreement with the observed ones in First order kinetic, cubic polynomial, Quadratic polynomial models. Furthermore, the correlation coefficient value (R^2) obtained for the experimental and predicted effluent COD concentration also confirmed the suitability of the kinetic model. The CP model fitted with the experimental values with highest accuracy (R^2 ranging between 0.9543 and 0.9999) followed by FOK and QP model. This showed that the Cubic polynomial model is a more applicable model for describing the kinetics of the organic removal in anaerobic baffled reactor for treating real time textile dye wastewater.*

Key Words: Anaerobic Baffled Reactor (ABR), Chemical Oxygen Demand, Degree of regression, Hydraulic retention time, kinetic parameters, Textile wastewater.

1. INTRODUCTION

With the increasing deterioration of world water resources, configuring a technical and economic viable wastewater treatment and recycle technology to satisfy the increasing complexity of wastewater and stringent environmental regulation has been a great challenge over the past decades. Developing reliable technologies for wastewater treatment is of urgent importance. In recent years anaerobic baffled reactor (ABR) treating wastewater effectively have received considerable attention in the literature. It was indicated that ABR had become a promising alternative for wastewater treatment with great further development potential. Among these reactors, the ABR was suggested by many researchers as a promising system for treatment of industrial and municipal wastewaters (Kuscu and Sponza, 2005; Dama *et al*., 2002). The development of ABR was undertaken which needed neither the sludge blanket nor the granular biomass by virtue of its configuration (Langenhoff *et al*., 2000; Bodkhe, 2009). The most significant advantage of the ABR is its ability for partial separation of the acidogenesis and methanogenesis phases longitudinally down the reactor without operational issues and costs related to the phased reactors (Vossoughi *et al*., 2003; Wang *et al*., 2004). Process modelling is a useful tool for describing and predicting the performance of anaerobic digestion systems (Jimenez *et al*., 2004). It seems that a combination of theoretical considerations and experimental findings can be used together in order to generate models with a more realistic fit (Noykova and Gyllenberg, 2000). Most models are not operationally useful, because of their complexity and the uncertainties in selection and measurement of input and output parameters crucial to effective simulation and prediction. Hence, modelling efforts often are based upon selected fundamental principles and then generalized in order to enhance applied facility for process and design control (Siles *et al*., 2008). There are different models for predicting the effluent substrate concentration in anaerobic treatment systems. In the models of Grau, Contois, Chen &Hashimoto, Kincannon-Stover and First-order kinetics, the effluent substrate concentration, Se, is a function of the influent substrate concentration, S_i. This is in contrast with the Monod model where S_e is independent of S_i. Meanwhile these models also most frequently assume completely mixed and steady-state conditions (Malina and Pohland, 1992). In order to better understand the ABR operation and to describe reactor performance, attempts have been made to model an ABR reactor (Xing *et al*., 1991).

Modelling is a valuable tool in both design and operation of biological treatment plants. In addition, modelling of wastewater treatment plants can also be used for process optimization and testing of control strategies to meet effluent quality requirements at a reasonable cost. Hence, modelling helps to develop a better understanding of the treatment processes and provides a significant potential for solving operational problems, as well as reducing operational cost in biological wastewater treatment process. Moreover, model results can be evaluated for different operating data before transferring the concepts to a full-scale plant (Yetilmezsoy K (2007). Development of kinetic models is a useful attempt in both designing and optimization of a particular treatment process by reducing laborious and complex experimental data to simple and convenient mathematical expressions (Yetilmezsoy K (2007). Kinetic modelling-based studies give a good insight into reaction mechanisms and help to describe several specific parameters for monitoring the system performance. Debik and Coskun (2009) have reported that results of kinetic studies can also be used for predicting treatment efficiencies of full-scale reactors running under the same operational conditions. For this purpose, the precise determination of kinetic coefficients and selection of appropriate mathematical relationship between process variables are obligatory to increase the applicability of such a model (Bhunia P, Ghangrekar MM, 2008). Therefore, the most appropriate kinetic model representing the extension of the experimental data should be selected to recognize possible technical faults and to reduce operating costs of plants in the planning stage (Yetilmezsoy K, Sapci-Zengin Z , 2009). In the present study, the several kinetic models available in literature three different models such as the first order kinetics, cubic polynomial and quadratic polynomial models were applied to determine the substrate removal kinetics of ABR using textile wastewater and verified the validity of the models by comparing the experimental and predicted data at decreasing HRTs.

1.1 MATERIALS AND METHODS

1.1.1 Reactor Configuration

In the present study an experimental model of Anaerobic baffled Reactor was fabricated to conduct experiment for real time waste streams of textile industry to evaluate the treatment efficiency under varying experimental conditions. The experimental laboratory model was made up of Plexiglass. The size of the anaerobic baffled reactor was: length 50cm, width 24cm, depth 30cm and working volume of the reactor was 36 litres. A proper construction of the baffles allowed wastewater to flow through the sludge bed from bottom up. The model have five compartments and the distance of the upper edge of baffles between the ascending and descending compartments from the water level was 3cm above the reactor's base at a 45° angle to direct the flow evenly through the up-corners. The liquid flow is alternatively upwards and downwards between compartment partitions. This produced effective mixing and contact between the wastewater and biosolids at the base of each up corners. Sampling ports were used for drawing biological sludge and liquid samples. A variable speed Peristaltic Pump (PP -30) was used to control flow rate. The schematic of the experimental setup is shown in Figure 1.1. The treatment process for acclimation was achieved by operating the plant with screened seed sludge drawn from the treatment facilities of Annamalai University. The textile effluent was collected from M R S Dyeing private limited, Avinashi road, Tirupur, Tamil Nadu. The samples were analyzed and characterized as per the Standard Procedures given in APHA, Standard Methods for the Examination of Water and Wastewater, 21st Edition 2005. The textile wastewater was allowed to the reactor in gradual addition of 20%, 40%, 60%, 80% and 100%. After allowing 100% textile wastewater to the reactor, the COD removal efficiency was monitored.

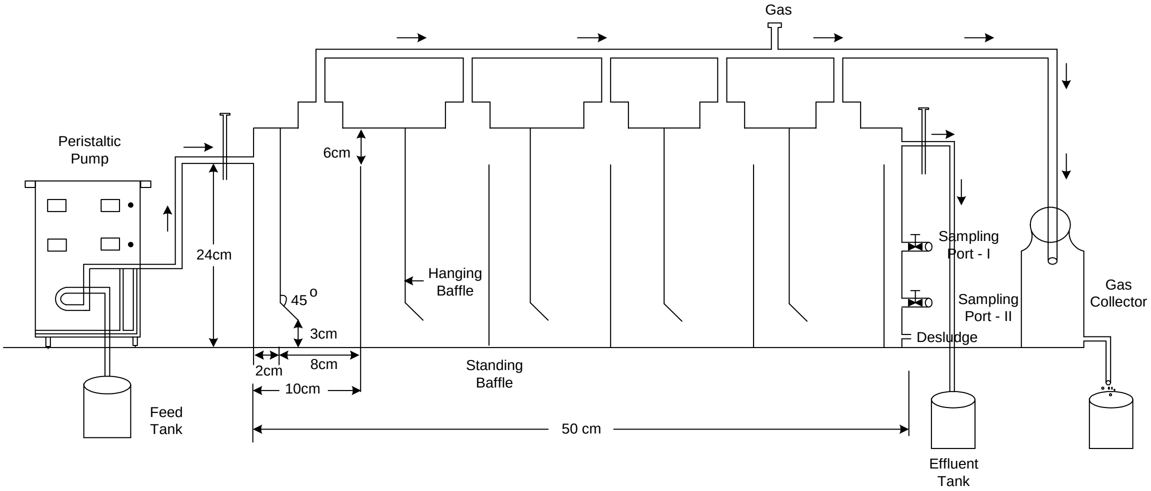

Fig. 1.1 Schematic of Anaerobic Baffled Reactor

1.2 Kinetic Modelling

Mathematical modelling and simulation studies find an important tool in the design of any process for its implementation and control. In the present research an aerobic baffled reactor on continuous mode of operation was used. Scaling up this reactor set up to industrial requirement is quite challenging in terms of design and control. It can be accomplished only by developing a model for the COD (s) removal in terms of the independent variable 'time'. In this perceptive the following models were tried to fit the experimental data.

First Order Kinetics

$$\frac{ds}{dt} = -kt$$

ie $s=s_0\, e^{-kt}$

Cubic Polynomial

$$s= At^3+Bt^2+Ct+D$$

Quadratic Polynomial

$$s=at^2+bt+c$$

Where

s = COD (mg/l)
s_0 = Initial COD (mg/1)
t = Time (h)
k = constant of the FOK model (h^{-1})
A, B, C, D = cubic polynomial constants
a, b, c = quadratic polynomial constants
$\frac{ds}{dt}$ = substrate removal rate (mg/l. d)

2. EVALUATION OF PARAMETERS

The fitting of models and evaluation of the parameters k (FOK), A,B,C,D (CP) a, b, c (QP) was carried out using the **CFTOOL** kit available in MATLAB 10 software.

2.1 Error analysis

Validation of any model to experimental data can be accomplished by estimating the error between model simulated values and experimental values with the latter as basis. In most of the cases errors are represented in percentages. In the present work the absolute error percentage is computed using the following equation and the overall error is calculated by calculating the average of errors for all the data points.

Error percentage = $100 * \left|\frac{\text{experimental}-\text{predicted}}{\text{experimental}}\right|$

3. RESULTS AND DISCUSSION

Mathematical modelling of any process involves understanding the mechanism of the process and to develop a model accordingly or vice versa (Bailey and Ollis, 2010). The model validation is always accomplished by comparing the real time data and model simulated finding by using error analysis. In the present investigation, the COD reduction was found at satisfactory level with the following models reasonably.

- First Order Kinetics (FOK)
- Quadratic Polynomial (QP)
- Cubic Polynomial (CP)

The model parameters k value for FOK model, a, b and c for QP and A, B, C and D for CP model for the 25 experimental runs are evaluated using cf tool kit in MATLAB 10 Software. The estimated parameters, validation of models (R^2 values and error analysis) are presented in the table 1 to 5. Also, the comparison between the experimental and predicted model, values of the COD reduction for the 25 runs also been discussed. The modelling investigation was carried out for the 3 models mentioned above using MATLAB software and MX EXCEL. The cftool kit in MATLAB software generated the models parameters of the equations along with the R^2 value. From the R^2 values it was found that of FOK, CP and QP models fit the experimental COD removal with reasonable accuracy. The estimated parameters for the 25 runs are presented in Table 1 to 5 along with the R^2 values.

Table.1 shows the comparison of the R^2 value among the first order kinetics, cubic polynomial and quadratic polynomial. In the first order kinetics constant (k (h^{-1})) ranges between 0.0239 and 0.0749 and the R^2 value ranges between 0.9429 and 0.9734. The cubic polynomial indicate the constants and A, B, C and D and the R^2 value with the maximum of 0.9969 and minimum of 0.9803. The quadratic polynomial has three constants, namely a, b and c and the R^2 having a range between 0.9591 and 0.9885. Table.2 shows the comparison of the R^2 value among the first order kinetics, cubic polynomial and quadratic polynomial. In the first order kinetics constant (k (h^{-1})) ranges between 0.02451 and 0.0584 and the R^2 value ranges between 0.9436 and 0.9804. The cubic polynomial indicate the constants and A, B, C and D and the R^2 value with the maximum of 0.9995 and minimum of 0.9728. The quadratic polynomial has three constants, namely a, b and c and the R^2 having a range between 0.9684 and 0.9932. Table.3 shows the comparison of the R^2 value among the first order kinetics, cubic polynomial and quadratic polynomial. In the first order kinetics constant (k (h^{-1})) ranges between 0.02482 and 0.06161 and the R^2 value ranges between 0.9395 and 0.9681. The cubic polynomial indicate the constants and A, B, C and D and the R^2 value with the maximum of 0.998 and minimum of 0.9834. The quadratic polynomial has three constants, namely a, b and c and the R^2 having a range between 0.9776 and 0.9933.

Table.4 shows the comparison of the R^2 value among the first order kinetics, cubic polynomial and quadratic polynomial. In the first order kinetics constant (k (h^{-1})) ranges between 0.0501 and 0.07113 and the R^2 value ranges between 0.9535 and 0.9909. The cubic polynomial indicate the constants and A, B, C and D and the R^2 value with the maximum of 0.9976 and minimum of 0.9816. The quadratic polynomial has three constants, namely a, b and c and the R^2 having a range between 0.981 and 0.9955. Table.5 shows the comparison of the R^2 value among the first order kinetics, cubic polynomial and quadratic polynomial. In the first order kinetics constant (k (h^{-1})) ranges between 0.05343 and 0.115 and the R^2 value ranges between 0.936 and 0.9998. The cubic polynomial indicate the constants and A, B, C and D and the R^2 value with the maximum of 0.9999 and minimum of 0.9243. The quadratic polynomial has three constants, namely a, b and c and the R^2 having a range between 0.9523 and 0.9987.

Table: 1 Model parameters for ABR treating textile wastewater for an average influent COD of 2912 mg/l (Without adding of Co-substrate)

Run No.	First Order Kinetics		Cubic Polynomial					Quadratic Polynomial			
	k (h^{-1})	R^2	A	B	C	D	R^2	a	b	c	R^2
1	0.0239	0.9544	0.05027	-2.754	-18.19	2955	0.9969	0.4134	-67.96	3069	0.9794
2	0.03947	0.9734	0.1105	-2.914	-65.67	2682	0.9936	1.726	-114.3	2757	0.984
3	0.0377	0.9468	-0.11	2.45	-85.42	2625	0.9903	-0.8482	-61.32	2604	0.9885
4	0.04749	0.9476	0.6996	-15.19	-56.93	3436	0.9803	3.704	-182.9	3550	0.9591
5	0.04567	0.9429	0.7682	-18.08	-9.189	3009	0.9952	-0.7937	-103.9	3071	0.9822

Table: 2 Model parameters for ABR treating textile wastewater for an average influent COD of 3224 mg/l (Without adding co-substrate)

Run No.	First Order Kinetics		Cubic Polynomial					Quadratic Polynomial			
	K(h^{-1})	R^2	A	B	C	D	R^2	a	b	c	R^2
6	0.02451	0.9649	0.02993	-1.674	-39.42	3459	0.9977	0.2116	-69.05	3527	0.9932
7	0.0358	0.9526	0.1089	-5.214	-9.286	3022	0.9984	-0.6399	-57.2	3095	0.9909
8	0.0424	0.9436	0.2951	-9.702	-23.77	3239	0.9995	-0.8482	-88.46	3296	0.9922
9	0.05605	0.9452	0.2881	-1.852	-157.7	3071	0.9728	5.926	-209.5	3118	0.9684
10	0.0584	0.9804	0.9053	-14.97	-104.2	3407	0.999	5.397	-215.8	3480	0.9861

Table: 3 Model parameters for ABR treating textile wastewater for an average influent COD of 4200 mg/l (Addition of Co-substrate 1 g/l Glucose)

Run No.	First Order Kinetics		Cubic Polynomial					Quadratic Polynomial			
	K(h^{-1})	R^2	A	B	C	D	R^2	a	b	c	R^2
11	0.02482	0.9395	-0.0046	0.2682	-79.71	4274	0.9857	-0.02646	-75.08	4263	0.9857
12	0.04346	0.962	0.1957	-6.791	-67.46	4088	0.988	1.429	-153.6	4220	0.9776
13	0.05797	0.9681	0.6192	-15.5	-99.59	4583	0.998	3.08	-235.3	4701	0.9863
14	0.05247	0.9409	0.4938	-13.33	-79.68	4289	0.9834	0	-168.6	4369	0.9782
15	0.06161	0.9554	0.5624	-14.8	-79.08	4004	0.9962	-2.143	-148.4	4050	0.9933

Table: 4 Model parameters for ABR treating textile wastewater for an average influent COD of 4576 mg/l (Addition of Co-substrate 2 g/l Glucose)

Run No.	First Order Kinetics		Cubic Polynomial					Quadratic Polynomial			
	K(h^{-1})	R^2	A	B	C	D	R^2	a	b	c	R^2
16	0.03922	0.9909	0.002338	1.222	-149.1	4736	0.9922	1.369	-151.4	4742	0.9955
17	0.0501	0.9543	0.303	-11.54	-40	4530	0.9976	1.19	-173.3	4733	0.981
18	0.06637	0.987	0.06366	2.456	-260.2	4881	0.9816	4.366	-274.2	4893	0.9925
19	0.05585	0.9556	-0.0823	2.434	-184.3	4189	0.9884	0.2116	-169.5	4175	0.9882
20	0.07113	0.9535	1.084	-23.67	-106	4551	0.9962	0.7143	-239.7	4639	0.9895

Table: 5 Model parameters for ABR treating textile wastewater for an average influent COD of 4774 mg/l (Addition of Co-substrate 3 g/l Glucose)

Run No.	First Order Kinetics		Cubic Polynomial					Quadratic Polynomial			
	K(h^{-1})	R^2	A	B	C	D	R^2	a	b	c	R^2
21	0.05343	0.9869	0.002338	2.346	-206.9	4843	0.9951	2.493	-209.2	4848	0.9951
22	0.07432	0.9943	-0.09785	8.973	-321.5	4636	0.9953	4.863	-278.4	4570	0.9938
23	0.09235	0.936	0.309	-4.887	-225.8	4683	0.9243	4.384	-293.6	4742	0.9523
24	0.09914	0.9998	-0.321	19.1	-466.2	4879	0.9999	10.43	-408.4	4842	0.9987
25	0.115	0.9986	-0.6475	28.09	-529.2	4619	0.9986	13.52	-449.4	4567	0.9966

4. CONCLUSION

Textile wastewater could be effectively treated using an ABR. By conducting experiments at the HRTs of 1.748 days, it was found that the maximum COD removal efficiency of 91.67%. In order to test the validity of the model the results obtained from the experimental effluent COD values were compared with the predicted values obtained from the models. From the obtained high statistical quality of the modelling (R^2=0.9543 and 0.9999 for CP model, between experimental and predicted values), it could be inferred that predicted results are in good agreement with the experimental data in case of CP. This showed that the CP model is a more applicable model for describing the kinetics of the organic removal in anaerobic baffled reactor for treating real time textile wastewater. Kinetic parameters were determined through linear regression using the experimental data. It was found that these simulated data were in good agreement with the observed ones in the model, such as, Cubic polynomial (CP). The obtained high statistical quality of the kinetic modelling (regression coefficient (R2) values between experimental and simulated values of substrate concentration), confirmed the suitability of the models. The results indicated that the kinetic models are capable of describing the bio-kinetic behaviour of the reactor.

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