JSCS-info@shd.org.rs • www.shd.org.rs/JSCS

J. Serb. Chem. Soc. 79 (7) 897–909 (2014) UDC 633.61.002.68+577.11:628.3

JSCS–4634 *Original scientific paper*

Bagasse wastewater treatment using biopolymer – A novel approach

KARICHAPPAN THIRUGNANASAMBANDHAM, VENKATACHALAM SIVAKUMAR* and JEGANATHAN PRAKASH MARAN

Department of Food Technology, Kongu Engineering College, Perundurai, Erode-638052, TN, India

(Received 19 June, revised 9 December, accepted 13 December 2013)

Abstract: In this study, the removal of turbidity, biological oxygen demand (*BOD*) and chemical oxygen demand (*COD*) in the treatment of bagasse-based wastewater from the paper and pulp industry were investigated *via* response surface methodology (RSM) under different operating conditions, such as agitation time (X_1: 15–25 min), initial pH (X_2: 4–8), chitosan dose (X_3: 1.2–2.0 g L^{-1}) and settling time (X_4: 40–80 min). The obtained experimental data were fitted to a second-order polynomial equation using multiple regression analysis and ANOVA (analysis of variance) was used to examine the significance of the developed mathematical models. The 3-D response surface plots were derived from the mathematical models in order to study the interactive effects of the process variables on the treatment efficiency. The Derringer desired function methodology was applied to determine the optimal conditions, which were found to be: an agitation time of 20 min, an initial pH of 6, a chitosan dose of 1.8 g L^{-1} and settling time of 60 min. Under these conditions, the removal of turbidity, *BOD* and *COD* were found to be 84, 90 and 93 %, respectively.

Keywords: chitosan; coagulation; Bagasse wastewater; BBD design; model development.

INTRODUCTION

The pulp and paper industry is one of the highest water consuming industries in which bagasse is a potential raw material.[1] Bagasse is a fibrous mass that is derived from the sugar industry after extraction of juice from sugarcane.[2] The wastewater generated from bagasse-based pulp and paper industry contains large amounts of organic and inorganic matter, resulting in high values of chemical oxygen demand (*COD*), biological oxygen demand (*BOD*) and turbidity, due to the processes involved in bagasse processing, such as storage, washing and bleaching with chemicals.[3] Discharge of this untreated bagasse wastewater into

* Corresponding author. E-mail: drvsivakumar@yahoo.com
doi: 10.2298/JSC130619153T

the environment has negative impact on the ecological systems. An extensive literature survey showed that little information has been reported regarding the treatment of wastewater from the bagasse-based pulp and paper industry, *i.e.*, a UASB reactor treatment process and treatment with white route fungus. However, these treatment processes have drawbacks, such as long treatment time, start-up problems, difficulty in maintaining environmental conditions and low treatment efficiency. Therefore, there is a critical need to develop an efficient and economic treatment process for bagasse-based paper and pulp industry wastewater, before its discharge into natural resources.

One of the most commonly used wastewater treatment techniques involves the process of coagulation/adsorption, which is the physical adhesion of chemicals onto the surface of a solid. Widely available biopolymers are being used for coagulation mainly because they are a cheap resource or a freely available resource. Chitosan is a biopolymer that is extracted from crustacean shells or from fungal biomass.[4] Chitosan has the potential to reduce and solve some environmental pollution problems for the creation of a "greener environment". Chitosan is a renewable polymer, which undergoes natural decomposition, is non-toxic to both the environment and humans and has no side effects or allergic effects if implanted in the body.[5,6] Chitosan has been used as a coagulant to treat various wastewaters, such as food processing industrial wastewaters, brewery wastewater, pulp and paper mill wastewater, olive oil wastewater and an effluent containing metal ions and phenol derivatives.[7] Moreover, the process parameters of chitosan-based treatment methods, such as initial pH, coagulant dose, settling time and agitation time are complex and their optimization will pave the way for effective treatment efficiency. Optimization and simulation studies of such treatment process variables are essential for industrial scale-up. To date, most studies on the optimization of wastewater treatment methods have focused on the tradetional one-factor-at-a-time approach. However, this approach does not take into account cross effects from the factors considered and results in poor optimization results. Response surface methodology (RSM) is a powerful statistical-based technique for modeling complex systems, evaluating the simultaneous effects of several factors, and thus searching for the optimum conditions for desirable responses.[8] In addition to analyzing the effects of independent variables, RSM generates a mathematical model that could be used to predict the response of a system to any new conditions.[9]

However, until now, RSM has not been used as a modeling and optimization tool for the treatment of bagasse-based paper and pulp effluent using chitosan as the coagulant. Hence, the present study was planned to investigate the individual and interactive effects of the process variables, such as agitation time, initial pH, chitosan dose and settling time, on the percentage removal of turbidity, biological oxygen demand (*BOD*) and chemical oxygen demand (*COD*) from bagasse wastewater using response surface methodology (RSM) coupled with the Box–Behnken experimental design (BBD).

EXPERIMENTAL

Wastewater sample

The wastewater used in this study was collected from the bagasse-based pulp and paper industry near Erode, Tamil Nadu, India. The characteristics of the wastewater, such as an initial pH of 5.08, a turbidity of 1768 NTU, a *BOD* of 2048 mg L^{-1} and a *COD* of 6500 mg L^{-1} indicates the presence of higher amounts of organic and inorganic matters in the bagasse wastewater. All the chemicals used in this study were of analytical grade. Chitosan powder was purchased from Sigma Chemicals, Mumbai, India.

Experimental procedure

Conventional batch studies were performed under different operating conditions, such as agitation time (15–25 min), initial pH (4–8), chitosan dose (1.2–2.0 g L^{-1}) and settling time (40–80 min) in 250 mL conical flask containing 100 mL of composite bagasse-based paper and pulp industry wastewater. The pH of the wastewater was adjusted by using either sulfuric acid (0.1 M) or sodium hydroxide solutions (0.1 M). The agitation was realized using incubator shaker equipment (SLM-INC-OS-250) with the desired dose of chitosan. Then the supernatant was filtered and used to determine its turbidity, *BOD* and *COD* values.

Analytical methods

The initial pH, turbidity, *BOD* and *COD* determinations were performed according to the procedures described by the American Public Health Association (APHA). The percentage removal efficiency (*RE*) of turbidity, *BOD* and *COD* were calculated using the following equation:[10]

$$RE = \left(\frac{c_0 - c_e}{c_0}\right)\times 100 \quad (1)$$

where, c_0 and c_e are the turbidity *BOD* and *COD* values before and after the process, respectively.

Experimental design

Response surface optimization is more advantageous than the traditional single parameter optimization in that it saves time, space and raw materials.[11] Thus, in this study, a Box–Behnken response surface experimental design (BBD) with four factors at three levels was used to investigate the influence of the operating variables, *i.e.*, agitation time, initial pH, chitosan dose and settling time on the removal of turbidity, *BOD* and *COD* from the bagasse-based wastewater using chitosan as a coagulant. The process variables and their ranges are given in Table I. The experiments were established based on a BBD and the complete design consisted of 29 experiments, the total number of experiments being calculated from the following equation:[12]

$$N = 2K\left(K-1\right)+C_0 \quad (2)$$

where, K is number of factors and C_0 is the number of central points. The initial pH, chitosan dose, agitation speed and settling time were referred to by the uncoded variables X_1, X_2, X_3 and X_4, respectively. The variables in uncoded form were converted to their coded form: x_1, x_2, x_3 and x_4 using the following equation:[13]

The general mathematical form of a second-order polynomial equation is given below:[14]

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k} \beta_{jj} X_j^2 + \sum_{i} \sum_{<j=2}^{k} \beta_{ij} X_i X_j + e_i \quad (3)$$

where, Y is the response; X_i and X_j are variables (i and j range from 1 to k); β_0 is the model intercept coefficient; β_j, β_{jj} and β_{ij} are the interaction coefficients of the linear, quadratic and the second-order terms, respectively; k is the number of independent parameters ($k = 4$ in this study); and e_i is the error. The experimental data was analyzed by multiple regression analysis (sequential sum of squares and model summary statistics) on the experimental data to evaluate the adequacy of various mathematical models, such as linear, interactive (2FI), quadratic and cubic.[15] Pareto analysis of variance (ANOVA) was used to study the statistical significance of mathematical model using student's F-test and the significance of the F-values at probability levels ($p \leq 0.05$). All the statistical analyses were realized using the Stat ease Design Expert 8.0.7.1 statistical software package (Stat-Ease Inc., Minneapolis, MN, USA).

Then the mathematical models were used for the construction of three dimensional (3D) response surface plots to predict the relationships between the independent and dependent variables.[16] The adequacy of the model equation for predicting the response values were validated under the selected optimized conditions.[17,18] Triplicate verification experiments were performed under the optimized conditions and the average value of the experiments was compared with the predicted values of the developed model equations.

TABLE I. The process variables and their ranges

Variable	Level		
	–1	0	1
Agitation time, min	15	20	25
Initial pH	4	6	8
Chitosan dose, g L^{-1}	1.2	1.6	2
Settling time, min	40	60	80

RESULTS AND DISCUSSION

The percentage removal of turbidity, biological oxygen demand (*BOD*) and chemical oxygen demand (*COD*) were investigated under different operating conditions, *i.e.*, agitation time (X_1: 15–25 min), initial pH (X_2: 4–8), chitosan dose (X_3: 1.2–2 g L^{-1}) and settling time (X_4: 40–80 min) using chitosan as a coagulant to treat bagasse-based paper and pulp industry wastewater *via* the response surface methodology (RSM). In this study, a four-factor three-level BBD was used to evaluate the effect and optimize the process variables on the responses. A total number of 29 batch experiments including three centre points were performed in triplicate using statistically designed experiments, the results of which are given in Table II.

BBD analysis

The BBD experimental data were analyzed by multi regression analysis, namely the sequential model sum of squares (Table III) and model summary statistics (Table IV), in order to select the best regression mathematical model among the various models, *i.e.*, linear, interactive, quadratic and cubic. From the results, it was found that the quadratic model shows the highest R^2, adjusted R^2, and predicted R^2 values and also had the lowest *p*-values compared to the other models considered. Therefore, the quadratic model was chosen to describe the effects of the process variables on the removal efficiency of turbidity, *BOD* and *COD* from bagasse-based paper and pulp industry wastewater.[19]

TABLE II. BBD experimental design results

No.	Agitation time, min	Initial pH	Chitosan dose, g L^{-1}	Settling time, min	Turbidity removal, %	*BOD* removal, %	*COD* removal, %
1	20	4	2.0	60	62.2	71.2	67.9
2	20	4	1.6	40	22.5	31.3	27.9
3	15	4	1.6	60	45.6	54.2	50.9
4	15	8	1.6	60	46.3	55.4	51.9
5	15	6	1.6	40	16.2	25.3	21.9
6	25	8	1.6	60	41.3	50.4	47.3
7	20	8	2.0	60	51.2	60.8	56.9
8	20	6	1.2	40	29.9	38.7	35.6
9	25	6	2.0	60	56.2	65.2	61.5
10	20	6	1.6	60	81.5	90.3	87.2
11	20	8	1.2	60	66.2	75.4	71.9
12	20	4	1.6	80	58.9	67.7	64.6
13	20	6	2.0	40	31.2	40.6	36.9
14	20	6	1.6	60	81.5	90.3	87.2
15	25	6	1.6	80	54.2	63.8	59.9
16	20	6	1.6	60	81.5	90.3	87.2
17	25	6	1.2	60	56.2	65.6	61.9
18	20	6	2.0	80	75.5	84.3	81.2
19	20	6	1.6	60	81.5	90.4	87.2
20	20	8	1.6	40	24.2	33.2	29.9
21	15	6	1.2	60	54.4	63.3	60.3
22	25	4	1.6	60	31.3	40.1	37.5
23	25	6	1.6	40	26.2	35.3	31.9
24	20	4	1.2	60	44.2	53.4	49.9
25	20	8	1.6	80	68.3	77.2	74.3
26	20	6	1.2	80	81.7	90.4	87.7
27	15	6	1.6	80	70.2	79.2	75.9
28	20	6	1.6	60	81.5	90.3	87.2
29	15	6	2.0	60	61.5	69.8	66.7

Mathematical equation development

An empirical relationship between the responses and independent variables was expressed by a second-order polynomial equation with interaction terms. Three empirical models were developed in order to understand the interactive correlation between the responses and the process variables. The final model obtained in terms of coded factors is given below (Eqs. (5)–(7)). These equations will help to predict the removal efficiency of different sets of combinations of the four process variables on the responses.[20]

$$Y_1 = 81.50 - 2.40X_1 + 2.73X_2 + 0.43X_3 + 21.55X_4 + 2.32X_1X_2 - \\ -1.77X_1X_3 - 6.50X_1X_4 - 8.25_1X_3 + 1.92X_2X_4 - \\ -1.88X_3X_4 - 19.78X_1^2 - 19.46X_2^2 - 5.93X_3^2 - 19.86X_4^2 \quad (5)$$

$$Y_2 = 90.32 - 2.23X_1 + 2.88X_2 + 0.42X_3 + 21.51X_4 + 2.27X_1X_2 - \\ -1.72X_1X_3 - 6.35X_1X_4 - 8.10X_2X_3 + 1.90X_2X_4 - \\ -2.00X_3X_4 - 19.70X_1^2 - 19.36X_2^2 - 5.81X_3^2 - 19.78X_4^2 \quad (6)$$

$$Y_3 = 87.20 - 2.30X_1 + 2.79X_2 + 0.32X_3 + 21.62X_4 + 2.20X_1X_2 - \\ -1.70X_1X_3 - 6.50X_1X_4 - 8.25_1X_3 + 1.93X_2X_4 - \\ -1.95X_3X_4 - 19.83X_1^2 - 19.42X_2^2 - 5.98X_3^2 - 19.82X_4^2 \quad (7)$$

where Y_1, Y_2, and Y_3 are turbidity, *BOD* and *COD* removal, respectively, and X_1, X_2, X_3 and X_4 are the agitation time, initial pH, chitosan dose and settling time, respectively.

TABLE III. Sequential model sum of squares results for the responses

Source	Sum of squares	*Df*	Mean square	*F*-value	Prob > *F*	Remarks
Sequential model sum of squares for turbidity removal						
Mean	86420.88	1.00	86420.88	–	–	–
Linear	5734.23	4.00	1433.56	5.61	0.0025	–
2FI	504.39	6.00	84.06	0.27	0.9444	–
Quadratic	5512.65	4.00	1378.16	167.02	< 0.0001	Suggested
Cubic	91.73	8.00	11.47	2.89	0.1064	Not fit
Sequential model sum of squares for *BOD* removal						
Mean	117176.67	1.00	117176.67	–	–	–
Linear	5717.16	4.00	1429.29	5.66	0.0024	–
2FI	486.80	6.00	81.13	0.26	0.9477	–
Quadratic	5467.70	4.00	1366.93	173.50	< 0.0001	Suggested
Cubic	87.25	8.00	10.91	2.84	0.1103	Not fit
Sequential model sum of squares for *COD* removal						
Mean	105398.38	1.00	105398.38	–	–	–
Linear	5770.26	4.00	1442.56	5.67	0.0023	–
2FI	502.24	6.00	83.71	0.27	0.9445	–
Quadratic	5504.32	4.00	1376.08	184.78	< 0.0001	Suggested
Cubic	83.53	8.00	10.44	3.02	0.0975	Not fit

TABLE IV. Model summary statistics for the responses

Source	*S.D.*	R^2	Adjusted R^2	Predicted R^2	*PRESS*	Remarks
Model summary statistics for turbidity removal						
Linear	15.9851	0.4832	0.3971	0.3410	7820.13	
2FI	17.6826	0.5257	0.2622	0.1110	10549.06	
Quadratic	2.8725	0.9903	0.9805	0.9439	665.66	Suggested
Cubic	1.9914	0.9980	0.9906	0.7113	3426.22	Not fit
Model summary statistics for *BOD* removal						
Linear	15.8965	0.4852	0.3995	0.3435	7734.63	
2FI	17.6037	0.5266	0.2635	0.1108	10476.54	
Quadratic	2.8069	0.9906	0.9813	0.9461	635.61	Suggested
Cubic	1.9602	0.9980	0.9909	0.7183	3318.80	Not fit
Model summary statistics for *COD* removal						
Linear	15.9567	0.4857	0.3999	0.3447	7785.60	
2FI	17.6519	0.5279	0.2657	0.1178	10481.87	
Quadratic	2.7290	0.9912	0.9824	0.9494	600.78	Suggested
Cubic	1.8590	0.9983	0.9919	0.7487	2985.87	Not fit

Adequacy of developed mathematical models

It is very important that the developed mathematical models described the coagulation process effectively. Thus, the adequacy of the models was evaluated by constructing diagnostic plots, *i.e.*, predicted *versus* actual for the data predicted by models and the experimental data (Fig. 1A–C). From the figures, it could be observed that the data points on these plots lie very close to the diagonal lines, which indicates good agreement between the experimental data and the data predicted by the developed models.[21] This confirms the normal distribution of the observed data and the adequacy of the developed models.

Statistical significance of the quadratic model

Pareto analysis of variance (ANOVA) was used to analyze the significance of the developed model equations by using their corresponding *F* and *p*-values, which are listed in Table V. The higher model *F* values and lower *p*-values ($p < < 0.0001$) of both the mathematical models demonstrated that the developed model was highly significant. The robustness of the model was analyzed by the determination of the coefficient (R^2), the adjusted determination coefficient (R_a^2), the predicted determination coefficient (R_p^2), the coefficient of variance (*CV*) and the adequate precision (*AP*). The high R^2 value of the developed models showed that the relationship between the operating variables and the response is well correlated. The lower *CV* values and the higher *AP* values clearly confirm that the deviations between the experimental and predicted values were low and showed the reliability of the conducted experiments.[22]

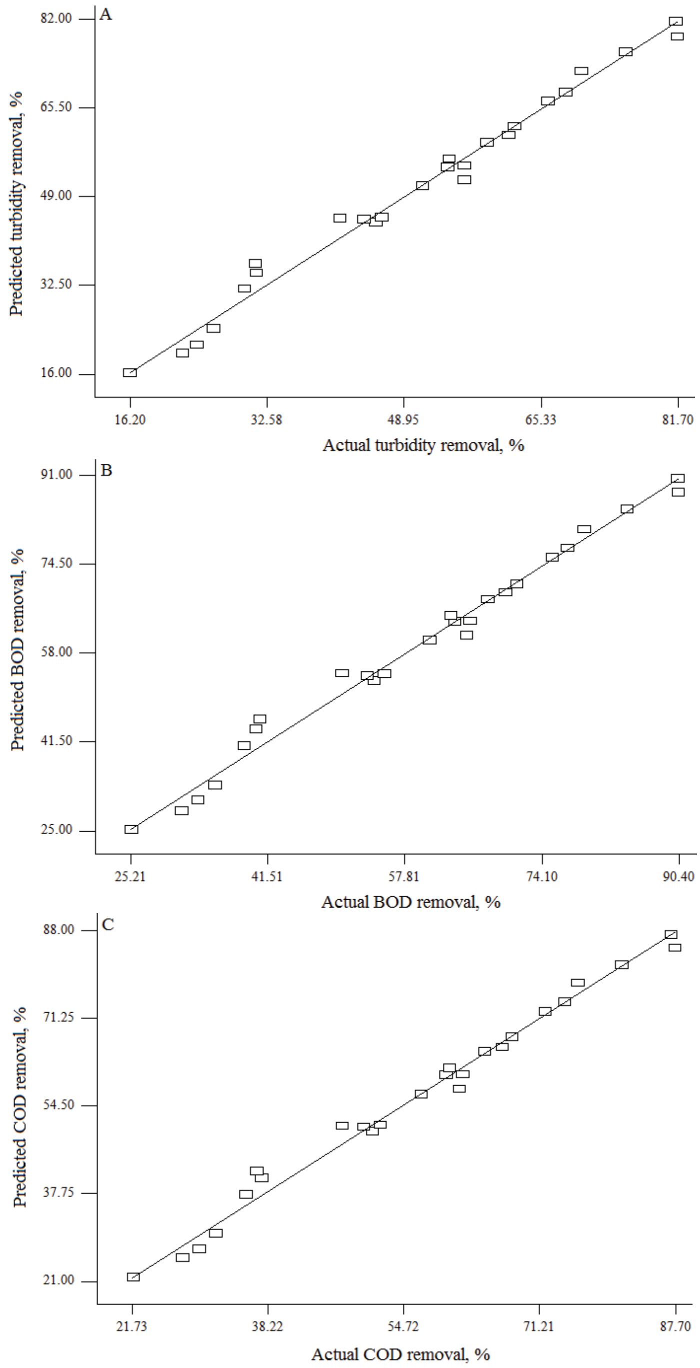

Fig. 1. Plots of the predicted *versus* the actual values for the responses. A – turbidity removal, B – *BOD* removal and C – *COD* removal.

TABLE V. ANOVA results for the responses

Response	Turbidity removal		*COD* removal		*BOD* removal	
	F-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value
Model	101.73	<0.0001	112.96	<0.0001	105.82	<0.0001
X_1	8.38	0.0118	8.52	0.0112	7.60	0.0155
X_2	10.88	0.0053	12.57	0.0032	12.60	0.0032
X_3	0.27	0.6102	0.16	0.6946	0.27	0.6089
X_4	675.16	<0.0001	753.28	<0.0001	704.92	<0.0001
X_1X_2	2.62	0.1278	2.60	0.1292	2.63	0.1273
X_1X_3	1.53	0.2371	1.55	0.2335	1.51	0.2395
X_1X_4	20.49	0.0005	22.70	0.0003	20.48	0.0005
X_2X_3	32.99	<0.0001	36.56	<0.0001	33.31	<0.0001
X_2X_4	1.80	0.2015	1.99	0.1801	1.83	0.1973
X_3X_4	1.70	0.2128	2.04	0.1749	2.03	0.1761
X_1^2	307.61	<0.0001	342.41	<0.0001	319.51	<0.0001
X_2^2	297.64	<0.0001	328.37	<0.0001	308.71	<0.0001
X_3^2	27.67	0.0001	31.14	<0.0001	27.83	0.0001
X_4^2	310.01	<0.0001	342.04	<0.0001	322.01	<0.0001
CV	5.2		4.5		4.4	
AP	31.6		33.3		32.2	

Effect of process variables

Three dimensional (3D) response surface plots were plotted from the developed models in order to study the individual and interaction effects among the process variables on the responses and to determine the optimal conditions of each process variable for the maximum removal of turbidity, *BOD* and *COD* from bagasse wastewater using chitosan as the coagulant. The response surface plots are shown in Fig. 2A–F.

Effect of agitation time

In order to investigate the effect of agitation time on the treatment efficiency, experiments were performed for various agitation times (15–25 min). From the results, it was observed that the removal efficiencies increased linearly with increasing agitation time from 15–20 min (Figs. 2A–C). Increasing the agitation time up to 20 min increases the collision between the chitosan and the organic matters present in the bagasse-based paper and pulp industry wastewater, which enhanced the removal efficiencies of turbidity, *BOD* and *COD*. However, agitation times longer than 20 min resulted in lower removal efficiencies of turbidity, *BOD* and *COD*.

Effect of initial pH

Experiments were performed to study the effect of the initial pH (4, 6 and 8) on the removal efficiency of turbidity, *BOD* and *COD*. From the results, it was observed that the removal efficiencies increased linearly with increasing pH from

4 to 6 (Fig. 2A–C). Increasing the pH up to 6 increases the solubility of chitosan, which increases the protonation of the chitosan surface and enhances the removal efficiencies of turbidity, *BOD* and *COD*.[23] However, an initial pH higher than 6 resulted in lower removal efficiencies of turbidity, *BOD* and *COD*, due to the decrease in the solubility of chitosan.[24]

Effect of chitosan dose

The chitosan dose is one of the important process variables for the coagulation process and it is associated with the removal efficiency of turbidity, *BOD* and *COD*. As can be seen in Figs. 2D–F, the removal efficiencies increased rapidly with increasing the chitosan dose in the range of 1.2–1.8 g L^{-1}. This phenomenon could be explained by the increased number of reactive site available for the coagulation process with increasing chitosan dose, which considerably increases the amounts of organic matter that can be adsorbed.[25,26] Increasing the chitosan dose above 1.8 g L^{-1} had negligible effects on the removal efficiencies of turbidity, *BOD* and *COD*.

Effect of settling time

The settling time is also a primary factor influencing the coagulation process. To examine the effect of settling time on the treatment efficiency, experiments were performed in which various settling times were examined and the results are shown in Figs. 2D–F. From Figs. 2D–F, it was observed that, the removal efficiency was increased with increasing settling time from 40–60 min. This could be explained by the fact that increases in settling time would lead to the formation of more compact flocs *via* the bridging mechanism, which increases the removal efficiencies of turbidity, *BOD* and *COD*.[27] A settling time longer than 60 min allows for desorption of organic matter from the surface of the chitosan,[28] which decreases the removal efficiencies of turbidity, *BOD* and *COD*.

Optimization

The Derringer desired function methodology[29,30] was applied to determine the optimal conditions and they were found to be an agitation time of 20 min, an initial pH of 6, a chitosan dose of 1.8 g L^{-1} and a settling time of 60 min. Under these conditions, the removal efficiencies of turbidity, *BOD* and *COD* were 83.6, 93.2 and 90.4 %, respectively, with a desirability value of 0.986 were predicted for the developed mathematical models. Under these conditions, the experimental removal efficiencies of turbidity, *BOD* and *COD* were 84, 93 and 90 %, respectively, which are in close agreement with the values predicted by the developed mathematical models. These results validate the optimized conditions.

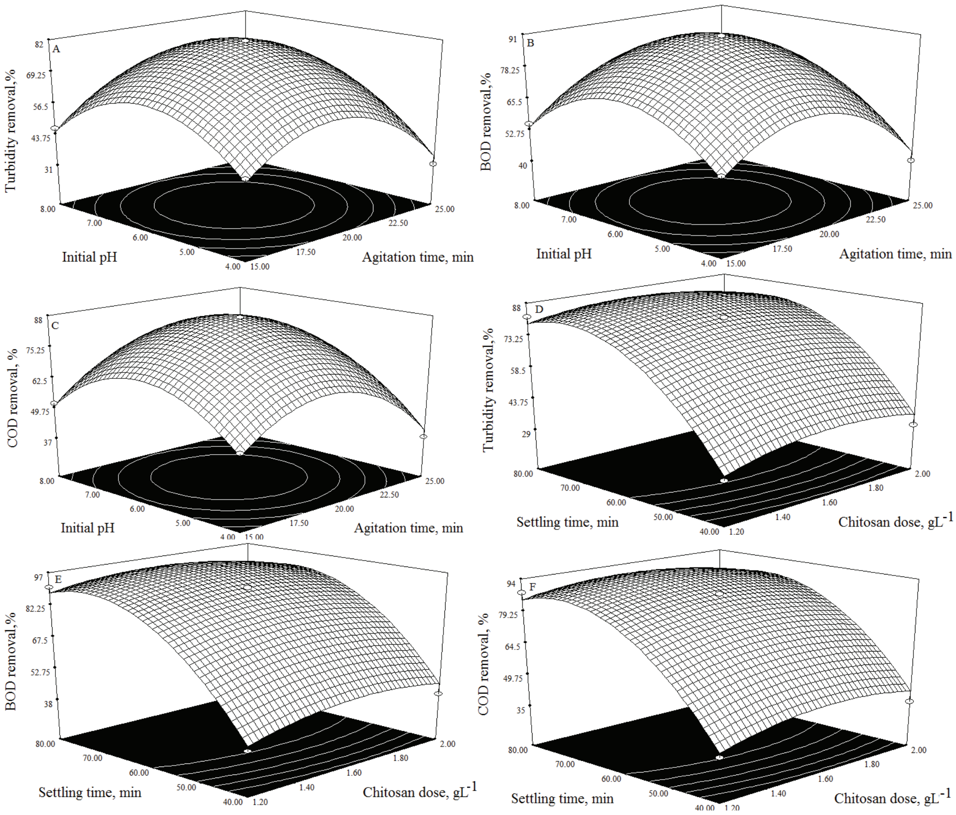

Fig. 3. Effect of the process parameters on the responses; A, B and C – effect of initial pH and agitation time on turbidity removal, *BOD* removal and *COD* removal, respectively; D, E and F – effect of initial settling time and chitosan dose on turbidity removal, *BOD* removal and *COD* removal, respectively.

CONCLUSIONS

In this study, BBD was employed to investigate and optimize the process variables, *i.e.*, agitation time, initial pH, chitosan dose and settling time, on the removal efficiencies of turbidity, *BOD* and *COD* to treat bagasse-based wastewater using chitosan as a coagulant. From the results, it was observed that the variables of the operating process have significant effects on the treatment efficiency. Quadratic models were developed from the experimental data and their adequacies were analyzed by the Pareto analysis of variance (ANOVA). 3D response surface plots were generated in order to study the interactive effect of the process variables on the treatment efficiency. The Derringer desired function methodology was applied to determine the optimal conditions, which were found to be: an agitation time of 20 min, an initial pH of 6, a chitosan dose of 1.8 g L^{-1} and a settling time of 60 min. Under these conditions, the removal efficiencies of turbidity, *BOD* and *COD* were 84, 93 and 90 %, respectively. These results show the effectiveness of chitosan as a coagulant for the eco-friendly treatment of bagasse wastewater.

ИЗВОД

ПРЕРАДА ОТПАДНЕ ВОДЕ ОД ТРШЧАНОГ ОТПАДА КОРИШЋЕЊЕМ БИОПОЛИМЕРА – НОВИ ПРИСТУП

KARICHAPPAN THIRUGNANASAMBANDHAM[1], VENKATACHALAM SIVAKUMAR[2] и JEGANATHAN PRAKASH MARAN[3]

[1]*Department of Food Technology, Kongu Engineering College, Perundurai, Erode-638052, TN, India, E-mail: thirusambath5@gmail.com,* [2]*Department of Food Technology, Kongu Engineering College, Perundurai, Erode-638052, TN, India и* [3]*Department of Food Technology, Kongu Engineering College, Perundurai, Erode-638052, TN, India, E-mail: prakashmaran@gmail.com*

У овом истраживању, уклањање замућености, биолошке потрошње кисеоника (*BOD*) и хемијске потрошње кисеоника (*COD*) испитани су под различитим радним условима, као што су време мешања (X_1: 15–25 min), почетна pH (X_2: 4–8), доза хитозана (X_3: 1,2–2,0 g L^{-1}) и време таложења(X_4: 40–80 min) у преради отпадне воде тршчаног отпада индустрије хартије, методологијом анализе површине одговора. Експериментални подаци су апроксимирани полиномном једначином другог реда коришћењем мултипне регресионе анализе, а метода ANOVA (анализа варијансе) је употребљена за испитивање значајности развијеног математичког модела. Из математичких модела су добијени графици тродимензионалне површине одговора, како би се проучили утицаји интеракције процесних променљивих на ефикасност прераде. За одређивање оптималних услова примењена је методологија Дерингерове (*Derringer*) жељене функције и дала следеће резултате: време мешања 20 min, почетни pH 6, доза хитозана 1,8 g L^{-1}, а време мировања 60 min. Под овим условима, нађено је да је замућеност 84 %, *BOD* 90 % и *COD* 93 %.

(Примљено 19. јуна, ревидирано 9. децембра, прихваћено 13 децембра 2013)

REFERENCES

1. A. G. Kulkarni, R. M. Mathur, S. Panwar, *Business meeting on energy recovery from pulp and paper mill effluent*, organized by the Indian Agro & Recycled Paper Mill Association, New Delhi, India, 2001
2. F. Shahidi, R. Abuzaytoun, *Adv. Food Nutr. Res*. **49** (2005) 93
3. F. H. Chi, W. P. Cheng, *J. Polym. Environ.* **14** (2006) 411
4. R. Divakaran, V. N. S. Pillai, *Water Res.* **36** (2002) 2414
5. M. Ashmore, J. Hearn, F. Karpowicz, *Langmuir* **17** (2001) 1069
6. P. S. Strand, K. M. Vårum, K. Østgaard, *Colloids Surfaces, B* **27** (2003) 71
7. E. Guibal, J. Roussy, *React. Funct. Polym.* **67** (2007) 33
8. K. Thirugnanasambandham, V. Sivakumar, J. Prakash Maran, *Carbohyd. Polym*. **112** (2014) 622
9. N. V. Ravi Kumar, *React. Funct. Polym.* **46** *(*2000) 1
10. B. Amit, S. Mika, *Adv. Colloid Interfac*. **152** (2009) 26
11. K. Thirugnanasambandham, V. Sivakumar, J. Prakash Maran, *J. Serb. Chem. Soc.* **78** (2013) 613
12. E. Ahmet, V. T. Nuket, T. Aydemir, S. Becerik, D. Ayse, *Chem. Eng. J.* **210** (2012) 590

13. J. Prakash Maran, S. Manikandan, K. Thirugnanasambandham, C. Vigna Nivetha, R. Dinesh, *Carbohyd. Polym*. **92** (2013) 604
14. M. S. Bhatti, A. S. Reddy, A. K. Thukral, *J. Hazard. Mater*. **172** (2009) 839
15. E. Ashtoukhy, N. K. Amin, *J. Hazard. Mater.* **179** (2010) 113
16. C. Escobar, C. Soto-Salazar, M. I. Toral, *J. Environ. Manage.* **81** (2006) 384
17. J. Prakash Maran, V. Sivakumar, R. Sridhar, V. Prince Immanuel, *Ind. Crop. Prod.* **42** (2013) 159
18. R. Sridhar, V. Sivakumar, V. Prince Immanuel, J. Prakash Maran, *Environ. Prog. Sustain. Energy* **31** (2012) 558
19. M. Helen Kalavathy, I. Regupathi, M. G. Pillai, L. R. Miranda, *Colloids Surfaces, B* **70** (2009) 35
20. R. Sridhar, V. Sivakumar, J. Prakash Maran, K. Thirugnanasambandham, *Int. J. Environ. Sci. Technol.* (2013), doi: 10.1007/s13762-013-0301-5
21. E. Gengec, M. Kobya, E. Demirbas, A. Akyol, K. Oktor, *Desalination* **286** (2012) 200
22. J. Prakash Maran, V. Sivakumar, K. Thirugnanasambandham, R. Sridhar, *Prep. Biochem. Biotech*. **44** (2014) 56
23. J. Prakash Maran, V. Mekala, S. Manikandan, *Carbohyd. Polym.* **92** (2013) 2018
24. K. Thirugnanasambandham, V. Sivakumar, J. Prakash Maran, S. Kandasamy, *Carbohyd. Polym*. **99** (2013) 593
25. T. Olmez, *J. Hazard. Mater*. **162** (2009) 1371
26. M. Kumar, F. Ponselvan, J. RamMalviya, V. Srivastava, I. Mall, *J. Hazard. Mater.* **165** (2009) 345
27. M. Y. Nordin, V. C. Venkatesh, S. Sharif, S. Elting, A. Abdullah, *J. Mater. Process. Technol.* **145** (2004) 46
28. K. Thirugnanasambandham, V. Sivakumar, J. Prakash Maran, *Carbohyd. Polym*. **97** (2013) 451
29. A. L. Ahmad, S. Sumathi, B. H. Hameed, *Water Res.* **39 (**2005) 2483
30. K. Thirugnanasambandham, V. Sivakumar, J. Prakash Maran, *J. Serb. Chem. Soc.* **79** (2014) 743.