Journal of Environmental Science and Pollution Research 2(1) (2016) 50–53

ISSN: 2455-0272

Contents List available at JACS Directory

Journal of Environmental Science and Pollution Research

journal homepage: http://www.jacsdirectory.com/jespr

Optimization of Anaerobic Conditions for the Treatment of Textile Dye Wastewater using Mixed Culture

S. Venkatesh Babu[1,*], S. Raghupathy[1], M. Rajasimman[2]

[1]*Department of Chemical Engineering, Arunai Engineering college, Tiruvannamalai – 606 302, Tamil Nadu, India.*
[2]*Department of Chemical Engineering, Annamalai University, Annamalainagar – 608 002, Tamil Nadu, India.*

ARTICLE DETAILS

Article history:
Received 17 January 2016
Accepted 30 January 2016
Available online 25 February 2016

Keywords:
Optimization
Anaerobic Digestion
Decolourization

ABSTRACT

In this study, anaerobic digestion of textile dye wastewater was carried in a batch reactor using mixed culture. Textile dye wastewater was collected and characterized. Response surface methodology (RSM) was employed to study the effect of process variables like pH, temperature, textile dye wastewater dilution ratio and MLVSS on dye decolourization and COD removal efficiency. The optimum condition was found for the maximum decolourization and COD removal efficiency. They are: pH – 7.1, temperature – 31.5 °C, wastewater dilution ratio 1:2, and MLVSS – 6200 mg/L. The maximum decolourization and COD reduction was found to be 70.3% and 72.6% at the RSM optimized conditions.

1. Introduction

Dyes are widely utilized in numerous industries such as textile, paper, printing, cosmetics, pharmaceuticals, colour photography and petroleum. Among these industries, textile dyeing industries produces huge amount of wastewater. They employs large amount of water during processing and also generate substantial amount of wastewater. During dyeing, about 10–15% of the dyes are lost in the wastewater [1] and causes detrimental effects to the human being and environment. Along with color, it also comprises pollutants like degradable organics, nutrients, pH altering agent, salts, sulfur, toxicants and refractory organics [2, 3].

Dye wastewater is generally treated by physical, chemical and biological methods. Physical and chemical methods are mostly ineffective, expensive and produce side reactions, high sludge and by products formation and not suited to degrade all dyes [4, 5]. The biological treatment is found as the best alternative because of low operational cost [6, 7]. Many works have been reported for decolorization of dye using aerobic microbes [8, 9]. Few works are carried out on anaerobic digestion of textile dye wastewater [10-12]. Hence this study is focused on anaerobic digestion of textile dye wastewater using mixed culture. The process variables are optimized using Response Surface Methodology (RSM). RSM is widely used to study the effects of the variables towards their response. This method is suitable for fitting a quadratic surface and it helps to optimize the effective parameters with a minimum number of experiments, as well as to analyze the interaction between the parameters [13]. It is successfully employed in biotechnology and environmental biotechnology [14, 15].

2. Experimental Methods

2.1 Materials

Textile dye wastewater was collected from a small scale industry located at Tiruppatur, Tamilnadu, India. The collected wastewater was characterized by analyzing pH, colour, COD, BOD, TS etc. The analysis was performed according to the procedure given in APHA (1999) [16] and given in Table 1. The wastewater was stored at 4±1 °C in air tight plastic containers. Mixed culture was collected from a textile dye wastewater pond. It is maintained at 4 °C in a freezer.

*Corresponding Author
Email Address: vbchemer75@gmail.com (S. Venkatesh Babu)

Table 1 Characteristics of textile dye industry wastewater

Parameters*	Values
pH	7.1-7.6
Colour	Brown
Total Suspended Solids	510
Total Dissolved Solids	3880
BOD	1132
COD	2450
Sulphates	232
Chlorides	1465

**All values except pH and colour are in mg/L*

In this study, Box-Behnken design was employed for the optimization of process variables. In order to determine the existence of a relationship between the factors and the response variables, the data collected is analyzed in a statistical manner, using regression. A regression design is normally employed to model a response as a mathematical function of a few continuous factors and good model parameter estimates are desired.

The coded values of the process variables are determined by the following equation.

$$x_i = \frac{X_i - X_o}{\Delta X} \quad (1)$$

where x_i – coded value of the ith variable, X_i – uncoded value of the ith test variable and X_0 – uncoded value of the ith test variable at center point.

The regression analysis was performed to estimate the response function as a second order polynomial.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1, i<j}^{k-1} \sum_{j=2}^{k} \beta_{ij} X_i X_j \quad (2)$$

Where Y is the predicted response, b_i, b_j, b_{ij} are coefficients estimated from regression. They represent the linear, quadratic and cross products of x_1, x_2, x_3 on response.

The regression and graphical analysis with statistical significance are carried out using Design-Expert software (version 7.1.5, Stat-Ease, Inc., Minneapolis, USA). To find the relationship between the experimental variables and responses, the response surface and contour plots are generated from the models. The optimum values of the process variables are obtained from the response surface.

2.2 Experimental Procedure

Experiments were carried out in a 500 mL Erlenmeyer flask, according to the Box-Behnken design given in Table 2. The process parameters chosen for this study were pH, temperature, wastewater dilution ratio and inoculum concentration. The pH of the wastewater was adjusted to 6.5, 7.5 and 8.5 by adding acid or base as required. Experiments were carried out by varying the temperature to 28 °C, 32 °C and 36 °C respectively. Wastewater dilution was varied as raw, 1:1 and 1:2 with normal water. Mixed liquor volatile suspended solids (MLVSS) was varied between 4500 to 8500 mg/L. Dye concentration was measured in bio-spectrophotometer (Model: BL-200, ELICO, India) at a wavelength of 390 nm. COD of the sample was analysed using the procedure given in APHA.

Table 2 BBD based experimental conditions and results for anaerobic digestion of textile dye wastewater

Run no.	A	B	C	D	%Decolorization		COD removal efficiency	
					Experimental	Predicted	Experimental	Predicted
1	0	0	0	0	60.0	60.00	66.9	62.90
2	0	-1	1	0	58.0	56.70	59.8	61.66
3	1	1	0	0	42.0	48.41	46	49.97
4	0	1	-1	0	40.0	43.89	40.7	47.08
5	0	0	1	1	66.0	66.39	61	62.65
6	-1	1	0	0	43.0	42.91	41.1	41.38
7	-1	0	0	1	57.0	59.12	55	55.78
8	0	1	1	0	64.0	59.55	60.2	57.60
9	1	0	1	0	56.0	55.55	55	55.03
10	0	0	0	0	60.0	60.00	65.8	62.90
11	0	-1	-1	0	31.0	38.04	35.6	39.37
12	1	-1	0	0	35.0	36.81	34	36.36
13	0	0	0	0	60.0	60.00	66.7	62.90
14	1	0	-1	0	51.0	44.64	50.3	44.86
15	0	0	-1	-1	39.0	40.33	38	38.99
16	-1	0	0	-1	40.0	44.47	42.6	45.05
17	1	0	0	-1	48.0	48.47	45	45.46
18	0	-1	0	1	50.0	51.42	48.5	51.01
19	0	0	1	-1	61.0	64.74	60.2	64.71
20	-1	0	1	0	61.5	63.55	62.8	64.46
21	-1	-1	0	0	50.5	45.81	52.7	51.35
22	1	0	0	1	53.5	51.62	50.4	49.10
23	0	1	0	1	56.5	56.47	55.4	53.64
24	-1	0	-1	0	44.0	40.14	45.6	41.79
25	0	-1	0	-1	47.5	43.22	46.6	44.57
26	0	0	-1	1	58.5	56.48	57.4	55.53
27	0	1	0	-1	52.6	46.87	51.9	45.61

3. Results and Discussion

The effect of pH, temperature, wastewater dilution ratio and inoculum concentration on decolourization and COD removal efficiency were studied. The experimental and predicted values of percentage decolourization and COD removal efficiency were given in Table 2. The second order polynomial coefficients for each term of the equation were determined using the Design Expert 7.1.5 and it was given in Table 3.

The results were analyzed by analysis of variance (ANOVA) and were given in Table 3. The ANOVA of the quadratic regression model indicates the model is significant. In this work, the model F-value 6.81 and 13.06 for decolourization and COD RE implies that the models were significant. The smaller the magnitude of the P, more significant is the corresponding coefficient. P value less than 0.05 indicate the model terms are significant. From the P values it is found that, the variables, C, D, A^2, B^2 were significant model terms for decolourization and C, D, AB, CD, A^2, B^2, C^2, D^2 were significant model terms for COD removal. From the ANOVA table it was found that the linear effect of dye wastewater concentration and MLVSS are more significant for textile dye wastewater treatment. Also the interactive effect of temperature and dye wastewater concentration is significant foe dye decolourization.

The fit of the model is also expressed by the coefficient of regression R2, which is found to be 0.9019 for decolourization and 0.9289 for COD reduction, indicating that more than 90% of the variability in the response could be explained by the model. This implies that the prediction of experimental data is quite satisfactory. Adeq precision measures the signal to noise ratio. A ratio greater than 4 is desirable. In this work, the ratio was found to be 8.69 and 11.445 for decolourization and COD reduction, which indicates an adequate signal.

Table 3 ANOVA for the decolourization and COD reduction of textile dye wastewater.

Source	% Decolorization		% COD reduction	
	Coefficient factor	P>F	Coefficient factor	P>F
Model	60.00	0.0005	78.72	<0.0001
A	-0.88	0.5323	0.092	0.1628
B	2.18	0.1338	-0.76	0.1844
C	8.58	<0.0001	3.48	<0.0001
D	4.45	0.0057	14.30	0.0048
A*B	3.63	0.1479	-10.44	0.0070
A*C	-3.13	0.2079	-1.91	0.1171
A*D	-2.88	0.2445	-2.55	0.3655
B*C	-0.75	0.7560	-4.10	0.5402
B*D	0.35	0.8845	0.75	0.8338
C*D	-3.63	0.1479	-2.00	0.0262
A*A	-7.55	0.0012	-2.68	<0.0001
B*B	-8.97	0.0003	2.55	<0.0001
C*C	-1.48	0.4381	-0.68	0.0070
D*D	-1.53	0.4232	-1.40	0.0006

To investigate the interactive effect of two factors on the decolourization and degradation of dye wastewater, response surface methodology was used and contour plots were drawn. Response surface plots as a function of two factors at a time, maintaining all other factors at fixed levels are more helpful in understanding both the main and the interactive effects of two factors. The response surface curves for the decolourization and degradation of textile dye wastewater were shown in Figs. 1-12. The nature of the response surface curves shows the interaction between the variables. The elliptical shape of the curve indicates good interaction between the two variables and circular shape indicates no interaction between the variables. From the figures it is observed that the elliptical nature of the contour in graphs depicts the mutual interactions of all the variables. There is a relative significant interaction between every two variables, and there is a maximum predicted yield as indicated by the surface confined in the smallest ellipse in the contour diagrams.

3.1 Decolourization of Textile Dye Wastewater

Fig. 1 shows the interactive effect of pH and temperature on textile dye decolourization. From the figure, it was inferred that increase in pH (up to 71) increases the dye decolourization efficiency. After that the decolourization efficiency decreases. Similar trend was observed in Figs. 2 and 3. The pH has a major effect on the efficiency of dye decolorization, and the optimal pH for color removal is often between 6.0 and 7 for most of the dyes. It is clear from Fig. 1 that percentage decolourization of dye increased with an increase in temperature from 28 to 31.5 °C. The percentage decolourization of dye decreased with further increase in temperature. Decolourizing activity was significantly suppressed at higher temperatures. This may be due to the loss of cell viability. From Fig. 3, it was observed that, the percentage of decolourization increases with increase in dilution ratio. Similar trend is observed in Fig. 4, 6. The increase in MLVSS upto 6520 mg/L increases the decolourization efficiency. This is clearly depicted in Figs. 3, 5, and 6.

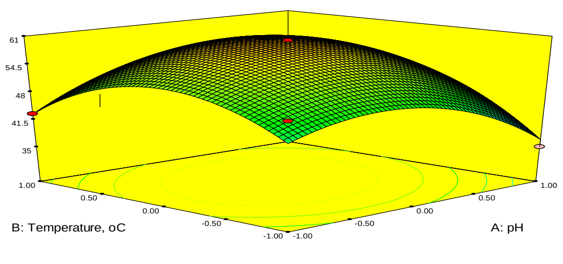

Fig. 1 Contour plot showing the interactive effect of pH and temperature on decolorization of textile dye wastewater.

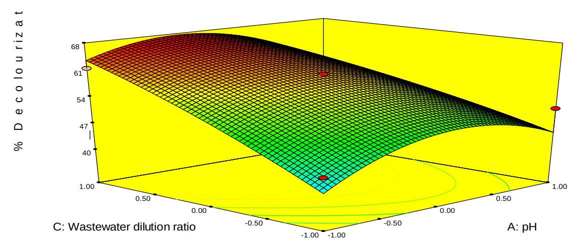

Fig. 2 Contour plot showing the interactive effect of pH and wastewater dilution ratio on decolorization of textile dye wastewater

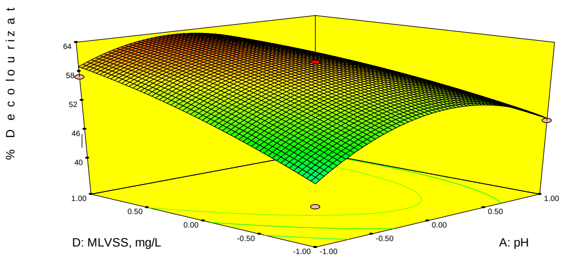

Fig. 3 Contour plot showing the interactive effect of pH and MLVSS on decolorization of textile dye wastewater

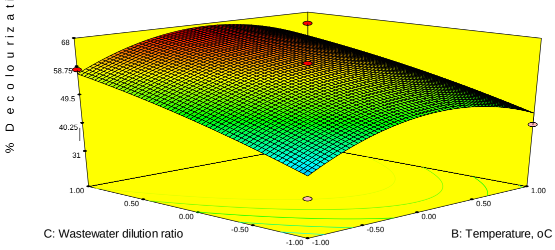

Fig. 4 Contour plot showing the interactive effect of temperature and wastewater dilution ratio on decolorization of textile dye wastewater

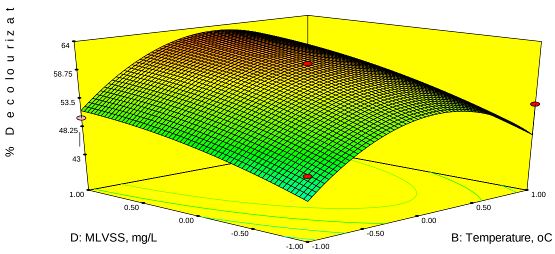

Fig. 5 Contour plot showing the interactive effect of temperature and MLVSS on decolorization of textile dye wastewater

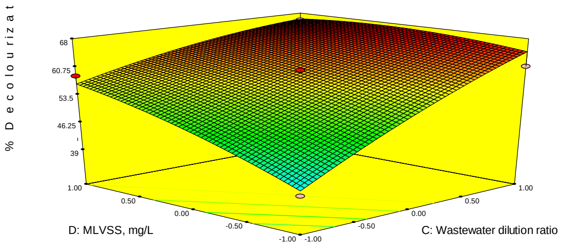

Fig. 6 Contour plot showing the interactive effect of wastewater dilution ratio and MLVSS on decolorization of textile dye wastewater

3.1 Degradation of Textile Dye Wastewater

pH is one of the important factor in the treatment of textile dye wastewater by microorganism. The interactive effect of pH and temperature on biodegradation of textile wastewater was shown in Fig. 7. From the figure it was observed that increase in pH upto 7.15 increases the COD reduction. Further increase in pH leads to decrease in COD reduction. The interactive effects of other parameters were shown in Figs. 8-12. The trend observed for other parameters was similar to the decolourization profile. The optimum conditions were also same.

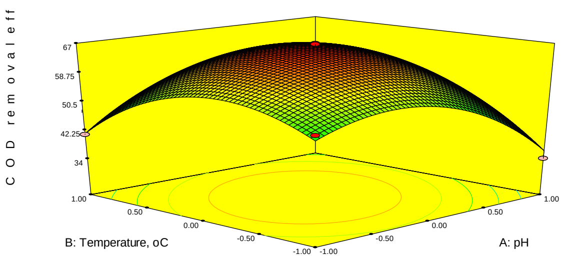

Fig. 7 Contour plot showing the interactive effect of pH and temperature on COD removal efficiency of textile dye wastewater

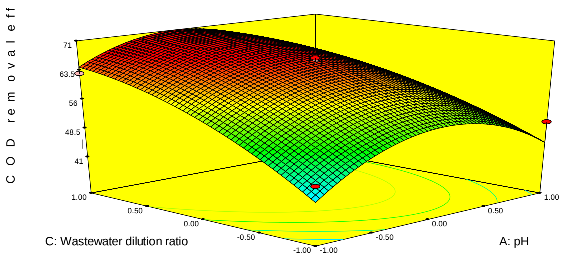

Fig. 8 Contour plot showing the interactive effect of pH and wastewater dilution ratio on COD removal efficiency of textile dye wastewater

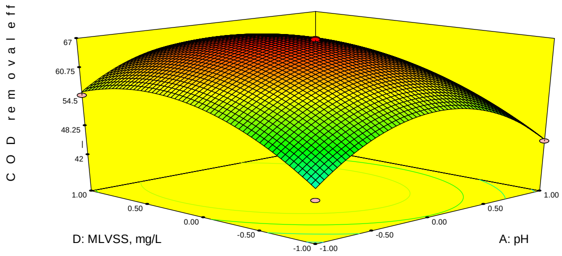

Fig. 9 Contour plot showing the interactive effect of pH and MLVSS on COD removal efficiency of textile dye wastewater

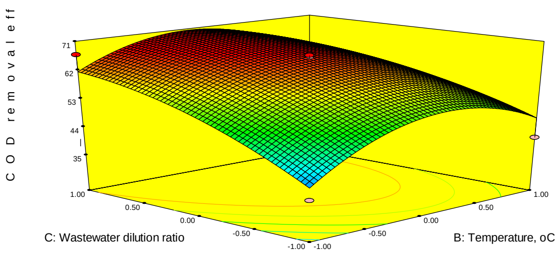

Fig. 10 Contour plot showing the interactive effect of temperature and wastewater dilution ratio on COD removal efficiency of textile dye wastewater

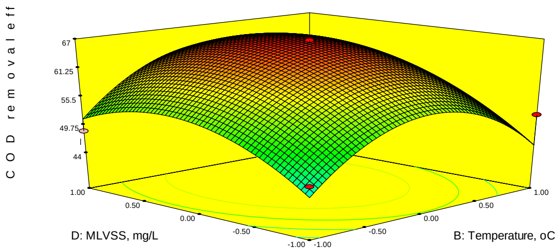

Fig. 11 Contour plot showing the interactive effect of temperature and MLVSS on COD removal efficiency of textile dye wastewater

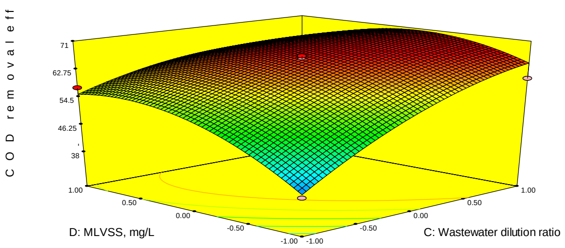

Fig. 12 Contour plot showing the interactive effect of wastewater dilution ratio and MLVSS on decolorization of textile dye wastewater

The second order polynomial equation obtained from RSM was used to find the optimum conditions. Equation was solved in MATLAB 7.0. The optimum condition for the maximum decolourization was found to be: pH – 7.1, temperature – 31.5 °C, wastewater dilution ratio 1:2, and MLVSS – 6200 mg/L. The optimal conditions predicted using RSM has been validated using experiments. At the optimized condition, the maximum colour removal and COD reduction were found to be 70.3% and 72.6% respectively.

4. Conclusion

In this study anaerobic digestion of textile dye wastewater was carried out. RSM was applied to optimize the process parameters. From the results it was found that a maximum of 70.3% colour removal and 72.6% COD reduction occurs at the optimized condition. Hence it was concluded that mixed culture can be utilized for the effective treatment of textile dye wastewater. The optimum conditions were: pH – 7.1, temperature – 31.5 °C, wastewater dilution ratio 1:2, and inoculum concentration – 8.2%.

Acknowledgments

The authors wish to express their gratitude for the support extended by the authorities of Arunai Engineering College, Tiruvannamalai, India in carrying out the research work in the Department of Chemical Engineering.

References

[1] H. Zollinger, Color chemistry-synthesis, properties and application for organic dyes and pigments, VCH Publications, New York, 1987, pp.92-102.

[2] W. Somasiri, X. Li, W. Ruan, C. Jian, Evolution of efficacy of upflow anaerobic sludge blanket reactor in removal of colour and reduction of COD in real textile wastewater, J. Bioresour. Technol. 99 (2008) 3692-3699.

[3] M. Haroun, A. Idris, Treatment of textile dye with an anaerobic fluidized bed reactor, J. Desalination 237 (2009) 357-366

[4] R. Krull, M. Hemmi, P. Otto, D.C. Hempel, Combined biological and chemical treatment of highly concentrated residual dyehouse liquors, J. Water Sci. Technol. 38 (1998) 339-346.

[5] P. Verma, D. Madamwar, Decolorization of synthetic dyes by a newly isolated strain of *Serratia marcescens*, J. Microbiol. Biotechnol. 19 (2003) 615-618.

[6] J.P. Jadhav, S.P. Govindwar, Biotransformation of malachite green by saccharomyces cerevisiae, J. Yeast 23 (2006) 315-323.

[7] S. Sathian, M. Rajasimman, C.S. Rathnasabapathy, C. Karthikeyan, Performance evaluation of SBR for the treatment of dyeing wastewater by simultaneous biological and adsorption processes, J. Water Process Engg. 4 (2014) 82-90.

[8] J.S. Chang, C. Chou, Y. Chen, Decolorization of azo dyes with immobilized *Pseudomonas luteola*, J. Process Biochem. 36 (2001) 757-763.

[9] M.S. Khehra, H.S. Saini, D.K. Sharma, B.S. Chadha, S.S. Chimmi, Decolorization of various azo dyes by bacterial consortium, J. Dyes Pig. 67 (2005) 55-61.

[10] S.A.Ong, E.Toorisaka, M. Hirata, T. Hano, Decolorization of orange II using an anaerobic sequencing batch reactor with and without co-substrates, J. Environ. Sci. 24 (2012) 291-296.

[11] M. Ahmed, A. Idris, A. Adam, Combined anaerobic-aerobic system for treatment of textile wastewater, J. Engg. Sci. Technol. 2 (2007) 55-69.

[12] J. Bell, C.A. Buckley, Treatment of a textile dye in the anaerobic baffled reactor, J. Water SA 29 (2003) 129-134.

[13] M. Rajasimman, P. Karthic, Application of response surface methodology for the extraction of chromium (VI) by emulsion liquid membrane, J. Taiwan Inst. Chem. Eng. 41 (2010) 105-110.

[14] M. Dilipkumar, M. Rajasimman, N. Rajamohan, K. Marxianus, Optimization, kinetics and modeling of inulinase production, J. Prep. Biochem. Biotech. 44 (2014) 291-309.

[15] N. Debasmita, M. Rajasimman, Optimization and kinetics studies on biodegradation of atrazine using mixed microorganisms, J. Alexandria Eng. 52 (2013) 499-505.

[16] APHA, WPCF, AWWA, Standard methods for the examination of water and wastewater, 20th Ed., American Public Health Association, Washington DC, 1999.