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Treatability of Optimized Direct Blue 5 Dye Used in Handmade Paper Unit by Ozonation Method

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Abstract

The present paper highlights the studies with direct blue 5 dyes which is widely used in handmade paper making and textile sector for dyeing purposes. The Central composite design experiment was studied for modeling of ozonation treatment for decolorization of direct blue 5 dye solution. The optimization of parameters ie. Initial concentration of dye solution and time of ozonation treatment on decolorization efficiency of ozonation treatment has been studied. The maximum decolorization was achieved for 125 ppm dye concentration after 60 minutes. The color removal of direct blue with ozone showed best fitting with linear model.

Keywords: Ozonation, central composite design, direct blue 5, decolorization.

Introduction

The Sanganer area of Jaipur is facing problem of colored effluent generated by handmade paper and textile industries[1]. Highly colored effluent (approx 10-15% of dye) being drained from these handmade paper units is posing threat to the environment[2-4.] In the past years, notable achievements were made in the use of ozonation as one of the potential color removal technologies for color removal of effluent of handmade paper units. The textile and paper industry is considered as one of the major water consumer and source of pollution[5, 6]. The present environment scenario made the restrictive pollution norms. The implementation of appropriate treatment technologies is required for minimization of pollution. The water used in textile industry range from 50 to 600 m^3 t-1 depending on the nature of fiber.

Reasonable ozone dosages usually allow very efficient color removal for direct, mordant, cationic, reactive, and sulfur dyes. Removal of a significant portion of the COD can also be anticipated[7,8], even if it is sometimes necessary to push the ozone dosage somewhat higher. Ozone on decomposition generates oxygen and free radicals and the later combines with coloring agents of effluent resulting in the destruction of color**.**

Ozone is relatively unstable molecule of oxygen which readily gives up one atom of oxygen providing a most powerful oxidizing agent. Ozone is produced by passing oxygen[9]through ultraviolet light or “cold” electrical discharge. It is very unstable and readily breaks into oxygen so it must be created on site and added to water through bubble contact. The aim of the present work is to study the factors affecting the rate of decolorization of synthetic waste solution. Normally conversion of oxygen to ozone is 6 to 12% by weight.

Table-1
Dye removal efficiency of some available treatment process

S.No.	Technology	% Color Removal
1	Ozone (chemical oxidation)	97.6
2	Electrohemial oxidation	97.5
3	Color Clear (chemical reduction)	76.8
4	Activated carbon	86.1

Material and Methods

Preparation of dye solution: Commercial grade Direct Blue of Clariant make was taken for the study. The stock solution of 1000 ppm concentration of direct blue dye was prepared by dissolving dry powdered form dye in 1000 ml of distill water. The dye solutions of various concentrations were prepared after dilution of stock solution for further studies.

Experimental set up: The experimental setup as shown in figure 1 consists of an ozone generator with gas washing bottle of borosil make of 500 ml capacity for reaction of ozone with dye solution and second gas washing bottle containing potassium iodide solution to destroy ozone[10,11]. The ozone generator of 301.7 (Erwin Sander) model has been used for the studies.

A general reaction of Ozonation:
$O_3 + H_2O \rightarrow 2HO_2\bullet$
$O_3 + HO_2\bullet \rightarrow HO\bullet + 2O_2$
$Dye + O_3 + O_2 \rightarrow CO_2 + NO_3^- + SO_4^{2-} + H^+ + H_2O$

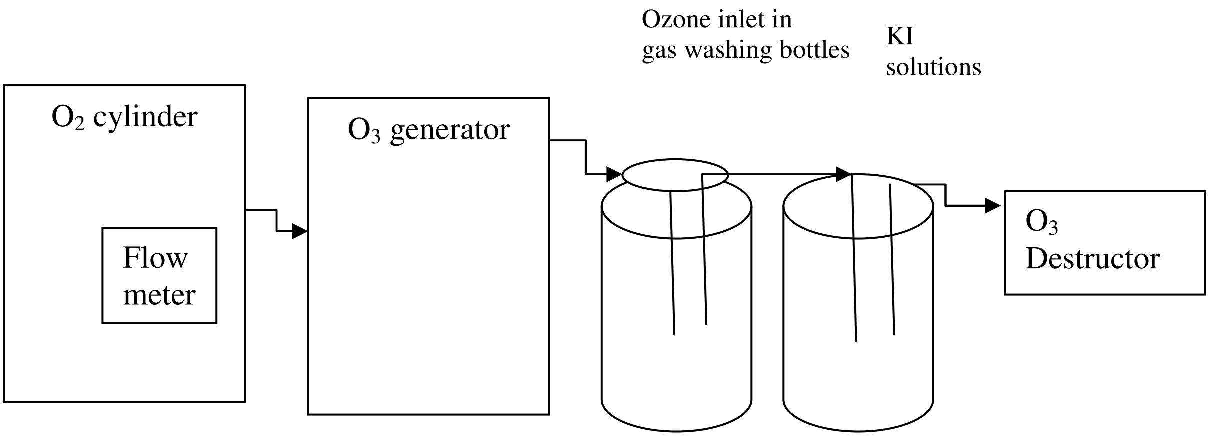

Figure-1
Scheme of process for decolorization of dye solution with ozone

The ozone gas from the outlet of ozone generator was allowed to pass through tygon tubing connected to the gas washing bottle. The gas flow rate was controlled by a flow meter.

Experimental design and optimization: The central composite design[12] is the most popular design in response surface in experimental design. The central composite design with two factors was applied using Design Expert 7.0. Each independent variable was coded at five levels. The decolorization efficiency of ozone was evaluated and the fitting of the model was studied. A quadratic model which included linear model is given as:

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j^{\ 2} + \sum_{i} \sum_{\langle j=2}^{k} \beta_{ij} x_i x_j + e_i$$

where η is the response, x_i and x_j are variables, βo is constant coefficients and βj, βjj and βij are interaction coefficient of linear, quadratic and second order terms and e_i is the error. The quality of fit of model was expressed by coefficient of R^2 and R^2adj. The statistical significance was checked by F-test. Analysis of variance was done to obtain interaction between process variables and response (color removal).

Analysis: The color removal analysis[13] was done with the help of double beam UV-VIS Spectrophotometer (ECA, Hyderabad).

$$Color\ removal = \frac{Absorbance_{initial} - Absorbance_{final}}{Absorbance_{initial}} X100$$

Results and Discussion

The two factors were studied in color removal ie. time and concentration with time ranging from 15 to 75 minutes while concentration ranging from 62.5 to 1000 mg/l as shown in table 2.

The batch runs were conducted in central composite designed experiments to visualize the effect of different factors on response (color removal efficiency) and the results are tabulated in table-3.

Table-2
Experimental range and levels of independent process variables

Factors/Range	-α	-1	0	1	α
Time, minutes	15	30	45	60	75
Concentration, mg/l	62.5	125	250	500	1000

Table-3
Central Composite design matrix

S. N	X_1 Time, minutes	X_2 Concentration, mg/l	Experimental Color removal, η %	Predicted Color removal, η % for linear model
1	-1	-1	82.66	54.93
2	1	-1	98.88	67.44
3	-1	1	61.47	70.27
4	1	1	88.11	82.77
5	-α	0	44.55	80.88
6	α	0	98.61	80.88
7	0	-α	98.65	79.47
8	0	α	50.55	86.55
9	0	0	86.84	80.88
10	0	0	86.84	80.88
11	0	0	86.84	93.39
12	0	0	86.84	93.39
13	0	0	86.84	-

Table-4
Model selection summary

Source	Adj R squared	Pred R squared
Linear	0.7564	0.5927
Quadratic	0.7783	0.0806
Cubic	0.8814	-2.1622

The model maximizing the adjusted and predicted R squared value is linear model as shown in table 4.

The predicted R squared of 0.5927 is in reasonable agreement with the adjusted R squared of 0.7564. Adequate precision ratio measures signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 12.992 indicated adequate signal and thus this model can be used to navigate the design space.

The experimental results were evaluated by Design 7.0 software and the color removal percentage obtained by Design Expert Software is given by the following equation:

$$\text{Color removal\%} = 81.36 + 14.91X_1 - 12.5X_2$$

The Anova results of the linear model is given as table-5

Table-5
Analysis of variance for Response Surface Linear Model

Source	Degree of Freedom	Sum of Squares	Mean of squares	F statistics	P
Model	2	3029.02	1514.51	19.63	0.0003
Time	1	1779.43	1779.43	23.06	0.0007
Concentration	1	1249.59	1249.59	16.19	0.0024
Residual Error	10	771.68	77.17	-	-
Lack of fit	6	771.68	128.61	-	-
Pure Error	4	0	0	-	-

The model F value of 19.63 implies the model is significant. There is only 0.03% chance that a “Model F-value” this large could occur due to noise. Values of “P>F” less than 0.05 indicate model terms are significant. In this case, time and concentration both are significant model terms.

The color reduction efficiency of ozonation treatment in response linear model with affecting factors studied (time and concentration) is shown in contour graph as figure 1 and 2.

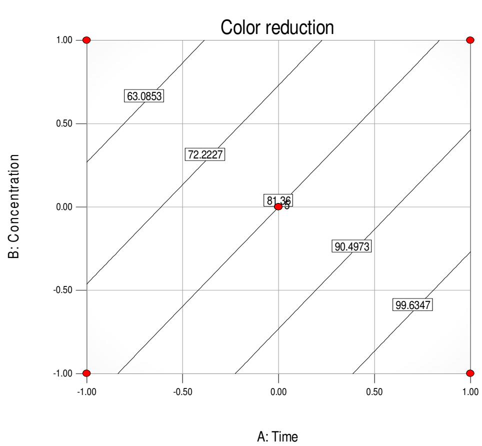

Figure-1
Contour representation of color removal efficiency of ozonation treatment

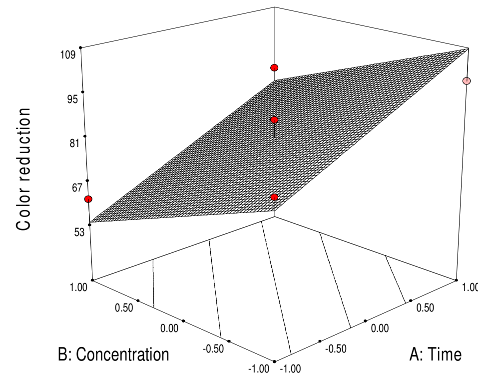

Figure-2
Three D representation of color removal efficiency of ozonation treatment

Conclusion

Color is an important concern for water treatment operators and handmade paper sector as handmade paper sector consumes quantum amount of dyes for making colored handmade paper which is in great demand in domestic and export market. The effect of ozonation technology for color removal proved to be effective technology for color removal.

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