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Nutrient Removal through Electrocoagulation

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Abstract: **-Several biological processes are having one major limitation for inefficient nutrient removal despite of type of nutrient like phosphate or nitrogen. Further large uses of fertilizer add on the concentration of nutrient in underground water as well in direct runoff which ultimately contributes to surface water. Recently anaerobic biological treatments are gaining wide interest by young researchers and hence understanding limitations of such treatment is necessary and research towards minimization of these limitations is also needed. Upflow anaerobic sludge blanket is one of the anaerobic treatments. In India there are more than 25 STP based on upflow anaerobic sludge blanket reactor. UASB reactor hardly alters nutrient level of effluent being treated. On the other hand electrocoagulation treatment promises good removal of pollutants. Hence simulated phosphate wastewater treatment was carried to understand nutrient removal possibility from anaerobically treated wastewater. Current density, electrolysis time, waste strength, NaCl dose, initial pH, interelectrode distance are various process variables which affect EC efficiency. This study reports effect of electrocoagulation process variables on phosphate wastewater. In this study effect of current density, electrolysis time and waste strength were studied using response surface methodology (RSM) as a statistical tool for design of experiments and statistical data analysis. RSM was done using Design Expert software version 8.0. It is reported through RSM studied that the variation in applied current, exposure time and phosphate concentration has direct effect on EC process efficiency.**

Keywords: ***Electrocoagulation, Current Density, RSM, Electrode.***

I. INTRODUCTION

Fast population growth and fast urbanization leads to more use of fertilizer in the farming activity and simultaneous demands efficient sewage treatment which can promise proper nutrient removal. Anaerobic technology presents a high potential in most developing countries for domestic wastewater treatment, and thus is a suitable and economical solution [5]. Within the spectrum of anaerobic sewage treatment technologies, the upflow anaerobic sludge blanket (UASB) reactor offers great promise, especially in developing countries that usually have hot climates [5]. India is one of the leading countries in terms of the amount of sewage volume treated by the UASB process (Sato et al, 2006). At present about 23 number of sewage treatment plants with total installed capacity of 985 MLD (MoEF, 2005 - 2006) based on the UASB are in operation and about 20 number are in pipeline which are likely to be commissioned within next 3-4 years.

Electrocoagulation is a process consisting of creating metallic hydroxide flocks within the wastewater by electro-dissolution of soluble anodes, usually made of iron or aluminium [1]. The difference between electrocoagulation and chemical coagulation is mainly in the way aluminium ions are delivered [1]. In electrocoagulation, coagulation and precipitation are not conducted by delivering chemicals – called coagulants – to the system but via electrodes in the reactor [2]. Suitable electrode choice is very important in electrocoagulation. Most common electrode materials are iron and aluminium. Both of these are cheap, easily found and effective materials [1].

There are several variables or factors which influence performance of electrocoagulation treatment process. These variables include current density, reaction time, electrolyte concentration (NaCl dose), initial pH, initial effluent concentration, type of electrode connection (monopolar, bipolar etc), sludge formation, interelectrode distance and temperature. In the present study effect of CD, time and waste strength has been studied to understand their effect on phosphate removal using response surface methodology as a statistical tool for process optimization.

II MATERIAL AND METHOD

A. *Experimental*

In the experimental study, simulated phosphate solution was prepared at laboratory using sodium phosphate salt ($Na_3PO_4.H_2O$). The experimental setup is shown in Fig. 1 for process optimization. The electrocoagulation cell was made up from glass with 250mm x 100mm x 100mm.

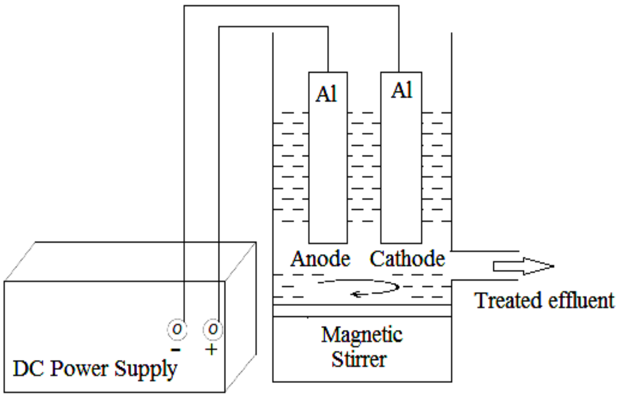

Fig. 1 Experimental set up for process optimization study (adopted from [6])

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Two aluminium electrodes (anode-cathode) assembly was used for process optimization. The anode and cathode are of 190 mm x 80 mm x 5 mm with effective sacrificial electrode area of 60 cm^2. The simulated phosphate solution used per batch run was 600 mL, interelectrode spacing was 15 mm. DC power supply was given to the electrodes to perform EC process. All treatment runs were performed at room temperature of 25-27°C. 100 rpm magnetic stirring was given to ensure proper mass transfer. After completion of each run treated wastewater was collected through the treated effluent outlet located at 20mm above the bottom of inner surface of EC cell. After each run electrodes were washed using 1N HCl to avoid passivation.

B. Experimental Design and Data Analysis

The Box-Behnken design (BBD) is an economical, efficient and rotatable quadratic design where factor combinations are at the midpoints of the edges and at the centre [3,4,6]. The central points are used to estimate the experimental error and to perform the model adequacy check.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} {x_i}^2 + \sum_{i=1}^{k=1} \sum_{j=i+1}^{k} \beta_{ij} x_i x_j + \varepsilon \qquad (1)$$

Where y represents the predicted response; xi and xj are the independent variables, b0, bi, bii and bij are regression coefficients for intercept, linear, quadratic and interaction coefficients respectively, ε is the error and k is the number of variables studied.

Table. I shows the independent variables used for RSM along with their coded values. The BBD factorial design with five replicates at central point is presented in Table 3. To evaluate the contribution of the three variables, experimental data were analysed and fitted to the following second-order polynomial model using Design Expert 8.0 software.

TABLE I EXPERIMENTAL RANGE AND LEVELS OF THE INDEPENDENT VARIABLES

Variable	Factors	Coded Form		
		-1	0	1
CD (mA/cm^2)	x_1	1	5	9
Time (min)	x_2	1	7	13
Waste strength as Phosphate (mg/L)	x_3	1	6	11

III. RESULTS AND DISCUSSION

Applied voltage is important process variable which has direct effect on the efficiency of EC process. Increase in applied voltage provides more sacrificial metal electrode ions to get dissolved in the solution and thus enhances the EC process. Therefore, more metal ion dissolution increases hydroxide floc formation in the reactor, which improves the efficiency of the process. More application of current will induce more metal dissolution which removes pollutant, but for any specific waste concentration there is a specific metal ion to pollutant load ratio which has to balance to suggest cost effective treatment.

Further, electrocoagulation process involves destabilization of particulate impurities and their aggregation. Destabilization of pollutant is faster stage in EC process but aggregation stage needs more time for accomplishment. The first stage is usually short, whereas the second stage is relatively long [7]. Efficient pollutant removal is possible when both stages are done, this can be achieved by giving enough time to the treatment.

Varying concentration of phosphate is necessary to take in to account due to varying concentration of nutrient in surface runoff as well as in anaerobically treated wastewater. Following tables shows design matrix along with observed and predicted response values.

TABLE II DESIGN MATRIX ALONG WITH OBSERVED AND PREDICTED RESPONSE VALUES

Std Run	Current density mA/cm^2	Time min	Influent phosphate mg/L	Phosphate removal (%)	
				Actual	Predicted
1	-1	-1	0	57.77	49.53
2	1	-1	0	39.6	44.59
3	-1	1	0	57.43	52.44
4	1	1	0	81.19	89.43
5	-1	0	-1	48.51	50.88
6	1	0	-1	77.23	66.90
7	-1	0	1	59.48	70.34
8	1	0	1	89.26	86.36
9	0	-1	-1	40.59	46.2
10	0	1	-1	52.28	54.63
11	0	-1	1	52.57	50.22
12	0	1	1	95.15	89.54
13	0	0	0	90.23	91.22
14	0	0	0	90.72.	91.22
15	0	0	0	90.94	91.22
16	0	0	0	92.94	91.22
17	0	0	0	91.25	91.22

A. Model Development and Validation

Obtained results of effluent phosphate removal (%)are presented in Table II. Observed removal percentages were used to develop the model using second order polynomial as shown in equation (1). Following equation (2) represents model for % phosphate removal in terms of coded factors.

$$\text{Phosphate removal (\%)} = +91.22 + 8.01x_1 + 11.94x_2 + 9.73x_3 + 10.48x_1\ x_2 - 11.87{x_1}^2 - 20.35{x_2}^2 - 10.72{x_3}^2 \qquad (2)$$

ANOVA test has given quadratic models for % phosphate removal. ANOVA results for effluent phosphate removal are represented in Table III. Fisher test was used to evaluate the significance of each factor and their interaction with each other. Values of "Prob > F" less than 0.0500 indicate model terms are significant [8].

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TABLE III ANALYSIS OF VARIANCE (ANOVA) TEST FOR EFFLUENT PHOSPHATE REMOVAL (%)

Model term	Source	Sum of Squares	p-value Prob > F	
	Model	6203.32	0.0035	significant
1	x_1-Current Density	513.44	0.0318	significant
2	x_2-Time	1140.51	0.0053	significant
3	x_3-Influent Phosphate	757.58	0.0141	significant
4	$x_1\ x_2$	439.53	0.0425	significant
5	$x_1\ x_3$	0.28	0.9519	Not significant
6	$x_2\ x_3$	238.55	0.1110	Not significant
7	x_1^2	593.55	0.0238	significant
8	x_2^2	1742.90	0.0017	significant
9	x_3^2	484.14	0.0355	significant
	Residual	512.19		

All model term - $R^2 = 0.9251$, $R^2_{adjusted} = 0.8288$, Model term 1,2,3,4,6,7,8,9 - $R^2 = 0.9251$, $R^2_{adjusted} = 0.8501$.

Coefficients with *p*-value greater than 0.1 were considered statistically insignificant and were eliminated from the quadratic equation [8]. Equation (2) was developed after eliminating statistically insignificant term ($x_1\ x_3$) based on p-value (0.9591 > 0.1) of coefficient for those terms. The *p*-value for all the model terms were less than 0.05 means model for % phosphate removal was found to be significant with 5% confidence interval. R^2 being the coefficient of determination, determines overall efficiency of model prediction. In this study R^2 and $R^2_{adjusted}$ ensures good correlation with each other. The *p*-value for phosphate was also 0.01 indicates significance of waste strength on the overall electrocoagulation process efficiency.

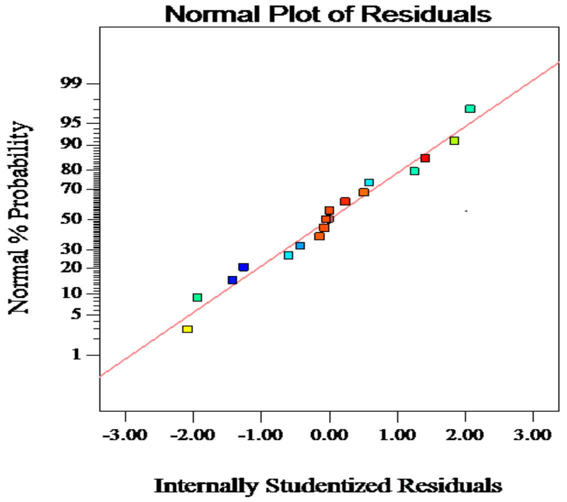
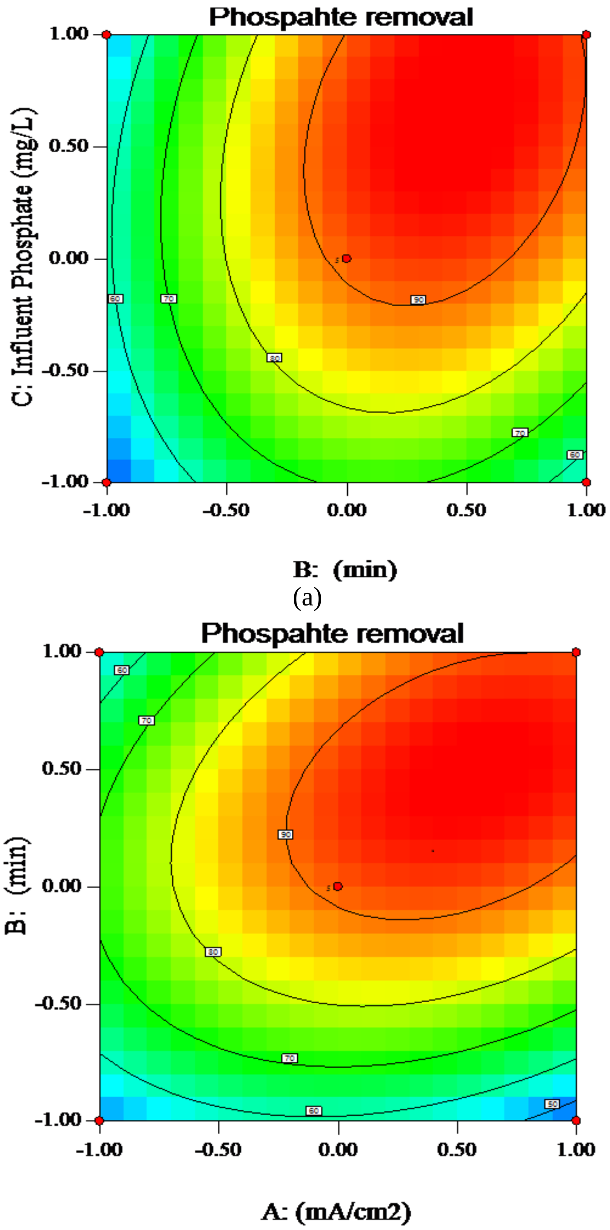


Fig 2. Predicted v/s actual values for (a) % phosphate removal

Fig 2 represents comparison of actual and predicted values of % phosphate removal with good agreement due to presence of all process variables which have significant effect on EC process.



(a)

(b)

Fig. 03 Contour plots for % phosphate removal as a function of (a) influent phosphate and time (b) current density and time

Fig. 03 (a) represents interaction effect of influent phosphate and time on % phosphate removal, it is visible that at lower time increase in phosphate up to certain extent shows good removal and then it reduces which at higher time with high phosphate concentration removal also increases due to better balance of pollutant to metal ion ratio. While fig. 03 (b) represents effect of time and current density on the same, where good removal were achieved at moderate time and applied current.

IV CONCLUSION

The study was conducted to understand effect of current density, electrolysis time and initial phosphate concentration on overall phosphate removal efficiency from simulated phosphate wastewater.RSM study showed all the three process variables having significant effect on the EC process

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efficiency. It was also concluded that specific concentration of waste strength cancan be treated at specific current density. If more current applied to mild waste there will be wastage of metal electrode and if less current is applied for complex waste there will be poor effluent quality hence optimization of EC process current, time and waste concentration are three necessary process variables due to significant interaction effect.

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