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UNDERSTANDING EFFECT OF ELECTROCOAGULATION PROCESS VARIABLES ON NUTRIENT REMOVAL FROM SIMULATED WASTEWATER

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ABSTRACT

Nutrient removal from wastewater is necessary action to be taken due to its ability to develop unhygienic conditions when disposed in natural water bodies. Various anaerobic biological processes and final polishing pond possess inability to alter nutrients from wastewater. At the same time, electrocoagulation despite of type of wastewater has showed good removal of variety of pollutants. Hence, focus of this study was kept on removal of phosphate from simulated wastewater and to better understand effect of various process variables of electrocoagulation treatment. Current density, electrolysis time and initial pH are studied process variables in this work, while phosphate removal percentage was response taken. Response surface methodology was used for designing experiments and statistical analysis of data. Design Expert software version 8.0 was used for this purpose. It has been revealed through study that applied current and time has significant effect on PO_4 removal but initial pH was found to be insignificant.

KEYWORDS: phosphate, electrocoagulation, current density, RSM, electrode

INTRODUCTION

Phosphorus is the basic nutrient on earth. The most important of phosphorus sources is basic rock in earth and the other source is water. Phosphorus movement from land to sea and from sea to land is at the heart of phosphorus circle [1]. As far as wastewater disposal is concerned, phosphorus removal is necessary due to its ability for eutrophication, which enhances growth of algae in the surface water. Recently various anaerobic treatments are gaining popularity, where anaerobic treatment like upflow anaerobic sludge blanket generates effluent without altering the nutrient level which also necessitates post treatment of UASB reactor treated effluent [2].

Electrocoagulation has several advantages hence there is possibility for better removal if phosphate wastewater is electrocoagulated. [3-5] have reported many advantages of EC as like faster separation of organic matter with more effectiveness compared to coagulation, pH supervision and control is not necessary except under extreme values, chemical requirements during treatment are nearly zero, solid/sludge generation is relatively less and operating cost is much lower than other conventional technologies.

At the same time study of any new treatment on certain wastewater involves requirement for clear understanding for effect of various process variables of adopted treatment and nature of complexity of effluent being treated. Hence in this research work significance of current density, electrolysis time and initial pH is analyzed based on phosphate removal (%) using electrocoagulation treatment. All design of experiments and statistical analysis of developed data was done using response surface methodology using Design Expert software version 8.0.

MATERIALS AND METHODS

Phosphate solution with 10 mg/L strength was prepared from sodium phosphate salt ($Na_3PO_4.H_2O$) at laboratory on diluting it in distilled water. One anode-one cathode electrocoagulation cell was used as shown in Fig. 01. The electrocoagulation cell was made up from glass with 250mm x 100mm x 100mm. The aluminium anode and aluminium cathode are of 190 mm x 80 mm x 5 mm with effective sacrificial electrode area of 60 cm^2. The

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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.

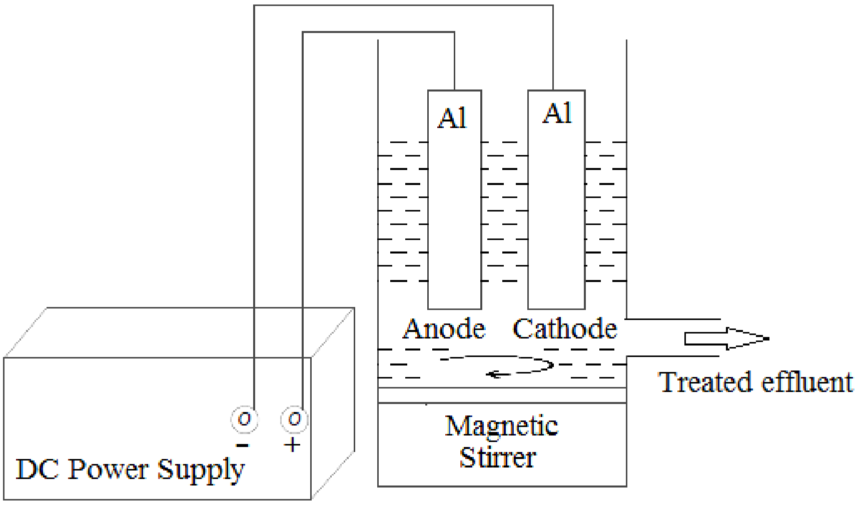

Fig. 1 Experimental set up for process optimization study (Makwana and Mansoor, 2017)

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 [2,7,8]. 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. 1 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 analyzed and fitted to the following second-order polynomial model using Design Expert 8.0 software.

Table 01. Experimental range and levels of the independent variables

Variable	Factors	Coded Factor Level		
		-1	0	1
CD (mA/cm^2)	x_1	1	5	9
Initial pH	x_2	1	5	9
Time (min)	x_3	1	7	13

RESULTS AND DISCUSSION

Electrocoagulation process will be enhanced when applied current will be more due to more sacrificial metal ion dissolution in the EC cell. There is specific ratio between metal ions to pollution load for all wastewaters. Optimization of this ratio is necessary to avoid wastage of metal and for efficient treatment. Hence current

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density was taken as necessary parameter to be optimized. 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 [6,9]. Efficient pollutant removal is possible when both stages are accomplished; this can be achieved by giving enough time to the treatment. Further initial pH was always significant parameter for electrocoagulation process because metal solubility and hydroxide floc characteristics are greatly affected by initial pH. Aluminium electrode performs better at pH ≤ 7 [11,12] hence optimization of initial pH is necessary Hence these parameters are taken into consideration and design matrix was developed as shown in Table 02.

Table 02: Design matrix along with observed and predicted response values

Std Run	Current density mA/cm^2	Initial pH	Time min	Phosphate removal (%)	
				Actual	Predicted
1	-1	-1	0	90.48	88.57
2	1	-1	0	99.41	99.66
3	-1	1	0	88.99	88.75
4	1	1	0	96.82	98.75
5	-1	0	-1	67.02	69.55
6	1	0	-1	84.42	84.78
7	-1	0	1	91.73	91.37
8	1	0	1	99.74	97.22
9	0	-1	-1	79.34	78.75
10	0	1	-1	78.69	76.41
11	0	-1	1	91.61	93.60
12	0	1	1	94.91	95.52
13	0	0	0	91.49	92.63
14	0	0	0	93.73	92.63
15	0	0	0	91.71	92.63
16	0	0	0	94.50	92.63
17	0	0	0	91.71	92.63

Modelling and validation

Table 02 also shows predicted and actual values of phospahte removal as per model developed as shown below in eqn.02 in terms of coded factors.

$$\% \text{ Phosphate removal} = +81.07 + 1.21x_1 - 2.57x_2 + 3.54x_3 + 0.30\, x_1x_2 - 0.14x_1^2 - 0.16\, x_3^2 \quad (2)$$

Fisher test was used to evaluate the significance of each factor and their interaction with each other. ANOVA test has given quadratic models for % phosphate removal. ANOVA results for effluent phosphate removal is represented in table 03. Values of "Prob > F" less than 0.0500 indicate model terms are significant [10].

Table 3: Analysis of variance (ANOVA) test for effluent phosphate removal (%)

Model term	Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
	Model	1154.38	9	128.26	20.35	0.0003	significant

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1	x_1-Current Density	452.44	1	452.44	71.79	<0.0001	significant
2	x_2-Initial pH	33.81	1	33.81	5.37	0.0537	significant
3	x_3-Time	442.78	1	442.78	70.26	<0.0001	significant
4	$x_1\ x_2$	24.51	1	24.51	3.89	0.0892	significant
5	$x_1\ x_3$	4.8	1	4.8	0.76	0.4116	Not significant
6	$x_2\ x_3$	15.82	1	15.82	2.51	0.1571	Not significant
7	x_1^2	24.41	1	24.41	3.87	0.0898	significant
8	x_2^2	0.27	1	0.27	0.043	0.8409	Not significant
9	x_3^2	148.78	1	148.78	23.61	0.0018	significant
	Residual	44.11	7	6.30			

$R^2 = 0.9632$, $R^2_{adjusted} = 0.9159$.

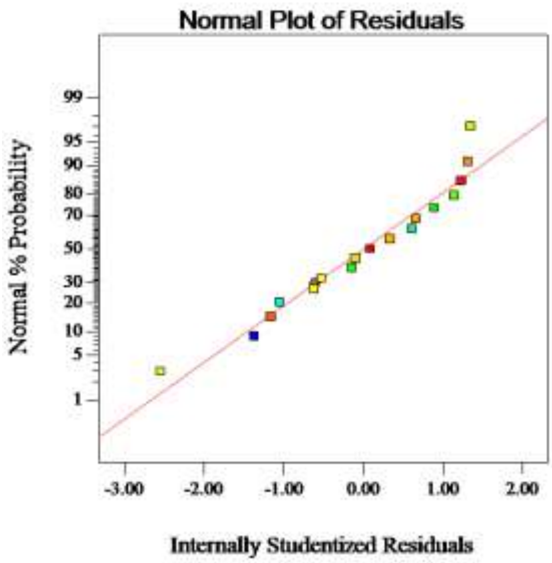

Fig 2 Actual v/s predicted values of % phosphate removal

Coefficients with *p*-value greater than 0.1 were considered statistically insignificant and eliminated from the quadratic equations [10,13]. Equations (2) was developed after eliminating statistically insignificant term ($x_1\ x_3$, x_2x_3 and x_2^2) based on p-value of coefficient for those terms. The *p*-value for all the model terms were less than 0.05 except for x_1x_2 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. Fig 2 represents comparison of actual and predicted values of % phosphate removal with close agreement due to presence of all process variables which have significant effect on EC process.

Fig. 03 represents interaction effect of various process variables on phosphate removal efficiency. Fig. 03 (a) shows that increase in current density increases removal but initial pH does not show much effect at the same time. While looking to fig. 03 (b), both time and current density has positive effect, again looking to fig. 03 (c) interaction effect o time and pH shows significance of time but less or null significance (only 5% increase in removal) of initial pH on removal efficiency.

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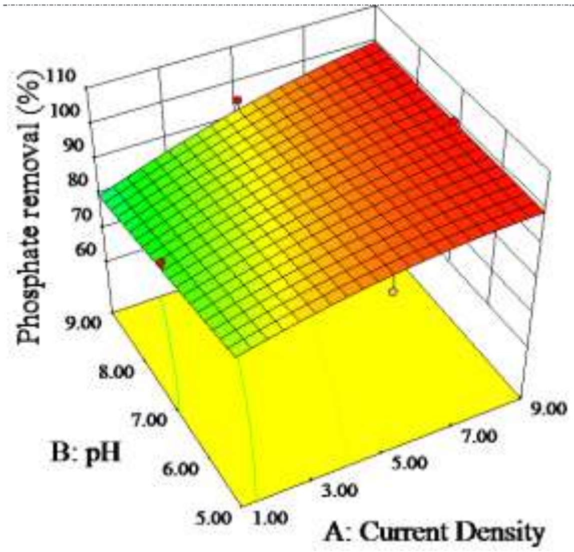
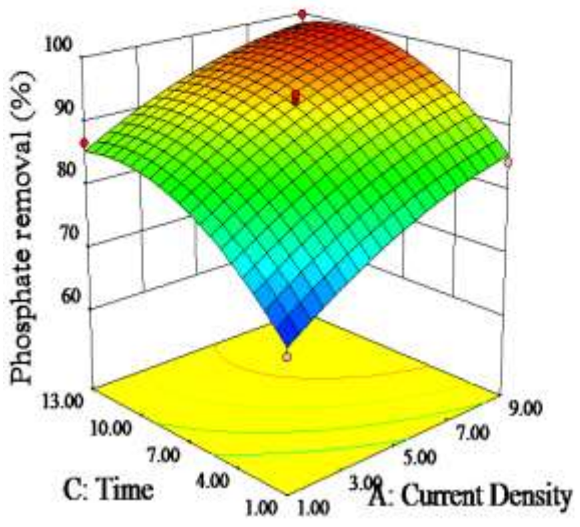
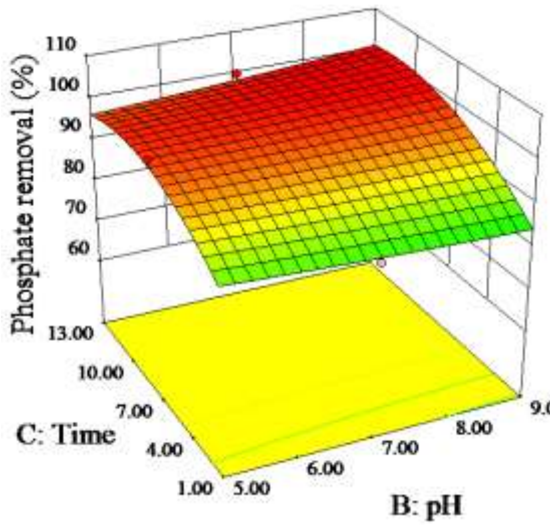


(a)



(b)



(c)

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

CONCLUSION

This work elaborates effects of applied voltage, reaction time and initial pH on phosphate removal from artificial phosphate solution. Statistical modeling showed good prediction capability of developed model. It was observed that current density, time and initial pH has significant effect on EC process and hence their optimization is necessary. To achieve more precise analysis using RSM tool, more care should be taken in selecting the range of process variables to be studied otherwise main or interaction effect of variable with wrong process range will be reflected as insignificant.

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