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Development of Mathematical Model to Predict the Removal Rate of Zinc in Zinc Barrel Plating wash water using Full Factorial Design

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Abstract

This study highlights the features of the development of inclusive mathematical models for correlating the interactive and higher order manipulates of the various parameters in the zinc barrel plating wash water. Full Factorial technique is used to perform the experiments. The response factors namely initial concentration, current density and time were involved by zinc removal rate in the zinc barrel plating wash water has been considered and examined. Analysis of variance (ANOVA) was employed to ensure the adequacy of the models so developed and student's t-test was utilized to check the significance of each factor to appear the final form of the mathematical models. The models so developed are utilized to conclude the values of the response parameters which influence the zinc barrel plating for each given set of variables within the ranges selected.

Keywords: Barrel Plating, DOE, Full Factorial Design.

1. Introduction

Most of the industrial processes result in the release of heavy metals into natural water systems with growing urbanization and rapid industrialization. The problem of the release of untreated waste water into the eco system has been of increasing concern in many parts of the world. Therefore, the removal of toxic pollutants from waste water has recently become the subject of considerable interest due to more strict legislations introduced in many countries to control water pollution[1]. Zinc compounds which are used in alloy, galvanized metal, fluorescence components, paint pigments, sunscreen lotions, fast-setting dental cements, deodorants, embalming and fire proofing lumber which cause mucous membrane damage, diarrhoea and dizziness[2]. The recommended standard quantity of zinc in drinking water by World Health Organization (WHO) is 15mg/L [3]. Therefore, it seems imperative that zinc should be removed from the effluent prior to discharge into the sewage system or into the aquatic environment.

The treatment of barrel plating wash water using electro coagulation(EC) process which offers several advantages including ease of operation, robustness to varying reaction conditions and effluent types, less retention time, rapid sedimentation of the electro generated flocculants, less sludge production and smaller space requirements and capital costs[4]. In addition to that, the EC process has been applied to treat various waste waters

such as electro plating waste water[5], paper mill bleaching waste water[6], chemical mechanical polishing waste water[7].

2. Experimental conditions

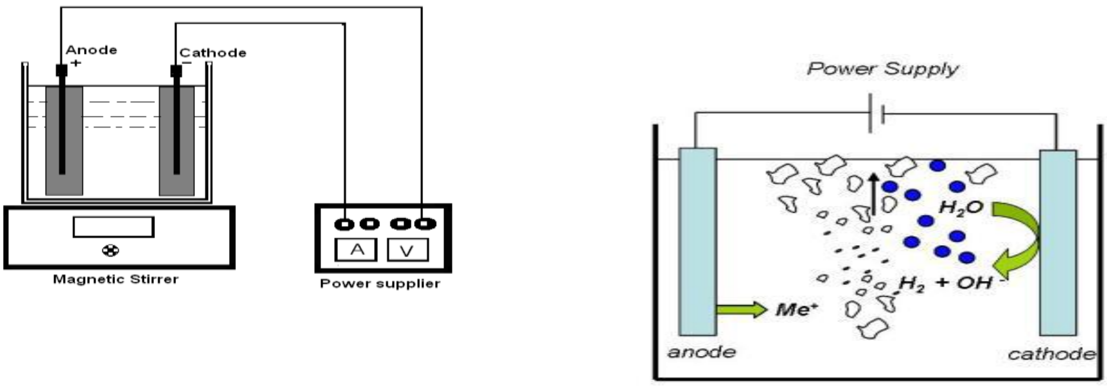

Fig 1 - Schematic diagram of Electro-chemical cell used for the electro-coagulation

The electrode used in this study consists of aluminium plates and stainless steel plates of 99.99% purity. All the chemicals used were of analytical grade and the reagents were prepared using double distilled water, obtained from Quartz double distiller. A raw (stock) solution containing zinc wash water of 433 mg/L was used in the experiment. The working samples consist of 433 and 216.5 mg/L of solution prepared by dilution with distilled water to required levels. The samples were used freshly from the ice cold deep freezer by dilution from the stock as and when required. Before the experimentation, pH of the solution was found to be 6.3. In due course of the experiment, pH 6.0, 7.0 and 8.0 were maintained by using 0.1N H_2SO_4 and 0.1N sodium hydroxide solutions. All measurements were carried out at ambient temperature. The working sample was prepared by taking 400 ml aliquots of real industrial wash water added with calculated and constant amount of Nacl (1gm/L) to avoid excessive ohmic drop and to restrict the formation of the passivation layer on anode (aluminium or mild steel) electrodes.

3. Plan of investigations

The research work was carried out in the following steps [8]

1. Identification of control parameters and their levels.
2. Developing the design matrix.
3. Conducting the experiments as per design matrix.
4. Development of mathematical model.
5. Evaluation of coefficients of the model.
6. Checking the adequacy of the model.
7. Testing the regression coefficients of the models and arriving at the final form of the mathematical model.
8. Validation of the mathematical model.

3.1. Identification of control parameters and their levels

The process variables or control factors such as initial concentration, current density and time were identified to carry out the experiments and to develop the mathematical models. A two level full factorial design 2^3 was used to study linear and first order interactions effects between the three process variables and one response. The design plan with high and low limits as indicated is utilized looking into practical considerations for the electro coagulation process is tabulated in Table 1.

Table 1 - Factors and Levels

S.No	Factors	Notation	Units	Factor levels			
		Coded		Natural		Coded	
				Low	High	Low	High
1	Initial concentration	X_1	mg/L	216.5	433	-1	+1
2	Current Density	X_2	A/dm^2	0.1	0.2	-1	+1
3	Time	X_3	Min	2	5	-1	+1

3.2. Developing the design matrix

Table 2. Shows the 8 sets of coded conditions used to form the design matrix of 2^3 full factorial design [9 & 10].

3.3. Conducting the experiments as per design matrix

The experiments were conducted as per design matrix. The zinc removal rate was measured using electro - coagulation setup and responses were recorded and are given in Table .2

S.No	Run	X_1	X_2	X_3	Response (Zinc removal rate)%
1	1	+	-	+	90.2
2	2	-	+	+	49.98
3	3	-	-	-	83.32
4	4	-	+	-	74.96
5	5	-	-	+	83.32
6	6	+	-	-	90.9
7	7	+	+	-	100
8	8	+	+	+	80

Table 2 – Design Matrix and Responses

3.4. Development of mathematical models

The effects caused by changes in three main factors and their first order interactions can be expressed as:

$$\mathbf{Y = b_0 + b_1}X_1 + \mathbf{b_2}X_2 + \mathbf{b_3}X_3 + \mathbf{b_{12}}X_1 X_2 + \mathbf{b_{23}}X_2 X_3 + \mathbf{b_{13}}X_1 X_3 \quad \text{---------} \quad \mathbf{(1)}$$

Where, Y represents the zinc removal rate; X_1,X_2,X_3 represent coded values of initial concentration, current density and time respectively; b_0 , b_1 …, b_{13} are the regression coefficients to be determined.

3.5. Evaluation of coefficients of the models

The main and interaction effects were determined by using the formula

$$\mathbf{b = (X^T X)^{-1} X^T Y} \quad \text{----------} \quad \mathbf{(2)}$$

Where, b represents matrix of parameter estimates

X represents calculation matrix

X^T represents transpose of above matrix

Y represents matrix of measured response

The coefficients are tabulated in Table 3.

Table 3 – Estimated values of the coefficients of the model

S.No	Coefficients	Response (Zinc removal rate)%
1	b_0	81.585
2	b_1	8.69
3	b_2	-5.35
4	b_3	-5.71
5	b_{12}	5.075
6	b_{23}	-5.535
7	b_{13}	0.535

3.6. Checking the adequacy of the models

The Analysis of variance (ANOVA) technique [9 and 10] was used to check the adequacy of the developed model. From the observed results, the model is adequate.

3.7. Testing the regression coefficients of the models and arriving at the final form of the models

The values of regression coefficients give an idea as to what extent the control variables affect the response. It is evident that those of the coefficients, which are not significant, can be eliminated along with the responses with which they are associated. To reduce this effect, Student's t-test [9 and 10] is used. When the significant coefficients are known, the model is re-developed by using these values. The model so developed is utilized to verify the values of response for each given set of variables. The test results were tabulated in Table 4 and the final mathematical model as determined by above analysis is given below:

Zinc removal rate, $\mathbf{Y = 81.585 + 8.69X_1 - 5.35X_2 - 5.71X_3 + 5.075X_1 X_2 - 5.535X_2 X_3 + 0.535X_1 X_3}$ ---------------- **(3)**

Table 4 - Test Results

S.No	Test Run	Initial Concentration mg/L	Current Density A/dm^2	Time Min	Response (Zinc removal rate)%	
					Predicted	Experiment
1	1	433	0.1	5	90.91	90.2
2	2	216.5	0.2	5	50.69	49.98
3	3	216.5	0.1	2	84.03	83.32
4	4	216.5	0.2	2	74.25	74.96
5	5	216.5	0.1	5	82.61	83.32
6	6	433	0.1	2	90.19	90.9
7	7	433	0.2	2	100.71	100
8	8	433	0.2	5	79.29	80

4. Conclusions

1. Full factorial design is well-situated to expect the main effects and the interaction effects of different combination of parameters, within the ranges of analysis on the rate of removal of zinc.

2. Mathematical models so developed can be used to predict the rate of removal of zinc in terms of electro coagulation process parameters attained from any combinations within the ranges of variables.

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