# **Application of Response Surface Methodology for Enhanced Electrochemical Process for the Removal of Phenol from Aqueous Solution using Graphite Electrodes**

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#### Abstract

The aim of the present work was to investigate the removal of phenol from a synthetic solution by the enhanced electrochemical oxidation process using graphite electrodes. Central composite design (CCD) and Box Behnken Design (BBD) under Response Surface Methodology (RSM) tool were used to investigate the effects of major operating variables viz. Current density (mA/cm<sup>2</sup>): (2.27 to 4.54), pH: (5.5 to 7.5) and electrolysis time (min): (30 to 90). The predicted values of BBD responses obtained using RSM were more significant than the CCD model in terms of reaction time, whereas under the desirability test CCD model was found more appropriate in terms of phenol removal and power consumption. The optimal result shows that the CCD model predicted and experimental values of phenol removal and power consumption are 92.87 %; 0.866 kWh/m<sup>3</sup> and 86.34 %; 1.12 kWh/m<sup>3</sup> respectively under optimized variable conditions, current density: 2.78 mA/cm<sup>2</sup>, pH: 6.98 and electrolysis time: 88.02 minutes at high desirability level.

### **1. INTRODUCTION**

**P**henol, white crystalline solid volatile in nature, also known as carbolic acid, is an aromatic organic compound consists of a phenyl group (" $C_6H_5$ ) bonded to a hydroxyl group ("OH). It requires careful handling due to its proclivity to cause chemical burns due to weakly acidic nature. Phenol and its vapours are corrosive to the eyes, the skin, and the respiratory tract and inhalation of phenol vapour may cause lung edema [1]. Central pollution control board (CPCB), India and US environmental protection agency (US EPA) have proposed an acceptable limit of 0.5 mg/L for phenol [2-4]. Therefore, it is necessary the removal/ recovery of phenolic compounds for letting down the concentrations to below under regulatory limits. The most significant pollution sources comprising phenol and its compounds are the effluent generated from the coking operations, oil refining, steel industry, petroleum refining, paint, pesticide, electroplating, wood preserving chemicals, pharmaceuticals [5-8]. Therefore, wastewater must be treated prior to discharge to natural water bodies. There are various methods available for treatment of industrial effluent such as physical [9], chemical [10,11] and biological treatment [12-14].

In the recent decade, the electrochemical oxidation techniques have received greater attention, due to their higher efficiency compared with other methods. Electrochemical technology has many advantages such as being convenient, efficient, low sludge generation and eco-friendly [15]. However, from the reported results in the literature, it is concluded that a single process is not effective for the treatment of industrial wastewater. The electrochemical systems have also been also applied with photo [16,17], ozone [18-20], hydrogen peroxide [21,22] and advanced oxidation processes [23] which can remove organic and inorganic pollutants and ensure the good condition of effluent in order to discharge.

In the electrochemical treatment of synthetic water, direct and indirect oxidation processes are being utilized. In a direct oxidation process, pollutants are first absorbed at the anode surface and then incinerated by the electron transferred reaction. However, in an indirect oxidation process, strong oxidants are electrochemically generated such as chlorine, hydrogen peroxide, hypochlorite, Fenton reagents, metal peroxide and ozone [25,26]. Thus, research is focused on the combination of hydrogen peroxide techniques with electrochemical for effective removal of phenol through modified oxidation.

Response surface methodology (RSM) is a statistical tool to achieve solution such an optimization by analyzing and modelling the effects of multiple variables and their responses and finally optimizing the process through numerically or graphically by selected criteria. This method has been successfully applied for the optimization of various processes in food chemistry, material science, chemical engineering and biotechnology, pulp mill wastewater, livestock wastewater, landfill leachate, industrial effluent, synthetic wastewater [27-31]. The two most used designs in RSM are Central Composite Design (CCD) and Box Behnken Design (BBD). The BBD is a collection of three-level designs that have various geometric constructions. In the traditional experimental design approaches used in RSM, such as central composite design, the number of experimental trials increases with an increase in experimental factors and so does the number of coefficients of the quadratic model equation

increases exponentially [32]. However, Box Behnken design provides compressive conclusions and detailed information even for a smaller number of experiments and interactive effects of operating parameters [31] on all responses.

The aim of the present study was to test the feasibility of electrochemical oxidation method for the degradation of phenol (carbolic acid) using graphite electrodes, which has the advantages of extremely high oxygen over voltage and high electrocatalytic activity [24]. The oxidation of wastewater is principally based on the hydroxyl radical (•OH) generated on the surface of the electrode [33]. Furthermore, the process optimization has been performed through the process variable using Response Surface methodology (RSM) tool, which fulfilled the research gap of the electrochemical technique using graphite electrode for the removal of carbolic acid and optimization through recent optimization tool. The main aim of optimization was to maximize the phenol removal and minimize the power consumption with the minimum of reaction time for removal of pollutants from synthetic water contain the phenolic compound.

### 2. MATERIALS AND METHODS

# **2.1** Experimental procedure and analysis of wastewater samples

A Perspex made reactor having specific dimension  $160 \text{ mm} \times 130 \text{ mm} \times 120 \text{ mm}$  was used to carry out the EC process to remove phenol as a batch type to conduct the experiments. Good quality metal sheets of graphite used as electrodes of  $150 \text{ mm} \times 100 \text{ mm} \times 4 \text{ mm}$  size for the electrochemical process. In each experiment, two plates were used in the electrochemical reactor and the distance (d) between the plates was kept 2 cm. The electrodes were placed using a monopolar configuration with a total anodic or cathodic surface area (S) of  $150 \text{ cm}^2$ .

The three current values were selected from 250 to 750 mA corresponding to a current density from

2.27 to 6.81 mA/cm<sup>2</sup> using a precision DC power supply (Microtech agencies Dhanbad, India) characterized by the ranges 0-2 A for current and 0-30 V for voltage. Before each experiment, the electrodes were polished with abrasive paper to get rid of any oxide film and then thoroughly rinsed in 0.1 N HCl. The pH of the solution was adjusted by 0.1N HCl and 0.1N NaOH solutions prepared from AR grade Merck chemicals.

All the solutions were prepared from analytical reagent AR grade reagents and double distilled water without phenol. The stock standard solution 1000 mg/L was prepared by dissolving 1.00 g of phenol available in crystal forms in 1000 ml of double distilled water. The solution was stable for at least 30 days therefore, kept in a refrigerator for further use. The reactor was initially filled with a synthetic solution containing phenol  $25\pm0.5$ , mg/L along with other chemical compositions of AR grade of Merck like sodium acetate, NaCl, KCl, CaCl<sub>2</sub>.2H<sub>2</sub>O, NH<sub>4</sub>Cl, K<sub>2</sub>HPO<sub>4</sub>.3H<sub>2</sub>O and trace element solution and freshly prepared for each experimental run.

The measured volume of water samples was periodically taken from the container at predetermined time intervals (30 to 120 min) to investigate the degradation of phenol and pH variation in the reactor throughout the experiment. The residual concentrations phenol was determined using a UV spectrophotometer (UV/ Vis 9100A, LabTech, China) as per standard protocol prescribed in APHA [34] at 510 nm wavelength.

#### 2.2 Response Surface Methodology

Experimental data were analysed using Design Expert Software 10.0.3 and fitted to a second-order polynomial model to optimize the variables in the Electrochemical process. The Quadratic equation model for the optimal conditions can be expressed as Eq. (1):

$$y = \beta_0 + \sum_{j=1}^k \beta_j X_j + \sum_{j=1}^k \beta_{jj} X_j^2 + \sum_{j=1}^{k-1} \sum_{i=2}^k \beta_{ji} X_j X_i + \varepsilon_j (1)$$

Where, Xi, Xj are coded independent variables,  $\beta_{i}, \beta_{ii}, \beta_{ii}$  (I = 1, 2, ..., k; j = 1, 2, ..., k) are the regression coefficients. The First order (i.e. Linear) model describes a flat surface. The second-order model, also called quadratic model has described a curving surface, including all terms in the linear model, all quadratic terms like  $\beta_{jj}X_{j}^{2}$ , and all interaction terms i.e.  $\beta_{ii}X_iX_i$ . This quadratic model is generally found adequate for RSM in most cases [35]. The independent variables are often called repressors, and therefore the first-order or second-order models are also called regression models. Finally, the optimal values of the critical parameters were obtained by analyzing the 3D surface plots and also by desirability function using Design Expert Software 10.0.3.

In the present work, the optimization of experimental conditions for removal phenol from synthetic water by electrochemical was conducted using Central Composite design and Box- Behnken design techniques under RSM for the three chosen variables using Design of Expert (DoE) Software (10.0.3). Each independent variable was coded at three levels between "1 to+1, where the variable current density ( $X_1$ ), solution pH ( $X_2$ ), and electrolysis time ( $X_3$ ) were changed in the range of 2.27–6.81 mA/cm<sup>2</sup>(250-750 mA), 5.5-7.5, and 30-90 min respectively. The Range of operating parameters, current density (mA/cm<sup>2</sup>), pH, time (min) were decided by conducting initial test runs in their coded levels.

#### 2.3 Analysis and Calculations

The percentage removal efficiency of electrocoagulation process was computed as a function of operating time by the Eq. (2):

Removal efficiency, %

$$R_{E} = \frac{C_{0} - C_{t}}{C_{0}} \times 100$$
 (2)

Where  $C_0$  and  $C_t$  are concentrations at times initial time, 0 and after *t* time of electrolysis.

The amount of electrical energy used is an important economical parameter in the electro coagulation process. This parameter is computed by the Eq. (3):

$$E = \frac{UIT}{V}$$
(3)

*E* is the electrical energy used (in kWh/m<sup>3</sup>), *U* is the voltage applied (in V), *I* is the current (in A), *T* is the coagulation time in hours. *V* is the volumes in liters.

#### 3. RESULTS AND DISCUSSION

### 3.1 Response functions with the determined coefficients

In the present study, three-factor with threelevels of CCD and BBD techniques were used to evaluate and optimize the effects of process variables of the peroxide assisted electrocoagulation process on the response phenol removal efficiency and power consumption. The total number of the experiments with three factors was 20 for Central Composite and 17 for Box Behnken design. The predicted values of responses were obtained from quadratic model fitting techniques for the percentage of phenol removal and power consumption using the Software Design Expert 10.0.3. The response functions with the determined coefficients for phenol removal and power consumption are presented by Eqs. (4) to (7) in terms of coded factors.

Final equation in terms of coded factors for CCD model:

Phenol Removal, (%)

$$\begin{split} \mathbf{Y}_{1} &= 85.83 + 4.32 \mathbf{X}_{1} + 8.80 \mathbf{X}_{2} + 12.10 \mathbf{X}_{3} + \\ 0.43 \mathbf{X}_{1} \mathbf{X}_{2} & 0.98 \mathbf{X}_{1} \mathbf{X}_{3} + 4.02 \mathbf{X}_{2} \mathbf{X}_{3} & 10.73 \mathbf{X}_{1}^{2} & \\ 9.67 \mathbf{X}_{2}^{2} + 1.33 \mathbf{X}_{3}^{2} & (4) \end{split}$$

Power consumption, (kWh/m<sup>3</sup>)

$$\begin{split} \mathbf{Y}_{2} &= + \ 1.36 \ + \ 1.13 \mathbf{X}_{1} + \ 0.056 \mathbf{X}_{2} + \ 0.73 \mathbf{X}_{3} + \\ 0.032 \mathbf{X}_{1} \mathbf{X}_{2} + \ 0.56 \mathbf{X}_{1} \mathbf{X}_{3} + \ 0.020 \mathbf{X}_{2} \mathbf{X}_{3} + \ 0.16 \mathbf{X}_{1}^{\ 2} + \\ 8.00 \ \mathrm{E}\text{-}003 \mathbf{X}_{2}^{\ 2} `` 0.020 \mathbf{X}_{3}^{\ 2} \end{split}$$

Final equation in terms of coded factors for BBD model:

Phenol Removal, (%)

$$Y_{3} = +89.75 + 8.10X_{1} + 13.83X_{2} + 10.32X_{3} + 2.25X_{1}X_{2} + 3.66X_{1}X_{3} + 2.21X_{2}X_{3} + 12.92X_{1}^{2} + 10.30X_{2}^{2} + 6.38X_{3}^{2}$$
(6)

Power consumption, (kWh/m<sup>3</sup>)

$$\begin{split} \mathbf{Y}_{4} &= +1.35 + 1.14\mathbf{X}_{1} + 0.061\mathbf{X}_{2} + 0.72\mathbf{X}_{3} + \\ &0.028\mathbf{X}_{1}\mathbf{X}_{2} + 0.58\mathbf{X}_{1}\mathbf{X}_{3} + 0.037\mathbf{X}_{2}\mathbf{X}_{3} + 0.15\mathbf{X}_{1}^{2} + \\ &5.00 \ \text{E} - 003\mathbf{X}_{2}^{2} \text{```} 0.020\mathbf{X}_{3}^{2} \end{split}$$

The terms in the response equations with Positive sign in front of them indicates synergistic effect, whereas negative sign indicates antagonistic effect on the response [35].

#### 3.2 ANOVA Analysis

The analysis of variance (ANOVA) tests was also conducted for each response for both model and predictability of the model is at 95 % confidence level. The coefficient of regression  $(R^2)$ is an important parameter to check the fitting of the model. According to Joglekar and May [36] value of  $R^2$  should be greater than 0.80 for good fitting of a model. In the present study, the value of  $R^2$  for removal of phenol: 0.8332 for Y<sub>1</sub>; 0.9900 for  $Y_3$  and for power consumption: 0.9989 for  $Y_2$ ; 0.9992 for  $Y_4$ ) for CCD and BBD, respectively show that all values are under satisfactory level which shows the good adequacy of the model. Adequacy of Precision measures the signal to noise ratio and ratio greater than 4 is desirable [37]. In the present study all values of the adequacy of precision 8.492 and 141.417 for CCD model and 24.817 and 115.012 for BBD model which are higher than 4.

The predicted residual error sum of squares, (PRESS) is the sum of the squared differences between the estimated and actual values over all the points for cross-validation used in regression analysis to provide a summary measure of the fit of a model to a sample of observations. A good model will have a low PRESS value [31]. Removal of phenol and energy consumption do not show high values of the PRESS as indicated in table 1, which indicate the better fitting quality of the model. The coefficient of variation, (CV) values expressed the variance in the actual and predicted values and CV values should be less than 10 and beyond this value, CV are not desirable or show higher variation in actual and model predicted data. For the present study, CV values for removal of phenol and electrical power consumption are under satisfactory level. The only CV value of phenol removal is near to 10 under the CCD model. Therefore, actual and model predicted values show very low variation to each other.

The P - value defines the significance of the model and P- values for both models are shown in Table 1 for removal of phenol and power consumption. The P-value is needed to check the significance of the each coefficient and mutual interaction between the selected test variables are also necessary to understand the pattern. The P-value < 0.05 shows that model is significant and less than 5% model term values are not significant. If the P - value > 0.1000 shows that model, terms are not significant. In this study, all P-values of responses are <0.05 which show higher significance of the model.

**Table-1:** ANOVA for Response Surface Quadratic model for removal of phenol and power consumption.

Donomotona	Phenol	removal	Power consumption			
rarameters	CCD model	BBD model	CCD model	BBD model		
Std. Dev.	9.04	2.54	0.038	0.042		
Mean	76.29	75.82	1.43	1.43		
% CV	11.85	3.35	2.68	2.95		
PRESS	5201.33	721.25	0.12	0.20		
R-squared	0.8332	0.9900	0.9993	0.9992		
Adequacy of precision	8.492	24.811	141.417	115.012		
F- value	5.55	76.96	1569.42	1001.95		
D voluo	0.0066	< 0.0001	< 0.0001	< 0.0001		
r- value	(Significant)	(Significant)	(Significant)	(Significant)		

### 3.3 Experimental versus predicted analysis of the process

The treatment process adequacy is the important part of the experiment for design through which the process provides an adequate approximation model to avoid misleading results. The experimental values and predicted values from the model shown in Fig. 1 demonstrated actual and predicted results of CCD and BBD model respectively. It was observed that the BBD model predicted values have matched with the experimental values and the data points lying close to the diagonal line in the model. However, prediction results of the CCD model were slightly mismatched with the experimental values for the phenol removal and deviated from the diagonal line as shown in Fig. 1a. The analysis of variance of the regression model for these two models was significant (p < 0.0001)for all quadratic equations. The analysis showed that these second order polynomial equations could satisfactorily predict the phenol removal and power consumption by peroxide assisted electrocoagulation process. The goodness of fit by the quadratic equation was verified by the determination of the regression coefficient R<sup>2</sup>. The values of R<sup>2</sup> for the quadratic equations for CCD were 0.8332 and 0.9993 for the phenol removal and power consumption respectively. However, the values of R<sup>2</sup> for the quadratic equations for BBD were 0.9900 and 0.9992 for the phenol removal and power consumption respectively. The BBD model was found more significant than CCD model for the removal of phenol and power consumption for optimization of the enhanced electrochemical process.

### 3.4 Sequential model sum of squares and model summary statistics analysis

The obtained CCD and BBD experimental data were also analyzed by two different modes, namely the sequential model sum of squares and model summary statistics in order to find effective regression models among various models such as linear, factor interactive, quadratic and cubic. The

results are shown in the tables 2 and 3 for the phenol removal percentage and for power consumption in order to CCD and BBD models. According to result in tables, it was found that the quadratic models exhibited higher  $R^2$ , adjusted  $R^2$ and predicted  $R^2$ , when compared to the other models. The cubic model has found aliased and cannot be used for further modelling of experimental data. A model is aliased means that not enough experiments have been run to independently estimate all the terms of that The model and the model are inappropriate for further investigation. The sequential model sum of squares showed that the p- values were lower than 0.0120 for the quadratic and linear models in CCD and less than 0.0001 for the quadratic model in case of BBD, quadratic model could be used for further study. However, the model summary statistics showed that the quadratic model was found to have the maximum "adjusted R2" and "predicted R2" Therefore R<sup>2</sup>" values after excluding the cubic model was aliased. Similarly, the analysis was carried out for power consumption and the results are given in table 2 and table 3. Therefore, the quadratic model was chosen to describe the effects of process variables on the treatment of synthetic water containing phenolic compound through the enhanced oxidation electrochemical process.

# **3.5** The interaction effects of pH and current density for phenol removal and power consumption

The effect of operating parameters obtained from the response surface analysis to estimate the maximum phenol removal and minimum power consumption with respect to each variable and the effects of each variable on the phenol removal and power consumption are depicted in Fig. 2a & b for CCD and Fig. 2c & d for BBD. The 3D plots in Fig. 2, which are simulations from Eqs. (4-7) describe the effect of the process variables on phenol removal and power consumption. The response surfaces of the quadratic model with one variable kept at the optimal level and the other

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two varying within the experimental ranges, with the phenol depletion efficiency as the response, are shown in Fig 2. The elliptical contour plots indicate that there were significant interaction effects between current density and pH. This was evidenced by the obvious peak in the response surfaces, in which the optimal conditions were exactly located inside the design boundary [29].



**Fig.1:** Regression plots of the actual data against the predicted values from the CCD and BBD response surface model: (a) Phenol removal and (b) power consumption by the EC process

The combined effect of current density  $(X_1)$  and pH  $(X_2)$  were carried out varying  $X_1$  from 2.27 to 6.81mA/cm<sup>2</sup> under different pH from 5.5 to 7.5, the results are plotted in Fig. 2 and revealed that the removal efficiency, increased with an increase in current density and optimum removal indicated in the range 4.54 and 5.57 mA/cm<sup>2</sup> of current density and pH was in the range of 6.5 and 7.0 as shown in Fig. 2a, while in case of BBD plot, the highest removal indicated near to pH of 7.0 as shown in Fig. 2c, at similar current density range. It was observed that percentage removal of phenol increased with current density. Power consumption

also increased with increasing current density at all pH value for both models as indicated Fig. 2b and 2d.

To optimize the process for high removal, the power consumption should be minimized. Therefore, optimize goal was selected by selecting a maximum removal and minimum power consumption through rating three out of five. Minimum consumption of energy 0.918 kWh/m<sup>3</sup> and 1.09 kWh/m<sup>3</sup> were achieved in 94.60 % and 90.92% removal of phenol through CCD and BBD of RSM response

by selected variables using graphite electrodes corresponding desirability. 0.885 and 0.829 respectively as show in table 4 for both the model of the RSM. Further, the optimization carried out under high level of desirability, through which the CCD model was found more significant than BBD and corresponding optimized variables were 2.78 mA/cm<sup>2</sup> current density; pH 6.98 and electrolysis time 88.02 for which predicted values of power consumption and removal percentage were 0.866 kWh/m<sup>3</sup> and 92.87 % respectively.

 

 Table-2: Sequential model sum of squares and model summary statistics for phenol removal and power consumption using the CCD model.

					Sequential mo	del sum of squar	es (CCD mode	l)				
			Phenol remov	al					Power of	consumption		
Source	sum of squares	df	Mean Square	F -Value	p- Value	Prob> F	sum of squares	Mean	Square	F -Value	p- Value	Prob> F
Mean vs Total	1.16E+05	1	1.16E+05				41.07	41	.07			
Linear vs Mean	2425.92	3	808.64	5.24	0.0104	Suggested	18.27	6	.09	36.98	< 0.0001	
2FI vs Linear	138.62	3	46.21	0.26	0.8545		2.5	0	.83	77.66	< 0.0001	
Quardratic vs 2FI	1513.72	3	504.57	6.18	0.012	Suggested	0.12	0.	041	28.05	< 0.0001	Suggested
Cubic vs Quardratic	499.25	4	124.81	2.36	0.1663	Aliased	0.014	3.46	5E-03	21.76	0.001	Aliased
Residual	317.28	6	52.88				9.54E-04	1.59	0E-04			
Total	1.21E+05	20	6064.29				61.98	3	3.1			
		М	lodel summary st	atistics								
Source	Std. Dev.	R-Squared	Adjusted R- Squared	Predicted R- Squared	PRESS		Std. Dev.	R-Squared	Adjusted R- Squared	Predicted R- Squared	PRESS	
Linear	12.42	0.4956	0.401	0.2107	3863.47	Suggested	0.41	0.874	0.8503	0.7066	6.13	
2FI	13.39	0.5239	0.3042	-1.0997	10277.61		0.1	0.9933	0.9903	0.9648	0.74	
Quardratic	9.04	0.8332	0.683	-0.0626	5201.33	Suggested	0.038	0.9993	0.9987	0.994	0.12	Suggested
Cubic	7.27	0.9352	0.7947	-78.6458	3.90E+05	Aliased	0.013	1	0.9999	0.9439	1.17	Aliased

 Table-3: Sequential model sum of squares and model summary statistics for phenol removal and Power Consumption using the BBD model.

				5	equential mod	el sum of squares	s (BBD Model)				
			phenol removal					Power Con	sumption		
Source	sum of squares	df	Mean Square	F -Value	p- Value	Prob> F	sum of squares	Mean Square	F -Value	p- Value	Prob> F
Mean vs Total Linear vs	97724.4	1	97724.4				34.83	34.83			
Mean	2905.51	3	968.5	7.87	0.003		14.59	4.86	43.15	< 0.0001	
2FI vs Linear Ouadratic vs	93.41	3	31.14	0.21	0.8894		1.36	0.45	41.56	< 0.0001	
2FI	1641.31	3	487.1	75.64	< 0.0001	Suggested	0.096	0.032	18.05	0.0011	Suggested
Cubic vs quadratic	45.08	3	15.03			Aliased	0.012	4.15E-03			Aliased
Residual	0	4	0				0	0			
Total	1.02E+05	17	6013.51				50.89	2.99			
Mode	l summarv stat	istics									

Source	Std. Dev.	R-Squared	Adjusted R- Squared	Predicted R- Squared	PRESS		Std. Dev.	<b>R-Squared</b>	Adjusted R- Squared	Predicted R- Squared	PRESS	
Linear	11.09	0.6449	0.563	0.4644	2413		0.34	0.9087	0.8877	0.811	3.04	
2FI	12.27	0.6556	0.465	0.1456	3849.32		0.1	0.9932	0.9892	0.9735	0.43	
Quadratic	2.54	0.99	0.9771	0.8399	721.25	Suggested	0.042	0.9992	0.9982	0.9876	0.12	Suggested
Cubic	0	1	1		-	Aliased	0	1	1		-	Aliased

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#### 3.6 Optimum conditions using desirability functions

For optimization results of RSM, a desirability function approach could be applied to obtain the most significant optimal conditions. The numerical optimization of the software has been selected in order to find the specific point that maximizes the desirability function. According to the results, the optimum operating conditions for the maximum phenol removal are found the current density 2.78 mA/cm<sup>2</sup>, pH 6.98 and time 88.02 min for CCD model. However, the optimum parameters were current density 5.24 mA/cm<sup>2</sup>, pH 7.31 and electrolysis time 72.32 minutes in case of BBD model for higher phenol removal for which the value of desirability was unity as indicated in table 4 selected goal was in the range. However, the goal change for maximum removal and minimum power consumption, the operating conditions were current density of 2.82 mA/cm<sup>2</sup>, pH of 7.10 and electrolysis time of 89.99 minutes under CCD model and 3.99, 7.11 and 58.43, respectively for BBD model, the desirability for these conditions lower down from unity value. An experimental test was conducted using the predicted optimum variable conditions as depicted in table 4. The experimental findings for all response parameters slightly deviated with all the values predicted by models using desirability function, but only the experimental results were found close to the BBD model predicted results under high desirable level when the desirability level was unity but corresponding power consumption has found high as indicated in table 4.



**Fig.2:** 3D response surface plots showing effect of pH and Current density on removal efficiencies of phenol and power consumption using graphite electrodes: (a) phenol removal CCD model (b) power consumption; for CCD model (c) phenol removal (d) power consumption; for BBD.

#### 4. CONCLUSIONS

The enhanced electrochemical oxidation process for the removal of carbolic acid from synthetic solution was studied using graphite electrodes. During enhanced electrochemical oxidation process a very high phenol removal i.e. 96.01 % was achieved at a current density of 4.54 mA/cm<sup>2</sup> under optimized pH of 6.5. The analysis of variance of the regression the model was significant (p < 0.0001) for all quadratic equations under CCD and BBD model of response surface methodology. The analysis demonstrated that these second order polynomial equations could satisfactorily predict the phenol removal and power consumption by peroxide assisted electro- coagulation process. The RSM results demonstrated significant effects of three operating variables as well as their interactive effects on two responses (phenol removal and power consumption by using electrocoagulation). The BBD model has demonstrated high R<sup>2</sup> value 0.99 for the phenol removal which revealed that the electrochemical oxidation process enhanced with hydrogen peroxide oxidation agent can be successfully applied for the phenol loaded water. In closing remarks, it was found that Graphite electrode under enhanced electrochemical oxidation process leads higher percentage removal of phenol at low power consumption.

 Table-4: Optimize conditions of electrochemical process

 based on desirability

	Inde	pendent var	iables					
	Current			Phenol 1	emoval, %	Power consu	mption, kWh/m <sup>3</sup>	
	density,			Model		Model		
Optimization	(mA/cm <sup>2</sup> )	pH	Time, (min)	predicted	Experimental	predicted	Experimental	Desirability
			Max - Mi	n based				
CCD based	2.82	7.1	89.99	94.6	85.98	0.918	1.18	0.885
BBD based	3.99	7.11	58.43	90.92	84.92	1.09	1.19	0.829
			Selected Ra	nge based				
CCD based	2.78	6.98	88.02	92.87	86.34	0.866	1.12	1
BBD based	5.24	7.31	72.32	93.42	91.23	2.156	2.46	1

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