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# Optimization of the electro coagulation process for the removal of cadmium from aqueous solution using RSM

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**Abstract—** A certain of industrialized wastewater streams include heavy metal ions, should be efficiently removal before the reuse or discharge of treated waters could occur. In this work, the removal of cadmium from aqueous solution was carried out by electro coagulation using aluminum electrodes as anode and cathode. Electro coagulation cell of 1litter was used in this research. Several operating parameters on the removal efficiency of cadmium were investigated, such as initial pH, voltage, initial cadmium ion concentration, NaCl concentration, spacing between electrodes, and type of electrode . The Cd(II) concentration (50 ,100,150,200 ppm),( stirring speed 120 rpm) at room temperature . A pH was use to be a constant best value when studied the impact of voltage values were chosen as 6,10, and 14 increasing voltage increased Cd(II) removals significantly Removal of 30.1%, 94.1%, 97.4%. The optimum removal efficiency of 97.4 % was achieved at a voltage of 14 V and pH 5 using (Al/Al.) electrodes, within 60 min of operating time. The concentration of NaCl was 0.6 g/l with a 0. 5 cm spacing between the electrodes.

**Keywords—** Cadmium, voltage, electro coagulation, RSM.

## 1. Introduction

At the present time, special heavy metal ions and complex organic molecules were release to the environment because of the rapid growth of industrial production and agricultural processes. The impure wastewaters are as a result accumulated in the environment Because of these actions. When these pollutants persevere in the environment caused serious health special effects to the humans[31 ,36] Heavy metals are defined as metals with a density usually more than 5.0 g/cm3, which is five times higher than water. The toxicity of heavy metals happens also in low concentrations of about 21 are non-metals, 16 are light-metals, 1.0-10 mg/l. Of the 90 naturally occurring elements, and the remaining53 are mainly toxic non-important heavy metals found in the environment, even at low concentrations[34] .high level of cadmium ions occur from a range of sources for example wastewater from nickel–cadmium batteries ,metal plating industries, mining, pigments ,phosphate compost, stabilizers, tanneries, petroleum refining ,alloys, welding car radiator batteries painting, as well as agricultural sources where fertilizers and fungicidal [28,24,17] The principle value 0f drinking water is 0.005 mg/L [6]. The toxicity caused by heavy metals is generally a result of strong coordinating abilities [34] Based on the toxicity impact , apart of heavy metals are (Cd As, U, Ag, Pb, Hg, Sb classified as High toxicity), (Cu, Zn, Co, V, Ni, C r, W classified as Average toxicity) and (Mn ,Mo Fe, classified as low toxicity) [35]. The Iraqi standards and the world health organization (WHO), all, limit for concentration of cadmium in a drinking water, rivers and wastewater, the the limit values were obtainable in Table .1.

**Table 1:** limit of cadmium concentration in rivers, wastewater and drinking water [9].

| Cd | Drinking water mg/l | river mg/l | wastewater mg/l |
|---|---|---|---|
| Iraqi standards | 0.005 | 0.01 | 0.05 |
| WHO | Nil | 0.04 | 0.05 |

Heavy metals are not biodegradable and beinclined to accumulate in living organisms, causing various diseases and disorders [**4**] .Reverse osmosis ,chemical precipitation, ion-exchange, membrane filtration and evaporation processes These techniques are used for removal heavy metal ions from the impure water **[15]** Because of costly, great amount of excess sludge formed during the process, so that a need of cost effective techniques these techniques are costly and un favorable to remove heavy metals from impure waters **[33, 3,21].** Because of the incomplete metal removal, high operational cost, and the generation of secondary wastes are not viable **[10].** Electro coagulation is a process consisting of creating metallic hydroxide flocks within the wastewater by electro dissolution of soluble anodes ,usually made of iron or aluminum[**19**].Electro coagulation is depend on that the stability of colloids, emulsions , and suspensions are effected by electric charges. As so, if additional electrical charges are given to the charged particles via appropriate electrodes, the surface charge of particles is neutralize and more than a few particles combine into larger and separate agglomerates **[27]**. Usually, the best electrode used in electro coagulation process are aluminum and iron, because they are available, proven effective and cheap **[7].** The reactions are as follows in Eq (1.2.3) used when aluminum is used as electrode material

- At cathode:

$$3H20 + 3e \longrightarrow \frac{3}{2}\text{H} + \text{OH} \qquad (1)$$

- At anode:

$$\text{Al} \longrightarrow \text{Al} + 3\text{e} \qquad (2)$$

- In the solution

$$\text{Al} + 3\text{H2O} \longrightarrow \text{Al (OH) 3} + 3\text{H} \qquad (3)$$

Metal anode dissolution is accompanied by hydrogen gas evolution at the cathodes, the bubble s capture and float the suspended solids formed and thus remove contaminants **[16].** Removal mechanisms reported in the electrolysis process generally include oxidation, reduction, decomposition, and deposition, whereas the mechanisms in the Electro coagulation process include coagulation, absorption, adsorption, Precipitation , and flotation. One of the most important parameter is voltage. It is strongly based on the conductivity of the water /wastewater to treat , current density, the distance of inter-electrode and the surface state of the electrodes **[8]** Removal process reported in the electrolysis process mainly involves deposition ,reduction ,oxidation, and decomposition, where as these process in the Electrocoagulation method include precipitation, adsorption ,absorption ,flotation, and coagulation. The Electro coagulation method used in some industrial process in petroleum refineries to treatment fat and oils that realse from it [**23**] oil in industrial wastewater **[26],** and in the treatment of textile wastewater [20]. The need for additional chemistry physical studied is indicated ,because electro coagulation is being satisfactorily used to treat wastewater, **[22],** Factorial design (FD) was helpful for screening some of factors to estimate main effect and interactions and discover the essential few using DX program Response surface methodology was used to describe the essentials of heavy metal removal from aqueous solution by EC **[29]** Response Surface Methodology (RSM) has an essential program for determining impact of certain absolute variables and interact impacts among the variables on the response **[29,37 ].** RSM was used to predict the EC results under different experimental conditions **[29, 18].** The important method parameter were optimized by used response surface methodology (RSM) based on the central composite design (CCD) **[2].**

### Objective of study

1. Removal heavy metal ions (cadmium) and study efficiency of them using electro coagulation technique and Optimization using RSM.
2. Operating variables on the cadmium removal efficiency pH, voltage, NaCl concentration, initial cadmium concentration, gap between electrodes, and type of electrode.

## 2. Experimental work

### 2.1 *Material*

work was conducted at the laboratories of the environmental Engineering Department of university of Baghdad cadimum stock solution of 1000 mg/L was prepared prepared by mixing proper amount of cadmium nitrate (Cd(NO3)2.4H2O) (2.47g) waited by Electrical balance: an electrical balance (digits) was used to weigh the materials Table.1 in one liter of di-ionized water .The chloride salt added to the solution can also prevent the formation of the oxide layer on the anode and therefore reduce the passivation problem of the electrodes. Table.2 shows the physical and chemical properties of the cadimum nitrate, atomic absorption spectrophotometer (AAS; SHIMADZU, Model: 7200, Japan) it use to determine cadmium concentration. NaOH and HNO3 with concentration of 0.1 M using a pH meter (WTW, inoLab 720, Germany was used as required for controlling the pH of the aqueous solution at room temperature.

**Table 2:** Properties of cadmium nitrate

| | |
|---|---|
| Boiling point | 765ºC |
| Melting point | 320.9ºC |
| Density | 4.25 g/cm3 |
| Atomic weight | 112.4 g/mole |
| Manufacturing company | neminath indi |
| impurity | 99% |
| Appearance | White colorless crystals |
| Chemical formula | Cd(NO3)2.4H2O |
| Hydrated ionic radius, Å | 4.26 |
| molecular weight | 308.7 |
| Solubility in water g/100 ml at 20 ºC | 136 |

Experiments were performed in bipolar batch in parallel. (bipolar mode) electrodes were joined to the power supply cathode and anodic when the voltage and current passed through the electrodes reactions occur on each surface of the internal electrode. The dimienision of electrode was **15cm× 2cm×2mm**: (length × width × depth) and size of cell of beaker of one litter with an effective volume of 1000 cm. The active area of electrode was 15×2 cm. The gap between of electrodes was 0.5 cm. A power supply having voltage from 0-14 V and highest current: of 2 ampere The temperature was maintained at room temperature °C. conductivity of the solution during the experiments a Samples were extract every( 0 ,30 , 60 min) and then directly filtered. The exploratory work was performed in a batch mode to remove cadmium from water. The exploratory tests were planned to consider the impacts of several operating parameters on cadmium removal efficiency .The parameters were , voltage , initial pH of the solution, initial cadmium concentration in the solution, electrodes material, gap between electrodes, NaCl concentration in the polluted water In the present work:

1. Cadmium nitrate (tetra hydrate) was used to prepare the stock solution. Synthetically polluted water was prepared by dissolving **2.74g** of cadmium nitrate in one litter de ionized of water to prepare stock solution 1000ppm in eq(4)

$$W = V\,Cst\,\frac{Mwt}{At.wt} \qquad (4)$$

Where:
W = weight of Cd (No3)2.4H2O (g)

V = volume of solution (L)

Cst = cadmium concentration in stock solution (g/l)

M.wt= molecular weight of $Cd\ (NO_3)2.4H_2O$ (308.47g/mol)

At.wt= atomic weight of cadmuim (112.4 g/mol).

The following laboratory grade reagents were used in **Table .3.**

**Table 3:** laboratory grade reagents were used in experimemt

| ChemicL used in experimental work | |
|---|---|
| 1. | Cadmium nitrate Cd(NO3)2 .4H20 |
| 2. | nitric acid 0.1 M. |
| 3. | Sodium chloride, solid powder, purity=99.5% wt. |
| 4. | Buffer solutions with pH=4, 7, 10 |
| 5. | de ionized water |
| 6. | two Al electrodes |

Each run was coordinated beginning with the DC control supply exchanging on. Amid the tests, anodic disintegration happened and hydrogen gas was created at the cathode. Samples of 10 ml were taken during each experiment at different time to be filtered and then analyzed. Each sample was taken from a distance between two electrodes and at fixed depth. After each run, the electrodes were washed and brushed then cleaned to remove any solids accumulated on the electrode surface.

## 2.2 *Batch study*

The impact of variable operation conditions for indicating the most extreme removal efficiency of cadimim particles were considered by group tests which are conducted in sixs step. These conditions are;

pH, salt concentration , voltage , distance between electrode, initial metal concentration and contact time. These steps were :

1. required the variation of pH (3, 5,7,9,10) while the other parameters; salt concentration of 400 ppm , initial cadimum concentration of 100 ppm voltage 10 v , distance between electrode 0.5 cm and time 30 min fixed at agitation speed.
2. required the variation of salt concentration (50, 400,600) ppm while the other parameters; pH of 5 , initial cadimum concentration of 100 ppm , agitation speed 120 rpm , voltage 10 v , distance between electrode 0.5 cm and time 30 min at fixed agitation speed.
3. required the variation of voltage values of ( 6.10.14 v) while the other parameters; pH of 5 , salt concentration 600, ppm initial cadimum concentration of 100 ppm , distance between electrode 0.5 cm and time 30 min at fixed agitation speed .
4. required the variation of distance between electrode values of ( 0.5 ,2,3 cm) while the other parameters; pH of 5 , salt concentration 600ppm ,voltage 14 v ,initial cadimum concentration of 100 ppm , and time 30 min at fixed agitation speed.
5. required the variation of initial cadimum concentration values ( 50 ,100,150,200 ppm) while the other parameters; pH of 5 , salt concentration 600ppm ,voltage 14 v , distance between electrode 0.5 cm and time 30 min at fixed agitation speed.
6. required the variation of time values ( 15 ,30,60 min) while the other parameters; pH of 5 , salt concentration 600ppm ,voltage 14 v , distance between electrode 0.5 cm , intial cadmium concentration 200 ppm at fixed agitation speed.

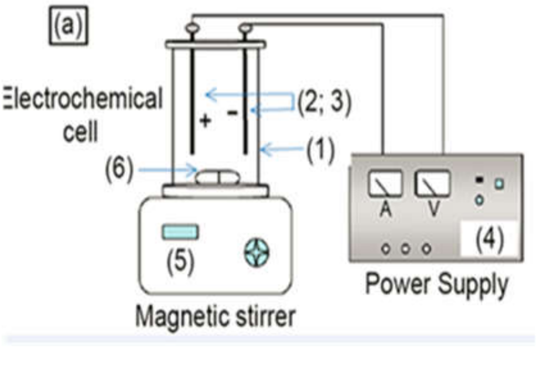


**Figure 1:** A schematic graph of the test setup

**Figure 2:** plate picture of EC cell in mid of experiment at Env. Eng. Labs

**Figure 3:** photographic picture of EC cell in end of experiment at Env. Eng. Labs

### 2.3 *Response Surface Methodology (RSM)*

The RSM comprises of a batch of experimental methods given to the assessment of relationship existing between a measured reactions agreeing to one or more chosen criteria and cluster of controlled test variables [13.18.29]. In later a long time, RSM has been for the most part connected to optimize test conditions. The ideal reaction was found employing a second-degree polynomial demonstrate. This model is only an approximation, because such a model is easy to estimate and apply, even when little is known about the process use it [14]. The true functional relationship between the set of independent variables (factors) (X1, X2, . .) and the dependent variable (response) (Y). The next higher order model is the second-order model and is given by Eq. (5):

$$Y = \beta_0 + \Sigma^{k}_{i=1} \beta_i X_i + \Sigma^{k}_{i=1} \beta_{ii} X^2_{ii} + \Sigma^{k}_{i=1} \beta_{ji} X_i X_j + \varepsilon \quad (5)$$

Where: Y= is the predicted response, Xi, Xj, Xk= are the input variables, which affect the response Y, $X^2_1$, $X^2_2$ ,… $X^2_K$ are the square effects, $\beta_0$ is the intercept term, $X_i X_j$, $X_j X_k$ and $X_i X_k$ are the interaction effects βi (i=1,2,k) is the linear effect ,βii (i=1,2,k) is the squared effect, βij j=(1,2,k) is the interaction effect and ε is a random error **[14,5]** While ANOVA used to study the model if it would be acceptable using F-value and p-value results. P > F less than 0.05 was regarded as significant. In **Table .4** factor of condition range in RSM

**Table 4:** Name, units and level of Factors used in the minimum run resolution v characterization design used to process using DRWAS optimized electro coagulation

| Factor | Name | Units | Level and range (coded) | |
|---|---|---|---|---|
| | | | -1 | 1 |
| x1 | pH | | 3 | 10 |
| x2 | NaCl concentration | Ppm | 50 | 600 |
| x3 | Initial cadmium ions concentration | mg/L | 50 | 200 |
| x4 | Voltage | V | 6 | 14 |
| x5 | Contact time | Min | 15 | 60 |
| x6 | Distance between electrode | Cm | 0.5 | 3 |

Where:

$X_1$= initial concentration, X2 =salt concentration, X3= distance, X4 =PH,

$X_5$= voltage, X6=time, $X_1X_6$=initial concentration*time, $X_2X_3$= salt concentration* distance, $X_2X_4$= salt concentration* PH, $X_2X_5$= salt

Concentration* voltage, $X_2X_6$= salt

Concentration* time, $X_3X_4$= distance

*PH, $X_4X_6$= PH *time, $X_1X_2X_6$=

Initial concentration *salt concentration

*time.

## 3. Results and discussion

The conditions of electro coagulation process which produce higher efficiency and give high quality of water were studied. The main operating parameters are: initial pH of the solution, current density, initial cadmium concentration, gap between the electrodes, temperature, NaCl concentration and electrodes type Cadmium removal efficiency was estimated from experimental tests.

One modes were studied during electro coagulation treatment [Batch mode]

### 3.1 *Effect of initial pH*

It has been established that the initial pH [7] is an important factor and has a considerable influence on the performance of electro coagulation process. The first effect in this study is the effect of pH change on the treatment effectiveness. The range of pH used in this work (3-10) to study the impact this parameter on the cadmium removal, pH of the solution can easily be altered by adding 1M HCl or NaOH. According to this a fig .4 it can be seen that the higher Cd removal efficiency (91.2%) achieved at pH equal to (5) with electrolysis time of (60) min may be due to at pH of 5,formation of Al(OH)2 which might be less dissolved in water. . A pH was use to be a constant best value when studied the impact of another parameters In the work to assess the impact of pH on the removal efficiency of cadmium, removal increased gradually when pH increased. Consequently, metal evacuation efficiency expanded significantly, to reach about 100% evacuation, due to the precipitation of the target analytics at an alkaline pH, [11]

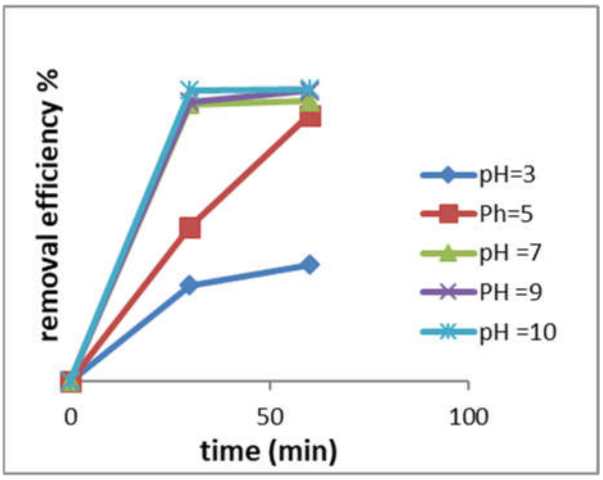


**Figure 4:** Effect of initial pH on Cd removal efficiency (Initial conditions: vertical (Al/Al) electrodes, V=10v [Cd] =100 ppm, [NaCl] =400ppm, gap=0.5cm, T=30º

## 4. Effect of salt concentration

In order to examine the effect of chloride ion concentration on the electro coagulation cell. Sodium chloride with concentrations (50-600) ppm was added. Fig.5 shows the relationship between cadmium removal efficiency and time for different values of NaCl This figure shows that the increasing of NaCl concentration leads to an increase in the removal rate and decreasing in reaction time, when using (50) ppm NaCl, the maximum cadmium removal decreased as the solution conductivity increased efficiency achieved (52.12%) at time (60) min, while increasing NaCl to (600) ppm resulted in (52.9%) removal efficiency at time (30) min but 94.1 % at time 60 min This means that the time decreased as the solution conductivity increased . The result agrees with that obtained by [25]

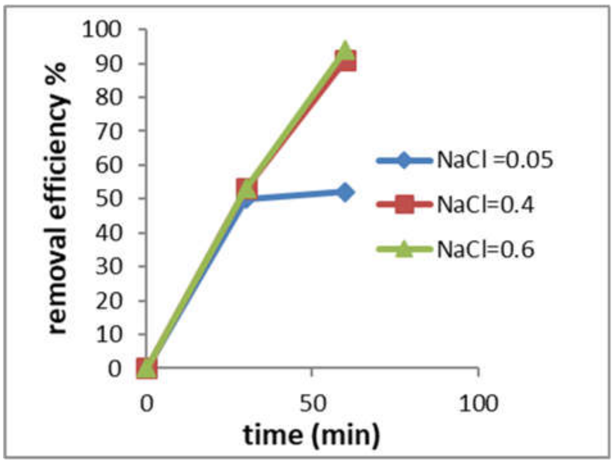


**Figure 5:** Effect of Nacl on CD removal efficiency (Initial conditions: vertical (Al/Al) electrodes, V=10v [CD] =100 ppm, PH= 5, gap=0.5 cm, T=30ºC

## 5. Effect of the gap between electrodes

The effect inter electrode spacing on cadmium removal was investigated with spaces of 0.5, 2, and 3cm. The results of gap effect are plotted in fig.6 As can be seen the removal efficiency increases with the decrease of space between electrodes while the highest removal efficiency of 94.1% was obtained at gap of 0.5cm after 60 min This can be explained that decreasing the space between electrodes results in low resistance through the solution which in effect results in increasing the rate of aluminum dissolution and $AL^{+}3$ releases and consequently leads to more cadmium removal from the solution. [1] The best gap between electrodes is (1 or 0.5) cm depend on type of electrode material and initial pH.

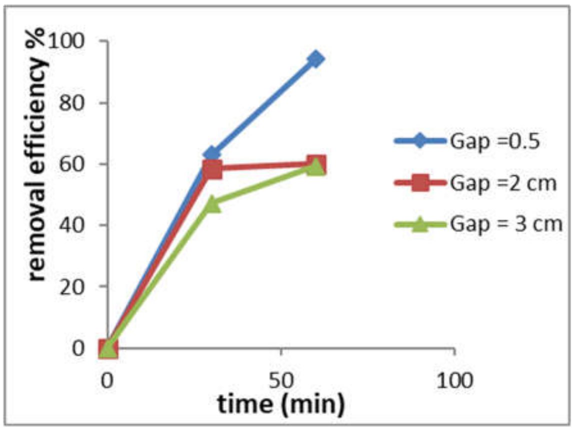


**Figure 6:** Effect of distance between electrode on cadmium removal efficiency (Initial conditions: vertical (Al/Al) electrodes, V=10v [cd] =100 ppm, PH= 5, Nacl= 0.6 ppm, T=30ºC

## 6. Effect of voltage

The amount of cadmium ion removal was measured at in electric potential range of 6, 10 and 14 volts. The results obtain at variance electrical potential view that cadmium initial concentration of can effect on efficiency removal and for cadmium higher concentration, higher electrical potential or more reaction time is needed The effect of voltage (6-14) V on the percentage of removal is shown in fig.7 This figure shows The most electrical potential (14 V) created the fastest treatment with96.5% cadmium reduction happening after as it were 60 min and the least cadmium evacuation effectiveness happened within the least electrical potential (6 V). Usually credited to the fact that at max current, the sum of aluminum oxidized expanded, coming about in a greater sum of precipitate for the evacuation of pollutant . In expansion, it was illustrated that bubbles thickness increases and their size decreases with expanding current thickness (Khosla et al., 1991), resulting in a greater upwards flux and a speedier removal of poisons and sludge flotation. As the current diminished, the time required to realize comparable efficiencies expanded and the results of this study affirm this fact.

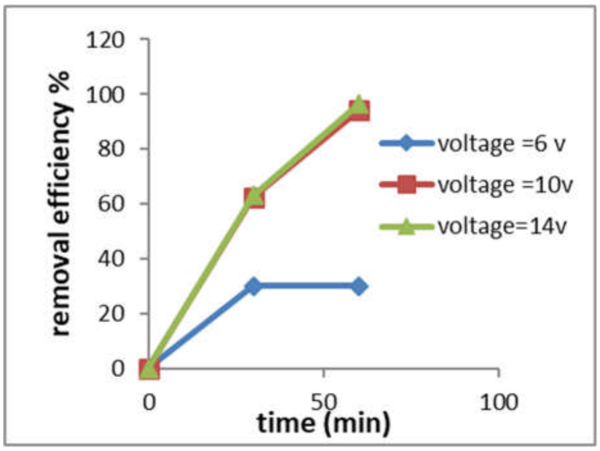


**Figure 7:** Effect of voltage on cadmium removal efficiency (Initial conditions: vertical (Al/Al) electrodes, ppm, PH= 5, Nacl= 0.6 ppm, gap= 0.5 cm T=30ºC

## 7. Effect of initial Cd concentration

The effect of metal concentration on removal rate was examined using an increased metal concentration (50-200ppm) for cadmium ion concentrations of cadmium ion were measured at same times. The experiments were performed using the constant pH level of 5, voltage of 14 v and the distance between electrode 0.5 cm during all experiments. In fig.8 shows The best concentration of Cd =50 ppm to reach 97.4% in time (60min) and shows that the higher concentration needed greater time to reach (95.5%) removal efficiency of cadmium . The time in utilize for reduction increments gradually with increments cadmium concentration and this may be explained by the hypothesis of dilute solution. In dilute solution, arrangement of the dissemination layer at the region of the electrode causes a quicker response rate, but in concentrated arrangement, the dissemination layer has no impact on the rate of movement of metal ions to the electrode surface (Chaudhary et al., 2003). This result proves that the amount of Al3+ delivered per unit of pollutant removed is not affected by the initial concentration.

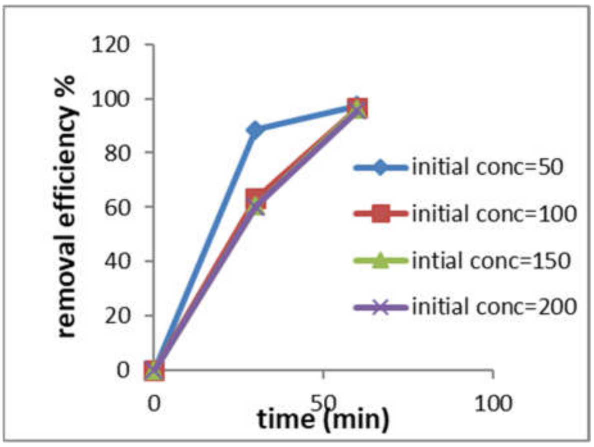


**Figure 8:** Effect of initial concentration between electrode on cadmium removal efficiency (Initial conditions: vertical (Al/Al) electrodes, V=14v ppm, PH= 5, Nacl= 0.6 ppm, gap= 0.5 cm T=30ºC6.

## 8. Effect type of electrode

Two types electrode (Al/AL and st/st) are used to study their effects on the removal efficiency of cadmium ions the results are shown in fig.9respectively. The first figure shown that the removal efficiency influences with electrodes type. The best electrode type is the vertical (Al/Al) electrodes which achieved (97.4%) removal efficiency in (60) min, while, the vertical (St/St) electrodes achieved (91%) removal efficiency in (60) min. The removal in both types is good but is considered stainless steel the stables better because it does not consume quickly.

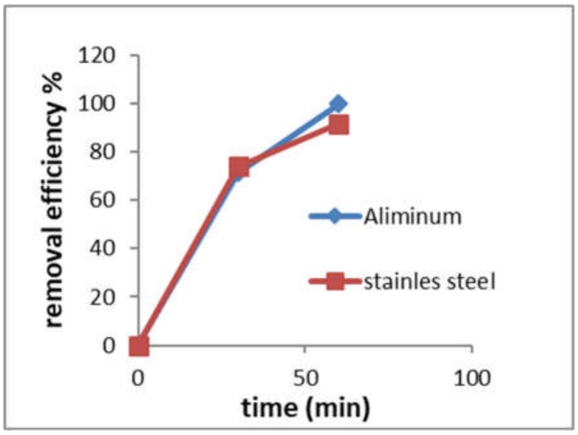


**Figure 9:** Effect of type of electrode (aluminum electrode and stainless steel on cadmium removal efficiency (Initial conditions: V=14v Cd =50 ppm, PH= 5, Nacl= 0.6 ppm, gap= 0.5 cm T=30ºC

## 9. Removal Efficiency

Each sample taken from the electro coagulation cell was filtered and then analyzed using atomic absorption spectrometer AAS for heavy metal midland oil company The removal efficiency of cadmium in artificial polluted water treated by electro

Coagulation is calculated as follows in eq (7)

$$\boldsymbol{Removal\ rate} = \ ((\boldsymbol{Co} - \boldsymbol{Ce}))/\boldsymbol{Co} \quad \times \mathbf{100\%} \tag{7}$$

Where:

ɳ%= cadmium removal efficiency.

C = cadmium concentration at any time (mg/l).

Co= cadmium or dyes concentration at initial (mg/l). RSM, CCD analyzed method were done by Design Expert 7.0 (trial version), for optimization of significant parameters under the study by 48 experiments to perform the locate of maximum The Model F-value of 38.50 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, D, F, AB, AF, BC, BD, BE, BF, CD, DF, ABF are significant model terms. Values higher than 0.1000 denote the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

$$\boldsymbol{Cadmium\ removal\ efficiency}\ (\%) = -\mathbf{38.15952} + \mathbf{0.10005} * (\boldsymbol{X1}) + \mathbf{0.087087} * (\boldsymbol{X2}) - \mathbf{7.28687} * (\boldsymbol{X3} + \mathbf{6.61036} * (\boldsymbol{X4}) + \mathbf{1.86334} * (\boldsymbol{X5}) + \mathbf{1.81022} * (\boldsymbol{X6}) - \mathbf{1.31975}\boldsymbol{E} - \mathbf{004} * (\boldsymbol{X1} * \boldsymbol{X6}) - \mathbf{0.011781} * (\boldsymbol{X2} * \boldsymbol{X3}) + \mathbf{4.88290}\boldsymbol{E} - \mathbf{003} * (\boldsymbol{X2} * \boldsymbol{X4}) - \mathbf{4.12770}\boldsymbol{E} - \mathbf{003} * (\boldsymbol{X2} * \boldsymbol{X5}) - \mathbf{1.70378}\boldsymbol{E} - \mathbf{003} * (\boldsymbol{X2} * \boldsymbol{X6}) + \mathbf{1.28496} * (\boldsymbol{X3} * \boldsymbol{X4}) - \mathbf{0.083225} * (\boldsymbol{X4} * \boldsymbol{X6} + \mathbf{9.77811}\boldsymbol{E} - \mathbf{006} * (\boldsymbol{X1} * \boldsymbol{X2} * \boldsymbol{X6}) \tag{8}$$

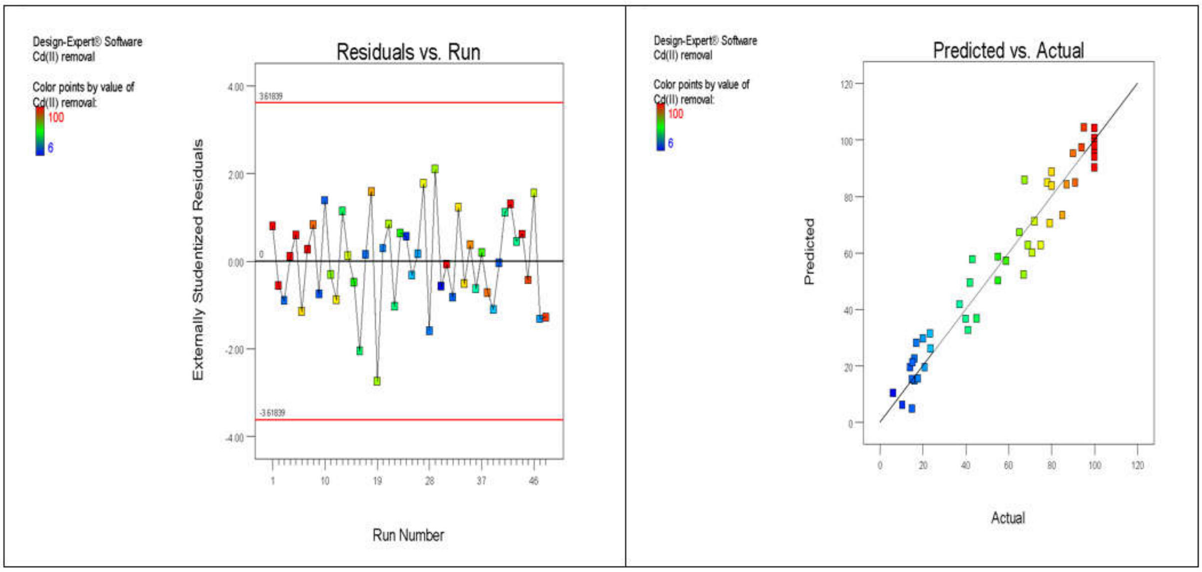
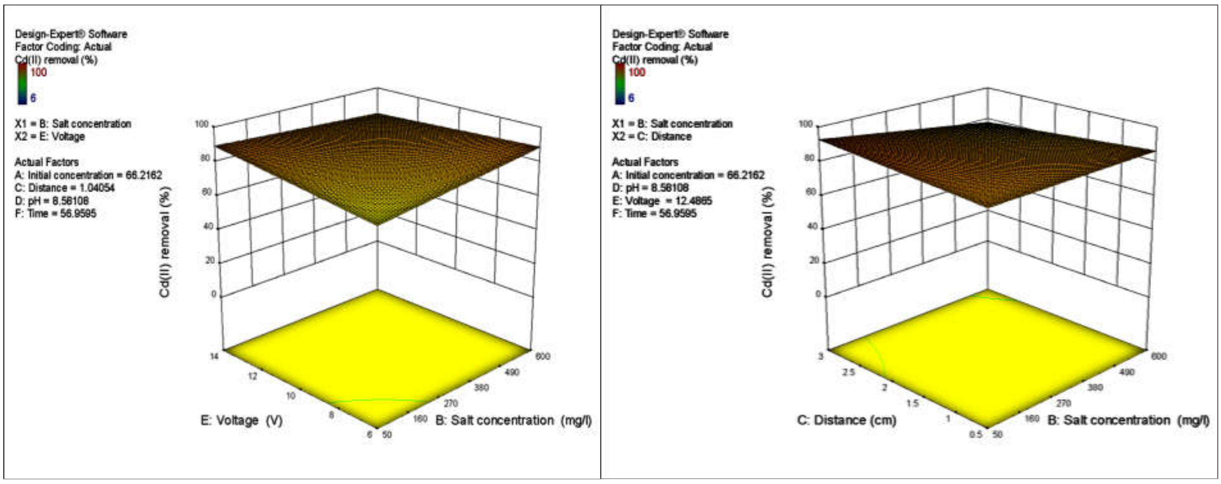


**Figure 10**: Actual and predicted values for Cd (II) for removal efficiency onto DRWAS

The "Pred $R^2$ of 0.8813 is in reasonable agreement with the "Adj $R^{2\ of}$ 0.9229; i.e. the difference is less than 0.2."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 19.123 indicates an adequate signal. This model can be used to navigate the design space in Table.5Analysis of variance F value and Prob>F for Cd (II) onto DRWAS removal efficiencies.

**Table 5:** Analysis of variance $P_{rob}$>F and F value for Cd (II) onto DRWAS removal efficiencies

| ANOVA for selected factorial model | | | | | | |
|---|---|---|---|---|---|---|
| Analysis of variance table [Partial sum of squares - Type III] | | | | | | |
| Sum of | | | Mean | F | p-value | |
| Source | Squares | df | Square | Value | Prob > F | |
| Model | 46883.89 | 15 | 3125.59 | 38.50 | < 0.0001 | Significant |
| $x_1$-Initial concentration | 2685.17 | 1 | 2685.17 | 33.07 | < 0.0001 | |
| $x_2$-Salt concentration | 1817.82 | 1 | 1817.82 | 22.39 | < 0.0001 | |
| $x_3$-Distance | 572.77 | 1 | 572.77 | 7.05 | 0.0122 | |
| $x_4$-pH | 31550.02 | 1 | 31550.02 | 388.61 | < 0.0001 | |
| $x_5$-Voltage | 185.90 | 1 | 185.90 | 2.29 | 0.1400 | |
| $x_6$-Time | 901.42 | 1 | 901.42 | 11.10 | 0.0022 | |
| $x_1x_2$ | 999.81 | 1 | 999.81 | 12.31 | 0.0014 | |
| $x_1x_6$ | 2126.38 | 1 | 2126.38 | 26.19 | < 0.0001 | |
| $x_2x_3$ | 787.24 | 1 | 787.24 | 9.70 | 0.0039 | |
| $x_2x_4$ | 1060.23 | 1 | 1060.23 | 13.06 | 0.0010 | |
| $x_2x_5$ | 879.61 | 1 | 879.61 | 10.83 | 0.0024 | |
| $x_2x_6$ | 426.08 | 1 | 426.08 | 5.25 | 0.0287 | |
| $x_3x_4$ | 1348.43 | 1 | 1348.43 | 16.61 | 0.0003 | |
| $x_4x_6$ | 2061.81 | 1 | 2061.81 | 25.40 | < 0.0001 | |
| $x_1x_2x_6$ | 878.52 | 1 | 878.52 | 10.82 | 0.0024 | |
| Residual | 2598.00 | 32 | 81.19 | | | |
| Cor Total | 49481.89 | 47 | | | | |



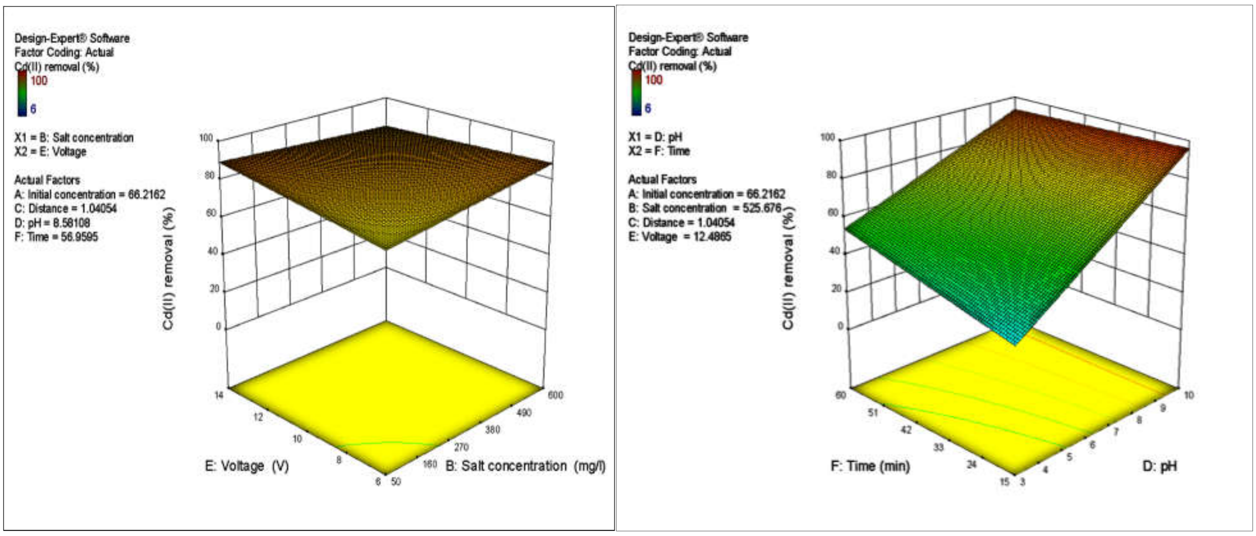


**Figure 11**: Graphical representation for the electro coagulation Cd (II) on to DAB in ternary system

## 10. Previous Studies of Water and Wastewater Treatment by EC Processes

Some important previous studies related with electro coagulation is given below in **Table .6.**

**Table.6:** Comparsin table between previos studies and current studies

| Type of heavy metal | Experiments procedure | Optimum conditions | R% | Reference |
|---|---|---|---|---|
| Cd[II] | 1. PH=[2-7]<br>2. NaCl concentration=[0, 2.5,5,10]<br>3. current density=[ 0,25, 0,50, 1,0, 1,5] mA/cm2<br>4. temperature= 293 k<br>5. intial concentration = 250mg/l<br>6. type of electrode = aluminum<br>7. time = [20- 60] min<br>8. stirring speed= 150 rpm | optimum conditions pH of 6,<br>, 150 rpm stirring speed, 250mg/L $Cd^{+2}$ concentration ,1.50 $mA/cm^2$ of current density<br>,temperature of 293 K | 99% | [11] |
| Cu<br>Pb<br>Cd | 1. PH=[3-10]<br>2. voltage=[ 20,30,40]<br>3. intial concentration=[5,50,500] mg/l<br>4. type of electrode = iron<br>5. time=[20-60] | removal for pH = 10 and voltage =40v and time 60 min | 99% | [3] |

| | | | | |
|---|---|---|---|---|
| Cu<br>Ni<br>Cr<br>Zn<br>Cd<br>Co | 1. PH=[ 2-10]<br>2. NaCl concentration=<br>3. distance between electrode = 2mm<br>4. Current density = [0.27- 1.35] mA/cm2.<br>5. intial concentration= [ 50-400] mg/l<br>6. type of electrode= iron<br>7. time=[5-30] | At pH= 7<br>Time = 6.4 min for zn, cr, cu<br>And 9 for Ni<br>And 30 min for co cd,<br>Current density (1.35 mA/cm2) | 99% for Zn,Cu,Ni,Cr<br>83% for Cd<br>80% for Co | [13] |
| Br | 1. PH=[3-10]<br>2. NaCl concentration=<br>3. distance between electrode<br>4. Current density = [1, 1.5, 2, 2.5, 3, 3.5, 4] mA/cm².<br>5. intial concentration=[3-7] mg/l<br>6. type of electrode =[Mg/St.St],[Al/Al]<br>7. time=[10-80] min<br>8. NaCl concentration=[0.01-0.2] g/l<br>9. distance between electrode =[0.5,0.75, 1] cm<br>10. Coexisting Anions (Carbonate)=[ 50, 100, 150, 200, 250] mg/l. | The optimum removal efficiency of was achieved at a current density of 3mA/cm² and pH = 7 using (Mg/St. St.) electrodes, within 45 min of operating time. The concentration of NaCl was o. 1 g/l with a 0. 5 cm spacing between the electrodes | 91. 5 % | [1] |
| Cd | The current study producer is<br>1. pH=[3,5,7,,9,10]<br>2. NaCl concentration =[50,400,600] ppm<br>3. distance between electrode =[0.5,2,3] cm<br>4. intial concentration of Cd =[50.100.150,200] ppm<br>5. voltage =[6,10,14 ] V<br>6. type of electrode =aluminum<br>7. temperature =30<br>8. stirring speed= 120 rpm | The optimum removal efficiency of was achieved at pH = 5 using (Al/Al.) electrodes voltage =14v within 60 min of operating time. The concentration of NaCl was 600 ppm with a 0. 5 cm spacing between the electrodes | 97.4 % | this study |

## 11. Conclusion

In the present study, electro coagulation process has been evaluated as a treatment technology for cadmium removal from industrial effluents. Cadmium removal efficiency at different condition(pH, electrical potential) It has been established in previous studies (Vik et al., 1984; Chen et al., 2000) The results showed that a removal efficiency of 97.4% can be achieved by an aluminum anode/cathode combination with voltage =40 volt reaction time of 60 min and pH 5 was found to give the best Cd+2 removal efficiency because Al+3 ions in the solution turned into Al(OH)3(beneath a constant current density and depending on pH In the study to evaluate the effect of pH, removal efficiency of cadmium, increased gradually when pH increased. Consequently At an alkaline pH, metal removal efficiency increased expanded significantly, to reach about 100% evacuation, due to the precipitation of the target analytics at an alkaline pH, [11].A set of tests was performed with different initial concentrations of cadmium (50, 100,150 and 200 mg /l The comes about gotten at optimum condition (pH=5 , reaction time=30 min and voltage =14 V= 97.4. % removal of cadmium At last, it can be completed that electro coagulation method process may be a safety dependable, cost-effective strategy and proficient for evacuation of cadmium from industrial. An effort has been made to model the electro coagulation process using response surface methodology these methodology have their own unique advantages. Response surface plots provide a good way for visualizing the parameter interactions and the resulting model for the electro coagulation process (R2=0.922) for cadmium removal efficiency.

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# تحسين عمليه التخثير الكهربائي بازاله ايونات الكادميوم من مياه المخلفات باستخدام تصميم ومنهجيه الاستجابه السطحيه

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**الخلاصة** – قد تحتوي العديد من مخلفات المياه الصناعية ع ايونات المعادن الثقيلة والتي يجب إزالتها بشكل فعال أو صرفها قبل أعاده استخدامها بصناعات أخرى في هذا البحث استخدمت طريقة التخثير الكهربائي لمعالجة الماء الملوث بالكادميوم وباستخدام أقطاب أنود من الألمنيوم كمخثر وأقطاب كاثود من الألمنيوم ايضا. خلية تخثير بحجم 1 لتر قد استخدمت أيضا في العمل تم دراسة العديد من العوامل المؤثرة على عملية معالجة المياه الملوثة بالكادميوم وكانت هذه العوامل كالتالي: الدالة الحامضية، الجهد، التركيز الأولي للكادميوم، تركيز كلوريد الصوديوم، المسافة بين الأقطاب، نوعية الأقطاب، الوقت. تم دراسة هذه المتغيرات بدرجه حرارة الغرفة وسرعه التحريك (120) دوره بالدقيقة وتركيز الكادميوم الأولي كان (50,100,150,200جزء بالمليون) وقد تم اخذ قيم فرق الجهد هي (6,10,14 فولت) وفي تحديد الرقم الهيدروجيني الأفضل وجد عند زيادة فرق الجهد تزداد عمليه أزاله ايونات الكادميوم بشكل ملحوظ الأولي وقد اطهرت النتائج بوقت معين ومن النتائج تبين ان الازالة المثلي كانت 93.2% وقد تحققت بزمن 60 دقيقة بدالة حامضة تساوي وفرق جهد 14 فولت وباستخدام أقطاب ألمنيوم. وبتركيز كلوريد صوديوم يساوي 0.6 ملغرام / لتر ومسافة 0.5 سنتيميتر