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Removal of Manganese Ions (Mn^{2+}) from a Simulated Wastewater by Electrocoagulation/ Electroflotation Technologies with Stainless Steel Mesh Electrodes: Process Optimization Based on Taguchi Approach

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Abstract

This study depicts the removal of Manganese ions (Mn^{2+}) from simulated wastewater by combined electrocoagulation/ electroflotation technologies. The effects of initial Mn concentration, current density (C.D.), electrolysis time, and different mesh numbers of stainless steel screen electrodes were investigated in a batch cell by adopting Taguchi experimental design to explore the optimum conditions for maximum removal efficiency of Mn. The results of multiple regression and signal to noise ratio (S/N) showed that the optimum conditions were Mn initial concentration of 100 ppm, C.D. of 4 mA/cm^2, time of 120 min, and mesh no. of 30 (wire/inch). Also, the relative significance of each factor was attained by the analysis of variance (ANOVA) which indicates that the percentage of contribution followed the order: time (47.42%), C.D. (37.13%), Mesh number (5.73%), and Mn initial Conc. (0.05%). The electrolysis time and C.D. were the most effective operating parameters and mesh no. had a fair influence on Mn removal efficiency, while the initial conc. of Mn. had no significant effect in the studied ranges of control factors. Regression analysis (R^2= 90.16%) showed an acceptable agreement between the experimental and the predicted values, and confirmation test results revealed that the removal efficiency of Mn at optimum conditions was higher than 99%.

Keywords: Mn removal, Electrocoagulation, electroflotation, stainless steel electrodes, screens electrodes, wastewater, Taguchi method

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1- Introduction

Heavy metals from various economic activities can be considered as very influential toxic agents. Due to their great solubility and low biodegradability in the aquatic environments, aqueous solutions, and many industrial wastewaters, the presence of these components even at low concentrations causes deterioration of many ecosystems and particularly human health. Further, Heavy metals lead to serious environmental pollution [1], [2].

Industries including mining, electro-plating or melting operations are developed rapidly. Wastewaters discharged into the environment from these industries holding excessive concentrations of toxic metals (e.g. Mn, Cd, Zn, and Cu), so destructive effects on the organism life would take place if no handling arise [3], [4].

The abundance of Manganese (Mn) metal in nature is very high and it is considered as a vital metal for the human system but with trace amounts due to its ability in enzymes activation. It is used widely in many applications like primary cells, alloys industry, ceramics, and electrical coils besides its presence naturally in the atmosphere as suspended particulates due to its disposal from different sources like industrial emission and soil erosion [5].

Several techniques were employed for the pollution abatement of heavy metal ions in wastewater which include: adsorption [6], chemical precipitation [7], ion-exchange [8], biosorption [9], membrane filtration [10], coagulation-flocculation [11], and flotation [12].

Many of these techniques have disadvantages. For example, precipitation can be considered as the most economical valid, but additional treatment is required due to the production of precipitate sludge. Reverse osmosis, ion-exchange, and other membrane separation techniques can efficiently be used in metal ions removal, but there are limitations in the use of these techniques like high material, and functional cost. In addition to their operative problems, these disadvantages, together with the requirement of effective low-cost treatment, have created innovative challenges for these technologies [13].

Electrocoagulation (EC) is not a new technology but it is an eco-friendly process. In this technique, there are no chemicals added as in the chemical coagulation process.

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So, there is no problem of neutralizing excess chemicals and no probability of secondary contamination initiated by chemical substances that added at high concentration.

EC technique also has many advantages include: producing effluent with a less total dissolved solids content (TDS), demanding simple equipment and it is easy to operate, producing a clear, odorless and colorless discharge. Besides, low amount of sludge is formed in this technique which consists mainly of metallic oxides/hydroxides which tend to be readily settable and easy to be removed. Also, the smallest colloidal particles can be removed by this technique due to the fast motion resulted from the applied electric field that facilitating the coagulation [4],[14], [15]. The high effectiveness of the EC process in the elimination of heavy metal ions from industrial/synthesis wastewater has been proved by several studies [5], [16]–[19]. Electrocoagulation/Electroflotation (ECF) is an electrochemical process in which the wastewater would be subjected to a direct current (DC) field. So, in-situ generation of coagulants by electro-dissolution of a soluble sacrificial anode dipped in the wastewater would take place. The most sacrificial anodes are Al and Fe. Solid flat electrodes are traditionally used, but in some previous studies, cylindrical perforated ones are implemented due to better dispersal of the applied DC field onto the wastewater to be handled [20], [21].

The ECF has often been considered for the wastewater treatment and it has a wide area of application, for example, heavy metals, organic chemicals, oil, Textile effluents, specific organics, turbid effluent, petroleum industry, suspended particles of all sorts, fluoride, nitrate, and arsenic [22]. There are complex chemical and physical changes that commonly take place in any electrocoagulation process. When a direct current or voltage is applied, positive ionic coagulants would be formed due to sacrificial anodes oxidation. Consecutively, generation of hydroxyl ions (OH^-) and some O_2 and H_2 gas bubbles would take place due to water reduction arising at the cathode. The formed ions is migrated to oppositely charged electrodes so destabilization of the contaminants and the particulate suspension would take place because of this movement leading to break down the emulsion. Metallic hydroxides of good adsorption properties would be formed because of interaction between the positive ion (Al^{3+} or Fe^{2+}) and the hydroxyl ion (OH^-), that are capable of destabilizing any dispersed particles existing in the wastewater. Larger aggregates formed because of adsorption of Pollutants into the hydroxide structures [2], [15]. The formed aggregates can be carried by flotation of hydrogen and oxygen bubbles which move upwards in the liquid phase where it can be more easily concentrated, collected and removed or can be precipitated if they have a quite high density in comparison with the medium [2], [15]. At the anode, anodic dissolution of stainless steel electrode takes place beside water oxidation to produce oxygen gas and hydrogen ions. At the cathode, generation of hydroxyl ion (OH^-) and hydrogen gas occur due to water reduction and these hydroxyl ions would react with Fe ions to produce $Fe(OH)_2$. The chemical reactions can be illustrated as follows [1], [14], [21]:

At the Anode: $Fe_{(s)} \leftrightarrow Fe^{2+}_{(aq)} + 2e^-$ (1)

$$H_2O \rightarrow \left(\frac{1}{2}\right) O_2 + 2H^+ + 2e^- \quad (2)$$

At the cathode:

$$2H_2O + 2e^- \rightarrow 2OH^- + H_{2(g)} \quad (3)$$

In the solution:

$$Fe^{2+}_{(aq)} + 2OH^- \rightarrow Fe(OH)_{2(s)} \quad (4)$$

However, Fe^{3+} ions can be generated in the presence of oxygen and at acidic pH, and many species can be existing in the electrolytic solution as represented in the following reactions [1]:

$$Fe^{3+} + H_2O \rightarrow Fe(OH)^{2+} + H^+ \quad (5)$$

$$Fe^{3+} + 2H_2O \rightarrow Fe(OH)^+_2 + 2H^+ \quad (6)$$
$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$$

Also, $Fe(OH)_3$ and $Fe(OH)^-_4$ can exist in the electrolytic solution in more amount under alkaline conditions. It is stated that $Fe(3^+)$ hydroxide coagulants have higher activity than $Fe(2^+)$ hydroxide due to the higher stability of $Fe(OH)_3$. So, the presence of these species gives an enhancement to the ECF process. In this case, the overall electrochemical reaction is [1]:

$$4Fe_{(s)} + 10H_2O_{(l)} + O_{2(g)} \leftrightarrow 4Fe(OH)_{3(g)} + 4H_{2(g)} \quad (7)$$

There are several previous studies deals with manganese ions removal from wastewater [23]–[25], however, there is a dramatic lack of results in case of applying different mesh no. of stainless steel screen electrodes in ECF process. The objective of this research is to examine the removal of Mn ions by ECF technique using Taguchi experimental design with L_{18} orthogonal array to optimize the parameters and analyze them successively. Also, the effect of the controllable parameters on the removal efficiency of Mn ions was determined, and the optimization was accomplished by applying the standard procedure proposed by the Taguchi to attain maximum Mn ions elimination. Four effective parameters that have a high influence on the removal efficiency were studied: Mn initial concentration, current density, time, and finally mesh number which has not been satisfactorily considered in previous studies. A confirmation experiment was also accomplished at the optimized conditions.

2- Experimental Work

2.1. Materials and system

In each batch ECF experiment, 1.5 L of a simulated aqueous solution was prepared. Distilled water was used in the preparation of the simulated aqueous solution and all chemicals were of the reagent grade.

The reagents used were as follows: Manganese sulfate ($MnSO_4.H_2O$, 99 %), Sodium dodecylsulfate (SDS) as a collector in a stoichiometric ratio of 1:1, ethyl alcohol (C_2H_5OH, 0.1 vol. %) as pH regulators and bubbly agent, and Sodium sulfate (Na_2SO_4, 99.5 %) for preparing 0.1 M supporting electrolyte which used for growing the ionic strength, reducing the resistance between the electrodes, decreasing the oxide layer formation on the electrode which prevents or minimize the release of different ions from electrodes into the polluted solution. pH for all experiments was adjusted at 7.5.

The ECF batch experiments have been conducted in a glass cell (17×12×14 cm) placed on a magnetic stirrer hot plate (JENWAY, Model 1000) at 250 rpm. **Fig. 1** shows a scheme of the experimental apparatus. Two stainless steel woven wire mesh electrodes (10×10 cm) were used as anode and cathode that fixed on a handmade acrylic frame (10.5×10.5 cm) with (L) shape. The vertical part of this frame is firmed on the edge of the cell, while the horizontal part is perforated with 42 holes (0.5 cm). The cathode is firmed at the top while anode at the bottom, the distance between the two electrodes was 1 cm. Both electrodes were connected to a DC power supply (UNI-T: UTP3315TF-L). Prior to each experiment, the electrodes were rinsed with HNO_3 solution (1M) in an ultrasound cleaner and then washed carefully with double-distilled water.

All experiments were carried out at the laboratory temperature and performed in duplicate and the average value of the removal percentage (Re%) was taken. To follow the progress of ECF experiments, samples were taken before each experiment and at the end. The final sample was filtered using Whatman filter paper (0.15µm) to exclude the sludge generated throughout electrolysis or centrifuged if necessary. The residual concentration of Mn was measured by atomic absorption spectroscopy (Varian SpectrAA 200 spectrometer).

Removal efficiency can be expressed as [26]:

$$Re\% = \frac{C_0 - C_f}{C_0} \times 100 \quad (8)$$

Where: C_0 and C_f represent the initial and final concentration of manganese ions in ppm respectively.

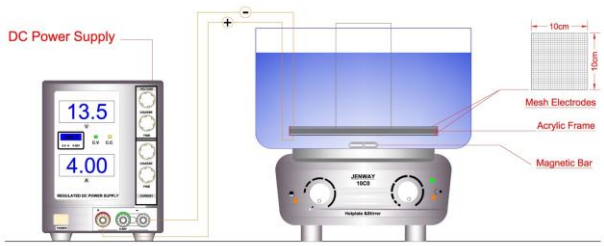

Fig. 1. A schematic photo of ECF cell

Three types of 316-AISI stainless steel screens were used with mesh numbers 18, 24, 30 wire/inch.

For each screen, the porosity (ε) was estimated by applying Eq. (9) [27]:

$$\varepsilon = 1 - \frac{m_s}{\rho_s \, l \, a_s} \quad (9)$$

Where the weight/area ratio (m_s/a_s) of the screen was equal to 0.1334, 0.1334, and 0.1237 (g/cm^2) for the three screens respectively, the screen thickness equal to (l=2d), and the density of 316-AISI stainless steel is 8.027 (gm/cm^3) [27].

The diameter (d) of the wire of each screen was measured by digital caliper, and they were 0.04, 0.034, and 0.03 cm for the three screens respectively. While the woven type of the screen was identified by using an Olympus BX51M with DP70a digital camera system and it was Plain Square.

The porosity values for the three screens were 0.7907, 0.7538, and 0.7146 respectively. Then the specific surface area (S) was estimated by Eq. (10) [27]:

$$s = (1 - \varepsilon) \, r \quad (10)$$

Where, r is the ratio of surface to volume of the wire forming the screen and it is equal to (4/d), and the calculated specific surface area was equal to be 20.93, 28.964, and 38.055 cm^{-1} for the three screens respectively.

2.2. Design of Experiments (DOE)

An operative method for the analyzing of experimental results of a study and evaluating the distinct contribution of controlling parameters on the objective functions can be obtained by applying DOE methods based on the statistical techniques.

Moreover, process optimization, cost minimization, quality enhancement as well as the provision of strong design solutions can be achieved by these methods. Taguchi optimization technique is known as a robust, distinctive, and prevailing optimization discipline that permits optimization with a minimum number of experiments [28], [29].

There are many previous studies deals with the investigation of removal of different pollutants from wastewater by applying Taguchi optimization method [30]–[35].

Taguchi design of experimental technique was used in this study to detect the most controlling parameters on Mn ions removal, minimize the number of experiments, optimize the four studied parameters, and obtain the optimal operating conditions for Mn ions removal which have a prevailing influence on the performance of ECF process.

Four factors were investigated in this present study: initial concentration of Mn (coded A) with two levels (100, 50 ppm) corresponding to levels 1 and 2; the other factors with three levels were current density (coded B) (20, 30, 40 mA/cm^2), electrolysis time (coded C) (40, 80, 120 min), and mesh number (coded D) (18, 24, 30 wire/inch) corresponding to levels 1, 2, and 3.

According to the Taguchi experiment design, the suitable orthogonal array which allows studying the influence of the considered parameters and the interaction between them for these mixed levels would be L_{18} either ($3^3 \times 2^1$) array that presented in **Table 1** and the experiments were conducted according to these conditions.

Table 1. Coded values of L_{18} orthogonal array

Exp. No.	Coded Values			
	A	B	C	D
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

Consequently, an analysis of the signal-to-noise (S/N) ratio is needed for assessing the experimental results. In Taguchi technique, the performance characteristics (*S/N*) are performed into three options: "larger is the better (LB)", "nominal the-best (NB)", and "smaller-the-better (SB)".

The highest Mn ions removal percentage (Re%) was the objective of this study, therefore the larger is the better criteria was implemented for the present study. The *S/N* ratio with LB characteristics can be performed as in Eq. (11) [36], [37]:

$$S/N_{LB} = -10 \log \left[\frac{\sum_{i=1}^{n} \frac{1}{y_i^2}}{n}\right] \quad (11)$$

Where n is the number of repetitions under the same experimental conditions, and y_i is the performance results of the *i*th experiment. **MINITAB 17** software was used for analyzing the experimental data.

3- Results and Discussion

3.1. Optimization and The Signal- to- Noise analysis

The investigation of the relationship between removal percentage of Mn ions and the controllable factors can be obtained by multiple linear regression equation which was developed by using **MINITAB 17** software. The mathematical model for Mn ions removal percentage through the statistical analysis is given by Eq. (12) (with the correlation coefficient R^2 being equal to 90.16%, which implicates a good fitting of the model):

$$Re\ \% = 59.0 - 0.426\ A + 0.841\ B + 0.2072\ C - 0.860\ D + 0.01815\ A * D \quad (12)$$

Table 3 shows the experimental and predicted values of the L_{18} orthogonal array for Mn ions removal percentage.

Table 2 also shows the response calculated based on Eq. (12) which represents the predicted values of Re% and the *S/N* ratios that determined based on Eq. (11) for all the responses of experiments.

Fig. 2 shows the comparison between the experimental results and the predicted results based on Eq. (12).

It is obvious that the model predicts reasonably well for Mn ions removal and Eq. (12) can be considered as a good tool for process assessment.

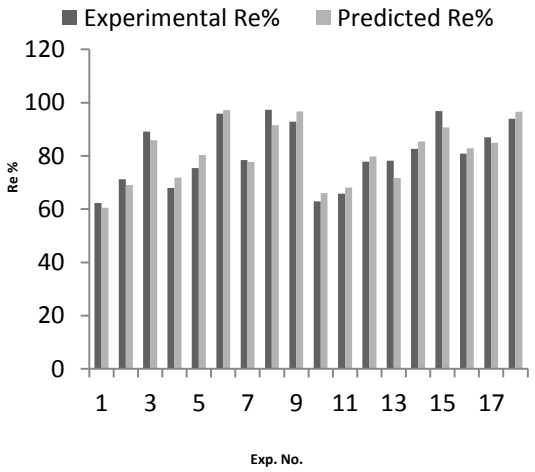

Fig. 2. Comparison between Experimental and predicted Re% values of Mn removal

Table 2. Experimental and predicted values of Re% and S/N ratios results of all experiments

Exp. No.	Real Values				Exp. *Re*%	Predicted *Re*%	*S/N* Ratio
	Mn Conc. (ppm)	C.D. (mA/cm^2)	Time (min)	Mesh number (mm)			
1	100	20	40	18	62.34	60.55	35.7609
2	100	20	80	24	71.20	69.03	36.8105
3	100	20	120	30	89.20	85.87	38.5413
4	100	30	40	18	67.98	71.85	37.0369
5	100	30	80	24	75.49	80.33	38.0865
6	100	30	120	30	95.94	97.17	39.8172
7	100	40	40	24	78.41	77.75	37.7845
8	100	40	80	30	97.30	91.50	39.2318
9	100	40	120	18	92.87	96.68	39.7352
10	50	20	40	30	62.96	66.07	36.4151
11	50	20	80	18	65.86	68.16	36.6351
12	50	20	120	24	77.85	79.73	37.9682
13	50	30	40	24	78.26	71.73	37.1494
14	50	30	80	30	82.67	85.47	38.5967
15	50	30	120	18	96.87	90.66	39.1002
16	50	40	40	30	80.90	82.90	38.2947
17	50	40	80	18	86.96	84.99	38.5147
18	50	40	120	24	93.93	96.56	39.8478

Table 3 shows the mean of the response of each factor at a certain level and it was represented graphically in **Fig. 3**.

At each column of this table, the bold values refer to the maximum calculated mean of response (Mn Re%). It is obvious from the results of mean response that the most essential factors are in the following order: time > C.D. > Mesh number > initial Mn concentration.

Table 3. calculated mean of response for data obtained from Mn removal experiments

Level	Mn Conc.	C.D	time	Mesh number
1	81.19	71.57	71.81	78.81
2	80.70	82.87	79.91	79.19
3	-	88.39	91.11	84.83
Delta	0.50	16.83	19.30	6.02
Rank	4	2	1	3

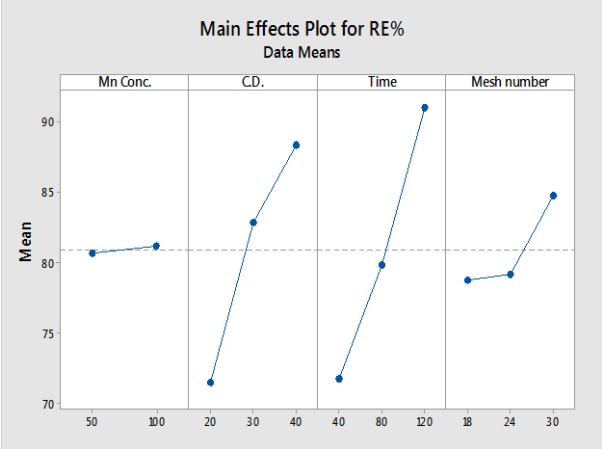

Fig. 3. Main effect plot for means values of Re% for Mn removal

The response table for the calculated Signal to Noise Ratios (LB) and the ranks of the four studied factors are shown in **Table 4** and which is represented graphically in **Fig. 4**; these ranks are based on delta statistics which compare the relative magnitude of effects.

The highest average for each factor minus the lowest average for the same is the delta statistics [38].

Lager the S/N ratio means higher the Mn Re%. So, in this table, the boldfaces refer to the maximum value of the S/N ratios of a certain factor among three levels for (time, C.D., and Mesh number) and for two levels of Mn Conc.,

It was obvious from the ranks attained for each factor that time is the most influential factor, whereas C.D., mesh size, and Mn Conc. were the least influential factors for Mn $Re\%$ respectively.

Based on the optimization of the multiple regression equation (Eq. (12)) and the results of means and S/N ratios, the optimum factors were initial Mn Conc. (A) of 100 ppm, C.D. (B) of 40mA/cm^2, Time (C) of 120 min, and mesh number (D) of 30 wire/inch.

Table 4. Response table for S/N (larger is better)

Level	Mn Conc.	C.D	time	Mesh number
1	38.09	37.02	37.07	37.80
2	38.06	38.30	37.98	37.94
3	-	38.90	39.17	38.48
Delta	0.03	1.88	2.09	0.69
Rank	4	2	1	3

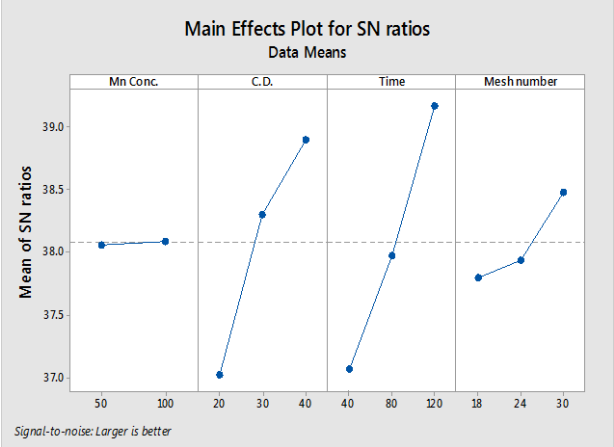

Fig. 4. Main effect plots of S/N (larger is better) for Mn *Re* %

3.2. Analysis of Variance (ANOVA)

ANOVA statistical method was implemented to evaluate the significance of the controlling parameters by estimating the percentage contribution of each factor which is the portion of a total observed variance in the experiment for each significant factor.

The greater value of contribution percentage for any studied parameter means that it has a high contribution to the final results. Also, a superior understanding can be obtained by this analysis and it shows if the detected results are reliable and whether or not the conductance of experiments was at the controlled conditions. ANOVA was established based on the degree of freedom (DF), the sum of the square (SS), the percentage contribution of each parameter, the adjusted sum of squares (Adj SS), the adjusted mean of the square (Adj MS), F-value, and P-value. All these values are calculated for each controllable factor [29], [39].

The results of ANOVA for the present study are depicted in **Table 5**. It is obvious from the results that the most significant factors that affect Mn removal efficiency were as in the following order: time > C.D. > Mesh size > Mn Conc., based on their contribution %.

The significance of each factor on the response is also can be determined by P-value, which is defined as a relation between the parameters' sum of the square to the total sum of square. If the p-value is lower than 0.05 (for a confidence level of 95%), this means that the parameter is significant [40].

It can be concluded from the results of P-values (which based on a confidence level of 95%) for time and C.D. that these parameters were significant, while mesh size had a fair significance and initial Mn conc. had no significance in the chosen range in this study.

When F > 1 for the controllable parameters, this revealed that the error variance is lower than variances of these factors, and signifying that these controllable factors had major effects on the responses [29]. So, based on the results of the present study all the studied factors were significant except initial Mn concentration.

Table 5. Analysis of Variance (ANOVA) for Mn removal

Source	DF	Seq SS	Contribution%	Adj SS	Adj MS	F-Value	P-Value
Mn Conc.	1	1.11	0.05 %	1.11	1.110	0.05	0.831
C.D.	2	882.74	37.13 %	882.74	441.371	19.19	0.000
Time	2	1127.22	47.42 %	1127.22	563.611	24.51	0.000
Mesh number	2	136.23	5.73 %	136.23	68.113	2.96	0.098
Error	10	229.95	9.67 %	229.95	22.995	-	-
Total	17	2377.25	100.00%	-	-	-	-

3.3. Confirmation experiment

The confirmation experiment is an important step and is highly endorsed by the Taguchi approach to validate the experiment results. In this study, two confirmation experiments were carried out by utilizing the optimum parameters. The results showed that Mn Re% was 99.34 and 99.45% respectively.\

3.3. Effect of Operative Factors

a. Effect of initial Mn Concentration

Fig. 5 was plotted by applying Eq. (12) at the optimum conditions and it shows the effect of Mn initial concentration on the removal efficiency of the ECF process. It is obvious that increasing the initial concentration of Mn leads to increase in the predicted removal efficiency and this result is in agreement with previous studies [4]. However, the chosen range of Mn initial concentration had not that great influence on the removal efficiency and this was clear from the results of S/N and ANOVA when the F- value was 0.05 either less than 1 and the contribution percentage was 0.05% which means that it was not a significant factor on the process performance.

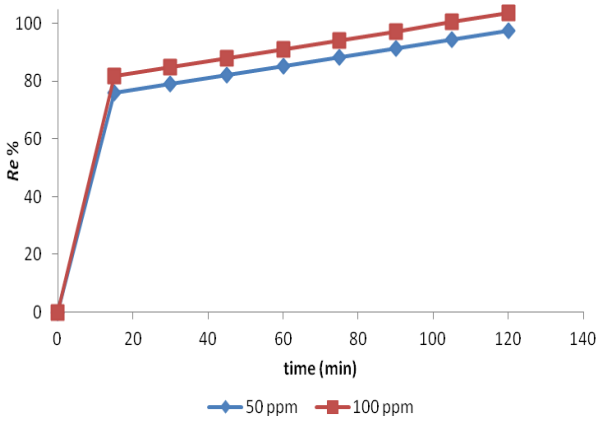

Fig. 5. Effect of initial Mn Concentration on Mn *Re*% at C.D. = 40 mA/cm^2 and mesh number = 30 mm

b. Effect of Current Density

It is well known that one of the most effective parameters in the ECF process generally is the current density. The efficiency of this process is affected directly by the value of this parameter.

Flocs size and growth are affected by current density. Increasing current density leads to flocs generation with significant amounts due to more release of ferric ions by anodic dissolution (according to **Faraday's law** [37] ($m = [ItM/zF]$)), and thereby more generation of iron hydroxides essential to coagulants formation. Also, the generation rate and distribution of H_2 gas bubbles formed at the cathode are affected directly by the value of current density. Increasing the current density leads to an increase in bubble generation rate with a decreased in bubble size which leads to high metal removal by H_2 flotation [15], [22], [41]–[43].

Fig. 5 was plotted by applying Eq. (12) to examine the effect of increasing the current density on Mn *Re* %. Current density increased from 20 to 40(mA/cm^2) with 100 ppm of Mn, 120 min of electrolysis time, and using a screen with mesh number of 30 wire/inch. the removal efficiency increased from 86.734 at 20 mA/cm^2 to > 100% at 40 mA/cm^2. Also, this was obvious from the results of S/N, increasing the current density leads to larger values of S/N which means higher *Re%* of Mn removal.

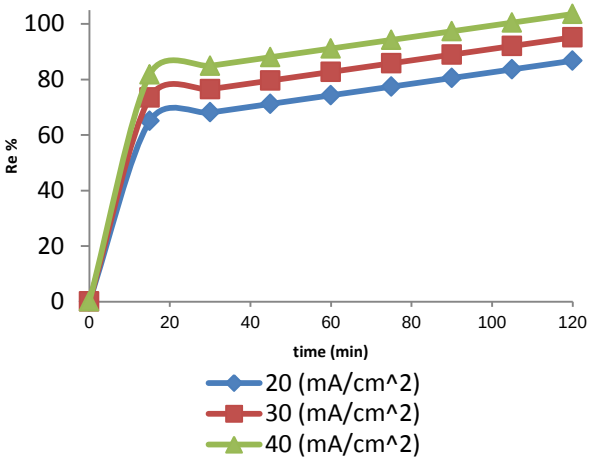

Fig. 6. Effect of C.D. on Mn *Re* % at initial Mn conc. = 100 ppm and mesh number =30 wire/inch

c. Effect of Electrolysis Time

According to Faraday's law mentioned previously, the amount of generated ferrous ions which is produced by anode dissolution is related to the electrolysis time of ECF process [13], [15], [44]. In the present, study it was clear from the results of *S/N* and ANOVA that electrolysis time had the greatest impact on ECF performance. Increasing electrolysis time leads to an increase in flocs generation which causing an enhancement in Mn removal efficiency.

The influence of electrolysis time on Mn *Re* % is obvious in Fig. 5 and Fig. 6 which was plotted by applying Eq. (12) at optimum conditions. It is evident that increasing electrolysis time gives an increase in Mn removal efficiency due to an increase in the number of generated ferrous hydroxide and an increase in the rate and size of H_2 bubble production. For the example at 20 mA/cm^2 the removal efficiency increased from 70.158 to 86.734% by increasing electrolysis time from 40 to 120 min.

d. Effect of Mesh number

The mesh number of screens in the present study had the following values 14, 24, and 30 wire/inch and higher porosity and specific surface area had been attained by increasing the mesh number. Increasing mesh no. leads to an increase in the number of H_2 bubbles which have a small size hence increasing the flotation efficiency and more pollutants can be removed. So, by increasing the mesh number the removal efficiency of Mn by ECF process was enhanced. This is obvious from **Fig. 7** which represents the effect of different mesh number on the removal efficiency at optimum conditions. The results of S/N and ANOVA showed that changing mesh size had a fair significance on Mn *Re* %.

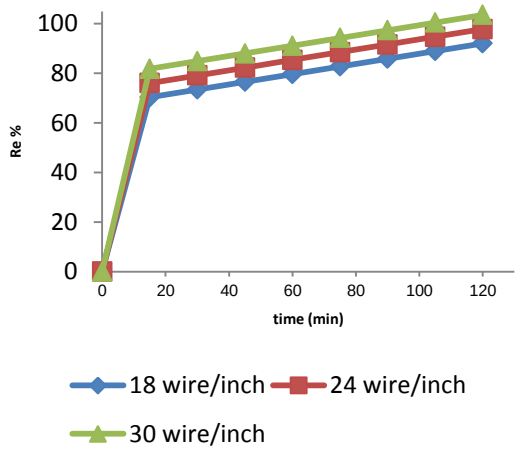

Fig. 7. Effect of mesh number on Mn Re % at initial Mn conc. = 100 ppm and C.D. = 40 mA/cm^2

It is worthy to mention that in Figures (5-7), some Mn *Re* % values exceeded 100 %. This result is attained because these figures were plotted by applying Eq.(12), which represents the predicted values not the real one and also Minitab software does not have any sense of the figures and it makes the calculations by numerical procedure, this result is in agreement with a previous study [29].

5- Conclusions

In the present work, the ECF batch process using stainless steel mesh sacrificial electrodes for the treatment of aqueous solution containing Mn was studied.

The effect of Mn initial concentration, current density, electrolysis time, and mesh size of the screen electrodes was examined to detect their impact on the removal efficiency.

Taguchi method was applied to optimize ECF operating factors. The results of S/N and ANOVA approved that the importance of operating parameters followed the order: time > C.D. > Mesh number > initial Mn Conc., with contribution percentage of 47.42, 37.13, 5.73, and 0.05 % respectively. The optimum conditions were 100 ppm of Mn concentration, 40 mA/cm^2 of current density, 120 min of electrolysis time, and 30 wire/inch of mesh number. It can be concluded from the results of the present study that electrolysis time and current density were the most influential parameters and the mesh size that has not been widely investigated in previous studies revealed a fair effect on ECF process, while Mn initial concentration had not any mentioned effect on the performance of the removal efficiency.

Two confirmation tests were conducted at optimum conditions gave Mn removal efficiency higher than 99%. Consequently, it can be concluded that the ECF process with stainless steel mesh electrodes was very effective in Mn removal.

Nomenclature

Nomenclature	Meaning	Units
a_s	Specified area of a screen	cm^2
C_0	Initial concentration	ppm
C_f	Final concentration	ppm
d	Wire diameter	m
F	Faraday's constant = 96486	C/mol
I	Current intensity	C/sec
l	Screen thickness	cm
M	Molecular weight of iron or hydroxide ion	g/mol
m	Iron and hydroxide ions amounts	g
m_s	Weight of screen	g
n	number of repetitions	-
r	ratio	cm^{-1}
s	specific surface area	cm^{-1}
t	time	sec
y_i	performance results of the ith experiment	-
z	Number of electrons	-
Re %	Removal percentage	-
ρ_s	density	gm/cm^3
ε	porosity	-

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إزالة أيونات المنغنيز (Mn^{2+}) من مياه الصرف المصنعة بواسطة تقنيات التخثر/ التعويم الكهربائية باستخدام أقطاب الفولاذ المشبكية: أيجاد الظروف المثلى بواسطة طريقة تاكوشي

الخلاصة

في هذه الدراسة ، تم التحقق في كفاءة إزالة أيونات المنغنيز من مياه الصرف الصحي بواسطة تقنيات التخثر/ التعويم الكهربائية. تمت دراسة تأثير تركيز المنغنيز الأبتدائي ، كثافة التيار (C.D.) ، زمن التحليل الكهربائي ، وحجم المشبك لأقطاب الفولاذ المشبكية في خلية دفعية من خلال تطبيق تصميم تاكوشي لايجاد الظروف المثلى لأقصى كفاءة إزالة للمنغنيز. أظهرت نتائج (S/N) أن الظروف المثلى كانت, التركيزالأبتدائي للمنغنيز هو 100جزء في المليون ، C.D. هو 4 مللي أمبير / سم 2 ، ووقت 120 دقيقة ، وشبكة ذات حجم 30 واير/أنج.
أيضا ، تم بحث الأهمية النسبية لكل عامل عن طريق تحليل التباين (ANOVA) الذي يشير إلى أن النسبة المئوية للمساهمة تتبع الترتيب: الوقت (47.42%) ، C.D. (37.13 %) ، حجم المشبك (5.73%) ، و التركيزالأبتدائي للمنغنيز هو (0.05%). وقت التحليل الكهربائي و C.D. كانت هي العوامل الأكثر تأثيراً وحجم الشبكة له تأثير مقبول على كفاءة إزالة أيونات المنغنيز ، في حين أن التركيزالأبتدائي للمنغنيز لم يكن له تأثير مذكور في المدى المدروس. أظهر تحليل الانحدار (R^2% = 90.16) اتفاقا جيدا بين القيم التجريبية والقيم المتوقعة ، وأظهرت النتائج تأكيد أن كفاءة إزالة المنغنيز في الظروف المثلى كانت أعلى من 99%.

الكلمات الدالة: أزالة المنغنيز, التخثرالكهربائي, التعويم الكهربائي, أقطاب الفولاذ, الأقطاب المشبكية, مياه الصرف , طريقة تاكوشي