Available online at http://ijcpe.uobaghdad.edu.iq and www.iasj.net
Iraqi Journal of Chemical and Petroleum Engineering
Vol.21 No.1 (March 2020) 1 – 7
EISSN: 2618-0707, PISSN: 1997-4884

Different Electrodes Connections in Electrocoagulation of Synthetic Blow down Water of Cooling Tower

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Abstract

In this research, the performance of electrocoagulation (EC) using aluminum (*Al*) electrodes with Monopolar- parallel (MP-P), and bipolar - series (BP-S) arrangement for simultaneous removal of dissolved silica, and hardness ions (calcium, and magnesium) from synthetic blowdown water of cooling tower were investigated. The effects of current density, initial pH and time of electrolysis on the removal efficiency were studied in a batch stirred unit to find out the best-operating conditions. The obtained results for each target species are evidence that BP-S approach is the best for both electrodes configuration operated at a Current density of 1mA/cm^2 through 30 min of treatment and pH=10 with the removal of 60 %, 97% and 98% for calcium, magnesium and silica, respectively. This arrangement required an electrical energy consumption of1.8 kWh/m3 which is higher than observed in a parallel arrangement.

Keywords: cooling tower blow down water, silica, hardness ions, electrocoagulation, Monopolar-parallel, bipolar- series.

Received on 04/11/2019, Accepted on 11/01/2020, published on 30/03/2020

https://doi.org/10.31699/IJCPE.2020.1.1

1- Introduction

It is recognized that a system that is in contact with the circulating water, for example, cooling tower, boilers, heat exchangers are subjected to the construction of deposition on the internal surfaces. Normal operation of cooling tower, consequences in the consumption of sensibly large amounts of water as makeup water, which it consists of a quantity of contamination and the impurities which, if not treated, lead to a steady build-up of deposits on the operational surfaces of the unit and as water is lost from the system, generally during evaporation, levels of concentration of these pollutants and contaminates increase and causing scaling, which is sever problem in system for the reason that the scale layer works as a thermal insulation[1]**.** Silica and hardness ions, especially calcium and magnesium, are the main causes of scaling problems in cooling towers [2]**.**

To prevent scaling in cooling towers a part of the water is discharged producing a stream called cooling tower blowdown (CTB) [3]**.** Various technologies have been used to remove silica and hardness ions some of these treatments required adding chemicals for water softening such as ion exchange and chemical precipitation, and other methods do not require to add chemicals, such as reverse osmosis, electrodialysis, nano-filtration, crystallization, distillation and evaporation [4]**.** These technologies have a number of problems like the high cost of operation, increased sludge, fouling of membrane, which demands an effluent post-treatment and removal of remaining sludge [5]**.**

One of the talented methods for the treatment of CTB water is an electrochemical technique based on EC. Electrocoagulation is a green technique. In this method, there are no chemicals added as in the chemical coagulation approach.

Therefore, there is no difficulty in neutralizing extra chemicals and no possibility of secondary pollution started via chemical matters that added at elevated concentration. EC process as well as many advantages comprises: generating effluent with a low content of total dissolved solids (TDS), required simple equipment and it is effortless to work, generating an obvious, odorless and colorless effluent. In addition, formation low quantities of sludge which consists mostly of metallic oxides/hydroxides which be inclined to be quickly settable and easy to be distant[6]**.**

A simple EC cell is fabricated from anode and cathode with MP-P or BP electrodes arrangements. Monopolar electrodes in a parallel arrangement (MP-P)**,** all anodes are connected together and to the positive pole of external DC- power supply and also the cathode electrodes connected together to the negative pole of DC supply. So the current is divided between each set of electrodes(anode or cathode)resulting in lower potential difference [7]**.**

Bipolar electrodes (Bp-S) configuration**,** in this form of connection, the sacrificial electrodes are sited between the two outermost parallel electrodes (anode and cathode) are not connected to DC- power supply.

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Only the outermost electrodes are connected to the power supply, as the flow of an electrical current, the neutral sides of the conductive surface of electrodes will be changed to charged sides, which have reverse charge contrast to the parallel side beside it **[7]**

EC process uses a direct current between two pairs or more from metal electrodes such as aluminum iron coagulant material that destabilize pollutants[8]**.** The EC method is a combination of various processes comprising oxidation, coagulation, flocculation and flotation [9]**.**

As a current is applied, positive ionic coagulants possibly bent due to metal anodes oxidation. Successively, hydroxyl ions (OH-) will form and some O_2 and H_2 gas bubbles would come to pass because of water reduction evolving at the cathode. Then the pollutions and suspensions particles destabilization due to transported of formed ions to oppositely charged electrodes and gone in front to break down the emulsion.

The interaction between the anode metal cations (Al^{3+} or Fe^{2+}) and the hydroxyl ions (OH^-), lead to generation of Metallic hydroxides of good adsorption properties, which are able of destabilizing any dispersed particles presented in the solution. The main reactions at electrodes are given in the following **Eqs. (1-4):**

Anode and cathode:

$$Al \rightarrow Al_{(aq)}^{3+} + 3e^- \qquad (1)$$

Cathode:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \qquad (2)$$

Formation of Al $(OH)_3$:

$$Al_{(aq)}^{3+} + 3OH^- \rightarrow Al(OH)_3 \qquad (3)$$

The neutral form of Al(OH)3 is polymerized, as follows, to form flocs which have the high-flocking capacity to eliminate the pollutants from wastewater by the adsorption process via the electrocoagulation cell [10]**:**

$$n\,Al(OH)_3 \rightarrow Al_n(OH)_{3n} \qquad (4)$$

After adsorption of contaminants into the hydroxide structures, bigger aggregates will form, and then these aggregates can be transmitted via flotation of hydrogen and oxygen bubbles which take upwards where it is able to be more simply concentrated, gathered and distant or can be precipitated if they have a fairly elevated density in contrast with the medium[6]**.**

EC has the ability to eliminate an extensive range of contaminant containing suspended solids, heavy metals, dyes, organic material, and ions[8]**.**

Few investigates have considered for the treatment of scale-forming species, such as $Ca^{2+,}$ $Mg^{2+,}$ and silica ions in the CTB water by EC **[2], [11[.** However, the comparison between different electrodes arrangements for removing hardness and silica ions from CTB water was never studied previously.

The objective of this study is to investigate the effect of EC process parameters like current density, initial pH and treatment time for remove silica, Ca^{2+} and Mg^{+2} ions from CTB water using different electrodes arrangements (monopolar parallel and bipolar series) with EC process.

In addition, calculate the energy consumption for each connection of electrodes.

2- Experimental Work

2.1. Wastewater Sample

Preparation and analysis of synthetic CTBW were conducted in the laboratory of higher education in chemical engineering at the University of Baghdad. In order to prepare CTBW with initial concentration for each ion, salts like sodium metasilicate nine-hydrate ($Na_2 SiO_3.9H_2O$), $MgCl_2$ and $CaCl_2$ weighted using an electrical balance (BL210s: Sartorius -4 digits) dissolved in 2.8 L of distilled water. Initial pH and electrical conductivity of simulated water were measured using a pH meter model (ATC Company) and digital conductivity, meter type (Sensodirect Oxi 200 Lovibond, England) respectively. The characteristic of synthetic CTBW is summarized in Table **1.**

Table 1. Properties of simulated CTB water

Parameters	units	Value
PH	-	10.5
Silica	mg/l	50
Calcium	mg/l	508
Magnesium	mg/l	292
Electrical conductivity	s/cmμ	2500

2.2. Experimental Set-Up

The experimental set-up for both electrodes arrangements is conducted in a rectangular EC cell of 3L having dimensions of (16×16×12)cm made of glass material on a magnetic stirrer (type Stuart, CB162).

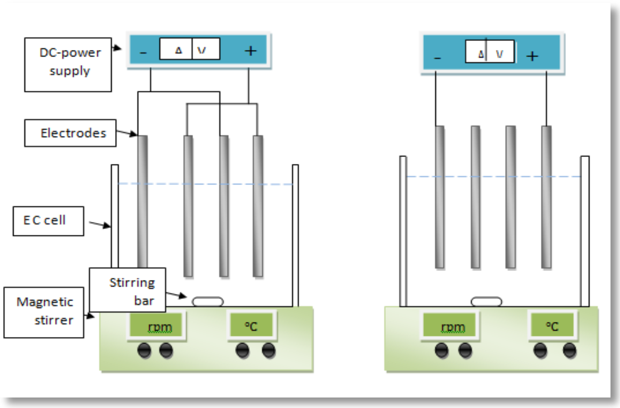
Four aluminum electrodes of the same dimensions (130×130×1) mm with an active area of 260 cm^2 for single electrodes immersed vertically in the electrolytic solution.

The distance between each electrode was maintained at 1.5 cm for MP-P and BP-P experiments. DC power supply (SYADGONG company- model: PS-305D) was used to provide a constant current for EC cell.

EC reactor with (MP-P) and (Bp-S) electrodes configurations are illustrated in Fig. **1** (a) and (b) respectively.

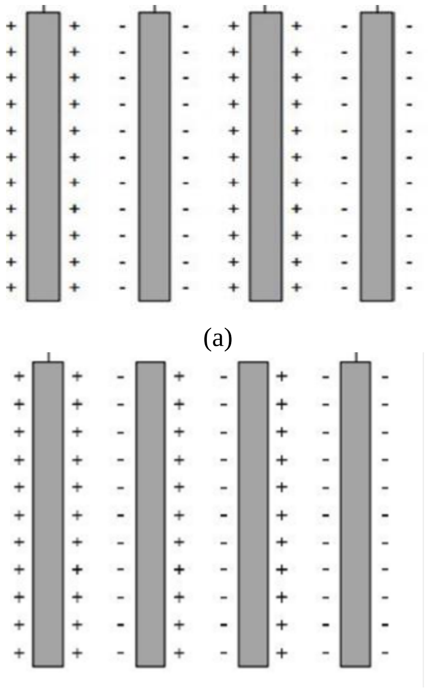
For BP-S configuration, the voltage connected between the electrodes via the power supply, leads to polarization of the middle bipolar electrodes, which at the point, show diverse polarities within the inverse face present different polarities in the opposite faces.

Fig. **2** explains the charge distribution for both configurations. The reactor was experienced with simulated CTBW samples of various pH values (5,9, 7, and 10) and three current densities (0.25,0.5, 1, and 2 mA/cm^2) below each experiment conditions, the treated samples (50mL) were with drown from the center of the cell through reaction durations and then were analyzed. Experiments of both electrodes connections were carried out at laboratory temperature and at 250 rpm of stirring rate based on the previous study[6].



(a) (b)

Fig. 1 representation view of the EC cell and schematic diagram: (a) MP-P (b) BP-S



(a)

(b)

Fig. 2. Charge distribution on electrodes (a) MP-P (b) BP-S [12].

3- Analytical Methods

The final concentration of silica ion for each sample was determined using the ultraviolet spectrophotometer model (UV- CECDIL, England) with a wavelength of (815 nm) in al-Duara thermal power plant, Baghdad. Iraq. Calcium and magnesium concentrations were determined using atomic absorption spectroscopy (AAS- type – Shimadzu -7000F) in central service laboratory / Abn- Al-Haithem collage.

The removal efficiency (η %) of each species was calculated using the Eq.5 [2]:

$$\eta\ \% = \frac{CI-CF}{CI} \times 100 \qquad (5)$$

Where: C_I and C_F are the initial and final ions concentrations (mg/l)

Electrical energy consumption *EEC* (KW h /m^3), is an essential economic factor in the electrocoagulation method. The *EEC* was estimated using Eq.6 [3].

$$EEC = \frac{U.I.t}{V(1000)} \qquad (6)$$

Where: *U* is the voltage (volt), *I* is the current (A), *t* is the treatment time (h) and V is the volume of treated samples (m^3).

4- Results and Discussion

4.1. Effect of Electrolysis Time

To deal with the effect of the treatment time, the experiments were conducted for EC with both electrodes arrangement at the time ranged from 15 to 60 minutes at current density 0.25mA/cm^2. The calcium, magnesium and silica ions removal efficiencies depend straight on the amount of aluminum generation via the electrodes, which is related to time, while by multiplication of the electrolysis time, an increase occurs in the concentration of ions and their hydroxide flocs.

For that reason, as revealed in Fig. **3**, for MP-P connections, an increase in the time of electrolysis from 15 min to 30 min yields an increase in the efficiency of calcium removal from 10.7 to 15.85%., magnesium from 80.63 % to 85.71%, and silica from 83% to 86.41%. Also, for BP-S connections as shown in Fig. **4**, the removal scale-forming ions were increased at the time of 15 to 30 min to attain removal efficiencies 23.71% to 25.92% for Ca, 85.73% to 88.62% for Mg, and 91% to 98.24% for Silica.

For both electrodes configurations, the removal efficiency of ions was increased with time and reached its highest value at the time of 30 min and increased steadily until the end of the treatment time of 60 min, so the best time was taken as 30 min for both electrodes connection.

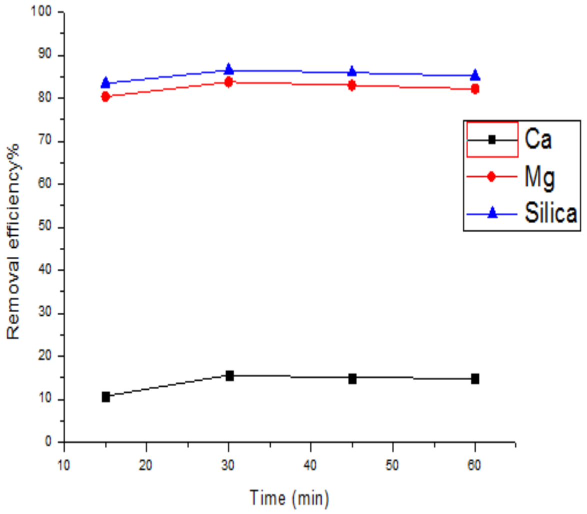


Fig. 3. Effect of the time of electrolysis on the removal efficiency of calcium, magnesium, and silica with MP-P connections of electrodes

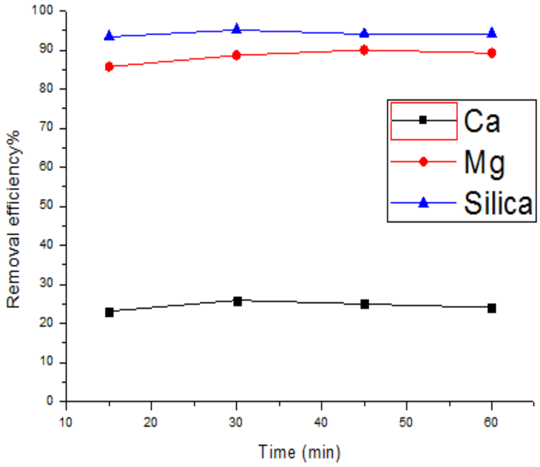


Fig. 4. Effect of the time of electrolysis on the removal efficiency of calcium, magnesium, and silica with BP-S connections of electrodes

4.2. Effect of Current Density

It is known that current density (CD) not simply finds out the coagulant dosage rate, other than also the bubble development rate, size and the flocs increment which can impact the treatment efficiency of the electrocoagulation[13].

The effect of CD on removal ions efficiency was studied at 0.25, 0.5, 1, and 2 mA/cm^2 and 30 min of EC time. it was seen from **Fig .5** for MP-P system, an increase of current density from 0.25 to 1 mA/cm^2 yields an improved in the removal efficiency from 25.3% to 35.21%, 88.06 to 95.21%, and 94 to 97.11% for Ca, Mg and Silica ions, correspondingly.

Also, for the BP-S system, **Fig.6** explained the progressively increased of ions removal efficiencies with current density from 0.25 t0 1mA/cm^2, and after that remind fairly stable until the end of the experiment.

So for both systems, an increment in current density delivers the anodic oxidation to require put more readily, which in turn favors the arrangement of amorphous aluminum hydroxides species satisfactorily within the region of the anode as well as within the bulk **[14]**.

In the EC cell with BP-S, a higher surface area contrasted to that of MP-P preferential the adequate anodic oxidation.

Thus, with the same current density for both sort of connection, the intensity is higher in the bipolar connection, as a result, the removal efficiency of ions was obtained more than that was observed in MP-P arrangement [15]**.**

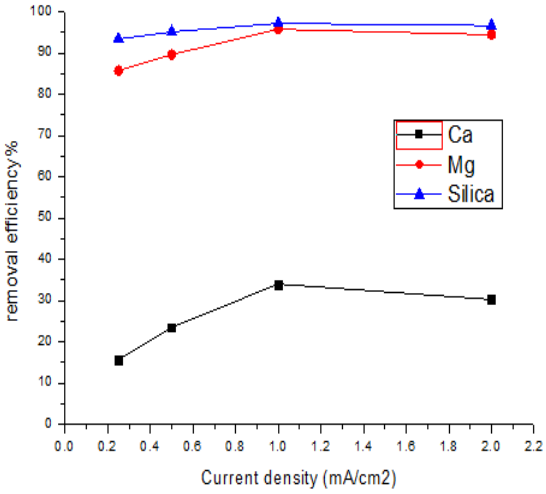


Fig. 5. Effect of the current density on the removal efficiency of scale-forming ions with MP-P cell at time=30min

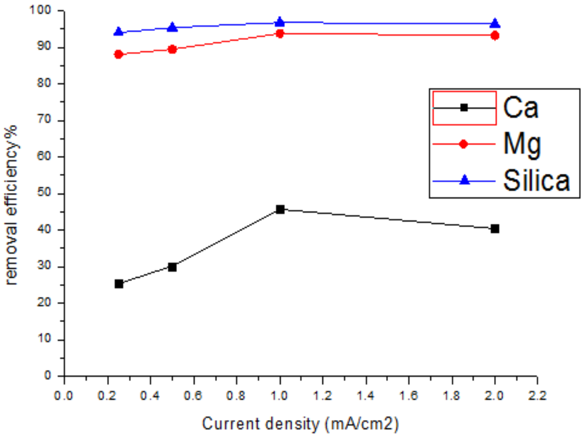


Fig. 6. Effect of the current density on the removal efficiency of scale-forming ions with BP-S cell at time=30min

4.3. Effect of Initial pH

It has been recognized that pH is a significant factor that effect on the performance of the EC process[16]**.** To study its effects on the removal efficiency of ions for both systems, the model wastewater was adjusted to a preferred value for each experiment using a sodium hydroxide solution or sulfuric acid solution (0.1M). MP-P and BP-P modes were studied to remove ions forming scaling from simulated CTBW in the initial pH of 5, 7, 9 and 10 at 1 mA/cm^2 and 30 min of reaction time.

Fig. **7** and Fig. **8** established the efficiency of calcium, magnesium and silica removal as function of the initial pH solution for MP-P and BP-P connection modes respectively, with Maximum removal efficiency were 40 %, 95%, and 96%, for MP-P and 60.18%, 97 % and 98% for BP-S at pH=10.

The efficiency of ions removal increased with pH increasing, it has been observed that both configurations of electrodes are effective in silica removal at pH=5 and 7 while the removal of Ca and Mg species were less, but at initial pH=10 the removal of hardness ions enhanced, this fact has as well been recognized by Liao in his study on the treatment of CTBW containing silica, magnesium and calcium ions via EC process with BP-S electrodes arrangement [11]. and also, with Malakootian investigation on hardness ions removal using EC with MP-P electrodes connections [17].

The reason of the increase of removal efficiency of silica can be attributed to chemical adsorption, while in case of the calcium and magnesium removal that for aluminum hydroxides, much higher pH values are needed to credited negatively charged precipitate, that means the mechanisms of Ca^{+2} and mg^{+2} ions includes physical adsorption, which consequences from electrostatic attraction via Ca^{+2} and mg $^{+2}$ to negatively charged sites on the precipitates **[11].**

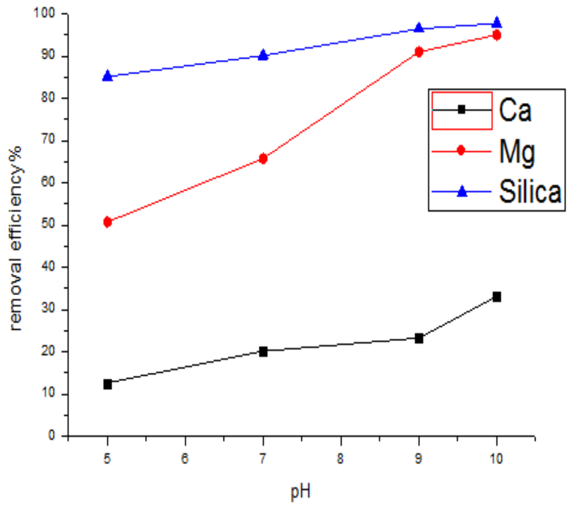


Fig. 7. Removal percent efficiency of silica Ca, and Mg for MP-P of EC cell at different initial pH value, at time=30min and current density=1mA/cm^2

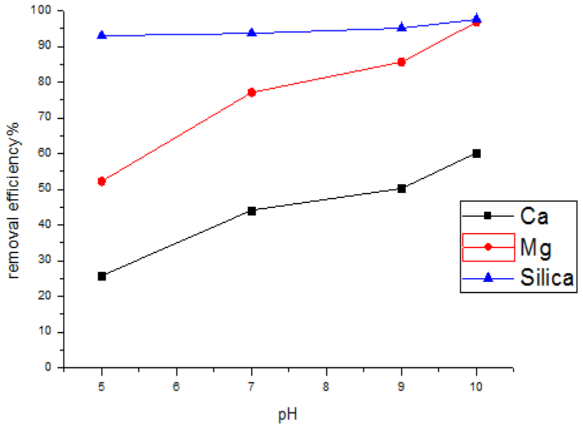


Fig. 8. Removal percent efficiency of silica Ca, and Mg for BP-S of EC cell at different initial pH value, at time=30min and current density=1mA/cm^2

4.5. Electrical Energy Consumptions

For both electrodes arrangement, it is clear that current and voltage values powerfully influence the choice of the type of electrode configuration for given wastewater treatment. **Fig.9** showed the change of EEC values with time for scale shaping species removal at current density =1mA/cm^2 and pH=10 for MP-P and BP-S connections .it was observed that BP-S has the higher energy consumption than MP-P system for the same current density and this agreement with Kobya investigation**[7].**

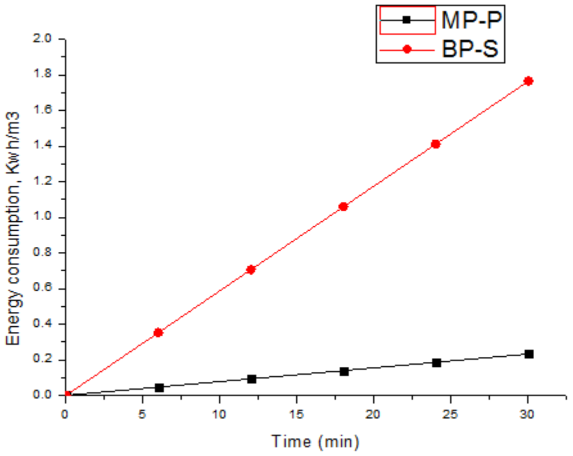


Fig. 9. The difference of EEC values with time for scale-forming ions removal for MP-P and BP-S connection at pH=10, (i = 1 mA/cm2)

5- Conclusion

- Electrocoagulation was assessed as a possible technique for the removal of ions causing scaling (silica, calcium, and magnesium) from synthetic cooling tower blowdown water using MP-P and BP-S.
- The results for EEC demonstrate that MP-P attained the lowest energy consumption in comparison with BP-S.

- The experiments were showed that BP-S mode has higher removal efficiency for each ion from CTBW. Therefore, this array generates more flocs than the MP-P mode. In addition, the growing Al^{+3}ions are more efficient in the coagulation method and it is renowned that aluminum hydroxide flocs are relatively big and having low density, which can be simply floated and separated **[13].**
- BP-S configuration is a simple system, only the outer electrodes are connected to the power supply and the inner electrodes without connections, which assist no difficulty of maintenance.

Nomenclature

Nomenclature	Meaning	Units
C_I	initial ions concentrations	mg/l
C_F	final ions concentrations	mg/l
% η	removal efficiency	
EEC	electrical energy consumption	KWh/m^3
I	current	Ampere
U	voltage	volt
t	time of electrolysis	hour
V	solution volume	m^3

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التوصيلات المختلفة للأقطاب في التخثير الكهربائي لمياه التصريف المحاكة لبرج التبريد

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الخلاصة

في هذا البحث ، تم دراسة أداء عمليه التخثير الكهربائي (EC) باستخدام أقطاب الألمنيوم (Al) مع ترتيب أحادي القطب المتوازي (MP–P) ، وسلسلة ثنائية القطب (BP–S) للإزالة المتزامنة للسيليكا الذائبة ، وأيونات الصلابة (الكالسيوم ، والمغنيسيوم) من مياه التصريف المحاكاة من برج التبريد.وكذلك تمت دراسة تأثيركثافة التيار ، ودرجة الحموضة الأولية ووقت التحليل الكهربائي على كفاءة الإزالة في وحدة دفعية للتعرف على أفضل ظروف تشغيل. النتائج التي تم الحصول عليها لكل الأنواع المستهدفة هي دليل على أن نظام BP–S هو الأكثر فعالية بكثافة تيار مقدارها 1 ملي امبير/سم2 خلال 30 دقيقة وقيمه الاس الهيدروجيني = 10 مع إزالة 60 ٪ ، 97 ٪ و 98 ٪ للكالسيوم والمغنيسيوم والسيليكا ، على التوالي ، يتطلب استهلاك طاقة كهربائية بمقدار 1,8 كيلو واط ساعة / متر مكعب اعلى مما يلاحظ في الربط المتوازي.

الكلمات لدالة: مياه برج التبريد, سيليكا, سلسلة ثنائية الاقطاب