



# Removal of major nutrients by sono-direct and sono-alternate current electrocoagulation process from domestic wastewater

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## Abstract

**Background:** Electrocoagulation is becoming a promising eco-friendly wastewater treatment technique. It is a low-cost wastewater treatment method suitably applied for various wastewater effluent characteristics. Nevertheless, there are different kinds of electrocoagulation; comparison among them in terms of nutrient removal is investigated in the present research. This study analyzed nitrate ( $\text{NO}_3^-$ ) and phosphate ( $\text{PO}_4^{3-}$ ) removal potential of the sono-alternate and direct-current electrocoagulation process.

**Methods:** Batch reactor and sono-direct current (SDC)/sono-alternate current (SAC) electrocoagulation cell were employed to investigate  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  removal efficiency from domestic effluents. The data gathered from laboratory experiments were analyzed using response surface methodology (RSM). ANOVA was used to examine the interaction effects of diverse parameters in terms of  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  removal from domestic wastewater effluents.

**Results:** At extreme experimental conditions, the percentage of  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  removal attained with sono-direct current electrocoagulation (SDCE) and sono-alternate current electrocoagulation (SACE) were 96.5%, 96.2% and 96.8%, 96.5, respectively. The SACE was more successful in eliminating  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  than the SDCE process. The appearance of resistant oxide coating on the cathode and the appearance of corrosion on the anode due to oxidation processes in the case of SDCE were identified as principal factors highly affecting  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  removal efficiency.

**Conclusion:** With optimum process efficiency, experimental findings show that the SACE process is more capable of  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  removal than the SDCE process.

**Keywords:** Electrocoagulation, Nitrates, Phosphates, Wastewater, Water purification

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## Introduction

Wastewater is the expended water after use from different settings including households, commercial centers, industrial centers, public organizations, and related bodies. Wastewater produced from the domestic and wet handling scheme commonly contains high organic contaminants including carbohydrates, fibers, polyphenols, pectin, proteins, and major nutrients of nitrate ( $\text{NO}_3^-$ ) and phosphate ( $\text{PO}_4^{3-}$ ) pollutants (1). Water quality is becoming increasingly a crucial problem nowadays, particularly for third-world countries, because of increased pollution from point and non-point sources. Domestic wastewater prevails as the principal origin of pollution on the world stage (2).

Domestic effluent is a thick, black liquid with raised levels of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) from the presence of large amounts of organic matters including polysaccharides, organic acids, proteins, and polyphenols. Crude wastewater from

domestic effluents can cause a high degree of pollution to soil and water (3). The release of unpurified domestic effluent, however, could result in significant water contamination on the surface as well as groundwater, and a possible increase in the concentration of these toxins could pose a severe danger to plants, animals, humans, and the ecosystem (4).

Direct release of excessive  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  into nearby water ecosystems leads to serious environmental disruption called eutrophication of water bodies (5). In water quality management, eutrophication became a major ecological problem appeared with increased discharge of principal nutrients of nitrate and  $\text{PO}_4^{3-}$  species (6). Eutrophication of water bodies due to increased plant growth and algal boom resulting in the creation of dead zones and loss of aquatic life (5).

Numerous existing methods available to remove  $\text{NO}_3^-$  and phosphate-containing pollutant species are chemical precipitation, biological treatment, membrane processes,



electrolytic treatment, ion exchange, adsorption, and microalgal mass culture (5,7,8). To eliminate low concentration levels of  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$ , nanoscale adsorbents such as zero-valent metal, metal oxides/metal hydroxides, and carbon-based materials have been found to be cost-effective solutions (5). No matter different adsorbents have been developed with excellent properties, the lack of compilation, consistency in operational conditions, and vital parameters used for practical use selection were exhibited (9).

There has been a growing interest in seeking inventive means to effectively remove contaminants from the environment in recent years (10). Electrocoagulation and electroflotation are the promising methods emerged recently and operate based on electrochemical technology (11).

Electrocoagulation is one form of the electrochemical process, which utilizes sacrificial resoluble iron (Fe) along with aluminum (Al) electrodes (12,13). In the process, metal ions ( $\text{Fe}^{2+}$  or  $\text{Fe}^{3+}$ ,  $\text{Al}^{3+}$ ) are released from anodic oxidation processes. The mechanism of the electrocoagulation process is discussed below:

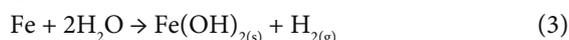
*Anodic reaction (14):*



*Cathode reaction (14):*



*General reaction:*

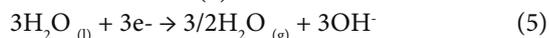


In the overall reaction,  $\text{Fe}(\text{OH})_2$  is formed when iron salts are used up as a major coagulant chemical in the process (12,13). When aluminum is being utilized as an electrode device in the process, the reactions become:

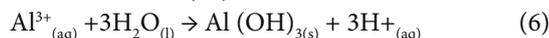
*Anodic reaction:*



*Cathode reaction (8):*



*Overall reaction (14):*



Electrocoagulation is a low-cost method (15-17) for the treatment of a broad variety of wastewater contaminants that appeared with domestic and industrial effluent (18). Even though different kinds of electrocoagulation exist and being in use, no study investigated major nutrient removal potential from institutional effluents using sono-alternative current (SACE) and sono-direct current electrocoagulation (SDCE) processes and compared these methods. The present study investigated  $\text{NO}_3^-$

and  $\text{PO}_4^{3-}$  removal potential of the integrated SACE and SDCE process. The integration of the SACE and SDCE process is to enhance the removal effectiveness of dependent parameters by merging electrocoagulation with ultrasound using AC/DC technique (19). The impacts of the current density, electrolysis period, and inter-electrode distance on the removal efficiencies of major nutrients were studied distinctively using an Al-Al electrode and simulated wastewater.

## Materials and Methods

### Materials and chemicals applied

The equipment used in the present research include a batch reactor, a DC/AC electrocoagulation cell, a DC/AC power supply, ultrasonic, parallel electrode, a magnetic stirrer, copper wires, a magnetic bar stirrer, electrical clips, locally available chip woods, kits, and a spectrophotometer. Chemicals used to determine  $\text{NO}_3^-$  levels are stock  $\text{NO}_3^-$  solution, standard  $\text{NO}_3^-$  solution, sodium arsenite solution, brucine-sulfanilic acid solution, sulfuric acid solution, and sodium chloride solution. Chemicals used to measure  $\text{PO}_4^{3-}$  levels in water are phenolphthalein, sulfurous acid, ammonium persulfate, and potassium antimony tartrate reagent. The stock  $\text{PO}_4^{3-}$  solution was also supplemented with ammonium molybdate and ascorbic acid.

### Sample size and sampling technique

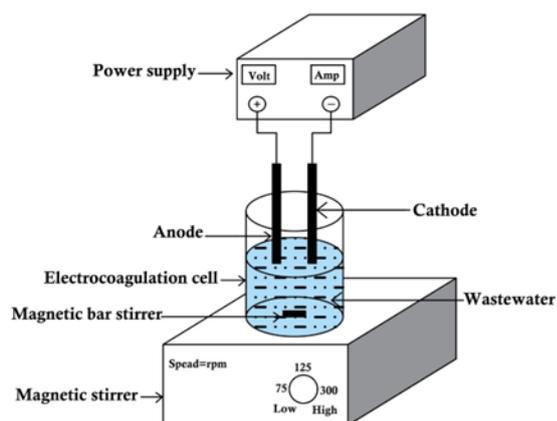
A purposive sampling technique was employed to collect samples from critical polluting sources. For all 40 experimental runs, the sample volume of 40 L was collected and examined by laboratory facilities.

### Sample collection and preservation method

All samples were entirely collected from the Jimma University, Institute of Technology student dining hall at the University's common effluent purification plant physically positioned in the southwestern part of Ethiopia. The samples were gathered in polyethylene bottles, taken to the lab facility within the time frame of 1 hour, and then, blanketed at a regulated temperature of 4 °C all through the testing.

### Experimental set-up

The setup applied for testing domestic effluent treatment was the SDCE and SACE processes (Figure 1). The reactor batch draft contains an acrylic sheet capacity of 2.25 L, with the effective capacity of effluent being 1.0 L. Electrode arrangement applied as anode along with cathode were (Al/Al) and Al dishes. The dimensions of the plates in terms of length, width, and thickness were 13 cm, 6 cm, 1 cm, respectively. The active surface area of both electrodes was 10 cm × 10 cm × 0.1 cm. To permit suitable stirring, a clear spacing of 2 cm was sustained between the electrode bottom and the electrochemical cell reactor.



**Figure 1.** Experimental arrangement of applied electrocoagulation

The electrode spacing altered was 2 cm. The electrodes were substantially cleaned using 15% HCl along with distilled water before launching each test. Both electrodes were joined in monopolar parallel link to SACE and SDCE sources (0–5 A, 0–270 V). Based on prearranged time intervals, the samples were collected and centrifuged (REMI, Model: R-24) for the run time of 15 minutes, and analyzed for removal of  $\text{PO}_4^{3-}$  and  $\text{NO}_3^-$ .

### Analysis

#### Nitrate removal efficiency determination

Nitrate determination tests were conducted by employing phenoldisulfonic acid method. The absorbance was measured at 410 nm about a blank composed of similar amounts of reagents applied in each sample. To produce the calibration curve,  $\text{NO}_3^-$ -N was applied in the range of 0–2 mg/L by adding 0, 0.2, 0.5, 1.0, 3.0, 5.0, and 10 mL of standard  $\text{NO}_3^-$  solution to isolate evaporating plates and handling them in a similar manner as samples. By referencing the calibration curve, the concentration of  $\text{NO}_3^-$ -N within the sample was determined.

For  $\text{NO}_3^-$ -removal efficiency:

$$(\%Y) = \left( \frac{C_i - C_f}{C_f} \right) * 100 \quad (7)$$

Where %Y: Nitrate removal efficiency of the substrate ( $\text{NO}_3^-$ );  $C_i$ : Initial Nitrate concentration and  $C_f$ : Final  $\text{NO}_3^-$  concentration

#### Phosphate removal determination

Phosphate determination tests were conducted by employing Stannous chloride method. A calibration curve was created in the range of 0–30  $\text{PO}_4^{3-}$  g/100 mL by putting 0, 0.2, 0.5, 1.0, 3.0, 5.0, and 6 mL standard  $\text{PO}_4^{3-}$  solution for the sake of isolating evaporating plates and managing them in analogous to the sample. One droplet (0.05 mL) of phenolphthalein indicator solution was applied to the sample to verify whether it turned into pink color or not. And strong acid solution was applied dropwise

till the color change was exhibited. Through a gauging pipette, 4 mL acid-molybdate solution was applied to a part of standards and sample. They were mixed carefully by overturning individual flasks several times (four to six). Using a medicine dropper, 10 drops (0.5 mL) of stannous chloride solution was applied to each standard and sample. Then, each of them were carefully stoppered. By overturning individual flasks for about six times within a duration of 12 minutes, all were gently mixed. The displayed color was measured photometrically at 690 nm by putting distilled water blank. Using standards, a calibration curve was drawn. Moreover, via referencing the calibration curve, the concentration of  $\text{PO}_4^{3-}$  present was determined.

For  $\text{PO}_4^{3-}$  removal efficiency:

$$(\%R) = \left( \frac{S_0 - S_f}{S_f} \right) * 100 \quad (8)$$

Where %R represents the nutrient removal rate of the substrate ( $\text{PO}_4^{3-}$ ),  $S_0$  is initial concentration at  $t=0$ , and  $S_f$  is the final concentration at  $t=f$ .

#### Optimization with response surface methodology (Design Expert 11)

The response surface methodology (RSM) is a scientific method used for optimizing chemical responses along with industrial practices. It is applied frequently for experimental designs that involve different types of animals (20). The RSM is a specific set of mathematical and statistical methods used to study the behavior of materials. These methods include experimental design, model fitting and validation, and condition optimization. RSM aims to optimize the response of a user's preferences, which is affected by several factors. The central composite design was applied to define the optimal EC settings (21). The whole design might be done with 14 points, with six central points. Electrolysis time and current density were the independent variables. The expected results are  $\text{PO}_4^{3-}$  and  $\text{NO}_3^-$  removal efficiencies. The simulation for gained outcomes was undertaken; subsequently, the optimal points for the action were resolved. The design of experiments was accomplished using Central Composite Design (CCD) and Design Expert version 11.

### Results

#### Wastewater characterization

The effluent samples were collected in polyethylene (PE) containers from the common inlet of the treatment plant at the Jimma University, Ethiopia. Until the finalization of the collection processes, the effluent samples were transported to the laboratory within one hour and kept at a protected temperature of +4°C. The effluent samples were analyzed for parameters such as pH, COD, BOD,  $\text{NO}_3^-$ , and  $\text{PO}_4^{3-}$  (Table 1).

All experiments were carried out at the standard

temperature in the laboratory in a batch reactor (Figure 2). One liter of wastewater effluent with beaker glass was used for each electrode combinations. For the EC method, Aluminum-Aluminum electrodes with dimensions of 13 cm × 6 cm × 1 cm (length, width, and thickness) were utilized. Each electrode weighs 30.70 g. Copper wires were connected to the SDC/SAC energy source. The wires were linked to electrodes using electrical clips. Upon the power supply, several experiments were conducted with various affecting parameters.

### Al-Al electrode combination

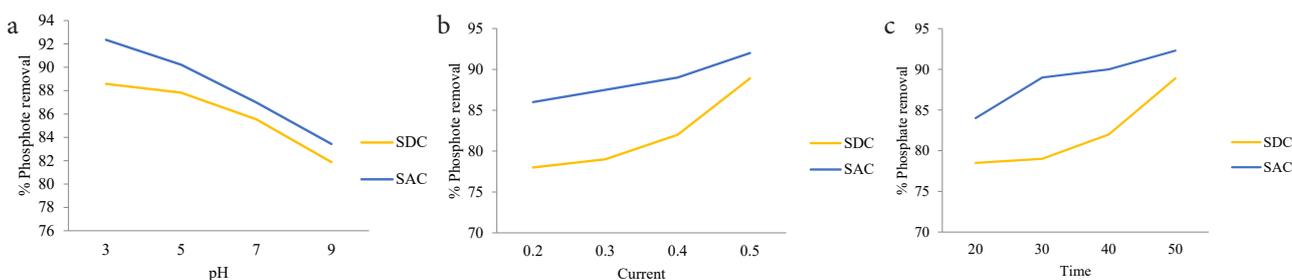
In the current testing for the removal percentage of NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>3-</sup> species, two Al electrodes were joined equivalently considering several factors (22-24).

**Table 1.** Characteristics of domestic effluent (Pre-treatment)

| Parameters                    | Quantity | Unit |
|-------------------------------|----------|------|
| pH                            | 6.8      | -    |
| COD                           | 960      | mg/L |
| BOD                           | 384      | mg/L |
| NO <sub>3</sub>               | 14.5     | mg/l |
| PO <sub>4</sub> <sup>-3</sup> | 19       | mg/l |



**Figure 2.** Actual setup of SDC and SACE processes



**Figure 3.** Phosphate removal with various operating parameters (a), (b), and (c), using Al-Al electrode

### The percent removal efficiency of Phosphate and Nitrate

The PO<sub>4</sub><sup>3-</sup> removal percentage was calculated considering the effluent PO<sub>4</sub><sup>3-</sup> concentration before and after treatment with SDC and SACE process. Operating factors including pH, electric current, and reaction time were examined through altered ranges (Figure 3). Thus, using Al-Al electrode, the removal efficiency for PO<sub>4</sub><sup>3-</sup> and NO<sub>3</sub><sup>-</sup> were 88.5% and 97.8%, respectively, in SDC electrocoagulation.

Similarly, operating parameters such as pH, electric current, and reaction time were examined through altered ranges for SAC electrocoagulation arrangement (Figure 4). Determination of removal efficiency was undertaken considering all those factors. Thus, using SAC electrocoagulation, the removal efficiency of both PO<sub>4</sub><sup>3-</sup> and NO<sub>3</sub><sup>-</sup> was 92.35% and 98.2%, respectively. Furthermore, the removal percentage of both PO<sub>4</sub><sup>3-</sup> and NO<sub>3</sub><sup>-</sup> is more elaborately depicted (Figures 3 and 4).

SACE exhibited greater PO<sub>4</sub><sup>3-</sup> and NO<sub>3</sub><sup>-</sup> removal within the margin of three operating parameters- pH, current, and time (Figures 3 and 4).

### ANOVA results for Nitrate removal using SDC electrocoagulation

The model appears to be significant (Table 2). Under these conditions A, B, C, BC, A<sup>2</sup>, and B<sup>2</sup> appear to be significant model expressions. All P value results are less than 0.0500. Thus, the model expressions are almost significant.

$$\text{Nitrate removal (\%)} = 92.25 - 3.89A + 0.7819B + 0.1694C + 0.4612AB + 0.5612AC + 0.5612AC + 0.5862BC - 0.8783A^2 - 0.3158B^2 - 0.1533C^2 \quad (9)$$

$$\text{Phosphate removal (\%)} = 92.81 - 2.38A + 0.6625B + 0.1125C - 0.1000AB + 0.0500AC - 0.1500BC - 0.4245A^2 - 0.3120B^2 - 0.0370C^2 \quad (10)$$

### ANOVA results for Phosphate removal using SDC electrocoagulation

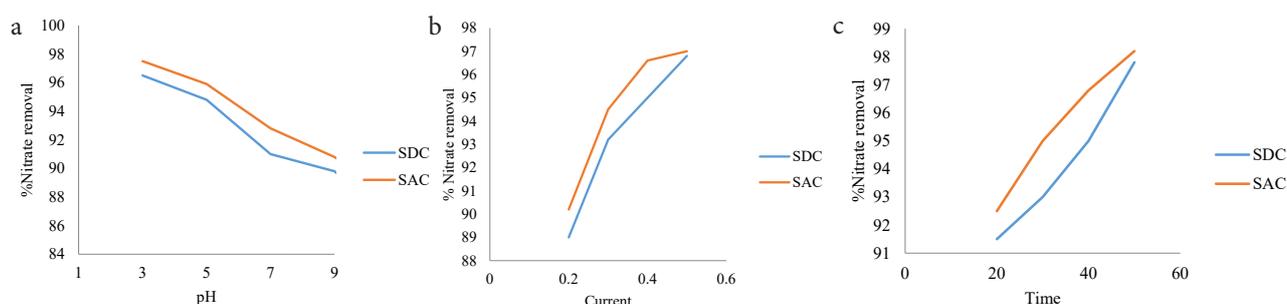
Similarly, the model appears to be significant (Table 3). Under these conditions A, B, C, BC, A<sup>2</sup>, and B<sup>2</sup> appear to be significant model expressions. All P value results are less than 0.0500. Thus, the model expressions are almost significant.

**Table 2.** Statistical summary of model terms in nitrate removal

| Source         | Sum of squares | df | Mean square | F value | P value |                    |
|----------------|----------------|----|-------------|---------|---------|--------------------|
| Model          | 279.63         | 9  | 31.07       | 475.97  | <0.0001 | Highly significant |
| A-pH           | 242.50         | 1  | 242.50      | 3715.01 | <0.0001 |                    |
| B-I            | 9.78           | 1  | 9.78        | 149.84  | <0.0001 |                    |
| C-Time         | 0.4590         | 1  | 0.4590      | 7.03    | 0.0242  | Significant        |
| AB             | 1.70           | 1  | 1.70        | 26.07   | 0.0005  |                    |
| AC             | 2.52           | 1  | 2.52        | 38.61   | <0.0001 |                    |
| BC             | 2.75           | 1  | 2.75        | 42.12   | <0.0001 |                    |
| A <sup>2</sup> | 19.40          | 1  | 19.40       | 297.12  | <0.0001 |                    |
| B <sup>2</sup> | 2.51           | 1  | 2.51        | 38.41   | 0.0001  |                    |
| C <sup>2</sup> | 0.5908         | 1  | 0.5908      | 9.05    | 0.0132  |                    |
| Residual       | 0.6528         | 10 | 0.0653      |         |         |                    |
| Lack of fit    | 0.3112         | 5  | 0.0622      | 0.9113  | 0.5394  | Not significant    |
| Pure error     | 0.3415         | 5  | 0.0683      |         |         |                    |
| Cor total      | 280.28         | 19 |             |         |         |                    |

**Table 3.** Statistical summary of model terms in phosphate removal

| Source         | Sum of squares | df | Mean square | F value | P value |                    |
|----------------|----------------|----|-------------|---------|---------|--------------------|
| Model          | 103.81         | 9  | 11.53       | 47.07   | <0.0001 | Highly significant |
| A-pH           | 90.25          | 1  | 90.25       | 368.26  | <0.0001 | Highly significant |
| B-I            | 7.02           | 1  | 7.02        | 28.65   | 0.0003  |                    |
| C-Time         | 0.2025         | 1  | 0.2025      | 0.8263  | 0.0038  |                    |
| AB             | 0.0800         | 1  | 0.0800      | 0.3264  | 0.0404  |                    |
| AC             | 0.0200         | 1  | 0.0200      | 0.0816  | 0.0210  |                    |
| BC             | 0.1800         | 1  | 0.1800      | 0.7345  | 0.0115  |                    |
| A <sup>2</sup> | 4.53           | 1  | 4.53        | 18.49   | 0.0016  |                    |
| B <sup>2</sup> | 2.45           | 1  | 2.45        | 9.99    | 0.0101  |                    |
| C <sup>2</sup> | 0.0345         | 1  | 0.0345      | 0.1408  | 0.7153  |                    |
| Residual       | 2.45           | 10 | 0.2451      |         |         |                    |
| Lack of fit    | 1.32           | 5  | 0.2631      | 1.16    | 0.4376  | Not significant    |
| Pure error     | 1.13           | 5  | 0.2270      |         |         |                    |
| Cor total      | 106.26         | 19 |             |         |         |                    |



**Figure 4.** Nitrate removal with various operating parameters (a), (b), and (c), using Al-Al electrode

**ANOVA results for nitrate removal using SAC electrocoagulation**

For the SACE method, the model appears to be significant (Table 4). Under these conditions A, B, C, BC, A<sup>2</sup>, and B<sup>2</sup> appear to be significant model expressions. All P value results are less than 0.0500. Thus, the model expressions are almost significant.

$$\text{Nitrate removal (\%)} = 93.40 - 3.11A - 0.1556B + 0.3456C - 0.5163AB + 0.2837AC - 0.1393BC - 0.6778A^2 - 0.2850B^2 - 0.0629C^2 \quad (11)$$

$$\text{Phosphate removal (\%)} = 92.22 - 2.26A - 0.2872B + 0.1452C - 0.7154AB - 0.010154AC - 0.4718BC - 0.5149A^2 + 0.2615B^2 + 0.1412C^2 \quad (12)$$

**ANOVA for phosphate removal with quadratic model by SAC electrocoagulation**

**ANOVA results for Phosphate removal using SAC electrocoagulation**

Similarly, the model appears to be significant (Table 5).

Under these conditions A, B, C, BC, A<sup>2</sup>, and B<sup>2</sup> appear to be significant model expressions. All P value results are less than 0.0500. Thus, the model expressions are almost significant.

**Discussion**

**Comparison of SDCE and SACE process**

To compare the SDCE and SACE processes in terms of nutrient removal from domestic wastewater, several experiments (40 in number) were conducted and test results were carefully recorded. Then, the experimental results were analyzed for the removal percentage of PO<sub>4</sub><sup>3-</sup> and NO<sub>3</sub><sup>-</sup>. The operating conditions like pH 6.8, current density of 0.50 A, distance between electrodes (1 cm), electrodes in use (Al/Al), and test running time of 1 hour were employed and the outcomes are presented (Figures 3 and 4). NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>3-</sup> removal percentage of institutional effluent was greater in the integrated SACE than in the integrated SDCE. Particular to SACE, the formation of high sludge concentration and the creation of the impervious coating was lesser than the

**Table 4.** Statistical summary of model terms in Nitrate removal with the SAC method

| Source         | Sum of squares | df | Mean square | F value | P value |                 |
|----------------|----------------|----|-------------|---------|---------|-----------------|
| Model          | 196.98         | 9  | 21.89       | 39.28   | <0.0001 | Significant     |
| A-pH           | 75.49          | 1  | 75.49       | 135.49  | <0.0001 |                 |
| B-I            | 0.2776         | 1  | 0.2776      | 0.4983  | 0.0163  |                 |
| C-Time         | 1.89           | 1  | 1.89        | 3.39    | 0.0954  |                 |
| AB             | 1.05           | 1  | 1.05        | 1.89    | 0.0292  |                 |
| AC             | 0.6288         | 1  | 0.6288      | 1.13    | 0.0130  |                 |
| BC             | 0.0232         | 1  | 0.0232      | 0.0416  | 0.0425  |                 |
| A <sup>2</sup> | 9.54           | 1  | 9.54        | 17.12   | 0.0020  |                 |
| B <sup>2</sup> | 1.68           | 1  | 1.68        | 3.01    | 0.1135  |                 |
| C <sup>2</sup> | 0.0835         | 1  | 0.0835      | 0.1499  | 0.7067  |                 |
| Residual       | 5.57           | 10 | 0.5572      |         |         |                 |
| Lack of fit    | 0.0348         | 4  | 0.0087      | 0.0094  | 0.9998  | Not significant |
| Pure error     | 5.54           | 6  | 0.9228      |         |         |                 |
| Cor total      | 202.55         | 19 |             |         |         |                 |

SDCE method. This result is consistent with the results of previous studies (25,26). Thus, when comparing the integrated SDCE with the integrated SACE process for the removal percentage of NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>3-</sup> from domestic wastewater, the integrated SACE technique was more suitable than the integrated SDCE method.

Experimental outcomes show that an increase in current density from 0.10 to 0.50 A/dm<sup>2</sup> increased NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>3-</sup> removal from 89% to 96.5%, 78% to 87%, respectively with SDCE and from 94.5% to 97%, 86% to 92%, respectively with SACE, which is consistent with the results of the study by Torabinejad-Yazdi and Delnavaz (27). Thus, current density appears the vital parameter in monitoring the effluent treatment process with SDCE and SACE methods (4,28).

According to a similar study by Shalaby et al, a very low range of pH is not desirable for PO<sub>4</sub><sup>3-</sup> and NO<sub>3</sub><sup>-</sup> removal (29). The highest PO<sub>4</sub><sup>3-</sup> removal is attained near neutral pH (29). At pH 7, the highest removal efficiency for PO<sub>4</sub><sup>3-</sup> and NO<sub>3</sub><sup>-</sup> was recorded by the electrocoagulation method (27). However, in the case of the present research, the highest removal for PO<sub>4</sub><sup>3-</sup> and NO<sub>3</sub><sup>-</sup> was recorded at acidic media, near pH 3. The obtained experimental results are not consistent with the results of the previous study since the present study employs somewhat integrated ultrasonic-electrocoagulation methods.

The conducted experiments showed that the best removal for nitrates was attained at a 40-minute reaction time. This result is similar to the results of the study conducted by Al-Marri et al employing the ultrasonic-

**Table 5.** Statistical summary of model terms in phosphate removal using the SAC method

| Source         | Sum of squares | df | Mean square | F value | P value |                    |
|----------------|----------------|----|-------------|---------|---------|--------------------|
| Model          | 129.60         | 9  | 14.40       | 41.21   | <0.0001 | Highly significant |
| A-pH           | 39.88          | 1  | 39.88       | 114.14  | <0.0001 |                    |
| B-I            | 0.9465         | 1  | 0.9465      | 2.71    | 0.0308  |                    |
| C-Time         | 0.3332         | 1  | 0.3332      | 0.9538  | 0.0118  |                    |
| AB             | 2.02           | 1  | 2.02        | 5.79    | 0.0369  |                    |
| AC             | 0.0018         | 1  | 0.0018      | 0.0053  | 0.0435  |                    |
| BC             | 0.2659         | 1  | 0.2659      | 0.7611  | 0.0034  |                    |
| A <sup>2</sup> | 5.50           | 1  | 5.50        | 15.75   | 0.0026  |                    |
| B <sup>2</sup> | 1.41           | 1  | 1.41        | 4.04    | 0.0721  |                    |
| C <sup>2</sup> | 0.4210         | 1  | 0.4210      | 1.21    | 0.2981  |                    |
| Residual       | 3.49           | 10 | 0.3494      |         |         |                    |
| Lack of Fit    | 1.82           | 4  | 0.4555      | 1.63    | 0.2811  | Not significant    |
| Pure Error     | 1.67           | 6  | 0.2787      |         |         |                    |
| Cor Total      | 133.09         | 19 |             |         |         |                    |

electrocoagulation method (30).

**Effects of operating parameters for the case of the SACE method**

With the SACE method, the effects of operating factors such as current density, preliminary pH of the effluent, preliminary NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup> concentrations, and the spacing between the electrodes and electrode combination type were investigated to define the optimum parameter settings for the maximum NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup> removal with the least electrical power utilization.

**Effect of current density**

Current density is a vital parameter in monitoring the effluent treatment process with SACE. Experimental outcomes show that an increase in current density from 0.10 to 0.50 A/dm<sup>2</sup> increased NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>3-</sup> removal from 89% to 96.5%, 78% to 87, respectively with SDC and from 94.5% to 97%, 86% to 92%, respectively with SAC. According to the Faraday’s law, the amount of electrochemically liquefied iron (Al) in the reaction is proportional to the charge applied in the process (31). Increasing the current density will increase the loading, causing an enlarged appearance of OH radicals as well as the elimination of impurities from effluents.

**Effect of initial pH wastewater**

In the (SDC and SAC) electrocoagulation processes, the effect of initial pH was exhibited very significant. There are various permissible concentrations of OH radicals and diverse aluminum hydroxide complexes under the

state of numerous pH solutions. Within acidic settings ( $\text{pH} < 5$ ), the furthestmost fortunate species are  $\text{Al}(\text{OH})^{2+}$ ,  $\text{Al}(\text{OH})_2^+$ , and  $\text{Al}(\text{OH})^{2-}$ , which simply combine with  $\text{H}_2\text{O}_2$  to yield  $\text{OH}^-$  (32). The highest concentration of  $\text{Al}^{2+}$  is reported at a pH solution of 3, and extra  $\cdot\text{OH}$  is produced in the reaction of  $\text{H}_2\text{O}_2$ . In the current testing, the pH of the sample was regulated using a sulfuric acid solution and sodium hydroxide. pH was regulated in the range of 3-9. This might provide essential data on how far acidic pH, neutral pH, and base pH would affect the overall electrocoagulation efficiency in terms of removing  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$ . Nevertheless, the highest reduction was documented at pH 3 (96.5%, 88.5%) with SDC, and (97.8%, 93%) with SAC methods.

### Effect of reaction time

The reaction time considered for all experiments was one hour. The removal efficiency was verified over different time intervals using the preliminary result as a baseline. In the present research, the laboratory outcomes show that a one-hour reaction time is somewhat enough to remove pollutants. Increasing reaction time would increase the removal efficiency of pollutants across domestic effluents (33).

### Conclusion

The present study demonstrated the treatment potential and comparison of SACE and SDCE methods applicable to domestic effluent constituting high nutrients –  $\text{PO}_4^{3-}$  and  $\text{NO}_3^-$  species. Batch reactors with SDC/SAC electrocoagulation cells were exclusively employed in the investigation processes.

For domestic effluents containing substantial concentrations of  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  pollutants integrated SACE and SDCE processes are found to be promising treatment techniques. Along with this, at the peak experimental settings, the  $\text{PO}_4^{3-}$  and  $\text{NO}_3^-$  removal is greater in the case of SACE than in SDCE processes. Moreover, with SACE, sludge generation is lower and water recovery is very high.

The current density, initial pH, reaction time, and effluent concentration are principal factors affecting the removal of major nutrients with both SACE and SDCE methods. The experimental outcomes revealed that the SACE process is a more promising technique for nutrient removal applied to domestic effluents than the SDCE method.

Future research work shall examine the possibility of enhanced nutrient removal from domestic wastewater with additional operating factors such as temperature and electrolyte concentration. In addition, future research work shall investigate nutrient removal potential for effluent flow conditions apart from batch flow.

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### Competing interests

The authors affirm that there is no conflict of interests.

### Ethical issues

All authors certify that all data collected during the study are as stated in the manuscript and no data from the study have been or will be published separately elsewhere.

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