OPEN JOURNAL SYSTEMS ISSN: 2595-4431

Brazilian Journal of Environment

Rampanelli et al



Effect of distance between electrodes and current density on the removal of salicylic acid in a electrocoagulation reactor

Júlio César Rampanelli¹, Rogério Marcos Dallago², Aline Schuck³, Fernando Zuchello⁴, Rúbia Mores^{5*}

¹Pharmacist, University of Contestado, Concórdia, Brazil

²*PhD in Chemistry, Department of Food Engineering, URI–Erechim, Brazil*

³PhD in Environmental Engineering, University of Contestado, Concórdia, Brazil

⁴*PhD in Agronomy, Instituto Federal Catarinense, Concórdia, Brazil*

⁵PhD in Food Engineering, University of Contestado, Concórdia, Brazil (*Corresponding author: rubia.mores@professor.unc.br)

Article History: Submitted: 08/02/2024 - Revised: 01/03/2025 - Accepted: 02/06/2025

ABSTRACT

In this work, the removal of salicylic acid (SA) by electrocoagulation in a batch system was evaluated using aluminum (Al) and iron (Fe) electrodes. The experimental parameters evaluated were distance between electrodes, current density and electrocoagulation time. The results revealed that SA removal increased with increasing current density and electrocoagulation time. The minimum electrocoagulation time required to achieve 90% removal of the SA using the Fe electrode was 20 minutes in the CD condition 38.9 mA.cm⁻² and DE 3 and 1 cm for the aluminum electrode occurs in the operating time of 40 minutes (CD 38.9 mA.cm⁻² and DE 1 cm). The results showed that, in all the studied conditions, the EC is efficient.

Keywords: Chemical Coagulation. Wastewater, Pharmaceuticals.

Efeito da distância entre eletrodos e densidade de corrente na remoção de ácido salicílico em um reator de eletrocoagulação

RESUMO

Neste trabalho, avaliou-se a remoção de ácido salicílico (AS) por eletrocoagulação em sistema batelada, utilizando eletrodos de Alumínio (Al) e Ferro (Fe). Os parâmetros experimentais distância entre os eletrodos, densidade de corrente e tempo de eletrocoagulação foram avaliados. Os resultados revelaram que a remoção de AS aumentou com o aumento da densidade de corrente e do tempo de eletrocoagulação. O tempo mínimo de eletrocoagulação necessário para atingir 90% de remoção do AS utilizando o eletrodo de Fe foi de 20 minutos na condição DC 38.9 mA.cm⁻² e DE 3 e 1 cm para o eletrodo de alumínio ocorre no tempo operacional de 40 minutos (DC 38.9 mA.cm⁻² e DE 1 cm). Os resultados mostraram que, em todas as condições estudadas, o a EC é eficiente. Palavras-chave: coagulação química, águas residuais, fármacos.

Palavras-Chaves: Coagulação Química, Águas Residuais, Fármacos.

Efecto de la distancia del electrodo y la densidad de corriente en la eliminación de ácido salicílico en un reactor de electrocoagulación

RESUMEN

En este trabajo se evaluó la remoción de ácido salicílico (SA) por electrocoagulación en un sistema discontinuo, utilizando electrodos de Aluminio (Al) y Hierro (Fe). Se evaluaron los parámetros experimentales distancia entre los electrodos, densidad de corriente y

Rampanelli, J.C., Dallago, R.M., Schuck, A., Zuchello, F., Mores, R. (2025). Effect of distance between electrodes and current density on the removal of salicylic acid in a electrocoagulation reactor. **Brazilian Journal of Environment (Rev. Bras. de Meio Ambiente)**, v.13, n.1, p.16-25.



tiempo de electrocoagulación. Los resultados revelaron que la eliminación de EA aumentó con el aumento de la densidad de corriente y el tiempo de electrocoagulación. El tiempo mínimo de electrocoagulación requerido para lograr la eliminación del 90% de AS utilizando el electrodo de Fe fue de 20 minutos en la condición DC 38.9 mA.cm-2 y DE 3 y 1 cm para el electrodo de aluminio ocurre en el tiempo de operación de 40 minutos (DC 38.9 mA.cm-2 y DE 1 cm). Los resultados mostraron que, en todas las condiciones estudiadas, la CE es eficiente. Palabras clave: coagulación química, aguas residuales, productos farmacéuticos.

Palabras clave: Coagulación Química, Aguas Residuales, Productos Farmacéuticos.

1. Introduction

In recent years, the presence of pharmaceutical compounds in wastewater has generated notable concern worldwide since the monitoring of these substances is insufficient. The incessant increase in the production and consumption of pharmaceutical products each year has progressively contributed to environmental pollution (Jindal, 2014). Ingestion and subsequent metabolism of drugs can result in the excretion of harmful metabolites, both for humans and for the environment (Chen et al., 2019b; Verlicchi et al., 2012).

Pharmaceutical products that have the potential to exist as pollutants in the environment through prescribed and/or consumed medication are those used to treat common short-term diseases, such as a common cold, fever and headaches. These drugs have a high propensity to contaminate the environment, as their high use facilitates continuous release into the environment, either through unused drugs or by excretion of consumed drugs (Jindal et al., 2014).

Among the substances widely found in wastewater, salicylic acid (SA) stands out, being the main molecule derived from the metabolism of acetylsalicylic acid (ASA), one of the most commercialized non-steroidal anti-inflammatory drugs worldwide. Being mostly excreted in the urine, the SA is directed to the sewage networks, thus becoming a potentially dangerous contaminant (Ozyonar et al., 2016; Rang & Dale, 2011).

The capacity of sewage treatment plants to eliminate drugs and their metabolites varies in relation to the chemical character of the pharmaceutical product and the number and types of processes that occur in the plant. The passage of pharmaceutical products through sewage treatment plants can result in pollution of surface and groundwater. If this pollution is transferred to drinking water, involuntary medication in low doses will occur in large population groups, thus compromising public health (Wennmalm et al., 2005).

Due to their chemical specificity, each pharmaceutical product requires a degradation technique exclusively designed for its complete destruction. As waste management plants use generalized degradation techniques, many pharmaceutical products are therefore not completely destroyed and/or removed (Jindal et al., 2014; Vera-Candioti et al., 2008).

Among the wastewater treatment alternatives, electrocoagulation (EC) has emerged in recent years as a promising single or combined process, post or pre-treatment, with biological processes and other industrial wastewater treatment processes (Al-Qodah, 2019). The method combines coagulation, flocculation and electrochemical properties, and presents high efficiency in the removal of particles, high energy utilization, low operating time, reduced sludge production and low operating cost, in addition to not requiring the addition of chemical compounds (Bracher et al., 2019; Ozyonar et al., 2016; Reátegui-Romero et al., 2018).

EC consists of the application of electrical current to metal electrodes, usually Iron (Fe) or Aluminum (Al), as they are easy to acquire and have low toxicity. The anode is responsible for releasing ions that act as coagulating agents, complexing with contaminating particles and forming flakes, while the cathode releases hydrogen gas (H₂) and oxygen (O₂), causing the flake to be deposited on the water surface. (Bracher et al., 2019; Chen, 2004a; Moussa et al., 2017; Reátegui-Romero et al., 2018).

In the present study, the variable distance between the electrodes and the current density were evaluated in relation to the removal of SA by the batch electrocoagulation method.

2. Material and Methods

To carry out the experiments, an SA solution was prepared at a concentration of 100 mg.L⁻¹, the pH of the solution was adjusted to 6.0 with 0.1 mol.L⁻¹ sodium hydroxide and a fixed amount of NaCl (0.1 mol.L⁻¹) was added to the aqueous solution to increase the conductivity of the solution and facilitate the process. The electrocoagulation was performed in an open batch reactor, with a working volume of 1.8L, Al and Fe electrodes, with dimensions of 70x130x2mm, were arranged in pairs (Anode - Cathode - Anode - Cathode), in vertical position, and connected to an electrical source of direct current. At the end of each experiment, the electrodes were cleaned with steel wool, rinsed with distilled water and dried in an oven at 105 °C for 1 h.

A 2^2 Factorial design was selected to understand how the variables current density (CD) and distance between the electrodes (DE) influence the SA removal process, during the electrocoagulation process using aluminum and iron electrodes (Table 1). The experiments were carried out in random order to avoid systematic errors.

Variables	Levels			
variables	-1	0	1	
*DE (cm)	1.0	2.0	3.0	
**CD (mA.cm ⁻²)	16.7	27.8	38.9	

* distance between the electrodes (DE); ** current density (CD)

The samples were collected at times: 0, 10, 20, 30, 40, 50, 60 and 80 minutes of each experiment. The pH of the solution was determined by immersing the electrode connected to a pH meter in the samples. The SA determination was performed according to the Brazilian Pharmacopeia (Brasil, 2010), using a spectrophotometer at an absorbance of 530 nm.

The removal percentage (CR) was calculated using the following equation (Eq. 8):

$$CR(\%) = \frac{A_0 - A_t}{A_0} x 100$$
 (8)

where A0 is the initial concentration of the constituents and At is the final concentration of the constituents (after EC).

Energy consumption was calculated according to (Eq. 9), as proposed by Kobya et al. (2015),

$$C_{\text{energy}} = \frac{U \, x \, i \, x \, t_{\text{EC}}}{V_{\text{ef}}} \qquad (9)$$

where U is the voltage (V), i the current density (A), tEC is the operating time (h), Vef is the volume of treated effluent (L).

The amount of H_2 gas emitted from an EC unit was estimated using the following equation (10) (Phalakornkule et al., 2010; Lakshmi et al., 2013; Hashim et al., 2017).

$$Q_{\rm H_2} = \frac{\rm CD.A.t.H}{\rm F} \quad (10)$$

where, QH₂; CD, A, t, H, and F are the amount of H₂ gas emitted (mole), current density applied in (A/m²), effective surface area of the electrodes (m²), treatment time (sec), number of hydrogen molecules (1/2) and Faraday constant (96,500), respectively. The amount of H₂ produced can be expressed in volumetric units

using the following ideal gas law:

$$P.V = n.R.T$$
 (11)

where p, V, n, R, and T represent pressure (kPa), volume (L), moles of gas, gas constant (8.314 J/kmol at atmospheric pressure) and gas temperature (K), respectively. Although the available energy of H_2 gas can be estimated using the following formula (Hashim et al., 2017).

$$E_{H_2} = m \left(0.244 \frac{MJ}{mol} \right) (12)$$

where EH_2 and m are the energy yield (MJ) and the amount of H_2 gas (mol), respectively. It is worth mentioning that each 3.6 MJ is enough to produce 1.0 kWh (Hashim et al., 2017).

3. Results and Discussion

For a better visualization of the effects of the independent variables (CD and DE) on the dependent response (SA), it can be seen in Table 2, that during the operational time of 40 minutes for the aluminum electrode and 20 minutes for the iron electrode, the variables do not show statistical significance for the 95% confidence level.

Table 2 -	Variance analysis (ANOVA)

Source	D	F	S	S	Μ	IS	F		Р	
Electrode	Al	Fe	Al	Fe	Al	Fe	Al	Fe	Al	Fe
Regression	2	2	53.48	31.74	26.74	15.87	2.08	1,296	0.325	0.436
Residual	2	2	25.72	24.50	12.86	12.24				
Total	4	4	79.20	56.25	1980	14.06				
$A1 D^2 0.000$	D D ²	0.751								

 $Al - R^2 = 0.822$ Fe $- R^2 = 0.751$

However, a removal difference occurred when comparing the operating time and the electrode material (Al and Fe). The chemical composition of the electrode used is a significant parameter for EC processes. In this study, Al and Fe electrodes were used, due to easy acquisition, good electrical conductivity and excellent hydroxide formation property, with subsequent flake formation (Bracher et al., 2019). Figure 1 shows the influence of the effects of the variables operating time, CD and DE during the process of removing the SA by EC using aluminum and iron electrodes according to the operating time.



Figure 1 - Removal of salicylic acid during electrocoagulation (a) aluminum electrode and (b) iron electrode

The values of SA removal are favored as the operational time increases, due to the concentration of metal hydroxides of Al and Fe dissolved in the EC system. These hydroxides neutralize the electrostatic charges on the dispersed particles, reducing the electrostatic repulsion between the particles to the point where Van der Waal's attractions become predominant and, thus, facilitate the agglomeration and adsorption of pollutants (Kobya et al., 2015), consequently increasing the coagulation and flocculation rate (Bracher et al., 2019).

The first highest removal rate for the aluminum electrode (92%) occurs in the 40-minute operating time (CD 38.9 mA.cm⁻² and DE 1 cm) while for the iron electrode this occurred in the 20-minute operating time, observing a 93% and 91% were removed at CD 38.9 mA.cm⁻² with DE 3 and 1 cm, respectively. The difference in operating times is related to the forms of hydroxides present during the EC process, and the parameter that controls these forms is the pH of the solution. Figure 2 shows the pH values according to the operational time.





The pH is decisive for flocculation to occur in an EC process as it determines the type of metallic hydroxide to be formed (Ascón, 2018; Khandegar et al., 2013; Kobya et al., 2003; Verlicchi et al., 2012). In Figure 2, an increase in the pH of the solution is observed for both electrodes according to the operating time. The pH values for the aluminum electrode ranged from 6.09 to 11.26 and for the iron electrode the values ranged from 6.02 to 12.06.

According to Chen (2000c), the increase in pH occurs due to the release of OH⁻ ions at the moment

when the metallic hydroxide formed by the anode interacts with the polluting substances. In the aluminum electrode, the electron aluminum (Al^{3+}) ions generated can generate different monomeric species such as: $Al(OH)^{2+}$, $Al(OH)_{22}^{+}$, $Al(OH)_{24}^{+}$, $Al(OH)_{4^{-}}$ and polymeric species: $Al_6(OH)_{15}^{3+}$, $Al_7(OH)_{17}^{4+}$, $Al_8(OH)_{20}^{4+}$, $Al_{13}O_4(OH)_{24}^{7+}$, $Al_{13}(OH)_{34}^{5+}$ are formed during the EC process (Can et al. , 2006, Gürses; Yalçin; Doğar, 2002) and in the iron electrode hydroxides (Fe(OH)n) of n = 2 or n = 3 can be formed (İrdemez et al., 2006) As it is a reaction of hydrolysis, the ideal pH for the formation of aluminum and iron hydroxide is between 6.5 and 7.0 (Holt et. al., 2002; Ozyonar, 2016).

The salicylic acid molecules undergo surface reaction by either inner-sphere complexation (specific adsorption), or by outer-sphere complexation (ion-pair adsorption), and produces the stable structures of the six-angle rings during an electrocoagulation. The adsorption sites on Fe (OH) 3 surface are amphoteric and can be simulated in protolysis reactions of the hydroxyl group. (Cheng, 2002).

In the EC process, CD is a parameter that controls the speed of reactions (Akyol et al., 2013; Thirugnanasambandham; Sivakumar; Maran, 2015), since it determines the coagulant dosage rate and the bubble generation rate, the size and growth of the flakes (Chen; Chen; Yue, 2000; Kobya; Can; Bayramoglu, 2003).

The highest removal rate is found under operational conditions where the applied CD is higher (38.9 mA.cm⁻²), mainly in the Fe electrode. The increase in CD results in a high amount of Al^{3+} and Fe^{2+} ions that bind to the OH⁻ formed, $Al(OH)_3$ and $Fe(OH)_2$ and consequently more flakes are generated, collaborating with the efficiency of the SA removal process (Adhoum & Monser, 2004; Nasrullah et al., 2020; Lakshmi et al., 2013; Moussa et al, 2016).

However, when a very high CD is applied, there is a great possibility of wasting energy in heating the water and reducing the efficiency of the electric current. In this context, the selection of an optimal CD value is affected by parameters such as pH, system temperature and DE (Moussa et al., 2016).

DE is a fundamental parameter in the removal of polluting particles and energy consumption by the EC cell (Mohora et al., 2012). Nasrullah (2020) states that the distance between the electrodes is proportional to the resistance generated between them. Thus, increasing the distance between electrodes causes an increase in the resistivity of the solution, requiring a high application of electrical voltage and may result in loss of energy by dissipation. Table III presents the 2^2 factorial design matrix and the responses of the dependent variables energy consumption, the theoretical volume of H₂ and the energy yield of H₂ produced experimentally (kWh) in relation to the removal of SA in the operating time of 80 minutes.

Run	*DE	**CD	***EC (kWh/m³) Al	*EC (kWh/m ³) Fe	Theoretical H2 volume(L)	Energy yield by Experimentally produced H ₂ (kWh)
1	-1 (1.0 cm)	-1 (16.7 mA.cm ⁻²)	2.3	2.4	906.8	2.6
2	1 (3.0 cm)	-1 (16.7 mA.cm ⁻²)	2.7	3.3	906.8	2.6
3	-1 (1.0 cm)	1 (38.9 mA.cm ⁻²)	8.6	8.3	2116.0	6.0
4	1 (3.0 cm)	1 (38.9 mA.cm ⁻²)	11.7	13.5	2116.0	6.0
5	0 (2.0 cm)	0 (27.8 mA.cm ⁻²)	6.7	7.4	1511.4	4.3
6	0 (2.0 cm)	0 (27.8 mA.cm ⁻²)	6.9	7.2	1511.4	4.3
7	0 (2.0 cm)	0 (27.8 mA.cm ⁻²)	6.9	7.4	1511.4	4.3

Table 3 - Matrix factorial design 2² with coded values, real values and responses for Al and Fe electrodes

* Distance between the electrodes (DE); ** Current density (CD); *** Energy consumption (EC)

Hydrogen gas (H_2) is one of the main by-products generated during an EC process, and is currently considered a promising source of ecological and renewable energy (Abdin et al., 2020; Dawood et al., 2020; Phalakornkule et al., 2010). Studies show that about 5.8 to 13% of all energy used to power the EC cell could be obtained by recycling the hydrogen gas released during the process (Hashim et al., 2017).

The energy consumption for the aluminum electrode varied from 2.3-11.7 kWh/m³ and while the energy consumption of the iron electrode varied from 2.4-13.5 kWh/m³. In relation to the theoretical volume of H_2 generated, values ranged from 906.8-1511.4 L and for the theoretical energy produced by the H_2 generated, values ranged between 2.6-4.3 kWh. These values are strongly related to CD, DE and operating time. The results show that the energy yield obtained from the production of H_2 is capable of significantly reducing the energy demand of the EC cell. Thus, EC can become an economically viable method, while reducing the environmental impacts related to energy production (Lakshmi et al., 2013).

In addition, EC is more effective in removing SA compared to methods such as ultrafiltration in hollow fiber and in spiral, as it achieves higher removal rates than these processes (> 80%). On the other hand, adsorption with activated carbon is slightly higher than EC in this case, reaching removal values of 98% (Ayyash et al, 2015). The use of microalgae also showed high rates of SA removal (94%), but required a longer operational time (4 days) (Escapa et al., 2016).

Non-biodegradable organic compounds are a significant concern in the context of water pollution. Their impact on the environment is manifested not only by their strong and harmful toxicity to the aquatic environment but also by their accumulation in living organisms in the food chain. Given this, it is essential to develop and improve treatment processes that are efficient in removing these compounds. These treatments must be enhanced to become an easy, low-cost and effective treatment alternative for the treatment of waste from the pharmaceutical industry (Boussouf, 2025; Köktaş, 2022).

4. Conclusion(s)

The iron electrode showed better removal rates due to its wide production of hydroxides that have a high affinity for SA. DE and CD were variables that simultaneously influenced removal rates, where the increase in DE is directly proportional to energy demand (CD), which results in greater removal of SA. The results obtained with electrocoagulation suggest that this process may be promising for the removal of salicylic acid from wastewater, as well as for the removal of other contaminating drugs.

5. Acknowledgments

The authors are grateful to the University Scholarships Program of the State of Santa Catarina at the University of Contestado - UNC Art. 170/UnC, both for the scholarship and the physical structure granted.

6. References

Abdin, Z., Zafaranloo, A., Rafiee, A., Mérida, W., Lipiński, W., & Khalilpour, K. R. (2020). Hydrogen as an energy vector. **Renewable and Sustainable Energy Reviews**, 120, 109620. https://doi.org/10.1016/J.RSER.2019.109620

Adhoum, N., & Monser, L. (2004). Decolourization and removal of phenolic compounds from olive mill wastewater by electrocoagulation. **Chemical Engineering and Processing: Process Intensification**, 43(10), 1281–1287. https://doi.org/10.1016/J.CEP.2003.12.001

Akyol, A., Can, O. T., Demirbas, E., & Kobya, M. (2013). A comparative study of electrocoagulation and electro-Fenton for treatment of wastewater from liquid organic fertilizer plant. **Separation and Purification Technology**, 112, 11–19. https://doi.org/10.1016/J.SEPPUR.2013.03.036

Al-Qodah, Z., Al-Qudah, Y., & Omar, W. (2019). On the performance of electrocoagulation-assisted biological treatment processes: a review on the state of the art. **Environmental Science and Pollution Research**, 26(28), 28689–28713. https://doi.org/10.1007/S11356-019-06053-6/TABLES/5

Ascón, E. A. A. (2018). Elimination of chemical oxygen demand from domestic residual water by electrocoagulation with aluminum and iron electrodes. **Revista Ambiente & Água**, 13(5), e2240. https://doi.org/10.4136/AMBI-AGUA.2240

Ayyash, F., Kamis, M., Khalaf, S., Thawabteh, A., & Karaman, R. (2015). Removal of Aspirin, Salicylic Acid, Paracetamol and p-Aminophenol by Advanced Membrane technology Activated Charcoal and Clay Micelles Complex. https://papers.ssrn.com/abstract=3402299

Bracher, G. H., Carissimi, E., Wolff, D. B., Graepin, C., & Hubner, A. P. (2021). Optimization of an electrocoagulation-flotation system for domestic wastewater treatment and reuse. **Environmental Technology**, 42(17), 2669–2679. https://doi.org/10.1080/09593330.2019.1709905

Boussouf, I., Medjram, M.S. (2025). Optimizing ultrasonic-assisted liquid–liquid extraction for an efficient removal of methylene blue dye from wastewater. **Euro-Mediterranean Journal for Environmental Integration**. https://doi.org/10.1007/s41207-024-00730-w

Can, O. T., Kobya, M., Demirbas, E., & Bayramoglu, M. (2006). Treatment of the textile wastewater by combined electrocoagulation. **Chemosphere**, 62(2), 181–187. https://doi.org/10.1016/J.CHEMOSPHERE.2005.05.022

Chen, G. (2004). Electrochemical technologies in wastewater treatment. **Separation and Purification Technology**, 38(1), 11–41. https://doi.org/10.1016/J.SEPPUR.2003.10.006

Chen, W. H., Wong, Y. T., Huang, T. H., Chen, W. H., & Lin, J. G. (2019). Removals of pharmaceuticals in municipal wastewater using a staged anaerobic fluidized membrane bioreactor. **International Biodeterioration & Biodegradation**, 140, 29–36. https://doi.org/10.1016/J.IBIOD.2019.03.008

Chen, X., Chen, G., & Yue, P. L. (2000). Separation of pollutants from restaurant wastewater by electrocoagulation. **Separation and Purification Technology**, 19(1–2), 65–76. https://doi.org/10.1016/S1383-5866(99)00072-6

Cheng, W. P. (2002). Coagulation mechanisms of iron salt and salicylic acid. **Separation Science and Technology**, 37(9), 2113–2127. https://doi.org/https://doi.org/10.1081/SS-120003504

Köktaş, İ.Y., Gökkuş, Ö. (2022). Removal of salicylic acid by electrochemical processes using stainless steel and platinum anodes. **Chemosphere**, 293, 133566. https://doi.org/10.1016/j.chemosphere.2022.133566

Dawood, F., Anda, M., & Shafiullah, G. M. (2020). Hydrogen production for energy: An overview.InternationalJournalofHydrogenEnergy,45(7),3847–3869.https://doi.org/10.1016/J.IJHYDENE.2019.12.059

Escapa, C., Coimbra, R. N., Paniagua, S., García, A. I., & Otero, M. (2017). Paracetamol and salicylic acid removal from contaminated water by microalgae. **Journal of Environmental Management**, 203, 799–806. https://doi.org/10.1016/J.JENVMAN.2016.06.051

Gürses, A., Yalçin, M., & Doar, C. (2002). Electrocoagulation of some reactive dyes: a statistical investigation of some electrochemical variables. **Waste Management (New York, N.Y.)**, 22(5), 491–499. https://doi.org/10.1016/S0956-053X(02)00015-6

Hashim, K. S., Shaw, A., Al Khaddar, R., Pedrola, M. O., & Phipps, D. (2017). Iron removal, energy consumption and operating cost of electrocoagulation of drinking water using a new flow column reactor. **Journal of Environmental Management**, 189, 98–108. https://doi.org/10.1016/J.JENVMAN.2016.12.035

Holt, P. K., Barton, G. W., Wark, M., & Mitchell, C. A. (2002). A quantitative comparison between chemical dosing and electrocoagulation. **Colloids and Surfaces A: Physicochemical and Engineering Aspects**, 211(2–3), 233–248. https://doi.org/10.1016/S0927-7757(02)00285-6

Irdemez, Ş., Demircioğlu, N., Yildiz, Y. Ş., & Bingül, Z. (2006). The effects of current density and phosphate concentration on phosphate removal from wastewater by electrocoagulation using aluminum and iron plate electrodes. **Separation and Purification Technology**, 52(2), 218–223. https://doi.org/10.1016/J.SEPPUR.2006.04.008

Jindal, K., Narayanam, M., & Singh, S. (2014). Pollution of aqueous matrices with pharmaceuticals. **Water and Health**, 9788132210290, 355–373. https://doi.org/10.1007/978-81-322-1029-0_21/COVER

Khandegar, V., & Saroha, A. K. (2013). Electrocoagulation for the treatment of textile industry effluent--areview.JournalofEnvironmentalManagement,128,949–963.https://doi.org/10.1016/J.JENVMAN.2013.06.043

Kobya, M., Ozyonar, F., Demirbas, E., Sik, E., & Oncel, M. S. (2015). Arsenic removal from groundwater of Sivas-Şarkişla Plain, Turkey by electrocoagulation process: Comparing with iron plate and ball electrodes. **Journal of Environmental Chemical Engineering**, 3(2), 1096–1106. https://doi.org/10.1016/J.JECE.2015.04.014

Kobya, Mehmet, Can, O. T., & Bayramoglu, M. (2003). Treatment of textile wastewaters by electrocoagulation using iron and aluminum electrodes. **Journal of Hazardous Materials**, 100(1–3), 163–178. https://doi.org/10.1016/S0304-3894(03)00102-X

Lakshmi, J., Sozhan, G., & Vasudevan, S. (2013). Recovery of hydrogen and removal of nitrate from water by electrocoagulation process. **Environmental Science and Pollution Research**, 20(4), 2184–2192. https://doi.org/10.1007/S11356-012-1028-4/FIGURES/4

Mohora, E., Rončević, S., Dalmacija, B. Ž., Agbaba, J., Watson, M., Karlović, E., & Dalmacija, M. (2012). Removal of natural organic matter and arsenic from water by electrocoagulation/flotation continuous flow reactor. **Journal of Hazardous Materials**, 235–236, 257–264. https://doi.org/10.1016/J.JHAZMAT.2012.07.056 Mollah, M. Y. A., Schennach, R., Parga, J. R., & Cocke, D. L. (2001). Electrocoagulation (EC) — science and applications. **Journal of Hazardous Materials**, 84(1), 29–41. https://doi.org/10.1016/S0304-3894(01)00176-5

Moussa, D. T., El-Naas, M. H., Nasser, M., & Al-Marri, M. J. (2017). A comprehensive review of electrocoagulation for water treatment: Potentials and challenges. **Journal of Environmental Management**, 186, 24–41. https://doi.org/10.1016/J.JENVMAN.2016.10.032

Nasrullah, M., Singh, L., Krishnan, S., Sakinah, M., Mahapatra, D. M., & Zularisam, A. W. (2020). Electrocoagulation treatment of raw palm oil mill effluent: Effect of operating parameters on floc growth and structure. **Journal of Water Process Engineering**, 33. https://doi.org/10.1016/J.JWPE.2019.101114

Ozyonar, F., & Aksoy, S. (2016). Removal of Salicylic Acid from Aqueous Solutions Using Various Electrodes and Different Connection Modes by Electrocoagulation. **Int. J. Electrochem. Sci**, 11, 3680–3696. https://doi.org/10.20964/110454

Phalakornkule, C., Sukkasem, P., & Mutchimsattha, C. (2010). Hydrogen recovery from the electrocoagulation treatment of dye-containing wastewater. **International Journal of Hydrogen Energy**, 35(20), 10934–10943. https://doi.org/10.1016/J.IJHYDENE.2010.06.100

Réategui-Romero, W., Pino, L. F. D., Guerrero-Guevara, J. L., Castro-Torres, J., Luis, M., Rea-Marcos, Santos, M. E., & Yuli-Posadas, R. (2018). Benefits of Electrocoagulation in Treatment of Wastewater : Removal of Fe and Mn metals, oil and grease and COD : three case studies.

Thirugnanasambandham, K., Sivakumar, V., & Prakasmaran, J. (2015). Optimization of process parameters in electrocoagulation treating chicken industry wastewater to recover hydrogen gas with pollutant reduction. **Renewable Energy**, 80, 101–108. https://doi.org/10.1016/J.RENENE.2015.01.030

Vera-Candioti, L., Gil García, M. D., Martínez Galera, M., & Goicoechea, H. C. (2008). Chemometric assisted solid-phase microextraction for the determination of anti-inflammatory and antiepileptic drugs in river water by liquid chromatography–diode array detection. **Journal of Chromatography A**, 1211(1–2), 22–32. https://doi.org/10.1016/J.CHROMA.2008.09.093

Verlicchi, P., Al Aukidy, M., & Zambello, E. (2012). Occurrence of pharmaceutical compounds in urban wastewater: Removal, mass load and environmental risk after a secondary treatment—A review. **Science of The Total Environment**, 429, 123–155. https://doi.org/10.1016/J.SCITOTENV.2012.04.028

Wennmalm, Å., & Gunnarsson, bo. (2005). Public Health Care Management of Water Pollution with
Pharmaceuticals: Environmental Classification and Analysis of Pharmaceutical Residues in Sewage Water.TherapeuticInnovation& RegulatoryScience,39(3),291–297.https://doi.org/10.1177/009286150503900307/METRICS.