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Purification of municipal wastewater by electrocoagulation process

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Abstract. In this work, the performance of electrocoagulation (EC) processes was investigated under currently defined operational conditions for the purification of municipal wastewater. The experimental removal efficiencies for COD, BOD, total P, turbidity and TSS were 55%, 60%, 79%, 89% and 86%, respectively for aluminum electrodes. For iron electrodes removal efficiencies of above-mentioned water quality parameters (COD, BOD, total P, turbidity and TSS) were 62%, 65%, 83%, 97% and 90%, respectively. In addition to, microbiological parameters showed great promise from the aspect of microbiologically safe reuse of purified wastewater for irrigation.

Keywords: wastewater, electrocoagulation, water reuse

1. Introduction

In the current environment of growing concern about global water shortages, the sustainable use of water resources should be one of the top goals of various industries, particularly high water consumers. This issue is especially concerning in poor countries, where it is estimated that 70% of industrial wastewater is dumped untreated. The United Nations acknowledged the importance of this issue, defining under goal number six ("Clean Water and sanitation") the target of increasing water quality, wastewater treatment, and safe reuse (Target 6.3) in its Sustainable Development Goals (SDG) to be realized by 2030. Water shortage and poor water quality are significant challenges that necessitate the widespread adoption of decentralized wastewater treatment systems in both large and small companies. These water treatment systems, which could be utilized as tertiary effluent treatment, must be compact, simple to run, and have minimal operating and investment costs. One approach is to use an integration methodology to combine numerous process units into a single unit to achieve smaller, cleaner, less expensive, and more energy-efficient processes (Liew et al, 2015; Huang et al, 2016). Wastewaters are conventionally treated using biological and physico-chemical processes. The use of biological processes can be limited by their strictly regulated conditions, large space requirements, high retention time, significant footprint, and the possible generation of undesired by-products. Moreover, the presence of nonbiodegradable or slow degradable Biological and physicochemical techniques are commonly used to treat wastewater. The utilization of biological processes can be limited due to their carefully regulated conditions, huge space needs, long retention time, enormous footprint, and the potential development of unwanted by-products. Furthermore, the presence of nonbiodegradable or slow degradable substances in wastewater can dramatically limit the performance of biological processes. Chemical methods necessitate the addition of chemicals to target specific contaminants, which not only raises global treatment costs but also raises the concentration of dissolved substances in wastewater, which may necessitate extra downstream treatment steps. Among the difficulties of implementing traditional methods, high investment and operation expenses can be a substantial hurdle to their implementation, particularly in small enterprises or developing nations. Electrocoagulation (EC) is a potential alternative to traditional wastewater treatment procedures. The process's characteristics, such as its flexibility, ease of operation, lack of the need for extra chemicals, and capacity to cope with various impurities, have increased interest in its adoption (Hamada et al., 2018). Additionally, EC produces about half the sludge of chemical coagulation, which is an essential advantage due to the potential negative impact of those residuals on the environment. Sludge resulting from wastewater treatment is often characterized by high biochemical oxygen demand- BOD and chemical oxygen demand - COD. Therefore, those residuals may require an additional post-treatment process. Another critical aspect of a wastewater treatment process is its associated costs. Published works showed that the chemical coagulation process could present a 2 to 3.5 higher cost for treating the same wastewater than the EC process. Treatment processes based on EC have been used to treat several kinds of wastewaters, such as industrial wastewater, municipal wastewater, textile wastewater, and laundry wastewater. Another important application of the EC process is in treating urban wastewaters, which has been used to remove turbidity, color, phosphorus compounds, COD, and BOD (Graça and Rodrigues, 2022).

Conventional municipal wastewater treatment plants (WWTPs) have been designed with the aim to reduce the concentration of some pollutants (mainly organic matter, suspended solids and nutrients) below limits established in the legislation. Hence, they follow a linear approach where resources contained in the wastewater are not utilized. However, WWTPs can be substituted by (or transformed into) reclamation facilities to maximize the production of reclaimed water, combined with energy and nutrient recovery, and transition towards a circular economy.

The limited use of reclaimed water is often related to the risks associated with the pollutants contained in wastewater effluents. This is more significant in developing countries, where wastewater is partially treated or even untreated. In addition, numerous end-users and the general public commonly consider wastewater as waste rather than a source for reclaiming water. To shift this paradigm, ensuring safety of the environment and public health in the use of reclaimed water is essential. These are the main goals of the Water Reuse Risk Management Plans (WRRMPs), which are mandatory for all reclaimed water facilities implemented in the European Union (EU) after applying the Regulation 2020/741 on minimum requirements for water reuse (Radini et al., 2023).

This Regulation establishes quality limits for certain pollutants as well as the frequency of monitoring and treatment performance targets for reclaimed water reuse in agriculture, depending on four different quality classes in a fit-for purpose approach. Water quality classes (Classes A–D) are defined in terms of pathogens, biochemical oxygen demand (BOD), total suspended solids (TSS) concentrations, and turbidity. Microbiological pollution is assessed by the E. coli concentration in water (bacterial indicator), combined with the total coliphages (alternatively, F-specific coliphages or somatic coliphages) and Clostridium perfringens spores (or spore forming sulphate-reducing bacteria), which act as virus and protozoa indicators, respectively.

In this study, preliminary testing of EC process using different electrodes has been suggested as an advanced alternative in improving wastewater quality prior its reuse for agricultural purposes.

2. Materials and methods

For electrochemical tests in this work, iron (Fe) and aluminum (Al) electrodes were used. The two types of EC experiments for purification of municipal wastewater were carried out (Table 1)

Table 1. EC experiments

Designation	Anode/Cathode
E1	Al/Al
E2	Fe/Fe

For all EC treatments, working conditions were:

- the distance between the electrodes - 3 cm,
- the current strength - 3.33 mA/cm^2,
- the rotation speed - 280/min,
- the surface of the immersed electrodes - 30 cm^2,
- the treatment time - 1 hour, and
- the volume of treated water - 0.5 l.

The raw municipal wastewater was characterized before EC treatment. The wastewater characteristics after EC were performed upon 24h of sedimentation. Basic chemical and microbiological parameters are determined such as: chemical oxygen demand (COD), biochemical oxygen demand (BOD), total phosphorous (P), total nitrogen (N), pH, turbidity, total suspended solids (TSS), total coliform bacteria, fecal coliform bacteria, *E.coli*, fecal streptococci, *Salmonella sp.*, sulfite-reducing clostridia.

3. Results and discussions

Parameters of wastewater characterization, prior and after electrocoagulation are presented in Table 1.

The experimental removal efficiencies for COD, BOD, total P, turbidity and TSS were 55%, 60%, 79%, 89% and 86%, respectively for aluminum electrodes. For iron electrodes removal efficiencies of above mentioned water quality parameters (COD, BOD, total P, turbidity and total suspended solids - TSS) were 62%, 65%, 83%, 97% and 90%, respectively. The effluent treated with iron electrode, appeared firstly in blackish color and after 45 minutes turned in slightly yellow clarified water solution. This phenomenon may be resulted from Fe^{2+} and Fe^{3+} ions generated during EC process. Fe^{2+} is the common ion generated in situ of electrolysis of iron electrode. It has relatively high soluble at acidic or neutral conditions and can be oxidized easily into Fe^{3+} by dissolved oxygen in water, where the effluent treated with aluminum electrode appeared as the first time white and stay white all the process, with sludge settled at the bottom and white foam is formed on the surface as the electrode liberated trivalent aluminum (Al^{3+}). The (Al^{3+}) formed an ionic pair with the pollutant of wastewater rich in magnesium and calcium. At the end of the tests, flocs were separated in the surface layer of the treated wastewater sample, and after the 24h of sedimentation, the treated wastewater solution was clarified totally. An excellent flocculation and coagulation was observed.

When it comes to pH measurements, slightly increase towards alkaline conditions is observed. Concerning nitrogen removal, one can conclude that these EC processes did not have an influence on removal efficiencies of total nitrogen.

Table 2. Chemical characterization of raw WW (E0) and EC treatments (E1-E2)

Parameters	E0 (mg/l)	E1 (%)	E2 (%)
COD (mg O_2/l)	315	55	62
BOD (mg O_2/l)	134	60	65
Total P (mg/l)	4.28	79	83
Total N (mg N/l)	35.44	2.2	0.5
pH	7.36	8.17	8.11
Turbidity	86.4	89	97
TSS (mg/l)	906	86	90

Microbiological parameters which have been investigated are presented in Table 3.

Table 3. Microbiological characterization of raw WW (E0) and EC treatments (E1-E2)

Parameters	E0	E1	E2

Total coliform (MPN/100ml)	18000	300	120
Fecal coliform (MPN/100ml)	1750	70	8
E.coli (MPN/100ml)	110	0	0
Fecal streptococci (CFU/100ml)	40200	4	0
Salmonela sp. (MPN/100ml)	0	0	0
Sulfite-reducing clostridia (CFU/100ml)	170000	14	6

The concentration of microbiologically essential parameters fell dramatically after EC treatments, particularly in the case of iron electrodes. This ensures that the treated wastewater is potentially free of microorganisms.

When we compare the results with Regulation 2020/741 on minimum requirements for water reuse, the electrocoagulation processes have a great impact on wastewater purification.

Under the conditions of the experiments currently described in the paper, the results show the fulfillment of the limit values when it comes to E.coli and turbidity.

4. Conclusion

This paper presents the preliminary results of examination of electrocoagulation processes on purification of municipal wastewater in order to establish whether it can be used as a pre-treatment or a polishing process when that purified effluent could be used as reclaimed water in agricultural purposes.

One can conclude, that EC processes are promising from the mentioned aspects. One can conclude that iron electrodes showed the highest removal efficiencies when it comes to investigated parameters, especially turbidity and TSS (97% and 90%, respectively). Also, microbiological parameters are especially important due to its destruction when direct current is applied. The next step will be focused on process optimization examining various process parameters (current density, surface of electrodes, reaction time, distance between electrodes etc.)

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