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TREATMENT OF INDUSTRIAL WASTEWATER BY ELECTROCHEMICAL AND MEMBRANE PROCESSES: EXPERIMENTAL STUDY AND MODELING

THESIS

Submitted in Partial Fulfilment of the Requirements
for the Degree of Doctorate in Process Engineering
Option: Pharmaceutical Engineering

By
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Title: **T**reatment of industrial wastewater by electrochemical and membrane processes: experimental study and modeling

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Abstract

The work presented in this thesis focuses on the study and optimization of electrochemical and membrane processes for the treatment of water and industrial liquid wastes, with particular emphasis on electrocoagulation and photo-electro-Fenton techniques. The main objective is to improve the efficiency of treating organic pollutants while optimizing the processes for industrial application. Throughout the work, three-dimensional (3D) prismatic aluminum electrodes, made from recycled materials, were used. These electrodes, derived from reclaimed materials, not only offer a large active surface area that promotes electrochemical reactions, but they also significantly reduce operating costs and add value to metal waste, thus contributing to a more sustainable and circular approach to water treatment.

In the first phase, methylene blue, a synthetic dye, was treated by electrocoagulation using recycled aluminum electrodes obtained from a local carpentry workshop. Process parameters such as pH, current density, pollutant concentration, and NaCl concentration were optimized, achieving a 96% removal efficiency within two hours. Electrode characterization analyses were performed using SEM and EDX. This phase was followed by the optimization of the treatment of Direct Violet 51 through an experimental design based on a response surface methodology generated using Python. Process modeling was carried out with artificial intelligence algorithms, and a genetic algorithm achieved a 99% removal of the dye in 30 minutes. Finally, an economic assessment and a life cycle analysis were conducted to evaluate the industrial viability of the process.

A third part of this thesis addressed the treatment of Ketoprofen, a pharmaceutical drug, using electrocoagulation with optimization of key parameters such as pH, NaCl concentration, and current density. Deep Learning modeling was used to complement the statistical analysis of this treatment, allowing for a better understanding of the removal mechanisms.

In a fourth study, electrocoagulation was applied to the treatment of wastewater from orange juice production from a local industry in Turkey. Recycled 3D aluminum electrodes were used, and their performance was compared with that of other electrodes such as iron, steel, and commercial aluminum. The recycled aluminum showed superior performance, and after optimizing the parameters, a pollutant removal of 62.81% was achieved. Subsequently, ultrafiltration and nanofiltration membranes were tested, with the nanofiltration (NF 270) showing the best results with an 84.98% removal and a COD concentration reduced to 896 mg/L.

The final part of the thesis examines the innovative photo-electro-Fenton process using a green catalyst, iron oxide, which was synthesized from an endemic plant – Oudneya Africana – known for its antioxidant properties. The obtained material underwent a comprehensive series of physicochemical characterizations to determine its structural, morphological, textural, and optical properties. The effectiveness of the photo-electro-Fenton process was tested for the removal of Direct Violet 51, and the encapsulation of nanoparticles in alginate and calcium chloride was performed to facilitate their recovery and reduce agglomeration due to the magnetic effects of iron oxide. This catalyst was then tested in the treatment of industrial wastewater from the BIFA (Didouche Mourad, Constantine) orange juice production facility, achieving a 55.09% reduction in COD within two hours. To further improve the process efficiency, a ceramic membrane manufactured in the laboratory was integrated into the system, enabling a total COD removal of 72.41%. Overall, the work conducted in this thesis demonstrates the effectiveness and relevance of electrochemical and hybrid processes in the treatment of contaminated waters. The use of recycled materials, such as aluminum wastes or locally manufactured ceramic membranes, as well as the green synthesis of catalysts, underscores a sustainable and eco-friendly approach.

Keywords: Industrial wastewater, Water treatment, Electrocoagulation, Photo Electro-fenton, membrane filtration processes, Sustainability.

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