A Systematic Literature Review of the Fenton-based Advanced Oxidation Technologies for the Dyes Degradation from the Textile Industry

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This study addresses the challenges for textile wastewater treatment using Fenton-based advanced oxidation technologies. The conventional Fenton, Photo-Fenton and Electro-Fenton processes are the most important processes and have been systematically reviewed. Nevertheless, innovative Fenton-based oxidation has shown good results for color removal from textile wastewaters. This literature review followed the PRISMA guidelines and the search focused on articles from 2013 to 2023, of which 100 were selected. The criteria for the review included peer-reviewed articles in English. The results indicate a dynamic scenario, predominant in the conventional Fenton process, but with an important increase in the Photo-Fenton and Electro-Fenton processes. The main catalysts used are presented and the applications to a variety of dyes were identified, consolidating the knowledge of Fenton type processes in the textile industry, providing valuable insights for future applications.

Introduction

Textile dyes are widely used organic compounds, but a significant proportion of the dyes are not fixed during the dyeing process and are released into textile wastewater. To overcome this, there are Advanced Oxidative Processes (AOPs), including Fenton processes, which can destroy several partial or total species of textile dyes [1]. The conventional Fenton process is based on the Fe^{2+} catalyzed decomposition of hydrogen peroxide into hydroxyl radicals, which are exceptionally strong oxidizing agents[2].

This review addresses the different Fenton-based advanced oxidation technologies that are most commonly used for the treatment of textile effluents. The types of processes and the different catalysts are discussed. In addition, the applications for different classes of dyes used in the textile industry are shown. The objective of this work is to provide a comprehensive overview of the available literature, identifying gaps, future research directions and highlighting areas studied.

Material and Methods

In this study, a systematic literature review was conducted using the SCOPUS database with the keywords "Fenton" AND "textile industry". The publication year was limited to a period of 2013 to 2023, the scope of the search was limited to article titles, abstracts and keywords. Review articles and conference papers were excluded, restricting to only research articles published in English.

Based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) method, the most relevant articles that met the following selection criteria were selected as: isolated, combined and derivative Fenton processes and different classes of synthetic dyes. The selected articles were organized allowing the investigation into the main challenges and current perspective changes that occurred. The bibliographic search initially revealed 233 published articles, of which 100 were selected after a detailed analysis based on predefined criteria. The methodology used is described in Figure 1.

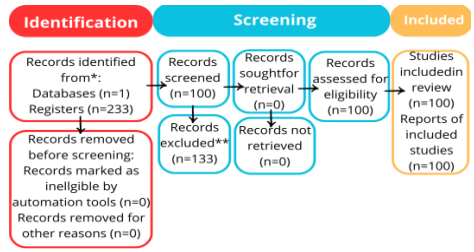

Figure 1. PRISMA methodology.

Results and Discussion

Among the selected research papers in the literature, several AOPs of the Fenton type have emerged in the current literature over the last 10 years, the most common is the conventional Fenton process [3], followed by the photo-Fenton process [4] and the Electro-Fenton process [5]. These processes have been extensively researched, whether individually or integrated. In Figure 2, comparative data between the number of articles using the Fenton and Photo-Fenton processes over the past 10 year is presented.

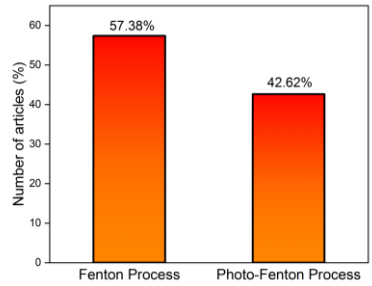

Figure 2. Comparative analysis of the number of articles using Fenton and Photo-Fenton processes.

It is noticeable that conventional Fenton was the most utilized with 57.38% due to being considered a cost-effective and environmentally friendly technique [6].

However, Photo-Fenton, which operates under UV light, has been increasingly chosen with 42.62% due to its effectiveness as an alternative treatment method [4]. The Electro-Fenton process generates Fenton reagents electrically in situ, eliminating the need for irradiation, making it a viable alternative for treating textile wastewater contaminated with persistent organic pollutants [5]. Over a 10-year period, 11 articles were identified that used the Electro-Fenton process, indicating a trend of increasing research related to this Fenton type.

The utilization of catalysts in the Fenton process for treating industrial textile effluents has garnered increasing attention due to its efficacy in degrading synthetic dyes [7]. Iron salts and derivatives has consistently been the predominant material, representing most of the studies conducted between 2013 and 2023. However, diversification in the catalyst precursor materials employed has also been observed, iron with the presence of other metals is gaining prominence during the same period and has an expressive growth of 15% in the last 5 years. Furthermore, the use of metal catalyst without the presence of any iron salt has start to be applied in 2016. This diversification reflects an ongoing quest for more efficient and sustainable materials for application in the Fenton process, aiming to optimize pollutant degradation and reduce the environmental impact of the textile industry [8].

Concurrently with the utilization of conventional materials, nanotechnology has emerged as a promising area in the development of catalysts for the Fenton process. The presence of nanomaterials in studies it is also presented. These nanomaterials can be presented in different forms and offer unique properties, such as high surface reactivity and enhanced stability, which can be harnessed to improve the efficacy of the Fenton process [9]. Additionally, the reuse of industrial waste, such as that from the metallurgy industry, as a source of catalysts has garnered increasing interest that employs solid residues as catalyst raw material. This approach contributes to cost reduction and also promotes circular economy principles, transforming by-products into valuable resources for effluent treatment in the textile industry [10].

Effluents in the textile industry contain a variety of dyes, which can be classified according to their structure, application method or solubility. The degradation of reactive dyes takes the lead as the subject of 35% of the literature within the search timespan, followed by basic dyes which makes up for 34%, and acid dyes with 29%. This discrepancy reflects the increasing use of reactive dyes, especially for dyeing materials such as cotton, silk and wool [7].

Conclusions

In conclusion, while the systematic review of Fenton-type processes has shed light on trends and challenges over the past decade, there remains a significant gap in optimizing catalyst materials and exploring alternative approaches to enhance textile wastewater treatment efficacy, particularly concerning the diverse range of textile dyes. Future research endeavors should prioritize investigating innovative catalyst materials, such as nanomaterials and waste-derived catalysts, to improve pollutant degradation and reduce environmental impact. Addressing this knowledge gap is crucial for advancing sustainable practices in the textile industry.

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