An analytical overview of processes for removing organic dyes from wastewater effluents

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Organic dyes are used in a wide range of industrial applications (e.g., textiles, food products, cosmetics and pharmaceuticals), so they are frequently found in wastewaters and are increasingly becoming an environmental problem. This critical overview covers the most frequently used strategies for dye removal and the most common analytical techniques for monitoring these processes and identifying any intermediates generated. We also analyze experimental design strategies for optimizing removal processes. Finally, our concluding remarks include a future outlook for dye-removal processes and the analytical techniques employed.

Keywords: Advanced oxidation process (AOP); Biodegradation; Dye degradation; Dye determination; Dye removal; Effluent; Environmental problem; Experimental design; Intermediate; Wastewater

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1. Introduction

Organic dyes are used in a wide range of industrial applications [e.g., textiles (the most significant), food products, cosmetics, pharmaceuticals or paper printing], which means that they are frequently found in industrial wastewater. Several groups of dyes can be distinguished on the basis of their compound structure (e.g., phthalocyanins, anthraquinones, quinone-imines and xanthenes) [1]. However, the most commonly used dyes are azo dyes, because they are easier and more cost effective to synthesize than natural dyes. To get an idea of the annual market in dyes, in 2003, the production of dyes was more than 7×10^5 tonnes [2]. Dyes are considered hazardous to the environment because many are toxic to living organisms, directly or through their absorption and reflection of sunlight entering the water, which interferes with the growth of aquatic organisms. Furthermore, they impart color to wastewater, giving rise to aesthetic issues [3,4].

Efforts are being made to study dye-removal or dye-degradation processes and to develop analytical methodologies for evaluating these processes. As evidence of the growing interest in this field, we made a bibliographic search for articles appearing in the Scopus database since the year 2007. Keywords ''dye determination'' yielded more than 2500 references and ''dye degradation'' 7810 references.

The objectives of this overview are the following:

(1) critical review of the most frequently employed strategies for dye removal from wastewater; and,
(2) review of the analytical techniques most commonly used to evaluate these strategies.

We have structured the review in three main parts, as follows.

(1) The first part presents the various dye-removal methodologies along with their respective uses since 2007. We also describe the drawbacks and the advantages of each technique.
(2) The second and most extensive part concerns the various analytical approaches in the field of dye removal. We discuss how experimental design is used to optimize removal processes and how separation or spectroscopic techniques are used to monitor degradation processes and to identify reaction intermediates.

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(3) The last section contains our concluding remarks and suggests what the future has in store for dye-removal processes and the analytical techniques employed.

The studies cited result from a representative selection of research dealing with some of the strategies considered. The vast scope of these scientific fields prevents our study from being exhaustive. Furthermore, many very interesting papers focusing on the theoretical bases of degradation processes or on specific technological aspects are beyond the scope of this overview and are not discussed here.

2. Dye-removal methodologies

Fig. 1 shows the most common techniques used to remove dyes from wastewater. Fig. 2 shows the percentage of all available scientific papers (since 2007) that use the different techniques, and was created from the information obtained through a search using the keywords ''organic dyes'' and the name of each technique.

Table 1 lists the studies published in the bibliographic sources that we focused on most closely in preparing our review. The referenced papers were selected to cover the whole range of dye-removal strategies, analytical

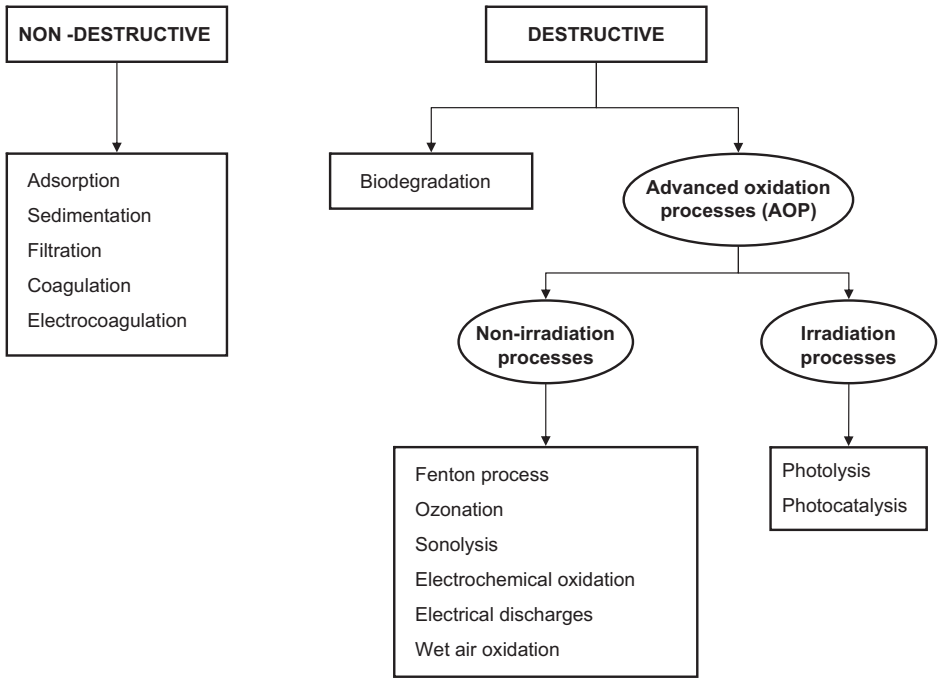

Figure 1. Dye-removal techniques.

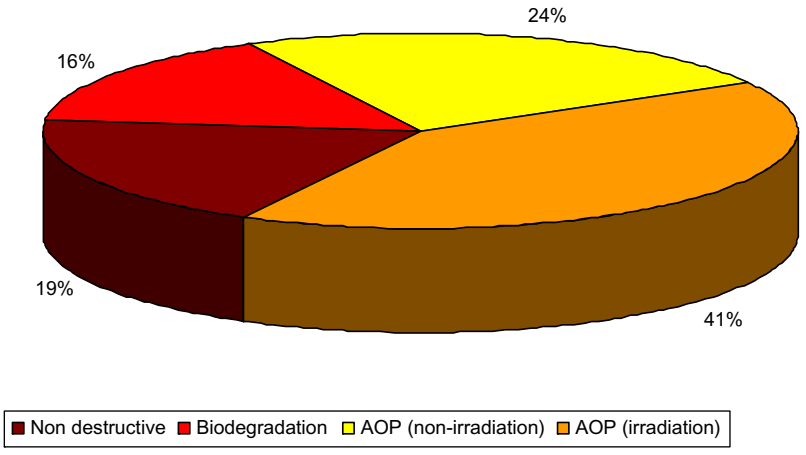

Figure 2. Papers published on dye removal according to the process employed.