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To cite this article: Osama H. Abuzeyad *et al* 2024 *J. Phys.: Conf. Ser.* **2830** 012003

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Journal of Physics: Conference Series **2830** (2024) 012003 doi:10.1088/1742-6596/2830/1/012003

Possible Remediation Approaches for Wastewater Containing Dyes; A Review

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Abstract. One of the most serious environmental problems is water scarcity and water pollution is a worldwide issue that can have an impact on people, plants, animals, and trees. Reusing wastewater makes sense in light of the limited availability of freshwater sources to conserve and expand the pool of available water sources. Numerous things can contaminate water supplies. Although the fundamental concepts are usually the same, the process of water restoration may vary from one location to another based on the source of contamination. Dyes are a versatile group of organic compounds found in many industries ranging from textiles, papermaking, leather tanning, and food processing. However, untreated or partially treated dye-containing wastewater in the environment can have a significant impact on human health and ecosystems. Dyes can color water bodies, making them aesthetically displeasing and inhibiting the penetration of sunlight. This may cause water plants and algae to produce less. While certain dyes are carcinogenic or mutagenic to humans, others are poisonous to aquatic life.

Keywords: Dyes, Wastewater, carcinogenic, Treatment methods.

1. Introduction

The most common and essential element for life on Earth is water. It is significant to the global economy since 70% of fresh water is used for agriculture. Every organism's life cycle and daily existence depend on having access to pure, fresh water. There are several applications for wastewater reuse, including aquaculture, factory use, recreational use, and agricultural soil irrigation[1]. As long as the proper treatment is carried out to restore the wastewater to a level appropriate for the intended use, it can generally be used for any purpose that requires fresh water. Therefore, before employing wastewater, specific standards and measurements like electrical conductivity (EC), the presence of the amount of dissolved organic matter, and heavy metals should be assessed [2]. Numerous techniques ranging from physical, chemical, and biological have been studied; some of these techniques are successful in eliminating a broad spectrum of colours from wastewater. Filtration, coagulation, adsorption, these methods physically remove dye particles from water. Oxidation is a well-known method in which chemicals break down dye molecules [3]. Bioremediation

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method where microbes naturally degrade dyes (slower but sustainable). Recent years have seen an increase in interest in the development of effective and long-lasting treatment methods for wastewater-containing dyes. Water that has been treated properly can usually be used for any purpose that calls for fresh water, provided that the degree of contamination is reduced to a suitable level for the intended use [4].

2. Contaminants persist in water/wastewater

Three categories inorganic, biological, and organic pollutants have been established for contaminants found in water and wastewater, based on their characteristics and radix. The classification of the many types of contaminants found in water and wastewater is summarized in Figure. 1 [5]. Metals bearing an atomic weight between 63.5 and 200.6 and a specific density more than 5g/cm are categorized as heavy metals [6].

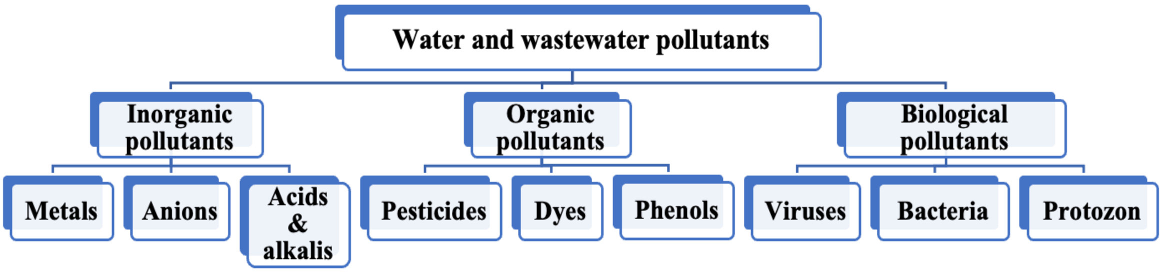

Figure. 1. The classification of the several kinds of contaminants found in water and wastewater

3. Dyes

Businesses generate a lot of wastewaters that is vividly colored and contains a variety of persistent toxins. This effluent is a major environmental polluter and has a negative impact on human health. Globally, every year, 7×107 tons of synthetic dyes are produced. Based on their composition, place of origin, and intended use, dyes can be divided into several groups. Among these synthetic pigments, the textile industry commonly utilizes azo, reactive, direct, mordant, dispersion, sulphide, acid and base dyes. Figure. 2. illustrates the classification of dyes [7].

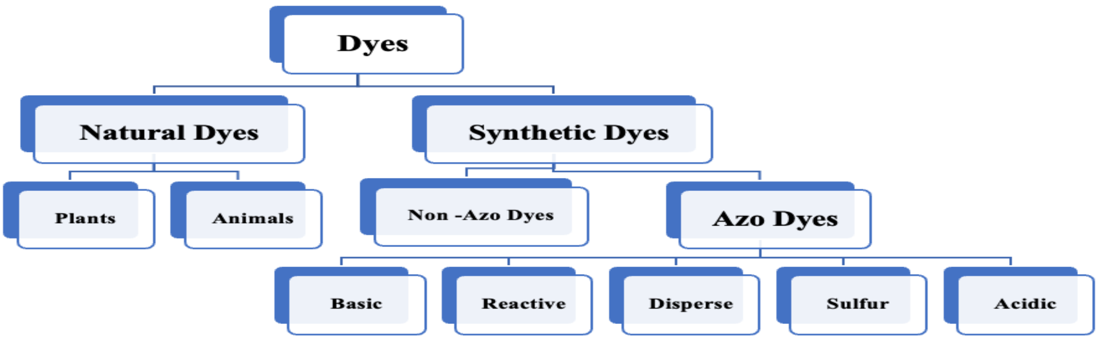

Figure.2. Classification of dyes

3.1. Toxicity of dyes on human health

The majority of dyes are hazardous, have been related to a range of illnesses in both people and animals, and may even cause cancer. Dye exposure results in dermatitis and problems with the central nervous system, among other illnesses [8]. When eaten or breathed in, dyes can cause irritation to the skin and eyes, particularly if they are near dust. Occupational asthma, rhinitis, allergic conjunctivitis, and contact dermatitis are among the allergic symptoms that workers who handle reactive hues may experience. The ovulation and spermatogenesis processes may be disrupted by some of the potentially hazardous substances to which the industry is exposed. Because benzidine-based azo dyes and their derivatives are generally used for production of textiles, papers, and leathers. their toxicity has been well investigated and linked to bladder cancer in humans [9]. Owing to their widespread usage, dyes are present in the environment and have been shown to physiologistically accumulate along the food chain in algae, freshwater plants and fish.

4. Numerous techniques and technologies employed to treat wastewater that contains dyes.

Depending on the properties of the effluent, wastewater can be treated physically, chemically, biologically, or by a mix of these methods.

4.1. Physical methods for treating of dye-containing wastewater

Wastewater containing dyes can be treated using a range of physical techniques, including ion exchange, adsorption and membrane filtration, with removal rates ranging from 85% to 99%, subject to the mass transfer mechanism [10].

*4.1.1. The adsorption***.** Surface-based adsorption involves attracting adsorbed ions or molecules to a solid adsorbent surface, as illustrated in Figure. 3. Chemisorption and physisorption are the two forms of adsorption. The way the adsorbent surface absorbs the dye determines this classification. Many mechanisms, such as, electrostatic interactions, hydrophobic, van der Waals forces, and hydrogen bonding, can participate in the adsorption of dye molecules. Adsorbents may be recycled, the procedure is highly efficient, and wastewater color can be swiftly eliminated [11].

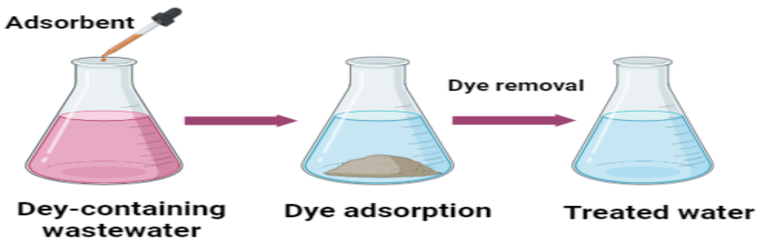

Figure.3. Dye wastewater treatment by adsorption.

4.1.2. The ion exchanges. The many benefits of the ion exchange technology including its affordability, regeneration, ease of use, versatility, and high efficiency have attracted a lot of attention recently for their potential application in the wastewater and textile effluent treatment industries. In a packed bed reactor, robust connections between resins and solutes enable efficient separation throughout the ion exchange process. According to Figure 4 [12], Robust interactions exist with the charges of dye molecules and the functional groups of resins which promote the ion exchange process used to remove dye. The process of exchanging dye molecules for other ions on the surface of an ion exchange resin is known as ion exchange.

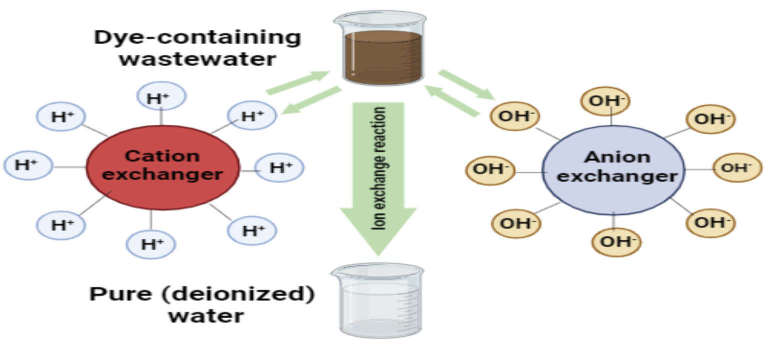

Figure.4. Dye wastewater treatment by ion exchange.

4.1.3. The membrane filtration. The membrane filtration is a very sophisticated physical method for treating coloured wastewater. A dye-free solution is produced as a result of the tiny pores in the membranes used in this approach trapping bigger solutes, Figure. 5. Despite the ease of use and efficiency of this approach, the membranes require periodic replacement [10]. The membrane-based filtration process, microfiltration (MF), is used for removing suspended particles and colours from wastewater by using a conventional membrane with pores ranging in size from 0.1 to 10 µm. Another innovative membrane approach that has been used recently to remove dyes from wastewater is nanofiltration (NF); the membranes used in this technology typically have a diameter of 0.5 to 0.2 nm [13].

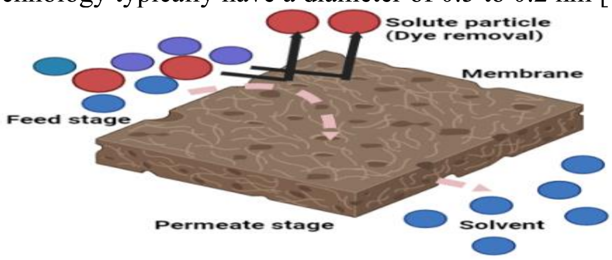

Figure.5. Membrane filtration for dye wastewater treatment

4.2. Chemical methods for treating dye containing wastewater

Wastewater containing dyes is chemically treated by complex oxidation processes, coagulation-flocculation, and electrochemistry techniques. These techniques are usually more expensive than biological and physical technologies, with the exception of electrochemical technology. Additionally, the large volumes of chemicals required, the high electricity consumption, and the requirement for specialised equipment are the primary obstacles to the efficient adaptation of chemical techniques for the elimination of wastewater's colour.

4.2.1. The coagulation-flocculation. It is common to find substantial amounts of poisons and pollutants in wastewater. Coagulants can be used to treat this before being disposed of Polymers and metal salts can be used as coagulants in this treatment process; flocculants are polymers that make flocs more aggregative in order to aid in their separation. The vigorous mixing stage is when the coagulants are added. The presence of coagulants then neutralises or reduces the charge of the finely distributed particles. To produce sizable particles that sedimentation can readily separate, the flocculants are lastly combined with the small particles. The dye-containing wastewater treatment process of coagulation-flocculation is schematically represented in Figure 6 [14].

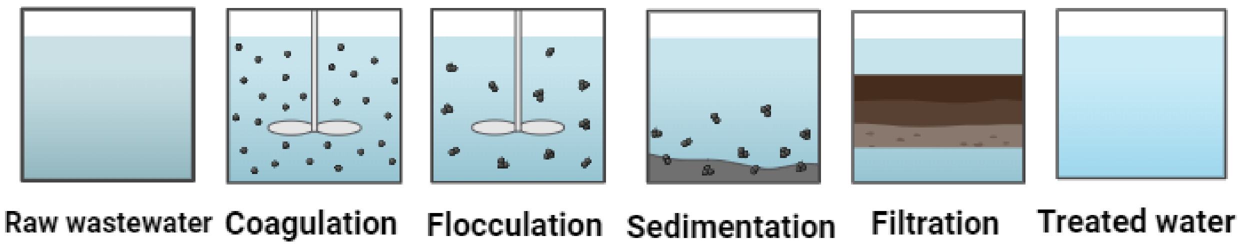

Figure.6. Dye wastewater treatment by coagulation-flocculation

4.2.2. The advanced oxidation techniques. In order to recover colour from wastewater in-situ, for instance, the theory behind "accelerated oxidation" relies about the creation of powerful oxidizers called hydroxyl radicals (OH•). Other advanced oxidation methods include photocatalysis, ozonation, Fenton, photo-Fenton, and electrochemical processes. These approaches may take on difficult situations and remove colour quickly and efficiently without leaving a mess behind. However, they have disadvantages as well, like high prices, a reliance on pH, and dangerous byproducts. The photocatalytic destruction of fuchsin basic dye molecules by the generation of OH• is illustrated in Figure 7. To produce holes and free radicals, which are necessary for the photocatalytic degradation of dyes, photocatalytic agents are used, like titanium peroxide and zinc oxide nanoparticles. Superoxide was formed by the electrons serving as reducing agents while the holes oxidised the organic dye molecules, producing OH• and mineralization byproducts. Photoelectrocatalysis in electrochemical technology generates hydroxyl radicals at the surface of the anode. Anodic oxidation, electro-Fenton or sono-electrolysis generates OH• radicals [15]. Recently, an enhanced oxidation technique called electrochemical technology has been developed to purify wastewater containing dyes. OH˙ radicals are produced at the anode surface by photoelectrocatalysis in electrochemical technology. However, anodic oxidation, sono-electrolysis or electro-Fenton processes produce OH• radicals. [15].

$$Fe^{2+} + H_2O_2 \longrightarrow OH^{\cdot} + Fe^{3+} + OH^- \quad (1)$$
$$UV + H_2O_2 \longrightarrow 2OH^{\cdot} \quad (2)$$
$$Fe^{3+} + UV + H_2O \longrightarrow OH^{\cdot} + Fe^{2+} + H^+ \quad (3)$$
$$H_2O + O_2 + hv \longrightarrow O_2 + 2OH^{\cdot} \quad (4)$$
$$OH^{\cdot} + O_3 \longrightarrow O_2 + OH^{\cdot 2} \quad (5)$$
$$OH^{\cdot 2} + O_3 \longrightarrow 2O_2 + OH^{\cdot} \quad (6)$$
$$OH^{\cdot 2} + OH^{\cdot} \longrightarrow O_2 + H_2O \quad (7)$$
$$2OH^{\cdot} \longrightarrow H_2O_2 \quad (8)$$

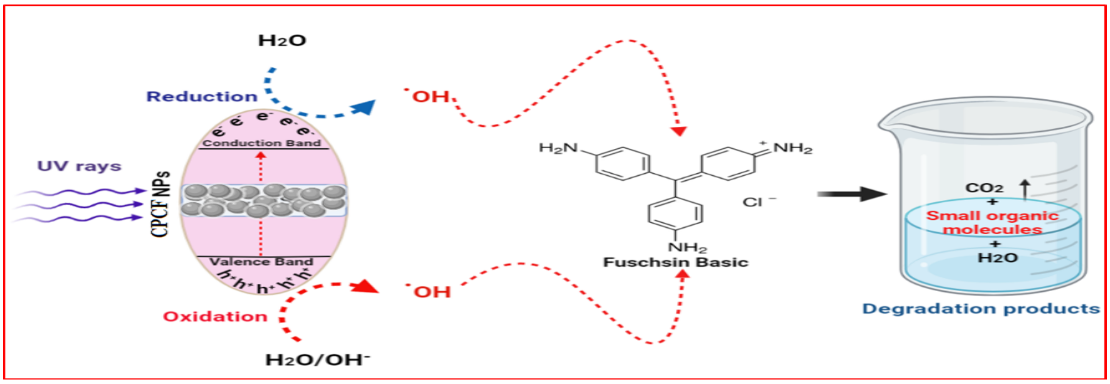

Figure.7. Dye wastewater treatment by photocatalytic degradation of toxic dye molecules [16].

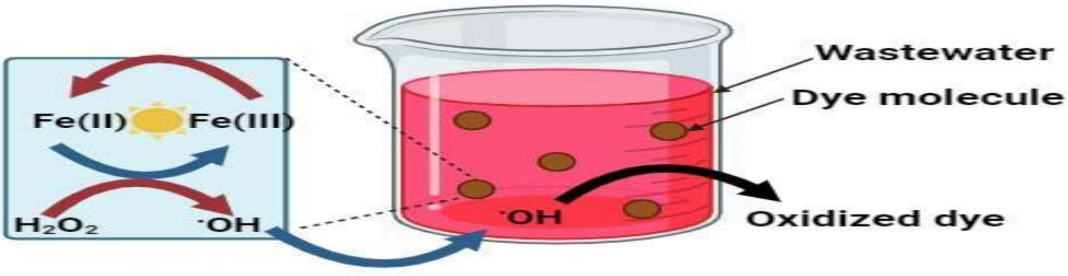

Figure.8. Dye wastewater treatment by photo-Fenton

4.2.3. Electrochemical approaches. Electrochemical treatment technologies don't produce sludge or require the addition of chemicals. Nevertheless, these techniques have disadvantages such as expensive electricity costs and lower efficacy compared to other treatment systems. Two connected procedures for oxidizing and coagulating can be used in the electro-Fenton, an oxidation technique that is most frequently applied practically to eliminate organic pollutants. This method is unique in that it doesn't have any damaging effects on the environment, utilizes less chemicals, and is safe [17]. H2 gas is produced by the cathode, and coagulant and catalyst are provided by the iron metal anode. Notable features of this approach include reduced sludge formation, lack of chemicals, easy usage, and low-cost [18]. Here are some of the most common electrochemical treatment technologies for dye remediation: Electrocoagulation (EC): This method uses electrodes to generate metal cations (like aluminum or iron) that coagulate and remove dye molecules from the water. Electrochemical oxidation (EO); During EO, organic pollutants like dyes are directly oxidized and mineralized on the anode surface or through electrogenerated oxidants like hydroxyl radicals. Indirect electro-oxidation; Here, a mediator (often chlorine or chloride ions) is used to indirectly generate oxidizing species that degrade the dye molecules. Photo-electrochemical (PEC) treatment; This combines light irradiation with electrochemical processes. Light enhances the generation of oxidizing species at the electrode surface, further promoting dye degradation. Electrodialysis (ED); While not strictly an oxidation process, ED utilizes electrically charged membranes to separate dyes and other ionic pollutants from the treated water [19].

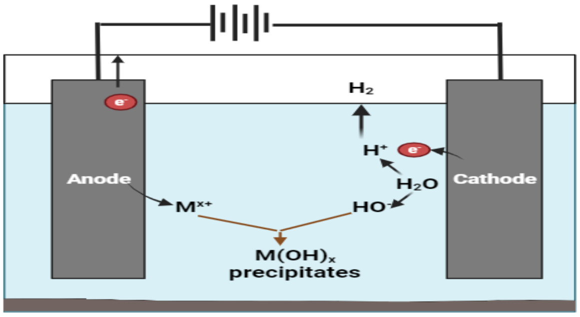

Figure 9. Dye wastewater treatment electrocoagulation.

4.3. Biological methods for treating wastewater containing dyes

As a sustainable and economical way to remove color from wastewater, biological approaches are becoming more and more common. Utilizing microorganisms such as algae, bacteria, and fungi is a biological process. to break down the pigments. These microorganisms can degrade dyes both aerobically and anaerobically (without oxygen), as seen in Figure. 10.

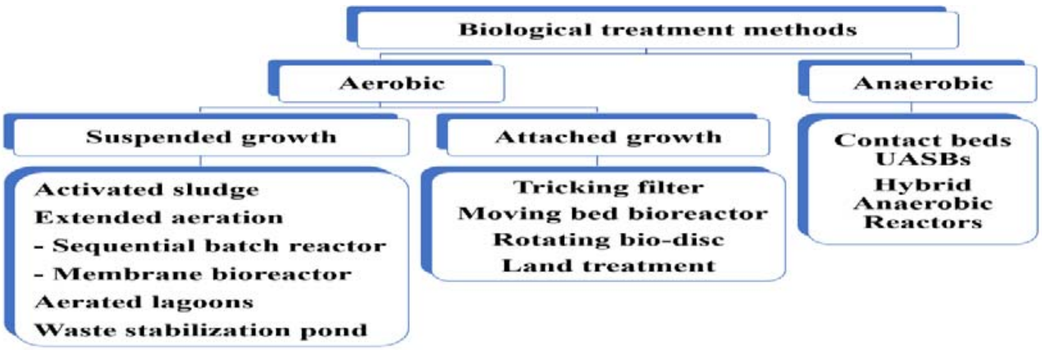

Figure 10. Biological wastewater treatment methods [20].

4.3.1 The advantages of biological methods for treating wastewater containing with dyes. The use of biological techniques for treating dye wastewater offer several advantages, including relatively inexpensive to operate and maintain, effective at removing a wide range of dyes from wastewater, they produce a sludge that is relatively easy to dispose of. And are environmentally friendly.

4.3.2 The disadvantages of biological methods for treating wastewater containing with dyes. Additionally, there are certain drawbacks for the treatment of dye wastewater through biological methods. For example, they may not be as effective at eliminating all types of dyes from wastewater as other methods, such as chemical oxidation, and they may be more sensitive to changes in pH and temperature in the surrounding environment.

5. Conclusions

A variety of remediation approaches are available for wastewater-containing dyes. The kind and concentration level of dyes in the wastewater, together with the financial and environmental limitations, will determine the optimal course of action. Research on the development of new and improved remediation approaches for wastewater-containing dyes is ongoing. Promising areas of research include the development of nanomaterials for adsorption and photocatalysis, the use of genetically engineered microorganisms for biodegradation, and the development of hybrid systems that combine different remediation approaches. Choosing the most suitable method depends on factors like the type of dye, its concentration, and the desired level of treatment. Sometimes, a combination of these approaches might be used for optimal results. There are some vital points to be considered in dye remediations. Sustainability; some methods, like bioremediation, are generally more sustainable than those requiring harsh chemicals. Cost-effectiveness; factors like energy consumption and chemical costs need to be considered. Regulations; Local regulations might dictate specific treatment requirements. By implementing effective remediation strategies, we can significantly reduce the environmental impact of dye-containing wastewater.

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