

Advanced Oxidation Process as a Green Technology for Dyes Removal from Wastewater: A Review

Azimi, Seyyedeh Cobra[•]; Shirini, Farhad^{+}*

Department of Chemistry, Faculty of Sciences, University of Guilan, Rasht, I.R. IRAN

Pendashteh, Ali Reza[•]

Department of Chemical Engineering, Faculty of Engineering, University of Guilan, Rasht, I.R. IRAN

ABSTRACT: *The combination of green chemistry and green engineering is needed for the production of minimum waste, renewable sources, increasing utilization of raw materials, the use of simpler and safer products, and novel technologies. The use of novel cleaner technologies leads to effective production in chemical industries. The dyes involve a complex structure, recalcitrant nature, and more intermediates. The generation of oxidative species with higher yields is obtained by advanced oxidation processes as a green and powerful treatment technology. These processes are effective, inexpensive, and eco-friendly methods for decaying toxic pollutants. The AOPs are classified as non-photochemical and photochemical processes. There are included various technologies such as ozonation, Fenton oxidation, wet air oxidation, electrochemical oxidation, and photocatalytic oxidation. The production of highly reactive free radicals is the main purpose of the AOPs process. The generation of free radical increases by the combination of two or more AOPs processes that leads to higher oxidation rates. This study was aimed to present the various attempts for degradation dyes in textile wastewater using the diverse advanced oxidation processes.*

KEYWORDS: *Advanced Oxidation Processes, Degradation, Dyes, Green Technologies*

INTRODUCTION

The precious materials in high-tech matters, agrochemicals, biomolecules, food products, dyes, cosmetics, medicines, polymers, nanoparticles, and liquid crystals have been provided by chemistry and chemical processes. Chemists' knowledge and skill have been applied to make a great number of new materials that are far efficient and more appropriate than natural products. These materials are produced in the laboratory and on an industrial scale. The industrial processes include many chemical reactions using vast quantities and wider

collections of smaller molecules, solvents, acids, alkali, reagents, and catalysts. These chemical procedures generate the required products. Furthermore, large quantities of the harmful materials produced, in the form of solids, liquids, and gases, are the biggest challenge in chemistry. Hence, minimizing chemical pollution is an urgent need for synthetic chemists [1].

The use of environmentally acceptable processes is needed in the chemical industry. This concept was shown in green chemistry, clean chemistry, environmental

** To whom correspondence should be addressed.*

+ E-mail: shirini@guilan.ac.ir ; cobra.azimi.phd@gmail.com

• Other Address: Department of Water and Environmental Engineering, Caspian Sea Basin Research Center, University of Guilan, Rasht, I.R. IRAN

1021-9986/2021/5/1467-1489

23/\$/7.03

chemistry or sustainable technology. In this way, chemical yield, the economic value of removing waste, and avoiding the use of toxic and hazardous materials are mainly focused [2-7]. The term “Green Chemistry” is the most favorable among other common methods.

Green Chemistry

At the beginning of 1990, the concept and definition of green chemistry were first introduced. It is defined as the “design of chemical products and procedures to remove or decrease utilization and production of hazardous materials” [2,5].

Designing is the most important characteristic of green chemistry, involving novelty, planning, and systematic conception. Chemists have achieved the purposeful goal of sustainability using the twelve principles of green chemistry as the “design rules” through the exact and safer planning of chemical synthesis and chemical transformations. In this way, an increasing emphasis on waste reduction in the required source is seen [8]. Therefore, a decrease in waste is the essential purpose of green chemistry. It is shown as a series of reductions (Fig. 1) [9]. These reductions lead to benefit the economic, environmental, and social enhancements through the saving of costs, materials, and energy. Moreover, the use of renewable resources will give sustainable industries. Careful design based on the twelve principles will remove or decrease intrinsic hazards within chemical processes [9].

The Twelve Principles of Green Chemistry

Paul Anastas and John Warner presented the twelve principles of green chemistry in 1998 (Table 1). They are the guiding principles for the design of novel chemical products from raw materials through chemical transformation [2].

A significant first step in pollution prevention is to redesign chemical transformations, which decrease the production of hazardous waste. It can produce many shapes and may affect the environment differently depending on nature, toxicity, quantity, or released source. The conversion of all raw materials into the final compound is one of the most beneficial ways that can prevent the production of wastes. The concept of the atom economy was determined as the second principle of green chemistry. The other principles have been dedicated to subjects such as energy, toxicity, solvent, and utilization of raw matters from renewable sources [10].

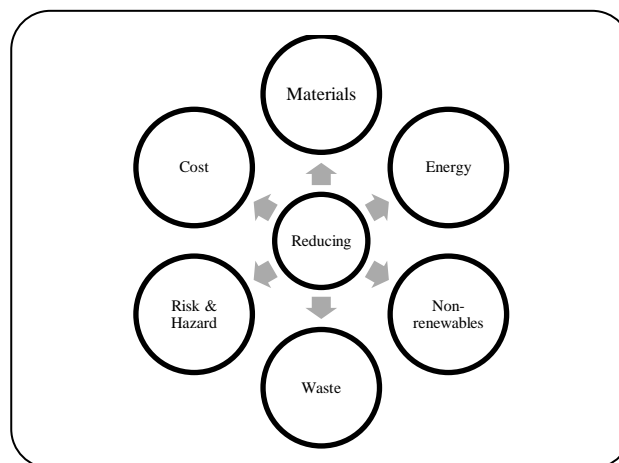


Fig. 1: Reducing: The main of green chemistry.

A synthesis of the organic compounds often generates by-products that may require removal. In this view, the degradation of chemical products to nontoxic, simple, and environmentally-friendly substances has been considered [10].

One important area of research in green chemistry is solvents [11,12], because they often generate the huge majority of waste in chemical syntheses [13]. Additionally, many conventional solvents are flammable, toxic, and corrosive. Their solubility and volatility are related to water, air, and land pollution. Solvents often consume high energy in the recovery and reuse process. Generally, large amounts of organic solvents are used in the pharmaceutical and fine chemicals industries for the chemical reactions and separation processes. These solvents often add to the environment. The cost of processing and recovery operations is due to their volatile and water-solubility to pollute air emissions and aqueous discharge streams [14]. Therefore, chemists studied for safer green solutions. Some examples included solventless systems [15,16], water [17,15], Super Critical Fluids (SCF) [15,18], and, more recently, ionic liquids [19-29].

Raw materials are extracted from the limited sources of the earth that cannot be replaced. Thus, renewable raw materials should be utilized. The major renewable material from living organisms is biomass that includes wood, crops, agricultural residues, food, etc. Cellulose, lignin, suberin and other wood compounds, poly hydroxyl alkanooates, lactic acid, glycerol, starch, chitin, and oil are examples of renewable materials. The efficiency of the chemical processes can be increased by using the catalyst.

Table 1: The twelve principles of green chemistry.

1- Prevention of Waste. It is better to prevent waste than to treat or clean up waste after it is formed.
2- Atom Economy. Synthetic methods should be designed to maximize the incorporation of all materials used into the final product as expressed by "atom economy".
3- Less Hazardous Chemical Syntheses. Wherever synthetic, practicable methodologies should be designed to apply and generate matters that possess little or no toxicity to human health and the environment.
4- Designing Safer Chemicals. Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5- Safer Solvents and Auxiliaries. The use of auxiliary substances (e.g. solvents, separation agents) should be made unnecessary wherever possible and, innocuous when used.
6- Design for Energy efficiency. Energy requirements should be identified for their economic and environmental impacts and should be minimized. Synthetic procedures should be conducted at ambient temperature and pressure.
7- Use of Renewable Feedstocks. A raw material of feedstock should be renewable rather than depleting wherever technically and economically practicable.
8- Reduces Derivatives. Unnecessary derivatization (temporary modification of chemical/physical processes, blocking group, protection/deprotection) should be avoided whenever possible.
9- Catalysis. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10- Design products for degradation. Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.
11- Analytical methodologies for pollution prevention. Analytical procedures need to be developed to allow for real-time, in-process monitoring and control prior to the generation of hazardous substances.
12- Inherently safer processes. Substances and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions and fires.

Lowering the input required energy, avoiding the use of the stoichiometric amount of reagents and the selectivity product will result. Consequently, the energy and waste will reduce. The production of minimum wastes is important through using the new computerized systems in "real-time" control of chemical processes. Thus, careful knowledge of the concentrations of materials used in the chemical process of green chemistry is needed [30].

Today, designing the chemical process in the context of green chemistry with new effective approaches and reduced toxicity is considered.

Dyes

Dyes include an organic compound or complex molecular constructions. They use extensively in different types of industries such as textiles, pharmaceuticals, cosmetics, waxes, greases, leather plastics, paper, food, and paint. The important groups of dyes are phthalocyanine, anthraquinone, triarylmethane, and azo dyes [31-33]. In this way, azo dyes are the most extensively applied commercial reactive dyes whose color is due to the nitrogen to nitrogen double bond [34,35].

In addition, azo dyes are the largest class of dye pollutants [36].

The effluents of the textile industry mainly contain large amounts of synthetic dyes, natural dyes, and organic dyes. They can affect the chemical and physical characteristics of water. The strong color is one of the chief properties of textile effluent that can cause serious problems in the environment. The synthetic dyes contain organic compounds with fused aromatic rings or connected by covalent bonds. These compounds were improved by several hydrophilic functional groups like carbonyl, amine, hydroxyl, and carboxylic acid groups. Synthetic organic dyes are often resistant to biodegradation in engineered treatment methods. Moreover, some types of dyes such as azo dyes and their derivatives can be mutagenic and carcinogenic. Therefore, the removal of dyes from wastewater is very important. Today, designing the chemical process in the context of green chemistry with new effective approaches and reduced toxicity is considered. A successful approach is the use of green technologies for dyes removal in the textile industry and wastewater treatment [31-36].

Green Technology

Dye wastewater from industries is one of the serious environmental problems due to the characteristics of wastewater such as strong color, low biodegradability, high pH, and high Chemical Oxygen Demand (COD) [37]. Dye-containing effluents are usually treated by Physico-chemical (coagulation, activated carbon adsorption, membrane filtration) and biological (bacterial, algal, fungal) conventional technologies [31,38,39]. The dye effluents often included stable, toxic, and non-biodegradable organic compounds. In fact, they are not treated suitably by conventional treatment methods. Physico-chemical treatments lead to the transfer of pollutants from one phase to other. Furthermore, the dye effluents can eliminate using anaerobic/aerobic and bacterial degradation in biological methods. In this method, the unsuitable removal of dyes leads to environmental or health problems and defective degradation, and insufficient decolorization. Therefore, it is essential to discover an effective treatment technology for complete degradation and effective decolorization. The emerging field for dye effluent treatment is the use of Advanced Oxidation Processes (AOPs) that are efficient, cheap, and eco-friendly methods for decaying toxic pollutants. In these methods, highly reactive radicals are produced that oxidize most of the complex chemical compounds in the dye effluents. In this regard, highly reactive free radicals can be generated by using ultraviolet irradiation, hydrogen peroxide (H_2O_2), ultrasound, ozone (O_3), and catalysts (homogeneous or heterogeneous) [37,40-45].

Advanced Oxidation Processes

Advanced Oxidation Processes (AOPs) are a class of chemical treatment techniques to eliminate organic compounds in water and wastewater. These methods have firstly suggested in 1987 for the purification of water by the generation of hydroxyl radicals. Today, these processes include techniques such as ozonation, photocatalytic degradation, Fenton's reagent (H_2O_2/Fe^{2+}), photo-Fenton, and Electro-Fenton, wet air oxidation, and UV/chlorine processes which are effective for the degradation of the organic pollutants at ambient temperature and pressures [46-54]. Moreover, combinations of advanced oxidation processes are used for the effective removal of the dyes from water and wastewater. The formation of strong oxidants (generally hydroxyl radicals) and the reaction of these radicals with

organic pollutants in water are two main stages of AOPs. The advanced oxidation processes can be categorized into two general groups based on using the ultraviolet irradiation source. The classification of AOPs is shown in Table 2 [55].

Nonphotochemical Advanced Oxidation Processes

These methods include four desirable nonphotochemical processes such as ozonation, Fenton's reagent oxidation, wet air oxidation, and electrochemical oxidation. The nonphotochemical processes of recent research will be given in the following sections.

Ozonation

Ozone and ozone-based advanced oxidation systems are well-known, powerful, and environmentally friendly technologies that can degrade the variety of organic pollutants [56]. In recent years, the use of ozonation in wastewater treatment has enhanced significantly. Interest in the use of ozone is due to the various benefits of this method, including the high oxidation power of ozone (2.08 V) even at low concentrations, high efficiency in the decomposition of organic matter, and the production of nontoxic residues [57,58]. Furthermore, ozonation is the preferred method for the removal of colored materials that have chromophore groups with conjugated double bonds. These substances can be easily broken down into smaller molecules by the ozone process in direct and indirect ways [59]. *Hoigne et al.* studied the mechanism of ozone reaction [60,61]. These studies showed that direct ozonation includes the reaction of double bonds or aromatic systems of reactive dyes with molecular ozone in acidic pH [61,62]. The degradation mechanism of organics dyes is investigated throughout hydroxyl radicals under basic pH. The hydroxyl radicals are generated through the radical chain reactions, which react with the organic compounds [63]. Sometimes, the ozone process cannot entirely oxidize the organic dyes to CO_2 and H_2O . This is due to the generation of partial oxidation products. In this case, the combination of ozone with homogeneous or heterogeneous catalysts is proposed for the improvement of organic compounds elimination [64].

Wijannarong et al. studied the wastewater treatment of reactive dyes with ozone in a batch reactor at 35 °C. In this experiment, the effects of time reaction and pH on the

Table 2: Classification of Advanced Oxidation Processes.

Non-photochemical	Photochemical
Ozonation	Photocatalytic oxidation, UV/Catalyst
Ozonation with hydrogen peroxide (O_3/H_2O_2)	UV/ H_2O_2
Fenton and related processes (Fe^{2+} or Fe^{3+}/H_2O_2)	UV/ O_3
Wet air oxidation (WAO)	UV/ O_3/H_2O_2
Electrochemical oxidation	Photo-Fenton and related processes (Fe^{2+} or $Fe^{3+}/H_2O_2/UV$)
Catalytic wet air oxidation (CWAO)	Heterogeneous photocatalysis oxidation: UV/ ZnO , UV/ SnO_2 , UV/ TiO_2 , UV/ TiO_2/H_2O_2

decolorization efficiency was investigated. The decoloration efficiency enhanced from 32.83% to 56.82% after two hours. In addition, color reduced by more than 92% after six hours [65].

The commercial reactive azo dyes with different structures were treated by ozone in a semi-batch reactor. The optimized conditions for decolorization were obtained in pH 10 and COD removal 95-99% for different dyes due to the complexity of their structures. This ozonation reaction revealed a significant technique for dye-containing wastewater treatment. The kinetics of reaction achieved pseudo-first-order [66].

Wu et al. used the catalytic ozonation process for the removal of organic pollutants. The organic pollutants were effectively removed at initial pH values of 7.18-7.52 with the iron shavings. The COD value was reduced from 142 to 70 mg/L. The toxicity effect decreased from 51% to 33% that was due to hydroxyl radical oxidation, co-precipitation and oxidation by other oxidants. Therefore, this method was introduced as a favorable method for the removal of organic [67].

Asgari et al. investigated a catalytic ozonation process to remove the reactive black 5 (RB5) dye using a bone-char (BC) ash improved with $MgO-FeNO_3$. Experimental parameters such as initial RB5 concentration, catalyst dosage, pH, and reaction time were optimized by the Taguchi method. The optimal conditions were achieved at an initial RB5 concentration of 10 mg/L, pH 10, 0.1 g/L catalyst dosage, and 15 min reaction time. The initial RB5 concentration had a considerable influence on RB5 elimination efficiency (54.03%), but the reaction time had a lower impact (2.04%) [68]. So far, numerous studies have established that dyes can be effectively degraded by ozone and ozone-based methods. In this regard, some of the results are summarized in Table 3.

Fenton's Reagent Oxidation

Fenton and Fenton-based oxidation processes have attracted attention as a favorable and remarkable AOPs technology. This reagent contains a mixture of a strong chemical oxidizer, hydrogen peroxide, and ferrous ions as a catalyst that is called Fenton's Reagent. It was introduced by Henry Fenton as an oxidant reagent in 1890. The catalytic chemical reaction between hydrogen peroxide and Fe^{2+} or Fe^{3+} ions under an optimum pH condition produced the hydroxyl free radical, which is the main component of Fenton's reagent [84,85]. The generation of hydroxyl radicals in Fenton reactions was determined by spin-trapping analysis [86]. The iron (III) ions are produced during the oxidation stage that promoting the elimination of pollutants through coagulation and sedimentation. In this process, the pollutants were converted to harmless compounds like carbon dioxide and water. The important advantages of this reagent are simplicity, the cost-effective source of hydroxyl radicals, and the lack of toxicity of the reagents [87]. The homogeneous or heterogeneous conditions can be utilized for Fenton oxidation. The traditional homogeneous Fenton oxidation was extensively utilized in degradation organic compounds. However, there are two important limits in this process, including acidic pH 2-4 and high amounts of iron ions. The iron ions should be separated at the end of the reaction that needs additional elimination procedures [88-92]. In recent years, the use of heterogeneous Fenton and the Fenton-like process has been increasingly regarded [91-97].

The Fenton process using Fe^{3+} or other metals at low oxidation states like Cu^{2+} and Co^{2+} is the so-called Fenton-like reaction that has a slower rate compared to the Fenton reaction [96]. Abo-Farha et al. studied the degradation of C.I. Acid Orange 8 (AO8) and C.I. Acid Red 17 (AR17)

Table 3: Summary of ozonation studies in the removal of dyes.

Entry	Dye	Time (min)	Catalyst	Color Removal (%)	COD Removal (%)	TOC Removal (%)	Ref.
1	Textile Dyeing Industrial Effluent	240-360	-	92	-	-	[65]
2	Commercial reactive azo	30-40	-	60-90	95-99	-	[66]
3	Textile auxiliaries and dye intermediates	120	Iron shavings	BOD ₅ /COD=0.17	46	-	[67]
4	Reactive black 5 (RB5)	5-20	MgO-FeNO ₃	90	60	-	[68]
5	C. I. Reactive Blue 5	-	LaCoO ₃	-	-	100	[69]
6	Acid Red 88	0.5-6	-	98	64	-	[70]
7	Acid Red B	60	Fe-Cu oxide	90	70	-	[71]
8	Acid black 1 (AB1), Acid yellow 19 (AY19), Acid orange 7 (AO7)	-	-	80-98	-	-	[72]
9	Reactive Blue 19	90	-	-	55	17	[73]
10	Procion red MX-5B	30	Metal ions	97	-	75	[74]
11	C. I. Acid Blue 113, C. I. Reactive Yellow 3, C. I. Reactive Blue 5	< 10	Activated carbon, cerium oxide, ceria-activated carbon composite	100	-	-	[75]
12	RR198	9	MgO nanocrystal	100	-	-	[76]
13	Reactive Blue 19	10	-	BOD ₅ /COD=0.33	-	-	[77]
14	Bomplex Red CR-L	10-30	-	100	35-56	-	[78]
15	Acid, Direct and Reactive	180	-	100	66	-	[79]
16	Red X-GLR	120	-	100	5.7-35	-	[80]
17	Remazol Black B	2-60	-	96	-	-	[57]
18	Remazol Black 5	360	-	-	40	25	[81]
19	Reactive red X-3B	30	MnO ₂	99	85	59	[82]
20	C. I. Direct Black 22	160	-	70-83	-	33	[34]
21	Direct Blue 86 (DB-86)	35	-	98	62	-	[83]

with Fenton and Fenton-like processes. The color was reduced 93% for AO8 and 98% for AR17 with Fenton oxidation under the optimum conditions, while were obtained 89% and 78% using the Fenton-like process [95]. Furthermore, the Fenton oxidation process was used for the degradation of Direct Blue 71 (DB71). The parameters such as dosages of Fe²⁺ and H₂O₂, pH, temperature, and dye concentration

in the color removal and COD reduction were studied. The color was reduced 94% and COD 50.7% under the optimum conditions of pH 3.0, 3 mg/L Fe²⁺, 125 mg/L and 100 mg/L H₂O₂ after 20 min [98].

Sohrabi et al. investigated the degradation of Carmoisine dye from aqueous solutions through the Fenton process. The effect of operating parameters such as pH,

Fe^{2+} , H_2O_2 , and dye concentration were optimized by Taguchi fractional factorial design. The optimal conditions for the Fenton oxidation were obtained equal to 0.015 mmol Fe^{2+} , 0.15 mmol H_2O_2 , 20 mg/L initial dye concentration, and pH 3.5. The color was reduced 92.7% for the Fenton in optimal conditions [99].

The heterogeneous Fenton system such as green Fe(II)/Fe(III) oxides/hydroxides nanoparticles with hydrogen peroxide was used for dye removal in less than 3 h of reaction. In this study, the effect of hydrogen peroxide concentration, pH, catalyst dosage, and temperature were investigated. The decolorization was obtained equal to 80% at 50°C in 14 min and 40% at 25°C [100].

The Fe(II) supported on Y-Zeolite (Fe(II)-Y-Zeolite) catalyst and hydrogen peroxide (heterogeneous Fenton process) were studied for the decolorization and mineralization of the azo dye C.I. Acid Red 14 by *Idel-Aouad et al.* [101]. The catalyst was prepared from a commercial Y-Zeolite by ion exchange with Fe^{2+} . The effect of operating parameters such as initial pH, H_2O_2 concentrations, temperature, and dosage of catalyst on the decolorization efficiency was investigated. The percentage of decolorization and mineralization of dye was obtained equal to 99.3±0.2% and 84±5% in pH 5.96, the initial concentration of 50 ppm dye, 8.7 mM H_2O_2 , 80°C temperature, the catalyst concentration of 15 g/L and 6 min contact time, respectively. In addition, the synthesized catalyst easily filtered from the solution without iron into the solution. This method was effective for the degradation of dye [102].

Daud and Hameed studied the decolorization of the azo dye reactive black 5 (RB5) using a Fenton-like oxidation process in the presence of Fe(III) immobilized on Montmorillonite K10 (MK10) catalyst and hydrogen peroxide (H_2O_2). The effect of various parameters such as catalyst dosage, temperature, the initial concentration of H_2O_2 , iron ions loading on the supported catalyst, pH was investigated. The decolorization efficiency was obtained equal to 99% with 3.50 g/L of 0.11 wt. % Fe(III) oxide on MK10 catalyst, 12 mM of H_2O_2 at pH 2.5 within 150 min [103]. Some studies, including Fenton's reagent oxidation of dye contaminant, are shown in Table 4.

Catalytic Wet Air Oxidation (CWAO)

Wet Air Oxidation (WAO) is an environmentally friendly process for the treatment of organic pollutants

in wastewater. It was firstly introduced by Zimmerman over 50 years ago. This method oxidizes the organic compounds using oxidative functions such as air or oxygen at pressures (0.5-20 MPa) and high temperatures (175-320 °C) [111,112]. The wet air oxidation oxidizes the organic contaminants to dioxide carbon, NH_3 , and inorganic salts [108]. In recent years, Catalytic Wet Air Oxidation (CWAO) processes were studied and used in the treatment of wastewater. This method has moderate reaction conditions and higher efficiency compared to conventional World Health Organization (WHO). The higher oxidation rates are obtained with the use of the catalysts. These catalysts involve homogenous and heterogeneous types. In the CWAO process, the organic contaminants oxidize to inorganic compounds like dioxide carbon, dissolved ions, and water at lower pressures and temperatures [113,114].

Liu and Sun synthesized a new $\text{Fe}_2\text{O}_3\text{-CeO}_2\text{-TiO}_2/\text{g-Al}_2\text{O}_3$ catalyst and used it for degrading the methyl orange in the CWAO process. The results showed that 98.09% of color and 96.08% of Total Organic Carbon (TOC) could be eliminated in 2.5 h. The catalyst had high stability and activity [113].

Zhang et al. prepared a new polyoxometalate $\text{Zn}_{1.5}\text{PMo}_{12}\text{O}_{40}$ catalyst and used it for the catalytic wet air oxidation of the Safranin-T. The Safranin-T (ST) is a hazardous textile dye. This catalyst showed good catalytic activity. The color was reduced 98% and 95% of COD was eliminated in 40 min under atmospheric pressure and room temperature. Total Organic Carbon (TOC) decreased 92%. In this method, the organic contaminants were converted to inorganic species such as Cl^- , HCO_3^- and NO_3^- [115].

Kumar Kondru et al. investigated the removal of congo red dye using modified Y-zeolite in catalytic wet peroxide oxidation. The effects of various parameters such as pH, temperature, hydrogen peroxide concentration, and catalyst dosage were studied. The optimum conditions were obtained at pH 7, 0.6 mL H_2O_2 , and 1 g/L catalyst. The color removal and COD reduction were found 100% in 45 min and 58% in 4 h. Therefore, the Fe exchanged Y-zeolite was introduced as an excellent catalyst for dye removal [116].

Hua et al. studied the catalytic effect of $\text{CuO}/\text{Y-Al}_2\text{O}_3$ on the wet air oxidation of three azo dyes (Methyl Orange, Direct Brown, and Direct Green) (2013). The COD removal, Total Organic Carbon (TOC) reduction, and decolorization were investigated. The color, TOC, and COD were removed 100%, 80%, and 70% in 2 h, respectively.

Table 4: Summary of Fenton's oxidation process studies in the removal of dyes.

Entry	Dye	Time (min)	[H ₂ O ₂]	[Fe ²⁺]	Catalyst	pH	Color Removal (%)	COD Removal (%)	TOC Removal (%)	Ref.
1	Reactive Black 5	-	4.0 mM	-	iron (III) impregnated on rice husk ash	3.0	89.18	-s	-	[88]
2	Alcian Blue	-	[H ₂ O ₂]/[Fe ²⁺] =1	[H ₂ O ₂]/[Fe ²⁺] =1	-	2.5	93.2	-	54.1	[89]
3	Acid Red 1 (AR1)	180	12 mM	1.0 %	Fe-ball clay (Fe-BC)	2.5	99	-	-	[92]
4	C.I. Acid Orange 8, (AO8), C.I. Acid Red 17 (AR17)	55	10 mM	1.0 × 10 ⁻⁵ M	-	3.0	89-99	-	-	[95]
5	Direct Blue 71 (DB71)	20	125 mg/L	3 mg/L	-	3.0	94	50.7	-	[98]
6	Carmoisine edible dye	12	0.15-0.3 mmol	0.012-0.015 mmol	-	3.5	92-95	-	-	[99]
7	C. I. Acid Red 14	6	8.7 mM	15 g/L	Fe (II)-Y Zeolite	5.96	99	-	-	[101]
8	Reactive Black 5	150	12	3.5 g/L 0.11 wt%	Montmorillonite K10	2.5	99	-	-	[102]
9	Yellow drimaren, Congo red, Methylene blue	30-120	-	0.5 mM	-	3.0	100	89	-	[91]
10	Remazol Black 5 (RB5), Remazol Red RB (RR), Remazol Yellow 84 (RY), Remazol Brilliant Blue (RB)	22	0.05-1.25 mM	0.05-1.25 mM	-	2.5-4.0	>90	>90	-	[104]
11	Methyl Orange, Reactive Black 5, Fuchsin Acid	1260	-	-	-	2.0	42.68	-	46.57	[105]
12	Reactive Black 5	15	7.3 × 10 ⁻⁴ mol/L	1.5 × 10 ⁻⁴ mol/L	-	3.0	97.5	21.6	-	[32]
13	Reactive Blue 19	5	300 mg/L	30 mg/L	-	3.0	80.2	41.8	-	[106]
14	Acid Red 1	120	8.0 mM	0.070 wt%	iron ions loading on rice husk	2.0	96	-	-	[107]
15	Direct Blue 15	50	2.8 × 10 ⁻³ mol/L	2.8 × 10 ⁻⁵ mol/L	-	4.0	100	-	-	[108]
16	Remazol Red RR, Remazol Blue RR and Remazol Yellow 84 (RY)	120	1000 mg/L	600 mg/L	-	3.0	98	94	-	[109]
17	Reactive Red 198 (RR-198)	90	50 mg/L	100 mg/L	-	3.0	92	-	-	[110]

The hydroxyl radicals oxidized the chromophoric groups of azo-benzene conjugated in the dye molecule. The oxidized molecules were converted to water and carbon dioxide [33].

Ovejero et al. investigated the removal of Crystal Violet (CV) dye using a nickel catalyst (7 wt.%) supported over Mg-Al mixed oxides. The effects of different parameters like pressure, dye concentration, gas flow, and temperature were studied in this process. The dye removal was obtained 86.1% at 180°C and 44.7% at 120°C. The Total Organic Carbon (TOC) varied from 59.5% to 18.7% and dye removal from 62.6% to 18.4% in an initial dye concentration of 10 to 50 mg/L [117].

MA et al. studied the Catalytic Wet Oxidation (CWO) process for the removal of the methyl orange and methyl blue using a new CuOMoO₃-P₂O₅ catalyst at atmospheric pressure and lower temperatures (35°C) (2007). The dye removal of MB was obtained equal to 99.26% at pH 7 and an initial concentration of 0.3 g/L within 10 min at 35°C. The color removal achieved 55% for methyl orange and 99.65% for MB under the same conditions [118]. Some studies on wet air oxidation of dye contaminants are listed in Table 5.

Electrochemical Oxidation

Electrochemical treatment is one of the advanced oxidation methods for the degradation of dyes. This method was increasingly applied in recent years due to its exclusive features, like energy efficiency, versatility, stability, and cost-effectiveness [128]. The electrochemical oxidation process is used *in situ* generations of hydroxyl radicals. Thus, it is introduced as an environmentally friendly process. In this technique, electrons are the main reagents that are produced on the surface of electrodes and consumed. Furthermore, the electrons are introduced as the "Clean Reagent". Electrochemical oxidation pollutants are performed by electrode reactions. The reactions depend on the anode material's effectiveness in the electrochemical treatment of the organic contaminant. Up to now, the electrodes such as Au, C, and Pt are used [129]. The mechanism of electrochemical treatment is complicated and can be categorized as direct or indirect. Direct oxidation is performed on the surface of the anode, while indirect oxidation is distant from the anode surface. The contaminants in the direct anodic oxidation are absorbed

on the anode surface and then degraded by electron transfer reaction in the anode. In indirect oxidation, the oxidants were generated by electrochemical oxidation in electrolysis reactions. Then, these oxidants destroy the pollutants [130].

Rajkumar and Kim investigated chlorine-mediated electrochemical oxidation for degrading the reactive dyes. The chlorine was generated *in situ* by using the titanium-based Dimensionally Stable Anode (DSA). The Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC) in electrochemical oxidation were measured. The COD and TOC were obtained from 39.5% to 82.8% and 11.3% to 44.7% for various dyes. The diazo compounds with higher molecular weight such as triazines need more time for degradation compared to the mono azo. The effects of various parameters such as pH, current density, temperature, initial dye concentration, and NaCl concentration were studied in mixed dyes. The optimum conditions were obtained: pH 6.5, 72.2 mA/cm² current density and 4 g/L NaCl concentration. The COD and TOC reduction were obtained equal to 73.5% and 32.8% in 120 min, respectively [131].

Jovic et al. studied the electrochemical oxidation of reactive textile dyes such as Reactive Blue 52, Reactive Black 5, Reactive Green 15, and Reactive Yellow 125 using the platinum electrode. In this study, the electrolysis reaction was performed in cells involving a standard membrane. The supporting electrolyte was determined 0.1 M sodium sulfate. The voltages of 6, 12, and 24 V were considered due to the effect of a membrane on electrolysis. The best dye removal was obtained at 12 V. The COD reduction achieved 57.95% with membrane and 35.28% without membrane after 60 min [132].

In the other study, *Morsi et al.* investigated the electrochemical oxidation of three types of textile dyes using lead dioxide anode. The effect of temperature, time, pH, current density, initial dye concentrations, and salt concentration were investigated. The optimum conditions were achieved in 20 mA/cm², pH 3, 30°C temperature, and sodium chloride (3 g/L). In this method, the color removal and COD removal was obtained equal to 100% [129].

In 2017, *Najafpoor et al.* studied the electrochemical oxidation process for decolorization of reactive red 120 (RR120) using graphite anodes and cellulosic separator. Designing the experiments was performed by central composite design. The experimental factors were sodium

Table 5: Summary of catalytic wet air oxidation studies in the removal of dyes.

Entry	Dye	Time	P (MPa)	T (°C)	Catalyst	pH	Color Removal (%)	COD Removal (%)	TOC Removal (%)	Ref.
1	Methyl Orange Direct Brown Direct Green	120 min	-	-	CuO/Y-Al ₂ O ₃	-	99	-	70	[32]
2	Methylene Orange	150 min	1.0	25	Fe ₂ O ₃ -CeO ₂ -TiO ₂ /Y-Al ₂ O ₃	-	98.09	-	96.08	[111]
3	Congo red	-	-	70	Y-Zeolite	7	100 (45 min)	58 (4 h)	-	[115]
4	Crystal Violet (CV)	350 h	-	180	nickel catalysts supported over Mg-Al mixed oxides	-	86.1	-	59.5	[116]
5	Methylene Blue	10 min	1.0	35	CuO-MoO ₃ -P ₂ O ₅	5	99.26	-	-	[118]
6	Safranin-T (ST)	40 min	1	25	Polyoxometalate Zn _{1.5} PMo ₁₂ O ₄₀	-	98	95	92	[119]
7	Orange II	100 min	0.6-3.0	160-290	H ₄ SiW ₁₂ O ₄₀ , Na ₂ HPW ₁₂ O ₄₀	-	-	-	92	[120]
8	Congo red	60 min	-	70	Y-Zeolite	2	99.52	88	-	[121]
9	Safranin-T	18 min	1.0	25	ZnO/MoO ₃	6.89	98	95	99.3	[122]
10	Reactive Black 5	90 min	-	70	Commercial activated carbons (AquaSorb 5000 P)	3	92	-	-	[123]
11	Orange II (OII) and Chromotrope 2R (C2R)	150 min	1	27	Activated carbon xerogels (ACXs)	3	49-67	-	-	[124]
12	Reactive Dye Solution	120 min	1.0	135-165	CoAlPO ₄ -5 CeO ₂	-	95-100	90-95	-	[125]
13	Chromotrope 2R	-	2.5	100-180	Ni/MgAlO	-	-	-	82	[126]
14	Cationic red GTL	60 min	1.0	25	Mo-Zn-Al-O catalyst	-	80.1	-	50.9	[127]

chloride (2500-12500 mg/L), dye concentration (100-500 mg/L), electrolysis time (7.5-37.5 min), and current intensity (0.06-0.3 A). The results showed that current intensity was the most important factor in RR120 decolorization. The optimum conditions were achieved equal to 200 mg/L RR120, 0.12 A current intensity, 7914.29 mg/L NaCl, and 30 min reaction time. The dye was removed 99.44% *via* electro-oxidation and 32.38% by the electro-reduction process [133]. Table 6 shows a brief account of the research for dye mixtures using the electrochemical oxidation process.

Photocatalytic oxidation

The irradiation of UV-Visible light is essential to generate photochemical changes in the compound. The wavelengths between 400 and 800 nm are related to the visible spectrum. The UV range is involved four regions: UV-A ($\lambda = 315$ -400 nm), UV-B ($\lambda = 280$ -315 nm),

UV-C ($\lambda = 190$ -280 nm) and VU-V (<190 nm). Generally, the reaction rate of AOPs is increased in comparison with the same technology in the absence of light. The lower reaction temperatures, higher reaction rate, and selectivity control are the photochemistry advantages compared to conventional treatment methods [143]. The photochemical processes like photocatalytic oxidation, photocatalytic ozonation (UV/O₃), hydrogen peroxide (UV/H₂O₂), and ultraviolet irradiation are presented below.

Photocatalytic oxidation can involve direct photolysis through the interaction of light with molecules without the adding of chemical reagents. In this method, irradiation leads to homolytic or heterolytic breakages in the molecules. Therefore, a molecule is transmitted from the fundamental state to an excited singlet state. Such excited states can lead to heterolysis, homolysis, or photoionization processes. In most cases, radicals are produced by homolytic dissociation. Generally, the radicals are hydroxyl and superoxide.

Table 6: Summary of Electrochemical oxidation studies in the removal of dyes.

Entry	Dye	Time (min)	Current Density (mA/cm ²)	pH	Color Removal (%)	COD Removal (%)	TOC Removal (%)	Ref.
1	Reactive dyes	120	72.2	6.5	>95	73.5	32.8	[131]
2	Reactive Textile Dyes	60	12	8	-	57.95	-	[132]
3	Textile dyes	20	20	3	100	100	-	[129]
4	Reactive red 120 (RR120)	30	0.12 A	-	99.44	-	-	[133]
5	Dye effluents	420	2.5 A/dm ²	2	99.48	100	-	[134]
6	Methylene Blue	300	1.75	-	-	62	-	[135]
7	Textile dyes	300	40	9	90	50	-	[136]
8	Textile dyes and dyehouse effluents	180	5	3	90	55	-	[137]
9	Textile effluent	50	3 A/dm ²	4.5	-	25	-	[138]
10	Dye effluents	-	2 A/dm ²	-	95	92	-	[139]
11	Textile Dyes	30	120	5	91	87	-	[140]
12	Synthetic dyes	60	350 mA	-	72.9	70.6	-	[141]
13	Reactive Black 5 (RB5)	160	100 A/m ²	6	-	33	18	[142]

These can be broken down into various types of organic compounds to water, CO₂, and mineral salts [144]. In this process, the photocatalysts such as TiO₂, ZnO, Fe₂O₃, WO₃, ZnS, and CdS were used for the degradation of organic pollution. In this regard, nano-titanium dioxide is applied more than the other ones due to its low cost, electrical and optical properties, chemical stability, nontoxicity, photo corrosion resistance, and remarkable photocatalytic activity [145].

Li *et al.* studied the photodegradation of rhodamine B and 4-(*p*-nitrophenylazo) resorcinol (Magneson I) using the TiO₂ hollow microspheres. This photocatalyst exhibited a higher photocatalytic activity compared to P25. A much higher photodegradation percentage for rhodamine B was obtained in the mixed solution. The catalyst degraded the two dyes with high efficiency. These results showed that the TiO₂ hollow microspheres would be very useful for use in wastewater treatment [146].

Nezamzadeh-Ejhi *et al.* investigated the photodecolorization of a mixture of the rhodamine B and methylene blue cationic dyes using CuO/nano-zeolite X catalyst in solar irradiation. The photocatalyst was synthesized by hydrothermal process. The particles sizes were determined in the ranges of 7-10 nm and 75-85 nm

using XRD and SEM analysis, respectively. The effects of different parameters such as catalyst dosage, pH, the initial dyes concentrations, and the amount of loaded CuO were studied. The decolorization efficiency was achieved by 12.5 mg/L MB, 12.5 mg/L RhB, pH 5.3, 0.1 g/L of catalyst, and the CuO loaded onto the zeolite X 88 mg [147]. The same group was also parallelly studied the photodecolorization of a mixture of Methyl Orange and Bromocresol Green was studied using CuS incorporated into an Iranian clinoptilolite (CuS-Cp) under sunlight irradiation. The effect of various parameters such as the amounts of the catalyst, pH, initial dye concentration, and contact time were studied. The COD reduction was obtained about 91.3% in pH 7, 20 mg/L of dyes mixture, and 0.1 g/L of CuS-Cp catalyst during 480 min irradiation [148]. In 2014, the effectiveness of CuO incorporated into clinoptilolite nanoparticles was investigated in the photodecolorization of Methylene Blue and Bromophenol Blue by Nezamzadeh-Ejhi and Zabihi-Mobarakeh. They showed that the best results can be obtained at pH 5.9, 0.2 g/L catalyst dosage and 4.9% loading of CuO. The decolorization percentage for MB and BPB were respectively achieved 61% and 32% during 180 min irradiation [149].

Table 7: Summary of photocatalytic oxidation studies in the removal of dyes.

Entry	Dye	Time (min)	T (°C)	UV Intensity mW/cm ²	Catalyst Type	pH	Color Removal (%)	COD Removal (%)	TOC Removal (%)	Ref.
1	Rhodamine B and Magneson I	60-120	-	-	TiO ₂ hollow microspheres	-	66.7 MgI-88.6 RhB	-	-	[146]
2	Methylene blue and Rhodamine B	180	-	-	CuO incorporated nanozeolite-X	5.3	68 MB-45 RhB	-	-	[147]
3	Methyl Orange and Bromocresol Green	480	-	-	CuS-nano-clinoptilolite	7	-	91.3	-	[148]
4	Methylene blue and Bromophenol blue	180	-	75 W	CuO-nano-clinoptilolite	5.9	61 MB-32 BPB	-	-	[149]
5	Methylene blue (MB) Real textile wastewater (TW)	120	25	15 W	Silver doped titania	6.8	-	99 MB-98 TW	-	[150]
6	Reactive Blue 2	-	-	32 W	Nano-titania	3	95.22	-	92.52	[151]
7	Acid Red 27	120	25	8	Nano ZnO	7	-	83.3	-	[152]
8	Orange II and Methyl orange	3600	25	5.14	P25 TiO ₂ -ZnO	6	88 OII 41 MO	-	-	[153]
9	Acid Black 2	15	25	250 mW	ZnO	8.17	97	-	-	[154]

Sahoo *et al.* investigated the photodegradation of methylene blue dye (MB) in an aqueous solution using Ag⁺ doped TiO₂ under UV irradiation. The comparison of TiO₂ and Ag⁺ doped TiO₂ showed that Ag⁺ doped TiO₂ was an efficient catalyst. The effect of various parameters like the dosage of catalyst, initial dye concentration, pH, and contact time were studied. The Langmuir-Hinshelwood pseudo-first-order rate law was obtained for the degradation kinetics. The decolorization percentage was achieved 99% in 20 mg/L MB, 2 g/L of Ag⁺ doped TiO₂ in 180 min while with untreated TiO₂ was 86% after 240 min. The COD removal was obtained 98% after UV irradiation for 420 min with 1 g/L Ag⁺ doped TiO₂ [150].

Alvia *et al.* synthesized the ZnO nanostructures through low-temperature solution methods and used them for the photodegradation of rhodamine B (RhB) (2017). The average diameter of nanostructures was 80-100 nm. The rapid photodegradation of RhB dye was obtained 97% in 120 min [151]. Some of the recent studies in photocatalytic oxidation of dyes are summarized in Table 7.

Photocatalytic Ozonation (UV/O₃)

The combination of ozone with UltraViolet (UV) radiation is an effective method to remove organic compounds. A larger quantity of hydroxyl radicals (OH[•]) is produced under UV radiation. In this process, the starting radicals are generated through electron transfer

from photocatalyst to oxygen. Thus, the important difference between photocatalyst/ozone degradation and ozone degradation is the initiation step of the reaction [155].

Rajendiran *et al.* studied the photocatalytic-ozonation of textile dye using (UV/TiO₂/O₃) processes. The dyes in textile industries are one of the major pollutions. The COD changed from 760 to 2080 mg/L and Total Organic Carbon (TOC) from 210 to 458 mg/L in this process. The COD removal was obtained 64% after 30 min of treatment with the maximum oxidation [156].

Mahmoodi investigated the photocatalytic ozonation of Reactive Red 198 (RR198) and Reactive Red 120 (RR120) using copper ferrite (CuFe₂O₄) nanoparticles. The nanocatalyst was prepared by the co-precipitation method. The effect of different parameters like the dosage of nanocatalyst, pH, salt (inorganic anions), and initial dye concentration were studied. The dominant aliphatic intermediates were determined formate, oxalate, and acetate anions. The mineralization products of dyes were obtained from nitrate and sulfate [157]. In another research, the same researcher studied the photocatalytic ozonation of Reactive Red 198 (RR198) and Direct Green 6 (DG6) dyes using nickel-zinc ferrite magnetic nanoparticle (NZFMN). The dyes were degraded 100% by hotocatalytic ozonation in the presence of NZFMN [158]. Furthermore, the photocatalytic ozonation (UV/O₃) of Reactive Red 198 (RR198) and also Direct Green 6 (DG6) dyes were investigated

Table 8: Summary of photocatalytic ozonation studies in the removal of dyes.

Entry	Dye	Time (min)	T (°C)	Catalyst Type	pH	Color Removal (%)	COD Removal (%)	TOC Removal (%)	Ref.
1	Textile dyeing industries	30	-	TiO ₂	10	98	64	-	[156]
2	Reactive Red 198 (RR198) and Reactive Red 120 (RR120)	20	25	Copper ferrite (CuFe ₂ O ₄) nanoparticle	3	66.7 MgI-88.6 RhB	-	-	[157]
3	Reactive Red 198 (RR198) and Direct Green 6 (DG6)	20	25	Nickel-zinc ferrite magnetic nanoparticle (NZFMN)	3	100	-	-	[158]
4	Reactive Red 198 (RR198) and Direct Green 6 (DG6)	-	25	Multiwalled carbon nanotube (MWCNT)	3	100	-	-	[159]
5	Aniline (ANL) aqueous solutions	60	25	TiO ₂ -carbon composite	5.6	-	-	70	[160]
6	Orange II	60	90	Bi ₂ O ₃ and Au/Bi ₂ O ₃ nanorods	5.3	75	-	-	[161]
7	Phenazopyridine (PhP)	35		TiO ₂ nanoparticles coated on ceramic plates	7	85	-	-	[162]

by Mahmoodi in the presence of a MultiWalled Carbon NanoTube (MWCNT). The optimal conditions were achieved in an initial RB5 concentration of 150 mg/L, pH 3, and 0.03 g/L catalyst dosage at room temperature (25°C) [159].

Orge *et al.* studied the photocatalytic ozonation of aniline (ANL) using multi-walled carbon nanotubes (MWCNT), neat titanium dioxide (TiO₂), and a composite of TiO₂ and MWCNT. 50 g/m³ of ozone was consumed in photocatalytic and catalytic ozonation of aniline in 15 min. The total aniline conversion was obtained by using commercial TiO₂, P25, and the composite of P25/MWCNT 80:20 (w/w) in longer reaction times. The TOC removal was 70% in all photocatalytic ozonation processes. The oxalic acid (OXA) was completely removed by photocatalytic ozonation, while oxamic acid remained [160]. The Combination of photocatalysis and ozonation for degradation of the organic dyes is introduced as an efficient method. Some of the recent studies in the photocatalytic ozonation of dyes are summarized in Table 8.

Photo-Fenton (Fe²⁺ or Fe³⁺/H₂O₂/UV)

The Fenton processes usually lead to uncompleted mineralization, reduction of the recycling of Fe (III), and other competitive reactions. The reaction of Fe(III) with organic compounds gives stable Fe(III) compounds. Thus, further oxidation and mineralization will be difficult. One of the ways for high mineralization is the photo-Fenton's method. The Fenton processes can be considerably increased under ultraviolet light that called photo-Fenton's

method. The complexation of ferric ions generates extra hydroxyl radicals under irradiation. These ions react with more H₂O₂ compounds in the Fenton reaction [163-167].

Shaban *et al.* studied the photo-Fenton oxidation of Congo red dye by natural chromite (FeO.Cr₂O₃). The effect of different parameters like the illumination time, dosage of catalyst, pH, and initial dye concentration were studied. The optimal conditions for photocatalytic degradation of Congo red dye were achieved at 12 mg/L of the dye concentration, 0.14 g of the chromite dosage, pH = 3, and 11 h of the illumination time. In addition, the percentage of degradation was observed 100% with 13.5 mg/L of the dye concentration, 0.10 g of the chromite dosage, pH 3, and 11 h of the illumination time. The chromium oxide and ferrous oxide generate the binary oxide system in Fe-chromite. The photocatalytic properties were obtained by H₂O₂ under photo-Fenton oxidation and UV irradiation. The percentage of degradation was observed with H₂O₂ 59.4% after 8 h and 54.6% after 12 h in the absence of H₂O₂. The second-order rate law was obtained for photocatalytic degradation and photo-Fenton oxidation kinetics. The photo-Fenton oxidation of Congo red dye in the presence of natural chromite was more effective than the photocatalytic degradation. Thus, the values of kinetic rate constants were great for the photo-Fenton oxidation in the competition of the photocatalytic degradation [168].

The magnetic diatomite/Fe₂O₃/TiO₂ composite was used as an efficient catalyst for the degradation of

Table 9: Summary of photo-Fenton's oxidation process studies in the removal of dyes.

Entry	Dye	Time (min)	[H ₂ O ₂]	[Fe ²⁺]	Catalyst	pH	Color Removal (%)	COD Removal (%)	TOC Removal (%)	Ref.
1	Congo red	600	1 mL	0.1 g	FeO.Cr ₂ O ₃	4	100	-	-	[168]
2	Methylene blue (MB)	40	1.2 mL	2 mg/L	diatomite/ Fe ₂ O ₃ /TiO ₂ composites	7	98.86	-	65.5	[169]
3	Rhodamine B (RhB)	60	40 mM	1 g/L	Iron molybdate Fe ₂ (MoO ₄) ₃ nanopowders	-	97	-	-	[170]
4	Malachite green (MG)	60	90 mM	0.1 g/L	Double shell hollow Fe ₂ O ₃	-	99.9	-	-	[171]
5	Reactive black 5 (RB5)	60	11 mM	-	-	3	100	-	-	[172]
6	Carmoisine edible dye	12	0.3 mmol	0.0125 mmol	-	3.5	95.8	89	-	[99]
7	Rhodamine B (RhB)	120	10 mM	1 g/L	Graphene oxide (GO)-FePO ₄ composites	2.18	93	-	-	[173]
8	Rhodamine B (RhB)	60	6 mM	0.4 g/L	Iron modified rectorite	3	99	-	-	[174]
9	Rhodamine B (RhB)	100	12 mM	2 g/L	Poly-hydroxyl-iron/sepiolite (H-Fe-S)	2.5	99.8	86.1	38	[97]
10	Acid Blue 193, Reactive Black 39	45	35 mM	1.5 mM	-	3	99	83	58	[175]

methylene blue dye under the photo-Fenton system by *Barbosa et al.* This reaction was performed under neutral pH. The catalyst was synthesized by the co-precipitation method in the presence of diatomite. Then, the catalyst was saturated with TiO₂. The optimal amount of the catalyst was obtained 2.0 g/L for photodegradation degradation. The percentage of the degradation of methylene blue was observed 98.86% with 2.0 g/L of the catalyst after 40 min at 75°C. Therefore, this procedure is very striking for industrial application in oxidative methods with an effective catalyst [169].

Rashad et al. studied the photo-Fenton-Like removal of Rhodamine B dye using iron molybdate Fe₂(MoO₄)₃ nanopowder under visible light irradiation. The catalyst was synthesized by co-precipitation and sol-gel auto-combustion methods. The highest photo-Fenton catalytic activity was exhibited 97% for the degradation of RhB dye after 60 min. These results are related to the strong absorption and the high surface area of Fe₂(MoO₄)₃ in visible light [170].

The degradation of Carmoisine edible dye by photo-Fenton and Fenton processes from aqueous solutions through Taguchi orthogonal design investigated by *Sohrabi et al* [99]. The effect of operating parameters such as the dosage of H₂O₂, pH, the dosage of Fe²⁺, and initial

dye concentration were studied. The optimal conditions for photo-Fenton of Carmoisine edible dye were achieved 0.3 mmol H₂O₂, 0.0125 mmol Fe²⁺, 20 mg/L of the initial dye concentration, pH 3.5. The percentage of degradation was observed 95.1% for the photo-Fenton processes in optimal conditions. Some studies using photo-Fenton's reagent oxidation of dyes are illustrated briefly in Table 9.

UV/Chlorine

The chlorine solutions are consumed in swimming pools under direct sunlight as a disinfectant [176]. The effect of chlorine solutions can be considerably increased under ultraviolet light as the UV/chlorine process. The hydroxyl radicals are the predominant active species of the UV/chlorine process [176]. Chatib et al. studied the decolorization kinetics of Ponceau S dye under sunlight/chlorine and UV/chlorine processes [50]. The decolorization rates of Ponceau S solutions were obtained 47.6%, 52.4%, and 99.2%, respectively in dark/chlorine, sunlight/chlorine, and UV/chlorine processes at pH 4.5. The efficacy of UV in combination with chlorine dioxide (UV/ClO₂) for color degradation of the azure C dye in an aqueous solution was investigated by *Habeeb and Khayoon* [177]. The maximum color removal of 93.8% was achieved under optimal conditions at a dosage of

Table 10: Summary of UV/Chlorine process studies in the removal of dyes.

Entry	Dye	Time (min)	T (°C)	UV Intensity mW/cm ²	Condition	pH	Color Removal (%)	TOC Removal (%)	Ref.
1	Ponceau S dye (PS)	5	25 ± 2	-	UV/Chlorine/	4.5	99.2	-	[50]
2	Ponceau S dye (PS)	5	25 ± 2	-	Sunlight/Chlorine	4.5	52.4	-	[50]
3	Ponceau S dye (PS)	5	25 ± 2	-	Dark/Chlorine	4.5	47.6	-	[50]
4	C.I. Reactive Red 2 (RR2)	6	25 ± 2	2	UV/Chlorine	7	97.9	-	[178]
5	Rhodamine-B (RhB)	75	30 ± 2	0.7	UV/Chlorine	7	98.5	40	[179]
6	Azure C	60	25 ± 2	173.7	UV/Chlorine	8	93.8	-	[177]

1×10⁻⁵ M of azure C, 173.7 mW/cm² of light intensity, 25 ± 2 °C of temperature, and pH of 8 at 60 mins. Some studies using UV/chlorine of dyes removal are illustrated briefly in Table 10.

CONCLUSIONS

In this review, the efficiency of AOPs techniques based on green approaches for successful wastewater treatment was discussed. The optimum operating parameters were differed due to the wastewater quantity and quality. The efficiency of degradation in many results was observed with high yields. However, the invention of new approaches with high efficiency and low environmental effect for the decolorization of the mixture of dyes is a challenge. Therefore, the introduction of new methods for the decolorization of the mixture of dyes is under investigation by many research groups.

THE RESEARCH METHODE

This review is presented according to library research involving the reviews, books, and literature.

Acknowledgments

We gratefully acknowledge the staff of the Research Council of the University of Guilan for their collaboration in this study.

Received : Feb. 27, 2020 ; Accepted : Jun. 8, 2020

REFERENCES

- [1] Badami B.V., *Concept of Green Chemistry, Resonance*, **13(11)**: 1041-1048 (2008).
- [2] Anastas P., Warner J.C., *“Green Chemistry: Theory and Practice”*, Oxford University Press, Oxford (1998).
- [3] Anastas P.T., Kirchoff M.M., *Origins, Current Status, and Future Challenges of Green Chemistry, Acc. Chem. Res*, **35(9)**: 686-694 (2002).
- [4] Clark J.H., *Green Chemistry: Challenges and Opportunities, Green Chem*, 1-8 (1999).
- [5] Deshpande B.D., Agrawal P.S., Yenkie M.K.N., Dhoble J.S., *Prospective of Nanotechnology in Degradation of Waste Water: A New Challenges, Nano-Struct. Nano-Objects*, **22**: 100442- (2020).
- [6] Agrawal P.S., Kale, S., Mangrulkar, V., *A Review on Cartridge Ink as an Adsorbent to Treat Waste Water; Our Heritage ISSN: 0474-9030*, **68(30)**: (2020).
- [7] Anastas P.T., Williamson T.C., *“Green Chemistry: Designing Chemistry for the Environment”*, American Chemical Series Books, Washington, DC (1996).
- [8] Anastas P, Eghbali N., *Green Chemistry: Principles and Practice, Chem. Soc. Rev*, **39**: 301-312 (2010).
- [9] Clark J.H., *“Green Chemistry and Environmentally Friendly Technologies, Green Separation Processes”*. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim (2005).
- [10] Manahan S., *“Green Chemistry and the Ten Commandments of Sustainability”*, 3rd ed. ChemChar Research, Inc Publishers, Columbia, Missouri (2010).
- [11] Anastas P.T., *“Clean Solvent Alternative Media for Chemical Reactions and Processing”*, ACS Symposium Series 819, Washington, DC (2002).
- [12] Sheldon R.A., *Green Solvents for Sustainable Organic Synthesis: State of the Art, Green Chem.*, **7**: 267-278 (2005).
- [13] Constable D.J.C., Curzons A.D., Cunningham V.L., *Metrics to ‘Green’ Chemistry-Which Are the Best? Green Chem*, **4**: 521-527 (2002).

- [14] Chiappe C., "Eco-Friendly Synthesis of Fine Chemicals, Task-specific Ionic Liquids for Fine Chemicals", Royal Society of Chemistry (2009).
- [15] Kerton F.M., "Alternative Solvents for Green Chemistry, RSC Green Chemistry Book Series", Royal Society of Chemistry (2009).
- [16] Varma R.S., Ju Y., "Green Separation Processes", Wiley-VCH Verlag GmbH & Co KGaA, Weinheim, Germany, 53-87 (2005).
- [17] Breslow R., "The Principles and Reasons for Using Water as a Solvent for Green Chemistry," Eds. Paul Anastas and Chao-Jun Li, Wiley-VCH, Weinheim Germany, 1-29 (2010).
- [18] Cole-Hamilton D.J., Tooze Robert P., "Catalyst Separation Recovery and Recycling", Chemistry and Process Design", Springer, Netherlands (2006).
- [19] Welton T., Room-temperature Ionic Liquids. Solvents for Synthesis and Catalysis, *Chem. Rev.*, **99**: 2071-2084 (1999).
- [20] Plechkova N.V., Seddon K.R., "In Methods and Reagents for Green Chemistry-Ionic Liquids: "Designer" Solvents for Green Chemistry", John Wiley & Sons Inc, Hoboken, 105-130 (2007).
- [21] Wasserscheid P., Welton T., "In Ionic Liquids in Synthesis", Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim (2007).
- [22] Vekariya R.L., A Review of Ionic Liquids: Applications Towards Catalytic Organic Transformations, *J. Mol. Liq.*, **227**: 44-60 (2017).
- [23] Shirini F., Rad-Moghadam K., Akbari-Dadamahaleh S., Application of ionic Liquids in Multicomponent Reactions, *Green Solvents II*, Springer, 289-334 (2012).
- [24] Shirini F., Abedini M., Seddighi M., Goli Jolodar O., Safarpour Nikoo Langroodi M., Zamani S., Introduction of a new bi-SO₃H Ionic Liquid Based on 2,2'-Bipyridine as a Novel Catalyst for the Synthesis of Various Xanthene Derivatives, *RSC Adv.*, **4(108)**: 63526-63532 (2014).
- [25] Shirini F., Abedini M., Mahmoodi N., Biglari M., Safarpour Langroodi M., Introduction of a New Ionic Liquid Catalyst for the Trimethylsilyl and Tetrahydropyranyl Protection of Alcohols, *Phosphorus, Sulfur Silicon Relat. Elem.*, **190(11)**: 1912-1921 (2015).
- [26] Rad-Moghadam K., Sharifi-Kiasaraie M., Azimi S.C., Synthesis of 4-substituted pyrano[4,3-b]pyran-2,5-Diones in an Ionic Liquid, *Tetrahedron*, **68**: 6472-6476 (2012).
- [27] Rad-Moghadam K., Azimi S.C., "Mg(BF₄)₂ Doped in [BMIm][BF₄]: A Homogeneous Ionic Liquid-Catalyst for Efficient Synthesis of 1,8 dioxo-octahydroxanthenes, Decahydroacridines and 14-aryl-14H-dibenzo[a,j]xanthenes, *J. Mol. Catal. A: Chem.*, **363-364**: 465-469 (2012).
- [28] Rad-Moghadam K., Azimi S.C., Abbaspour-Gilandeh E., Synthesis of Novel Pyrano[3,2-c]quinoline-2,5-Diones Using an Acidic Ionic Liquid Catalyst, *Tetrahedron Lett.*, **54**: 4633-4636 (2013).
- [29] Azimi S.C, Rad-Moghadam K., [BMIm]BF₄-LiCl as an Effective Catalytic System for the Synthesis of Dicoumarols, *Iran. Chem. Commun.*, **3**: 356-366 (2015).
- [30] Lofrano G., "Emerging Compounds Removal from Wastewater-Natural and Solar Based Treatments", Springer (2012).
- [31] Lucas M.S., Peres J.A., Decolorization of the Azo Dye Reactive Black 5 by Fenton and Photo-Fenton Oxidation, *Dyes Pigm.*, **71(3)**: 236-244 (2006).
- [32] Chatwal G.R., "Synthetic Dyes". Himalaya Publishing House Pvt. Ltd (2009).
- [33] Hunger K., "Industrial Dyes: Chemistry, Properties, Applications". Wiley-VCH. Verlag GmbH & Co. KGaA, Weinheim (2007).
- [34] Hua L., Ma H., Zhang L., Degradation Process Analysis of the Azo Dyes by Catalytic Wet Air Oxidation with Catalyst CuO/γ-Al₂O₃, *Chemosphere*, **90(2)**: 143-149 (2013).
- [35] Shu H.Y., Chang M.C., Pre-Ozonation Coupled with UV/H₂O₂ Process for the Decolorization and Mineralization of Cotton Dyeing Effluent and Synthesized C.I. Direct Black 22 Wastewater, *J. Hazard. Mater.*, **121(1-3)**: 127-133 (2005).
- [36] Kusic H., Koprivanac N., Srsan L., Azo Dye Degradation Using Fenton Type Processes Assisted by UV Irradiation: A Kinetic Study, *J. Photochem. Photobiol.A: Chem.*, **181**: 195-202 (2006).
- [37] Sharma S.K., "Green Chemistry for Dyes Removal from Wastewater, Research Trends and Applications", John Wiley & Sons Inc. (2015).

- [38] Chaudhari K., Bhatt V., Bhargava A., Seshadri S., [Combinational System for the Treatment of Textile Waste Water: A Future Perspective](#), *Asian J. Water Environ. Pollut*, **8**: 127-136 (2011).
- [39] Azimi S.C., Shirini F, Pendashteh A.R., [Evaluation of COD and Turbidity Removal from Woodchips Wastewater Using Biologically Sequenced Batch Reactor](#), *Process Saf. Environ. Prot.* **128**: 211-227 (2019).
- [40] Ebrahimzadeh M.A., Naghizadeh A., Amiri O., Shirzadi-Ahodashia M., Mortazavi-Derazkola S., [Green and Facile Synthesis of Ag Nanoparticles Using Crataegus Pentagyna Fruit Extract \(CP-AgNPs\) for Organic Pollution Dyes Degradation and Antibacterial Application](#), *Bioorg. Chem.*, **94**: 103425 (2020).
- [41] Naghizadeh A., Nabizadeh R., [Removal of Reactive Blue 29 Dye by Adsorption on Modified Chitosan in Presence of Hydrogen Peroxide](#), *Environ. Prot. Eng*, **42**(1): 149-168 (2016).
- [42] Kamranifar M., Naghizadeh A., [Montmorillonite Nanoparticles in Removal of Textile Dyes from Aqueous Solutions: Study of Kinetics and Thermodynamics](#), *Iran. J. Chem. Chem. Eng. (IJCCE)*, **36**(6): 127-137 (2017).
- [43] Zhao V., Zhai J.Y., Chen J., Bian W., Li J., [Equilibrium and Kinetics Study of Reactive Dyes Removal from Aqueous Solutions by Bentonite Nanoparticles](#), *Desalin. Water Treat*, **79**: 329-377 (2017).
- [44] Naghizadeh A., Ghafouri M., [Synthesis and Performance Evaluation of Chitosan Prepared from Persian Gulf Shrimp Shell In Removal of Reactive Blue 29 Dye from Aqueous Solution \(Isotherm, thermodynamic and kinetic study\)](#), *Iran. J. Chem. Chem. Eng (IJCCE)*, **36**(3): 25-36 (2017).
- [45] Dehghani M.H., Naghizadeh A., Rashidi A., Derakhshani E., [Adsorption of Reactive Blue 29 Dye from Aqueous Solution by Multiwall Carbon Nanotubes](#), *Desalin. Water Treat*, **51**(40-42): 7655-7662 (2013).
- [46] Bergamini R.B.M., Azevedo E.B., Araujo L.R.R., [Heterogeneous Photocatalytic Degradation of Reactive Dyes in Aqueous TiO₂ Suspensions: Decolorization Kinetics](#), *Chem. Eng. J.*, **149**: 215-220 (2009).
- [47] Chen T.Y., Kao C.M., Hong A., Lin C.E., Liang S.H., [Application of Ozone on the Decolorization of Reactive Dyes Orange](#), *Desalination*, **249**: 1238-1242 (2009).
- [48] Devi L.G., Kumar S.G., Reddy K.M., Munikrishnappa C., [Photo Degradation of Methyl Orange an Azo Dye by Advanced Fenton Process Using Zero Valent Metallic Iron: Influence of Various Reaction Parameters and Its Degradation Mechanism](#), *J. Hazard. Mater*, **164**: 459-467 (2009).
- [49] Gupta V.K., Ali I., Saleh T.A., Nayak A., Agarwal S., [Chemical Treatment Technologies for Waste-Water Recycling-an Overview](#), *RSC Adv.*, **2**: 6380-6388 (2012).
- [50] Chatib B., Boussaoud A., Khayar V., Laftani Y., Elmakhfouk M., Hachkar M., [Decolorization Kinetics of Ponceau S Dye by Chemical Chlorination: A Comparison with Sunlight/ Chlorine and UV/Chlorine Processes](#), *Iran. J. Chem. Chem. Eng. (IJCCE)*, **40** (1) :111-121 (2021).
- [51] Yenkie M., ["Optimization of Dye Degradation Process By Oxidative Technology"](#), *Proceeding: AIChE Annual Meeting* (2018).
- [52] Deshpande B.D., Agrawal P.S., Yenkie M.K.N., ["AOP as a Degradative Tool for Oxidation of 4-Hydroxybenzoic Acid"](#), *AIP Conference Proceedings 2104(1):020034; International Conference on 'Multidimensional Role of Basic Science in Advanced Technology' Icmbat* (2018).
- [53] Deshpandea B.D., Agrawal P.S., Yenkie M.K.N., ["Advanced Oxidative Degradation Of Benzoic Acid and 4-Nitro Benzoic Acid-A Comparative Study"](#), *AIP Conference Proceedings 2142:210003* (2019).
- [54] Deshpande B.D., Agrawal P.S., Yenkie M.K.N., ["Nanoparticles Aided AOP for Degradation of p-Nitro Benzoic Acid"](#), *Materials Today: Proceedings*, (2020).
- [55] Mota A.L.N., Albuquerque L.F., Beltrame L.T.C., Chivone-Filho O., Machulek A., Nascimento C.A.O., [Advanced Oxidation Processes and Their Application in the Petroleum in the Petroleum Industry: A Review"](#), *Braz. J. Petroleum. Gas*, **2**(3): 122-142 (2008).
- [56] O'Shea K.E., Dionysiou D., [Advanced Oxidation Processes for Water Treatment](#), *J. Phys. Chem. Lett*, **3**: 2112-2113 (2012).

- [57] De Souza S.M.G.U., Bonilla K.A.S., De Souza A.A.U., Removal of COD and Color from Hydrolyzed Textile Azo Dye by Combined Ozonation and Biological Treatment, *J. Hazard. Mater*, **179**: 35-42 (2010).
- [58] Liakou S., Cornaros M., Lyberatos G., Pretreatment of Azo Dyes Using Ozone, *Water Sci. Technol*, **36**: 155-163 (1997).
- [59] Sukanchan P., An Overview of Ozonation Associated with Nano-Filtration as an Effective Procedure in Treating Dye Effluents from Textile Industries with The Help of a Bubble Column Reactor, *Int. J. Chem. Sci.*, **16(2)**: 83-86 (2012).
- [60] Hoigne J., Bader H., The Role of Hydroxyl Radical Reactions in Ozonation Processes in Aqueous Solutions, *Water Res.*, **10**: 377-386 (1976).
- [61] Hoigne J., "The Chemistry of Ozone in Water. Process Technologies for Water Treatment", Plenum Publishing Corporation, New York 121-141 (1998).
- [62] Hoigne J., Chemistry of Aqueous Ozone and Transformation of Pollutants by Ozonation and Advanced Oxidation Processes, *Quality and Treatment of Drinking Water II*: 83-141 (1998).
- [63] Kormmuller A., Karcher S., Jekel M., Cucurbituril for water treatment. Part II: Ozonation and Oxidative Regeneration of Cucurbituril. Cucurbituril for Water Treatment. Part II: Ozonation and Oxidative Regeneration of Cucurbituril, *Water Res.*, **35**: 3317-3324 (2001).
- [64] Kasprzyk-Hordern B., Ziółek MM., Nawrocki J., Catalytic Ozonation and Methods of Enhancing Molecular Ozone Reactions in Water Treatment, *Appl. Catal. B: Environ.*, **46**: 639-669 (2003).
- [65] Wijannarong S., Aroonsrimorakot S., Thavipoke P., Kumsopa C., Sangjan S., Removal of Reactive Dyes from Textile Dyeing Industrial Effluent by Ozonation Process, *APCBEE Procedia*, **5**: 279-282 (2013).
- [66] Sarayu K., Swaminathan K., Sandhya S., Assessment of Degradation of Eight Commercial Reactive Azo Dyes Individually and in Mixture in Aqueous Solution by Ozonation, *Dyes Pigm.*, **75**: 362-368 (2007).
- [67] Wu J., Ma L., Chen L., Cheng Y., Liu Y., Zha X., Catalytic Ozonation of Organic Pollutants from Bio-Treated Dyeing and Finishing Wastewater Using Recycled Waste Iron Shavings as a Catalyst: Removal and Pathways, *Water Res.*, **92**: 140-148 (2016).
- [68] Asgari G., Akbari S., Mohammadi A.S.M., Poormohammadi A., Ramavandi B., Preparation and Catalytic Activity of Bone-Char Ash Decorated with MgO-FeNO₃ for Ozonation of Reactive Black 5 Dye from Aqueous Solution: Taguchi Optimization Data, *Data in Brief*, **13**: 132-136 (2017).
- [69] Orge C.A., Orfao M.J.J., Pereira M.F.R., De Farias A.M.D., Fraga M.A., Ceria and Cerium-Based Mixed Oxides as Ozonation Catalysts, *Chem. Eng. J.*, **200-202**: 499-505 (2012).
- [70] Muthukumar M., Sargunamani D., Selvakumar N., Venkata Rao J., Optimisation of Ozone Treatment for Colour and COD Removal of Acid Dye Effluent Using Central Composite Design Experiment, *Dyes Pigm.*, **63**: 127-134 (2004).
- [71] Liu X., Zhou Z., Jing G., Fang J., Catalytic Ozonation of Acid Red. B in Aqueous Solution over a Fe-Cu-O Catalyst, *Sep. Purif. Technol.*, **115**: 129-135 (2013).
- [72] Kasiri M.B., Modirshahl M., Mansouri H., Decolorization of Organic Dye Solution by Ozonation; Optimization with Response Surface Methodology, *Int. J. Ind. Chem.*, **4(3)**: 2-10 (2013).
- [73] Tehrani-Bagha A.R., Mahmoodi N.M., Menger F.M., Degradation of a Persistent Organic Dye from Coloured Textile Wastewater by Ozonation, *Desalination*, **260(1-3)**: 34-38 (2010).
- [74] Pachhade K., Sandhya S., Swaminathan K., Ozonation of Reactive Dye, Procion Red MX-5B Catalyzed by Metal Ions, *J. Hazard. Mater*, **167(1-3)**: 313-318 (2009).
- [75] Faria P.C.C., Orfao J.J.M., Pereira M.F.R., Activated Carbon and Ceria Catalysts Applied to the Catalytic Ozonation of Dyes and Textile Effluents, *Appl. Catal. B*, **88(3-4)**: 341-350 (2009).
- [76] Moussavi G., Mahmoudi G., Degradation and Biodegradability Improvement of the Reactive Red 198 Azo Dye Using Catalytic Ozonation with MgO Nanocrystals, *Chem. Eng. J.*, **152(1)**: 1-7 (2009).
- [77] Fanchiang J.M., Tseng D.H., Degradation of Anthraquinone dye C.I. Reactive Blue 19 in Aqueous Solution by Ozonation, *Chemosphere*, **77**: 214-221 (2009).
- [78] Oguz E., Keskinler B., Celik Z., Ozonation of Aqueous Bomaplex Red CR-L Dye in a Semi-Batch Reactor, *Dyes Pigm.*, **64(2)**: 101-108 (2005).

- [79] Gokcen F., Ozbelge T.A., [Pre-ozonation of Aqueous Azo Dye \(Acid Red-151\) Followed by Activated Sludge Process](#), *Chem. Eng. J.*, **123**(3): 109-115 (2005).
- [80] Zhao W.R., Shi H.X., Wang D.H., [Ozonation of Cationic Red X-GRL in Aqueous Solution: Degradation and Mechanism](#), *Chemosphere*, **57**(9): 1189-1199 (2004).
- [81] Wang C., Yediler A., Lienert D., Wang Z., [“Ozonation of an azo dye C.I. Remazol Black 5 and toxicological Assessment of Its Oxidation Products](#), *Chemosphere*, **52** (7): 1225-1232 (2003).
- [82] Ruan X.C., Liu M.Y., Zeng Q.F., Ding Y.H., [Degradation and Decolorization of Reactive Red X-3B Aqueous Solution by Ozone Integrated with Internal Micro-Electrolysis](#), *Sep. Purif. Technol*, **74**: 195-201 (2010).
- [83] Hassaan M.A., Nemr M.E., Madkour F.F., [Testing the Advanced Oxidation Processes on the Degradation of Direct Blue 86 Dye in Wastewater](#), *Egypt J. Aquat. Res*, **43**: 11-19 (2017).
- [84] Kuo W.G., [Decolorizing dye Wastewater with Fenton's Reagent](#), *Water Res*, **26**(7): 881-886 (1992).
- [85] Walling C., [Intermediates in the Reactions of Fenton Type Reagents](#), *Acc. Chem. Res*, **31**(4): 155-157 (1998).
- [86] Jiang D.B., Liu X., Xu X., Zhang Y.X., [Double-shell Fe₂O₃ Hollow Box-Like Structure for Enhanced Photo-Fenton Degradation of Malachite Green Dye](#), *J. Phys. Chem. Solids*, **112**: 209-215 (2018).
- [87] Arnold S.M., Hickey W.J., Harris R.F., [Degradation of Atrazine by Fenton's Reagent: Condition Optimization and Product Quantification](#), *Environ. Sci. Technol*, **29**: 2083-2089 (1995).
- [88] Ersoz G., [Fenton-Like Oxidation of Reactive Black 5 Using Rice Husk Ash-Based Catalyst](#), *Appl. Catal. B: Environ*, **147**(5): 353-358 (2014).
- [89] Bicaksiz Z., Aytimur G., Atalay S., [Low-Pressure Catalytic Wet-Air Oxidation of a High-Strength Industrial Wastewater Using Fenton's Reagent](#), *Water Environ. Res*, **80**(6): 540-546 (2008).
- [90] Hassan H., Hameed B.H., [Fenton-Like Oxidation of Acid Red 1 Solutions Using Heterogeneous Catalyst Based on Ball Clay](#), *Int. J. Environ. Sci. Dev*, **2**: 218-222 (2011).
- [91] Taghavi K., Purkareim S., Pendashteh A., Chaibakhsh N., [Optimized Removal of Sodium Dodecylbenzenesulfonate by Fenton-Like Oxidation Using Response Surface Methodology”](#), *Iran. J. Chem. Chem. Eng (IJCCE)*, **35**(4): 113-124 (2016).
- [92] Taghavi K., Pendashteh A., Purkareim S., [Combined Fenton-Like Oxidation and Aerobic MBBR Biological Processes for Treatment of the Wastewater of Detergent Industries](#), *Desalin. Water Treat*, **77**: 206-214 (2017).
- [93] Kanaani, F., Tavakoli, B., Pendashteh, A.R., Chaibakhsh, N., Ostovar, F., [Coagulation/Fenton Oxidation Combined Treatment of Compost Leachate Using Quince Seed Mucilage as an Effective Biocoagulant](#), *Environ. Technol.* 1-26 (2019).
- [94] Abedinzadeh, N., Monavari, M., Shariat, M., Pendashteh, A.R., [Optimization Pulp and Paper Wastewater Treatment by Using Advanced Chemical Oxidation Fenton Method](#), *J. Environ. Studies.*, **43**(3): 365-377 (2017).
- [95] Abo-Farha S.A., [Comparative Study of Oxidation of Some Azo Dyes by Different Advanced Oxidation Processes: Fenton, Fenton-Like, Photo-Fenton and Photo-Fenton-Like](#), *J. Am. Sci*, **6**(10): 128-142 (2010).
- [96] Nichela D.A., Berkovic A.M., Costante M.R., Juliarena M.P., Garcia Einschla F.S., [Nitrobenzene Degradation In Fenton-Like Systems Using Cu\(II\) as Catalyst. Comparison between Cu\(II\)- and Fe\(III\)-Based Systems](#), *Chem. Eng. J.*, **228**: 1148-1157 (2013).
- [97] Gao Y., Gan H., Zhang G., Guo Y., [Visible Light Assisted Fenton-Like Degradation of Rhodamine B and 4-Nitrophenol Solutions with a Stable Poly-Hydroxyl-Iron/Sepiolite Catalyst](#), *Chem. Eng. J.*, **217**: 221-230 (2013).
- [98] Ertugay N., Nuran Acar F., [Removal of COD and Color from Direct Blue 71 Azo Dye Wastewater by Fenton's Oxidation: Kinetic Study](#), *Arabian J. Chem*, **10**: S1158-S1163 (2017).
- [99] Sohrabi M.R., Khavaran A., Shariati S., Shariati S., [Removal of Carmoisine Edible Dye by Fenton and Photo Fenton Processes Using Taguchi Orthogonal Array Design](#), *Arabian J. Chem*, **10**: S3523-S3531 (2017).
- [100] Carvalho S.S.F., Carvalho N.M.F., [Dye Degradation by Green Heterogeneous Fenton Catalysts Prepared in Presence of Camellia Sinensis](#), *J. Environ. Manage*, **187**: 82-88 (2017).

- [101] Idel-Aouad R., Valiente M., Yaacoubi A., Tanouti B., Lopez-Mesas M., [Rapid Decolourization and Mineralization of the Azo Dye C.I. Acid Red 14 by Heterogeneous Fenton Reaction](#), *J. Hazard. Mater.*, **186**(1): 745-750 (2011).
- [102] Daud N.K., Hameed B.H., [Fenton-Like Oxidation of Reactive Black 5 Solution Using Iron-Montmorillonite K10 Catalyst](#), *J. Hazard. Mater.*, **176**(1-3): 1118-1121 (2011).
- [103] Lahkimi A., Oturan M.A., Oturan N., Chaouch M., [Removal of Textile Dyes from Water by the Electro-Fenton Process](#), *Environ. Chem. Lett.*, **5**: 35-39 (2007).
- [104] Meric S., Kaptan D., Tunay O., [Removal of Color and COD from A Mixture of Four Reactive Azo Dyes Using Fenton Oxidation Process](#), *J. Environ. Sci. Health.*, **38**(10): 2241-2250 (2003).
- [105] Rosales E., Pazos M., Longo M.A., Sanroman M.A., [Electro-Fenton Decoloration of Dyes in a Continuous Reactor: A Promising Technology in Colored Wastewater Treatment](#), *Chem. Eng. J.*, **155**: 62-67 (2009).
- [106] Guimaraes J.R., Maniero M.G., De Araujo R.N., [A Comparative Study on the Degradation of RB-19 Dye in an Aqueous Medium by Advanced Oxidation Processes](#), *J. Environ. Manage.*, **110**: 33-39 (2012).
- [107] Daud N.K., Hameed B.H., [Decolorization of Acid Red 1 by Fenton-Like Process Using Rice Husk Ash-Based Catalyst](#), *J. Hazard. Mater.*, **176**: 938-944 (2010).
- [108] Sun J.H., Shi S.H., Lee Y.F., Sun S.P., [Fenton Oxidative Decolorization of the Azo Dye Direct Blue 15 in Aqueous Solution](#), *Chem. Eng. J.*, **155**(3):680-683 (2009).
- [109] Meric S., Selcuk H., Gallo M., Belgiorino V., [Decolourisation and Detoxifying of Remazol Red Dye and Its Mixture Using Fenton's Reagent](#), *Desalination*, **173**: 239-248 (2005).
- [110] Dehghani M., Ghadami M., Gholami T., Ansari Shiri M., Elhameyan E., Javaheri M.R., Shamsedini N., Shahsavani S., [Optimization of the Parameters Affecting the Fenton Process for Decolorization of Reactive Red 198 \(RR-198\) from the Aqueous Phase](#), *J. Health. Sci. Surveillance Sys.*, **3**: 139-145 (2015).
- [111] Sharma S., Kapoor S., Christian R.A., [Effect of Fenton Process on Treatment of Simulated Textile Wastewater: Optimization Using Response Surface Methodology](#), *Int. J. Environ. Sci. Technol.*, **14**(8): 1665-1678 (2017).
- [112] Zhou M., He J., [Degradation of Azo Dye by Three Clean Advanced Oxidation Processes: Wet Oxidation, Electrochemical Oxidation and Wet Electrochemical Oxidation-A Comparative Study](#), *Electrochimica Acta.*, **53**: 1902-1910 (2007).
- [113] Liu Y., Sun D.Z., [Development of Fe₂O₃-CeO₂-TiO₂/g-Al₂O₃ as Catalyst for Catalytic Wet Air Oxidation of Methyl Orange Azo Dye under Room Condition](#), *Appl. Catal. B: Environ.*, **72**: 205-211 (2007).
- [114] Fu J., Kyzas G.Z., [Wet Air Oxidation for the Decolorization of Dye Wastewater: An Overview of the Last Two Decades](#), *Chin. J. Catal.*, **35**: 1-7 (2014).
- [115] Zhang Y., Li D.L., Chen Y., Wang X.H., Wang S.T., [Catalytic Wet Air Oxidation of Dye Pollutants by Polyoxomolybdate Nanotubes under Room Condition](#), *Appl. Catal. B*, **86**: 182-193 (2009).
- [116] Kumar Kondru A., Kumar P., Chand S., [Catalytic Wet Peroxide Oxidation of Azo Dye \(Congo Red\) Using Modified Y Zeolite as Catalyst](#), *J. Hazard. Mater.*, **166**: 342-347 (2009).
- [117] Ovejero G., Rodriguez A., Vallet A., Garcia J., Ni [Supported on Mg-Al Oxides for Continuous Catalytic Wet Air Oxidation of Crystal Violet](#), *J. Appl. Catal. B*, **125**: 166-171 (2012).
- [118] Ma H., Zhuo Q., Wang B., [Characteristics of CuO-MoO₃-P₂O₅ catalyst and its Catalytic Wet Oxidation \(CWO\) of Dye Wastewater Under Extremely Mild Conditions](#), *Environ. Sci. Technol.*, **41**(21): 7491-7496 (2007).
- [119] Levec J., Pintar A., [Catalytic Wet-Air Oxidation Processes: A Review](#), *Catal. Today.*, **124**: 172-184 (2007).
- [120] Arslan-Alaton I., Ferry J.L., [Application of Polyoxotungstates as Environmental Catalysts: Wet Air Oxidation of Acid Dye Orange II](#), *Dyes Pigm.*, **54**: 25-36 (2002).
- [121] Acharya N., Gupta V., Pawar N., Kumar Chaudhari P., [Catalytic Treatment of Dye Bearing Wastewater](#), *Chem. Mater. Res.*, **7**(12): 25-34 (2015).
- [122] Huang J., Wang X., Li S., Wang Y., [ZnO/MoO₃ Mixed Oxide Nanotube: A Highly Efficient and Stable Catalyst for Degradation of Dye by Air Under Room Conditions](#), *Appl. Surf. Sci.*, **257**: 116-121 (2010).

- [123] Ersoz G., Napoleoni A., Atalay S., [Comparative Study Using Chemical Wet Oxidation for Removal of Reactive Black 5 in the Presence of Activated Carbon](#), *J. Environ. Eng.*, **139**: 1462-1469 (2013).
- [124] Ribeiro R.S., Fathy N.A., Attia A.A., Silva A.M.T., Faria J.L., Gomes H.T., [Activated Carbon Xerogels for the Removal of the Anionic Azo Dyes Orange II and Chromotrope 2R by Adsorption and Catalytic Wet Peroxide Oxidation](#), *Chem. Eng. J.*, **195-196**: 112-121 (2012).
- [125] Chang D.J., Chen I.P., Chen M.T., Lina S.S., [Wet Air Oxidation of A Reactive Dye Solution Using CoAlPO₄-5 and CeO₂ Catalysts](#), *Chemosphere*, **52(6)**: 943-949 (2003).
- [126] Vallet A., Ovejero G., Rodriguez A., Peres J.A., Garcia J., [Ni/MgAlO Regeneration for Catalytic Wet Air Oxidation of an Azo-Dye in Trickle-Bed Reaction](#), *J. Hazard. Mater.*, **244-245**: 46-53 (2013).
- [127] Xu Y., Li X., Cheng X., Sun D., Wang X., [Degradation of Cationic Red GTL by Catalytic Wet Air Oxidation over Mo-Zn-Al-O Catalyst under Room Temperature and Atmospheric Pressure](#), *Environ. Sci. Technol.*, **46**: 2856-2863 (2012).
- [128] Gutierrez M.C., Crespi M., [A Review of Electrochemical Treatments for Color Elimination](#), *J. Soc. Dyers Colour.*, **115**: 342-345 (1999).
- [129] Morsi M.S., Al-Sarawy A.A., Shehab El-Dein W.A., [Electrochemical Degradation of Some Organic Dyes by Electrochemical Oxidation on a Pb/PbO₂ Electrode](#), *Desalin. Water Treat.*, **26**: 301-308 (2011).
- [130] Elahmadi M.F., Bensalah N., Gadri A., [Treatment of Aqueous Wastes Contaminated with Congo Red Dye by Electrochemical Oxidation and Ozonation Processes](#), *J. Hazard. Mater.*, **168(2-3)**: 1163-1169 (2009).
- [131] Rajkumar D., Kim J.G., [Oxidation of Various Reactive Dyes with in Situ Electro-Generated Active Chlorine for Textile Dyeing Industry Wastewater Treatment](#), *J. Hazard. Mater.*, **B136**: 203-212 (2006).
- [132] Jovic M., Stankovic D., Manojlovic D., Andelkovic I., Milic A., Dojcinovic B., Roglic G., [Study of the Electrochemical Oxidation of Reactive Textile Dyes Using Platinum Electrode](#), *Int. J. Electrochem. Sci.*, **8**: 168-183 (2013).
- [133] Najafpoor A.A., Davoudi M., Rahmanpour Salmani E., [Decolorization of Synthetic Textile Wastewater Using Electrochemical Cell Divided by Cellulosic Separator](#), *J. Environ. Health. Sci. Eng.*, **15**: 1-11(2017).
- [134] Raghu S., Lee C.W., Chellammal S., Palanichamy S., Ahmed Basha C., [Evaluation of Electrochemical Oxidation Techniques for Degradation of Dye. Effluents-A Comparative Approach](#), *J. Hazard. Mater.*, **171**: 748-754 (2009).
- [135] Indu M.S., Gupta A.K., Sahoo C., [Electrochemical Oxidation of Methylene Blue Using Lead Acid Battery Anode](#), *APCBEE Procedia.*, **9**: 70-74 (2014).
- [136] Araujo C.K.C., Oliveira G.R., Fernandes N.S., Zanta C.L.P.S., Castro S.S.L., Da Silva D.R., Martinez-Huitle C.A., [Electrochemical Removal of Synthetic Textile Dyes from Aqueous Solutions Using Ti/Pt Anode: Role of Dye Structure](#), *Environ. Sci. Pollut. Res.*, **21(16)**: 9777-9784 (2014).
- [137] Chatzisyneon E., Xekoukoulotakis N.P., Coz A., Kalogerakis N., Mantzavinos D., [Electrochemical Treatment of Textile Dyes and Dyehouse Effluents](#), *J. Hazard. Mater.*, **B137**: 998-1007 (2006).
- [138] Anthuvan Babu S., Raja S., Sibi S., Neera ja P., [Electrochemical Oxidation of Textile Polluted Water and its Reuse](#), *J. Ind. Pollut. Control.*, **28(1)**: 73-82 (2012).
- [139] Ramesh Babu B., Kuber Parande A., Arun Kumar S., Udaya Bhanu S., [Treatment of Dye Effluent by Electrochemical and Biological Processes](#), *Open J. Saf. Sci. Technol.*, **1**: 12-18 (2011).
- [140] Tahir H., Rauf Shah A., Iqbal S., Kifayatullah H.M., [The Statistical Optimization of Indirect Electrochemical Oxidation Process for the Treatment of Dye from Simulated Textile Discharge](#), *Int. J. Environ. Sci. Nat. Res.*, **2(2)**: 555-583 (2017).
- [141] Nidheesh P.V., Zhou M., Oturan M.A., [An Overview On The Removal Of Synthetic Dyes From Water by Electrochemical Advanced Oxidation Processes](#), *Chemosphere*, **197**: 210-227 (2018).
- [142] Jager D., Kupka D., Vaclavikova M., Ivanicova L., Gallios G., [Degradation of Reactive Black 5 by Electrochemical Oxidation](#), *Chemosphere*, **190**: 405-416 (2018).
- [143] Litter M.I., [Introduction to Photochemical Advanced Oxidation Processes for Water Treatment](#), *Environ. Photochem. Part II*, 325-366 (2005).

- [144] Mahadwad O.K., Parikh P.A., Jasra R.V., Patil C., Photocatalytic Degradation of Reactive Black-5 Dye Using TiO₂-Impregnated Activated Carbon, *Environ. Technol.*, **33**(3): 307-312 (2012).
- [145] Yoon J., Baek M., Hong J., Lee C., Suh J., Korean, Photocatalytic Degradation of Azo Dye Using TiO₂ Supported on Spherical Activated Carbon, *J. Chem. Eng.*, **29**(12): 1722-1729 (2012).
- [146] Li H., Zhu L., Ma C., Zhang H., TiO₂ Hollow Microspheres: Synthesis, Photocatalytic Activity, and Selectivity for a Mixture of Organic Dyes, *Monatsh Chem.*, **145**(1): 29-37 (2013).
- [147] Nezamzadeh-Ejhih A., Karimi-Shamsabad M., Decolorization of a Binary Azo Dyes Mixture Using CuO Incorporated Nanozeolite-X as a Heterogeneous Catalyst and Solar Irradiation, *Chem. Eng. J.*, **228**: 631-641 (2013).
- [148] Nezamzadeh-Ejhih A., Moazzeni N., Sunlight Photodecolorization of a mixture of Methyl Orange and Bromocresol Green by CuS incorporated in a Clinoptilolite Zeolite as a Heterogeneous Catalyst, *J. Ind. Eng. Chem.*, **19**(5): 1433-1442 (2013).
- [149] Nezamzadeh-Ejhih A., Zabihi-Mobarakeh H., Heterogeneous Photodecolorization of Mixture of Methylene Blue and 3-Bromophenol Blue Using CuO-Nano-Clinoptilolite, *J. Ind. Eng. Chem.*, **20**(4): 1421-1431 (2014).
- [150] Sahoo C., Gupta AK., Indu M., Pillai S., Photocatalytic Degradation of Methylene Blue Dye from Aqueous Solution Using Silver Ion-Doped TiO₂ and Its Application to the Degradation of Real Textile wastewater, *J. Environ. Sci. Health. Part A*, **47**: 1428-1438 (2012).
- [151] Alvia M.A., Al-Ghamdia A.A., ShaheerAkhtar M., Synthesis of ZnO Nanostructures via Low Temperature Solution Process for Photocatalytic Degradation of Rhodamine B Dye, *Mater. Lett.*, **204**: 12-15 (2017).
- [152] Stanthi M., Kuzhalosai V., Photocatalytic Degradation of an Azo Dye, Acid Red 27, in Aqueous Solution Using Nano ZnO, *Indian J. Chem.*, **51A**: 428-434 (2012).
- [153] Ashraful Islam Molla M., Furukawa M., Tateishi I., Katsumata H., Suzuki T., Kaneco S., Photocatalytic Decolorization of Dye with Self-Dye-Sensitization under Fluorescent Light Irradiation, *Chem. Eng.*, **1**(8): 1-10 (2017).
- [154] Thamer Jaafar M., UV-A Activated ZnO Mediated Photocatalytic Decolorization of Nigrosine (Acid Black 2) Dye in Aqueous Solution, *J. Geosci. Environ. Prot.*, **5**: 138-147 (2017).
- [155] Prengle H.W., Experimental Rate Constants and Reactor Considerations for the Destruction of Micropollutants and Trihalomethane Precursors by Ozone with Ultraviolet Radiation, *Environ. Sci. Technol.*, **17**: 743-747 (1983).
- [156] Rajendiran S., Shriram B., Kanmani S., Photocatalytic-Ozonation of Textile Dyeing Waste Water Using Fixed Catalyst System, *Int. Adv. Res. J. Sci. Eng. Technol.*, **3**(3): 107-112 (2016).
- [157] Mahmoodi N.M., Photocatalytic Ozonation of Dyes Using Copper Ferrite Nanoparticle Prepared by Co-Precipitation Method, *Desalination*, **279**: 332-337 (2011).
- [158] Mahmoodi N.M., Bashiri M., Jebeli Moeen S., Synthesis of Nickel-Zinc Ferrite Magnetic Nanoparticle and Dye Degradation Using Photocatalytic Ozonation, *Mater. Res. Bull.*, **47**: 4403-4408 (2012).
- [159] Mahmoodi N.M., Photocatalytic Ozonation of Dyes Using Multiwalled Carbon Nanotube, *J. Mol. Catal. A., Chem.*, **366**: 254-260 (2013).
- [160] Orge C.A., Faria J.L., Pereira M.F.R., Photocatalytic Ozonation of Aniline with TiO₂-Carbon Composite Materials, *J. Environ Manage*, **195**: 208-215 (2017).
- [161] Anandan S., Lee G.J., Chen P.K., Fan C., Wu J.J., Removal of Orange II Dye in Water by Visible Light Assisted Photocatalytic Ozonation Using Bi₂O₃ and Au/Bi₂O₃ Nanorods, *Ind. Eng. Chem. Res.*, **49**: 9729-9737 (2010).
- [162] Fathinia M., Khataee A., Photocatalytic-Ozonation of Phenazopyridine Using TiO₂ Nanoparticles Coated on Ceramic Plates: Mechanistic Studies, Degradation Intermediates and Ecotoxicological Assessments, *Appl. Catal A., General*, **491**: 136-154 (2015).
- [163] Neamtu M., Yediler A., Siminiceanu I., Macoveanu M., Kettrup A., Decolorization of Disperse Red 354 Azo Dye in Water by Several Oxidation Processes -A Comparative Study, *Dyes Pigm.*, **60**: 61-68 (2004).
- [164] Pignatello J., Oliveros E., MacKay A., Advanced Oxidation Processes for Organic Contaminant Destruction Based on the Fenton Reaction and Related Chemistry, *Crit. Rev. Environ. Sci. Technol.*, **36**: 1-84 (2006).

- [165] El-Desoky H.S., Ghoneim M.M., Zidan N.M., Decolorization and Degradation of Ponceau S Azo-Dye in Aqueous Solutions by the Electrochemical Advanced Fenton Oxidation, *Desalination*, **264**: 143-150 (2010).
- [166] Laftani Y., Chatib B., Boussaoud A., El Makhfouk M., Hachkar M., Khayar M., Optimization of Diazo Dye Disappearance by UV/H₂O₂ Process Using the Box-Behnken Design, *Water Sci. Technol.*, **80(9)**: 1731-1739 (2019).
- [167] laftani Y., Boussaoud A., Chatib B., Hachkar M., El Makhfouk M., Hachkar M., Khayar M., Comparison of Advanced Oxidation Processes for Degrading Ponceau S Dye: Application of the Photo-Fenton Process, *Maced. J. Chem. Chem. Eng.*, **38**: 197-205 (2019).
- [168] Shaban M., Abukhadra M.R., Ibrahim S.S., Shahien M.G., Photocatalytic Degradation and Photo-Fenton Oxidation of Congo Red Dye Pollutants in Water Using Natural Chromite-Response Surface Optimization, *Appl. Water Sci.*, **7**: 4743-4756 (2017).
- [169] Barbosa I.A., Zanatta L.D., Espimpolo D.M., De Silva D.L., Nascimento L.F., Zanardi F.B., De Sousa Filho P.C., Serra O.A., Iamamoto Y., Magnetic Diatomite(Kieselguhr)/Fe₂O₃/TiO₂ Composite as an Efficient Photo-Fenton System for Dye Degradation, *Solid State Sci.*, **72**: 14-20 (2017).
- [170] Rashad M.M., Ibrahim A.A., Rayan D.A., Sanad M.M.S., Helmy I.M., Photo-Fenton-Like Degradation of Rhodamine B Dye from Waste Water Using Iron Molybdate Catalyst under Visible Light Irradiation, *Environ. Nanotechnol. Monit. Manage.*, **8**: 175-186 (2017).
- [171] Jiang D.B., Liu X., Xu X., Zhang Y.X., Double-shell Fe₂O₃ hollow Box-Like Structure for Enhanced Photo-Fenton Degradation of Malachite Green Dye, *J. Phys. Chem. Solids*, **112**: 209-215 (2018).
- [172] Dias F.F., Oliveira A.A.S., Arcanjo A.P., Moura F.C.C., Pacheco J.G.A., Residue-Based Iron Catalyst for the Degradation of Textile Dye via Heterogeneous Photo-Fenton, *Appl. Phys. B: Environ.*, **186(5)**: 136-142 (2016).
- [173] Guo S., Zhang G., Yu J.C., Enhanced Photo-Fenton Degradation of Rhodamine B Using Graphene Oxide-Amorphous FePO₄ as Effective and Stable Heterogeneous Catalyst, *J. Colloid Interface Sci.*, **448**: 460-466 (2015).
- [174] Zhao X., Zhu L., Zhang Y., Yan J., Lu X., Huang Y., Tang H., Removing Organic Contaminants with Bifunctional Iron Modified Rectorite as Efficient Adsorbent and Visible Light Photo-Fenton Catalyst, *J. Hazard. Mater.*, **215-216**: 57-64 (2012).
- [175] Arslan-Alaton I., Tureli G., Olmez-Hanci T., Optimization of the Photo-Fenton-Like Process for real And Synthetic Azo Dye Production Wastewater Treatment Using Response Surface Methodology, *Photochem. Photobiol. Sci.*, **8**: 628-638 (2009).
- [176] Jin J., IEl-Din G.M., Bolton J.R., Assessment of the UV/Chlorine Process as an Advanced Oxidation Process", *Water Res.*, **45(4)**: 1890-1896 (2011).
- [177] Habeeb H.A., Khayoon H.A., COD and Color Mineralization of Azure C Dye Using UV/ClO₂ Technique, *J. College Educ. Pure Sci.*, **5(2)**: 46-67 (2015).
- [178] Wu Q., Li Y., Wang W., Wang T., Hu H., Removal of C.I. Reactive Red 2 by Low Pressure UV/Chlorine Advanced Oxidation, *J. Environ. Sci.*, **41**: 227-234 (2016).
- [179] Benvenuti T., Preis Gabriele A., Heberle N.A.A., Lucena M.P.P., Melo Halmenschlager Petter P., Meneguzzi A., Moura Bernardes A., Evaluation of Direct Photolysis, Electrooxidation and Photoelectrooxidation for Rhodamine-B Degradation, *Braz. J. Chem. Eng.*, **35(3)**: 957-968 (2018).