

Coupling of the coagulation/flocculation and the anodic oxidation processes for the treatment of textile wastewater

Sourour Bouznif and Mahmoud Bali

ABSTRACT

The increased demand for textile products leads to an increase in the quantity of wastewater discharged. It becomes indeed one of the most critical health and environmental problems in the world. The main challenge, therefore, is to develop innovative techniques for treating this wastewater with low production costs and better efficiency. The major objective of this work was to investigate the efficiency of the coupling of the coagulation–flocculation and the anodic oxidation processes on the platinum electrode in the removal of organic, mineral, and microbial pollution contained in textile effluents. A series of experiments is carried out on samples prepared in the laboratory, in which the textile effluent was mixed with a secondary effluent from an urban wastewater treatment plant. The treatment consists of two steps: a coagulation–flocculation process using aluminum salts as a coagulant and an anodic oxidation on the platinum electrode using photovoltaic panels for the production of electric current. The treatment at optimized conditions reveals that the coupling of the two processes made it possible to achieve satisfactory results. The abatement rates were 95.97% for the turbidity, 90% for COD, 100% for BOD, 100% for NH_4^+ , 53.6% for NO_3^- , and 100% for PO_4^{3-} . The coupling of the two processes ensured the complete elimination of fecal germs. Thanks to the satisfactory results, the obtained permeate can be reused in the dyeing process in the textile industry.

Key words | anodic oxidation, coagulation–flocculation, photovoltaic panels, platinum, textile effluent

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HIGHLIGHTS

- Coupling of the coagulation–flocculation process with anodic oxidation allowed removing contaminants.
- The coupling of the two processes ensured the complete elimination of fecal germs.
- The total elimination of organic, nitrogen, and phosphorus pollution was obtained.
- The treated water can be reused for different purposes.
- Mixing urban wastewater with the textile effluent improves the pollutant removal rate.

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INTRODUCTION

Worldwide environmental issues related to the textile industry are typically those associated with water pollution caused by the discharge of wastewater effluent since it contains toxic substances. In addition, the composition of wastewater from dyeing and textile processes varies considerably from day to day and even from hour to hour, depending on dye, fabric, and concentration of fixing compounds that are added (Kim *et al.* 2004). This wastewater is very stable in the environment and resistant to oxidation and biodegradation (Croce *et al.* 2017). It is considered a source of esthetic pollution and it permits the disturbance of the aquatic ecosystem. Photosynthesis and reduced oxygen solubility result from the discharge of wastewater made up of dye compounds, even at low levels (Rahmani *et al.* 2015). However, textile mills are not designed to eliminate all kinds of pollutants such as inorganic and organic substances, which should be included in the treatment priorities. Furthermore, leachate has high values of biological oxygen demand (BOD), chemical oxygen demand (COD) and, because of its toxic potential (Anvari *et al.* 2014; Garcia-Segura *et al.* 2018), can pose a problem for the environment (Clement *et al.* 1997; James & Stack 1997). The treatment of textile effluents is a major concern since the rejection of such wastewater drastically decreases oxygen concentration in the aquatic ecosystems.

Apart from the unsightly appearance, the coloring agents are able to interfere with the transmission of light in the water, thus blocking the photosynthesis of aquatic plants (Mansour *et al.* 2011). The works on these azo dyes have shown that these chemical compounds have carcinogenic effects on humans and animals (Combes & Haveland-Smith 1982; IARC 1982; Medvedev *et al.* 1988; Percy *et al.* 1989; Brown & Devito 1993; DEPA 2000; Tsuda *et al.* 2000; Chen 2006). These authors unanimously agreed on the gravity of these polluted waters, which requires cleaning them. Depending on the characteristics of the effluents, it will be necessary to resort to new methods such as coagulation–flocculation (C-F) coupling with the advanced oxidation process on the platinum electrode.

In this study, C-F has been chosen, for its simplicity to remove turbidity and reduce the COD value of dye

wastewater. El-Gohary & Tawfik (2009) confirmed this idea. The cycle of treatments involved coagulation/flocculation/decantation by using aluminum sulfate as a coagulant. This last neutralizes the charge of the particles, allowing them to agglomerate, and settle at the bottom of the tank (Verma *et al.* 2012). This mechanism occurs because the coagulants form monomeric and polymeric species in contact with water, with metallic hydroxides (Alkarkhi *et al.* 2013). Depending on the volume of water treatment, chemical coagulation can be very expensive. One of the possible problems is the difficulty of being able to reduce the solubility enough so that the components can form flocculants to be removed from wastewater (Verma *et al.* 2012). Consequently, according to Nabi *et al.* (2007) and Georgiou *et al.* (2003), many attempts were made to combine treatment methods for better and improved to treat wastewater. C-F combines almost all types of treatment methods currently available to treat wastewater (Butler *et al.* 2016).

On the other hand, with the ever-increasing level of drinking water supply and strict environmental regulations regarding the discharge of wastewater, electrochemical technologies have regained their importance worldwide over the past two decades (Chen & Hung 2007). Subsequently, a great deal of research has been devoted to this goal, highlighting the prominent role of a special class of oxidation techniques defined as advanced oxidation processes (AOPs), which generally operate at or near ambient temperature and pressure (Aieta *et al.* 1988). These AOPs have been applied in several sectors, such as the treatment of industrial wastewater (Martínez-Huitle & Ferro 2006). Unlike conventional methods, anodic oxidation does not need any additional processes and chemicals, and the system does not lead to the formation of byproducts (Rahmani *et al.* 2015). The AOPs rely on the production of highly reactive hydroxyl radicals (OH[•]). These strongest oxidants are highly oxidizing and nonselective in nature (Asghar *et al.* 2015), and they are able to decompose mainly organic matter (Farhatziz & Ross 1977; Hoigné & Bader 1983) up to their mineralization (Sirés *et al.* 2014; Verma & Samanta 2018). These compounds react with the double bonds –C=C– and attack the aromatic

nuclei, the major components of the refractory compounds (Gogate & Pandit 2004).

The hydroxyl radicals are produced from a hemolytic rupture of a covalent bond, that is to say, that the two electrons involved during this bond share one electron for each atom (Millet 1992a, 1992b). This characteristic gives it a strongly polar character, and consequently, it is highly reactive with respect to numerous organic (aromatic and aliphatic), inorganic, and bacterial compounds (Zaviska *et al.* 2009). The results obtained by Cong *et al.* (2008) confirmed that this hydroxyl radical is generated under neutral, basic, and acid conditions (reactions (1) and (2)).



MATERIALS AND METHODS

The experimental study lasted 4 months, from November 2018 to February 2019. The experiments were carried out in the Laboratory of Applied Hydro-Science of the Higher Institute of Sciences and Techniques of Waters (University of Gabès, Tunisia).

In order to determine the best method of treating textile wastewater to remove organic, mineral, and microbial pollution, the effluent has been treated successively by the C-F and the anodic oxidation (AO) processes on the platinum electrode.

Wastewater characteristics

In order to reduce the high load of pollutants in this industrial sewage effluent, the treatment was carried out using a textile effluent (TE) diluted 20 times with a secondary effluent from the wastewater treatment plant of the city of Gabès_Metouia (southeast of Tunisia) in the proportion of 5 and 95%, respectively,

The main physicochemical and microbiological characteristics of this mixed solution (M-5% solution) used during the experiments are presented in Table 1.

Table 1 | Physicochemical and microbiological characteristics of the M-5% solution

Parameters	Values
pH	7.2
EC (mS/cm)	4.8
Temperature (°C)	19.9
Turbidity (NTU)	35
BOD (mg O ₂ /L)	6.4
COD (mg O ₂ /L)	239.9
Dissolved oxygen (mg/L)	7.76
NH ₄ ⁺ (mg/L)	39.2
NO ₃ ⁻ (mg/L)	15.54
PO ₄ ³⁻ (mg/L)	0.027
TC (colonies/mL)	150
FC (colonies/mL)	43
FS (colonies/mL)	64

C-F experiments

Several studies have shown that the removal efficiency of organic compounds by the aluminum salt is improved by optimizing the pH and the dose of coagulant used (Lefebvre & Legube 1990; Al-Malack *et al.* 1999). The optimal pH of the C-F process is between 6 and 7.4 for aluminum (Bratby 1980; Gregory 2005). In this study, the pH was in this optimal range. Practically, the optimal dose of coagulant can be determined by a laboratory test, known as the 'Jar test' (Lounnas 2009).

The C-F experiments using inorganic coagulants, namely aluminum sulfate (Al₂SO₄)₃ (18H₂O), were carried out by the standard Jar test apparatus consisting of a flocculator with six agitators, to determine optimum operating conditions.

In the first step, the Jar test experiments were carried out on the mixed solutions, in different graduated glass beakers. The coagulant (aluminum) was prepared in solutions at 5 g/L concentration, and the flocculant (PolyDiAllyl Diméthyl Ammonium Chlorure 'polyDAD-MAC' at a concentration of 1.09 g/L) was tested. A different dose of coagulants was added separately and quickly mixed at 120 rpm for 2 min. Then, the flocculant was added, and the speed was reduced to 40 rpm for 20 min. In the second step, the particles are left to settle

for about 120 min. After decantation, turbidity, COD, BOD, NH_4^+ , NO_3^- , PO_4^{5-} , and fecal germs were measured in the supernatant to determine the most adequate quantity of coagulant for the abatement of this pollution.

AOP on the platinum electrode

In particular, elegant solutions for cleaning up environmental pollutants have been provided by the electrochemical methods. These processes are significantly efficient, versatile, and environmentally friendly (Vasudevan & Oturan 2013; Sirés *et al.* 2014). In these processes, the oxidation of pollutants occurs at the surface of the anode where the hydroxyl radicals are formed, in the presence of an aqueous electrolytic solution (Verma & Samanta 2018).

In order to study the mode of operation of the AOP and to determine its purification performance, an experimental study was carried out using two electrodes: a platinum anode and a steel cathode (Figure 1). The platinum electrode used in this treatment has the physical properties, as shown in Table 2. Its oxidation potential is equal to 1.18 (V/SHE) (Daniel 2007). The steel cathode used in this work is characterized by thickness: 2 mm, width: 2.5 cm, and length: 5 cm.

Table 2 | Physical properties of the platinum

Chemical symbol	Pt
Atomic number	78
Thickness	0.5 mm
Width	2 cm
Length	2 cm
Density	21.45 g/cm ³

The characteristics of the panels used, which are of the 'polycrystalline silicon' type, are illustrated in Table 3.

The part of a centimeter of the cathode was placed vertically in the solution while the anode was completely immersed, in order to guarantee that the submerged surface is equal, of which the production of electrons at the level of two electrodes is proportional. The current applied between these two electrodes was imposed by a series of photovoltaic panels. The influence of electric intensity (250, 500, 750, and 1,000 mA) and electrolysis time were investigated. The solutions were homogenized using a magnetic stirrer at a moderate speed. A volume of 1 liter of mixed solution was treated.

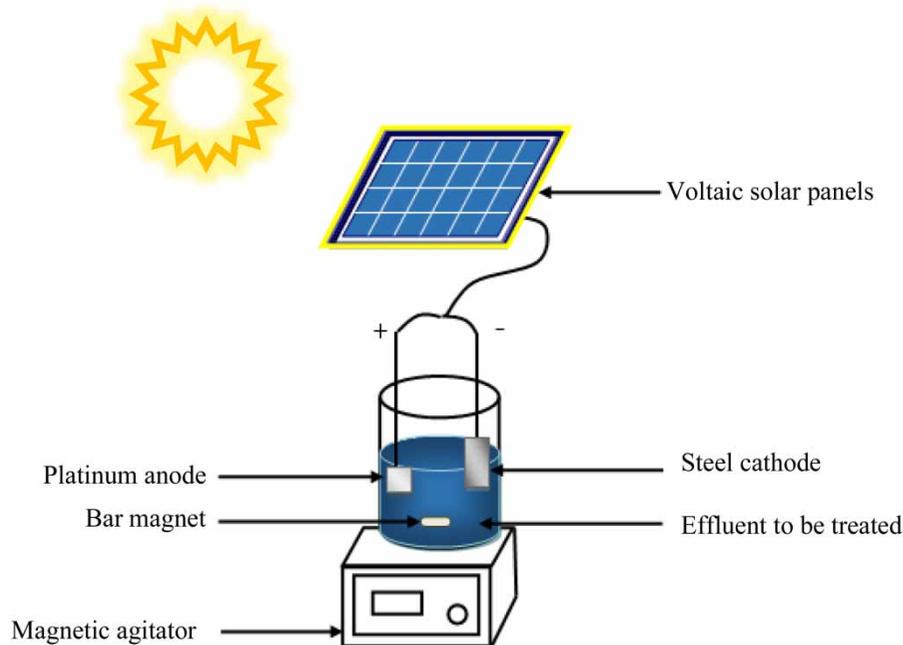


Figure 1 | Anodic oxidation experimental device on platinum.

Table 3 | The characteristics of the photovoltaic panels

Model	001
Construction material	Polycrystalline silicon
Maximum power (P_{max})	2 W
Voltage at maximum power (V_{mp})	8 V
Current at maximum power (I_{mp})	0.25 A
Open-circuit voltage (V_{oc})	9.2 V
Short-circuit current (I_{sc})	0.263 A
Maximum system voltage	500 V
Size	170 × 130 × 4 mm

C-F treatment combined with the AOP on the platinum electrode

The optimal conditions previously obtained where the applied C-F was combined with the AOP in the reactor previously described in order to improve the dye wastewater quality. Firstly, an optimal dose (80 mg/L) of coagulant ($Al_2(SO_4)_3$) was added to the dulled solution. Secondly, after settling, the supernatant was recovered to be treated for 2 h by the AO with an intensity of 1,000 mA brought by the photovoltaic panels. Finally, to evaluate the treatment efficiency of the diluted effluent, the following parameters are studied: turbidity, COD, BOD, ammonia, nitrogen, orthophosphates, and fecal germs.

RESULTS AND DISCUSSION

Following pH and electrical conductivity

The results obtained showed a slight decrease in pH and electrical conductivity (EC) (Table 4). The study published by Sefraoui (2013) confirmed this decrease in the pH value

Table 4 | pH and electrical conductivity of the raw and treated effluents

Effluent	pH	EC
Textile effluent (TE)	7.1	7.6
Urban effluent (UE)	7.3	4.37
M-5%	7.3	4.43
C-F + AO	6.9	4.41

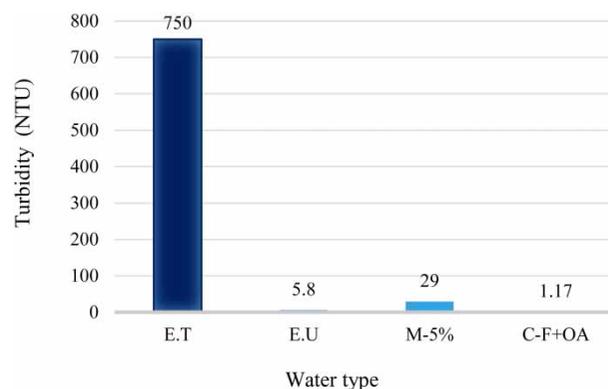
after treatment with aluminum which is always less than or equal to the initial value, since it is strongly related to the concentrations injected with the products (coagulant and flocculant) during the C-F process. The results obtained confirm the bibliographic data, concerning the addition of the coagulant that causes the formation of the hydroxide of the metal with the release of a certain acidity (hydrolysis) which explains the decrease in the pH value. This reduction is due to the formation of H_3O^+ ions and to the reactions that take place at the level of the anode favoring the production of hydroxyl radicals (OH^\cdot) which attack organic matter by promoting the production of short-chain carboxylic acids that acidify the middle (Gaied *et al.* 2019).

Concerning the EC, it remains almost stable, and it records a very slight decrease, which can be explained by the decrease in the dissolved salts in the solution (Total Dissolved Solids).

Removal of turbidity

Figure 2 shows the evolution of turbidity of the raw and analyzed water by the coupling of the two processes. The mixture of the industrial effluent with the urban effluent (UE), in the respective proportion of 5 and 95%, allowed a very important decrease of turbidity with a rate of abatement that was equal to 96.14% compared with the initial value of the TE. This confirms the efficiency and good purification performance of the mixture of the industrial and urban effluents.

As shown in Figure 3, the abatement rate was 93.43 and 94.36% for water treated by the C-F and the AOPs on the platinum electrode, respectively. After the treatment of the sample

**Figure 2** | The turbidity of raw and analyzed water.

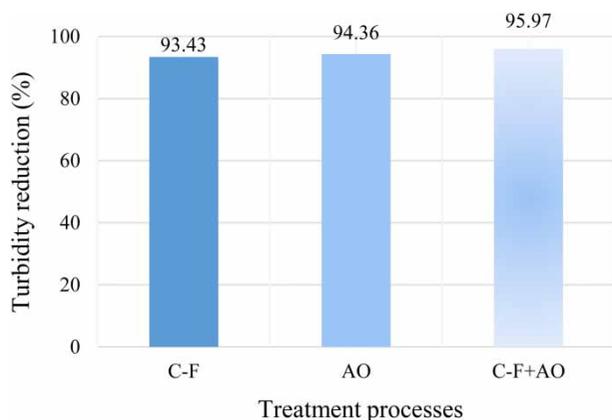


Figure 3 | Variation in the rate of turbidity reduction in water treated with C-F, AO, and C-F + AO.

by a coupling of the two treatment processes with the optimal conditions, the rate of abatement was 95.97% compared with the value of the mixed solution (M-5%). This reduction of turbidity depends on both the optimal dose of the coagulant, which has guaranteed the majority removal of colloidal particles and dissolved organic substances, whose main reaction mechanism is the neutralization of the charge of colloids (negatively charged) by cationic hydrolysis products. The duration of the electrolysis and the intensity of the current have significantly improved the purification efficiency by the oxidation of the organic matter expressed in turbidity.

The reaction mechanisms involved are different and complementary. On the one hand, the destruction of organic pollutants takes place by conversion or combustion (Comninellis 1994). During electrochemical conversion, nonbiodegradable organic compounds are partially oxidized to more biodegradable compounds, while during electrochemical combustion, organic pollutants are completely degraded in the form of CO_2 and H_2O (Grimm *et al.* 1998). On the other hand, the hydrolysis of alum makes it possible to form hydroxyaluminous radicals (monomers) which, in turn, form the precipitate $\text{Al}(\text{OH})_3$ or polycationic species. These species act on the colloidal particles by compression, neutralization, and adsorption, which make possible the formation of flocs (Lakhdari 2011).

Removal of COD

The evolution of the COD of the raw and analyzed water is illustrated in Figure 4. The results indicated that the COD

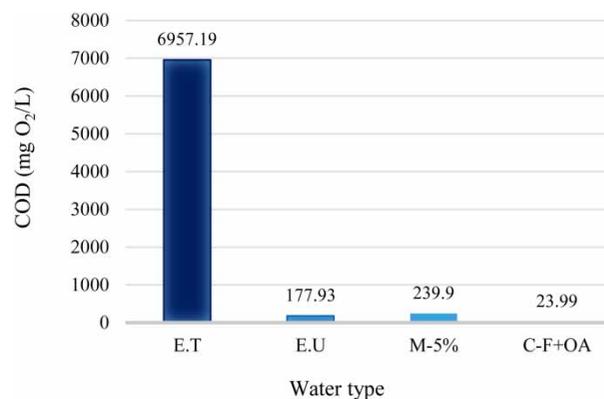


Figure 4 | The COD of raw and analyzed water.

of the TE was highly fluctuating, with an average of 6,957.19 mg O_2/L . This high concentration rate was due to the presence of significant organic pollution that is difficult to biodegrade. After mixing the two effluents, the abatement rate was 96.55%, hence confirms the efficiency and good purification performance of the industrial effluent mixture with the UE in the proportion of 5 and 95%, respectively.

The results obtained showed a reduction rate of the order of 56.67 and 76.67% after the independent treatment of the solution by the C-F and AO on the platinum electrode, with the optimal conditions, respectively (Figure 5). The coupling of the two processes with the optimal conditions ensured almost complete oxidation of the carbon pollution expressed in terms of COD (90%), which can occur due to the contribution of multiple oxidation mechanisms. According to the studies of Tipping & Backes (1988) and Lefebvre

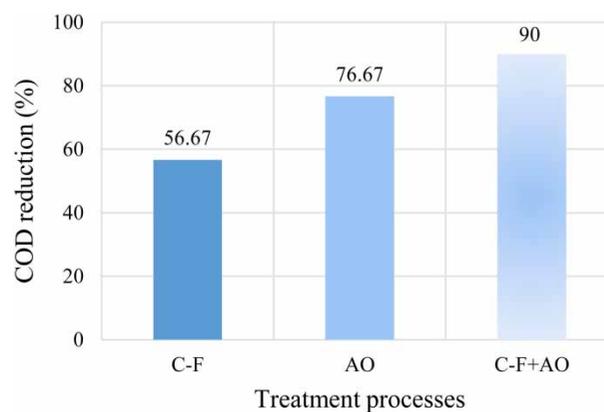
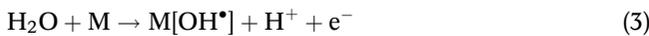


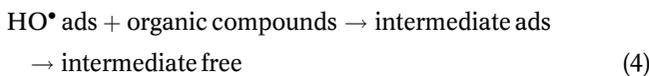
Figure 5 | Variation in the rate of COD reduction in water treated with C-F, AO, and C-F + AO.

& Legube (1990), the elimination of organic matter by the coagulant is explained by a complexation or exchange of ligand between the monomers, dimers or cationic metallic polymers and the organic matter.

Similar results have been found by Rosie *et al.* (2012), Chiang *et al.* (1995), Jardak (2015) and Torres *et al.* (2019) who confirmed that the reduction of COD depends on both the duration of electrolysis and the intensity current. The increase in the intensity of the current has ensured a greater production of hydroxyl radicals (OH^\bullet) which can instantly oxidize most organic compounds by addition reactions and hydrogen abstraction reactions. This phenomenon corresponds to the oxidation of the water molecule on the surface of the anode to form hydroxyl radicals also known as adsorbed oxygen (reaction (3)) (Comminellis 1994).



In our case, platinum is a nonactive electrode (with a high oxygen overvoltage) whose hydroxyl radicals are weakly bonded to the surface of the anode. This situation allows the hydroxyl radicals to degrade the pollutants into intermediate compounds and to mineralize them in the final stage (reactions (4) and (5)) (Jardak 2015).



Removal of BOD

In Figure 6, it is observed that there is a total degradation of the BOD. After mixing the TE with the UE, the BOD content was decreased to 6.4 mg O_2/L . These results expressed the good purification performance of this mixture with an abatement rate that exceeds 97.71% compared with the initial value of the TE. The treatment of the M-5% solution by the C-F and AO separately with the optimal conditions favored a total reduction in BOD (100%) which confirms the effectiveness of each of these two processes with respect to the elimination of easily biodegradable organic matter (Figure 7). After the coupling of the two processes with the optimal conditions, the BOD has been completely

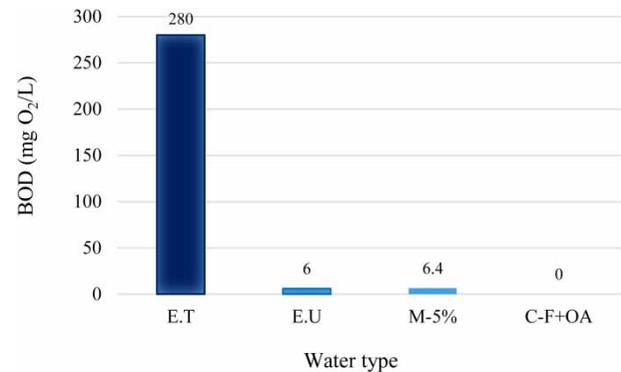


Figure 6 | The BOD of raw and analyzed water.

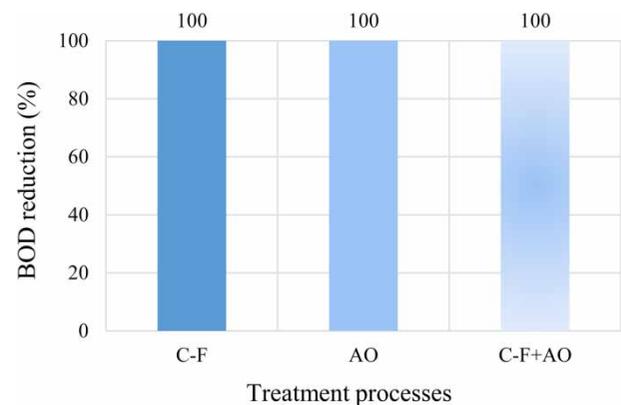
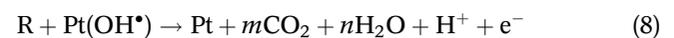
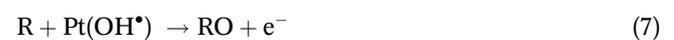
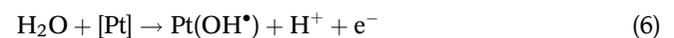


Figure 7 | Variation in the rate of BOD reduction in water treated with C-F, AO, and C-F + AO.

degraded. The almost total disappearance of BOD in the water treated by the coupling could be explained by the good role of the coagulant during the C-F process.

This excellent yield also comes back to the oxidation power of hydroxyl radicals (OH^\bullet) which will react instantly with organic components by hydroxylation with a loss of hydrogen atom following a radical mechanism until their total mineralization according to the following reactions:



The attack of these radicals on organic pollutants initiates a radical mechanism, leading to mineralization by

three modes of action: electrophilic addition, abstraction of hydrogen atom, and electronic transfer (Guergour 2014).

Removal of NH_4^+

However, as shown in Figure 8, the combination of two processes allowed the complete elimination of ammoniacal nitrogen. The results showed that the mixture provided a significant reduction in the initial value of ammoniacal nitrogen with an abatement rate of 65%. After treating the mixed solution by the two methods independently with the optimal conditions, a total reduction in NH_4^+ was noted for each method (Figure 9). The coupling permitted a total oxidation of nitrogen pollution resulting in an almost total reduction of this parameter. Similar results have been found by Binette & Pepin (2003) which confirmed the

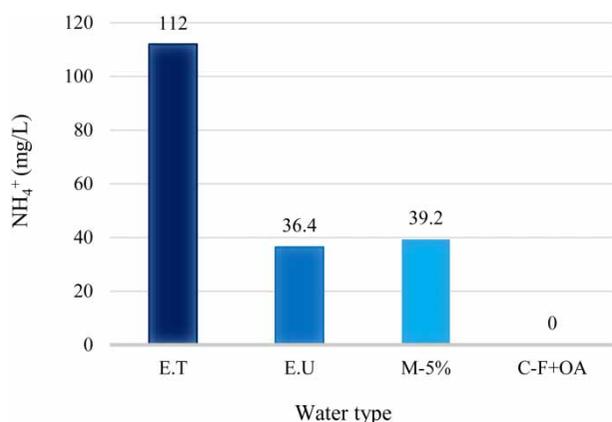


Figure 8 | The NH_4^+ of raw and analyzed water.

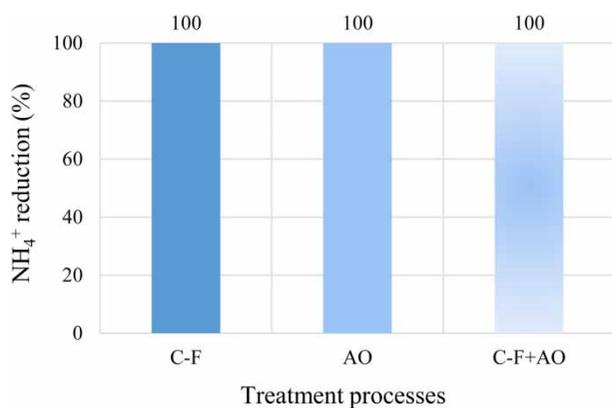


Figure 9 | Variation in the rate of NH_4^+ reduction in water treated with C-F, AO, and C-F + AO.

effectiveness of the C-F process with regard to the reduction of nitrogen pollution.

Szpyrkowicz *et al.* (2005) showed that the elimination of nitrogen is done by electrochemical conversion. Canizares *et al.* (2005) and Amor (2018) confirmed that the elimination of ammoniacal nitrogen is done by a reduction of this oxidized nitrogen whose principle of the electro-conversion of ammoniacal nitrogen is based on the reduction of the latter into gaseous nitrogen at the cathode and the oxidation of water into gaseous oxygen at the anode by applying an electric current through an aqueous solution.

Amor (2018) proved that the ammonia could be completely oxidized and the majority of it has been transformed into nitrogen N_2 whose yields were higher in the presence of ammonium chloride, which demonstrated the advantageous contribution of chloride ion to the electro-conversion reaction of ammoniacal nitrogen by increasing the time of electrolysis.

This is likely due to excessive electrolysis of the chloride ion to chlorine gas at the anode (reaction (9)), to the detriment of its reaction with water to generate hypochloric acid (reaction (10)).



In other words, the removal efficiency of ammoniacal nitrogen increases with the current density and the Cl^- concentration due to their strong effect of cooperation with the current density.

Removal of NO_3^-

After mixing the abatement rate of NO_3^- was almost 15.22% relative to the industrial effluent. This decrease could be explained by the denitrification, which consists in eliminating the nitrates present in the water under the action of the microorganisms of the urban wastewater. The coupling of the two processes allowed a rather large decrease in the nitrate content. It was equal to 53.6% relative to the mixing solution (Figure 10). The results obtained showed that the C-F allowed a reduction rate equal to 38.35%, while the reduction rate by AO reached 44.93% (Figure 11).

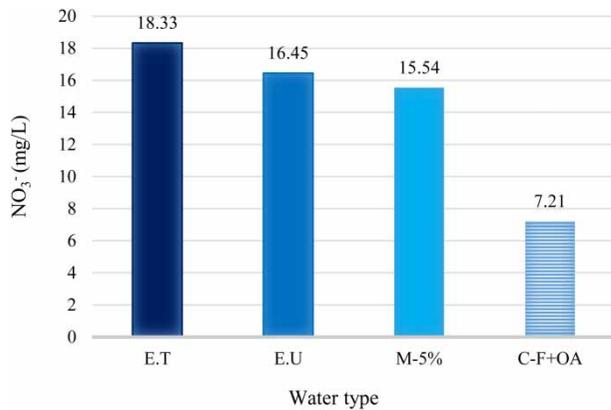


Figure 10 | The NO₃⁻ of raw and analyzed water.

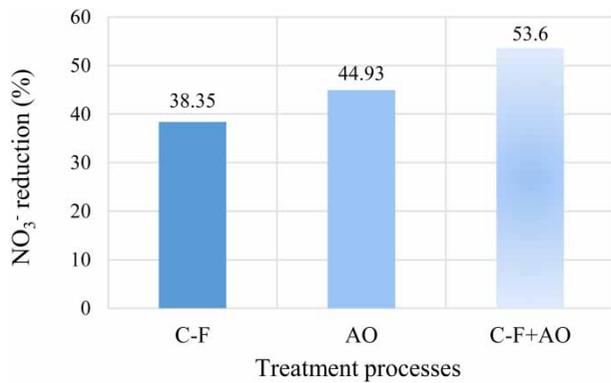
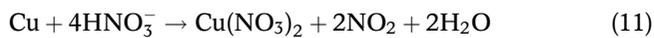


Figure 11 | Variation in the rate of NO₃⁻ reduction in water treated with C-F, AO, and C-F + AO.

This nitrate removal can be explained by the possibility of copper in the secondary effluent. The oxidation of copper ensures the reduction of nitrate anions to nitric oxide, then oxidation by the oxygen of the monoxide to nitrogen dioxide according to the following reaction:



From Amor (2018), the reduction reaction can be more or less complete and can give rise to intermediate species such as nitrites, nitrates or nitrogen gas. After some electrolysis times, the formation of nitrates begins to decrease. This confirms the fact that this secondary product is a reaction intermediate, the nitrates probably being converted, in turn, into nitrogen gas.

Li *et al.* (2009) proved that the elimination of nitrate has resulted in cathodic reduction of nitrate and anodic

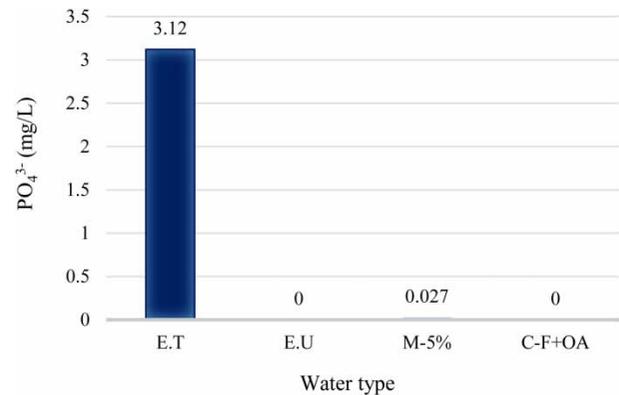


Figure 12 | The PO₄³⁻ of raw and analyzed water.

oxidation of ammonia and nitrite byproducts have been achieved.

Removal of PO₄³⁻

As seen in Figure 12, the PO₄³⁻ concentration is directly eliminated after the treatment by the two processes. The results showed that the abatement rate of PO₄³⁻ in the mixed solution exceeded 99% compared with the initial value of the TE, hence confirms the efficiency and good purification performance of the mixture of the industrial effluent and the UE in the respective proportion of 5 and 95%, respectively. The treatment of the mixed solution by the C-F and AO separately under the optimal conditions also allowed a total reduction of the PO₄³⁻ (100%) which confirms the effectiveness of each of these two processes with respect to the elimination of the phosphate pollution (Figure 13). A similar study by Seghairi *et al.* (2017) confirmed the effectiveness of the C-F process in the reduction of phosphate pollution. Good performance with respect to the abatement of phosphate pollution could be explained by the precipitation of orthophosphates, according to the following reaction:



Removal of pathogenic germs

Experimental results showed that the UE is highly loaded with *total coliforms* (TC), *fecal coliforms* (FC), and *fecal streptococci*

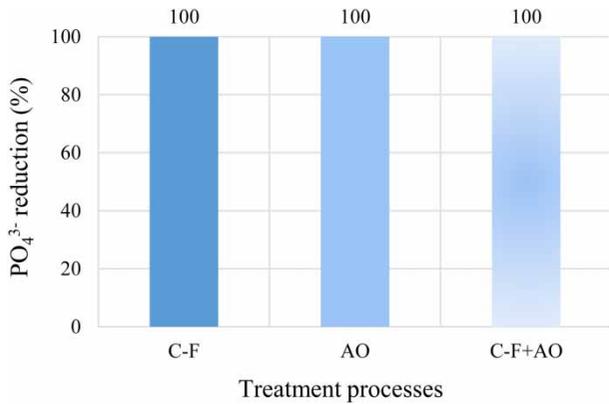


Figure 13 | Variation in the rate of PO₄³⁻ reduction in water treated with C-F, AO, and C-F + AO.

(FS). After mixing the two effluents, a reduction in this pathogenic germs content compared with the UE was observed (Figures 14–16). This decrease can be explained by the substances found in the industrial effluent and the products

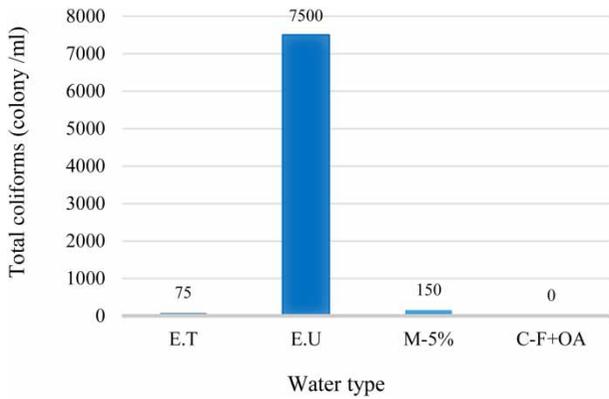


Figure 14 | The total coliforms of raw and analyzed water.

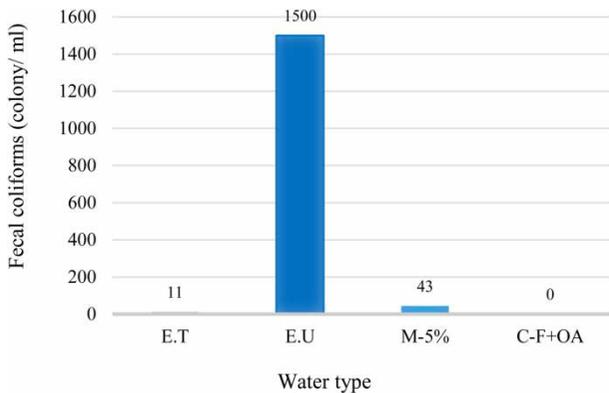


Figure 15 | The fecal coliforms of raw and analyzed water.

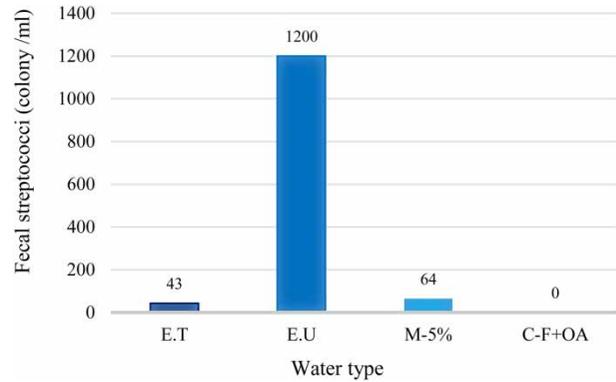


Figure 16 | The fecal streptococci of raw and analyzed water.

(acid, NaOH, H₂O₂, etc.) used during the textile production chain, which are capable of destroying the pathogenic germs.

As shown in Figure 17, the treatment of the M-5% solution by the C-F and AO process separately with the optimal conditions favored a total reduction in TC, FC, and FS (100%). The coupling of these two processes permits the elimination of micropollutants. The works of Gaied *et al.* (2019) have shown a decrease in the number of bacteria; this may occur not only due to the effect of the current but also due to the generation ‘OH that destroys and kills the microorganisms.

According to Alem (2015), a bactericidal effect can occur by the formation of oxidants such as hydrogen peroxide or hypochlorous acids obtained during the oxidation of chlorides. Zaviska *et al.* (2009) mentioned the importance of the electric field between the electrodes, which leads to the destruction of certain strains of bacteria thanks to their power as a

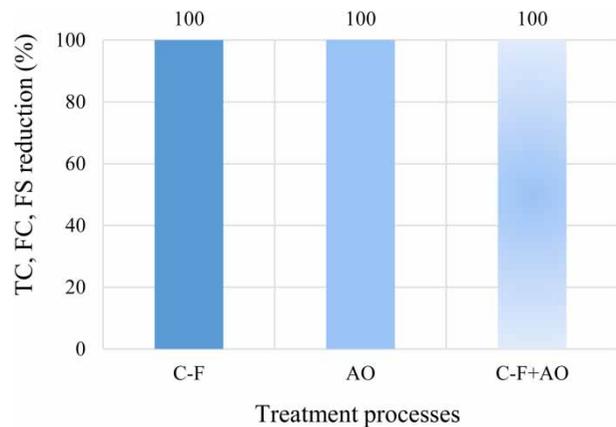


Figure 17 | Variation in the rate of TC, FC, and FS reduction in water treated with C-F, AO, and C-F + AO.

bactericidal action. A similar study by Kahoul & Belhachani (2016) has shown that the elimination of pathogenic microorganisms is due to the hydroxyl radicals (OH[•]) which are very reactive with respect to many bacterial compounds.

CONCLUSION

The main objective of this work was to study the elimination of organic, nitrogen, phosphorus and microbial pollution contained in the TE by the coupling of the C-F and the AOPs. The experiments showed that combining these two processes improved the purification of the TE mixed with the secondary effluent. The technique of C-F applied in the laboratory uses a Jar test, which seems to be a durable system of the elimination of pollutants such as turbidity, organic matter, nitrogen, phosphorus, and pathogenic microorganisms. In addition, AO is an effective process that can contribute to the satisfactory removal of organic and mineral matter, and micropollutants contained in the mixed solution. These high yields were obtained thanks to the high oxidation power of the water molecule on the surface of the anode to form hydroxyl radicals, and the current applied between these two electrodes, which was produced by a series of photovoltaic panels.

The coupling of the C-F and the AOPs, by using the optimal treatment conditions, has made it possible to increase the purification performances. The results obtained, after the coupled treatment of the urban wastewater mixture with SARTEX textile industrial wastewater in the proportion of 5 and 95%, respectively, are very satisfactory in terms of removal of turbidity, COD, BOD, NH₄⁺, NO₃⁻, PO₄³⁻, TC, FC, and FS. All these parameters are in accordance with the Tunisian standard of rejection. In order to recover these effluents after their purification, they can be reused for domestic, agricultural, or industrial purposes. It may become one of the solutions that can respond to the problems of water scarcity in the world, and the growing needs for this subject.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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