Original Article

Tertiary treatment of wastewater by electro-coagulation, electro-Fenton and advanced electro-oxidation processes: Comparative and economic study

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Abstract

Due to water scarcity and population growth the use of treated wastewater in agriculture has become more frequent. With this motivation, several technologies have been introduced for the treatment of wastewater. The present work aimed at the tertiary treatment of the polluted water of Tataouine sewage treatment plant (Tunisia) using three alternative processes, namely electro-coagulation (EC), electro-Fenton (EF), and advanced electro-oxidation (AEO). After 180 min, chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5) abatement rates reached respectively 56% and 14% with sharp deterioration of germs by EC process, and 75% and 52% with complete degradation of germs when EF process was applied. On the other hand, with AEO process, abatement rates of COD and BOD_5 were 92% and 57%, respectively, with complete degradation of germs. The economic study showed that the EF process is technically and economically the best of these alternatives for treatment of this wastewater.

Keywords: urban wastewater, microbial loads, organic matter, electro-coagulation, electro-Fenton, advanced oxidation, economic study

1. Introduction

Water effluents from urban and / or industrial sources are pollutants that are generally laden with organic and mineral matter. These make them aggressive and harmful to the receiving environment if they remain untreated. To overcome the environmental problems that can be caused by these releases and to limit the damage to human health, many treatment processes have been implemented.

Biological treatment is the most widely used technique worldwide, and is mainly used to treat municipal effluents and industrial biodegradable wastewater. This technique is based on microbial metabolic activity and the ability of microbes to degrade organic matter. The alternative implementations of this type of treatment are activated sludge, biological disc and aerated lagoon (Dinçer & Kargi, 2001; Hammadi *et al.*, 2016; Montalvo *et al.*, 2009; Moura *et al.*, 2009; Palma & Verdone, 2009; Wang, Liu, Zhao, Wei, & Sun, 2016; Wu *et al.*, 2016).

Aside from biological techniques there are physico-chemical techniques, which have the ability to treat recalcitrant effluents that are toxic to microorganisms. The removal of pollutants by physicochemical processes can be carried out by flotation, coagulation, sedimentation, filtration, and adsorption. However, these technologies do not completely solve the problem of pollution since they merely displace it, giving rise to sludge and residues that themselves

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require further processing (Baghdadi, Ghaffari, & Aminzadeh, 2016; Bolzonella, Fatone, di Fabio, & Cecchi, 2010; Devi & Saroha, 2017; Dionisi, Bruce& Barraclough, 2014; Hai, Nghiem & Modin, 2013; Hu, Aarts, Shang, Bas, & Rietveld, 2016; Liakos & Lazaridis, 2014; Pitakpoolsil & Hunsom, 2013; Zhang, Liu, Yang, Chen, & Lu, 2014).

The need to develop new wastewater treatment methods that are more efficient and do not generate secondary pollution has become imperative and very pressing. The Anodic Oxidation Process (AEO) has proved to be an effective solution for many bio-resistant or refractory pollutants in synthetic and industrial waters (Brillas & Martínez-Huitle, 2015; Martínez-Huitle, & Ferro, 2006; Martínez-Huitle, Rodrigo, Sires, & Scialdone, 2015; Panizza, & Cerisola, 2009; Sirés, Brillas, Oturan, Rodrigo & Panizza, 2014; Subba Rao & Venkatarangaiah, 2014). These are highly efficient techniques based on the production of highly active radical intermediates, mainly hydroxyl radicals (•OH). Indeed, these very reactive radicals are able to act on the organic matter in a rapid and non-selective manner (Bilińska, Gmurek, & Ledakowicz, 2016; Rodriguez, Santos, & Romero, 2011; Rueda-Márquez *et al.*, 2016; Soares*et al.*, 2016).

These promising techniques have been studied in the treatment of various discharges, such as effluents from textile and agro-food industries. These processes can be used for removing suspended solids, COD, effluent color, oily emulsions, etc (Belaid *et al.*, 2013; Koprivana *et al.*, 2004;).

The novelty of this work lies in studying the possibility of using electrochemical techniques for the tertiary treatment of urban wastewater from the treatment plant of Tataouine-Tunisia. The electrochemical treatment was based first on iron electrodes by both electro-coagulation (EC_{iron}) and electro-Fenton (EF_{iron}) processes, then on platinum (Pt) electrode by the anodic electro-oxidation process (AEO_{Pt}) to further reduce the microbial loads and organic matter. Afterwards, an economic evaluation was conducted to study and compare the costs of the studied processes.

2. Experimental

The electrochemical treatment was carried out in an electrochemical cell, which consisted of a perfectly stirred discontinuous reactor with two electrodes: iron-iron for EC_{iron} or EF_{iron} and iron-platinum for AEO_{Pt}. The specific surface areas of the electrodes were 28.5 cm^2 and 8 cm^2 for iron and platinum electrodes, respectively. The electrode gap was 2 cm. The solution volume was 0.5 dm^3. The temperature was kept constant at 25 °C. Magnetic stirring was maintained during the experiments. EC_{iron} and EF_{iron} experiments were carried out under galvanostatic conditions at a current density (J_{app}) of 57 mA/cm^2. AEO_{Pt} experiments were conducted at 250 mA/cm^2.

The electrodes were inserted into a polytetra-fluoroethylene (PTFE) sample holder (Radiometer PEK 29), then they were mechanically eroded using successively finer grades of abrasive paper, polished with 0.3 μm alumina, and rinsed with a solution of 1.3 M HCl and then with deionized water.

3. Materials and Methods

3.1 Quality of inlet and outlet water from the wastewater treatment plant

The inlet and outlet COD and BOD_5 values for the wastewater treatment plant of Tataouine-Tunisia are given in Table1.

Table 1.   Inlet and outlet COD and BOD_5 values from the Tataouine-Tunisia wastewater treatment plant.

	Inlet	Outlet
COD (mg/dm^3)	860	64
BOD_5(mg/dm^3)	410	21

3.2 Measurement of chemical oxygen demand (COD)

COD indicates the amount of organic matter degraded during the process (Lu,Wang, Shan,Li, & Wan, 2006). The COD of different samples at different reaction times was determined by The Standard Methods of American Public Health Association (APHA) (American Public Health Association [APHA], 1999). Two milliliters of each sample were introduced into corresponding digestion tube containing a reagent such as potassium dichromate, sulfuric acid, silver sulphate, or mercury sulphate. These tubes were heated to 150°C for two hours and then allowed to cool to room temperature. The oxidation took place in the digestion tubes. In fact, the silver salt acts as a catalyst for the oxidation of organic compounds and mercury sulphate saves interferences by chlorides. The COD values were measured using a Photolab VWR S12 analyzer based on the dichromate oxidation method.

3.3 Measurement of 5-day biochemical oxygen demand (BOD_5)

BOD_5 reflects the amount of biodegradable organic matter contained in water. This biodegradable organic material is evaluated via the oxygen consumed by the micro-organisms (Liu & Mattiasson, 2002).

The BOD_5 of samples taken at predetermined time intervals was determined by the standard method of APHA. The amount of oxygen that is consumed by the micro-organisms during biological oxidation of organic solutes over a time period of 5 days is measured (APHA, 1999). The BOD_5 values were determined by the Lovibond Oxidirect analyzer based on the pressure difference method.

3.4 Microbiologic analyses

The objective of the microbiological study was to determine the bacteria concentration remaining after the electrochemical treatment. Microbiological analyses were performed at the Research Veterinary Laboratory in Gabes-

Tunisia. It concerns (GMT) and especially Aerobic bacteria, Staphylococcus aureus, Salmonella-Shigella (Enterobacteria-ceae) and coliform. The culture media for each method are given in Table 2.

3.4.1 Aerobic bacteria (GMT)

For this type of bacteria the culture medium used was PCA agar. PCA agar or Glucose agar, which is the yeast extract called by the Anglo-Saxons "Plate Count Agar", is used in food bacteriology for aerobic bacteria enumeration in milk, meats, meat products, or other food products, as well as for the analysis of pharmaceutical products, cosmetics, and their raw materials.

3.4.2 Staphylococcus aureus (Staph)

For this type of bacteria the culture medium used was the Baird Parker medium. It contains a rich nutrient base and growth accelerators: sodium pyruvate and glycine.

3.4.3 Salmonella and Shigella

For Salmonella and Shigella the selective medium is Salmonella-Shigella Agar (SS Agar) allowing the isolation of pathogenic enteric bacteria (Enterobacteriaceae). For this type of bacteria the culture medium used was Hajna-Kligler, which is a complex medium allowing the search for several bioche-mical characteristics. It is widely used in Enterobacteriaceae identification.

3.4.4 Coliform (E. coli)

For this bacteria type, the culture medium used was triphenyltetrazolium chloride (TTC) tergitol. It is mainly used in water colimetry by the filtration method.

3.5 The pH measurement

Digital ThermopHmeter (mod BE105, BICASA) equipped with a Metrohm combined glass electrode was used to measure pH of the aqueous solutions. The pH was adjusted using solutions of 0.1 M H_2SO_4 and/or NaOH.

4. Results and Discussion

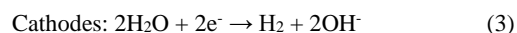### 4.1 Treatment of wastewater solutions by electro-coagulation

4.1.1 COD degradation

The decrease of the COD in the solution during the electrolysis time at a current intensity (I) equal to 2A is shown in Figure 1. The initial COD (COD°) was 64 mg O_2/dm^3 (Table 1) and decreased during treatment to 30 mg O_2/dm^3. This can be explained by the adsorption of organic matter on the insoluble iron hydroxide forms ($Fe(OH)_2$, $Fe(OH)_3$, $Fe_2O_3 \cdot xH_2O$), which are known to be strong adsorbents (Brillas, Calpe, & Casado, 2000; Canizares, Jimenez, Martinez, Saez, & Rodrigo, 2007; Lakshmanan, Clifford, & Samanta, 2009). In fact, the compounds $Fe(OH)_2$ and

Table 2. Microbiologic analyze for EC-$_{iron}$, EF-$_{iron}$ and AEO-$_{pt}$ processes.

Time (min)	0	30	60	120	180
Bacteria					
GMT (PCA Agar) (EC)	21.10^5	2.10^2	7.10^2	15.10^2	10^2
E.coli (triphenyltetrazolium chloride (TTC) tergitol) (EC)	13.10^3	<10	<10	<10	<10
Staph (Baird Parker medium) (EC)	10^2	<10	<10	<10	<10
Salmonella (SS Agar) (EC)	<10	<10	<10	<10	<10
GMT (PCA Agar) (EC) (EF)	29.10^6	2.10^2	7.10^2	5.10	10
E.coli (triphenyltetrazolium chloride (TTC) tergitol) (EF)	13.10^4	<10	<10	<10	<10
Staph (Baird Parker medium) (EF)	10^2	<10	<10	<10	<10
Salmonella (SS Agar) (EF)	<10	<10	<10	<10	<10
GMT (PCA Agar) (AEO)	29.10^6	2.10^2	7.10^2	5.10	10
E. coli (triphenyltetrazolium chloride (TTC) tergitol) (AEO)	13.10^4	<10	<10	<10	<10
Stoph (Baird Parker medium) (AEO)	10^2	<10	<10	<10	<10
Salmonella (SS Agar) (AEO)	<10	<10	<10	<10	<10

$Fe(OH)_3$ are gelatinous metal coagulants generated in the solution during the treatment, which is responsible for the coagulation that enables decantation (Mansouri, Elsaid, Bedoui, Bensalah, & Abdel-Wahab, 2011). In this work, these are generated by dissolution of the iron anode and by water reduction at the iron cathode. Indeed, the main reactions occurring in the electrochemical medium are as follows (1-3):

$$\text{Anode: } 2H_2O \rightarrow O_2 + 4 H^+ + 4 e^- \quad (1)$$

$$Fe \rightarrow Fe^{2+} + 2e^- \quad (2)$$

$$\text{Cathodes: } 2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (3)$$

The resulting Fe^{2+} ions are oxidized to Fe^{3+}, which combine with the OH^- formed at the cathode to produce insoluble Fe $(OH)_3$ as follows (Brillas *et al.*, 2000).

$$Fe^{3+} + 3OH^- \rightarrow Fe (OH)_3 \quad (4)$$
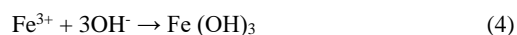
4.1.2 BOD₅ degradation

With EC$_{iron}$ process BOD$_5$ decreased for the first 30 min, and then it remained constant until the end of the treatment (Figure 2). In fact, the BOD$_5$ decreased from initial 21 mg /dm^3 (Table 1) to 18 mg/dm^3 after 180 min. This can be explained by two facts: the first is due to the adsorption of

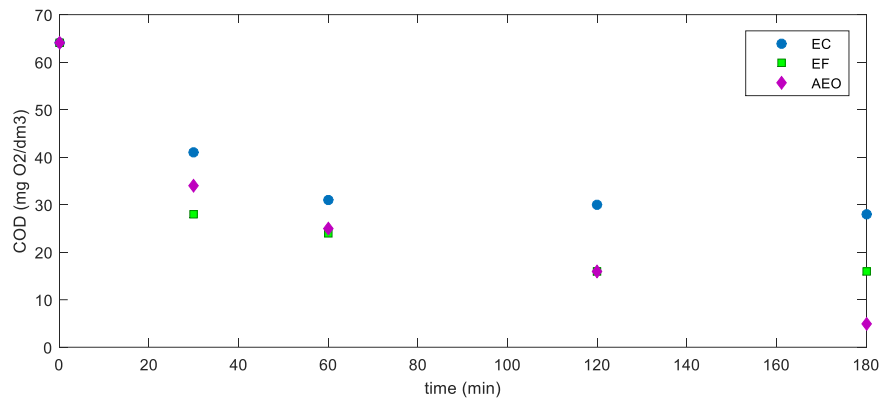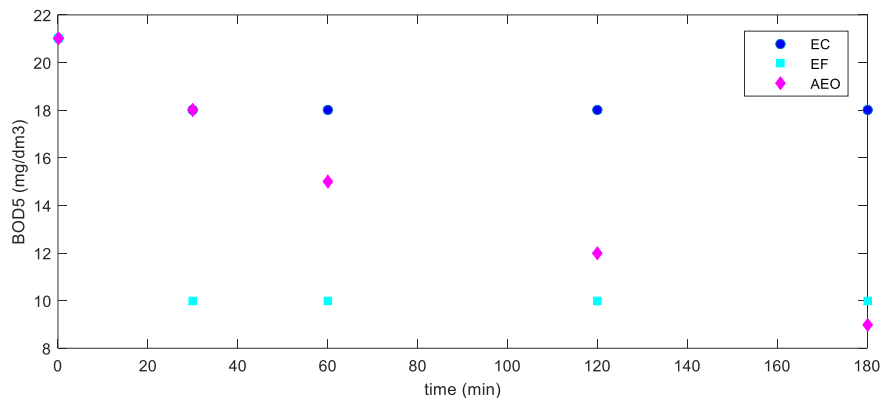Figure 1.   Degradation of COD by EC, EF and AEO processes during the electrolysis time (I=2A, T=25°C).

Figure 2.   Degradation of DBO5 by EC, EF and AEO processes during the electrolysis time (I=2A, T=25°C).

organic matter on Fe (OH)$_3$ mineral monomers and the second one follows from the passage of the current through the wastewater. The latter can be lethal to microorganisms.

4.1.3 pH evolution

Figure 3a shows the pH evolution in the solution versus the electrolysis time for all processes.

As can be seen in Figure 3a, in the case of EC$_{iron}$ process, the pH increased towards alkaline and became stable until the electrolysis was completed. This can be explained by the reaction that takes place at the cathode, which produces OH$^-$.

### 4.2. Treatment of wastewater solutions by electro-Fenton

4.2.1 COD degradation

In the EF$_{iron}$ process, a reduction of COD from 64 to 16 mg O$_2$/dm^3 was observed at pH 3 after a treatment time of 200 min (Figure 1). Fenton processes are more effective in acidic conditions.

Indeed, the EF$_{iron}$ process is based on the Fenton reaction in which H$_2$O$_2$ is generated from the electrochemical reduction of oxygen at the cathode, as follows:

$$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2 \tag{5}$$

The oxidation power of the generated H$_2$O$_2$ is usually enhanced by the Fe^{2+} ions produced by dissolution of iron from the anode to the acid solution (sulfuric acid) to generate free •OH radicals and Fe^{3+} ions via the well-known Fenton reaction (Pignatello, Oliveros, & Mackay, 2006):

$$Fe^{2+} + H_2O_2 + H^+ \rightarrow Fe^{3+} + H_2O + •OH \tag{6}$$
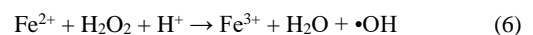
At the cathode, Fe^{2+} ions are continuously regenerated from the reduction of Fe^{3+}:

$$Fe^{3+} + e^- \rightarrow Fe^{2+} \tag{7}$$
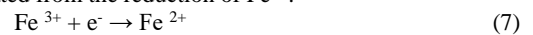
4.2.2 BOD$_5$ degradation

Figure 2 shows that BOD$_5$ decreases and then remained constant at 10 mg/dm^3 after 30 min of treatment by the EF process. This may be due to the acidic medium affecting microbes. Moreover, the acidic pH of solution inhibits the development of microbes and causes their mortality.

4.2.3 pH evolution

In EF$_{iron}$ process the initial pH must be in the acidic range to generate maximal amounts of •OH and to oxidize the
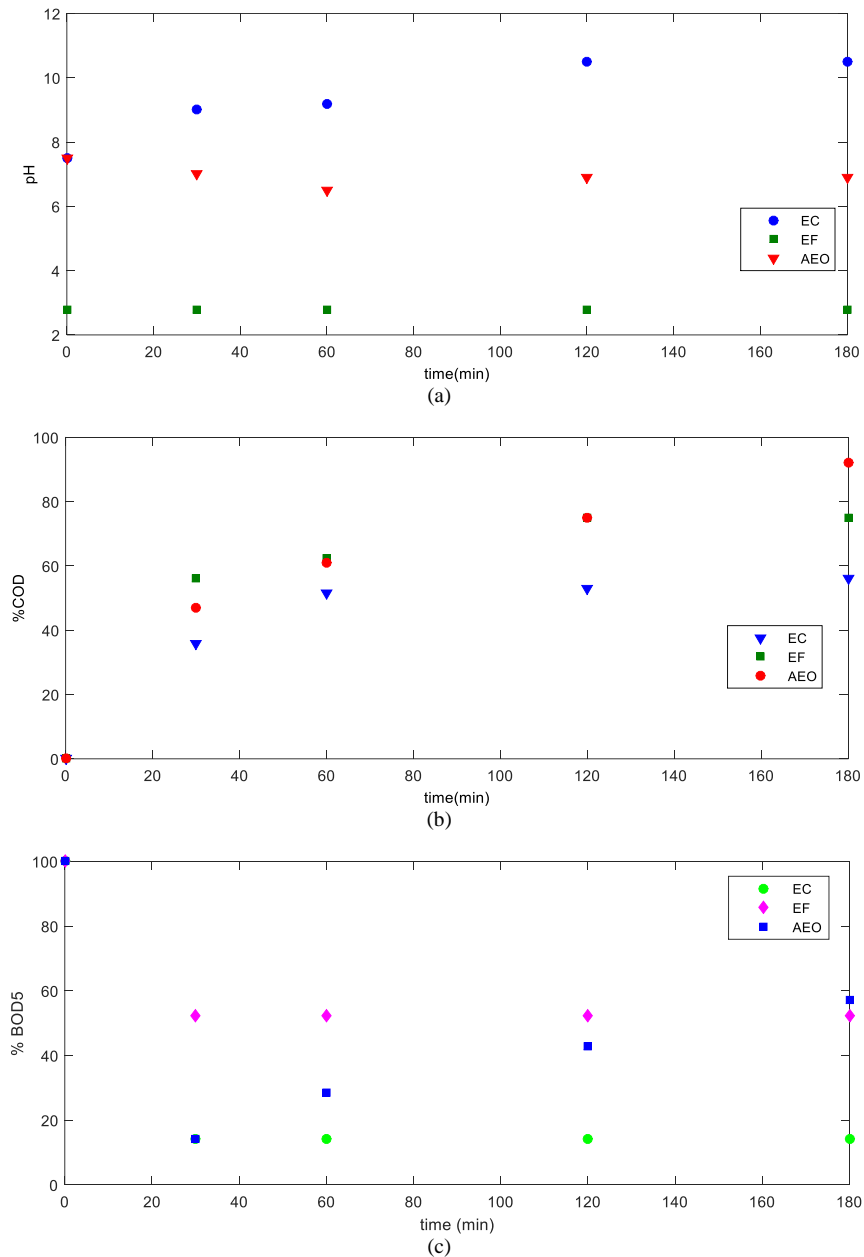
Figure 3.   (a) pH evolution, (b) COD removal efficiency, and (c) DBO$_5$ removal efficiency by EC, EF and AEO processes during the electrolysis time (I=2A, T=25°C).

organic compounds. Most studies have also indicated that the optimum pH for the EF$_{iron}$ process is pH 2.8-3, where the catalytic behavior of the Fe^{2+}/Fe^{3+} coupling can be maintained (Wang, Zheng, Zhang,&Wang, 2016).

4.3. Treatment of wastewater solutions by advanced oxidation

4.3.1 COD degradation

As can be seen from Figure 1, the COD decreased progressively during electrolysis reaching 5mgO$_2$/dm^3 at the end of the treatment. The •OH radicals, produced directly by the anodic oxidation of water, have the ability to degrade the greatest part of the organic matter in the treated wastewater.

4.3.2 BOD$_5$ degradation

The BOD$_5$ decreased to 9mg/dm^3 in the AEO$_{Pt}$ process (Figure 2). This can be explained by organic matter degradation and bacteria destruction by the actions of •OH radicals. Also, the current flowing through the wastewater treated can be lethal to these microorganisms.

4.3.3 pH evolution

With AEO process, it is observed in Figure 3a that the pH decreased slightly and then became stable. This can be explained by the reaction at the anode, which favors the production of •OH. The radicals attack the organic matter and promote the production of short chained carboxylic acids, which acidify the medium, but then the pH increases because of degradation of these acids (Bensalah, Louhichi, & Abdel-Wahab, 2012; Canizares, Paz, Saez, & Rodrigo, 2007; Özcan, Şahin, Koparal, & Oturan, 2007;).

4.4. Comparison between EC, EF and AEO

4.4.1 COD and BOD removal

After 180 min of electrolysis time, the COD removal efficiency increased to 56%, 75% and 92% (Figure 3c) and the BOD_5 removal efficiency increased to 14%, 52% and 57% (Figure 3b) with EC_{iron}, EF_{iron} and AEO_{Pt} processes, respectively.

The pH, % COD removal and % BOD_5 removal by EC_{iron}, EF_{iron} and AEO_{Pt} processes after 180 min of electrolysis time are given in Table 3. The findings indicate that in AEO_{Pt} process the medium remained neutral (pH≈7). Therefore, the AEO_{Pt} process reached the highest COD and BOD_5 removal.

In EC_{iron} process the medium was transformed to alkaline. This can be explained by the generation of great amounts of $Fe(OH)_3$ and OH^- that increase pH. The COD and BOD_5 were the lowest among the processes tested. This is may be due to the film, which covered the anode and inhibited the electrolysis. This can reduce the kinetics of organic matter degradation sharply.

Table 3.　Removal efficiencies of COD and SEEC by EC-$_{iron}$, EF-$_{iron}$ and AEO-$_{pt}$ processes after 180 min.

Process	EC-iron	EF-iron	AEO-pt
pH	10.5	2.8	6.9
COD removal(%)	56	75	92
DBO5 rem(%)	14	52	57

4.4.2 Bacteria removal

Table 2 summarizes the microbiological analyses of bacteria (GMT, E. coli, Staph and Salmonella) before and after treatment by EC_{iron}, EF_{iron} and AEO_{Pt} processes. The bacteria counts decreased for all types measured. This may be due to the current passage, which decelerates the micro-organism development in EC_{iron} process. However, for EF_{iron} and AEO_{Pt} treatment, this may be due not only to the effect of current but also to the •OH generation, which destroys and kills microorganisms.

4.5 Economic evaluation

4.5.1 Energy consumption

The energy consumption (W) is necessary to evaluate the energy costs. It was calculated from

$$W \ (KWh / m^3) = Q * U \tag{8}$$

where U is the cell voltage (V) and Q the specific electrical charge (Ah/m^3).

The specific electrical energy consumption (eq 10) (SEEC, KWh/kgCOD) is calculated from the specific electrical charge (Q) given by equation (9):

$$Q \ (Ah / m^3) \ = \ \frac{I \ x \ t}{V} \tag{9}$$

I is current intensity (A), t is time (h) and V is reactor volume (m^3).

$$SEEC \ = \ \frac{I \ x \ U \ x \ t}{(COD_{t0} - COD_t) \ x \ V} = \ \frac{Q \ x \ U}{COD_{t0} - COD_t} \tag{10}$$

where COD_{t0} = COD° and COD_t (COD at time=t)

Table 4 shows the SEEC values for each studied process, i.e. EC, EF and AEO. The treatment by AEO_{Pt} was the most expensive as it consumed the most energy, namely 2.6 kwh/kgCOD among the studied processes, the others being EC_{iron} (2.3 kwh/kgCOD) and EF_{iron} (2.2 kwh/kgCOD) (Table 4).

Table 4.　SEEC for EC-$_{iron}$, EF-$_{iron}$ and AEO-$_{pt}$ processes after 180 min.

Process	EC-iron	EF-iron	AEO-pt
SEEC (kwh/kgCOD)	2.3	2.2	2.6

The costs of energy, reagent consumption, iron dissolved and sludge removal are estimated for EC, EF and AEO processes (Tables 5-6). About 0.014 m^3 of sludge generated / m^3 of solution was determined experimentally for the EC and EF processes. No deposit of sludge was detected during the treatment by EAO_{Pt} because the platinum anode is dimensionally stable. The unit electricity price for industrial use is of the order 0.14€ per KWh and the total costs of 1 m^3 of treated wastewater is in the range commonly seen in the literature; and the cost of sludge disposal is assumed to be 150 € m^{-3} (157.868 $ m^{-3}) (Canizares, Paz, Saez, & Rodrigo, 2009).

The price of the main equipment is given by the William equation (Llanos, Camarillo, Perez, Canizares, & Rodrigo, 2011). This estimate assumes 10-year linear type, without value for money update. In fact, the cost P of the electrochemical reactor estimated in 2010 is

$$P = 21662 \ A^{0,7953} \tag{11}$$

Here A is the electrode area (Cañizares *et al.*, 2007):

$$A = \frac{Q(Ah/m^3) \ x \ 1000 \ x \ flow \ rate \ (m^3/d)}{j_{app} \ ^{(A/m2) \ x \ 24}} \tag{12}$$

As shown in Table 7 the reactor cost and total capital investment (without anode, for flow rate 1 $m^3.d^{-1}$) (in €) was estimated to be 19518.3€ and 111059.1€, respectively for EC_{iron} and EF_{iron}. However, the estimates for AEO_{Pt} were 6022.9€ for reactor cost and 34270.5€ for total capital

Table 5.   Estimated cost per 1 m^3 wastewater (COD$^\circ$=64mgO$_2$/dm^3) of reagents used in each process, of iron dissolved, and of sludge generated by both EC-$_{iron}$ and EF-$_{iron}$.

Process	EC-$_{iron}$	EF-$_{iron}$	AEO-$_{pt}$
Reagent added	H$_2$SO$_4$	H$_2$SO$_4$	H$_2$SO$_4$
Quantity added (kg/m^3) solution	0	0.2	0
Reactive cost (€)	0.52	0.52	0.52
Total cost of reagents added (€)	0	0.104	0
amount of anode matter dissolved(kg/m^3)	2	2	0
cost of iron anode matter dissolved(€)	1.001	1.001	1.001
cost of sludge treatment (€/m^3)	150	150	150
Amount of sludge (m^3) (0.014 m^3 sludge/ m^3)	0.014	0.014	0
cost of sludge treated (€)	2.10	2.10	0

Table 6.   Quantity of energy consumed (W). Estimated energy cost and total cost (anode price not included) of each process. (Electricity price 0.14 € / kwh used in estimates.)

Process	EC-$_{iron}$			EF-$_{iron}$			AEO-$_{pt}$		
Time (min)	60	120	180	60	120	180	60	120	180
W (KWh/m^3)	28	56	84	36	72	108	52	104	156
Energetic cost (€)	3.9	7.8	11.7	5.1	10.1	15.1	7.3	14.6	21.8
cost of sludge treated (€)	2.10	2.10	2.10	2.10	2.10	2.10	0	0	0
Total cost of reagents added (€)	0	0	0	0.104	0.104	0.104	0	0	0
Total cost (€)	6.0	9.9	13.8	7.3	12.3	17.3	7.3	14.6	21.8

Table 7.   Reactor cost and total capital investment (in €) of EC-$_{iron}$, EF-$_{iron}$ and AEO-$_{pt}$ (without anode, flow rate 1m^3.d^{-1}).

	Q (Ah.m^{-3})	A (m^2)	P (€)	Total capital investment(€)
EC-$_{iron}$ or EF-$_{iron}$	12	0.877	19518.3	111059.1
AEO-$_{pt}$	12	0.2	6022.9	34270.5

investment. In this work, j$_{app}$ (AEO$_{Pt}$) ≥ j$_{app}$ (EC$_{iron}$ or EF$_{iron}$) so A(AEO$_{Pt}$)≤ A(EC$_{iron}$ or EF$_{iron}$). Consequently, the AEO$_{Pt}$ process had the lowest reactor cost but required the use of a platinum electrode, which is very expensive and rare. The treatment cost of 1 m^3 of wastewater was estimated at 13.8, 17.3 and 21.8 €/m^3 respectively for EC$_{iron}$, EF$_{iron}$ and AEO$_{Pt}$ processes. This is due to the availability of iron and it being less expensive than platinum.

5. Conclusions

In the present work we conducted tertiary treatment experiments on wastewater and showed that:
- COD removal efficiency increased in the treated wastewater by EC$_{iron}$, EF$_{iron}$ and AEO$_{Pt}$ processes respectively up to 56%, 75% and 92%.
- The BOD$_5$ removal efficiency reached 14%, 52% and 57% with EC$_{iron}$, EF$_{iron}$ and AEO$_{Pt}$ processes, respectively.
- The bacteria counts decreased for the studied types (GMT, E. coli, Stoph and Salmonella) after treatment by EC$_{iron}$, EF$_{iron}$ and AEO$_{Pt}$ processes. This is due to the current passage, which decelerates microorganism development and destroys them.

- The treatment cost of 1 m^3 of wastewater was estimated at 13.8, 17.3 and 21.8 €/m^3 for EC$_{iron}$, EF$_{iron}$ and AEO$_{Pt}$ processes respectively.
- Reactor cost and total capital investment (without anode, for flow rate 1 m^3.d^{-1}) (in €) were 19518.3 € and 111059.1 € respectively for both EC$_{iron}$ and EF$_{iron}$. However, estimates for AEO$_{Pt}$ were 6022.9€ for reactor cost and 34270.5€ for total capital investment.

Wastewater treatment by the different processes reduced organic and bacterial loads. These waters could then be used for irrigation of some types of plants, such as forages. An economic study of amortization is required for proper choice of the best alternative process.

Acknowledgements

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