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Disinfection of Naturally Contaminated Underground Well Water in an Electrochemical Cell with Platinum/Carbon Black-Based Anodes

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ABSTRACT

This work studies the performance of a platinum/carbon black-based anode for an electrochemical cell for water disinfection. Platinum is deposited onto the surface of carbon black (CB) particles by an electroless method using H_2PtCl_6 as precursor (1.5% Pt:CB black weight ratio). The impregnated C particles are adhered to the surface of a stainless-steel mesh (SSM) to fabricate the electrode. SEM micrographs show a CB layer on the surface of the SSM and the presence of platinum on it is confirmed by EDS analysis. The disinfection of water is accomplished by applying a potential of 2.5 V vs Ag/AgCl(3 M KCl) to the anode for 90 minutes. The catalytic activity of the anode is characterized by measuring the free-chlorine concentration vs time during disinfection experiments, which shows an average increase of ca. 94% when compared to a clean SSM and reaches a CT value of ca. 23.9 mg min L^{-1} of free-chlorine. After disinfection, the water samples show the absence of microorganisms and the presence of residual disinfection agents. Since the disinfection process presents a moderate energy requirement of ca. 0.2 kWh m^{-3} and a high inactivation of microorganisms (ca. 99.9%), it appears to be a promising technology for water disinfection.

1. Introduction

Water disinfection processes can be considered one of the biggest achievements of the 20th century. Conventional disinfection methods can be divided in chemical and physical processes: while in chemical processes disinfecting species (such as ozone, chlorine, sodium hypochlorite or chlorine dioxide) are dissolved in the water to be treated, physical processes accomplish disinfection by means of irradiation with ultraviolet or ionizing radiation, heating to elevated temperatures, or separation through membrane filtration [1,2]. Even though both methods present satisfactory results, they show certain drawbacks. Physical disinfection has no residual effect, thus the World Health Organization (WHO) recommends that when physical methods are used a small dose of a persistent disinfectant such as chlorine or monochloramine must be added to the treated water to act as a preservative [3]. On the other hand, chemical disinfection processes are based mainly on the use of chlorinated compounds that have a residual effect, but also produce by-products (e.g., trihalomethanes and/or halogenated acids) which, according to recent studies, could promote diseases such as cancer and reproductive problems [4]. Considering all this, there is a need for developing alternative methods to give access to drinking water, hopefully, to all communities and at a reasonable price.

Among the non-traditional methods studied for water disinfection, the electrochemical approach appears to be a promising alternative to chemical methods based on chlorination [1,2]. Some advantages of the electrochemical approach are: (i) transport, storage and administration of external chemicals are not required since disinfecting species are produced *in situ*; (ii) the amount of disinfecting species "added" to water can be accurately controlled by the operating conditions (e.g., potential, time); and (iii) the energy requirements of the processes can be easily fulfilled using renewable energy sources (e.g., photovoltaic panels or wind turbines coupled to the electrochemical cell).

Electrolytic disinfection of water containing chloride (Cl^-) is based on the synergistic effect of the free chlorine produced in the electrochemical cell and the electric field established, which affects irreversibly the activity of microorganisms [2]. Basically, an electrolytic cell for water disinfection operates due to a DC potential difference applied between the cathode and the anode, which promotes the hydrogen evolution reaction (HER) in the first and the oxygen evolution reaction (OER) in the latter:

$$2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)} \quad (1)$$

(or, $2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)}$ in alkaline medium)

$$\frac{1}{2}O_{2(g)} + 2H^+_{(aq)} + 2e^- \leftarrow H_2O_{(l)} \quad (2)$$

(or, $\frac{1}{2}O_{2(g)} + H_2O_{(l)} + 2e^- \leftarrow 2OH^-_{(aq)}$ in alkaline medium)

In addition to the OER, a group of reactive chlorine species (RCS) is produced at the anode surface from the chloride present in water. These RCS include disinfection agents such as free chlorine (Cl_2, HClO and ClO^-) and species such as chloride ions [5], which can be produced according to the following secondary reactions [1]:

$$Cl_{2(aq)} + 2e^- \leftarrow 2Cl^-_{(aq)} \quad (3)$$

$$Cl_{2(aq)} + H_2O_{(l)} \rightarrow HClO_{(aq)} + HCl_{(aq)} \quad (4)$$

$$HClO_{(aq)} \rightarrow ClO^-_{(aq)} + H^+_{(aq)} \quad (5)$$

Regarding the electrode materials used for the fabrication of the electrochemical cells, cathodes are usually made of iron and stainless steel, while several alternatives have been reported for the anode depending on the concentration of chloride in the water to be treated [6,7]. It has been shown that titanium electrodes coated with iridium and/or ruthenium oxide(s) can produce free chlorine more effectively (higher production efficiencies) than platinum and boron-doped diamond electrodes, which makes them suitable for a wider concentration range of chloride in water. However, equally important than the production efficiency of free chlorine is the lifetime of the electrodes. Platinum electrodes have proven to be almost unaffected during long-term experiments, presenting a lifetime longer than eight years, that is contrasting with the lifetime of iridium and/or ruthenium oxide(s)-based electrodes which is less than one year.

Since anode fabrication involves precious metals, coatings of precious metals (or oxides) or other costly materials, the use of electrodes coated

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with an active layer of supported catalysts can be considered instead to reduce the capital costs associated to electrolytic processes for water disinfection. Electrodes fabricated using supported catalysts are widely known in electrochemistry (e.g., in fuel cells and CO_2 reduction applications), and the methods most commonly used for their synthesis are electroless plating and wet impregnation [8,9].

This research project aims to fabricate an anode for an electrochemical cell for water disinfection using a stainless-steel mesh and platinum supported on carbon black produced by the electroless method.

2. Experimental Methods

2.1 Mesh Pre-Treatment

A stainless-steel mesh (SSM) (AISI 304) with mesh size 60 and wire diameter of 0.17 mm was pre-treated with sandpaper (grit size 320) to generate surface abrasion. Subsequently, the mesh was dipped in a 1 M solution of sulfuric acid (H_2SO_4) (Merck, grade A) for 24 hours to remove superficial oxides without affecting its roughness [10].

2.2 Catalyst Preparation

Platinum was deposited on carbon black particles by the electroless method using an aqueous solution containing hexachloroplatinic(IV) acid (H_2PtCl_6) (Merck) as precursor and sodium borohydride ($NaBH_4$) (Merck) as the reducing agent. Firstly, 300 mg of carbon black (Vulcan XC72) were dispersed in 5 mL of isopropanol (Merck) along with 10 mL of distilled water, and ultrasonically stirred for 15 minutes. Then, 31.7 mg of H_2PtCl_6 and 0.5 mL of ethylenediamine (EN)(Merck) were added to the aforementioned mixture (to obtain a Pt/carbon black weight ratio of 1.5% Pt/C) and ultrasonically stirred for 30 minutes [9]. Following this, 30 mg of $NaBH_4$ were added to the solution and it was stirred ultrasonically for one hour [11]. Finally, the mixture was calcined in air at 250 °C for one hour using a temperature ramp rate of 5 °C min^{-1}.

2.3 Anode Fabrication

The supported catalyst particles prepared as stated in section 2.2 were suspended in a mixture of 3 mL of ethanol (absolute, Merck) and 3 mL of distilled water. Subsequently, 30 mg of polyvinylpyrrolidone (Sigma-Aldrich) were added [12] and the suspension was stirred (magnetically) for 10 minutes.

Planar electrodes with a geometric area of 2 cm^2 were prepared by a dipping process, after the SSM was pre-treated and dried, it was dipped into the suspension described in the above. Subsequently, the SSM was taken out from the suspension and the as-prepared electrode was dried. This process was repeated 4 times to obtain the final electrode.

2.4 Electrode Characterization

The catalyst distribution on the SSM was characterized by scanning electron microscopy (SEM), which was performed using a JEOL microscope (JSM-IT300LV). The content of platinum on the surface of the anode was confirmed by energy-dispersive X-ray spectroscopy (EDS) analysis. In addition, a Pt content characterization was made by the oxygen evolution reaction (OER) using linear sweep voltammetry (LSV). For this purpose, a 100 ml glass cell was filled with 50 mL of a 0.1 M sodium sulfate (Na_2SO_4) (Merck) solution as electrolyte; Pt/C electrodes were tested as working electrodes (with a geometric area of 2 cm^2), platinum wire was used as counter electrode and a Ag/AgCl(3 M KCl) electrode was used as reference. Linear sweep voltammetry studies (LSVs) were performed between 0 V and 1.6 V at a scan rate of 25 mV s^{-1}, a step size of 10 mV and experiments were conducted at a constant temperature of 22 ± 1 °C, using a Gamry Reference 3000 potentiostat. All the experiments were repeated at least three times to confirm the reproducibility of the results.

2.5 Disinfection Experiments

Underground well water with natural microbial contamination was used in this work for testing the anode kinetics for disinfection (hereinafter named model water). Samples of this model water were cultured to determine its initial cells density, which resulted to be ca. 3.4 x 10^4 CFU mL^{-1}. The microorganisms were cultured in selective growth media and the presence of total coliforms (including *Escherichia coli*), *Staphylococcus aureus* and *Bacillus subtilis* was confirmed. Table 1 shows the chemical characterization of the model water, which contains chloride in a concentration of 55.92 mg L^{-1}. The measured conductivity of this water is ca. 354 µS cm^{-1}, while its pH is ca. 7.2.

The use of water naturally contaminated with microorganisms adapted to the water environment makes the study closer to a real disinfection process, in contrast to the use of synthetic contaminated water. Furthermore, it has been demonstrated that the use of water with only one microbial indicator as total coliforms, is inadequate to predict the response of microorganisms in disinfection treatments [13]. The model water here used meets all the chemical requirements for drinking water but presents microbial contamination; in particular *S. aureus* and *B. subtilis* are Gram positive microorganisms that form a three-dimensional structure of high mechanical strength which is difficult to damage by disinfection agents [14], thus these bacteria are a good model for testing the disinfection process.

Table 1 Chemical characterization of the naturally contaminated underground well water used in this work

Species	Concentration / mg L^{-1}
Ca^{2+}	36.98
Fe^{3+}	0.0383
K^{+}	3.88
Mg^{2+}	25.70
Mn	0.0529
Na^{+}	17.30
Al^{3+}	0.0684
As	0.0021
Cl^{-}	55.92
NO_3^{-}	57.40
SO_4^{2-}	9.43
HCO_3^{-}	129.40

Electrolytic disinfection experiments were performed in a three electrodes system consisting of a 100 mL glass cell filled with a sample of 50 mL of the model water (no supporting electrolyte was added). The Pt/C-based electrodes fabricated were used as anodes (working electrode), while a stainless-steel mesh (AISI 304) previously treated was used as the cathode (counter electrode). An Ag/AgCl(3 M KCl) electrode was used as reference. Anode and cathode were placed in the cell with a separation of 2 cm and connected to a Gamry Reference 3000 potentiostat. A constant potential of 2.5 V was applied to the anode for 90 minutes on each disinfection experiment performed. All the experiments were conducted at a constant temperature of 22 ± 1 °C.

Before and after each experiment, the pH and conductivity of water were measured using a Thermo Scientific pH meter and a Jenway (4510) conductivity meter, respectively, although no significant changes of these parameters were observed (less than 8% in both cases). The concentration of free active chlorine before, during and after each experiment was measured by the N,N-diethyl-p-phenylenediamine (DPD) colorimetric method using an Ezdo chlorine meter [13]. It is important to mention that during the experiments other potential oxidants besides free chlorine could be produced (such as H_2O_2 and ozone [15]) and oxidize DPD, thus the free chlorine measurements reflect the total oxidizing capacity of the system. The inactivation of microorganisms was measured by plating and counting colony-forming units (CFU) according to that stated in water analysis literature [16]. The spread plates method with R2A agar was used for the culture. The samples were analyzed in duplicate and three consecutives 1:10 dilutions were prepared to ensure accuracy of the results. Each sample was cultured for 48 hours at 37 °C.

All these experiments were repeated at least three times to confirm the reproducibility of the results.

3. Results and Discussion

3.1 Fabrication of Platinum/Carbon Black Anode

3.1.1 Morphological Characterization

Fig. 1 shows the SEM micrographs of the stainless-steel mesh (SSM) before and after pre-treatment, and the 1.5% Pt/C-based anode fabricated. As can be seen, the SSM exhibits a rough surface after pre-treatment, which is required to improve the catalyst adherence to the surface of the support. As for the anode fabricated, it presents a homogeneous layer of carbon black on the surface of the SSM. Table 2 summarizes the results of the EDS analysis of the catalyst synthesized with different platinum loads (0.5, 1.5 and 2.0% Pt/C), which confirms the presence of platinum on the catalyst surface.

Table 2 Elemental composition analysis (energy dispersive spectroscopy, EDS) of the synthesized catalysts

Nominal Pt load (Pt/C ratio)	EDS analysis (Pt/C ratio)
0.5	0.48
1.5	1.56
2.0	1.83

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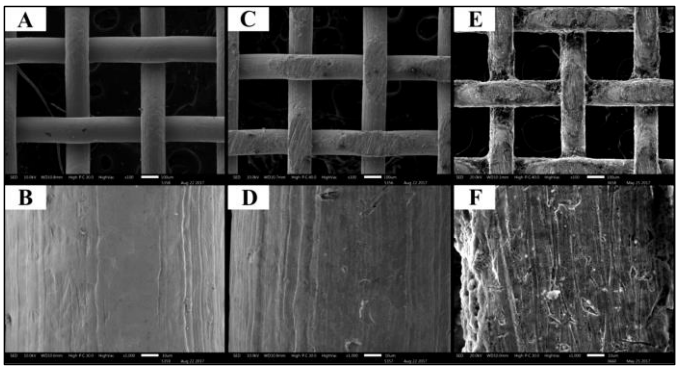

Fig. 1 Scanning electron microscopy images of the stainless-steel mesh: before pre-treatment (A and B), after pre-treatment (C and D), and covered with the 1.5% Pt/C catalyst (E and F)

3.1.2 Analysis of Electrode Catalytic Activity: Effects of Pt Content

The OER is one of the reactions occurring at the anode on an electrolytic cell for water disinfection (the other reactions are related to the production of reactive chlorine species, RCS, which kinetics are analyzed in section 3.2.1. Therefore, it is expected that changes in the platinum load of the fabricated anodes will be associated with changes in their catalytic activity for the OER (in the absence of chloride ions).

Fig. 2 shows the voltammograms obtained for the clean SSM (pre-treated) and three anodes with nominal platinum to carbon black ratios equal to 0.5, 1.5 and 2.0% Pt/C. The clean SSM electrode produces an average current density of ca. 1.79 mA cm^{-2} in the potential range between 1.0 and 1.5 V. On the other hand, the 0.5% Pt/C-based electrode shows an increase of ca. 23.5% in the average current density measured in this potential range compared to the clean SSM, while the 1.5% Pt/C-based electrode and the 2.0% Pt/C-based electrode show an increase of ca. 47.5% and 45.8%, respectively. This results in an increase on the catalytic activity for the OER, as can be observed over 1.5 V, when the amount of platinum in the catalysts is increased. However, no significant differences are observed between the catalytic activities of the 1.5 and 2.0% Pt/C-based electrodes, which can be partly explained considering that the real Pt/C ratio (measured by EDS, Table 2) is similar in both cases. Therefore, the 1.5% Pt/C-based electrode seems an attractive option for the fabrication of electrolytic cells for water disinfection (considering the lower amount of platinum required for its fabrication), subjected to its catalytic activity to produce RCS.

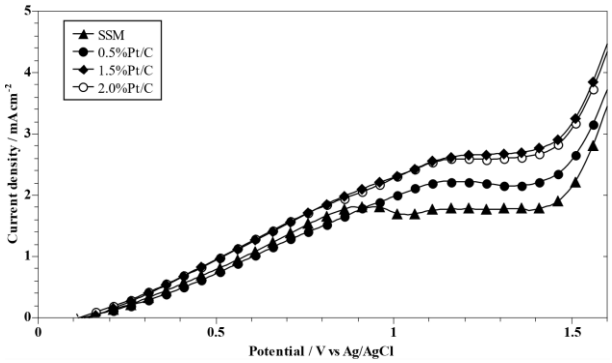

Fig. 2 Voltammograms obtained for the oxygen evolution reaction on the Pt/C-based electrodes fabricated using catalysts with different platinum to carbon black ratios (% Pt/C)

3.2 Electrochemical Disinfection of Naturally Contaminated Underground Well Water

3.2.1 Anode Catalytic Activity for the Production of Free Chlorine Species

The concentration of free chlorine species (Cl_2, HClO and ClO^-) before, during and after disinfection experiments of the model water was measured by the DPD colorimetric method using a clean SSM electrode (pre-treated) and three anodes with nominal platinum to carbon black ratios equal to 0.5, 1.5 and 2.0% Pt/C. The results are presented in Fig. 3, that includes a "baseline experiment" in which a 1.5%Pt/C electrode was used as anode and deionized water was used as electrolyte, instead of the contaminated water under study. The objective of this "baseline experiment" was to isolate the formation of other oxidizing species, such as H_2O_2 and O_3, from the DPD analyses, by using a source without chlorine species. Therefore, Na_2SO_4 was added to the deionized water samples to obtain a similar conductivity to that of the treated water (ca. 360 μS cm^{-1}), without modification of its chloride content.

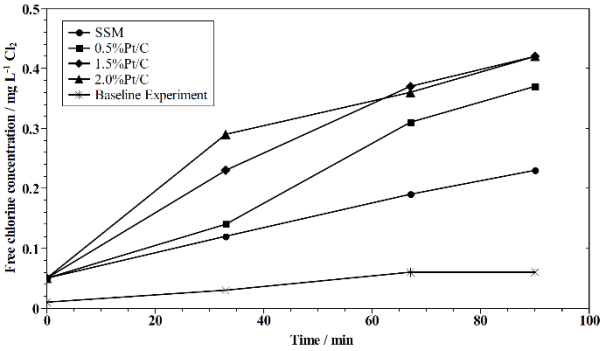

Fig. 3 Free chlorine concentration before (0 min), during and after (90 min) electrolytic disinfection of model water (expressed as mg L^{-1} Cl_2)

As can be seen in Fig. 3, all the experiments (using the clean SSM, 0.5, 1.5 and 2.0% Pt/C electrodes) present an increasing production of free chlorine over time. However, substantial differences can be noticed when comparing the behavior of the clean SSM electrode with that of the 1.5% Pt/C and 2.0% Pt/C electrodes. Finally, it can be observed that negligible amounts of free chlorine are produced when using deionized water in the "baseline experiment" (< 0.06 mg L^{-1} Cl_2), which evidences that the DPD analyses presented in this work are associated predominately with the formation of oxidized chlorine species rather than with H_2O_2 or O_3.

The influence of the applied anodic potential on the free chlorine generation in the model water is shown in Fig. 4. A higher production of free chlorine can be observed when potential is increased, and low average current densities were measured during these processes: 168 μA cm^{-2} (E_{appl}=1.0 V), 164 μA cm^{-2} (E_{appl}=1.5 V), 0.55 mA cm^{-2} (E_{appl}= 2.0 V), 0.82 mA cm^{-2} (E_{appl}= 2.5 V) and 1.69 mA cm^{-2} (E_{appl}=3.0 V). Pt anodes have a low O_2 overvoltage which is characterized by a high electrochemical activity toward oxygen evolution. It has been reported that effective oxidation at these anodes may occurs at low current densities; at high current densities, significant decrease of the current efficiency is expected due to the generation of O_2 [17]. Consequently, an applied potential of 2.5 V was stablished as the process working potential to avoid too high current densities (over 1 mA cm^{-2}).

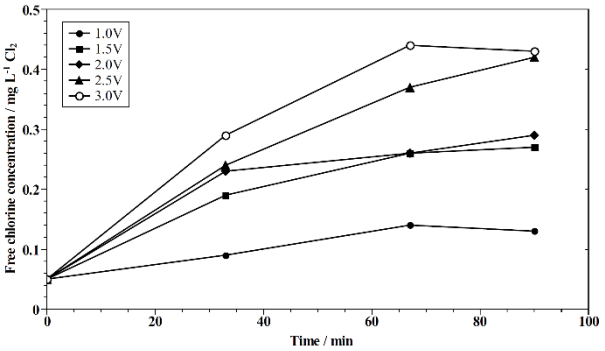

Fig. 4 Free chlorine concentration during electrolytic disinfection of model water (expressed as mg L^{-1} Cl_2) under different applied anodic potentials

The free chlorine concentrations measured in these experiments are lower than that obtained with other electrolytic disinfection processes reported in the literature [5,18]. However, as it is discussed in detail in section 3.2.2, disinfection is still accomplished. Furthermore, most of the electrochemical water disinfection processes reported in the literature require the addition of a salt as supporting electrolyte, to increase the ionic conductivity of the treated water [5,13,18]. On the contrary, this work did not consider the addition of any supporting electrolyte to the treated water, which allows to obtain a product that can be directly distributed for human consumption.

3.2.2 Microorganisms Deactivation and Energy Consumption

Disinfection experiments were performed using clean SSM and 0.5, 1.5 and 2.0% Pt/C anodes, according with the procedure described. Additionally, to the plate analysis of the microorganisms, water was examined before disinfection experiments by optical microscopy. As can be seen in Fig. 5, the treated water presented originally pseudo-colonies of microorganisms in suspension. Complementary SEM micrographs of these microorganisms (before and after electrolytic disinfection) were obtained by using polyvinylidene difluoride (PVDF) filters to retain the cells and cellular materials contained in the water samples analyzed. As can be seen in Fig. 6, before disinfection bacterial cells were forming aggregates and

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showed a smooth surface, while after the disinfection process serious cell damage can be observed as a large amount of cellular material is dispersed on the surface of the PVDF filter. This cell damage is produced by the combined effects of the electric field established and the production of oxidants during electrolytic disinfection: the electric field induces permeabilization of the cell membranes (and the formation of pores) and enables the disinfection agents produced to go inside these cells causing oxidation of the vital cellular constituents [2,19,20].

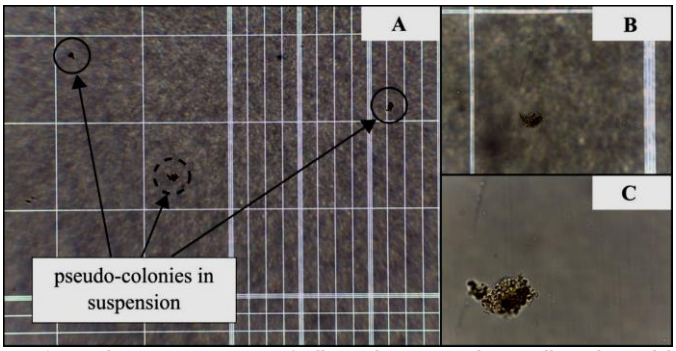

Fig. 5 Optical microscopy images of cell samples contained originally in the model water: (A) 10x objective, (B) 40x objective and (C) 100x objective (images (B) and (C) correspond to the colony indicated in the dashed line circle)

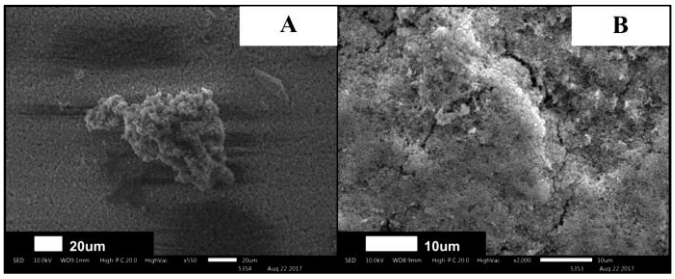

Fig. 6. Scanning electron microscopy (SEM) images of microorganisms in the model water: (A) before disinfection and (B) after disinfection

The disinfection effectiveness and electrical energy requirement of the electrolytic process were determined using Eqs.(6) and (7), and the results obtained are summarized in Table 3. As can be seen from these results, the electrodes containing platinum present a higher disinfection effectiveness compared to that of the clean SSM electrode, particularly those containing 1.5 and 2.0% of this noble metal (Pt/C ratio). Considering that almost identical levels of disinfection effectiveness were obtained using these anodes, the 1.5% Pt/C electrode is considered the best option for electrochemical water disinfection since a smaller amount of platinum is required for its fabrication.

$$D_{effectiveness} = \frac{CFU_{t_0} - CFU_{t_f}}{CFU_{t_0}} \quad (6)$$

where CFU_{t0}: colony-forming units before disinfection; CFU_{tf}: colony-forming units after disinfection.

$$Energy \ / \ \left(kWh\ m^{-3}\right) = \frac{E_{Cell} \cdot I \cdot t}{V} \quad (7)$$

where E_{Cell}: cell potential; I: cell current; t: disinfection time; V: volume of treated water.

Table 3 Disinfection effectiveness and electrical energy requirement of the electrolytic disinfection process using different anodes

Anode	Disinfection effectiveness / %	Electrical energy requirement / kWh m^{-3}
SSM	86.4	0.26
0.5% Pt/C	87.5	0.22
1.5% Pt/C	98.4	0.23
2.0% Pt/C	98.5	0.23

In order to study the effects of hydrodynamics during the disinfection process, experiments using magnetic agitation were performed with the 1.5% Pt/C anode. As a result, no microbial growth was observed in plates after analysis of the model water (disinfection effectiveness of ca. 99.9%), and the electrical energy requirement of the process was ca. 0.20 kWh m^{-3}. It is important to emphasize that this energy requirement is substantially lower than that obtained for similar electrochemical devices for water disinfection (6.3 kWh m^{-3} [21]), and is comparable to alternative technologies such as UV disinfection (0.3 kWh m^{-3} [22]). Therefore, the electrochemical system studied in this work appears to be a promising alternative for the disinfection of naturally contaminated water.

Finally, it is pertinent to evaluate the disinfection potential of this process for other microorganisms different to total coliforms. In this context, the CT value (product of the concentration of free chlorine and the contact time with the water being disinfected) can be used to determine whether the levels of free chlorine produced are high enough to inactivate other microorganisms [23]. The CT value for the disinfection process here studied was calculated integrating over time the free chlorine concentration curve shown in Fig. 3 for the 1.5% Pt/C anode, giving as a result 23.9 mg min L^{-1}. It is known that a CT value of 2 mg min L^{-1} is required for a 4-log inactivation of viruses (at 25 °C and pH equal to 7.0) [24], while a CT value of 24 mg min L^{-1} can generate a 2-log inactivation of *Giardia* (protozoa) (at 25 °C and pH equal to 7.0) [24]. Therefore, this process should be capable of inactivating viruses and protozoa together with total coliforms.

Using the curves presented in Fig. 4, the CT values for the different anodic applied potentials was estimated. For *Giardia*, a 0.5-log inactivation is obtained for 1.0 V (9.3 mg min L^{-1}), a 1-log inactivation for 1.5 V (17.7 mg min L^{-1}), a 1.5-log inactivation for 2.0 V (19.2 mg min L^{-1}) and a 2.0-log inactivation for 3.0 V (28 mg min L^{-1}). As can be noted, the processes applying 2.5 V and 3.0 V are estimated to have the same range of inactivation for *Giardia*.

3.2.3 Residual Disinfection

To determine whether the residual concentration of free chlorine remains at the required levels for water disinfection after the electrochemical process, the concentration of free chlorine was measured for three hours (every 10 minutes for 1 hour, and after 2 and 3 hours) immediately after a disinfection experiment using the 1.5% Pt/C anode.

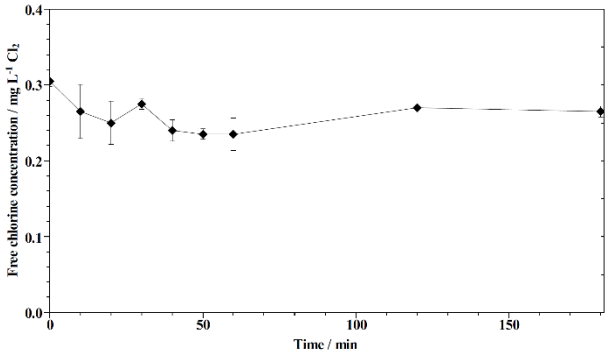

Fig. 7 Residual concentration of free chlorine in the model water after electrolytic disinfection

As can be seen in Fig. 7, the treated water presents a residual concentration of ca. 0.3 mg L^{-1} Cl_2 after its electrochemical disinfection. This result suggests that the disinfection mechanism is based on the generation of long-term oxidants (such as, hypochlorite and hypochlorous acid) rather than short-term oxidants (such as, hydroxyl radicals), which is in good agreement with the results discussed initially.

Residual disinfection is essential to inhibit microbial activity within the manipulation of water. In this context, The World Health Organization recommends a residual concentration of chlorine between 0.2 and 0.5 mg L^{-1} Cl_2 for drinking water [3]. Consequently, since the electrolytic cell studied in this work produces a residual concentration of chlorine of ca. 0.26 mg L^{-1} Cl_2 (steady state value observed in Fig. 7), it can be said that the water produced attains to the recommended limits for human health and wellness.

4. Conclusion

A Pt/C-based anode for electrolytic water disinfection was fabricated by the electroless method using H_2PtCl_6 as precursor and $NaBH_4$ as reducing agent to deposit platinum on the surface of carbon black, which was subsequently adhered to a stainless-steel mesh. Electrolytic disinfection of naturally contaminated underground well water using 1.5% Pt/C (mass ratio)-based anodes was accomplished for inactivating total coliforms as well as gram positive bacteria such as *S. aureus* and *B. subtilis.* This electrolytic disinfection process allows a 99.9% of microorganism inactivation, without the addition of any supporting electrolyte. Residual disinfection can be detected in the treated water, which indicates that the mechanism of disinfection is based on the production of long-term oxidants (free chlorine produced from chloride ions present in water). The electrolytic disinfection process showed a

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moderate energy requirement (0.20 kWh m^{-3} under agitation) and a high disinfection effectiveness, which makes it a promising alternative for the disinfection of naturally contaminated water.

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