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Short Communication Greening Electrocoagulation Process for Disinfecting Water

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Abstract: Electrocoagulation (EC) process is an efficient method for treating water especially in terms of killing pathogens. This paper discusses some tools to promote the large industrial usage of EC as a green technology. Concerning EC process design, the focus should be accorded to intensify the EC device in terms of residence time and close contact opportunities between water pollutants and electrodes area. The laminar *vs*. turbulent regime should be given more interests to better increase the metallic cations liberation from the anode and avoid or reduce the passivation of the electrodes. Evolution of hydrogen form cathode and oxygen from anode should be well optimized; at the same time, chlorine emanation from anode should be avoided or decreased to avoid disinfection by-products generation. Moreover, increasing the water temperature using solar energy heating would enhance the EC process efficiency technically, energetically, and economically. The heated EC process combines EC with distillation (or its similar version, even if at low temperature between 20-100°C) or membrane distillation using solar radiation. Finally, the EC method remains promising vis-à-vis pathogens' removal and water treatment in a general manner.

Keywords: Electrocoagulation (EC), Drinking Water, Electrochemical Disinfection, Disinfection By-Products, Green Chemistry

1. Introduction

In urban wastewater, bacteria, viruses, protozoa, and metazoa have been found; several of them provoke illnesses to humans and animals [1, 2]. These pathogens are diverse and their demobilization is therefore influenced by the used treatment [3, 4]. As a rule, the treated water value is rated in terms of microorganisms' presence using measures such as fecal coliforms; however, its rightness to confirm the action of treating water upon viruses, protozoa or non-fecal bacteria is not sure [5-7]. Different indices like heterotrophic bacteria, enterococci, bacteriophages, and adenovirus have been as well examined. As an illustration, researchers suggested the spores of sulfite-reducing clostridia as parameters for *Cryptosporidium* total oocysts. Frequently, quality conditions of treated water are set by National Environmental Protection Agencies. As an illustration, in Spain, 100 colony-forming unit (CFU) per 100 mL is the maximal tenor of *Escherichia coli* allowed for reuse in food crops, whereas 200 CFU per 100 mL is the limit for urban unrestricted reuse [2].

Municipal sewage arriving in wastewater treatment plants (WWTPs) [8] is frequently passed throughout several stages method consisting of (i) first treatment to eliminate solid matter, (ii) the following process to reduce the amount of organic matter (OM) and bacteria and (iii) a tertiary method for killing microorganisms and demolition of remaining OM. Usually, the second step is composed of a biological treatment that needs huge spaces and considerable contact periods, while the third step implicates chlorination [9-13] or UV irradiation [14-18]. Electrochemical disinfection may be an attractive option since it is more eco-friendly and cost-effective [19-23], being electrocoagulation (EC) one of the most encouraging methods for this end [2, 24-26].

EC means the in situ formation of coagulants through oxidizing electrochemically a sacrificial anode (iron [27] or aluminum) in a single compartment [28]. The liberated metal ions are then converted into hydroxides that balance electric charges or take action as *sweep* flocs [29-31] with huge surface areas and accordingly, they boost their assemblage or sedimentation in the form of mud, fixing the solubilized contaminants [32-34]. As an illustration, employing Fe as the anode, Fe^{2+} is produced from Reaction (1) and in the presence of solubilized $O_{2(g)}$, it is transformed into Fe (III) from the global Reaction (2) [35, 36]. Another gas, $H_{2(g)}$ may be generated at the cathode from water reduction through Reaction (3). Fe $(OH)_{2(s)}$ at pH > 5.5 and Fe $(OH)_{3(s)}$ from pH > 1.0 play the role of: (1) coagulants that eliminate particles through surface complexation or electrostatic attraction and (2) flocculants that remove particles through *sweep* flocculation [2, 29-31].

$$Fe \rightarrow Fe^{2+} + 2e^- \quad (1)$$

$$4Fe + 10H_2O + O_{2(g)} \rightarrow 4Fe(OH)_{3(s)} + 4H_{2(g)} \quad (2)$$

$$2H_2O + 2e^- \rightarrow 2OH^- + H_{2(g)} \quad (3)$$

Many researchers have used EC with Fe or Al anodes to purify municipal wastewaters from WWTPs, discovering a complete elimination (>99.99%) of *E. coli* [37-39], total coliforms [40, 41] or *Staphylococcus aureus* [42]. Moreover, some researchers [43] observed a total elimination of total coliforms, *E. coli*, *Shigella* and *Salmonella spp.* from urban effluent at through the action of EC coupled with H_2O_2 injection (considered as Electro-Fenton by [43]). Nevertheless, a detailed examination of the decrease of municipal effluent microbiota through EC has not been mentioned until now [2].

This short communication focuses on EC process as an electrochemical disinfection method and discusses its performance in killing pathogens. A special interest is affected to means for bridging the link between EC and the green chemistry with a view to treat water.

2. Municipal Effluent Bacteria Demolition Through EC Process

Anfruns-Estrada et al. [2] evaluated the capacity of EC using an Fe/Fe cell to demobilize bacteria carried in real municipal effluent collected from primary and secondary WWTP clarifiers. Taking into account the microbiological complexity of both wastewaters, heterotrophic bacteria, *E. coli*, enterococci, *Clostridium perfringens* spores, somatic coliphages and eukaryotes were chosen as measures. The destruction of bacteria tenor through the EC period was evaluated at a constant current density (j) to show if the EC application is greatly useful to treat municipal effluent.

Anfruns-Estrada et al. [2] realized the EC tests with 200 mL of the primary and secondary effluents employing an agitated Fe/Fe tank reactor at j = 200 A/m^2 during 90 min. The initial pH of 7.54 ± 0.16 augmented up to a final value of 9.08 ± 0.27; at the same time, the conductivity was observed to remain fixed, oscillating between 2.50 and 2.04 mS/cm.

Figures 1 a and b focus on the irregular vanishing of the various bacteria through the treatment of both wastewater samples. Somatic coliphages were the less enduring microbes, being unnoticeable after 20 min in both wastewaters, followed by the eukaryotes, whose amount diminished importantly at that period with total disappearance at 60 min. On the other hand, the amount of heterotrophic bacteria decreased to ~10^3 CFU/mL during 90 min, corresponding to a decay of 3.66 and 2.81 log units for the primary and secondary effluents, respectively. Figure 2 exposes a fast elimination of such bacteria in both matrices in the initial 10 min of EC, pursued by a lazier density decomposition up to the termination of the electrochemical process. An identical fashion was detected for all the other bacteria tested. In all situations, a more important amount decrease was reached for the primary effluent comparatively with the second one, likely due to its larger quantity of microbiota and the existence of a bigger mass of organic matter with the capacity to be coagulated and fix bacteria. As a rule, the elimination phenomenon was steadied at the end of 30-40 min of EC, after that no more bacteria removal was observed.

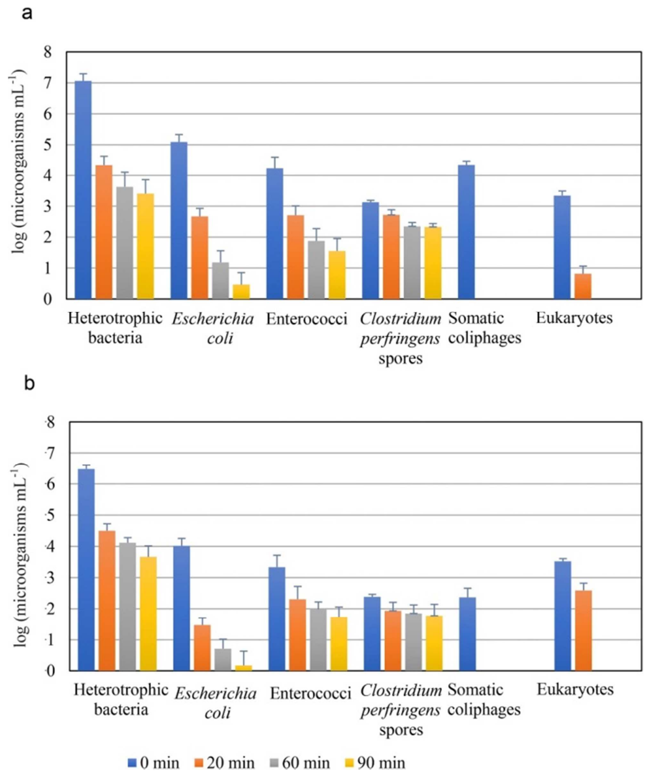

Figure 1. *Variation of the logarithm of concentration of heterotrophic bacteria, Escherichia coli, enterococci, Clostridium perfringens spores, somatic coliphages and eukaryotes with electrolysis time upon electrocoagulation (EC) of 200 mL of (a) primary and (b) secondary effluents using an undivided Fe/Fe cell (electrodes with 10 cm^2 area) at current density (j) of 200 Am^2 and 25°C [2].*

Moreover, nearly full inaction of *E. coli* was reached, with a vigorous lowering of 4.62 log units in the primary effluent and 3.84 log units in the secondary effluent. *E. coli* was the less solid bacterium to EC among those examined. Much smaller decreases of 2.68 and 1.60 log units in such media were detected for enterococci. More important, *C.*

perfringens spores became the most solid object, with a decrease as small as 0.80 and 0.61 log units did in the primary and secondary effluents, respectively. Finally, the considerable impact of the electrochemical coagulation on the eukaryotic community, as shown in Table 1, is as well remarkable, with no obvious vitality of all these bacteria following 60 min of EC. The existence of eukaryotes was slightly more prolonged in the case of dealing with the secondary effluents. At 5 min, only some flagellated volvocales could not be eliminated from the primary effluent, while all kinds of eukaryotes still lived in the second one despite their intense amount decrease. At 20 min, only amoebae could not be removed greatly in the latter effluent [2].

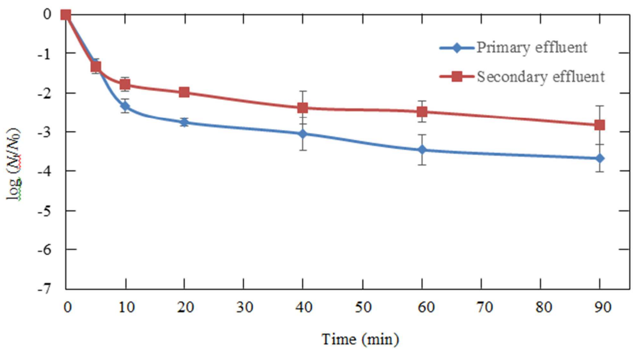

Figure 2. *Heterotrophic bacteria demolition through the EC tests shown in Figure 1 [2].*

Table 1. *Time course of eukaryotic community (in microorganisms/mL) during the treatment of primary and secondary effluents by electrocoagulation (EC). EC was carried out in an undivided Fe/Fe cell with electrodes of 10 cm² area at j = 200 A/m². Temperature was kept at 25°C in all trials [2].*

Eukaryote	Primary effluent				Secondary effluent			
EC time (min)	0	5	20	60	0	5	20	60
Amoebae	70	<1	<1	<1	597	296	101	<1
Flagellates	2190	362	4	<1	1540	48	<1	<1
Ciliates	34	<1	<1	<1	798	467	1	<1
Metazoa	2	<1	<1	<1	29	10	5	<1

Regardless of the huge evanescence of all the bacteria upon examination, total organic carbon (TOC) amount subjected a rather incoherent elimination for both types of wastewater under EC application (EC of 200 mL of primary and secondary effluents at j = 200 A/m^2 for 90 min). TOC decreased 17.6 mg/L (24.6% of the initial 71.4 mg/L) for the primary effluent and 5.5 mg/L (35.2% of the initial 15.6 mg/L) for the secondary one. The comparatively bigger cleaning of the latter wastewater may be linked to its less significant organic charge, which is mainly eliminated through precipitation over the $Fe(OH)_n$ flocs generated upon the treatment at the same j value [2].

More analyses were performed with the sludge gathered through the EC applications, proving that a little fraction of coagulated bacteria was still live. This proposes that their coalescence with encapsulation on the flocs produced [44]. The effective microorganisms' killing of sewage water samples is in conformity with the findings achieved by different researchers employing EC with various anodes at different applied currents. As an illustration, researchers [37] depicted a total extinction of *E. coli* and algae from surface water with aluminum, stainless steel, and common steel anodes [45]. Microorganisms' killing in surface water and in synthetic suspensions employing aluminum anode has been mentioned well-reported [46]. The fast removal for somatic coliphages [2] harmonizes with the findings of Zhu et al. [47] for MS2, a kind of coliphage, spiked into simulated natural water and treated by EC and membrane microfiltration [2, 48].

3. Conclusions

The main points drawn from this short communication may be given as:

Physical process, such as adsorption on activated carbon and/or membrane process like microfiltration or nanofiltration, should follow EC method to ensure that remaining radicals, generated disinfection by-products, residual metals (Al/Fe, and others) are completely removed from water before its distribution to consumers.

Concerning EC process design, the focus should be accorded to intensify the EC device in terms of residence time and close contact opportunities between water pollutants and electrodes area. Laminar *vs*. turbulent regime should be given more interests to better increase the metallic cations liberation from anode and avoid or reduce the electrodes passivation. Evolution of hydrogen form cathode and oxygen from anode should be well optimized; at the same time, chlorine emanation from anode should be avoided or decreased to avoid disinfection by-products generation.

Solar energy should be used to reduce the electric power costs. Moreover, increasing the water temperature using the solar energy heating would enhance the EC process efficiency technically, energetically, and economically. The heated EC process combines EC with distillation (or its similar version, even if at low temperature between 20-100°C) or membrane distillation using solar radiation.

That, at least, what should be done as strategies towards greening EC process for disinfecting water particularly and treating it generally. Finally, EC method remains promising vis-à-vis pathogens' removal and water treatment in a general manner.

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