Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.807474

52 (2014) 5380–5389
August

Taylor & Francis
Taylor & Francis Group

Investigations of the mechanism and efficiency of bacteria abatement during electrocoagulation using aluminum electrode

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Received 14 January 2013; Accepted 15 May 2013

ABSTRACT

The mechanism of bacteria abatement during an electrocoagulation treatment was investigated with the soluble aluminum electrodes on *Escherichia coli* cultures in model solutions. The efficiency of *E. coli* abatement was established under two kinds of experiments: in a 1 L batch reactor and in a 10 L pilot reactor with flowing solution. About 97% of abatement was obtained after 35 min with a current intensity of 0.22 A. Electrocoagulation exhibited greater bacteria abatements by a 2-log factor than for a chemical coagulation using identical quantities of aluminum. The decanted flocs of electrocoagulation were analyzed by X-ray diffraction which showed that electrogenerated alumina contained nanocrystallites of boehmite AlOOH. Moreover, these flocs contained living bacteria. This observation suggests that bacteria removal during electrocoagulation could be attributed to a strong bacteria adhesion on the surface of electrogenerated alumina particles followed by a separation of the decanted solids. The abatement of *E. coli* by electrocoagulation was the result of concomitant processes: mortality due to depletion of oxygen and nutrient species and adsorption on alumina and sedimentation. Redox potential measurement showed that during electrocoagulation the solution was not oxidizing and that *E. coli* removal can not be attributed to chlorine formation. The electrocoagulation treatment led to bacteria removal but it was not a true disinfection process.

Keywords: Electrogenerated alumina; Nanocrystallites; Separation; Redox potential; *Escherichia coli*

1. Introduction

Nowadays there is a great deal of interest in developing effective electrochemical disinfection systems as alternative of the conventional water treatment processes [1,2]. The technique is also known to inactivate a wide variety of microorganisms from bacteria to viruses and algae [1–8]. The use of electrochemical techniques offers many advantages: better environmental compatibility, versatility, energy efficiency, safety, selectivity, and cost effectiveness [9,10].

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A lot of studies concern electrolysis which generates a variety of oxidants in the presence of molecular oxygen, including hydrogen peroxide and ozone, as well as free chlorine and chlorine dioxide when chloride ions are present in the solution [11–13]. Most of the published studies in the field of electrochemical disinfection deal with drinking water treatment and using model solutions and conventional dimensionally stable anodes with mixed oxide coatings to elucidate the base mechanisms. Boron doped diamond material was recently developed as the most promising anode. It is known to achieve high efficiency due to its high oxygen overvoltage in producing electrogenerated oxidants from water or dissolved substances. These oxidants are short-lived free radicals or stable molecular substances [14]. The most popular form of electrochemical disinfection is the electro-chlorination. The main advantage of this method lies in the on-site preparation of disinfectants from nonhazardous substances, thus avoiding the problems of chlorine uses like its transport and storage. The electro-chlorination can be classified in two types [15]. One is to produce chlorine from brine prepared for the electrolytic generator, and the other is to produce the oxidants directly from the water to be treated through the electrolyses.

As a variant of an electrochemical process, electrocoagulation (EC) appears as a promising and efficient electrochemical technology [16–25]. EC is a process involving many chemical and physical phenomena that uses a soluble anode to supply ions into the treated water. EC, like a chemical coagulation, is influenced by an electric charge effect on the stability of colloids, suspensions, and emulsions. Therefore, when multivalent ions are added to charged particles their surface charge is neutralized, so several particles combine into larger and separable agglomerates. Flocs formed by EC are similar to chemical flocs, except that EC flocs tend to be much larger, contain less bound water, are acid-resistant and more stable, and therefore can be separated faster by filtration [19]. EC process involves three successive steps: (i) ion formation by electrolytic oxidation of the soluble anode, (ii) destabilization of contaminants or emulsion breaking, and then (iii) aggregation of the destabilized phases leading to floc formation. The EC process avoids uses of chemicals, and so there is no problem of neutralizing excess chemicals and no possibility of secondary pollution caused by chemical substances added at high concentration as during chemical coagulation of wastewater [19]. The efficiency of EC has been established in the removal of algae [26–28] and bacteria [22,29,30]. These papers show that EC works as a disinfection-like process, which allows the use of surface waters and industrial wastewaters.

In the present study, synthetic solutions which contained *Escherichia coli* bacteria were used in order to investigate the mechanism of bacteria removal during an EC with aluminum electrodes. *E. coli* is well known as a pathogenic species for human. The presence of these gram negative bacteria is generally used as a reliable indicator of the quality of drinking water [5,10,30–37]. In the present study, the bacteria removal occurred without the formation of electrogenerated oxidant species. In order to establish the efficiency of EC in *E. coli* removal some chemical coagulation experiments were performed.

2. Materials and methods

2.1. Chemicals and water substrates

All the chemicals were commercial compounds used without further purification. *E. coli* were provided by Institut Pasteur (genotype 5530). 100 μL of *E. coli* suspension in a peptone broth were diluted in 1 L of tap water. This solution was brought to room temperature before experimentation. The conductivity and the pH of the solutions were controlled by addition of NaCl and NaOH or HCl solutions, respectively. The main physicochemical data of the investigated solutions are gathered in Table 1.

Table 1
Physicochemical characteristics of the investigated solutions

Parameters	Conductivity 0.6 mS cm^{-1}	Conductivity 1 mS cm^{-1}
CAT (mEq L^{-1})	1.84	1.86
Chloride (mg Cl^{-} L^{-1})	12.93	52.25
Total hardness (Ca, Mg) (°F)	15.27	15.76
Hardness (Ca) (°F)	12.67	12.39
Nitrate (mg L^{-1})	26.00	28.50
Phosphate (mg L^{-1})	Not detected	0.73 E−02
Permanganate index (mg O_2 L^{-1})	1.71	3.50

2.2. Electrolysis

The electrodes were made of commercial aluminum plates. Before electrolysis, the aluminum electrodes were scraped with emery paper in order to remove alumina layer. The electrodes were connected to a direct current generator (Micronix MX300-1) which was used at controlled voltage.

2.2.1. Batch experiments

Electrolyses were carried out with 1 L solution in a 2 L cylindrical reactor equipped with two parallel aluminum electrodes. The immersed electrode surface was around 40 cm^2. All the runs were performed at room temperature, during 30 min, under a magnetic agitation with a constant voltage of 30 V. The current and the temperature were measured during the experiments. About 5 mL samples were taken from the electrolyzed solutions for analysis. Bacterial and chemical analyses were conducted on the supernatant solution after sedimentation during 30 min. The amount of aluminum dissolved in an EC experiment was calculated by Faraday's law (Eq. (1)) where w is the theoretical weight of the oxidized aluminum (g), I is the electrolysis current (A), t is the duration of the electrolysis (s), M is the molecular weight of Al (27 g mol^{-1}), n is the number of electrons involved in the oxidation of Al ($n = 3$), and F is the Faraday constant (96,500 C mol^{-1}).

$$w = (ItM/nF) \quad (1)$$

2.2.2. Pilot treatments

Electrolyses were carried out with the pilot equipment which is schematized in Fig. 1. The upper rectangular tank of 2 L was the electrolytic reactor. It was equipped with aluminum electrodes which were arranged in a bipolar or monopolar mode (Fig. 2). The electrolytic reactor was connected to a 10 L rectangular tank which contained solution to be treated. The solution was continuously pumped through both the tanks by a centrifugal pump (Prolabo). The flow was measured by a flow-meter. The experiments were performed at different flow rates and with varying bacteria concentrations. All experimental conditions are given in Table 2. Generally, the experiment time was 1 h and at interval of 5 min, 5 mL of solution were taken for biological analysis.

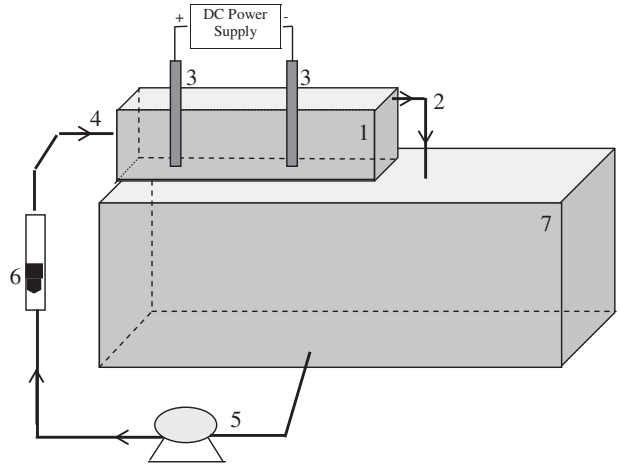

Fig. 1. Schematic diagram of the pilot reactor. (1) 2 L electrocoagulation cell, (2) water out, (3) aluminum electrodes, (4) water in, (5) water pomp, (6) flow-meter, and (7) 10 L water tank.

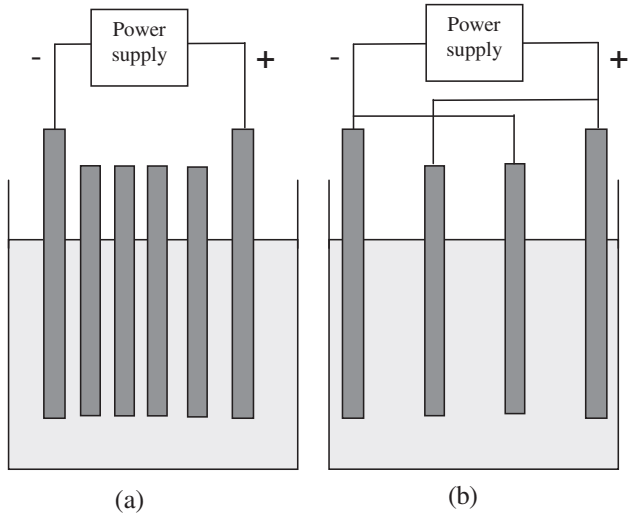

Fig. 2. Schemes of electrochemical cells: (a) with bipolar electrodes, (b) with monopolar electrodes.

2.3. Chemical coagulation experiments

Chemical coagulation experiments were conducted on 1 L of *E. coli* solutions, following the standard Jar test technique. The coagulant was a solution of aluminum sulfate ($Al_2(SO_4)_3$, $18H_2O$, 51% pure) provided by Panreac. Aluminum sulfate doses were equivalent to the amount of dissolved aluminum calculated with Eq. (1) for EC experiments. Sodium hydroxide solution was added for any subsequent pH adjustment. The Jar test was equipped with stainless steel paddles (7.5 cm × 2.5 cm). Appropriate contact times were 30 min for mixing at 150 rpm followed by a 30 min

Table 2
Experimental conditions of EC in the pilot reactor

Flow ($L\,h^{-1}$)	Initial bacteria content ($UFC\,mL^{-1}$)	Electrodes: number and nature	Conductivity ($mS\,cm^{-1}$)	Temperature variation (°C)
100	2.0 E + 04	4; monopolar	0.4	+15
400	3.8 E + 04	6; bipolar	0.5	+11

step without agitation. The supernatant solutions were taken for analysis.

2.4. Chemical analysis

Chemical analyses were carried out with the following standard methods: Alcalimetric Title and Complete Alcalimetric Title (AT and CAT) NF EN ISO 9963-1 (T 90-036); Total hardness ($Mg^{2+} + Ca^{2+}$) (NF T 90-003); Hardness (Ca^{2+}) (NF T 90-016); Chloride (NF T 90-014); Permanganate Index ($KMnO_4$) NF EN ISO 8467 (T 90-050); Phosphate NF EN ISO 6878 (T 90-023); and Free chlorine (NF T 90-037). Nitrate concentration was measured by the Reflectoquant method (Merck). Chemical oxygen demand was measured using a spectrophotometer (Hach Company, USA), after an oxidation by potassium dichromate during 2 h at 150 °C. The solid material isolated after coagulation or EC was collected by filtration. It was rinsed with water and dried at room temperature before its characterization by X-ray powder diffraction (Bragg-Brentano geometry, Rigaku-Geigerflex diffractometer). The diffraction pattern was scanned from 4 to 110° (2θ) using Cu Kα radiation of 1.54178 Å and a step length of 0.02° (2θ).

2.5. Bacteria analysis

E. coli bacteria were counted according to the standard method NF EN ISO 6222 (T 90401). The count of the revival bacteria was obtained at 37 °C on lauryl sulfate for *E. coli* analysis and on Plate Count Agar for total flora. Two characteristics were determined: T_0, the initial bacteria content in unit-forming colonies ($UFC\,mL^{-1}$), and T_f, the final bacteria content ($UFC\,mL^{-1}$).

3. Results and discussion

3.1. Batch electrolysis

The electrolysis current determines the coagulant dosage rate and also the hydrogen production rate. The coagulation and the floc formation, and consequently the collision between solid particles and bacteria are dependent upon the current. The current passing through the solution is accompanied by a Joule effect which can change the solution temperature [38]. The temperature effect on the microbial inactivation of electric fields has been reported [39]. In order to control the temperature influence during EC treatments, a preliminary study was carried out about the choice of the conductivity parameter. Batch electrolyses were performed with a voltage control at 30 V on solutions characterized by their conductivity. As shown in Fig. 3, the solution temperature increases with time and solution conductivity. In a first approximation, at a constant voltage ΔV, the electrolysis current I is dependent upon the solution resistance R between the electrodes ($I = \Delta V/R = \Delta VG$). The current increased with the solution conductance G, and consequently, the increasing Joule effect (RI^2) led to a temperature increase. Taking into account the bacteria viability in the range 15–45 °C, the temperature was controlled to be less than 40 °C by selecting solutions of low conductivity. Therefore, the observed decrease in viable counts can be attributed only to the applied electric field treatment and not to a temperature increase which would be due to the Joule effect.

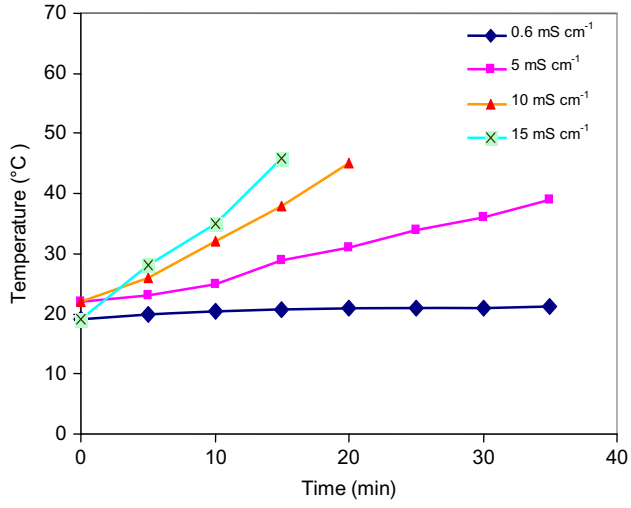

Fig. 3. Variation of solution temperature during electrocoagulation (voltage 30 V). The solution conductivities are given in the figure.

3.2. Electrolysis effects on chemical parameters

It is well known that EC has an effect on the chemical parameters of the electrolyzed solutions. The results (Table 3) show a notable decrease of nitrate content and permanganate index. The value of permanganate index is a quantitative measure of compounds which are oxidized by MnO_4^- in an acidic solution. During the treatment, the organic components can be removed by reduction or by adsorption on the generated sludge. Al^{3+} and OH^- ions arise from the anodic and cathodic reactions (Eqs. (2) and (3)), respectively. In solution, these ions react and lead to various monomeric and polymeric species which afford finally $Al(OH)_3$ (Eq. (4)) according to a complex precipitation kinetics. Freshly formed amorphous Al $(OH)_3$ (sweep flocs) has large surface areas for adsorption of organic compounds or trapping of colloidal particles [40–42].

$$Al \rightarrow Al^{3+} + 3e^- \quad (2)$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (3)$$

$$Al^{3+} + 3OH^- \rightarrow Al(OH)_3 \quad (4)$$

As shown by Moreno-Casillas et al. [43], the residual value of permanganate index after treatment is due to soluble compounds that do not react with Al (III) to form insoluble species. The nitrate removal results confirm the previous EC works [44,45] which report that there was a linear relationship between the nitrate abatement and the increase of the electrolysis current.

3.3. Hypothesis of a chlorine effect

During electrolysis, the electrode reactions are controlled by thermodynamics and kinetics. Oxidation of water or chloride anion and reduction of water are known to involve a large overvoltage which is dependent upon the nature of the electrode [46]. The standard potentials of possible redox couples (Eqs. (5) and (6)) show that the most expected oxidation is that of aluminum ((Eq. (7)) [46]. Indeed, this potential is much lower than the redox potential of Cl_2/Cl^-. It is also lower than the formal standard potential of O_2/H_2O which is calculated at +0.815 V/SHE at pH 7.

$$H_2O \rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^- \ (E^\circ_{O_2}/H_2O = 1.228V/SHE) \quad (5)$$

$$2Cl^- \rightarrow Cl_2 + 2e^- \ (E^\circ_{Cl_2/Cl^-} = 1.395V/SHE) \quad (6)$$

$$Al \rightarrow Al^{3+} + 3e^- \ (E^\circ_{Al^{3+}/Al} = -1.663V/SHE) \quad (7)$$

As a consequence of the cathodic reaction leading to hydrogen, the concentration of oxygen decreases in solution [22]. More than an oxygen reduction at the cathode, the oxygen decrease is the result of a degassing process. The oxygen decrease does not allow a reduction leading to superoxide anion O_2^- or hydrogen peroxide H_2O_2 which could be biocide species. Moreover, the measured redox potential during EC is not in agreement with the formation of chlorine. Indeed, the redox potential is measured at −0.2 V/SCE in KCl solution [22]. In order to prove that chlorine is not involved during electrolysis of chloride solution, one electrocoagulation experiment was carried out on 1 L of solution which contained 1.5 mg/L of free chlorine. A 100% abatement of free chlorine was observed after 30 min of electrolysis with a current of 0.2 A. All these observations prove that chlorine cannot be formed by chloride oxidation during electrocoagulation, and if it is present it would be removed. So, when a chloride solution is submitted to an EC with aluminum anode, the observed bacteria removal cannot be attributed to a disinfection process which would involve oxidant species.

An electrochemical reaction involving bacteria must be excluded because the bacteria abatement was too fast to be, due to an electron transfer at the electrodes. Vital centers of bacterial cells are protected by a membrane which is constituted essentially by layers of phospholipids with hydrophobic and hydrophilic parties. Protein inclusions which are inside the membrane allow ionic change with the cell environment. A phospholipidic membrane cannot be oxidized. Its destruction requires an oxidant able to pass through the membrane and to reach vital centers [8].

Table 3
Decrease of the chemical parameters after EC (30 min of electrolysis at 30 V followed by 30 min of sedimentation)

Chemical parameters	Abatement (%)	
Solution conductivity	0.6 mS cm^{-1}	1 mS cm^{-1}
CAT	17	17
Chloride	4	4
Total hardness	6	8
Hardness	7	8
Nitrate	16	5
Phosphate	Not detected	68
Permanganate index	17	47

Table 4
Influence of the electrode gap on the efficiency of EC treatment of *E. coli* solutions (conductivity 0.6 mS cm^{-1}; voltage 30 V; and current 0.22 A)

Electrode gap Ref.	1 cm		2 cm		4 cm	
	EC 1	EC 2	EC 3	EC 4	EC 5	EC 6
T_0 (UFC mL^{-1})	6.60 E+04	3.95 E+04	1.60 E+04	2.48 E+04	2.50 E+04	5.00 E+04
T_f (UFC mL^{-1})	3.50 E+02	6.35 E+02	7.70 E+01	4.45 E+02	8.30 E+01	1.70 E+01
Bacteria abatement (%)	99.5	98.4	99.5	98.2	99.7	99.9

3.4. Influence of experimental parameters on bacteria abatement

3.4.1. Effect of the electrode gap

In order to discriminate between the effect of the current flowing in the solution and the effect of the electrolysis products, the influence of the electrode gap was investigated. The gap between anode and cathode was at 1, 2, and 4 cm corresponded to electric fields of 30, 15, and 7.5 V cm^{-1}, respectively. Results of bacteria abatements in Table 4 show that under EC conditions the electrode gap did not affect the process. Indeed, the bacteria abatements were constant and greater than 98%. A 2 cm gap was applied to all experiments when it is not specified.

The mechanism underlying the inactivation of microorganisms using an electric field is not yet fully understood. Exposure of a biological cell to an electric field can produce a variety of profound biochemical physiological responses. Most of these responses are based on the modification of the trans-membrane potential by the application of an external electric field. If the field strength exceeds a certain threshold value (in the range 0.2–1 V), it can result in pore formation in the membrane. This phenomenon is called electroporation or electropermeabilization. The lowest values of trans-membrane potential are reached in the cell poles and are proportional to the cell diameter. Considering this fact, larger cells are more fragile than smaller ones and the greatest damage is caused in the cell poles. The critical potential is also dependent on the membrane structure, as well as of the temperature, decreasing with temperature increase or with membrane tension [1,47–51].

3.4.2. Influence of the solution conductivity

The solution conductivity is a key parameter of electrolysis. It must be quite large (about 1 mS cm^{-1}) to allow the passage of the electric current through the solution. As discussed in Section 3.1, the solution conductivity influences the control of the temperature whose increase by a Joule effect may be involved in kinetic modifications [38,39,52].

For a 2 cm gap between the electrodes, when the solution conductivity was at 0.6 mS cm^{-1}, the bacteria abatement was already large at 98.2 or 99.5% (Table 4). Raising the conductivity to 1 mS cm^{-1} did not lead to a significant increase of the *E. coli* abatement. This absence of a conductivity effect may be due to the fact that the abatement was already notable at 0.6 mS cm^{-1}. It may be also explained by the control of the electrolysis current, which did not allow a temperature increase more than 2°C. It is known that a 2°C variation does not cause any bacterial inactivation effect [49].

3.4.3. Effect of the solution pH

The results of the pH effect on the bacteria abatement are gathered in Table 5. When the initial pH increased from 7.5 to 9.5, the abatement decreased significantly from 96 to 72%. It is well known that alumina precipitates in pH range 4–9 during EC. When the pH is alkaline, the mononuclear anionic specie $Al(OH)_4^-$ is formed (Eq. (8)) and does not exhibit any positive effect on the EC process performance [53,54]. Bacteria abatements involved the trapping of particles into the flocs and suggested that the dissolution of electrogenerated alumina released some bacteria in solution.

$$Al(OH)_3 + OH^- \rightarrow Al(OH)_{4^-} \quad (8)$$

3.5. Effect of a chemical coagulation

In order to establish the involvement of coagulation in the bacteria removal, some chemical coagulation

Table 5
Effect of initial pH on the efficiency of EC treatment (1 L; 35 min; voltage 30 V; current 0.35 A; electrode gap 2 cm; and 30 min of sedimentation)

pH initial	7.5	8.5	9.5
pH final	8.4	8.8	9.1
Abatement of *E. coli* (%)	96	90	72

Table 6
Abatements of *E. coli* by EC or chemical coagulation (CC) treatments (EC: 1 L; 30 min; voltage 30 V; current 0.22 A; electrode gap 2 cm; 30 min of sedimentation; initial pH = 6.3. CC: 1 L; 30 min at 150 rpm; 30 min of sedimentation; and initial pH = 6.0)

Experiment Ref.	CC Test 1	CC Test 2	EC	Blank
T_0 (CFU mL^{-1})	5.75 E+04	8.30 E+04	3.00 E+05	8.35 E+04
T_f (CFU mL^{-1})	9.75 E+03	1.40 E+04	5.40 E+02	5.40 E+04
Abatement (%)	83.0	83.1	99.8	35.3

experiments were carried out. The results of bacteria abatements are presented in Table 6. Under chemical coagulation, they were not as efficient as with EC. Using the same amount of Al(III) in both experiments, the abatement was at 99.8% by EC, while only 83% bacteria reduction were reached with the chemical coagulation. The abatement of *E. coli* by EC can be understood as the result of concomitant processes: mortality due to oxygen and nutriment depletions, adsorption on electrogenerated alumina, and sedimentation of the flocs. Notable differences were observed for the abatements, but also for the solution and the solids that were isolated after chemical coagulation and EC experiments.

Chemical coagulation treatment and EC afforded bacteria abatement, but a difference was observed about pH of the solutions. During chemical coagulation, pH was maintained constant by NaOH addition after hydrolysis of the aluminum salt, while pH increased during EC. But this pH increase was not sufficient to lead to a significant abatement decrease, as observed in section 3.4.3, so the better efficiency of EC cannot be only explained by the pH effect.

During EC, bacteria are trapped into the flocs which contain living bacteria [22]. We checked that during coagulation or EC treatment of *E. coli* solutions, living bacteria were found in the decanted solids. According to Van Oss [55], bacteria adhesion to surfaces results from the Lifshitz–van der Waals interaction free energy and the Lewis acid–base interaction free energy. Taking into account the occurrence of a bacteria adhesion, the kinetic effect would be in favor of EC. Indeed, during the chemical coagulation the surface arising from the hydrolysis of the aluminum salt is created quickly. While for EC, the formation of the surface occurred all along the electrolysis, so allowing a more efficient adhesion of bacteria.

The decanted flocs were separated at the end of the experiments and then dried at room temperature and finally analyzed by X-ray diffraction (XRD). The corresponding patterns are presented in Fig. 4. The solid arising from the chemical coagulation experiment (Fig. 4(A)) was more amorphous than the electrogenerated alumina of EC, as shown by the intensity of the diagram background. The solid arising from EC (Fig. 4(B)) exhibits very broad peaks at 2θ values of 14, 28, and 49°. These peaks were attributed to nanocrystallites of boehmite AlOOH [22]. This result shows that during EC the nucleation of electrogenerated alumina was not modified by the presence of *E. coli*.

During EC, indirect effects occurred in the solution and would be involved in the bacteria abatement. These effects were investigated and discussed in a previous paper [22]: partial oxygen depletion, possible biocide property of alumina, nanoparticules and abatement of major bacteria nutriments like nitrate and phosphate. The oxygen decrease, which is due to a deoxygenating action of the hydrogen evolved at the cathode, leads to an unfavorable environment for aerobic bacteria. This effect cannot be efficient because the oxygen removal is not complete during EC when it is performed in an open reactor. The nutriment phosphate and nitrate were not quantitatively removed, as shown by results of Table 3. The formation of nanocrystallites of boehmite AlOOH was observed, but the presence of living bacteria in the flocs proves that their nanostructure is not associated to a strong biocide activity. This absence of biocide phenomenon suggests that the main effect in the bacteria removal of EC lay in a strong bacteria adhesion on the surface of the electrogenerated alumina. This adhesion was promoted by the nanostructured alumina. Then, the bacteria removal from the solution occurred concomitantly with the alumina sedimentation.

3.6. Continuous electrocoagulation of a flowing solution

The EC rate of *E. coli* abatement has been studied in a continuous process with the reactor described in Fig. 1. A 2 L reactor of EC afforded electrogenerated alumina in the 10 L tank that contained the bacteria solution. Two electrode configurations were used in the electrolysis, and the bacteria abatements are

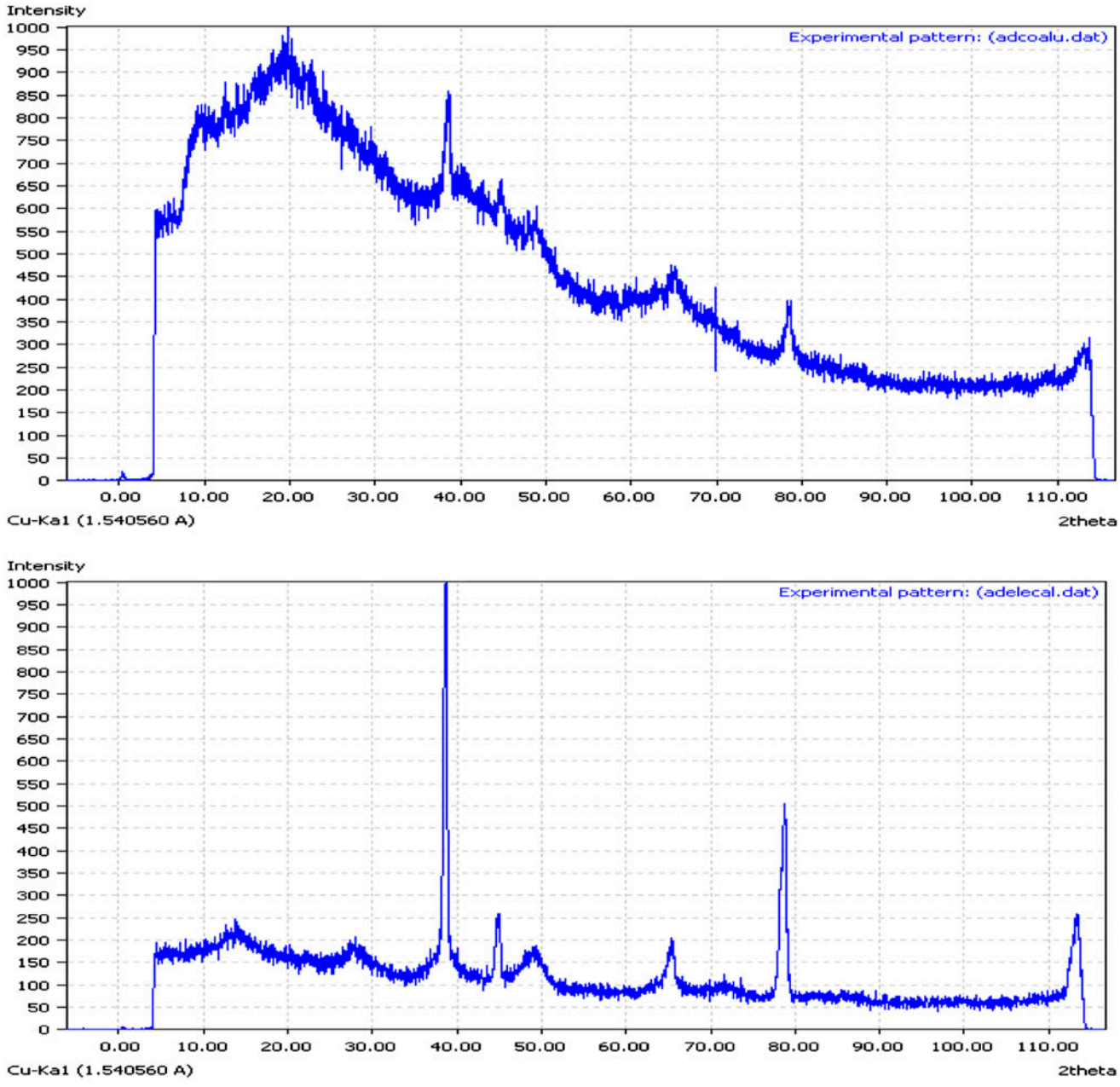

Fig. 4. XRD patterns of solids isolated after chemical coagulation experiment (A) or EC (B) of *E. coli* cultures. Peaks marked (*) are due to the diffraction of aluminum of the sample holder.

presented in Fig. 5. *E. coli* inactivation occurred through two distinct stages. In the first stage, 75% abatement was reached in 15 min with monopolar electrodes instead of 6 min with bipolar electrodes. This better efficacy of bipolar electrodes was due to the formation of a greater quantity of Al(III) species. Indeed, in this electrode configuration, there were more working anodes while the electrolysis current was the same. Whatever the electrode configuration was, 90 and 97% abatements were obtained after 20 and 35 min, respectively.

The EC rate was too fast for the bipolar assembly, so a slow flow rate was used in order to allow a good mixing of the electrogenerated coagulant and *E. coli*. After 60 min, a 2-log reduction was achieved with both electrode systems.

4. Conclusion

The bacteria removal from solutions that contained *E. coli* was carried out by EC with aluminum electrodes. Under equivalent conditions of doses, EC was

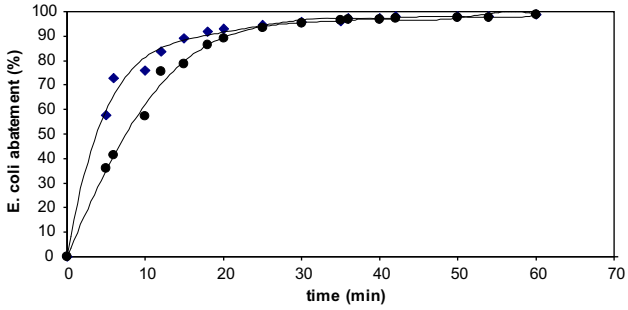

Fig. 5. Effect of electrode configuration on *E. coli* abatement during EC: ● with monopolar electrodes; ◆ and with bipolar electrodes.

more efficient than a chemical coagulation treatment with aluminum sulfate. Owing to its efficiency which was 97%, EC appeared as an electro-disinfection process despite the absence of strong electrogenerated oxidant. The analysis of all direct and indirect electrochemical effects which are involved during electrolysis leads to the conclusion that the key phenomenon of bacteria abatement was the bacteria adhesion on the surface of the electrogenerated alumina.

Acknowledgments

The authors are grateful to Yvane Lelièvre of Ecole des Métiers de l'Environnement for her helpful assistance during the bacteria analyses.

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