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Wastewater disinfection by electrocoagulation process and its interaction with abiotic parameters

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ABSTRACT

In this study, we evaluated the influence of abiotic factors and their interaction on the bactericidal effects of electrocoagulation. We followed the kinetics of bacterial density vs. time and some abiotic parameters such as pH, conductivity, turbidity, TSS, and COD, by setting the intensity of the current to 3 A using aluminum electrodes. To determine the effectiveness of the treatment, the behavior of bacteria towards the electric current was investigated by calculating the mortality rate (log 10) or bacterial survival (UFC mL^{-1}) after treatment. The results show that the removal rate of the bacteria is 6 log 10 with a significant correlation ($R_2 = 0.98$) by increasing the time. A strong correlation was observed with the pH increase which is $R_2 = 0.93$. A positive correlation has been demonstrated with the elimination of bacterial biomass and COD and negative with TSS.

Keywords: Electrocoagulation; Wastewater; Disinfection; Bacteria; Correlation; Interaction

1. Introduction

The deterioration of the quality and the decrease of the quantity of water lead to a greater interest in treating or recycling waters with physical means such as membrane separation or electrolytic process [1,2]. Several wastewater treatment methods for effluents that allow achieving a good quality before disposal into municipal sewage systems are available. The wastewaters vary in terms of their pollutant composition depending on the origin of the industry [2].

Electrocoagulation (EC) has been tested on several waters such as alcohol distillery wastewaters [3], synthetic natural waters [4], pasta and cookie processing wastewaters [5], polluted rivers [6], laundry wastewaters [7], fluoride [8–13], pesticide [14], Boron [15], azo dye [16], and chromium [17]. EC electrodes are made from aluminum, iron, or a combination of these. In the electrocoagulation process, the aluminum can be dissolved from aluminum anodes and cathodes. Aluminum dissolves from anodes according to the simple electrochemical reaction Eq. (1) and forms hydroxides in water Eq. (2). Meanwhile, aluminum cathodes dissolve due to high pH on the cathode surface, which is caused by OH^{-} that is produced by an electrochemical reaction Eq. (3):

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$$Al \rightarrow Al^{3+} + 3e^- \quad (1)$$

$$2Al + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2 \quad (2)$$

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

Hydrogen formation on the cathode Eq. (3) is desirable if flotation is used for separating flocculated material from water. Hydrogen bubble size distribution depends on pH, current density, electrode material, and cell arrangement.

Electrocoagulation treatment of surface waters and removal of NOM from waters has been studied in several articles [18]. Electrocoagulation performed better for COD removal than chemical coagulation for the model-colored water, for the lowland surface water both processes had similar performance [19,20] studied the effect of initial pH, supporting electrolyte, applied potential and initial humic substance concentration on TSS removal [21,22]. Little research on the removal of bacteria in wastewater, and how it is affected by the chemical parameters was done.

EC has proven to be an efficient technology for the removal of several harmful substances from wastewater. However, there are no studies concerning the interaction between the removal of bacteria and physical parameters. The main objective of this study was to investigate the effects of alternating current on the removal of bacteria from wastewater using aluminum electrodes and to determine the interaction of several parameters, namely initial pH, turbidity, conductivity and electrolysis time, concentration DCO, TSS, on the bacteria removal efficiency.

2. Experimental

2.1. Water substrate

Wastewater samples were collected from the river of El Harrah (North of Algeria). Physico-chemical and bacteriological properties of the samples before treatment are presented in Table 1. The EC process was used to remove TSS, DCO, and turbidity and to disinfect bacteria. In this case, initial pH values were selected neutral on preliminary tests with initial ambient temperatures.

2.2. Equipment and electrolysis

The EC reactor was a 1-L electrolytic cell with two parallel aluminum plates, each having dimensions of 4.5 cm in length and 5.5 cm in width. The electrodes were installed vertically in the middle of the reactor with an electrode gap of 1.5 cm. Experimental setup is shows in Fig. 1. Before electrolysis, the electrodes were immersed in 2 M NaOH during 5 min and then rinsed with water. The electrodes were connected to a DC power supply (P.FONTAINE-France). In this study, the current intensity chosen was 3 A in order to avoid any heating of the solution, a phenomenon which would influence the disinfecting action of electrolysis. All the runs were performed at room temperature, under a magnetic agitation. The applied tension and the water temperature were measured during the electrolysis. The conductivity and the pH of the waters were measured with EC214 and pH211 (HANNA), respectively. Turbidity was measured with model Hi 88713 ISO turbidimeter, the COD parameter was measured by standard methods flux heating colorimetric (ISO 6060, 1989) and TSS was measured by filtration methods with ISO (1193). Neither centrifuging nor filtration was performed after each run.

Table 1
Physico-chemical and biological characteristics of river water

Parameters	Values
pH	7–7.50
Conductivity (mS cm^{-1})	1–1.4
Temperature (T°C)	16–18
Turbidity (NUT)	254
COD (mg L^{-1})	250–400
TSS (mg L^{-1})	800
Total bacteria (CFU mL^{-1})	10^6

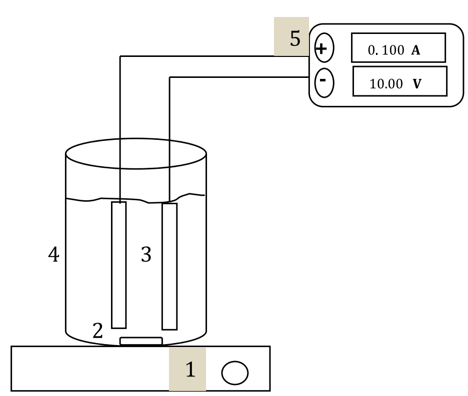

Fig. 1. Schematic diagram of the experimental setup.
Notes: (1) magnetic stirrer, (2) magnetic bar-stirrer, (3) aluminum electrodes, (4) electrochemical cell, and (5) DC power supply.

2.3. Bacteria analysis

Total bacteria (Gt) were counted according to the standard method NF EN (CEAEQ, 2003) [23]. The count of the revivable colonies was obtained at 30˚C on Plate Count Agar (PCA). During electrolysis, samples of 5 ml were taken every 5 min to count total bacteria. We have determined at T_0, the initial bacterial concentration in unit forming colonies by milliliters (CFU mL^{-1}).

2.4. Statistical analysis

The principal components analysis (PCA), the representation of trio's size and correlation analysis were performed by STATISTICA 7 software to complete the interpretation of results.

3. Results and discussion

The first point of interest was to investigate the efficiency of EC in improving the water quality. The second point concerned to establish interactions and correlations between the chemical compositions and the disinfection of the surface waters by EC process.

3.1. Removal of chemical species

The result of efficiency of the EC process on the chemical and biological composition of river water is given in Table 2. The experiments were carried out at 25 and 15.3˚C with river water having an initial pH 7.50 and a conductivity of 1 mS/cm. The calculation of the chemical removal efficiency (RE %) was performed using formula (4) where C_0 and C are concentrations of the chemical before and after electrolysis:

$$\mathrm{RE}(\%) = (C_0 - C)/C_0 \times 100 \quad (4)$$

Table 2
Removal efficiency of EC treatment applied to surface water

Parameters	RD (%)
Turbidity	98%
COD	90%
TSS	53%
Bacteria	100%
	Values before treatment
Conductivity (mS/cm)	0.2–0.5
pH	7.6–8.02
T˚C	30–33˚C

The results (Table 2) show a very good efficiency for COD, and turbidity removal. But for TSS, the results show that the efficiency varies greatly.

The bacteriological results after 30 min of electrolysis are listed in Table 2. They show that the micro-organisms are totally eliminated, thus, the disinfection efficiency is good found similar results with surface water [24].

Fig. 2 shows that the removal rate of the bacteria is 6 log 10 units during one hour of treatment with a large coefficient of correlation ($R_2 = 0.98$). Which confirms the efficiency to remove bacteria in the waste water by increasing the time, so a good disinfection by the method of EC.

Fig. 3 shows that there is a remarkable correlation between the elimination of bacterial biomass and the change in pH with an interesting coefficient $R_2 = 0.93$. During treatment by the electrocoagulation process, we noticed a gradual increase in the pH to reach a basic pH (8.5). Bacterial biomass decreases linearly with pH. The pH increase during treatment is due to the release of hydrogen and the formation of metal hydroxides which leads to the formation of flocks on which bacteria adhere to form a slurry material (or sludge), which may be removed by decantation at the end of the process.

The results presented in Fig. 4 indicate that the efficiency of COD reduction (90%) is probably related to the decrease in bacteria (100%). Indeed, every time the reduction of COD is important the bacterial survival rate decreases. When the reduction in COD is 90%, the bacterial survival rate is 5 CFU mL^{-1}. This correlation has allowed us to see a part of the removed COD is related to the bacterial biomass eliminated.

Treatment efficacy is due to the strong solubilization of the electrodes during the process which therefore

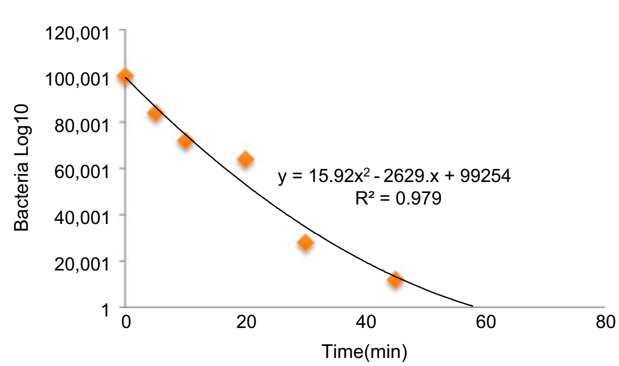

Fig. 2. Bacterial elimination over time of electrocoagulation treatment, conductivity = 1 mS/cm inter-electrode distance = 1.5 cm and intensity = 3.0 A.

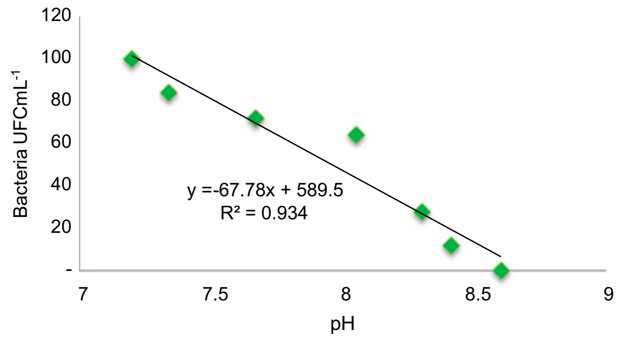

Fig. 3. Elimination bacterial function of pH electrocoagulation, conductivity = 1 mS/cm = 1.5 cm inter-electrode distance and intensity = 3.0 A.

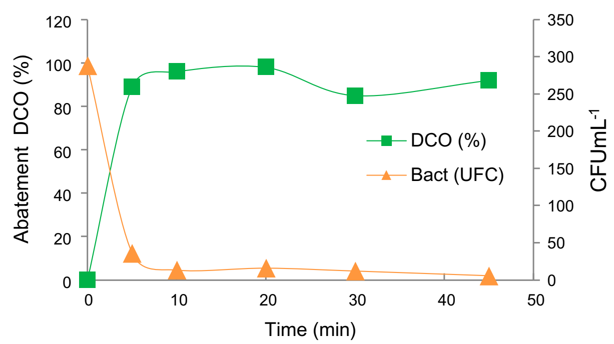

Fig. 4. Change in bacterial survival rate depending on the COD during electrocoagulation treatment, conductivity = 1 mS/cm inter-electrode distance = 1.5 and intensity = 3.0 A.

results in a destabilization of the particles of the pollutants. Furthermore, the production rate of the hydrogen bubbles increases and their size decreases as the voltage rises [25,26]. All these effects are beneficial for effective removal of pollutants by flotation [27,28]. Another model proposed by Khemis et al. [29] is based on the adsorption of Al $(OH)_3$ of the case removed; it gives a good correlation to the evolution the COD removal in the effluent.

A 10 min time is required to enable the electrolytic reactor to produce enough of Al $(OH)_3$ and initiate the polymerization reactions. The formation of polymeric complexes helps to remove a small fraction of the organic matter present in the wastewater and that, either by:

(1) Surface Complexation: the pollutant behaves as a ligand (L) that binds chemically to the hydrated ion Al $(OH)_n$.

(2) Electrostatic attraction: the hydrated metal oxide particles have positively and negatively charged areas, which will attract the opposite charges of pollutants and remove them from the solution by decantation [30–32].

Concerning the variation in TSS, it is also related to the survival rate of bacteria (Fig. 5). TSS is positively correlated with the bacteria at the beginning of treatment and negatively towards the end of treatment. For 45 min, the bacterial density decreases (5 CFU mL^{-1}) while the concentration of TSS increases to 1,230 mg L^{-1} in the treated solution. This can be explained by the destruction of bacteria by co-precipitation adhering to returning flocks of hydroxides that are in suspension in the solution.

The statistical study of three dimensions (Fig. 6) shows the existence of a strong positive interaction between the reduction in the number of bacteria and other abiotic factors. The efficiency of COD removal is positively correlated with the mortality rate of bacteria and as a function of time (a, b). Mortality rate increases as the pH (8.0) and time (30 min) increase (c), which is not the case with TSS (d), during treatment the mortality rate increases with increasing the concentration of TSS in the solution, this is probably due to the diffusion of flocks in the solution and the components of the cells are diffused in the solution with the outbreak of the bacterial cell under the effect of the electrocoagulation process and the electric field.

During our tests, we found a significant and progressive increase in the temperature of the treated solution [33–35]. We have pointed out that the temperature plays an important role in the inactivation of micro-organisms. This increase acts on the fragile membrane of the cell particularly the lipid bilayer. Bacteria can also

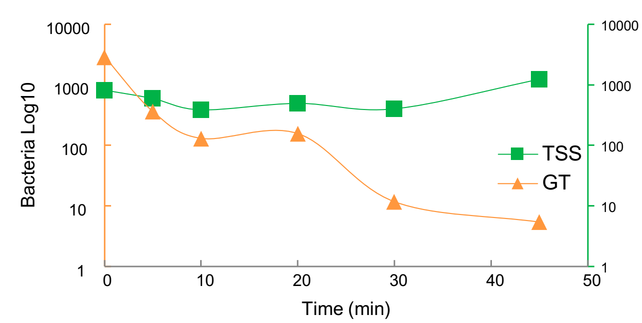

Fig. 5. Variation of the bacterial survival rate depending on the TSS during electrocoagulation treatment, conductivity = 1 mS/cm inter-electrode distance = 1.5 and intensity = 3.0 A.

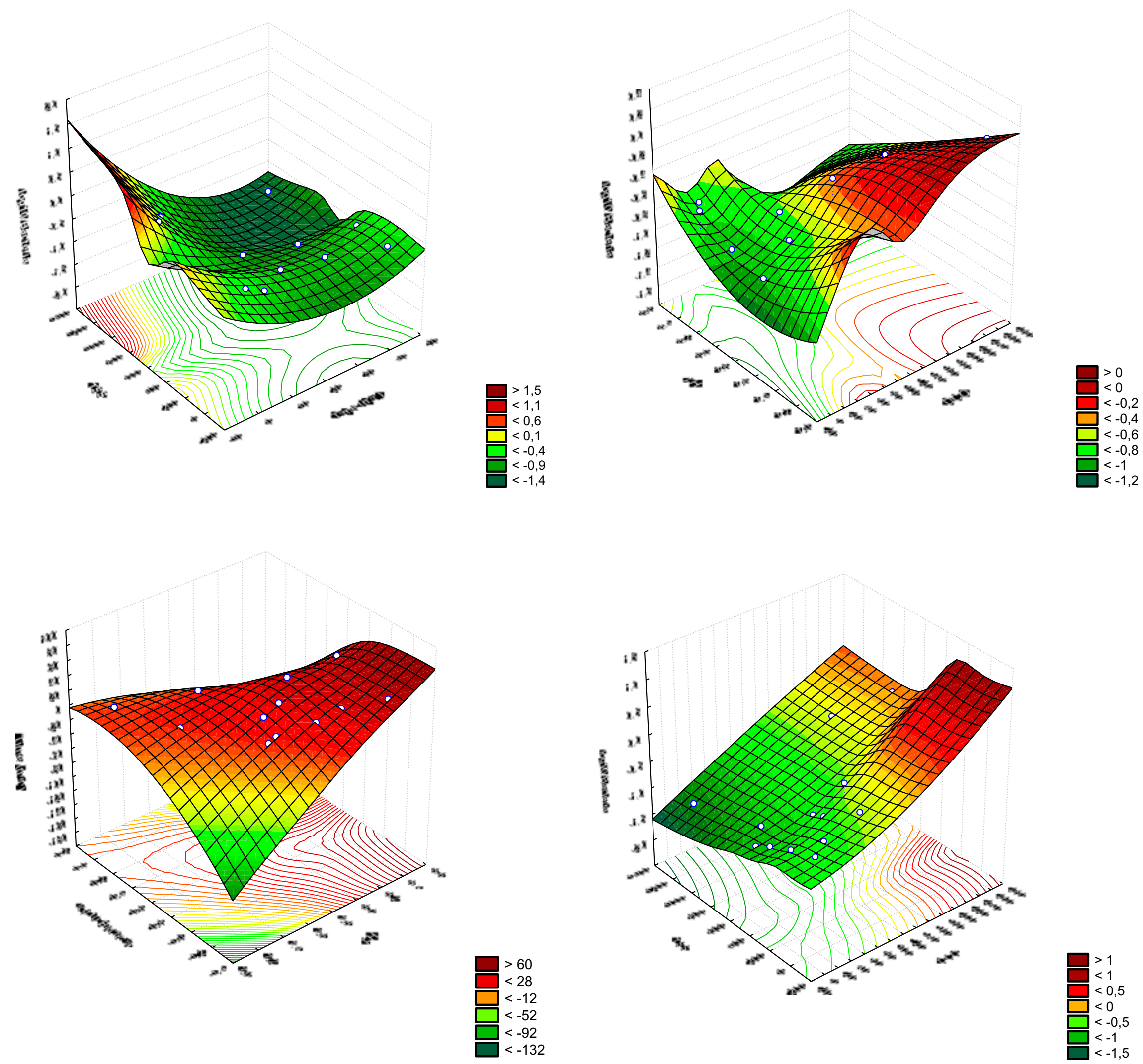

Fig. 6. Three dimension for bacteria Interaction with chemical parameters; pH, time, DCO, TSS.

Table 3
Correlation between wastewater disinfection (bacteria) with abiotic factor by electrocoagulation process

Equations	Correlation coefficient (r)
$Gt = -0.362 - 0.016 \times Time$ (5)	$r = -0.63$
$Int = 2140E3 - 258E3 \times pH$ (6)	$r = -0.78$
$Gt = 5.374 - 0.775 \times pH$ (7)	$r = -0.73$
$Gt = -1.00 + 0.401 \times Cond$ (8)	$r = 0.37$
$Int = 47066 + 858.08 \times Tur$ (9)	$r = 0.61$
$Gt = -1.00 + 0.004 \times Tur$ (10)	$r = 0.82$
$Int = 31083 + 1057.6 \times COD$ (11)	$r = 0.79$
$Gt = -1.00 + 0.004 \times COD$ (12)	$r = 0.9$
$Gt = -0.753 + 0.0002 \times TSS$ (13)	$r = 0.2$

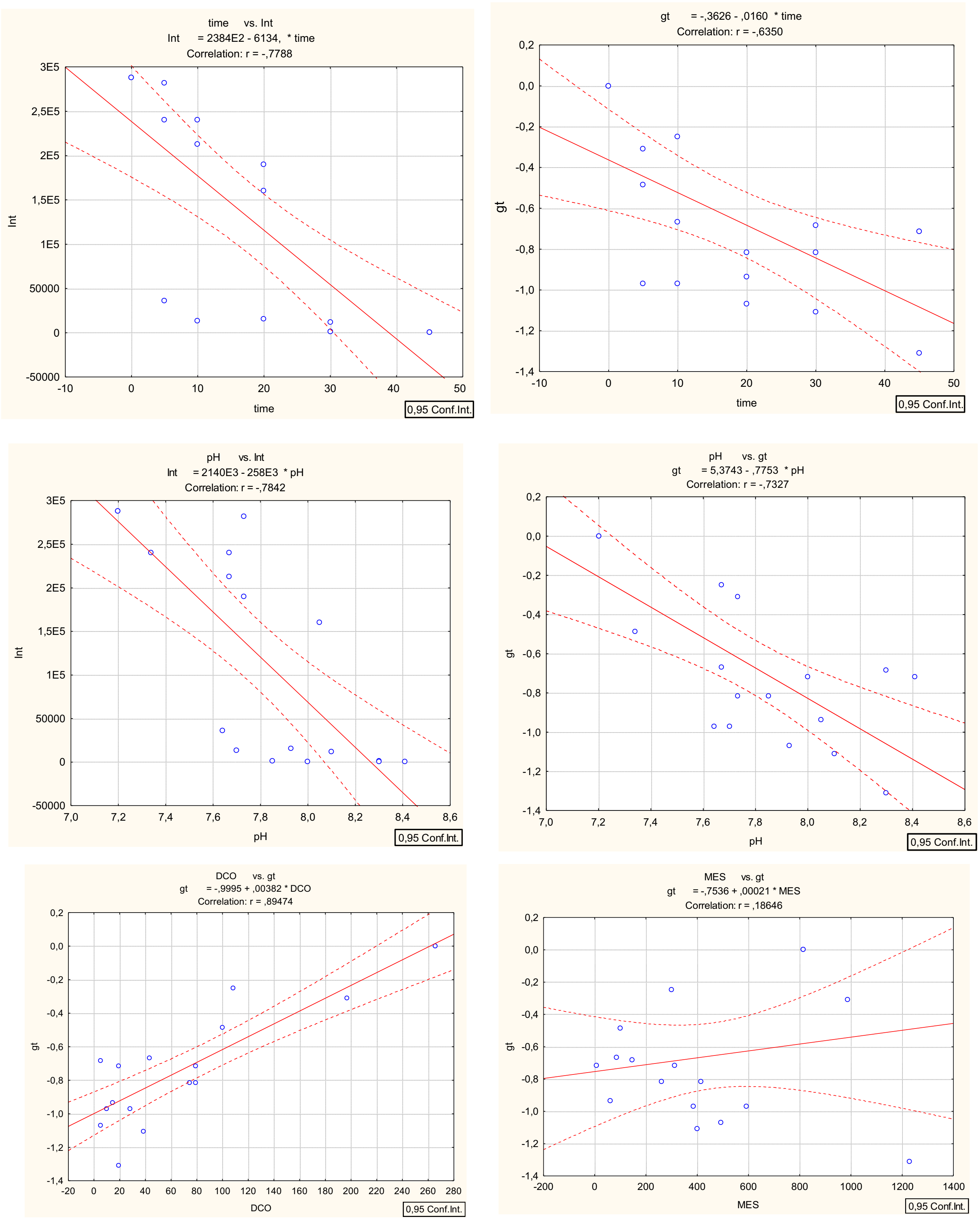

Fig. 7. Correlation between survival of total germs (GT) and abiotic factors.

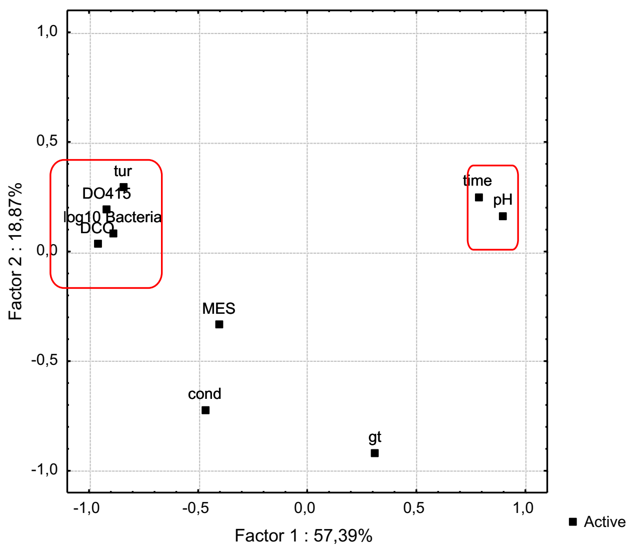

Fig. 8. Ordination of physico-chemical parameters and bacterial mortality rate from the values obtained during electrocoagulation with treatment of 60 min along two main axes after principal component analysis.

be precursors and catalysts in sorption reactions and many mineral precipitations [36,37].

Temperature also affects the activity of the coagulation treatment. Temperature has greater effects especially in low-turbidity water when aluminum sulfate is used as a coagulant chemical. To date, the effect of temperature on EC efficiency is not widely studied [38].

Correlations between bacteria and abiotic survival rates are summarized in Fig. 8 and Table 3.

This Table 3 summarizes different correlations between disinfection and abiotic factors. There is a good correlation with pH, $r = -0.73$ (Eq. (7)), Turbidity $r = 0.82$ (Eq. (10)) and COD with a correlation coefficient $r = 0.9$ (Eq. (12)). But TSS and conductivity don't have a big influence on the disinfection effect (on bacteria) by the electrocoagulation process. A comprehensive study of several variables from the set of experiments performed by the electrocoagulation process is shown in Fig. 7. We noticed that most of the biological factors are correlated positively and negatively with time and pH. The rates of bacteria removal are positively correlated with COD and turbidity. This multivariate analysis (PCA bacteria) shows the existence (Fig. 8) of strong interactions between the effectiveness of eliminating bacteria and experimental factors.

Ordination of physico-chemical variables and bacterial mortality rates from the values obtained during electrocoagulation treatment for 60 min along two main axes after principal component analysis.

The microbial community is influenced by the physico-chemical conditions of their environment exercised by the electrocoagulation process. Obviously, these issues are interrelated, and a combination thereof determines the rate of elimination of bacteria. The current, pH, time of treatment on removal characteristics of organic matter and micro-organisms in the form of flock (or sludge) are determined.

Interactions between bacteria and the solid phases were facilitated by electrostatic bonds. Bacteria under stress produce exopolysaccharides (EPS) negatively charged. These EPS then promote the dissolution or precipitation of metal hydroxides (aluminum or iron). The temperature intervenes by reducing the critical transmembrane potential [39–41], or by reducing the thickness of the lipid bilayer.

4. Conclusion

We can conclude that the process of electrocoagulation is a suitable method for disinfecting wastewater. Significant interactions were demonstrated by abiotic factors (pH, time, COD, TSS) and the effectiveness of the disinfection process by electrocoagulation. What remains to be done is the determination of the disinfection mechanism and how the bacterial cells are affected by the process of electrocoagulation.

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