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Continuous treatment of industrial dairy effluent by electrocoagulation using aluminum electrodes

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ABSTRACT

Electrocoagulation is one of the most efficient and convenient techniques for the elimination of several types of pollutants. Its efficiency has been validated for numerous industrial effluents (food, mechanical, textiles, paper industries, etc.). This paper deals with the treatment of dairy wastewater in Algeria by electrocoagulation using aluminum electrodes. The experiments were conducted in a small continuous reactor at laboratory scale. Turbidity and chemical oxygen demand (COD) were followed continuously during the startup period and at steady-state, where as BOD_5 (five-day biological oxygen demand), greases, and phosphorus were analyzed punctually at steady state using the better operating conditions. The effect of operational parameters, such as current density, initial pH, inlet flow rate, and the temperature of waste water, were examined to optimize the effectiveness of the treatment. A satisfactory reduction of 98% of the turbidity and 90% of the COD were obtained for the optimal conditions. The abatements of BOD_5 and greases were close to 97%, whereas 70% of the phosphorus was eliminated. Treatment of industrial wastewater concentrated with several milk powder concentrations has been also analyzed. Reasonable energy consumption of around 2 to 3.5 kWh/m^3 for adequate operating conditions validates the economic reliability of this choice of treatment.

Keywords: Dairy effluent; Turbidity; Aluminum electrodes; Continuous reactor

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1. Introduction

Agro-industries generate a huge amount of wastewater often characterized by high chemical oxygen demand (COD). The dairy industry is particularly concerned since it uses lots of water for the production of recombined milk and its sub products as cheese and butter but also for cleaning and disinfection of vessels production. A large volume of this water cannot be re-used, being able to generate pollution of the receiving medium (river, sea…). Wastewater from dairy industry may be regarded as full cream milk strongly diluted with cleaning water. When it is released in the medium, it raises several problems: increase in the microbial biomass, reduce of the dissolved oxygen concentration, mushroom and algae proliferation, deposits of mud, and a

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possible eutrophication of the medium [1,2]. Treatment of the effluents of dairy is difficult because it is a multi-emulsion complex mixture. Many processes are employed to treat such wastewater; anaerobic [3] or aerobic [4] biological treatments, coagulation/flocculation [5], nanofiltration, and reverse osmosis [6] as well as the treatment by adsorption on activated carbon [7]. Electrocoagulation is another alternative which has been already successfully used for wastewater treatment issued of food industries. This method implies sacrificial anode, generally aluminum or iron, where the metal cations of coagulation are released *in situ* when the electric current is applied. At the same time, the reactions of electrolysis generate hydrogen bubbles to cathode and oxygen bubbles to the anode, which favors flotation of the particles. Although it is known for a long time [8] and that it requires inexpensive equipment; this technique presents only recently a renewed interest within the ecological situation to improve [9].

If the technology is easy to implement, its behavior remains complex to understand because its performances are depending on coupling electrochemical, physical, chemical, and flow effects. The influence of current density, initial pH of the effluent to be treated, its temperature, composition of the waste, and the mean residence time (for continuous reactor) or treatment time (for batch reactor) have to be investigated. Electrocoagulation was employed successfully for several types of industrial effluents: oil refinery [10], petrochemicals [11], tannery [12], slaughter-houses [13], as well as the clarification of drinking waters [14], and numerous others applications. The recent studies devoted to dairy wastewater are relating to the treatment of synthetic effluent (i.e. containing commercial dried milk) in a batch reactor. Sengil and özacar [15] obtained using sacrificial iron anode, with 98% abatements of COD and 99% abatement of grease. Tchamango et al. [16] have eliminated 61% of COD, 81% nitrogen compounds, and 100% of turbidity. Bensadok et al. [17] carried out abatements of 70% of phosphates, 100% of turbidity, and 80% of COD using Al and Ti/Pt electrodes.

The particularity of this work is that experiments have been conducted with real wastewater taken directly from a dairy industry in a continuous reactor. The reduction of pollution of the wastewater has been evaluated during the startup by the continuous measurement of turbidity and COD. Five-day biological oxygen demand (BOD_5), greases, and phosphorus, were controlled punctually before and after the treatment.

2. Materials and methods

2.1. Experimental setup

The experiments were carried out at the laboratory scale using a 1 L cylindrical vessel maintained at the desired temperature. Two parallel plate electrodes of aluminum were placed inside the vessel. The two electrodes are roughly equal to 15 cm length and 3 cm width for a surface of 45 cm^2; the depth of their immersion inside the vessel is 12 cm. The electrodes gap was fixed to 1 cm, in order to limit the ohmic voltage drop. The current density applied to the electrodes was fixed using a potentiostat (Metrix – AX – 502). The current was fixed through the potentiostat and controlled with an Ampere-meter (SKY-Sronic-600-527), connected in series. The effluent was continuously stirred in a tank in order to assume the homogeneity and it was fed at the bottom of the vessel between the electrodes. The outlet was placed at 8 cm of the top of the reactor to permit to the liquid to circulate inside the reactor in order to favor the contact time between pollutant and hydroxide. The inlet and outlet flow rates were maintained constant and equal thank to the use of only one peristaltic pump (Master degreeFlexL/SModel77202-60) supplied with the same head for the two pipes. pH and conductivity were continuously measured at the outlet of the reactor. The temperature of the vessel was maintained constant with the help of heating/cooling water. Fig. 1 illustrates the experimental setup.

2.2. Samples of wastewater and experimental procedure

The local industrial dairy studied in this paper rejects an average daily volume of 720,000 L of waste water. It produces only pasteurized recombined milk and soft cheese “Camembert cheese”. The tests of characterization of waste water, showed strong and irregular polluting load with average values of: 1,270 mg/L of BOD_5, 500 mg/L of greases, 36.3 mg/L phosphorus, 2,300 mg/L of COD, and ~1,000 NTU in turbidity. The daily variation of each parameter has been studied in details and published by Hazourli et al. [18]. The dairy wastewater is a complex mixture of several wastewaters issued from three different food unit productions: milk, cheese, and butter production units but also from other effluents issued from mechanic workshop and cleaning units. All the effluents are mixed together in a general collector where the samples were taken for this study under the same procedure conditions proposed by Hazourli et al. [18]. Dairy industries are working as a succession of batch production steps which leads to a strongly variability of both flow-rate and composition.

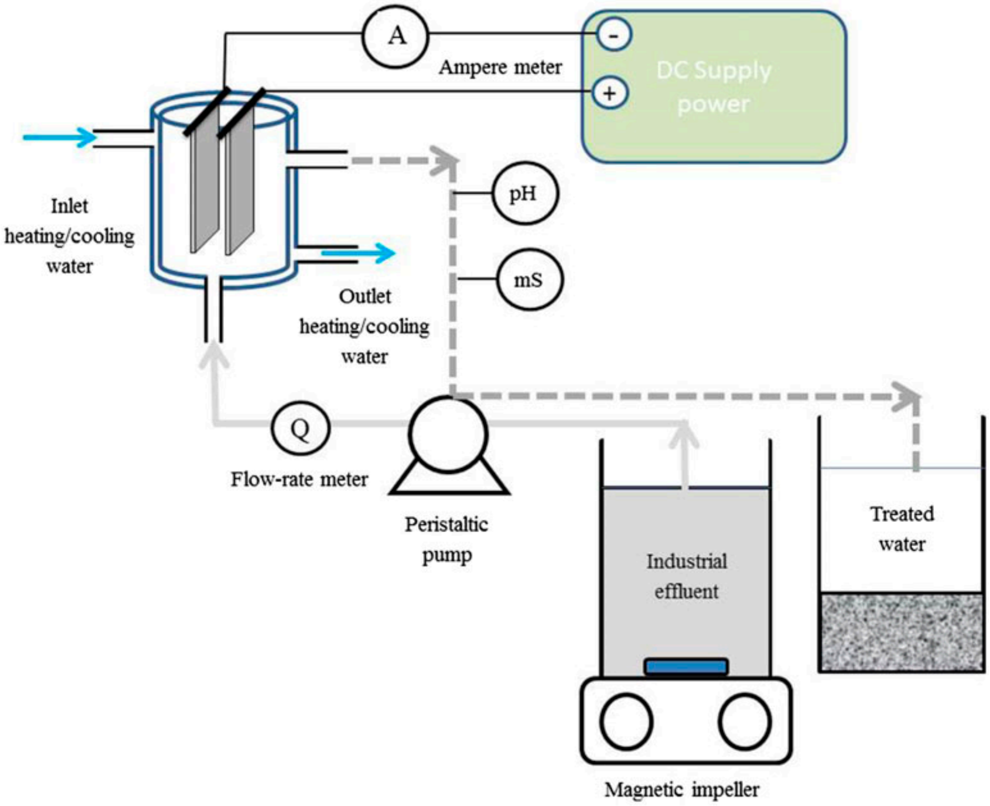

Fig. 1. Experimental setup.

These variations have been previously studied in detail by Hazourli et al. [18] in order to select the optimal day time to take out a sample representative of average wastewater composition and more or less constant from day to day. These samples were used for the tests carried out in the experimental setup.

The efficiency of the treatment was mainly evaluated by the measurement of the turbidity (turbidimeter: Phywe System GMBH2100N, Germany) and the COD. The BOD_5, greases, and phosphorus, were controlled punctually before and after the treatment for satisfactory operating conditions. For these measurements, the standard analytical methods were employed [19]. It is important to recall that the uncertainty on the COD measurement was around 10%. This low uncertainty of COD measurement is often underestimated in the publication relative to electrocoagulation treatment of industrial wastewaters. The rate of abatement of the pollution for a given, parameter X (COD, turbidity…), is expressed as a percentage TX (%), given by Eq. (1):

$$\text{TX }(\%) = \frac{(C_iX - C_fX)}{C_iX} \times 100 \quad (1)$$

where C_iX and C_fX are, respectively, the concentrations of a given parameter before and after treatment. The operating parameters of the treatment are: current density (from 1 to 55 mA/cm^2), the electrolyte support (KCl with concentration between 0.5 and 4 g/L), the initial pH (from 2 to 10), the flow rate (from 1.75 to 40 mL/min), and the temperature (from 10 to 35°C). A preliminary test was carried out continuously during 55 h to test the stability of the treatment assuming the reliability of the continuous treatment. All the chemical compounds used were of high analytical purity (Sigma$^{®}$-Aldrich, the UK), and all the solutions were prepared with pure ultra-water with a resistivity of 18 MΩ cm. Each test was run with a clean electrode, at the end of each test, the electrodes were cleaned with diluted hydrochloric acid (0.01 M) then, abundantly rinse with distilled water, in order to remove the salt deposits or the possible oxidation. The adjustment of the initial pH was realized with 1 M solution of HNO_3 for initial acid pH of the wastewater to be treated and 1 M solution of NaOH for initial basic pH, respectively.

In a continuous reactor, the theoretical concentration of dissolved aluminum is given by Faraday law expressed by Eq. (2):

$$C_{\mathrm{Al}} = \frac{M.I.\tau_{\mathrm{react}}}{n.F.V_{\mathrm{react}}} \tag{2}$$

where C_{Al}, M, I, τ_{react}, n, F, and V_{react}, are, respectively, the theoretical aluminum concentration in the reactor (g/L), the aluminum molecular weight (27 g/mol), the current intensity applied (A), the mean residence time in the reactor, the number of electrons involved in reaction of dissolution ($n = 3$ for aluminum), the constant of Faraday (96,500 C/mol), and the volume of the reactor (1 L in the present case).

The consumed energy by unit of treated wastewater volume is given by Eq. (3):

$$E\ (\mathrm{kWh\ m^{-3}}) = \frac{U.I.\tau_{\mathrm{react}}}{V_{\mathrm{react}}} \tag{3}$$

where U is the applied tension during the treatment (Volt).

3. Results and discussions

On the contrary to the treatment in batch reactor for which the operating time is one of the major operating parameter, for the continuous reactors, the efficiency is mainly governed by the mean residence time. Nevertheless, it is pertinent and useful to analyze the startup of the reactor treatment, thus to follow the abatement of the pollution vs. time, in particular for several flow rates.

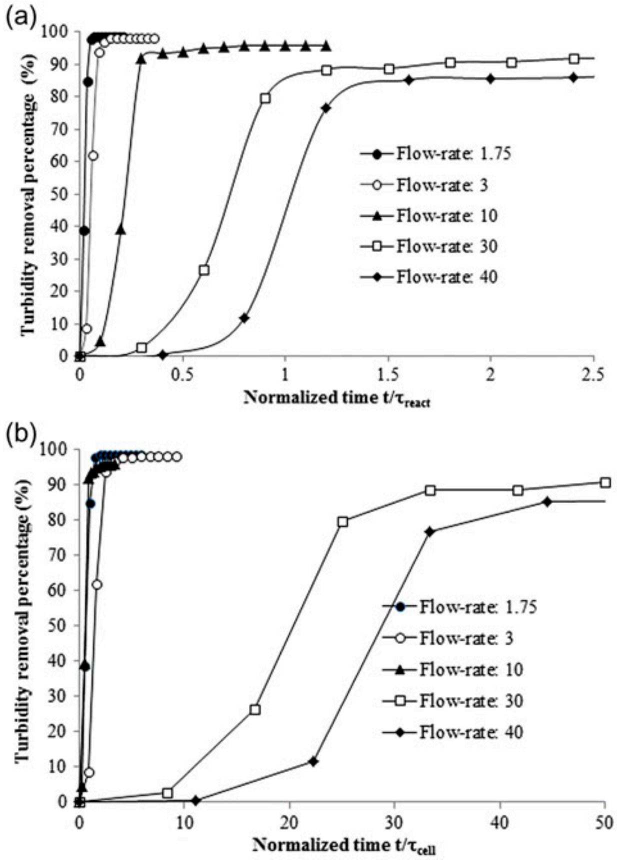

Fig. 2. Turbidity removal percentage vs. normalized time based on total volume of the vessel (a, upper figure) and on volume of electrochemical cell (b, lower figure) for several flow rates. Current density = 15 mA/cm^2, temperature = 20°C, electrodes gap = 1 cm, pH 7.03, electrolyte support KCl 2×10^{-2} M.

3.1. Startup of the reactor and influence of the flow rate

The time evolution of treatment of wastewater by electrocoagulation is often presented in the literature by plotted a parameter used to follow the treatment (turbidity, COD, total organic carbon…) vs. time. It is much more appropriate to normalize the time by the mean residence time to analyze properly the effect of the flow rate (or others parameters). Fig. 2 shows the evolution of turbidity vs. two normalized time parameters. The first one is calculated based on the total volume of the vessel t/τ_{react} and the second one based on the volume between the two electrodes named as the volume of electrochemical cell t/τ_{cell}. τ_{react} is the mean residence time in the reactor given by $\tau_{\mathrm{react}} = V_{\mathrm{react}}/Q$, where Q is the flow rate of effluent and V_{react} the effective volume of the reactor: 1 L in the present case. τ_{cell} is the mean residence time in electrochemical cell given by $\tau_{\mathrm{react}} = V_{\mathrm{cell}}/Q$, 0.025 L. For higher flow rates, the startup time is of the same order of magnitude of the mean residence time in the reactor. For small flow rates, the startup time is ten times lower than the mean residence time in the reactor. This indicates that the flocculation coagulation is very fast and most of the process occurred certainly between the two electrodes. However, in order to reach the highest level of treatment (98% of abatement), the whole volume is necessary to finish the treatment. As a matter of fact, when the flow rate is too high, the final conversion remains unsatisfactory with values comprise between 87 and 92%. The Fig. 2(b) confirms this explanation. For the high flowrates, the normalized startup is 10–20 times the normalized time in the electrolytic cell.

It should be noted that these rates of effectiveness of treatment were preserved for all the operating conditions applied until 50 h of electrolysis. Beyond this time, the reactor starts to be saturated with floating mud. This is why, the industrial reactors necessitate a coupling between electrochemical treatment and separation process [20,21].

In order to study the effect of the operating parameters, the flow rate has been fixed at the smallest value: 1.75 mL/min. This value has been selected in order to favor the pollution level abatement to the detriment of productivity of treatment. The objective is to reach the maximum of abatement by a proper selection of operating parameters. So that, the influence of other operating parameters on the performances, will not be affected by a too much higher flow rate. Moreover, as already indicated before, the industrial electrochemical cell unit has to be coupled with a separation unit (flotation of settling). The mean residence time in the separation unit is usually very high to ensure a satisfactory separation of solid and liquid. Because of this, the flow rate of electrochemical unit has to be reasonable, otherwise the volume of the separation unit will be very large. In opposite, the calculated energy consumption will be higher for a small flow rate since it is calculated based on the treated volume per unit of time. A compromise between final conversion and energy consumption has to be determined since the few last pollutant to remove cost necessitates a longer residence time and consequently more energy.

Table 1 gives the theoretical quantity of aluminum dissolved and energy consumption as function of flow rate (mean residence time). These results show that a flow rate of around 20 mL/min represents a good compromise because the abatement of nearly 95% is satisfactory with a reasonable energy consumption of 3.6 kWh/m^3. The lowest flow rate allows 98% abatement but with no acceptable energy consumption, even if some published results already obtained such range of values. Hanafi et al. [22] showed that in a batch system, at a current density of 25 mA/cm^2, the energy to treat the margins from their polyphenols, the COD and the color, was a round 23 kWh/m^3, and the concentration of dissolved aluminum could reach 1 g/L.

3.2. Influence of current density

The current density is the most sensitive parameter which can influence the effectiveness of electrocoagulation treatment [23]. It determines not only the amount of coagulant but also the rate and the size of the bubbles produced at the electrodes [24,25]. Figs. 3 and 4 represent, respectively, the abatement of turbidity and COD vs. time for several current densities. The startup period is reduced when the current density increases, which is due to the high production of Al^{3+} coming from anodic dissolution. This phenomenon of dissolution or loss of mass to the iron or aluminum anodes was modeled by many authors while making use of the Faraday’s law (Eq. (2)). The efficiency at steady state is less affected by the current density certainly because of the low flow rate chosen for the experiment. The contact time between pollutant and aluminum hydroxide is enough to ensure the maximal efficiency. The effectiveness of the treatment remains of the same order of magnitude with ~90% for the COD and ~99% for turbidity. As already pointed out by Holt et al. [24], when the current densities raise, the formation of the aluminum ions is quicker produced, compared to the processes of coagulation. Kholska et al. [25] showed that, the density of the bubbles increases and their size decreases with the increase of current density, leading to the fast removal of the aluminum hydroxide of the solution by flotation and a reduction of the probability of collision between the pollutants and the coagulant. The increase in the rate of generation of H_2 bubbles with the rise of the density of current is favorable when the phase separation is carried out by flotation [13].

Table 2 gives the abatement, the theoretical concentration of aluminum and the energy consumption for the different current densities. Due to the low flow rate, the COD and turbidity removal percentages are very high even with a low current density. The aluminum and energy consumption are thus acceptable for

Table 1
Turbidity percentage removal, energetic consumption, and theoretical aluminum dissolved for several flow rates

Flow rate (mL/min)	Mean residence time (min)	Measured applied tension (V)	E (kWh/m^3)	Al (g/L)	Turbidity removal (%)
1.75	571	6.4	41.15	2.16	97.76
3	333	6.3	24	1.26	96.97
10	100	6.1	7.2	0.377	95.07
20	50	6.1	3.6	0.189	94.62
30	33	6.1	2.4	0.125	92.65
40	25	6.1	1.8	0.094	87.52

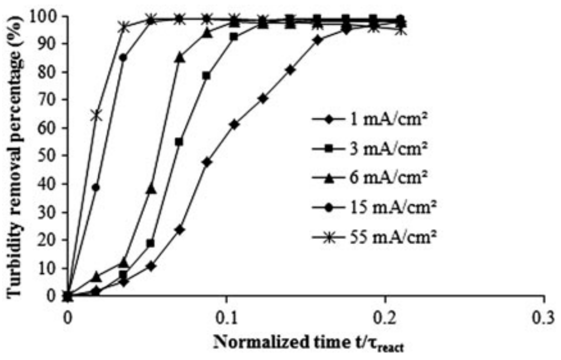

Fig. 3. Turbidity removal percentage vs. normalized time for several current densities. Inlet flow rate = 1.75 mL/min, temperature = 20°C, electrodes gap = 1 cm, pH 7.03, electrolyte support KCl 2×10^{-2} M.

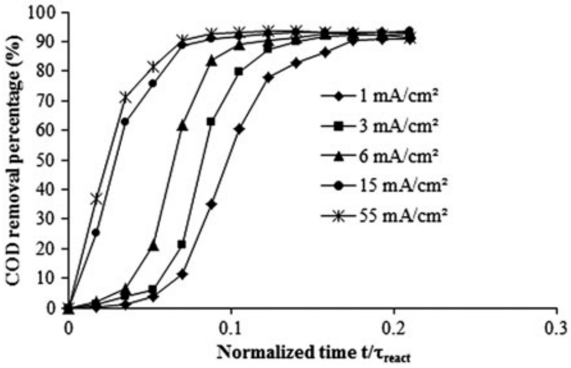

Fig. 4. COD removal percentage vs. normalized time for several current densities. Inlet flow rate = 1.75 mL/min, temperature = 20°C, electrodes gap = 1 cm, pH 7.03, electrolyte support KCl 2×10^{-2} M.

industrial application. For the high current densities, the energy consumption and aluminum concentration are very high, but such values has to be used only to have a high treatment productivity using higher flow rates. At this level, it should be pointed out that the concentrations of aluminum are underestimated since it is well known that Faradic yields are often higher than 100%.

3.3. Influence of conductivity

The electric conductivity of a solution may be adjusted when necessary because it affects the tension of the cell, the effectiveness of the current and electric energy consumption in the electrolytic cells. Because of this, the effect of type and concentration of electrolytes on the effectiveness of the processes of electrocoagulation were largely studied [17,26]. The conductivity of dairy effluent is low and it has to be increase artificially except when certain accidental discharges containing acid or basic flushing water occurred. Without electrolyte support, the treatment would require more energy to overcome the strong ohmic voltage drop between the two aluminum electrodes. KCl, at various concentrations between 0.5 and 4 g/L, was selected as electrolyte support. Fig. 5 shows the time evolution of turbidity during the startup. It is little affected by the increase of conductivity. Fig. 6 illustrates the optimal concentration to reach a high reduction of turbidity (97.7%) obtained with 1.5 g of KCl per liter of solution. The tension controlled is minimal to 6.62 V, whereas conductivity is of 3.36 mS/cm. Bensadok et al. [17] found similar results for the reduction of turbidity by employing the electrolyte support NaCl with 1.5 g/L, corresponding to a conductivity of 3 mS/cm. The chlorides affect the passivation layer at the surface of the electrode and increase the dissolution of the sacrificial aluminum anode, by localized pitting. The localized corrosion of metals was already described in detail by Foley [27]. The increase of the concentration of KCl behind 1.5 g/L does not have a significant improvement on the treatment. According to Wang et al. [28], the presence of chlorides in solution containing $Al(OH)_3$, can form several intermediate species: $Al(OH)Cl_2$, $Al(OH)Cl_2$, and $AlCl_3$. However, a large excess of chloride, can also form the $AlCl_4^-$ anion, contributing to the dissolution of aluminum species. Consequently, the aluminum species available for coagulation are lower, involving a limitation of the effectiveness of the treatment. In addition, to these reactions, the formation of Cl_2 may also occur by the following reaction:

Table 2
Turbidity percentage removal, energetic consumption, and theoretical aluminum dissolved for several current densities

Current density (mA/cm^2)	Measured applied tension (V)	E (kWh/m^3)	Al (g/L)	COD removal (%)	Turbidity removal (%)
1	1.2	0.51	0.144	90.98	97.8
3	2.1	2.57	0.432	92.52	98.71
6	4.4	11.3	0.864	93.32	97.84
15	6.4	41.1	2.16	93.37	98.64
55	15.1	355	7.92	93.5	98.85

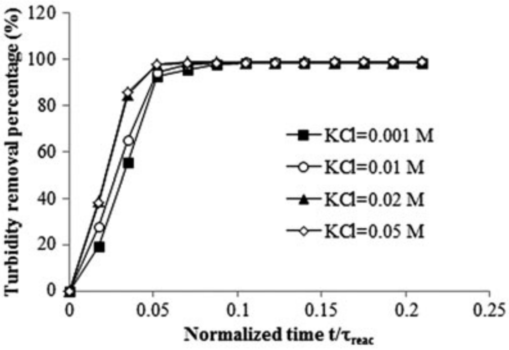

Fig. 5. Turbidity removal percentage vs. normalized time for several Electrolyte support KCl concentration. Inlet flow rate = 1.75 mL/min, temperature = 20˚C, electrodes gap = 1 cm, pH 7.03, current density = 15 mA/cm².

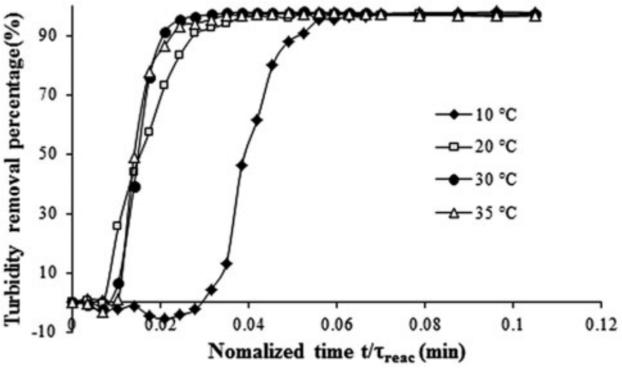

Fig. 7. Influence of temperature: Current density = 15 mA/cm², electrodes gap = 1 cm, flowrate = 1.75 mL/min; pH 7.03, electrolyte support KCl 2 × 10⁻² M.

$$2Cl^- \rightarrow Cl_2 + 2e^- \quad (4)$$

The generated molecular chlorine is hydrolyzed to form hypochlorous acid and hypochlorite ion.

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \quad (5)$$

The hypochlorous acid and hypochlorite ion can decompose organism because of their high oxidative potentials. Meanwhile, if the anode potential is high enough, other reactions such as direct oxidation of organic compounds may occur at the anode.

Chlorides reduce also considerably, the undesirable effects of other anions such as HCO_3^- and SO_4^{2-}, by avoiding the precipitation of the ions calcium (Ca^{2+}) contained in the waste waters [8]. The precipitate would form an insulating layer on the surface of the electrode and would increase the resistance of the electrochemical cell or inhibit metal dissolution. Consequently, the value of concentration of 1.5 g/L of KCl seems to allow optimal operating conditions for both treatment efficiency and operating cost.

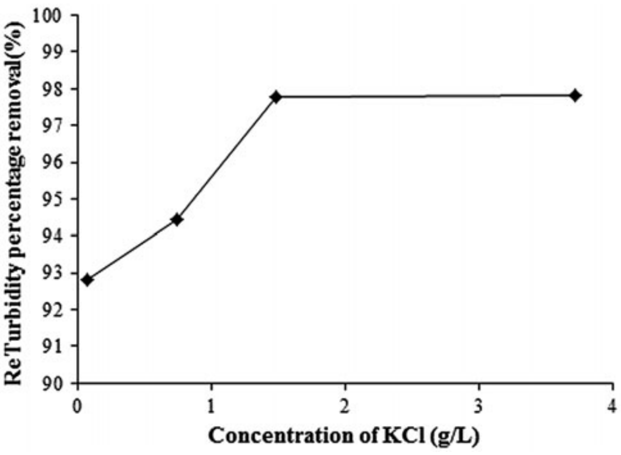

Fig. 6. Influence of KCl concentration on turbidity percentage removal. Current density = 15 mA/cm², electrodes gap = 1 cm, temperature = 20˚C, flowrate = 1.75 mL/min, pH 7.03.

3.4. Influence of pH

It is well established that the pH influences the performance of the treatment by electrocoagulation since, it determines the speciation of metal dissolved at the electrode [26]. Even if numerous publications have already investigated this problematic, it is necessary to quantify the effect of the pH for each new type of effluent. Thus, the inlet pH was adjusted using one molar solution of HNO_3 or NaOH. Table 3 shows the effectiveness of elimination of the COD and turbidity according to the initial pH at steady state. As expected when electrodes of aluminum are used, the maximum of elimination of pollution was observed within a pH close to neutrality (pH 7.3). This result was experimentally validated by various authors: Bensadok et al. [17], Koparal et al. [29] and it is consistent with the speciation of aluminum. During the startup process the pH of the medium changes, especially for the lower values. This evolution is due to the production of OH^- at the electrode. This particularly prevents the abrupt change of pH in alkaline medium [8]. The effectiveness of the treatment according to the pH can be explained within the species formed in solution. With low pH (lower than 4), the cation species Al^{3+} et $Al(OH)^{2+}$ prevail. When the pH lies between 4 and 9, Al^{3+} and ions OH^- generated by the electrodes react to form various monomeric species which are

Table 3
Influence of initial pH on final turbidity and COD percentage abatement (current density = 15 mA/cm^2, temperature = 20˚C, flowrate = 1.75 mL/min, electrolyte support KCl 2×10^{-2} M)

	Abatement (%)		
Inlet pH	COD	Turbidity	Outlet pH
2	70.12	85.15	6.62
4	73.43	94.91	7.31
6	75.56	96.45	7.80
7	77.79	97.76	7.47
8	75.34	97.30	8.62
10	52.09	80.09	9.77

transformed finally into amorphous in soluble compounds $Al(OH)_3$ by polymerization kinetic complexes/precipitation [30]. The formed precipitate increases solubility when the solution becomes very basic [31]. For example, with pH higher than 10, monomers $Al(OH)^{4-}$ increase the concentration of anions to the detriment of $Al(OH)_3$. Flocculation is favored with pH of 7.3 (approximate pH of the studied effluent) without one being obliged to fix the initial pH because of buffer effect.

3.5. Effect of the temperature

The effect of the temperature on electrocoagulation was rarely studied, although this technology has been known for more than 100 years and that industrial units are often running outside at ambient temperature or in low heating industrial premises. We investigated the influence of the temperature from 10 to 35˚C (Fig. 7). These values cover more or less the range of operating temperatures in industrial premises from European north countries to sub-Saharan countries.

This can be allotted to the kinetics of formation and collision of the flocs of aluminum hydroxides generated in the reactor, which decreases at low temperature. For the temperatures beyond 20˚C, the reduction ratio of turbidity decreases with the rise in the temperature; this can be partly related to the same phenomenon. In this case, the kinetics is faster; the mobility of the formed ions increases considerably and their probabilities of collision to form the aluminum hydroxide, is reduced. Also, the increase in the temperature leads to an increase in the solubility of the precipitates of aluminum hydroxide formed [32]. Consequently, the effectiveness of the reduction of turbidity decreases. Energy consumption generally decreases with the increase in the temperature. This reduction would be alotted to the quoted phenomena: mobility, probability of collision between the particles as well as solubility.

3.6. Efficiency of the treatment

The COD and turbidity are very convenient to follow the pollution since the measurements are easy to handle and representative of the quality of the effluent. Nevertheless, it is necessary to estimate more in detail the removal of others pollutants or pollution characteristics. Table 4 illustrates the efficiency of the process in particular with a high level of abatement for grease and BOD_5. Even if it is not fully remove the abatement of phosphate presents in dairy effluent and responsible for eutrophication of the water when it is rejected in the natural medium is really satisfactory regarding the high level of pollution of this effluent. If the final value of COD remained slightly higher than the maximum level for direct discharge, the pollution would be low enough to carry out a touches finishing treatment in urban wastewater plant.

Table 4
Maximum percentage of pollutant removal for current density = 15 mA/cm^2, electrodes gap = 1 cm, flow rate = 1.75 mL/min; pH 7.03, electrolyte support KCl 2×10^{-2} M

Pollutant X	Initial composition of the effluent	Pollutant removal and final composition of the effluent	Standard norms in Algeria: Maximum concentration allowed for industrial wastewater discharge
Greases	500 mg/L	97% (15 mg/L)	20 mg/L
Phosphors	36.3 mg/L	72% (10 mg/L)	10 mg/L
BOD_5	1,270 mgO_2/L	97% (38 mg/L)	35 mgO_2/L
COD	2,300 mgO_2/L	92% (184 mg/L)	120 mgO_2/L
Turbidity	1,037 NTU	99% (10 NTU)	–

Note: *JORA, Journal Officiel de la République Algérienne du 23 Avril, Annexe des valeurs limites maximales des paramètres de rejet des installations de déversement industrielles, n˚26 (2006).*

3.7. Influence of milk powder addition

The real industrial effluent composition is fixed by the activity of the dairy and it is not very easy to test the influence of the pollutant concentrations. In order to have a first estimation of the efficiency of the process for highly concentrated wastewater, we added some milk powder in the industrial effluent at different concentrations. Fig. 8 represents the initial turbidity of the obtained effluent for several milk powder concentrations.

Fig. 9 represents the turbidity percentage removal vs. the normalized time for several concentration of powder milk. The startup is delayed when the concentration increases but fortunately, the concentration at steady state is few affected with 99% of abatement for all the experiments. Indeed, the experiments have been conducted with a low flow rate but a lower efficiency for a very high concentration of powder milk was expected. Also an increase of the flow rate will certainly affect the final conversion but this result rise the pertinence of using an artificial dairy solution as it has been done mainly in the literature. It is also important to estimate the increase of sludge volume involved by the higher concentration of milk powder.

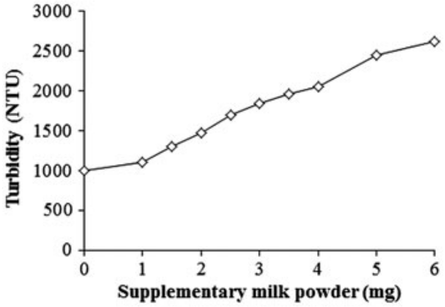

Fig. 8. Evolution of the turbidity with the concentration of powder milk added in industrial effluent.

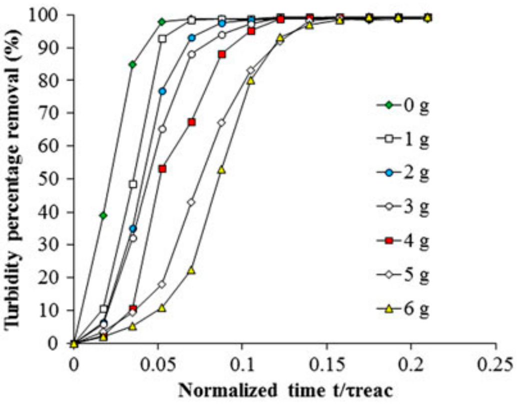

Fig. 9. Turbidity removal percentage vs. normalized time for several concentrations of powder milk. Support KCl concentration, inlet flowrate = 1.75 mL/min, temperature = 20°C, electrodes gap = 1 cm, pH 7.03, current density = 15 mA/cm^2.

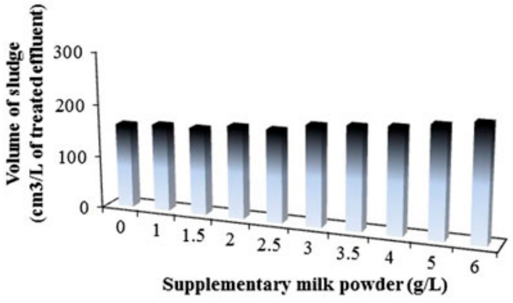

Fig. 10. Volume of sludge per liter of treated effluent vs. supplementary milk powder.

Fig. 10 shows the volume of sludge is few increased when supplementary milk powder is added. In fact, the final volume of sludge varied from 16 (i.e. 160 cm^3 per liter of treated solution) to 22% (i.e. 220 cm^3 per liter of treated solution). If this result is representative of those obtained with different COD concentrations of real dairy industrial wastewater, the scaleup of the process and particularly the separation part will be few affected by the variability of the wastewater. If this result is an artifact due to the use of powder milk, attention must be paid since actually all the researches relative to the treatment of dairy wastewater has been carried out with artificial wastewater.

4. Conclusion

Treatment of real industrial dairy wastewater has been carried out in a continuous electrocoagulation vessel at laboratory scale. The waste water is characterized by high values of BOD$_5$ and COD. The startup of the process shows that mean residence time between the electrodes should be considered first. Influence of operational parameters: flow rate, current density, initial pH, and temperature were studied. The reduction of turbidity is close to 99% for the optimal conditions, whereas COD was reduced to approximately 92%. A high level of 97% of abatement for BOD$_5$, and greases were measured for the optimal conditions. Phosphorus contained in the dairy wastewater was reduced to 72% of the initial concentration. The final pH reaches 7.4, thanks to buffer effect that makes it possible to reject the effluent directly in the natural receiving mediums without adjustment. Energy consumption for the treatment remains reasonable compared to other processes. Results obtained with addition of milk powder showed that the volume of sludge is few affected by the initial turbidity level of the wastewater.

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